Safety in Mines Research Advisory Committee

Final Report

Investigation of dry drilling in the mining of kimberlite deposits and pollutant control during such drilling

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Executive Summary

Dry drilling is not permissible under South African mining regulations. However, due to the physical and chemical properties of kimberlite, water has been found to have undesirable effects on blue ground, causing swelling and disintegration. Consequently, no water is used in drilling operations within a blue ground pipe.

This investigation was conducted over a twelve-month period and covered both large and small-scale mining operations with their different mining methods. The five mines surveyed are considered to be representative of the range of deposits found and the methods used in the mining of kimberlite in South Africa, and therefore include the major geological occurrences encountered underground for kimberlite deposits.

An international literature search failed to turn up any direct references to dry drilling practices and dust control. It cannot be concluded that dry drilling is not practised anywhere else in the world, merely that such practices have not been specifically reported on. Mining techniques or methods are described without any reference to pollutant control. This situation is similar to the absence of reporting on noise levels at rock drills.

Point or stationary gravimetric dust samples were collected primarily at and during drilling operations. Mass concentrations were determined and, in addition, the quartz content was assessed, but mainly for the samples collected at the return air positions. The total toxin index (TTI), i.e. the summation of pollutant indices for the quartz and non-quartz fractions of the samples, was computed as recommended in the *Guidelines for Gravimetric Dust Sampling* issued by the Department of Minerals and Energy (DME). These TTIs were used to compare levels of dustiness in workplaces and the effectiveness of dust control measures. However, because of the unpredictable and variable nature of quartz concentrations, it is considered that measured dust concentrations rather than TTIs will provide a better method of comparison for evaluating control measures.

Although point sampling does not equate to measuring personal exposure levels over a full shift, it does provide a measure of workplace dust levels and, if workplace dust levels can be controlled, it follows that personal exposure levels will also be controlled. People at the working face who work in atmospheres that are heavily polluted with dust, even if not for the entire shift, are being exposed to unhealthy working conditions. Although the eight-hour Time Weighted Average (TWA) dust concentrations may not be significantly

elevated, these workers could nevertheless be exposed to very high dust levels for short periods of time. These are known as "peak exposure levels" and the role of peak exposures in the development of lung disease is receiving increasing attention. If it is assumed that, for example, machine operators are exposed to very high dust concentrations for only a quarter of the shift and that no further dust is inhaled for the rest of the shift, approximate eight-hour TWA dust concentrations can be derived by multiplying the dust concentrations point-sampled at the face by 0,25. In many instances these derived eight-hour TWAs were still found to be unacceptably high.

For various reasons it was not possible to test the effectiveness of surfactants or wetting agents for dust control during the investigation; instead the researchers had to rely on reports from mines on why surfactants are not used. This is the same situation as for air mist drilling.

It was also not possible to test the effectiveness of dust control equipment in the large, mechanised mines because the personnel would not disconnect the devices for tests, even for short periods. Conditions with and without such devices could therefore not be measured directly. Nevertheless, an idea of the potential dust generation without dust control measures could be obtained when a dust control device malfunctioned or else was not correctly applied. Obviously, this did not often happen and therefore conditions in the workplaces had to be evaluated by normal assessment methods, taking into account dust loadings and quartz content. In terms of this type of evaluation, conditions in workplaces in the large excavations in blue ground were found to be acceptable.

Kimberlite does not occur only in large vertical pipes but also in narrow fissures or veins. Clearly, different mining methods have to be used for the different types of deposits and this is also the case with the methods used for dust control. In the large excavations, as found in the big vertical pipes, dust control at the point of generation is favoured and was largely found to be effective if diligently applied. The equipment used also requires maintenance of a very high standard and conscientious application to ensure that the dust generated during drilling is kept under control. Although this method of dust control has mostly been found to be effective, an improper seal between the extraction cowl (through which drilling takes place) and the working face, due to the contour of the face or to interference by the safety mesh, does allow dust to escape into the work environment. Better methods of sealing with the face being drilled need to be developed. However, this method of dust capture, which involves bulky equipment and is usually associated with mechanised mining and relatively short suction pipes, cannot be considered to be practical in narrow, vertical stopes. Where percussion drills are used in the pipe deposits, ventilation is also used for the dilution and removal of dust, and although ventilation fans and columns are used, this method was found to be ineffective in controlling the exposure of personnel to high dust concentrations. In the narrow stopes of fissure mining, there is heavy reliance on ventilation for the dilution and removal of dust-laden air.

