Although the cutting costs were encouraging, there were three areas of concern which needed to be addressed: blade jamming, rig design and the relationship of blade diameter and the depth of cut achieved.

The biggest problem discovered to date, was that of blade jamming in the slot. Three causes of blade jamming were proposed:

- spalling of rock onto blade
- closure of slot onto blade
- moving of rig/saw causing distortion of blade.

The equipment was relocated to President Brand 2 Shaft to the high stress stope, to determine whether stress and closure of the slot was the main reason for blade jamming. In addition, the rig was modified to give it more rigidity.

During the trials spalling of the rock onto the blade, as a cause of blade jamming, was ruled out as no pieces of rock were observed on removing the blade. Initially a reduction in the frequency of jamming occurred. However, as tests progressed, jamming occurred more often and appeared to be related to rock movement.

This trapped the blade at the segment and occurred rapidly (through localised rock movement), rather than gradually.

Blade jamming accounted for 4% of the total operating time at President Brand 2 Shaft but would not represent a major problem to any future production system. This is due to the fact that if the blade jammed the sawing could be continued by another blade and the jammed blade would then be released by the non-explosive breaking system.

6.4 Development of a Slot-Based Mining Method

The test work carried out underground to date has concentrated on developing a slot-based mining method to complement the research being carried out with the various slotting tools.

The first underground tests were carried out at 30/41 President Steyn 1A Ventilation shaft using the dry abrasive waterjet cutting equipment.

Initially the cutting parameters (mentioned in Section 1.5) were optimised, in terms of performance, for producing depths of cut in quartzite. Similar findings to the surface research, i.e. increasing depth of cut with pressure, orifice size, abrasive flowrate and exposure time, were observed. Although this test work proved the concept of slotting hard rock underground, the other aspect of the project, breaking out the rock between the slots, was less successful. The method used for these breaking tests was a hydraulic pulse method, referred to as Flowex (see Section 2.4), which hydraulically pressurised pre-drilled holes.

The Flowex device (see Section 2.4) could propagate fractures in hard rock. It did not however, have sufficient energy to liberate the rock from the face.

The end result was that blocks of quartzite became "keyed" together in the stope face. Another problem was when existing fractures intersected the pre-drilled holes, energy was dissipated through the cracks instead of being used to break the rock.

Finally, even when circumferential and longitudinal notches were made in the hole (using ultra high pressure water), to act as stress raisers, the device was only 33% successful in removing the rock from the face.

Needless to say, the use of ultra high pressure water to form these notches made the process both costly and time consuming.

As the aim of slot based non-explosive mining is to intersect stress induced fractures ahead of the face, it was decided to move to a high stress stope to determine the effect of stress on breaking. This was carried out by first moving to 66/100, President Steyn 4 Shaft and more recently to 60/69, President Brand 2 Shaft.

Operating in a high stress environment has facilitated the rock-breaking operation to the extent that when the rock is fractured it can be removed from the face by conventional barring techniques. Breaking rates of up to 1 m^3/h have been achieved using pinch bars, and this could be improved upon, by the use of hydraulic impact hammers mounted on suitable support and traverse mechanism.

Another finding has been, the deeper the slot, the easier it is to break out the rock between the slots. A deeper slot increases the chance of intersecting the vertical stress fractures ahead of the face.

Abrasive waterjet cutting is easily adapted to the rock conditions (fracture spacing), by merely adapting one of the cutting parameters (normally traverse speed). Generally the parameters have been set to produce the maximum depth of cut, although the traverse speed is different as it directly governs the cutting and mining rate. Due to the prototype nature of the dry abrasive waterjet cutting equipment the traverse speed has been kept low (approximately 30 mm/min) to g reasonable depths of cut (average = 350 mm) to assist breaking.

This gives an average cutting rate of approximately 0,7 m^2/h in underground quartzite. If the dry abrasive equipment was to be replaced by slurry abrasive equipment, then this cutting rate could be doubled using similar cutting power.

The problems encountered underground have mainly centred around the positioning and advancing of the nozzle and cutting equipment, causing delays to the cutting process. The main reason for this has been stand-off distance, which is a critical factor in reducing the effectiveness of the dry abrasive cutting waterjet. Typically the cut depth would be reduced by 60% with a stand-off distance of 400 mm.

A slurry abrasive cutting jet would only loose 10% in depth of cut over the same stand-off distance. This would reduce the problem of negotiating irregular stope faces and the associated repositioning time required to maximise cut depth.

Rig development is a crucial area of concern, because it must supply a continuous steady traverse to the slotting tool, but at the same time be flexible enough to negotiate faults and rolls in reef.

Figure 6.31, shows the rig developed during trials at President Brand 2 Shaft. The rig consists of 2 m rail sections which are connected by a flexible joint, allowing 7 degrees of movement in any direction. The rail sections can be moved incrementally forward, up to 1 m, before they are fixed to the next line of props.

This captive rail system enabled excellent control of the stoping width as illustrated in Figure 6.32. A system which does not use a rail (non-captive rig) would require continual repositioning to maintain good stope width control.

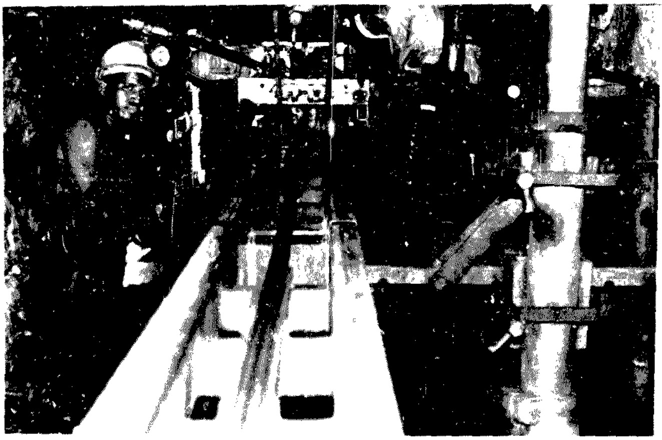


Figure 6.31 : Face Rig Developed Underground for Abrasive Waterjet Cutting

Figure 6.32 : Stope Width Control Achieved Using Slot-Based Mining (President Brand 2 Shaft, 60/69 Stope)

Although slot-mining can address hard patches, by producing multi slots in the hard patch or cutting the hard patch out by block slotting (see Section 1.4), these methods were found to be both time consuming and costly. In addition, block slotting although proved to be practically feasible, requires a more complicated traverse system which moves the nozzle both vertically and horizontally. It is for these reasons that an alternative hard patch breaking method is being investigated.

7. FINANCIAL EVALUATION OF SLOT-BASED NON-EXPLOSIVE MINING SYSTEMS

Mechanisation, is generally more capital extensive than conventional mining. Furthermore, in the case of slot-based non-explosive mining methods, the mechanised operating costs are usually higher than those presently experienced underground. However, the increase in production and reduction in waste rock trammed from the stope, more than compensates for these additional costs. This is reflected in the overall working cost, in R(000's)/kg of gold produced, being far less than conventional mining (typically R 2000 per kg of gold produced).

For these reasons, it is important to identify all the benefits and disadvantages of a mechanised system and to translate them in financial terms, to ascertain whether the overall net effect is favourable.

To achieve this a software package was developed, to financially justify the efforts put into the development of a slot based non-explosive mining system. This is able to assess the relative advantages and disadvantages of the slot-mining method. The main advantages of a slot-based mining system are:

- reduced tramming width (by waste packing in stope and reduced stoping width)
- increase mine call factor (reduced fines)
- increased face advance (continuous operation)
- improved support and environmental conditions (waste packed ribs or stonewalls)

On the other hand the disadvantages are:

- more capital expenditure
- higher working costs

Other advantages/disadvantages may be reduced/increased power consumption, over conventional mining. A program, such as Heatflow or Ventflow, Von Glehn et al (70), calculates the overall effect of heat loads on a mines ventilation system. This allows the positive or negative effect on NPV profits to be calculated.

Diamond Circular Saws use less power overall than conventional mining. However, Slurry Abrasive Waterjet cutting uses far more power than conventional mining and is still able to make a substantial improvement on NPV profits, Figure 7.1.

Power and water (Diamond Saw) accounts for approximately 1% of the total costs of a slot-based mining system. Hence, in the overall financial evaluation of slot-based non-explosive mining, it is more important to realise the overall benefit of the system, rather than concentrate on the effect of one single parameter, such as power.

The financial evaluation package, schematically illustrated in Figure 7.2, incorporates a program called Goldplan, Splaine et al (71) (72).

Goldplan is the name given to a set of concepts, expressed in mathematical terms, which enables many different studies to be made of the broad mining and financial behaviour of a gold mine in the Republic of South Africa. Goldplan is not a "total system" which accepts input data and produces all the answers, but is rather a collection of modelling concepts and calculation procedures which can be used in conjunction with each other, in the combination appropriate to answering a specific question.

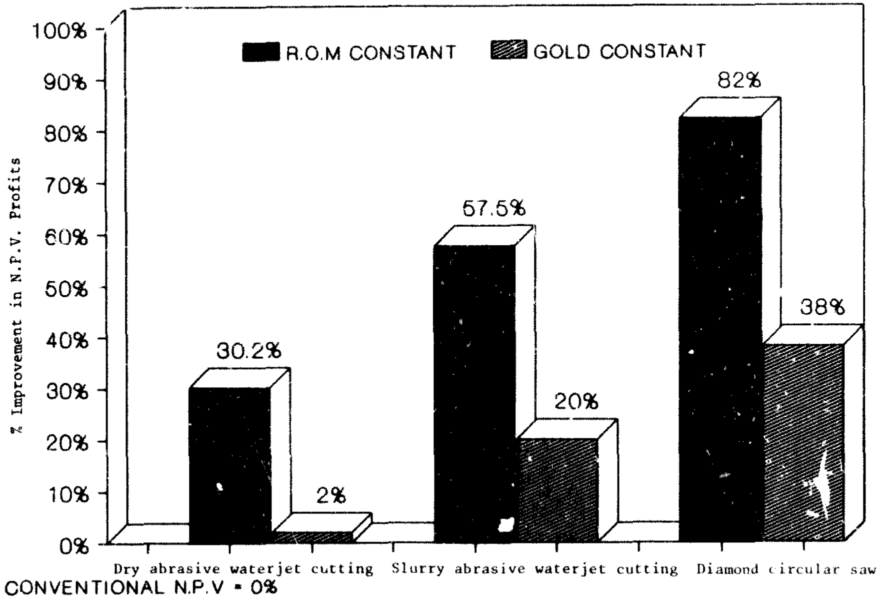


Figure 7.1 : **Effect of the Slot-Based Mining Methods on % Improvement in NPV Profits**

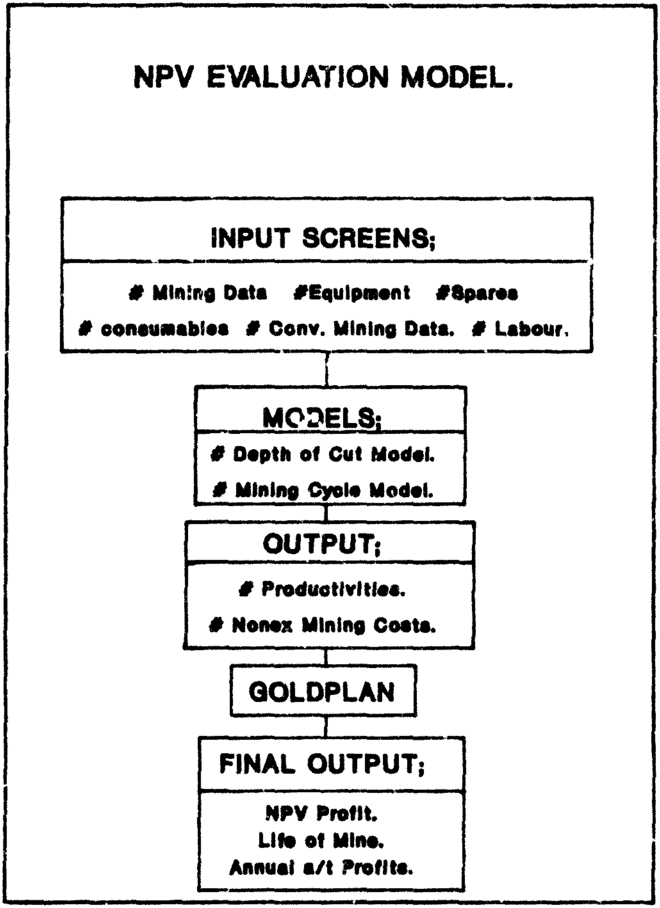


Figure 7.2 : Schematic Illustration of the NPV Evaluation Model Developed for Slot-Based Mining

This financial model, **Goldplan**, needed to be modified so that it could address the particular benefits associated with slot mining. As an example, **Goldplan** needed to be able to address the notion of waste packing i.e. mining a certain stoping width and hoisting another.

Front-end software was developed to calculate some of the inputs necessary for **Goldplan** to work. The user has at his disposal several screens where he can input basic operating parameters such as mining layout, slotting and breaking parameters, description and cost of equipment, cost and life of consumable spares, labour breakdown, conventional mining data and additional costs derived from "in-house" technical evaluations. This front-end program also incorporates several models developed by T&DS such as depth of cut and mining cycle models.

After calculation of these models, the program arranges the results into several output screens such as production and productivity, costs, etc. This output data is then fed into **Goldplan** and the financial calculations are performed.

The end product of this series of events details values such as Net Present Value (NPV) profit, life of mine, revenues, gold yield, unpayable reserves, etc.

A print of the inputs and detailed results for a typical run, can be found in Appendix 6.

This is a fairly complex program which can address three types of slot mining methods, namely:

- ultra high pressure dry abrasive waterjet cutting
- high pressure slurry abrasive waterjet cutting
- diamond circular saw cutting.

The incorporation of other non-explosive mining systems, slot-based or not, is relatively easy as this would only require modifications to the front end software.

The major assumptions used to carry out this evaluation were as follows:

- The model mine used was a typical deep level Transvaal gold mine.
- The non-explosive mining deployment on reefs was 33% on Ventersdorp Contact Reef (VCR) and 100% on Carbon Leader Reef (CLR).
- Longwall mining was carried out on both reefs.
- A reliable breaking system was available to liberate the rock between the slots.
- The stoping width was 1 m.
- The mine call factor of the non-explosively mined panels was 95%, or an increase of 3% over conventional mining.
- A minimum depth of cut of 300 mm to facilitate breaking operations.

To enable a comparative evaluation of different slot-based non-explosive mining systems, it was necessary to define a base case for each system. These base cases were then evaluated against the reference case, i.e. conventional mining performance.

To arrive at these base cases the cutting parameters of each slotting system were set to give a depth of cut of 300 mm. A depth of 300 mm was chosen, mainly for the following reasons:

- It is believed that shallower slots would not intersect face parallel fractures present ahead of the stope face.

- 300 mm has been achieved by the dry abrasive prototype equipment underground.

The need to intersect in-situ fractures may well require slots in excess of 300 mm depth and the implications of this will be discussed later in this section.

The input parameters for these base cases have been verified as far as possible. However, there is always a certain amount of guess work in this type of evaluation. The assumptions made for this study have been on the conservative side.

Figure 7.1 illustrates the percentage improvement in NPV profits over conventional mining for the three slotting systems.

One of the findings from the previous "in-house" evaluations was that, in a scenario of gradual implementation of non-explosive mining, two major options are available.

The first option, called here "Run-of-Mine Constant", keeps the mill full. This implies that over any period of time, more ground needs to be mined then with a conventional set up, to make up for the tonnage lost due to waste packing. As a result, more gold is produced over the given period of time and the life of the mine is reduced.

The second option referred to as "Gold Constant" keeps the gold output of the mine at the same value as that obtained by conventional mining. Hence, over any period of time, the same area is mined, but the mills are working below capacity.

The life of the mine is, for this option, longer than for the run-of-mine constant option.

Figure 7.1 clearly illustrates the financial advantages to be derived from an extensive, shorter lived mining operation.

The economic ranking of the 3 slot-based mining systems is also apparent, the diamond saw system featuring 82% improvement in NPV profits over conventional mining, followed by the slurry abrasive system [illegible]7,5% and, finally the dry abrasive system with 30,2% improvement.

It should be realised that ultra high pressure dry abrasive waterjet cutting has already been financially optimised at its base case. However, the slurry abrasive and diamond circular saw systems can still be improved with optimisation of their cutting parameters.

As mentioned earlier larger depths of cut than 300 mm may be required for effective rock breaking reasons. When using circular saws, the deeper the slot needed, the larger the blade diameter required. As the blade diameter increases, so will the blank (hub) and segment thickness. Hence, the cost of the blade increases more than proportionally with its diameter, due to the increased volume of diamonds required. This has the effect of decreasing NPV profits with increasing blade diameter. To off-set this decrease, an improvement in blade life is required. However, at this stage the relationship between blade diameter and blade life has not been established and further research work is required.

For slurry abrasive waterjet cutting, increases in pressure, orifice, abrasive flowrate or exposure would give increased depths of cut. However, there are practical limitations to all of these parameters. Despite this, although not yet optimised, depths of cut of over 300 mm can be achieved with a slurry cutting unit.