"Natural ventilation" is the preferred and permitted method used to ventilate the workings, but this technique cannot and should not be regarded as either effective or acceptable. Depending on temperatures and other factors, airflow directions can reverse and air movement may even cease altogether, in which case the removal (and dilution) of pollutants from the workings will be non-existent. Controlled ventilation through the use of main or booster fans is largely deemed to be impossible due to the presence of extensive worked-out honeycombs, which would result in either the recirculation of air or the short-circuiting of air, depending on the location of the fan within the workings.

Mines exploiting pipe deposits face a similar problem, although not to the same extent as the fissure mines. A positive ventilation pressure is needed at all times where underground workings connect with the open hole. If this positive pressure is not maintained, air flow reversals can occur, in which case dust control measures can be by-passed and polluted air can be carried into the workings and then contaminate other areas by raising the levels of pollutants in the intake air. The establishment and maintenance of positive ventilation pressures at the open hole interface should receive careful consideration.

As a result of the largely uncontrolled dust generation in fissure kimberlite mining operations, dust concentrations in excess of 100 mg/m^3 were measured in some instances. This in turn led to very high pollutant indices (PI) and, coupled with a sometimes high quartz content in the dust, yielded very high total toxin indices (TTIs).

The situation is greatly exacerbated where workings are series-ventilated. In such instances highly polluted air exiting from one working place can become the intake air to the next workplace in the ventilation sequence. This then leads to the superimposition of one dense dust cloud on another and to increasingly unacceptable workplace conditions.

Although dry mining is practised because it is claimed that water has adverse effects on the blue ground, in one fissure stope the ingress of water due to the intersection with natural underground water sources did not appear to have had any deleterious effects on the kimberlite vein or on the production levels in this workplace, and this aspect warrants further investigation. It must, however, be noted that travelling in such narrow, vertical stopes that are very wet must be regarded as extremely dangerous, but no more so than for other mining sectors which mine vertical or near-vertical deposits. Since naturally occurring water was not considered to be a problem in a specific narrow seam, with regard to either the kimberlite or the production rate, this aspect should be further researched. From the results of this investigation it is apparent that the workforce in the fissure mines is being exposed to considerably higher dust concentrations than that in the pipe deposit mines.

Whereas there may be some justification for drilling dry in the blue ground, there are no obvious reasons why all drilling in country rock should not be carried out with water.

In fissure mining it is obvious that in the first instance controlled ventilation systems are required to dilute and remove dust from the workings. In the second instance, the capture, containment and removal of dust generated during dry drilling should be researched on an industry basis since no single "small" mine or mining group is likely to be able to fund such a project alone.

The United States Bureau of Mines (USBM) has reported remarkable success in reducing dust from drilling under controlled test conditions through the use of polycrystalline drill bits. However, this was for a rotary drill configuration and loose drill bits – a configuration not used in South African diamond mines. Nevertheless, this aspect should also be researched, but it should be noted that this measure on its own is unlikely to be able to prevent high exposure levels. If rotary drilling coupled with the use of polycrystalline drill bits and other additional dust control measures can assist in reducing dust emission levels, the introduction of this drilling technique should receive serious consideration and needs researching.

Even if the problems of the generation of high concentrations of dust due to drilling dry can be successfully addressed, it must be borne in mind that essentially the mining process itself is dry, not just the drilling. Consequently, ore is moved and handled dry from the mining face to the tip. Thus, other processes such as dry lashing may also be responsible for high dust levels as was found at some test sites. Although the handling of dry ore was not specifically investigated, it is another aspect that warrants further research.

Although mining the different geological deposits of kimberlite necessitates the deployment of different mining equipment, there is one fundamental similarity in the mining methods: dry drilling is used wherever kimberlite is mined.

Where kimberlite is mined in pipe deposits, large mining equipment is used and there is space to make use of dust control equipment, which can be substantial in size. However, where kimberlite is mined in steeply dipping fissure deposits, the working space is severely limited and the use of currently available dust control equipment, especially if it is large, is not feasible. It is therefore obvious that there can be no common solution to the problem of controlling dust during drilling operations in the different mining configurations. The exception is where drilling takes place in the country rock, i.e. not kimberlite. At such localities there does not appear to be any reason why water cannot be used for dust control and it is strongly recommended that this practice be enforced. This should be regarded as the first priority in controlling the liberation of dust into the working environment of mines exploiting kimberlite.

For the reasons stated above, it is clear that solutions that can be applied for dust control in pipe deposits may be totally unsuitable for fissure deposits. They are therefore discussed separately.

Pipe deposits

In theory, the performance of central dust-extraction systems should not differ from that of the on-board type used at drill rigs. However, the monitoring results of airborne pollutant concentrations showed that the performance of on-board systems was better than that of the remote central systems. This was probably due to shorter extraction ducts, which are vulnerable, can be damaged and can also become blocked, thereby affecting air control flow rates.

The fit of the extraction cowl to the working face to capture the dust generated at source is of paramount importance in controlling dust emissions. Problems have been identified with this specific equipment and research into this aspect of primary dust control should receive attention on an industry-wide basis.

Because large excavations are used in mining the ore body, even though apparently large air volume flow rates are used for ventilation, air velocities can be slow and any airborne pollutants, especially dust, may not diluted and removed quickly enough to prevent unnecessary exposure. It is therefore recommended that consideration be given to applying minimum air velocities of at least 0,5 m/s in excavations.

In the mining of pipe deposits, it is inevitable that holing with the open pit will occur, mostly on a planned basis. Where this happens, air can enter the mine, overcome or reduce the effectiveness of any dust control measures and convey polluted air into the workings, thus exposing the personnel to unsatisfactory pollutant levels. This aspect can be addressed through ventilation planning and the application of strategically sized and sited underground booster fans which will ensure that where holings take place with the open pit, the flow of air will always be into the pit.

Another problem identified during the project was that encountered when the dust collected by the extraction systems at the drill rigs is deposited on the footwall and then disturbed and liberated into the working environment. This appears to be an operational problem and should be addressed by the mines concerned. What is of concern on an industry-wide basis is the control of dust on the footwalls and roads throughout the workings. Limited work has been carried out on this aspect of dust control and the exposure of personnel from this source is widespread.

As a final remark, it must be stated that irrespective of what equipment is used or how it is applied to control dust emissions into the working environment, only if such equipment is well maintained and conscientiously deployed can any success be expected with efforts to contain and minimise the liberation of dust and prevent the exposure of personnel to unacceptable dust levels.

Fissure deposits

In this type of mining, natural ventilating pressure has been favoured and heavily relied on to cause air to flow through the mine for the dilution and removal of airborne pollutants. However, this cannot be considered to be satisfactory as airflow can be severely influenced by atmospheric conditions and can become stagnant and even reverse direction. This appears to be an operational problem; it should be addressed by individual mines and should receive high priority.

Dust control in the very confined spaces of the fissure mines is a problem that is unlikely to be solved by any individual mine and should be addressed on an industry-wide basis. Consideration should be given to incorporating a dust control system into a totally enclosed drill, such as is being developed for noise control. Furthermore, the use of polycrystalline drill bits, reportedly used with a large measure of success in the USA, should be investigated on an industry-wide basis.

It is likely that no single control technique will solve the problem of dust liberation in fissure mines but a combination of measures, e.g. positive ventilation and polycrystalline drill bits, may be the answer.

Both types of mining

Only very limited work has been carried out by individual mines on the use of surfactants for dust control. Since this is a technique that could assist in controlling the liberation of harmful dust into the working environment, it should be researched, industry-wide.