Financial sensitivities of the various parameters and parameter interactions are out of the scope of this dissertation, however, the optimised slurry cutting system could achieve an NPV profit increase of 70% over conventional mining, just by optimising the cutting parameters.

The computer package developed by T&DS is a very powerful tool for analysing the value of the research work into non-explosive mining. Financial justification is only part of what the package can offer, as it can also highlight areas where more research is required and derive equipment specifications.

8. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The detailed findings of each part of the investigation have been discussed under appropriate headings in the preceding chapters. The following is a summary of the principle conclusions reached and an overall appraisal of the results. The conclusions have been divided into six headings, namely: dry abrasive waterjet cutting, slurry abrasive waterjet cutting, diamond circular saw cutting, breaking, computer evaluations and recommendations for future research.

8.1 Dry Abrasive Waterjet Cutting (up to 240 MPa)

Various cutting parameters (pressure, orifice, mass flow ratio and exposure) have been tested by factorial design, to determine their effect on depth of cut in norite and quartzite.

The trends of the cutting parameters tested were similar to those found previously, **Hashish** (67). Due to the nature of the test work performed, a depth of cut model based on the cutting parameters tested, was also produced. Hence the depth of cut, in norite, for a given waterjet pressure, orifice diameter, traverse rate, exposure time and abrasive mass flow ratio, can be calculated for dry abrasive waterjet cutting. From the depth of cut model it has been found that increases in pressure, orifice size, exposure time and abrasive flowrate all increase depth of cut. However, there are practical limitations, where above certain values, little or no gain in depth of cut is realised for further increase in the respective cutting parameter.

A Q/N (Quartzite/Norite) ratio of approximately 1 was obtained for dry abrasive waterjet cutting. This implies that within confidence limits the depth of cut being tested on surface in norite blocks would not be significantly different from the depths of cut achieved underground. This allows valuable research to be carried out in norite on surface and for the results to be related to what could be expected in the underground environment. These findings have been verified by underground test work.

During surface research, abrasive recycling was tested successfully as a means of reducing abrasive consumption and hence cost. A loss of 3.2% in depth of cut per cutting cycle was observed. This loss in depth of cut has been explained by the reduction in mean particle size with successive cutting cycles.

Dry abrasive waterjet cutting has a poor cutting rate compared to slurry waterjet cutting and diamond circular sawing, Table 8.1. It also has the worst specific power consumption of the three slotting mechanisms.

Table 8.1 : Typical Operating Parameters of Slotting Tools

SLOTTING TOOL	WATER PRESSURE MPa	WATER FLOW l/min	ABRASIVE CONSUMPTION kg/min	CUTTING POWER kW	INSTANTANEOUS CUTTING RATE m^2/h	SPECIFIC POWER CONSUMPTION FOR METHOD ONLY kW/m^2
ULTRA-HIGH PRESSURE DRY ABRASIVE WATERJET CUTTING	220	15	3	55	0,7	78,6
HIGH PRESSURE SLURRY ABRASIVE WATERJET CUTTING	40	60	10	40	1,4	28,6
DIAMOND CIRCULAR BLADE SAWING	-	10*	-	24	3,0	8,0

* Blade flushing water at mine pressure.
Cutting power defined as power available at slotting tool after system inefficiencies are taken into account.

The cutting rate, for dry abrasive cutting can be maximised to 1,2 m²/h using approximately 110 kW nozzle power. However, the specific power consumption per m² of slot is even greater at these values. This would add to the overall ventilation requirement of a mine (typically dry abrasive waterjet cutting would double the ventilation requirements of Western Deep Levels Gold Mine) with the increased heat flow into the workings.

In addition, ultra high pressure waterjet equipment has complex components which require specialised maintenance at frequent intervals. This implies high working costs. Furthermore, ultra high pressure waterjet cutting, cannot make use of the benefits of hydropower.

It can be concluded that dry abrasive waterjet cutting has no future as a slot-based mining system.

8.2 Slurry Abrasive Waterjet Cutting (up to 40 MPa)

As in the case with the dry abrasive waterjet cutting, equipment, increasing pressure, orifice size, exposure time and abrasive mass flow ratio results in an increase in depth of cut.

However, overall, slurry abrasive waterjet cutting was found to be more than twice as efficient as dry abrasive waterjet cutting, in terms of nozzle cutting power and depth of cut achieved, Table 8.1.

The effect of stand-off distance (distance between end of nozzle and target material) with slurry abrasive waterjet cutting was found to be approximately one sixth of the stand-off effect of dry abrasive waterjet cutting.

This is of major benefit when slotting an irregular stope face underground.

Abrasive recycling was also investigated. No loss in depth of cut was observed. This has reduced one of the major disadvantages of slurry abrasive waterjet cutting, which is the high quantity of abrasive consumed (compared to dry abrasive waterjet cutting).

An angle of attack (angle between nozzle and target material) experiment, Section 6.2.5, determined which nozzle position gave the largest depth of cut. The optimum angle of attack was found to be a leading angle (nozzle angled in the direction of traverse) of approximately 13°. This gave an increase in depth of cut, compared to the vertical nozzle position, of approximately 2%. Previous work by **Saunders** (8) also found the leading angle to be approximately 13° with an improvement in cut depth of around 3,5%. Although this improvement is small, it represents additional performance for no extra cost.

Due to the large quantities of abrasive used, quartzite abrasive was tested in an attempt to reduce abrasive cost. The overall quartzite/chromite abrasive cutting ratio was found to be 73%. Hence, to achieve the same depth of cut using quartzite abrasive, as those achieved with chromite and an iron based abrasive, more power or abrasive would be required.

A depth of cut model for slurry cutting has been proposed which calculates the depth of cut for a given nozzle power and abrasive flowrate value. Although further research is required to improve the confidence in the model at higher power levels, it has enabled financial comparisons with dry abrasive cutting to be made.

Although slurry cutting can utilise hydropower more readily than dry abrasive cutting, it still consumes a great deal of water, Table 8.1. Thus water recycling or more effective/efficient nozzles need to be investigated. However, slurry cutting appears to be the best abrasive waterjet cutting system on which to develop a slot based mining method.

8.3 Diamond Circular Saw Cutting

Diamond circular saw cutting was investigated as an alternative to abrasive waterjet cutting. Because of the complex interactions between cutting parameters, an impractical amount of test work would be required to achieve results similar to those obtained with the abrasive waterjet cutting. It was therefore decided to analyse the results empirically in the underground environment.

The lowest cutting cost achieved to date, in underground quartzite, is R 80/m² (blade cost only). Despite this high consumable cost, diamond sawing is still vastly superior to abrasive waterjet cutting, in terms of power consumption, cutting cost and cutting rate. It has the potential to double conventional mining rates and offers the best improvement in net present value profits over conventional mining.

The diamond circular saw is the only slotting tool which out of the three tested, actually uses less water and power than conventional mining. Furthermore, its ventilation requirements could be significantly lower than conventional methods.

Diamond sawing technology is ideally suited to hydropower. The application of hydropower would significantly reduce equipment costs and complexity. Another benefit of diamond sawing technology over abrasive waterjet cutting is that it consumes no abrasives.

Diamond circular saw equipment is fairly simple compared to abrasive waterjet cutting and this is reflected in the capital cost and reliability of the equipment.

Finally, with the possible reduction in blade wear rates by using higher powered saw units, and the addition of flushing water additives (to cool the segments and help flush out cut material), the cutting costs could drop even lower. This could lead to diamond saw in-stope costs competing with conventional stope costs, a benefit not normally associated with mechanised mining.

One of the areas, in diamond circular saw cutting which still requires further investigation is blade jamming. The diamond saw unit was moved to a high stress regime located at the President Brand Gold Mine to determine the effect of stress on blade jamming. During the test work, blade jamming accounted for 4% of the total operating time. The main causes identified for blade jamming were rig movement and rock closure. Tests using higher powered saw units in the future may alleviate the blade jamming problem. In the practical context of a slot- based mining system, blade jamming would not represent a major problem as the cutting could be continued by an alternative blade and the jammed blade removed by the subsequent breaking operation.

Another area requiring further investigation, is whether it is practical/economical to cut slots using multi-pass techniques as used in the construction industry.

Because diamond circular saw blades are clamped by a central hub, the full blade diameter can not be utilised for cutting. This means that large depths of cut require large blade diameters Blade cost increases exponentially with blade diameter due to the increased diamond cost (increased volume of diamonds). It also causes problems with regard to maximising the depth of cut in an irregular stope face. Furthermore, circular blades do not cut around corners very easily and as such would not be suited to rolling reef or highly faulted stope conditions.

Despite problems with the inherent inflexibility of diamond circular saw blades, it remains the slotting tool with the most potential. It could be possible in the future that diamond circular saws would be used in unfaulted flat reef conditions and a slurry abrasive waterjet cutting system used in more geologically complex stopes.

8.4 Breaking Out of Rock Between the Slots

The cutting of three slots underground (hangingwall, footwall and reef/waste contact) has shown that the rock is easily removed between the slots in fractured rock conditions. Conventional barring techniques have achieved breaking rates of up to 1 m^3/h. There is little doubt that with future mechanisation, using rig mounted hydraulic impact hammers, greater breaking rates can be achieved.

The major area requiring further development remains the removal of unfractured ground or hard patches. A slot-based, non-explosive mining method can address the hard patch problem by producing multi-slots, in the form of block slotting (cutting out the hard patch in blocks) or slashing the unfractured ground, and driving wedges into the slots.

These methods, although having been proved feasible underground, are both costly and time consuming.

The development of a suitable breaking device for removing unfractured quartzite would widen the application of a slot-based mining method.

The two non-explosive rockbreaking methods discussed in this dissertation are Flowex, a hydraulic water pulse method and bullwedging, a mechanised method. Both of these methods require a hole to be drilled into the stope face for the device to be inserted.

Flowex was unsuccessful in breaking the rock from the face. Although the device, under certain conditions, could fracture the quartzite, the fractured rock remained "keyed" together.

Bullwedging appears more promising than Flowex, as burden spacings of up to 150 mm have been broken out in quartzite underground. Further work is required to determine whether this burden spacing can be increased further by using larger blow energy hammers.

8.5 Computer Evaluations

A computer package has been developed to evaluate the practical and financial advantages of slot-based mining.

Diamond circular saw cutting is highlighted as the most cost effective slotting tool on which to base a slot-mining system.

This study concludes that the successful implementation of a slot-based mining system could result in significant financial benefits for the gold mining industry.

Although further refinement in the computer model can still be made, to make the financial evaluation even more accurate, the computer package has proved itself to be a powerful evaluation tool for non-explosive mining. This financial evaluation model could be adapted easily, simply by changing the front-end software, so that other types of mechanisation may also be assessed.

8.6 Recommendations for Future Research

Apart from the development of the diamond circular saw and slurry cutting units, to optimise their cutting performance further, research should concentrate on the development of an effective rock breaking system capable of addressing all rock conditions.

Future research into rock breaking should follow two distinct paths: The first avenue of research should re-evaluate the existing non-explosive breaking methods with the benefit of slots. The second avenue should investigate the fundamental principles of rock breaking such that new concepts can be identified and tested to break hard unfractured quartzite.

Other areas requiring investigation are the development of a suitable rig to support and traverse the slotting and breaking devices along the face, as well as a cleaning and rockhandling system, suitably integrated into the non-explosive mining method.

Although slot-based mining has at present been looked at under the confines of present mining layouts and stope geometries, this should be continually re-evaluated. If the mining layout or mining method can be changed, to make better use of the advantages of slot mining, then this should be considered. More work will be required in the future, on mining layouts, as further information becomes available.

REFERENCES

1. **Wagner, H.**, The challenge of deep-level mining in South Africa (Presidential Address), J.S.Afr.Inst.Min.Metall., Vol 86, no.9, September 1986, pp.377-392.

2. **Cook, N.G.W., Immelman, D.A. & Mrost, M.**, Planning research and development policy for large South African gold mines - an economic analysis, 9th Commonwealth Min. and Metall. Cong., London, May 1969.

3. [illegible], **N.C.**, [illegible] measurement and analysis of earth [illegible] resulting from [illegible] and rock failure, PhD [illegible] University of Witwatersrand, 1966.

4. **Haase**, [illegible] & **Pickering, R.G.B.**, The status of non-ex[illegible] mechanised mining in narrow reefs, Chamber of Mines of South Africa, Research Report No 5/87, January 1987.

5. **Marlowe, A.C., Worsley, S.L. & Price, C.J.**, The use of abrasive entrained high pressure waterjets as a tool for the non-explosive mining of gold bearing quartzites, 8th International Symposium on Jet Cutting Technology, Durham, England, 9-11 September 1986, (Paper 11).

6. **Marlowe, A.C., Fenn, O., Worsley, S.L. & Price, C.J.**, The use of abrasive entrained high pressure waterjets as a tool for the non explosive mining of gold bearing quartzites, The S.Afr.Inst.Min.Metall., Welkom Branch, September 1987.

7. **Fenn, O. & Marlowe, A.C.**, Development of a mechanised mining system for South African gold mines The ultimate challenge.

8. **Jager, A.J. & Turner, P.A.,** The influence of geological features and rock fracturing on mechanised mining systems in South African gold mines, Gold 100, Johannesburg, September 1986.

9. **Saunders, D.H.,** Evaluation of the performance potential of the BHRA Diajet for slotting hard rocks for mining applications, Report No. CR2711, BHRA Fluid Engineering Centre, December 1986.

10. **Cook, N.G.W. & Joughin, N.C.,** Rock fragmentation by mechanical, chemical and thermal methods, Proc. 6th Int. Min. Cong., Madrid, 1970, pp.1-66.

11. **Riemann, K.P.,** Die zeroponung van hartgesteinen beim schlitzhabeln, Ph.D. Thesis, T.U. Hanover, 1974.

12. **Hood, M.,.** A study of methods to improve the performance of drag bits used to cut hard rock. Ph.D Thesis University of the Witwatersrand, 1977.

13. **Joughin, N.C.,** Progress in the development of mechanised stoping methods. J.S.Afr.Inst.Min.Metall., Vol 17, no.8, pp.207-217, 1978.

14. **Bingham, H. & Clemmow, R.J.,** A description of the full thrust radial rockslotter, Boart Research Laboratories, Report No. BRL 74/33 (MT), November 1974.

15. **Tonshoff, H.K. & Warnecke, G.,** Research on stone sawing, Proceedings of De Beers Seminar, 27th/28th October 1976.

16. **Bienert, P.,** Kreissagen von beton mit diamantverkzeugen, Doctoral Thesis of Hanover University, 1979 - In German.

17. **Lutz, G.,** Advances in stone cutting, 1978 Stone Colloquium, Hanover University - In German.

18. **Hatch, H.P.,** Diamond sawing of reef in the gold and platinum mining industries. Boart Research Laboratory. Report no.BRL.77/7(MT), 1977, pp.1-14.

19. **Gouws, J.,** The use of diamond saws in underground sampling at Randfontein Estates Gold Mining Company; Witwatersrand, Limited, J.S.Afr.Inst.Mine.Surv., Vol 23, no.6, June 1986, pp.85-97.

20. **Wright, D.N. & Wapler, H.,** Investigation and prediction of diamond wear when sawing, De Beers Industrial Diamond Division, Annals of the CIRP, Vol 35, no.1, 1986, pp.239-244.

21. **Cullingworth, B.,** Syndite's potential in tile cutting, Industrial Diamond Review, Vol 45, no.510, May 1985, pp.243-244.

22. **Schneider, W.,** Laser welding instead of brazing, Industrial Diamond Review, Vol 45, no.510, May 1985, pp.242-243.

23. **Herbert, S.,** Labour costs halved with one-man diamond wire, Industrial Diamond Review, Vol 45, no.510, May 1985.

24. **Le Scanff, A.,** New wire saw machine, Industrial Diamond Review, Vol 48, no.527, April 1988.

25. **Daniel, P.,** More granites succumb to diamond wire, Industrial Diamond Review, Vol 46, no.516, May 1986.

26. **Lagesse, R.B.,** Literature survey of high pressure water-jets, for rock breaking, Chamber of Mines of South Africa, Task no. GS3B02, Report no.399, February 1987.

Hashish, M., Cutting with abrasive waterjets, presented at the U.S.A. Waterjet Symposium, University of Missouri, Rolla, 1983, pp.1-10.

28. **Maurer, W.C.,** Advanced drilling techniques, Maurer Engineering Inc., 1979.

29. **Pols, A.C.,** High pressure jet-drilling experiments in some hard rocks, Paper ASME 76-PET-50 presented at the ASME Petroleum Mechanical Engineering and Pressure Vessels and Piping Conference, Mexico City, September 1976

30. **Wyllie, M.R.J.,.** Jetted particle drilling, Proc. 8th World Pet. Cong., Moscow, 1972, pp.403-411.

31. **Fair, J.C.,** Development of high pressure abrasive-jet drilling, J. of Pet. Tech., August 1981, pp.1379-1388.

32. **Baumann, L., Böing, R. & Hessling, M.,** Fundamental investigations into the improvement of waterjet performance by the use of abrasive additives, Proceedings of 8th International Symposium on Jet Cutting Technology, Durham, England, 1986, pp.277-286.

33. **Iihoshi, S., Nakao, K., Tori, K. & Ishi, T.,** Preliminary study on abrasive waterjet assist roadheader, Proceedings of 8th International Symposium on Jet Cutting Technology, Durham, England, September 1986.

34. **Scott-Russell, H., Morris, R & Bertram, R.C.,** New innovations within the Gold and Uranium Division of the Johannesburg Consolidated Investments Company Limited as a result of the introduction of trackless mechanised mining methods, The S.Afr.Inst.Min.Metall., Welkom Branch, Mining and Metallurgical Innovations for the Nineties, September 1987.

35. **Fairhurst, R.M., Heron, R.A. & Saunders, D.H.,** "Diajet" - a [illegible] abrasive waterjet cutting technique, Proceedings of [illegible]ternational Symposium on Jet Cutting Technology, Du[illegible] England, September 1986, pp.395-402.

36. **Krasnoff, E.L.,** Liquid/Abrasive jet cutting apparatus, U.S.A. Pat.no.4,707,952, Filed 1/10/186, November 1987.

37. Krasnoff, E.L., Personal communication, September 1988.

38. **Nakaya, M., Kitagawa, T. & Satake, S.,** Concrete cutting with abrasive waterjet, Proceedings of 7th International Symposium on Jet Cutting Technology, Ottawa, Canada, June 1984, pp.281-292.

39. **Bloomfield, E.,** Personal communication, BHRA, The Fluid Engineering Centre, Cranfield, Bedford, England, September 1988.

40. **Müller, M.,** Personal communication, Woma Systems, Benoni, South Africa, October 1988.

41. **Carstens, J.P. et al,** An evaluation of heat weakening hard rock as an assist to mechanical tunnelling, Dynamic Rock Mechanics, A.I.M.E., New York, 1970.

42. **Carstens,** J.P. et al, Heat assisted tunnel boring machines, DOT FR-9-0035, 1970.

43. **McGarry, F.J. et al,** Laser assisted rock cutting study, MIT, Final Report for United Aircraft Research Labs., Contract No. FR-9-0035, April 1970.

25×10

44. **Jurewicz, B.R. et al,** Rock-kerfing with high power lasers. Proc. 3rd Cong. Int. Soc. Rock Mechanics., Colorado, 1974.

45. **Jager, A.J; Margaret Westcott & Cook, N.G.W.,** A geological assessment of the applicability of reef boring to mining the basal, carbon leader and Vaal Reefs, Chamber of Mines of South Africa, Project No. GT1 P01, Research Report no.20/75, May 1975.

46. **Adams, G.R.,** A study of fractured formed in the rock around an opening made by a reef boring machine, Chamber of Mines of South Africa, Project No. GT1 P02, Research Report no.60/78, December 1978.

47. **Conradi, V.R; Hill, B.S; Joubert, H. & Nesbitt, A.C.,** Stopecorer, The S.Afr.Inst.Min.Metall. Colloquium on Mechanical Equipment for Underground Use, November 1977.

48. **Debex (Pty) Ltd,** Personal communication, May 1988.

49. **Pickering, R.G.B. & Haase, H.,** Non-explosive mining for South African Gold Mines, Gold 100, Proc.Int.Conf.on Gold, Johannesburg 1986, Vol 1, pp.105-112.

50. **Joughin, N.C.,** Potential for the mechanisation of stoping in gold mines, J.S. Afr. Inst. Min. Metall., Vol 76, no.3, 1976, pp.285-300.

51. **Bührmann, R.,** The development, testing and evaluation of a swing hammer mining system, Chamber of Mines of South Africa, Project No GT2I01, Research Report no. 43/80, December 1980.

52. **Spies, R.C. & Wouters, C.,** Rockbreaking rates obtained with impact ripper at experimental mining sites, Chamber of Mines of South Africa, Research Report no.38/82, July 1982.

53. **Haasse, H.,** Review of non explosive rockbreaking, Confidential Report, Chamber of Mines of South Africa, 1988.

54. **Cudemann, F.K.,** High energy gas-fracturing development, Sandia National Laboratory, Report no.SAND83-1379, Albuquerque, New Mexico, July 1983.

55. **Blight, T.P.,** Gaseous detonations at very high pressures and their application to a rock breaking device, Dissertation, University of the Witwatersrand, 1972.

56. **Brinkman, J.R.,** The influence of pressure pulse characteristics on fracture radiation from drill holes, Technical note, Chamber of Mines of South Africa, November 1986.

57. **Souden, P.M..** An investigation of the suitability of the Armstrong airbreaker as a rockbreaking device in the mining of Witwatersrand quartzites, Chamber of Mines of South Africa, Research Report no.47/70, August 1967.

58. **Clement, D.,** A comparison of the amount of energy available from the shock-wave rockbreaker and that from other non-explosive rockbreaking devices, Research Report no. 47/70, Chamber of Mines of South Africa, Johannesburg, September 1970.

59. **Fenn, O.,** Underground investigations of methods for breaking hard patches at West Rand Consolidated Gold Mine: West Shaft, Internal Report no.344, Chamber of Mines of South Africa, Johannesburg, February 1986.

60. **Joughin, N.C.,** Research for the mechanical excavation of rock in the South African gold mining industry, 1982.

61. **Burrow, K.P. & Lagesse, R.B.,** Comparison of devices based on drilled holes to fracture hard unfractured rock, Chamber of Mines of South Africa, Project no.GS3B01, December 1987.

62. **Buckmaster, A.C.,** Secondary breaking with Darda rock splitters and with bull wedges, Chamber of Mines of South Africa, Research Report no.40/76, Johannesburg, July 1976.

63. **Anderson, S.J. & Swanson, D.E.,** Capability evaluation of the radial-axial splitter, Report of Investigation, RI9071, US Bureau of Mines, 1987.

64. **Fenn, O.,** The use of thermal fracturing as a possible method for breaking hard rock (a literature search), Chamber of Mines of South Africa, Task no.GS3B01, June 1986.

65. **Fenn, O.,** The use of waterjets to enhance the performance of free rolling cutters in hard rock, PhD Thesis, University of Witwatersrand, November 1985.

66. **SAS User's Guide:** Statistics, Version 5 Edition, Cary, North Carolina: SAS Institute Inc., 1985, pp.956.

67. **Brownlee, K.A.,** Industrial Experimentation, Fourth Edition, H.M.S.O., London, 1949.

68. **Hashish, M.,** Aspects of abrasive waterjet performance optimisation, Proceedings of 8th International Symposium on Jet Cutting Technology, Durham, England, 1986, pp.297-308.

69. **Hashish, M.,** Experimental and theoretical investigation of the abrasive-waterjet cutting process, Flow Industries Report, no.363, 1986.

70. **Von Glehn, F.H., Wernick, B.J., Chorosz, G. & Bluhm, S.J.** ENVIRON: A computer program for the simulation of cooling and ventilation systems on South African Gold Mines, APCOM 87, Proceedings of the Twentieth International Symposium on the Application of Computers and Mathematics in the Mineral Industries, Volume 1, SAIMM, 1987, pp.319-330.

71. **Splaine, M. & Ashworth, S.J.E.,** A kinematic model of slot-cutting by the dry abrasive waterjet system in hard rock, Operations Research Department, T&DS Internal Report, June 1987.

72. **Splaine, M. & Browner, S.J.,** A fast financial evaluator for changes in practice at a gold mine, International Conference on Operations Research in Resources and Requirements in Southern Africa, CSIR Conference Centre, Pretoria, April 1984.

73. **Splaine, M. & Beeforth, C.G.,** Goldplan User's Manual, Management Sciences Department, Technical & Development Services, AAC, August 1976.

Appendix 1

Test Results and Experimental Parameters
for the Abrasive Waterjet Cutting Testwork

DRY ABRASIVE WATERJET CUTTING

TABLE 1 : 81 RUN EXPERIMENTATION

T/S No	PRESSURE (MPa)	ORIFICE DIA. (mm)	ABRASIVE RATIO	TRAV RATE (mm/min)	PASS No.	TIME (sec)	ABR. FLOW (kg/min.)	DEPTH OF CUT (mm)			
								1	2	3	4
1	138	0.89	0.10	100	1	311	1.29	94	96	97	90
					1	302		99	96	103	96
					2	305		154	158	157	139
					3	304		174	188	177	176
2	138	0.89	0.20	200	1		2.61	79	78	70	80
					2			170	130	122	120
						153		190	187	187	190
						154		224	248	215	215
3	138	0.89	0.15	400	1	73	2.09	37	40	44	35
					4	73		112	112	110	113
					8	72		170	170	165	160
					12	73		216	201	187	183
4	172	0.89	0.15	100	1	291	2.30	132	131	150	141
					2	290		142	218	218	218
					3	288		190	230	240	248
5	172	0.89	0.10	200	1	144	1.47	68	70	85	84
					2	140		120	123	125	139
					3	144		150			
					4	143		171	178	183	185
					5	144		196			
					6	141		210	222	222	222
6	172	0.89	0.20	400	1	74	3.00	58	51	55	52
					2			98			
					3	75		120			
					4	74		144	149	145	151
					5			162			
					6	74		182			
					7	75		198			
					8			228	209	212	230
					9	81		232			
					10	78		252			
					11	77		265			
					12	78		274	248	260	271
7	241	0.89	0.20	100	1	303	3.59	171	184	148	166
					2	282		258	244	248	265
					3	275		318	292	329	311
8	241	0.89	0.15	200	1	146	2.40				
					2	145		163	160	166	154
					4	146		228	232	232	232
					6	137		274	275	260	270
9	241	0.89	0.10	400	1	75	1.84	46	54	55	50
					2	75		95			
					3	75		125			
					4	75		146	149	153	180
					5	75		151			
					6	75		175			
					7			185			
					8	75		182	198	211	221
					9	74		196	221		
					10	76		206	230		
					11	75		210	250		
					12	74		223	239	248	240
11	138	0.89	0.15	100	1	291	2.10	98	98	108	109
					2	291		192	153	170	194
					3	285		228	220	227	234
12	138	0.89	0.10	200	1	150	1.25	56	55	55	56
					2	144		120			
					3	148		115	119	113	114
					4	148		124			
					5	147		145	140	140	145
					6	147		168	164	168	175
12R	138	0.89	0.10	200	1	150	1.25	60	50	59	59
					2	144		98	102	104	98
					3	138		140	139	138	124
					4	149		161	150	156	140
					5	147		175	178	181	176
					6	147		188	180	191	190
13	138	0.89	0.20	400	1	75	2.50	52	55	40	50
					2	75		80			
					3	76		105			
					4	76		129	142	140	144
					5	75		151			
					6	75		173			
					7	76		189			
					8	76		171	178	190	205
					9	75		214			
					10	75		229			
					11	75		235			
					12	75		240	218	222	247

TABLE 1 : 81 RUN EXPERIMENTATION

T/S No	PRESSURE (MPa)	ORIFICE DIA. (mm)	ABRASIVE RATIO	TRAV RATE (mm/min)	PASS No.	TIME (sec)	ABR. FLOW (kg/min.)	DEPTH OF CUT (mm) 1	2	3	4
14	172	0.89	0.20	100	1	267	3.20	140	142	150	140
					2	289		235	238	245	228
					3	288		303	302	307	300
15	172	0.89	0.15	200	1	141	2.30	87	85	78	84
					2	144		141	130	135	154
					3	145		177			
					4	147		218	214	220	215
					5	145		221			
					6	149		228	253	270	256
16	172	0.89	0.10	400	1	75	[illegible]	44	43	44	42
					2	74		86			
					3	75		109			
					4	75		122	120	124	115
					5	75		145			
					6	75		157			
					7	75		172			
					8	77		185	173	165	175
					9	74		195			
					10	74		208			
					11	76		217			
					12	77		228	226	240	231
17	241	0.89	0.10	100	1	274	1.80	145	141	126	136
					2	305		195	[illegible]	230	219
					3	303		280	290	297	288
18	241	0.89	0.20	200	1	149	3.59	103	115	115	117
					2	148		170	190	177	230
					3	152		237	222	260	246
					4	151		269	255	270	295
					5	152		305			
					6	149		331	334	320	334
19	241	0.89	0.15	400	1	76	2.60	62	60	61	65
					2	75		102			
					3	76		137			
					4	76		159	167	171	173
					5	76		173			
					6	77		185			
					7	77		195			
					8	75		212	239	220	234
					9	74		213			
					10	77		219			
					11	77		233			
					12	78		251	286	331	264
21	130	0.89	0.20	100	1	305	2.40	123	126	134	139
					2	301		188	182	190	168
					3	305		230	232	246	223
22	138	0.89	0.15	200	1	147	2.10	52	66	67	64
					2	149		108	100	115	131
					3	150		142	157	140	159
					4	150		172	165	175	165
					5	150		180	196	204	200
					6	149		[illegible]	230	218	218
23	138	0.89	0.10	400	1	74	1.30	25	30	30	24
					2	75		43			
					3	76		66			
					4	75		81	89	89	94
					5	75		95			
					6	75		100			
					7	73		118			
					8	75		119	135	144	120
					9	76		102			
					10			136	125		
					11	74		158	152		
					12	75		170	165	183	174
24	172	0.89	0.10	100	1	300	1.50	99	118	117	100
					2	335		203	213	193	156
					3	302		241	252	240	220
25	172	0.89	0.20	200	1	148	3.48	81	96	85	80
					2	147		152	146	153	163
					3	148		189			
					4	149		215	220	210	228
					5	149		249			
					6	147		277	270	243	[illegible]
26	[illegible]	0.89	0.15	400	1	75	2.30	48	41	49	48
					2	75		65			
					3	75		94			
					4	76		113	122	135	122
					5	75		141			
					6	75		158			
					7	76		174			
					8	76		177	179	188	192
					9	76		164			
					10	76		210			
					11	77		219			
					12	77		226	246	230	225
27	241	0.89	0.15	100	1	301	2.95	152	137	158	166
					2	300		240	214	215	220
					3	303		255	268	289	255

TABLE 1 : 81 RUN EXPERIMENTATION

T/S No	PRESSURE (MPa)	ORIFICE DIA. (mm)	ABRASIVE RATIO	TRAV RATE (mm/min)	PASS No.	TIME (sec)	ABR. FLOW (kg/min.)	DEPTH OF CUT (mm)			
								1	2	3	4
28	241	0.89	0.10	200	1	144	1.90	66	92	78	94
					2	146		148	167	157	165
					3	147		200			
					4			244	270	218	218
					5	149		252			
					6	148		267	299	236	247
29	241	0.89	0.20	400	1	75	3.60	60	67	63	65
					2	75		92			
					3	76		111			
					4	76		165	150	170	170
					5	76		184			
					6	76		192			
					7	76		195			
					8	77		198	198	223	215
					9	77		221			
					10	76		228			
					11	76		235			
					12	76		241	237	263	252
31	138	1.40	0.10	100	1	603	3.30	170	161	146	153
					2	570		258	258	260	265
					3	593		290	315	316	340
32-1	138	1.40	0.20	200	1	308	7.00	110	98	112	107
					2	304		184	163	189	170
32	138	1.40	0.20	200	1	291	7.00	103	109	103	112
					2	299		140	142	150	147
					3	299		217	199	196	218
					4	303		240	256	250	277
					5	303		284	291	289	317
					6	325		301	329	309	343
33	138	1.40	0.15	400	1	148	5.3	65	73	63	65
					2	150		111	112	106	100
					3	150		147	155	145	146
					4	150		173	172	180	172
					5	150		196	182	180	202
					6	151		220	201	215	213
					7	150		230	222	218	233
					8			239	248	242	252
					9	150		267	254	260	268
					10	149		280	276	282	270
					11	151		296	290	295	292
					12	150		298	292	304	299

TABLE 1 : 81 RUN EXPERIMENTATION

T/S No	PRESSURE (MPa)	ORIFICE DIA. (mm)	ABRASIVE RATIO	TRAV RATE (mm/min)	PASS No.	TIME (sec)	ABR. FLOW (kg/min.)	DEPTH OF CUT (mm)			
								1	2	3	4
34	172	1.40	0.15	100	1	606	5.60	217	211	221	215
					2	607		300	316	321	320
					3	604		375	350	370	350
35	172	1.40	0.10	200	1	307	3.80	131	135	134	121
					2	306		199	218	202	192
					3	293		247	255	255	247
					4	301		298	280	279	290
					5	302		325	328	347	318
					6	303		360	353	370	330
36	172	1.40	0.20	400	1		7.60	80	82	66	67
					2	152		150	142	135	134
					3	152		173	198	178	171
					4	153		228	223	221	200
					5	253		249	245	231	240
					6	153		270	265	265	257
					7	153		282	283	283	284
					8	153		305	325	298	290
					9	151		320	312	291	298
					10	254		326	329	325	332
					11	153		350	331	341	349
					12	152		352	347	344	363
37	138	1.80	0.15	100	1	515	8.20	202	221	216	204
					2	627		219	270	274	280
					3	630		272	338	327	350
38	138	1.80	0.20	200	1	301	5.60	125	135	136	139
					2	[illegible]		142	198	193	213
					3	[illegible]		263	244	262	267
					4	[illegible]		289	285	293	307
					5	[illegible]		[illegible]	312	315	321
					6	300		360	333	343	354
39	138	1.80	0.20	400	1	148	10.70	78	71	75	86
					2	152		141	141	138	118
					3	149		175	181	179	174
					4	149		210	214	238	210
					5	150		229	248	256	235
					6	149		250	267	287	240
					7	149		260	286	280	260
					8	148		270	317	320	270
					9	147		290	323	340	294
					10	148		290	335	350	310
					11	148		297	341	360	330
					12	147		326	349	381	347
41	138	1.40	0.20	100	1	616	6.50	187	196	202	191
					2	608		286	335	337	315
					3	614		378	386	383	354