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Abbreviations

Calcium chloride	$CaCl_2$
Department of Mineral and Energy Affairs	DME
Eight-hour time weighted average	TWA
Kilotons per month	kton/month
Litres per minute	P/min
Metres	m
Milligrams per cubic metre	mg/m^3
Microgram	:g
Micrometre	:m
Natural ventilation pressure	NVP
Particles not otherwise classified	PNOC
Particles per millilitre	ppmP
Pollutant index	PI
Return airway	RAW
Safety in Mines Research Advisory Committee	SIMRAC
South African Bureau of Standards	SABS
Threshold limit value	TLV
Ton per ton	t/t
Total toxin index	TTI
United States Bureau of Mines	USBM

1 Introduction

There are several hundred known kimberlite pipes and fissures in South Africa. Few are diamondiferous and fewer still are capable of economic exploitation.

Pipes are generally vertical, circular to elliptical in shape and vary considerably in size, tending to decrease gradually with depth.

Fissures are nearly vertical and vary in width from a few centimetres to several metres, with occasional local enlargements or "blows". They persist in depth and sometimes extend for several kilometres on strike.

Kimberlite constitutes the ore body in the volcanic pipes and fissures. It consists of a bluish-grey matrix composed largely of serpentine together with various subsidiary minerals, including calcite, diopside, enstatite, ilmenite, phylogopite, pyrite, pyrope and, very occasionally, a diamond. Characteristic of kimberlite are inclusions, sometimes enormous boulders, of the igneous and sedimentary rocks through which the pipes erupted.

Owing to the weathering and relatively weak nature of kimberlite, special consideration is given to development headings in kimberlite. The chemical and physical properties of kimberlite are such that contact with water causes a rapid decomposition of the kimberlite, which can cause drill holes to close, thereby preventing charging up with explosives and possibly resulting in loss of production. Under some conditions, the decomposition of kimberlite could pose a safety hazard to the workforce. Drilling in kimberlite is therefore a dry operation and, unless dust control measures are extremely effective and methodically maintained, the possibility of liberating dust (and other impurities) into the working environment is great. Development ends are therefore commenced as late as possible in the mining programme and the basic method is similar to that used during development mining in waste or country rock, i.e. non-kimberlite deposits.

As kimberlite deposits differ from region to region, different types of mining method are used. This study was conducted in different regions and included both pipe deposits and fissure deposits. The geology associated with each site is discussed in the report.

For obvious reasons, the methods used to mine pipe deposits will differ significantly from those used in fissure mining. Several methods are used to mine pipe deposits and those encountered during the investigation were block caving, sub-level caving, vertical retreat stoping and the modified underhand method (discussed in more detail in Appendix A).

Because of rapid weathering and the relatively weak nature of kimberlite, it is common practice to use as little water as possible in the ore-winning process. This practice is contrary to the requirements of current mining regulations and therefore exemptions have to be granted on a continuous basis. The unions regard this as an unsatisfactory situation. This project investigated dust control methods for dry drilling operations, taking into account the different geological formations of the diamond-bearing ore.

It is well known that dry drilling techniques will generate a great deal of dust which, if liberated into the working environment, could be very unhealthy for the workforce. This project examined the methods used for dust control in both pipe type deposits and fissure deposits.

The effectiveness of dust control measures was determined by collecting gravimetric dust samples, in pairs, at intake air positions, face positions and return air positions. The samples were not intended to be personal eight-hour Time Weighted Averages (TWA), but were used to determine a level of "dustiness" for a working place. Furthermore, the samples were not intended to prove that uncontrolled dry drilling produces more dust than dry drilling with dust control measures, although this would have been a simple matter. A tyndallometer, i.e. a real-time dust monitor, was also set up at the return-air sampling position to monitor for possible peak dust concentrations which, through observation, could be linked to events or practices.

In addition, one of the objectives of the project was to assess whether dust control measures that are successfully used in one mine, or type of mine, could be used at another mine, or type of mine ('type of mine' refers to either a pipe or a fissure deposit).

The project also examined the literature for references on the dust control measures used in other dry mining operations.