TABLE 1 : 81 RUN EXPERIMENTATION

T/S No	PRESSURE (MPa)	ORIFICE DIA. (mm)	ABRASIVE RATIO	TRAV RATE (mm/min)	PASS No	TIME (sec)	ABR. FLOW (kg/min.)	DEPTH OF CUT (mm) 1	2	3	4
42	138	1.40	0.15	200	1	305	5.10	114	91	105	118
					2	302		181	193	192	210
					3	300		257	235	267	240
					4	303		294	289	289	271
					5	304		320	341	329	315
					6	300		342	378	389	364
43	138	1.40	0.10	400	1	151	3.30	63	65	69	70
					2	153		115	111	115	113
					3	151		130	137	130	128
					4	156		155	166	169	167
					5	158		160	190	186	174
					6	156		186	195	194	189
					7	147		200	201	216	208
					8	151		226	218	243	216
					9	148		234	215	240	245
					10	149		250	240	247	250
					11	149		265	245	259	260
					12	151		263	265	260	280
44	172	1.40	0.10	100	1	603	3.70	205	202	198	195
					2	612		325	301	282	301
					3	601		345	355	345	370
45	172	1.40	0.20	200	1	303	7.60	161	157	165	[illegible]
					2	304		207	219	205	221
					3	303		253	253	248	279
					4			317	305	295	328
					5	329		378	355	350	355
					6	313		423	405	386	423
46	172	1.40	0.15	400	1	149	5.60	100	98	85	100
					2	149		163	165	167	170
					3	150		215	211	210	225
					4	151		265	265	245	261
					5	151		280	285	275	285
					6	151		300	289	315	323
					7	152		316	321	330	348
					8	153		327	335	350	355
					9	153		357	345	374	345
					10	153		355	355	385	356
					11	151		365	370	365	365
					12	149		394	380	425	430

TABLE 1 : 81 RUN EXPERIMENTATION

T/S No	PRESSURE (MPa)	ORIFICE DIA. (mm)	ABRASIVE RATIO	TRAV RATE (mm/min)	PASS No.	TIME (sec)	ABR. FLOW (kg/min.)	DEPTH OF CUT (mm) 1	2	3	4
47	138	1.80	0.10	100	1	610	5.60	200	211	218	198
					2	612		299	300	331	334
					3	600		359	375	386	415
48	138	1.80	0.20	200	1	307	10.70	148	137	123	142
					2	310		239	215	240	221
					3	315		303	265	293	259
					4	314		338	310	307	300
					5	310		372	318	350	356
					6	311		400	360	377	382
49	138	1.80	0.15	400	1	143	8.20	83	71	77	73
					2	147		114	130	138	141
					3	148		177	187	159	185
					4	146		218	219	190	210
					5	147		245	254	218	232
					6	146		259	275	246	[illegible]
					7	146		287	296	271	268
					8	145		276	313	280	285
					9	145		300	335	296	304
					10	148		335	346	307	310
					11	148		354	355	320	335
					12	147		358	357	338	370
52	138	1.40	0.15	100	1	598	5.10	198	209	211	203
					2			295	263	279	340
					3			355	370	363	385
53	138	1.40	0.10	200	1	260	3.40	103	105	100	100
					2	265		171	188	165	170
					3	306		264	225	218	210
					4	312			272	273	271
					5	320			310	318	315
					6	300			330	366	350
54	138	1.40	0.20	400	1	152	6.60	73	70	84	90
					2	155		132	130	140	147
					3	155		183	177	168	179
					4	156		209	200	219	208
					5	154		228	238	238	230
					6	157		258	238	252	277
					7	157		264	270	285	280
					8	157		282	305	306	305
					9	155		330	330	318	335
					10	155		330	350	338	355
					11	155		400	390	355	368
					12	154		410	407	385	400
55	172	1.40	0.20	100	1	602	7.80	251	280	263	250
					2	582		384	383	387	384
					3	568		452	460	495	440

TABLE 1 . 81 RUN EXPERIMENTATION

T/S No	PRESSURE (MPa)	ORIFICE DIA. (mm)	ABRASIVE RATIO	TRAV RATE (mm/min)	PASS No.	TIME (sec)	ABR. FLOW (kg/min.)	DEPTH OF CUT (mm)			
								1	2	3	4
56	172	1.40	0.15	200	1		5.60	123	132	132	130
					2	300		220	234	226	213
					3	300		267	286	310	311
					4	300		320	370	335	325
					5	301		350	363	378	373
					6	300		373	400	403	400
57	172	1.40	0.10	400	1	151	3.80	99	87	85	100
					2	151		174	163	151	170
					3	146		229	220	193	200
					4	148		245	229	228	238
					5	140		240	252	240	258
					6	149		254	278	289	280
					7	150		305	298	310	310
					8	142		315	316	322	310
					9	145		335	332	335	325
					10	140		350	332	358	335
					11	154		355	345	370	398
					12	153		385	375	385	420
57-1	172	1.40	0.10	400	1	154	3.80	90	90	84	87
					2	154		155	145	150	140
					3	152		197	199	189	180
					4	152		220	248	229	225
					5	152		269	261	250	250
					6	155		270	285	265	274
57-2	172	1.40	0.10	400	1	154	3.80	93	94	94	94
					2	146		150	150	171	132
					3	154		208	180	213	205
					4	154		236	204	249	222
					5	149		245	268	265	268
					6	155		275	280	285	265
58	138	1.80	0.20	100	1	615	10.70	191	183	191	175
					2	606		291	289	329	341
					3	600		354	363	368	389
59	138	1.80	0.15	200	1	301	8.20	134	131	125	135
					2	301		220	220	245	219
					3	310		263	256	287	273
					4	300		295	290	330	313
					5	301		327	318	384	343
					6	300		355	325	405	376

TABLE 1 : 81 RUN EXPERIMENTATION

T/S No	PRESSURE (MPa)	ORIFICE DIA. (mm)	ABRASIVE RATIO	TRAV RATE (mm/min)	PASS No.	TIME (sec)	ABR. FLOW (kg/min.)	DEPTH OF CUT (mm)			
								1	2	3	4
60	138	1.80	0.10	400	1	152	5.60	75	72	81	78
					2	152		140	123	133	133
					3	151		180	168	178	181
					4	150		199	214	202	217
					5	151		231	222	232	244
					6	151		251	250	245	253
					7	151		262	258	260	277
					8	150		285	275	268	290
					9	251		288	277	279	314
					10	150		314	292	291	325
					11	150		331	300	330	342
					12	151		347	306	415	347
61	241	1.40	0.10	100	1	601	4.50	218	222	220	225
					2	601		342	355	340	390
					3	578		388	408	430	434
62	241	1.40	0.20	200	1	301		152	157	134	135
					2	300		228	205	217	247
					3	304		268	260	289	300
					4	300		364	319	334	330
					5	300		372	345	364	355
					6	309		386	371	392	412
63	241	1.40	0.15	400	1	160	6.80	105	104	101	117
					2	162		181	165	195	199
					3	157		215	220	224	229
					4	156		283	263	286	273
					5	157		215	220	224	229
					6	156		321	305	344	315
					7	156		340	320	352	334
					8	155		357	347	375	295
					9	155		372	350	367	370
					10	154		378	360	404	416
					11	156		400	370	424	456
					12	152		418	380	432	468
64	172	1.80	0.10	100	1	610	6.70	265	258	239	250
					2	589		399	436	347	432
					3	602		501	442	432	485
65	172	1.80	0.20	200	1		12.40	183	163	175	161
					2	300		275	301	307	232
					3	300		342	326	346	351
					4	301		355	415	433	365
					5	300		423	444	473	386
					6	300		460	463	476	454

TABLE 1 : 81 RUN EXPERIMENTATION

T/S No	PRESSURE (MPa)	ORIFICE DIA. (mm)	ABRASIVE RATIO	TRAV RATE (mm/min)	PASS Nc	TIME (sec)	ABR. FLOW (kg/min.)	DEPTH OF CUT (mm)			
								1	2	3	4
66	172	1.80	0.15	400	.	144	9.10	105	108	100	101
					2	146		190	203	195	180
					3	146		241	254	222	232
					4	151		248	280	278	276
					5	146		288	314	313	305
					6	146		331	317	331	328
					7	146		366	364	351	350
					8	147		400	396	361	371
					9	146		420	417	386	405
					10	147		440	419	413	415
					11	147		450	438	418	456
					12	147		475	458	480	467
69	241	1.40	0.15	100	1	628	6.80	236	246	276	278
					2	616		388	428	438	445
					3	630		442	535	545	603
70	241	1.40	0.10	200	1	304	4.50	166	153	177	155
					2	300		246	243	267	307
					3	317		280	247	287	300
					4	301		245	265	290	335
					5	305		314	314	303	334
					6	292		345	375	376	378
71	241	1.40	0.20	400	1	151		102	115	113	111
					2	152		160	196	184	207
					3	151		211	236	220	259
					4	152		241	262	254	285
					5	150		245	269	260	274
					6	148		319	308	308	323
					7	150		317	330	326	326
					8	151		371	347	355	384
					9	149		396	370	378	360
					10	152		379	386	401	375
					11	152		400	401	429	398
					12	152		403	412	415	414
72	172	1.80	0.15	100	1	601	9.10	320	300	311	327
					2	600		486	501	518	533
					3	601		562	600	598	559
73	[illegible]	1.80	0.10	200	1	296	6.70	170	191	174	105
					2	300		313	280	298	296
					3	300		388	354	380	396
					4	306		469	462	480	405
					5	300		495	474	515	438
					6	315		527	500	550	470

TABLE 1 . 81 RUN EXPERIMENTATION

T/S No	PRESSURE (MPa)	ORIFICE DIA. (mm)	ABRASIVE RATIO	TRAV RATE (mm/min)	PASS No.	TIME (sec)	ABR. FLOW (kg/min.)	DEPTH OF CUT (mm)			
								1	2	3	4
74	172	1.80	0.20	400	1	148	12.40	105	107	107	103
					2	151		195	192	198	190
					3	150		258	237	239	223
					4	151		295	276	296	291
					5	150		314	329	330	312
					6	151		343	325	354	339
					7	150		365	348	373	360
					8	149		381	418	390	383
					9	150		400	390	417	403
					10	249		433	447	467	486
					11	149		441	465	480	503
					12	150		460	484	524	518
75	241	1.40	0.20	100	1	614	8.20	266	247	270	264
					2	602		433	413	417	373
					3	603		533	469	505	498
76	241	1.40	0.15	200	1	300	6.80	156	168	176	180
					2	300		274	270	251	261
					3	300		330	378	317	343
					4	300		397	425	384	387
					5	300		447	452	405	439
					6	300		483	490	455	465
77	241	1.40	0.10	400	1	145	4.50	79	73	75	85
					2	148		121	127	153	154
					3	150		194	200	202	205
					4	150		238	250	241	250
					5	151		265	250	270	286
					6	151		283	276	296	300
					7	151		306	294	307	318
					8	151		310	290	320	357
					9	150		380	312	336	356
					10	151		386	325	350	386
					11	152		407	330	359	386
					12	150		417	339	369	401
78	172	1.80	0.20	100	1	600	12.40	302	234	299	278
					2	600		468	507	470	456
					3	600		562	519	550	555
79	172	1.80	0.15	200	1	304	9.10	176	185	181	176
					2	316		283	280	302	316
					3	319		359	378	386	370
					4	319		435	435	456	411
					5	320		500	480	488	445
					6	322		528	517	516	484

TABLE 1 : 81 RUN EXPERIMENTATION

T/S No	PRESSURE (MPa)	ORIFICE DIA. (mm)	ABRASIVE RATIO	TRAV RATE (mm/min)	PASS No.	TIME (sec)	ABR. FLOW (kg/min.)	DEPTH OF CUT (mm)			
								1	2	3	4
80	172	1.80	0.10	400	1	149	6.70	115	111	120	121
					2	150		195	195	192	166
					3	135		248	231	248	230
					4	148		288	276	273	254
					5	149		300	297	322	293
					6	145		324	323	345	308
					7	147		354	350	365	316
					8	148		385	380	385	362
					9	146		404	396	402	386
					10	147		418	414	430	399
					11	147		433	438	452	412
					12	146		440	444	463	429
81	241	1.80	0.10	100	1	634	7.10	304	317	330	321
					2	615		521	462	504	447
					3	610		610	580	590	579
82	241	1.80	0.20	200	1	310	14.40	175	172	185	170
					2	300		276	300	279	231
					3	300		345	327	306	295
					4	300		418	379	397	367
					5	301		450	416	435	387
					6	300		489	463	483	465
83	241	1.80	0.15	400	1	145	10.70	70	123	123	125
					2	145		151	210	208	205
					3	146		214	243	242	253
					4	134		262	273	276	291
					5	140		296	310	311	300
					6	149		332	343	333	310
					7	148		328	356	355	346
					8	149		373	407	370	355
					9	148		400	421	389	370
					10	145		406	400	403	417
					11	146		445	444	415	424
					12	145		465	464	419	430
85	241	1.80	0.20	100	1	621	14.40	295	310	314	297
					1	620		315	263	300	301
					2	602		523	494	502	473
					3	600		610	620	631	628
86	241	1.80	0.15	200	1	302	10.70	195	188	197	194
					2	300		335	[illegible]	300	330
					3	303		391	426	422	418
					4	300		441	491	448	434
					5	393		459	515	[illegible]	484
					6	311		521	555	[illegible]	509
87	241	1.80	0.10	400	1	145	7.10	125	131	129	133
					2	151		218	217	226	210
					3	152		269	274	242	303
					4	151		301	354	343	336
					5	152		341	385	419	390
					6	150		377	405	446	425
					7	151		400	460	479	456
					8	150		423	484	496	477
					9	150		442	511	508	500
					10	150		458	510	535	517
					11	150		500	511	545	535
					12	151		520	520	564	560
88	241	1.80	0.15	100	1	616	10.70	311	355	324	310
					1	600		282	284	310	290
					2	614		517	515	482	572
					3	600		650	658	630	600
89	241	1.80	0.10	200	1	284	7.10	197	205	204	190
					1	284		198	205	165	210
					2	291		310	340	308	315
					3	288		410	435	403	392
					4	294		488	492	475	4
					5	294		532	568	494	557
					6	297		640	600	606	540
90	241	1.80	0.20	400	1	152	14.40	135	130	131	131
					2	153		210	235	207	222
					3	154		316	326	291	317
					4	153		360	372	351	378
					5	153		386	418	382	404
					6			421	424	426	457
					7			430	447	448	494
					9	151		490	535	487	537
					9	154		518	532	490	558
					10			512	574	515	585
					11	153		565	572	562	590
					12			580	610	580	602

NOTE : Nine (9) test numbers were set aside for duplicates, to determine experiemental error, but were never used (test numbering for 81 run experimentation was up to 90, including the duplicates). This was due to the fact that there were few enough significant effects, such that the residual error sum of squares had a large number of degrees of freedom. Thus the experimental error was well established already.

Table 2 : Results in Quartzite to Determine Q/N Ratio

TEST NO	PRES-SURE MPa	STAND-OFF mm	NOZZLE SIZE mm	BLOCK	DEPTH OF CUT (mm) 1	2	3	4	# D.O.C mm	ABRAS. FLOW RATE kg/min	ABRAS. RATIO
1	138	20	1,63	C	190 280 385	200 275 405	230 280 377	205 315 370	206,25 287,50 384,25	2,3	0,05
2	138	20	1,63	B	165 290 395	195 320 455	215 350 440	185 335 456	190,00 323,80 436,50	4,6	0,10
3	138	20	1,63	A	170 215 290	110 225 290	145 200 257	145 230 277	142,50 217,50 [illegible]	9,3	0,20
4	186	20	1,63	B	235 404 540	230 410 491	235 400 548	225 428 490	231,25 410,50 517,25	2,7	0,05
5	186	20	1,63	A	227 315 380	188 322 341	200 420 480	170 305 493	196,25 340,50 423,50	5,4	0,10
6	186	20	1,63	C	303 508 528	301 484 590	498 534 545	368 621 640	367,50 539,25 575,75	10,7	0,20
7	228	20	1,63	A	200 365 CUT THROUGH BLOCK	258 415	270 425	435 478	290,75 420,75 -	3,0	0,05
8	228	20	1,63	C	249 430 485	262 425 527	274 465 534	284 433 535	267,25 438,25 520,25	5,9	0,15
9	228	20	1,63	B	343 467 550	295 428 585	340 485 525	305 510 580	320,75 472,50 560,00	11,4	0,20
10	138	20	1,26	A	130 210 275	133 212 256	146 225 288	121 212 270	132,50 214,75 272,25	1,4	0,05
11	138	20	1,26	C	141 220 269	135 245 290	110 241 311	171 207 315	139,25 228,25 296,25	2,7	0,10
12	138	20	1,26	B	150 250 348	161 210 248	157 245 307	135 255 320	150,75 240,00 305,75	5,5	0,20
13	186	20	1,26	C	178 240 277	198 250 280	135 250 310	162 276 309	168,25 254,00 294,00	1,6	0,05

Table 2 : Results in Quartzite to Determine Q/N Ratio
(Continued)

TEST NO	PRES-SURE MPa	STAND-OFF mm	NOZZLE SIZE mm	BLOCK	DEPTH OF CUT (mm) 1	2	3	4	MEAN D.O.C mm	ABRAS. FLOW RATE kg/min	ABRAS. RATIO
14	186	20	1,26	B	177 251 365	187 297 340	185 292 330	186 231 335	183,75 267,75 342,50	3,2	0,10
15	186	20	1,26	A	190 259 325	171 256 285	168 244 265	169 242 289	174,50 250,25 291,00	6,4	0,20
16	228	20	1,26	B	172 185 373	186 214 325	151 324 335	271 335 340	195,00 264,50 343,25	1,8	0,05
17	228	20	1,26	A	255 373 510	284 394 515	159 400 479	244 445 519	235,50 403,00 505,75	3,6	0,10
18	228	20	1,26	C	128 280 357	168 300 365	201 296 356	230 357 405	181,75 308,25 370,75	6,7	0,20
19	138	20	0,89	B	104 124 150	111 131 165	109 130 161	101 178 193	106,25 140,75 167,25	0,72	0,05
20	138	20	0,89	A	142 167 175	82 120 192	65 105 145	84 130 182	93,25 130,50 173,50	1,46	0,10
21	138	20	0,89	C	153 213 291	155 215 292	161 211 270	143 232 285	153,00 217,75 284,50	2,95	0,20
22	186	20	0,89	A	113 171 210	105 166 221	108 177 210	95 177 217	105,25 172,75 214,50	0,8	0,05
23	186	20	0,89	C	149 250 290	179 240 305	165 250 290	189 275 319	170,50 253,75 301,00	1,6	0,10
24	186	20	0,89	B	170 252 295	188 265 331	180 275 346	180 277 338	179,50 267,25 327,50	3,2	0,20
25	228	20	0,89	C	192 270 318	160 255 310	181 228 283	162 245 300	173,75 249,50 302,75	7,5	0,05

Table 2 : Results in Quartzite to Determine Q/N Ratio (Continued)

TEST NO	PRES-SURE MPa	STAND-OFF mm	NOZZLE SIZE mm	BLOCK	DEPTH OF CUT (mm) 1	2	3	4	MEAN D.O.C mm	ABRAS. FLOW RATE kg/min	ABRAS. RATIO
26	228	20	0,89	B	192 300 333	178 290 350	192 316 350	180 283 339	185,50 297,25 343,00	1,8	0,10
27	228	20	0,89	A	154 314 340	149 237 287	159 240 319	146 220 275	152,00 252,75 305,25	3,6	0,20
28	138	20	1,63	A	101 191 229	55 134 194	92 117 305	66 199 306	78,50 160,25 258,50	1,23	0,025
29	186	20	1,63	C	129 260 272	122 188 229	102 265 275	128 198 230	120,25 227,75 251,50	1,23	0,025
30	228	20	1,63	B	95 270 376	93 281 363	153 270 320	93 320 359	108,50 285,25 354,50	1,5	0,025
31	138	20	1,26	B	76 122 140	77 129 155	76 120 141	79 119 158	77,00 122,50 148,50	0,62	0,025
32	186	20	1,26	A	114 192 324	90 180 245	102 236 361	130 275 298	109,00 220,75 282,00	0,80	0,025
33	228	20	1,26	C	166 300 333	221 284 339	261 333 352	234 323 347	220,50 310,00 342,75	0,90	0,025
34	138	20	0,89	C	77 120 177	67 119 156	67 104 138	72 124 158	70,75 116,75 157,25	0,32	0,025
35	186	20	0,89	B	82 129 164	80 128 160	67 140 148	80 138 153	77,25 133,75 156,25	0,46	0,025
36	228	20	0,89	A	92 147 185	86 141 180	87 138 180	94 144 186	89,75 142,50 182,75	0,46	0,025

Table 3 : Results Achieved During Abrasive Recycling Tests

ABRASIVE NAME	CYCLE NO.	NO. OF CUTS	ABRASIVE MASS AVAILABLE (kg)	MASS LOST PER CUT (kg)	DEPTH OF CUT ACHIEVED CYCLE MEAN (mm)	σ (mm)	NO. OF OBS	ABRASIVE MEAN (mm)	95% LIMITS ABOUT MEAN FOR ABRASIVE (mm)	CHANGE IN DEPTH PER CYCLE (mm)
CI S22 2A			25,3							
	1	4		2,6	133,8	16,2	16			
			15,1							
	2	3		1,5	146,7	12,9	12		142,5	
			10,5							
	3	2		2,0	151,9	21,5	8	135,5	129,3	-5,9 (98% SIG.)
			6,5							
	4	1		1,6	113,8	15,5	4			
			4,9							
	5	1		2,5	102,5	13,2	4			
			2,4							
SS HARD 2A			25,5							
	1	3		4,4	119,2	12,4	12			
			12,1							
	2	2		0,5	133,1	11,6	8		128,1	
			11,1							
	3	1		2,6	108,8	15,5	4	121,8	115,5	-1,1 (NOT SIG.)
			8,5							
	4	1		1,8	120,0	25,8	4			
			6,7							
SS 280 2A			25,1							
	1	3		2,1	126,7	14,0	12			
			18,8							
	2	3		1,6	114,2	17,7	12		121,4	
			14,0							
	3	2		1,6	115,6	15,5	8	115,3	109,2	-6,8 (99% SIG.)
			10,8							
	4	1		1,7	97,5	29,9	4			
			9,1							
	5	1		2,0	101,3	16,5	4			
			7,1							
CI D4 2A			23,0							
	1	3		3,5	112,9	16,6	12			
			14,6							
	2	2		2,5	111,9	23,9	8		121,3	
			9,6							
	3	1		1,1	125,0	12,9	4	114,4	107,5	+1,4 (NOT SIG.)
			8,5							
	4	1		1,3	103,8	13,8	4			
			7,2							
	5	1		1,6	123,8	25,6	4			
			5,6							
SS Unk 2A			25,0							
	1	3		4,1	111,7	13,9	12			
			12,7							
	2	2		3,6	110,0	17,1	8		114,0	
			9,1							
	3	2		3,5	105,0	16,0	8	108,6	103,0	-3,4 (NOT SIG.)
			5,6							
	4	1		0,8	101,7	12,6	3			
			4,8							

Slurry Jet Experiment No 1 - Initial Investigation Into Slurry Cutting

Table 4

TEST NO	PRESSURE (MPa)	STAND-OFF (mm)	NOZZLE SIZE (mm)	BLOCK	MEAN DEPTH OF CUT 1ST PASS (mm)	MEAN DEPTH OF CUT 2ND PASS (mm)	WATER FLOWRATE (l/min)	ABRASIVE FLOWRATE (kg/min)	ABRASIVE MASS FLOW RATIO
1	19,0	20	2,4	A	93,00	161,50	35,0	6,50	0,186
2	20,5	20	2,8	A	123,75	274,75	48,0	18,00	0,375
3	39,0	20	2,8	A	226,00	344,00	70,0	18,00	0,257
4	38,0	100	2,8	A	215,75	410,00	63,5	27,75	0,437
5	38,0	100	2,4	A	172,00	289,25	49,5	10,00	0,202
6	20,0	100	2,8	A	105,50	181,50	57,0	9,00	0,158
7	36,5	20	2,4	A	164,25	269,75	43,5	17,25	0,396
8	21,0	100	2,4	A	105,00	192,50	36,5	13,25	0,363
9	21,0	100	2,8	B	121,25	211,25	52,0	19,25	0,370
10	21,0	20	2,8	B	124,50	204,25	57,0	13.00	0,228
11	40,5	100	2,8	B	222,50	364,50	63,0	15,25	0,242
12	38,0	20	2,8	B	238,25	376,25	73,0	30,25	0,414
13	37,5	100	2.4	B	177,75	310,75	48,0	17,75	0,369
14	21,5	100	2,4	B	100,50	169,00	44,0	8,00	0,182
15	36,5	20	2,4	B	164,25	276,00	58,5	9,75	0,167
16	20,5	20	2,4	B	105,00	169,75	40,5	15,00	0,370

Slurry Jet Experiment No 2 - Further Investigation into Slurry Cutting

Table 5

TEST NO	PRESSURE (MPa)	STAND-OFF (mm)	NOZZLE SIZE (mm)	BLOCK	MEAN DEPTH OF CUT 1ST PASS (mm)	MEAN DEPTH OF CUT 2ND PASS (mm)	WATER FLOWRATE (l/min)	ABRASIVE FLOWRATE (kg/min)	ABRASIVE MASS FLOW RATIO
1	21,5	100	2,4	A	85,50	140,50	[illegible]	4,25	0,083
2	20,5	100	2,8	A	112,50	180,50	68,75	7,55	0,109
3	39,5	100	2,8	A	179,75	273,50	86,86	8,70	0,099
4	36,0	400	2,8	A	79,50	133,25	95,79	2,50	0,026
5	40,5	400	2,4	A	123,00	246,75	63,88	8,13	0,127
6	21,5	400	2,8	A	80,75	155,00	75,00	9,39	0,125
7	36,0	100	2,4	A	169,50	265,00	62,02	9,00	0,145
8	22,0	400	2,4	A	76,50	128,00	43,84	5,25	0,105
9	21,0	400	2,8	B	92,50	152,75	74,16	9,25	,125
10	21,5	100	2,8	B	117,25	172,25	74,55	6,75	0,090
11	38,0	400	2,8	B	111,50	147,75	97,50	6,50	0,067
12	38,5	400	2,4	B	100,50	195 50	66,73	5,35	0,080
13	36,0	100	2,8	B	69,50	111,75	96,49	2,37	0,024
14	22,0	400	2,4	B	55,00	103,00	49,94	3,50	0,070
15	39,0	100	2,4	B	138,25	229,25	68,35	4,12	0,060
16	21,5	100	2,4	B	87,50	138,75	49,81	3,62	0,073

Slurry Jet Experiment No 3 - **Maximum Depth Achievable From a Multipass Cut**

Table 6

PARAMETERS			%ERROR
Pressure	(MPa)	35	± 5
Stand-off	(mm)	100	± 5
Nozzle Size	(mm)	2,8	-
Abrasive Ratio	(Turns on valves)	2	-
Traverse Rate	(mm/min)	100	± 5
Abrasive Type		Chromite	-

Table 7

TEST NO	PRESSURE MPa	STANDOFF mm	NOZZLE SIZE mm	BLOCK	DEPTH OF CUT (mm) 1	2	3	4	MEAN D.O.C mm	INCREASE IN D.O.C mm	WATER FLOW RATE l/min	ABR. FLOW RATE kg/min	MASS FLOW RATIO	
1	32	100	2,8	A	179	164	135	126	151,00	-	96,02	15,00	0,155	
					223	189	218	193	205,75	54,75	98,14			
					382	351			366,50	160,75	95,88			Cut Abandoned
2	35	100	2,8	A	220	229	233	230	228,00	-	96,23	24,00	0,210	
					382	388	361	353	371,00	143,00	97,04	18,50		
					440	464	516	529	487,25	116,25	98,46	19,00		
					539	578	595	593	576,25	89,00	96,88			
					607	679	685	679	662,50	86,25	98,43			
					675	686	695	703	689,75	27,25	98,07			
					700	697	765	769	732,75	43,00	97,39			Cut Abandoned
3	33,5	130	2,8	A	225	218	210	180	208,25	-	99,45	24,00	0,151	
					324	323	342	334	330,75	122,50	98,42	10,50		
					388	389	397	441	403,75	73,00	96,38	10,00		
					430	435	460	420	436,25	32,50	99,92	14,50		
					475	472	499	477	480,75	44,50	95,97	17,00		
					506	531	519	507	515,75	35,00	98,22	13,00		
					565	551	558	607	570,25	54,50	95,56	16,00		
					599	582	645	635	615,25	45,00	96,93			
					631	634	685	686	659,00	43,75	98,45			
					650	723	681	715	692,25	33,25	97,71			
					670	700	768	745	720,75	28,50	99,38			
					705	755	792	804	764,00	43,25	98,26			
					725	765	770	826	771,50	7,50	100,73			
					775	796	786	854	802,75	31,25	100,54			
					782	803	861	815	815,25	12,50				
					820	820	882	894	854,00	38,75	100,14			
					846	840	892	904	870,50	16,50	106,99			
					870	858	912	925	891,25	20,75	98,13			
					873	867	928	933	900,25	9,00	99,71			
					871	875	943	941	907,50	7,25	101,03			
					895	897	956	967	928,75	21,25				
					919	906	980	982	946,75	18,00	99,39			
					932	898	923	1016	939,75					
					925	890	930	1013	939,50					

Slurry Jet Experiment No 4 - **Effect of Stand-Off on Depth of Cut**

Table 8

PARAMETERS			%ERROR
Pressure	(MPa)	39	± 7
Stand-off	(mm)	Varried	± 5
Nozzle Size	(mm)	2,8	-
Abrasive Ratio	(Turns on valves)	2	-
Traverse Rate	(mm/min)	100	± 5
Abrasive Type		Chromite	-

Table 9

TEST NO	PRESSURE MPa	STANDOFF mm	NOZZLE SIZE mm	BLOCK	DEPTH OF CUT (mm) 1	2	3	MEAN D.O.C mm	WIDTH OF CUT mm	WATER FLOW RATE l/min
1	38,5	900	2,8	A	140	138	138	138,7	60	85,32
2	38,0	1000	2,8	A	133	132	136	133,7	68	82,00
3	37,0	1100	2,8	A	129	132	123	128,0	68	-
4	37,5	1200	2,8	A	121	127	126	124,7	78	77,03
5	37,5	1500	2,8	A	111	112	96	106,3	94	77,64
	38,0	2000	2,8	A	92	111	91	98,0	114	75,20
7	36,5	2500	2,8	A	71	89	70	76,7	137	-
8	37,5	2835	2,8	A	66	69	64	66,3	145	-
9	38,0	3500	2,8	B	55	47	42	48,0	155	-
10	38,0	4440	2,8	B	49	37	65	50,3	210	-

Slurry Jet Experiment No 5 - Determination of Most Effective Angle of Attack for Nozzle

Table 10

PARAMETERS			%ERROR
Pressure	(MPa)	39	± 8
Stand-off	(mm)	100	± 5
Nozzle Size	(mm)	2,8	-
Abrasive Ratio	(Turns on valves)	4	-
Traverse Rate	(mm/min)	100	± 5
Abrasive Type		Chromite	-

Table 11

TEST NO	PRESSURE MPa	STANDOFF mm	NOZZLE SIZE mm	BLOCK	DEPTH OF CUT (mm) 1	2	3	4	MEAN D.O.C mm	ANGLE OF ATTACK	WATER FLOW RATE l/min
1	38	100	2,8	A	205	205	195	196	200,3	+20	83,83
					210	207	201	205	205,8	0	81,45
					202	187	180	195	191,0	-30	79,38
					234	233	226	207	225,0	+10	
					202	207	187	193	197,3	-20	82,93
					212	211	225	210	214,5	+30	83,18
					210	219	233	203	216,3	-10	84,99
2	38	100	2,8	B	220	245	250	256	242,8	+20	85,03
					226	235	235	210	226,5	0	83,74
					212	182	190	170	188,5	-30	83,63
					231	247	230	221	232,3	+10	85,30
					205	186	187	182	190,0	-20	85,67
					246	233	238	223	235,0	+30	85,59
					232	212	207	195	211,5	-10	84,40
3	38	100	2,8	B	198	220	243	215	219,0	+40	88,79
					226	218	230	210	221,0	0	87,74
					110	94	83	70	89,3	-60	88,13
					238	244	234	229	236,3	+20	89,58
					134	131	116	108	122,3	-40	89,61
					115	153	155	187	152,3	+60	89,72
					197	189	154	159	174,8	-20	91,66
4	38	100	2,8	A	194	201	204	206	201,3	+40	90,36
					230	217	212	214	218,3	0	91,31
					112	90	90	68	90,0	-60	92,40
					230	232	247	223	233,0	+20	92,06
					145	154	132	111	135,5	-40	92,36
					135	164	175	197	167,8	+60	91,21
					226	207	185	199	204,3	-20	91,29

Slurry Jet Experiment No 6 - Investigation into Quartzite as an Abrasive

Table 12

PARAMETERS		HIGH	LOW	%ERROR
Stand-off	(mm)	100	20	± 10
Pressure	(MPa)	39		± 7
Nozzle Size	(mm)	2,8	2,4	-
Abrasive Ratio	(Turns on valves)	4	2	-
Traverse Rate	(mm/min)	100		± 7
Abrasive Type		Quartzite	-	-