2 Literature survey

An initial literature survey was conducted by doing a computer search of engineering, mining and occupational hygiene databases. The files included Compendia (1970 to 1997), GeoArchive (1974 to 1997), GeoRef (1985 to 1997) and Occupational Safety and Health (1973 to 1996). The keywords used to generate the first search identified 264 references to dust emission in mines and these were reduced to 26 relating to drilling. Perusal of the titles of these 26 references identified only five of relevance to dry drilling in underground mines and from these four complete articles were obtained; the fifth, entitled *Physiological and hygienic characteristics of work conditions in placer mines of the (Russian) far north*, was not obtainable.

The literature items can be divided into two categories, namely those referencing the need to drill dry and those referring to methods used for dust control. The results of the literature search are discussed along these lines.

Hodgson and Sievel (1960) reported that due to the relative softness of blue ground, it was initially decided that rotary drilling for blast holes of up to approximately 20 m in length would be preferable to percussion drilling. This was vindicated by an experiment done in 1946 which showed that in percussion drilling the volume of cuttings, resulting from the fast advance in soft ground, could not be sludged fast enough to prevent the rods from jamming in the hole, due to the lack of clearance between the couplings and the diameter of the hole. Increasing the clearance in the hole served only to set up vibrations, which damaged drill steel equipment. The inference here is that if a sludge is referred to, water must have been used for drilling at that time. This is confirmed in a reference to non-coring diamond crowns being unsuccessful due to the high rotational speed and fine grinding of the diamond bit which produced an extremely fine blue-ground slime that blocked the water holes in the crown. The blue ground was reported as being "rubbery" and full of cross-slips, which makes primary fragmentation difficult. It was also reported that, from experience, many drilled holes could not be charged successfully if left standing. This supports the claim that holes close rapidly due to the nature of the blue ground.

In a description of mining methods, Gallagher and Lofties (1960) clearly point out that in De Beers diamond mines a notable feature of mining practice is that no water is used in drilling operations within the pipe due to its undesirable effects on blue ground, such as swelling and disintegration. It was considered that this practice was permissible due to the ultra-basic composition of the kimberlite. No further comments on this aspect were offered.

In another paper, Allan (1961) reported that the ore becomes extremely sticky when wet. It was also claimed that the nature of the kimberlite filling the fissure being mined is such that it weathers very rapidly and tends to become self-mining after a short period of time. Consequently, conditions in the drives quickly became hazardous and eventually the drives themselves were lost. This led to a development technique involving the advance of twin ends in which the main tramming drive is located in the country rock.

In overhead shrinkage stopes, great difficulties were experienced in withdrawing the stope shrinkage owing to the effects of surface water on the kimberlite which has the property of swelling and compacting when wet. This also led to hazardous conditions in the stopes where the ore was liable to hang up. In an attempt to overcome these difficulties, an underhand method of stoping was resorted to, with tramming drives on fissure. This necessitated leaving safety pillars above and below these drives. This was an improvement on the overhead shrinkage stopes but, because of the kimberlite's unfortunate property (already referred to) of weathering rapidly and thereby becoming self-mining, the method was not completely successful. Underfoot conditions quickly became dangerous and difficulties were experienced in keeping the fissure drives open. Consequently, a modified underhand stoping method was employed. However, it was noted that, owing to the difficulties experienced when kimberlite becomes wet and because (it was claimed) the ore contains a very low percentage of silica, all drilling in the stopes and fissure drives is done dry. As far as possible, general drainage water is also diverted away from the stoping area.

Giles (1960) also noted that in normal blue ground, blastholes are drilled by air-driven rotary machines using non-coring, two-wing tungsten carbide bits. When hard blue ground or boulder is encountered, a diamond-impregnated carbide coring crown of appropriate gauge is substituted. Furthermore, to avoid having to do this later, all holes are charged as soon as possible after drilling and are not left standing for more than a month.

Work done in Indian mica mines (Mukherjee *et al.*, 1975) confirmed that dust can be successfully suppressed at source using water injection through the drill steel, but this is not practicable when drilling kimberlite, as discussed.