Table 13

TEST NO	PRES-SURE MPa	STAND-OFF mm	NOZZLE SIZE mm	BLOCK	DEPTH OF CUT (mm) 1	2	3	4	MEAN D.O.C mm	INCREASE IN D.O.C. mm	WATER FLOW RATE l/min	ABRAS. FLOW RATE kg/min	MASS FLOW RATIO
1	36,5	20	2,4	C	94	99	101	99	98,25		56,94	6,00	0,105
					153	156	160	159	157,00	58,75	56,24	5,00	0,089
2	37,5	20	2,8	C	116	115	116	122	117,25		78,53	12,00	0,153
					172	207	212	201	198,00	80,75	75,72	12,00	0,158
3	41,0	100	2,8	C	115	132	131	115	123,25		83,06	8,50	0,102
					185	200	208	209	200,50	77,25	84,69	8,00	0,084
4	39,5	100	2,4	C	117	119	110	111	114,25		59,02	10,00	0,169
					163	201	189	190	185,75	71,50	56,97	8,00	0,140
5	39,5	100	2,8	B	128	125	128	124	126,25		[illegible]	12,00	0,148
					216	231	213	[illegible]	218,25	92,50	81,39	10,50	0,129
6	39,0	20	2,8	B	130	127	125	129	127,50		82,72	9,30	[illegible]
					215	205	212	213	211,25	83,75	84,17	8,50	0,101
7	38,5	100	2,4	B	100	81	104	103	97,00		59,26	5,00	0,084
					172	173	178	174	174,25	77,25	59,19	6,00	0,101
8	37,5	20	2,4	B	117	119	112	114	115,50		62,44	10,00	0,110
					195	216	188	194	198,25	82,75	61,22	9,00	0,147

Slurry Jet Experiment No 7 - <u>Recycling of Abrasive</u>

Table 14

PARAMETERS			%ERROR
Pressure	(MPa)	36	± 2
Stand-off	(mm)	260	± 5
Nozzle Size	(mm)	2,4	-
Abrasive Ratio	(Turns on valves)	2	-
Traverse Rate	(mm/min)	100	± 10
Abrasive Type		Chromite Quartzite Iron Grit E5	-

Table 15

TEST NO	PRES-SURE MPa	STAND-OFF mm	NOZZLE SIZE mm	BLOCK	DEPTH OF CUT (mm) 1	2	3	4	MEAN D.O.C mm	MASS OF ABRAS. kg	% OF ORIG. SAMPLE	WATER FLOW RATE l/min
1	36,0	260	2,4	C	145	147	141	140	143,25	60,00	100	59,64
CHROMITE					80	68	102	111	90,25	49,00	82	66,39
					59	65	67	90	70,25	31,25	52	66,49
					67	76	67	68	69,50	18,50	31	69,87
					45	59	54	35	48,25	11,50	19	
										7,25	12	
2	36,0	263	2,4	C	56	58	65	50	57,25	33,00	100	60,00
QUARTZITE					55	53	44	45	49,25	21,75	66	68,78
					50	52	31	49	45,50	16,00	48	72,00
					52	55	42	40	47,25	11,50	35	73,80
					43	54	39	35	42,75	8,00	24	68,77
										5,50	17	
3	36,0	255	2,4	C	66	65	75	69	68,75	72,50	100	63,53
IRON GRIT					86	85	78	70	79,75	68,75	95	63,17
					88	100	96	86	9[illegible],50	60,75	84	64,26
					93	99	87	88	91,75	[illegible]5,50	77	65,23
					88	94	87	72	85,25	48,50	67	64,99
					93	107	89	92	95,25	42,50	59	65,48
					83	95	99	88	91,25	37,25	51	66,62
					98	87	90	92	91,75	34,25	47	66,65
					102	107	100	105	103,50	31,50	43	64,19
					95	99	99	107	100,00	29,25	40	70,56
					117	111	94	83	101,25	26,00	36	66,31
										23,75	33	

Slurry Jet Experiment No 7 - <u>Replenishing of Abrasives</u>

Table 16

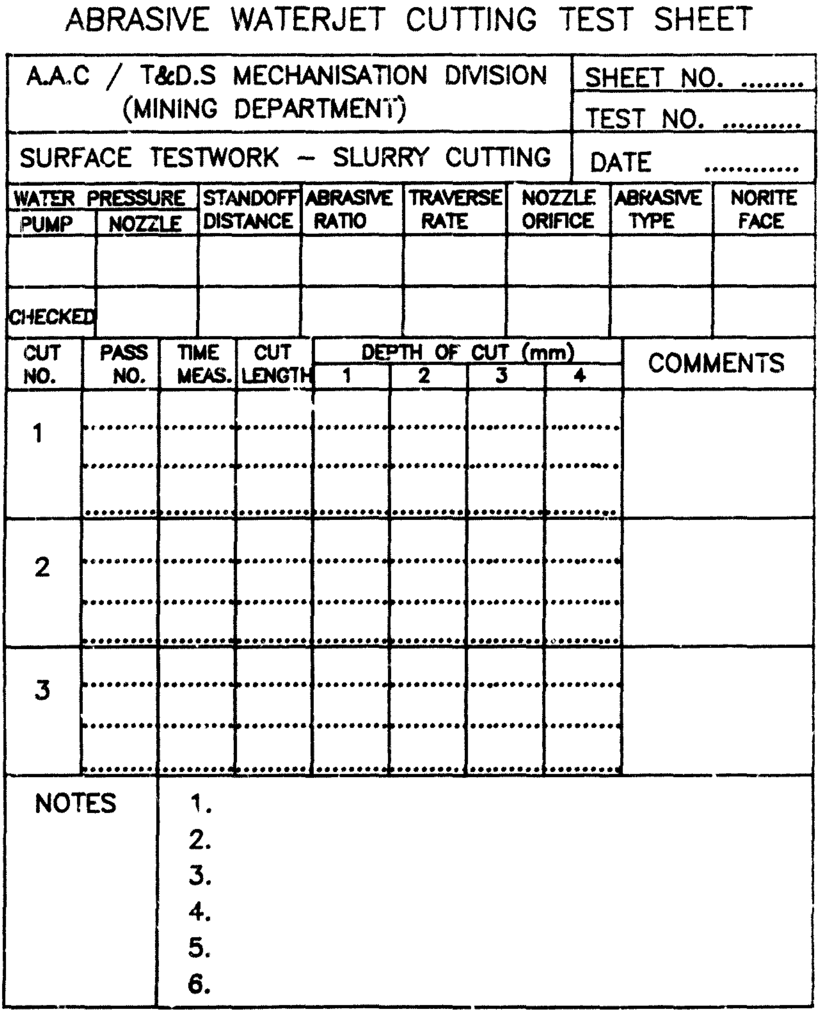
PARAMETERS			%ERROR
Pressure	(MPa)	36	± 5
Stand-off	(mm)	260	± 6
Nozzle Size	(mm)	2,4	-
Abrasive Ratio	(Turns on valves)	2	-
Traverse Rate	(mm/min)	100	± 10
Abrasive Type		Iron Grit E5	-

Table 17

TEST NO	PRES-SURE MPa	STAND-OFF mm	NOZZLE SIZE mm	DEPTH OF CUT (mm) 1	2	3	4	MEAN D.O.C mm	WATER FLOW RATE l/min	MASS OF ABRAS. kg	ABRAS. ADDED kg	ABRAS. LOST %
1	36.0	270	2,4	89	91	89	80	87,25	59,11	70,00		3,57
	Grit			105	114	101	91	102,75	65,61	70,00	2,50	2,14
				112	107	104	95	104,50	64,04	35,00	1,50	10,00
				111	95	93	95	98,50	69,44	35,00	3,50	2,86
				102	106	107	98	103,25	67,14	35,00	1,00	10,00
				100	116	93	111	105,00		35,00	3,50	17,14
				113	100	112	95	105,00	71,55	35,00	6,00	14,29
				95	97	107	111	102,50	70,85	35,00	5,00	16,43
				94	111	106	118	107,25	70,78	35,00	5,75	10,00
				118	120	106	103	111,75	67,97	35,00	3,50	11,43
				117	122	120	104	115,75	71,42	35,00	4,00	11,43
				110	100	115	107	108,00	72,52	35,00	4,00	12,86
				103	91	116	113	105,75	[illegible]	35,00	4,50	
											MEAN	10,10

Appendix 2

Abrasive Waterjet Cutting Test Sheet



ABRASIVE WATERJET CUTTING TEST SHEET

A.A.C / T&D.S MECHANISATION DIVISION (MINING DEPARTMENT)	SHEET NO. ....
	TEST NO. ....
SURFACE TESTWORK – SLURRY CUTTING	DATE ....

WATER PRESSURE		STANDOFF DISTANCE	ABRASIVE RATIO	TRAVERSE RATE	NOZZLE ORIFICE	ABRASIVE TYPE	NORITE FACE
PUMP	NOZZLE						
CHECKED							

CUT NO.	PASS NO.	TIME MEAS.	CUT LENGTH	DEPTH OF CUT (mm)				COMMENTS
				1	2	3	4	
1								
2								
3								

NOTES	1. 2. 3. 4. 5. 6.

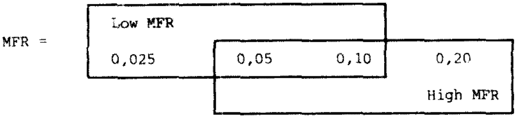
Appendix 3

Derivation of a Model for Q/N Ratio
(Dry Abrasive Waterjet Cutting)

DERIVATION OF A MODEL FOR Q/N RATIO

In order to obtain maximum information from the limited number of test runs the experiment was designed such that two separate analyses would have to be undertaken as indicated by the following diagram:

Table 1



The reason for this was that only in this way could balanced sets of data be obtained to take account of the quartzite block effect. Hence two Q/N ratio models were derived, one for low MFR's and one for high MFR's. Each data element of the depth of cut in quartzite was divided by the corresponding depth of cut in norite (according to parameter settings) as provided by the depth of cut model. Hence a series of Q/N ratios were obtained for analysis.

High Mass Flow Ratio Model (MFR = 0,05, 0,10, 0,20)

The effects which were found to be significant compared to the experimental (background) error were established, and a model derived which forms a prediction equation for Q/N ratio.

The following equation represents the best fit to the data and contains the effects found to be significant in affecting the Q/N ratio.

Q/N ratio = $1{,}064$	Mean for Experiment* (See note below)
$+0{,}034\ P$	Main effect of Pressure
$-0{,}038\ O + 0{,}051\ (O^2-2/3)$	Main Effect of Orifice
$-0{,}078\ R - 0{,}058\ (R^2-2/3)$	Main Effect of Ratio
$-0{,}053\ OR+0{,}102(O^2-2/3)R+0{,}109(R^2-2/3)O$	Interaction between Orifice and Ratio
$-0{,}130(P^2-2/3)(O^2-2/3)$	Interaction between Orifice and Pressure
$-0{,}094(P^2-2/3)R-0{,}078(R^2-2/3)P$	Interaction between Pressure and Ratio

where $P = -3{,}026 + 0{,}0101$ Pressure $+ 0{,}000033$ Pressure^2

$O = -3{,}4054 + 2{,}7027$ Orifice

$R = -2{,}3333 + 30$ Ratio $- 66{,}6667$ Ratio^2

Pressure is in MPa, Orifice is Diameter in mm, Ratio is Mass Flow Ratio in kg/kg and Exposure is Time Spent Slotting in minutes per metre of face.

The effect of Exposure was not found to be significant on Q/N ratio.

*** NOTE:**

The mean for the experiment (1,064) was not found to be exactly the same as the mean of 1,063 discussed in the "Determination of Q/N Ratio" section due to rounding differences between different computer packages.

This equation can now be used in conjunction with the log of depth of cut model derived from the earlier experimentation to calculate actual depth of cut in quartzite under different operating conditions. Having entered the different operating conditions under the log of depth of cut in norite model, and then antilogged to give the actual depth of cut in norite, then the equation derived above is used as a multiplicative factor to determine depth of cut in quartzite.

To simplify this:

Antilog (Log depth of cut in norite) x Q/N ratio

$$= \text{Depth of cut in norite} \times \frac{\text{Actual depth of cut in quartzite}}{\text{Actual depth of cut in norite}}$$

The two depth of cuts in norite cancel, leaving the actual depth of cut in quartzite. Although the equations are cumbersome, it should not be difficult to obtain a series of results by computing methods in order to pursue an economic analysis.

The following Analysis of Variance table may be drawn up to identify the amount of variability explained by the model.

Table 2

SOURCE	DEGREE OF FREEDOM	SUM OF SQUARES	MEAN SQUARE
Model (explained by operating parameters)	11	3,94	0,36
Error (background)	312	9,99	0,03
Total	323	13,93	0,043

The proportion of the variability accounted for by the model can be calculated as the Model Sum of Squares divided by Total Sum of Squares,

$$= \quad 3{,}94 + 13{,}93 = 0{,}283.$$

Therefore just over 28% of the variability is accounted for by the model.

Low Mass Flow Ratio Model (MFR = 0,025, 0,05, 0,10)

The following equation was found to be the best model of Q/N ratio at the low MFR's:

* Predicted Q/N ratio =

1,020	Mean for Experiment* (See note below)
$+0,048\ P$	Main effect of Pressure
$-0,029\ O + 0,128\ (O^2-2/3)$	Main Effect of Orifice
$-0,134\ R - 0,155\ (R^2-2/3)$	Main Effect of Ratio
$-0,053\ P\ O + 0,06(P^2-2/3)O - 0,110\ (O^2-2/3)P$	Interaction of Pressure and Orifice
$-0,041\ OR + 0,181(O^2-2/3)R - 0,121\ (R^2-2/3)O - 0,153(O^2-2/3)(R^2-2/3)$	Interaction of Orifice and Ratio
$-0,084\ (R^2-2/3)P$	Interaction of Ratio and Pressure
$+0,036\ OE$	Interaction of Orifice and Exposure

where $P = -3,026 + 0,0101\ \text{Pressure} + 0,000033\ \text{Pressure}^2$

$O = -3,4054 + 2,7027\ \text{Orifice}$

$R = -2,3333 + 60\ \text{Ratio} - 266,6667\ \text{Ratio}^2$

$E = -2 + 0,1\ \text{Exposure}$

The effect of Exposure (in an interaction) becomes significant on Q/N ratio at low MFR's.

* **NOTE:**

Since the earlier experimentation using norite as the target material was not conducted at low mass flow ratios, then the predicted depth of cut in norite is an extrapolated model. Since it is not advisable to do this and at the same time strongly believe in the result, then the result is a predicted (rather than actual) Q/N ratio (and it is in fact the best prediction at low MFR).

Therefore at low mass flow ratios we find that the predicted mean Q/N ratio is 1,020 and so we expect a 2% increase in depth of cut in quartzite over norite.

Despite the above note we can still use the predicted depth of cut in norite model and the predicted Q/N ratio to estimate actual depth of cut in quartzite as before.

$$\text{Predicted depth of cut in norite} \times \frac{\text{Actual depth of cut in quartzite}}{\text{Predicted depth of cut in norite}}$$

where the predicted ("predicted" because the norite model has been extrapolated) depths of cut in norite cancel out leaving the actual depth of cut in quartzite.

This may seem a long-winded method of determining a depth of cut model in quartzite at low mass flow ratios, but it should be remembered that at the same time the value of the (predicted) Q/N ratio is of interest, and computing methods make the determination relatively easy.

The following Analysis of Variance table is drawn up to identify the amount of variability explained by the model.

Table 3

SOURCE	DEGREE OF FREEDOM	SUM OF SQUARES	MEAN SQUARE
Model (explained by operating parameters)	15	11,65	0,78
Error (background)	308	8,85	0,03
Total	323	20,51	0,063

The proportion of the variability explained by the model is (11,65 ÷ 20,51) = 0,568.

Therefore nearly 57% of the variability is accounted for by the model.