Foam injection at 38 mP/s of liquid has been shown to reduce dust emission by 95 % in a gypsum mine (Page, 1982). Since foam achieves similar results with far less water, it could be expected to reduce the deleterious effects on the kimberlite. An article (not retrieved by the computer search: published in *World Mining*, 1974) stated in 1974 that De Beers Consolidated Mines were considering the use of foam. The article describes work done to introduce the chemical solution into the drill steel and briefly discusses tests which led to the conclusion that the best drilling and dust control were achieved when a dispersant only, and no air, was passed down the drill steel. Dust concentrations were reduced from 2 000 ppmP for uncontrolled dry drilling to 85 ppmP with dispersant. This can be compared with the 244 ppmP reported with dust extraction. However, later communications with mine staff indicated that foam or mist injection during drilling had not been successful, partially due to problems with excess water, skin and eye problems caused by the foam additive and dust filter blockages. It does not seem that every possibility was explored to optimise the system or the additive. Because foam or mist injection is not known to be practised anywhere locally at present, it was not possible to evaluate this approach as thoroughly as it may deserve. This is a possible future research topic and the application of this technique to fissure mining would need careful planning.

The other two papers identified by the initial search apply to rotary drilling. It was found (Khair *et al.*, 1992) that the generation of fine dust increases as the drilling mechanism changes from the cutting of chips to an abrading action due to deterioration of the bit. Similarly it was found (Sundae *et al.*, 1996) that polycrystalline diamond bits produce 71 to 88 % less dust than tungsten carbide bits. Rotary drilling is unlikely to be practicable in narrow fissures but it may be worth pursuing where rigs are used, although the reduction in dust is unlikely to eliminate the need for dust extraction.

In addition to the structured literature search, other references relating to dust control in mines were consulted. There are numerous references to preventing dust emissions and capturing dust by scrubbing, using foam or water with and without wetting agents or other chemicals. The majority of these references refer primarily to coal mining but most of the techniques could be applied to kimberlite if the deleterious effects of water could be allowed for. A few of the references that give quantitative data are discussed below.

Tests carried out under laboratory conditions (Schröder *et al.*, 1986) showed that respirable dust particles can be removed from air at efficiencies of more than 80 % using air-powered sonic atomising spray nozzles and that this technique also reduces airborne asbestos fibres by over 70 %. Up to 90 % of the water was retained by the use of a lamella impact mist eliminator. Water consumption was between 5 and 10 mP/s for air flow of up to 2 m^3/s.

Laboratory testing with a model continuous miner (Wang *et al.*, 1991) found that dust scrubber efficiency could be improved from around 50 %, using water, to about 80 %, using surfactant, for respirable quartz and from about 35 % to 80 % for respirable coal dust. Twelve surfactants were tested. This article lists 49 references to earlier work on scrubbing and related technology up to 1990.

Another source of dust, especially in mechanised mines, is dry material on the footwall, which is dispersed by traffic or moving air. Various methods of binding this dust have been used in different types of mining. One of the better methods, which would be acceptable in kimberlite mines since it maintains damp conditions without free water, is the use of a hygroscopic material mixed with the loose footwall material. No references to measurements in diamond mines were found but experiments done in a local colliery (Schröder *et al.*, 1981) showed that when calcium chloride solution was poured onto the footwall, it reduced dust generation markedly for long periods. Calcium chloride applied at a rate of 228 g/m^2 of footwall covered with 5 to 10 mm of fine dust limited dust generation for more than five months without the need for retreatment. Where only 105 g/m^2 were used, the initial control was just as effective but the surface was beginning to break up after three months. A spray cart was used to apply the solution of calcium chloride.

No recommendations were found for dust control practices in fissure mining operations.

3 Test sites

3.1 Mine 1

This is a diamond mine exploiting a kimberlite pipe deposit, which intrudes Bushveld Complex rocks and is one of eleven known kimberlite occurrences in the area. Several very large blocks of Waterberg quartzite occur within the pipe and a thick gabro sill cuts across the pipe and has baked the kimberlite.

A total of 252 kt/month is mined at an average depth of 650 m below surface. The total underground labour force is 480 people per shift.

Although most of the mining operations involve dry drilling, water is pumped to surface at a rate of 3 300 kℓ/day (0,4 t/t).