Appendix 4

Statistical Analysis of Slurry Cutting Results

TABLE 1 : **SLURRY CUTTING DESIGNED EXPERIMENT 1 - FIRST EXPOSURE**

```
ADMIN. DETAILS                                   KEY:
    NO. OF REPLICATES =  4                        A IS  PRESSURE      B IS  STANDOFF
    NO. OF BLOCKS     =  4                        C IS  RATIO         D IS  ORIFICE
    NO. OF TRIALS     = 64
    NO. OF RESPONSES  =  1

    DATA FORMAT IS (11,13,711,1205.0)


RESPONSE: CUT DEPTH LOGARITHMS

DATA STATISTICS
  MEAN=  4.98241, VARIANCE=  0.10692

BARTLETT'S M=  -3.4750 +  3.4750 =   0.0000 WITH K=  1

CALCULATION OF ERROR VARIANCE
    SOURCE                S.S.      DF     M.S.

BETWEEN REPLICATES       0.28863    48    0.00601
 NAMED EFFECTS           0.03096     1    0.03096
    TOTAL                0.31959    49    0.00652

BETWEEN BLOCKS VAR.      0.00000     0    0.00000

  DATA     DEVIATION    NAME  FLAG     EFFECT        M.SQ.      F        SIGNIFICANT EFFECTS
                        ABCD                                             ON DEPTH OF CUT
18.12821 13.14580       0000
20.40162 15.41921       1000          0.58249      5.42971   832.341           A
18.43901 13.45660       0100         [illegible]   [illegible] 0.503
20.58413 15.60172       1100         [illegible]   0.00460     0.706
18.61427 13.63186       0010          0.04574      0.03347     5.132           C
20.40223 15.41982       1010         -0.03300      0.01743     2.672
18.61520 13.63279       0110          0.00364      0.00021     0.032
20.70147 15.71906       1110         -0.01733      0.00480     0.736
19.29512 14.31272       0001          0.22193      0.78808   120.830           D
21.67132 16.68891       1001          0.06419      0.06593    10.108           AD
18.56635 13.58394       0101         -0.06391      0.06535    10.020           BD
21.61950 16.63709       1101          0.00634      0.00064     0.099
19.27127 14.28886       0011         -0.00302      0.00015     0.022
21.88210 16.89969       1011          0.00102      0.00002     0.003
19.18782 14.20541       0111          0.01571      0.00395     0.605
21.49455 16.51214       1111    E    -0.04399      0.03096     4.747
```

TABLE 2 : **SLURRY CUTTING DESIGNED EXPERIMENT 1 - SECOND EXPOSURE**

```
ADMIN. DETAILS                                   KEY:
    NO. OF REPLICATES =  4                        A IS  PRESSURE      B IS  STANDOFF
    NO. OF BLOCKS     =  4                        C IS  RATIO         D IS  ORIFICE
    NO. OF TRIALS     = 64
    NO. OF RESPONSES  =  1

    DATA FORMAT IS (11,13,711,1205.0)


RESPONSE: CUT DEPTH LOGARITHMS

DATA STATISTICS
  MEAN=  5.50382, VARIANCE=  0.39979

BARTLETT'S M=  -6.8312 +  6.8312 =   0.0000 WITH K=  1

CALCULATION OF ERROR VARIANCE
    SOURCE                S.S.      DF     M.S.

BETWEEN REPLICATES       0.51045    48    0.01063
 NAMED EFFECTS           0.00108     1    0.00108
    TOTAL                0.511[illegible] 49    0.01044

BETWEEN BLOCKS VAR.      0.00000     0    0.00000

  DATA     DEVIATION    NAME  FLAG     EFFECT        M.SQ.      F        SIGNIFICANT EFFECTS
                        ABCD                                             ON DEPTH OF CUT
20.33754 14.83372       0000
22.47842 16.97460       1000          0.53800      4.63119   443.629           A
20.51548 15.01165       0100          0.02623      0.01101     1.054
22.66002 17.15620       1100          0.02809      0.01263     1.210
20.52014 15.01632       0010          0.07162      [illegible] 7.862           C
22.38623 16.88241       1010         -0.03700      [illegible] 2.098
21.03917 15.53535       0110          0.01913      [illegible] 0.561
22.51137 17.00755       1110         -0.01663      [illegible] 0.424
21.25704 15.75322       0001          0.22961      [illegible] 80.807           D
23.35840 17.85456       1001          0.06152      [illegible] 5.801           AD
20.77805 15.27423       0101         -0.03651      0.02132     2.042
23.59135 18.08753       1101          0.05248      0.04407     4.221           ABD
21.65727 16.[illegible]5345  0011     0.04253      0.02894     2.772
23.70754 18.20372       1011          0.02220      0.00788     0.755
21.40944 15.90562       0111          0.00134      0.00003     0.003
24.03695 18.53313       1111    E     0.00821      0.00108     0.103
```

TABLE 3 : **MEAN RESPONSE AND MAIN EFFECTS - FIRST EXPOSURE**

		ORIFICE	
		0	1
		DEPTH OF CUT (MM)	DEPTH OF CUT (MM)
		MEAN	MEAN
PRESSURE	STANDOFF DISTANCE		
0	0	99.00	124.13
	1	102.75	113.38
1	0	164.25	232.13
	1	174.88	219.13

VARIABLE	MAIN EFFECT ON DEPTH OF CUT OF INCREASING FROM LOW TO HIGH SETTING (MM)	STATISTICAL SIGNIFICANCE
PRESSURE	87.78	>99.9% (SIG.)
ORIFICE	36.97	>99.9% (SIG.)
RATIO	5.34	>95.0% (SIG.)
STANDOFF	− 2.34	<80.0% (NOT SIG.)

TABLE 4 : **MEAN RESPONSE AND MAIN EFFECTS - SECOND EXPOSURE**

		ORIFICE	
		0	1
		DEPTH OF CUT (MM)	DEPTH OF CUT (MM)
		MEAN	MEAN
PRESSURE	STANDOFF DISTANCE		
0	0	165.63	214.50
	1	180.75	196.38
1	0	272.88	360.13
	1	300.00	387.25

VARIABLE	MAIN EFFECT ON DEPTH OF CUT OF INCREASING FROM LOW TO HIGH SETTING (MM)	STATISTICAL SIGNIFICANCE
PRESSURE	140.75	>99.9% (SIG.)
ORIFICE	59.75	>99.9% (SIG.)
RATIO	21.88	>99.0% (SIG.)
STANDOFF	12.81	<80.0% (NOT SIG.)

TABLE 5 : ANGLE OF ATTACK EXPERIMENTS

```
                             ANALYSIS OF VARIANCE

                          SUM OF          MEAN
SOURCE        DF         SQUARES         SQUARE         F VALUE        PROB>F

MODEL          2      172683.62    86341.81101         266.781        0.0001
ERROR        109    35277.15476      323.64362
C TOTAL      111      207960.78

      ROOT MSE          17.9901       R-SQUARE          0.8304
      DEP MEAN         194.3304       ADJ R-SQ          0.8273
      C.V.             9.257482

                            PARAMETER ESTIMATES

                      PARAMETER         STANDARD       T FOR H0:
VARIABLE   DF          ESTIMATE            ERROR     PARAMETER=0        PROB > |T|

INTERCEP    1         222.53879       2.28178057          97.529            0.0001
ANGLE       1        0.68942672       0.05230413          13.181            0.0001
ANGLESQ     1       -0.02650075      0.001439319         -18.481            0.0001
```

TABLE 6 : QUARTZITE ABRASIVE - FIRST EXPOSURE

```
 ADMIN. DETAILS                          KEY:
     NO. OF REPLICATES =  4                A IS  STANDOFF       B IS  RATIO
     NO. OF BLOCKS     =  4                C IS  ORIFICE              EXPOSURE
     NO. OF TRIALS     = 32
     NO. OF RESPONSES  =  1

     DATA FORMAT IS (I1,I3,7I1,12D5.0)

RESPONSE: CUT DEPTH LOGARITHMS

DATA STATISTICS
  MEAN=  4.73823, VARIANCE=  0.01251

CALCULATION OF ERROR VARIANCE
     SOURCE                S.S.      DF     M.S.

BETWEEN REPLICATES       0.07307    24    0.00304
 NAMED EFFECTS           0.00000     0    0.00000
    TOTAL                0.07307    24    0.00304

BETWEEN BLOCKS VAR.      0.00000     0    0.00000
                                                                        SIGNIFICANT EFFECT
   DATA    DEVIATION      NAME  FLAG     EFFECT        M.SQ.       F    ON DEPTH OF CUT
                          ABC
 18.34865 13.61042        000
 18.27874 13.54051        100           0.00236      0.00004    0.015
 18.99599 14.25776        010           0.06805      0.03704   12.168         B
 18.95131 14.21308        110           0.02912      0.00679    2.229
 19.39207 14.65384        001           0.15463      0.19127   62.826         C
 19.24786 14.50963        101           0.01668      0.00223    0.731
 19.05613 14.31790        011          -0.09694      0.07518   24.694         BC
 19.35266 14.61442        111           0.02597      0.00539    1.772
```

TABLE 7 : QUARTZITE ABRASIVE - SECOND EXPOSURE

```
SUBJECT: QUARTZITE SLURRY CUTTING DES. EXPT. AT SURFACE - 2ND EXPOSURE

 ADMIN. DETAILS                          KEY:
     NO. OF REPLICATES =  4                A IS  STANDOFF      B IS  RATIO
     NO. OF BLOCKS     =  4                C IS  ORIFICE
     NO. OF TRIALS     = 32
     NO. OF RESPONSES  =  1

     DATA FORMAT IS (I1,I3,7I1,12D5.0)

RESPONSE: CUT DEPTH LOGARITHMS

DATA STATISTICS
  MEAN=  5.25638, VARIANCE=  0.01295

CALCULATION OF ERROR VARIANCE
     SOURCE                 S.S.      DF     M.S.

BETWEEN REPLICATES        0.07850    24   0.00327
 NAMED EFFECTS            0.00000     0   0.00000
    TOTAL                 0.07850    24   0.00327

BETWEEN BLOCKS VAR.       0.00000     0   0.00000
                                                                             SIGNIFICANT EFFECT
   DATA     DEVIATION     NAME  FLAG     EFFECT        M.SQ.      F          ON DEPTH OF CUT
                          ABC
 20.22437 14.96799        000
 20.54162 15.38524        100            0.02169     0.00376     1.151
 21.15258 15.89620        010            0.07825     0.04899    14.978                B
 20.88583 15.62944        110           -0.00384     0.00012     0.036
 21.41153 16.15515        001            0.14971     0.17931    54.820                C
 21.19855 15.94216        101            0.00248     0.00007     0.020
 21.14010 15.88372        011           -0.06830     0.03732    11.408                BC
 21.54963 16.29324        111            0.08165     0.05334    16.308                ABC Confounded with
                                                                                          block effect
```

TABLE 8 : MEAN RESPONSE AND MAIN EFFECTS - FIRST EXPOSURE

```
-----------------------------------------------------------
|                                |        ORIFICE         |
|                                |------------------------|
|                                |     0     |     1      |
|                                |-----------+------------|
|                                |DEPTH OF CUT|DEPTH OF CUT|
|                                |-----------+------------|
|                                |    MEAN   |    MEAN    |
|--------------------------------+-----------+------------|
|MASS FLOW RATIO                 |           |            |
|--------------------------------|           |            |
|0                               |      97.53|      125.38|
|--------------------------------+-----------+------------|
|1                               |     114.88|      121.75|
-----------------------------------------------------------

-------------------------------------------------------------
| VARIABLE  |  MAIN EFFECT ON DEPTH OF   | STATISTICAL       |
|           |  CUT OF INCREASING FROM    | SIGNIFICANCE      |
|           |  LOW TO HIGH SETTING (MM)  |                   |
|-----------+----------------------------+-------------------|
| ORIFICE   |          17.31             | >99.9% (SIG.)     |
|-----------+----------------------------+-------------------|
| RATIO     |           6.81             | >99.0% (SIG.)     |
|-----------+----------------------------+-------------------|
| STANDOFF  |           0.56             | <80.0% (NOT SIG.) |
-------------------------------------------------------------
```

TABLE 9 : **MEAN RESPONSE AND MAIN EFFECTS - SECOND EXPOSURE**

	ORIFICE	
	0	1
	DEPTH OF CUT	DEPTH OF CUT
	MEAN	MEAN
MASS FLOW RATIO		
0	165.63	205.88
1	192.00	208.38

VARIABLE	MAIN EFFECT ON DEPTH OF CUT OF INCREASING FROM LOW TO HIGH SETTING (MM)	STATISTICAL SIGNIFICANCE
ORIFICE	28.31	>99.9% (SIG.)
RATIO	14.44	>99.9% (SIG.)
STANDOFF	3.69	<80.0% (NOT SIG.)

TABLE 10 : **CHROMITE ABRASIVE RECYCLING**

```
     NON-LINEAR REGRESSION MODEL OF THE FORM DOC=A+B*EXP(C*CUTNO)

NON-LINEAR LEAST SQUARES SUMMARY STATISTICS      DEPENDENT VARIABLE DOC

    SOURCE                  DF SUM OF SQUARES      MEAN SQUARE

    REGRESSION               3  162446.20662       54148.73554
    RESIDUAL                17    2737.79338         161.04667
    UNCORRECTED TOTAL       20  165184.00000

    (CORRECTED TOTAL)       19   23054.20000

    PARAMETER       ESTIMATE      ASYMPTOTIC              ASYMPTOTIC 95 %
                                  STD. ERROR            CONFIDENCE INTERVAL
                                                        LOWER          UPPER
    A              51.0436575    8.327474567    33.47432046    68.61298452
    B             197.6884956   36.380176213   120.93368480   274.44350514
    C              -0.7718722    0.216370518    -1.22837158    -0.31537277


           ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS

      CORR                A                B                C

      A              1.0000           0.5897          -0.8703
      B              0.5897           1.0000          -0.8752
      C             -0.8703          -0.8752           1.0000
```

TABLE 11 : **QUARTZITE ABRASIVE RECYCLING**

```
LINEAR REGRESSION MODEL OF THE FORM DOC=A+B*CUTNO

                         ANALYSIS OF VARIANCE

                      SUM OF          MEAN
SOURCE      DF       SQUARES        SQUARE        F VALUE       PROB>F

MODEL        1     384.40000     384.40000          7.250       0.0149
ERROR       18     954.40000   53.02222222
C TOTAL     19    1338.80000

    ROOT MSE        7.281636      R-SQUARE         0.2871
    DEP MEAN            48.4      ADJ R-SQ         0.2475
    C.V.             15.0447

                         PARAMETER ESTIMATES

                   PARAMETER        STANDARD       T FOR HO:
VARIABLE  DF        ESTIMATE           ERROR     PARAMETER=0      PROB > |T|

INTERCEP   1     57.70000000      3.81852211          15.111          0.0001
CUTNO      1     -3.10000000      1.15132774          -2.693          0.0149
```

TABLE 12 : **IRON GRIT 75 ABRASIVE RECYCLING**

```
QUADRATIC REGRESSION MODEL OF THE FORM DOC=A+B*CUTNO+C*CUTNO**2

                         ANALYSIS OF VARIANCE

                      SUM OF          MEAN
SOURCE      DF       SQUARES        SQUARE        F VALUE       PROB>F

MODEL        2    3106.66200    1553.33100         21.800       0.0001
ERROR       41    2921.33800   71.25214623
C TOTAL     43    6028.00000

    ROOT MSE        8.441099      R-SQUARE         0.5154
    DEP MEAN              91      ADJ R-SQ         0.4917
    C.V.            9.275933

                         PARAMETER ESTIMATES

                   PARAMETER        STANDARD       T FOR HO:
VARIABLE  DF        ESTIMATE           ERROR     PARAMETER=0      PROB > |T|

INTERCEP   1     69.24242424      4.63504063          14.939          0.0001
CUTNO      1      5.49625175      1.77525695           3.097          0.0035
CUTNOSQ    1     -0.24417249      0.14408718          -1.695          0.0977
```

TABLE 13 : **REPLENISHING WITH IRON GRIT ES ABRASIVE**

```
                   SLURRY REPLENISHING WITH IRON GRIT ES ABRASIVE
INVERSE NEGATIVE EXPONENTIAL MODELLING DEPTH OF CUT AGAINST NUMBER OF REPLENISHMENTS

      NON-LINEAR LEAST SQUARES SUMMARY STATISTICS      DEPENDENT VARIABLE DOC

         SOURCE                  DF  SUM OF SQUARES      MEAN SQUARE

         REGRESSION               3    568158.59962     189386.19987
         RESIDUAL                49      3546.40038         72.37552
         UNCORRECTED TOTAL       52    571705.00000

         (CORRECTED TOTAL)       51      4896.51923

         PARAMETER      ESTIMATE     ASYMPTOTIC              ASYMPTOTIC 95 %
                                     STD. ERROR           CONFIDENCE INTERVAL
                                                          LOWER         UPPER
         A           91.69843135   3.6166418834   84.430533399   98.966329297
         B           16.06935864   7.3574094735    1.284123350   30.854593939
         C            0.36574346   0.0344014457    0.296611319    0.434875601


                ASYMPTOTIC CORRELATION MATRIX OF THE PARAMETERS

            CORR                 A                  B                  C

            A               1.0000            -0.8281             0.4449
            B              -0.8281             1.0000            -0.8378
            C               0.4449            -0.8378             1.0000
```

Appendix 5

Sieve Analyses for Abrasive Recycling Testwork

Table 1 : **Mass Distribution by Size Band for Successive Cycles of Use (%)**

Abrasive: SS Unh 2A

S[illegible]-BAND	MID POINT	NEW		AFTER 1 CYCLE		AFTER 2 CYCLES		AFTER 3 CYCLES		AFTER 4 CYCLES
+ [illegible]	1 075	19,33		13,97		13,36		13,96		13,46
- 1 000 + 850	925	27,92		23,24		27,50		27,08		27,93
- 850 + 710	780	18,36		17,29		17,82		20,02		20,78
- 710 + 600	655	13,54		12,59		13,44		14,05		14,30
- 600 + 500	550	3,35		8,06		9,20		8,26		8,02
- 500 + 425	462,5	4,22		[illegible]		5,06		3,97		3,52
- 425 + 300	362,5	4,41		5,88		5,88		3,89		[illegible]
- 300 + 212	256	1,59		3,29		3,07		1,64		1,50
- 212 + 150	181	0,66		2,11		2,04		1,13		1,01
- 150 + 75	112,5	0,48		2,06		3,04		1,55		1,66
- 75 + 38	56,5	0,19		3,47		[illegible]		2,72		2,48
- 38	19,5	0,06		2,02		1,22		1,72		1,76

WEIGHTED MEAN SIZE (µm)		790,0		695,4		699,9		736,5		741,4

Table 2 : **Mass Distribution by Size Band for Successive Cycles of Use (%)**

Abrasive: C1 D4 2A

SIZE-BAND (µm)	MID POINT	NEW		AFTER 1 CYCLE		AFTER 2 CYCLES		AFTER 3 CYCLES		AFTER 4 CYCLES		AFTER 5 CYCLES
+ 1 000	1 075	24,37		23,45		15,87		14,92		14,09		13,06
- 1 000 + 850	925	40,99		27,48		29,19		27,53		24,41		24,81
- 850 + 710	780	22,13		17,79		20,66		20,00		18,28		18,98
- 710 + 600	655	9,39		10,89		13,70		13,87		13,65		14,10
- 600 + 500	550	2,19		5,56		7,79		8,13		8,76		9,12
- 500 + 425	462,5	0,42		2,82		3,70		4,04		4,47		4,39
425 + 300	362,5	0,26		3,15		2,72		3,32		5,25		4,78
- 300 + 212	256	0,08		1,77		1,36		1,46		2,60		2,39
- 212 + 150	181	0,05		[illegible]		0,79		[illegible]		1,63		1,53
- 150 + 75	112,5	0,04		1,03		1,17		1,57		2,15		2,62
- 75 + 38	56,5	0,06		2,87		1,47		2,87		2,73		2,15
- 38	19,5	0,02		2,02		0,65		1,32		1,97		2,07

WEIGHTED MEAN SIZE (µm)		890,6		781,2		779,0		746,4		711,1		711,5

Table 3 : Mass Distribution by Size Band for Successive Cycles of Use (%)

Abrasive: SS 280 2A

SIZE-BAND (µm)	MID POINT	NEW		AFTER 1 CYCLE		AFTER 2 CYCLES		AFTER 3 CYCLES		AFTER 4 CYCLES		AFTER 5 CYCLES
+ 1 000	1 075	9,71	10	36,62		31,52		29,74		26,93		31,85
- 1 000 + 850	925	52,23	2	34,67		36,00		35,37		33,42		28,80
- 850 + 710	780	29,39	19	18,76		19,83		20,08		19,80		18,75
- 710 + 600	655	7,69		5,86		6,93		7,34		8,38		8,06
- 600 + 500	550	0,79		0,79		1,16		1,51		2,32		2,67
- 500 + 425	462,5	0,10		0,23		0,42		0,64		1,14		1,33
- 425 + 300	362,5	0,02		1,23		0,45		0,79		1,35		1,63
- 300 + 212	256	0,01		0,16		0,28		0,48		0,80		0,98
- 212 + 150	181	0,02		0,[illegible]		0,29		0,45		0,67		0,87
- 150 + 75	112,5	0,02		0,46		0,21		0,53		1,66		1,45
- 75 + 38	56,5	0,03		0,69		1,73		2,73		2,03		2,20
- 38	19,5	0,01		0,77		1,08		0,34		1,49		1,38

WEIGHTED MEAN SIZE (µm)		872,1		907,1		885,3		867,0		837,5		841,9

Table 4 : Mass Distribution by Size Band for Successive Cycles of Use (%)

Abrasive: SS HARD 2A

SIZE-BAND (µm)	MID POINT	NEW		AFTER 1 CYCLE		AFTER 2 CYCLES		AFTER 3 CYCLES		AFTER 4 CYCLES
+ 1 000	1 075	30,55		25,98		21,99		19,87		17,51
- 1 000 + 850	925	27,21		27,67		28,80		29,37		30,34
- 850 + 710	780	15,52		17,03		17,57		18,04		18,85
- 710 + 600	655	10,08		10,93		11,37		11,78		12,82
- 600 + 500	550	5,75		5,92		5,57		5,41		6,12
- 500 + 425	462,5	2,79		3,26		2,83		2,45		2,96
- 425 + 300	362,5	3,40		3,31		3,17		3,05		3,43
- 300 + 212	256	1,54		1,07		1,59		1,51		1,60
- 212 + 150	181	1,30		1,01		1,09		1,09		1,08
- 150 + 75	112,5	1,[illegible]		1,10		1,42		1,91		1,77
- 75 + 38	56,5	0,68		1,50		2,50		2,48		2,31
- 38	19,5	0,16		0,60		2,01		2,54		1,20

WEIGHTED MEAN SIZE (µm)		831,7		806,1		779,7		769,8		769,2

TABLE 5 : MASS DISTRIBUTION BY SIZE BAND FOR SUCCESSIVE CYCLES OF USE (%)

Abrasive : C1 822 2A

SIZE-BAND (µm)	MID POINT	NEW		AFTER 1 CYCLE		AFTER 2 CYCLES		AFTER 3 CYCLES		AFTER 4 CYCLES		AFTER 5 CYCLES
+ 1 000	1 075	11,26	11	17,82		17,94		17 55		13,05		14,59
- 1 000 + 850	925	43,70	37	40,96		40,63		41,00		40,14		38,60
- 850 + 710	780	27,00	23	21,61		20,57		19,75		20,31		19,62
- 710 + 600	655	15,19		12,48		12,16		11,15		12,48		12,14
- 600 + 500	550	2 28		2,51		2,70		2,93		4,50		5,20
- 500 + 425	462,5	0,38		0,92		1,04		1,21		2,10		2,38
- 425 + 300	362,5	0,12		0,80		1,18		1,33		2,29		2,37
- 300 + 212	256	0,02		0,44		0,52		0,60		1,10		1,04
- 212 + 150	181	0,01		0,32		0,33		0,43		0,67		0,68
- 150 + 75	112,5	0,01		1,08		0,61		0,71		0 63		1,19
- 75 + 38	56,5	0 04		1,57		1,30		1,76		1,64		1,27
- 38	19,5	0,01		0,07		1,01		1,57		1.09		0,93

WEIGHTED MEAN SIZE (µm)		850,2		840,9		836,3		825,9		800,4		800,7

TABLE 6 : RECYCLING OF CHROMITE - MASS DISTRIBUTION BY SIZE FOR SUCCESSIVE CYCLES

MESH SIZE BAND (µm)	MID POINT	NEW (% RET)		AFTER 1 CYCLE (% RET)		AFTER 2 CYCLES (% RET)		AFTER 3 CYCLES (% RET)		AFTER 4 CYCLES (% RET)		AFTER 5 CYCLES (% RET)
+ 1000	1075	0.6		0.3		0.1		0.0		0.1		0.3
- 1000 + 850	925	0.6		0.7		0.2		0.1		0.1		0.3
- 850 + 710	780	11.3		1.3		0.3		0.2		0.2		0.3
- 710 + 600	655	15.1		2.5		0.8		0.5		0.5		0.5
- 600 + 500	550	16.3		4.3		1.4		0.8		0.7		0.7
- 500 + 425	462.5	13.1		5.2		2.2		1.2		[illegible]		0.9
- 425 + 300	362.5	19.3		14.2		7.9		4.9		3.6		3.2
- 300 + 212	256	6.2		14.8		12.2		9.5		7.0		6.4
- 212 + 150	181	1.3		13.6		14.5		14.0		12.1		10.8
- 150 + 75	112.5	0.2		25.9		37.0		41.8		46.7		59.2
- 75 + 38	56.5	0.0		13.8		16.5		19		21.9		14.3
- 38	19.5	0.0		5.2		7.0		7.1		6.1		3.2
WEIGHTED MEAN SIZE (µm)		597.70		234.30		166.81		142.73		133.82		142 46

MESH SIZE RANGE (µm)	MID POINT	NEW (% RET)	AFTER 1 CYCLE (% RET)	AFTER 2 CYCLES (% RET)	AFTER 3 CYCLES (% RET)	AFTER 4 CYCLES (% RET)	AFTER 5 CYCLES (% RET)
+ 1000	1075	23.3	3.2	0.9	0.3	0.2	0.1
- 1000 + 850	925	14.7	4.6	1.9	0.9	0.4	0.3
- 850 + 710	780	14.0	4.9	[illegible]	1.3	0.8	0.5
- 710 + 600	655	14.7	7.1	3.9	2.3	1.6	1.0
- 600 + 500	550	16.1	9.0	5.7	3.4	2.4	1.7
- 500 + 425	462.5	10.1	9.4	6.3	4.3	3.4	2.6
- 425 + 300	362.5	4.9	17.1	15.3	12.0	10.3	8.[illegible]
- 300 + 212	256	0.7	12.7	15.5	16.0	15.4	13.0
- 212 + 150	181	0.2	9.4	13.6	16.3	18.0	17.3
- 150 + 75	112.5	0.4	14.2	23.9	28.6	33.5	37.0
- 75 + 38	56.5	0.7	6.5	8.3	11.1	11.2	14.7
- 38	19.5	0.0	2.0	2.0	3.1	2.8	2.8
WEIGHTED MEAN SIZE (µm)		[illegible]0.11	386.20	284.18	229.64	205.45	181.37

TABLE 7 : RECYCLING OF QUARTZITE - MASS DISTRIBUTION BY SIZE FOR SUCCESSIVE CYCLES

MESH SIZE RANGE (µm)	MID POINT	NEW (% RET)	AFTER 1 CYCLE (% RET)	AFTER 2 CYCLES (% RET)	AFTER 3 CYCLES (% RET)	AFTER 4 CYCLES (% RET)	AFTER 5 CYCLES (% RET)	AFTER 6 CYCLES (% RET)	AFTER 7 CYCLES (% RET)	AFTER 8 CYCLES (% RET)	AFTER 9 CYCLES (% RET)	AFTER 10 CYCLES (% RET)	AFTER 11 CYCLES (% RET)
+ 1000	1075	[illegible]	0.3	[illegible]	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2
- 1000 + 850	925	0.8	0.9	0.6	0.9	0.6	0.6	0.3	0.5	0.6	0.9	0.8	0.7
- 850 + 710	780	1.6	2.4	1.0	1.9	1.0	0.9	[illegible]	0.6	0.6	0.8	0.7	0.7
- 710 + 600	655	[illegible]	5.8	3.1	4.3	4.0	4.2	3.6	3.1	3.0	3.6	3.3	3.2
- 600 + 500	550	17.4	14.6	10.6	10.4	13.0	8.9	8.2	7.3	7.7	8.7	8.1	8.6
- 500 + 425	462.5	17.7	14.8	12.1	13.3	10.7	11.7	[illegible]	10.1	10.4	11.4	10.7	12.3
- 425 + 300	362.5	[illegible]	27.2	[illegible]	27.6	27.8	28.9	28.3	28.2	28.6	29.9	28.9	30.8
- 300 + 212	256	13.6	16.9	21.0	20.4	21.2	22.9	24.0	23.3	24.0	24.2	25.1	25.1
- 212 + 150	181	6.0	6.7	9.2	9.1	10.2	14.3	12.5	13.3	13.6	11.8	12.0	13.2
- 150 + 75	112.5	2.3	4.8	5.6	8.2	6.9	9.1	9.3	10.1	10.1	7.7	8.0	8.0
- 75 + 38	56.5	0.6	1.7	2.6	1.4	1.3	1.0	0.8	0.8	0.8	0.5	0.7	0.7
- 38	19.5	0.3	0.8	0.5	0.4	0.3	0.3	0.2	0.2	0.3	0.2	0.3	0.3
WEIGHTED MEAN SIZE (µm)		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 8 : RECYCLING OF IRON GRIT E5 - MASS DISTRIBUTION BY SIZE FOR SUCCESSIVE CYCLES

Appendix 6

A Typical Financial Evaluation of a Slot Based Non-Explosive Mining System

Table 1 : Inputs

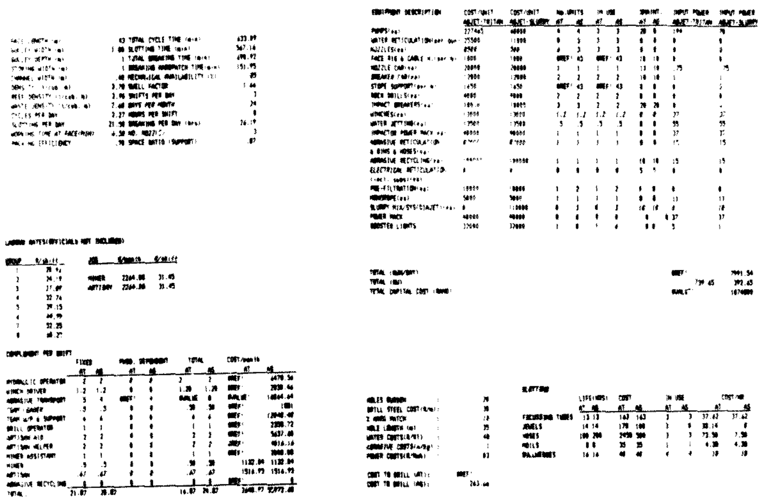


Table 2 : Models

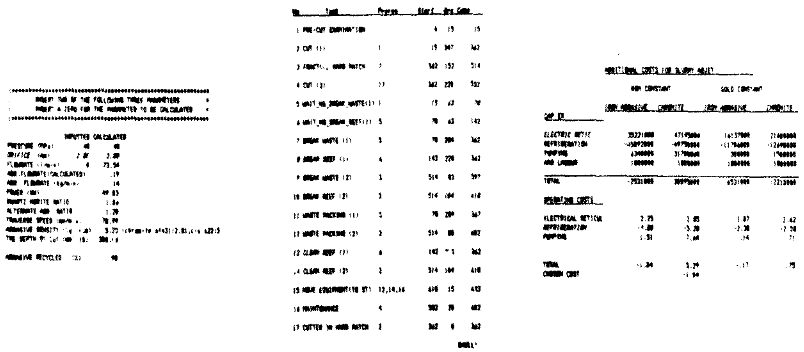


Table 3 : Outputs

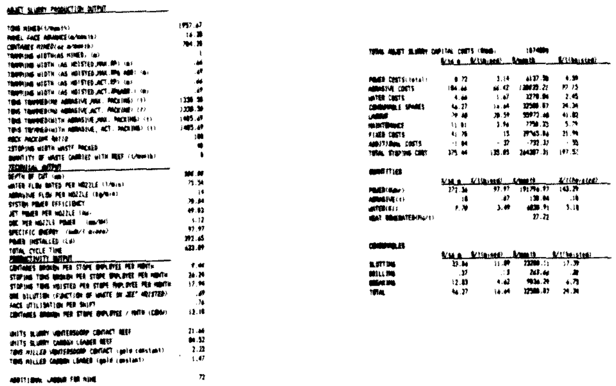


Table 4 : Goldplan

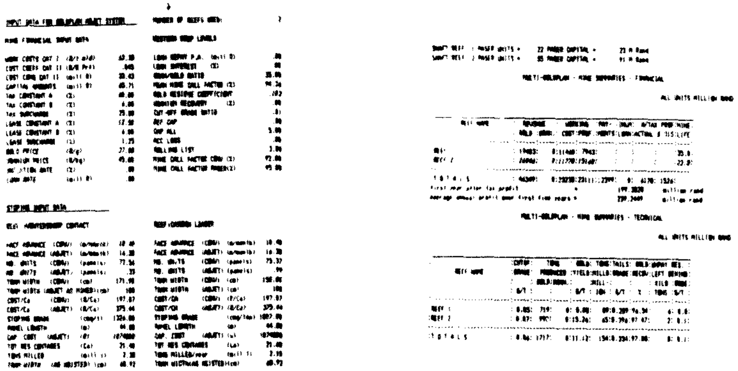


Table 3 : Outputs

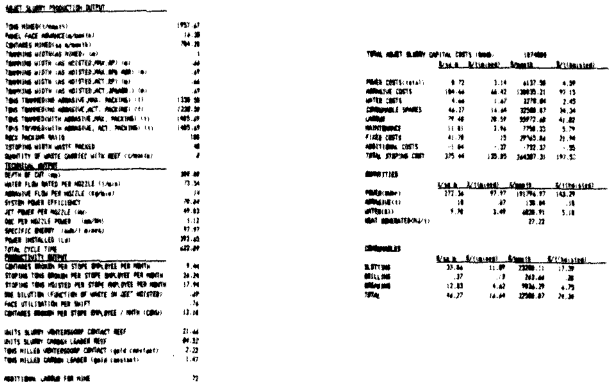
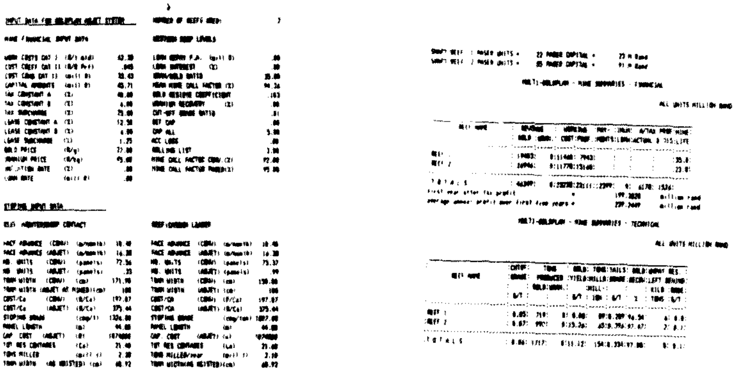


Table 4 : Goldplan



Author Dunn Paul Gregory
Name of thesis The Non-explosive Mechanisation Of The South African Gold Mine Stoping Operation. 1989

PUBLISHER:
University of the Witwatersrand, Johannesburg