The volume of air flow through the mine is 780 m^3/s.

The drilling methods employed are:

- Long-hole drilling - with dust cassette filtration, either on-board or remote
- Hand-held percussion drill - wet drilling operation
- Percussion drill rig - wet and dry drilling operation.

The mining method in use is commonly known as block cave mining.

3.2 Mines 2 and 3

These mines are situated in Beaufort sediments, which are dyke-like bodies of kimberlite and may be offshoots from pipes. They sometimes have considerable length and may occasionally swell locally to form "blows".

The kimberlite is generally of the micaceous type. Composite fissures and several blows are mined adjacent to the dolerite, which dips at 28°, with the shale forming a bedding plane parallel to the fissures.

An average of 8 000 t per month is mined from each mining operation, at a depth of 400 to 500 m below surface. The total labour force is approximately 130 employees per mine.

Mining is carried out at both sites with conventional percussion machines as follows:

- Development in country rock (dolerite), which is done by means of wet drilling using a 1,2-m-long drill steel and 36-mm-diameter drill bit
- Development in shale (also called fissure development), but without water
- Underhand stoping: dry drilling with 0,9-m-long and 36-mm-diameter drill rods.

As the ore body is contained in a fissure, the mining methods used on both mines vary from underhand stoping to typical conventional open stoping. Examples of these are shown in Appendix A.

3.3 Mine 4

This country rock intrusion is a lithological succession of alternating shale and dolerite horizons of Karoo age, which rest unconformably on the archian granite gneiss basement.

With an underground labour force of 500 people, a total of 259 kt/month is mined, approximately 560 m below surface.

Water pumped to surface amounts to 118 kP/day (0,3 t/t), and air is circulated at a flow rate of 585 m^3/s.

Dust filtration is done remotely by means of a Rootes-type, double-lobe, high-pressure blower fitted with a silencer (of the straight-through absorption type).

Occasionally, when drilling takes place in a tunnel open to the open pit, the ventilation tends to reverse, resulting in air entering the mine (working zone) from the pit. In order to eliminate this, counterflow is created through an electrically driven, in-line low-pressure, high-volume flow fan (air jet). Although a reversal would introduce fresh air into the tunnel, it would also carry contaminated air from the entry point of the tunnel to other parts of the workings and therefore it must be countered.

Two types of mining method are practised, namely sub-level caving and block caving with long-hole drilling, as described in Appendix A.

3.4 Mine 5

The mine is an almost vertically sided (86° dip in places) intrusion into the country rock, the latter consisting of dolomite, dolomitic limestone with chert bands and almost pure lenses of limestone. The most significant intrusion is a diatreme facies tuffisitic kimberlite breccia. Large internal waste masses of Drakensberg basalt occur within the kimberlite. A segregationary-textured tuffisitic kimberlite breccia is also present. This kimberlite is petrologically similar to that mentioned above, but contains fewer country rock inclusions.

With an underground labour force of 550 employees, ore is mined at a rate of 314 kt/month at an average mining depth of 510 m below surface.

The total water pumped to surface amounts to 3 900 kP/day (0,4 t/t). The air in circulation for ventilation amounts to 900 m^3/s. The drilling operations used are:

- Long-hole dry drilling
- Return-airway dry drilling – percussion hand-held machines
- Main development wet drilling – drill rig.

The mining method used is the same as for Mine 1 (described in Appendix A).

4 Methodology

Although kimberlite can be mined in either pipe deposits or fissures, in both cases mining operations are carried out using dry drilling techniques, except for the mining of country rock or waste material. Such dry drilling operations inevitably generate substantial dust in the working place unless control measures are implemented. In order to determine the dust levels generated, it was necessary to monitor the quality of the intake air supply (as a reference level), the dust levels at the working face (being representative of the conditions to which operators are exposed), and the airborne dust concentrations in the return air. In this way the "make" of dust, i.e. the difference between the dust concentrations leaving and entering the workplace, during each of the drilling operations could be determined, or alternatively the effectiveness of the control measures could be gauged. The underground dust sampling positions are shown in Figure 4.

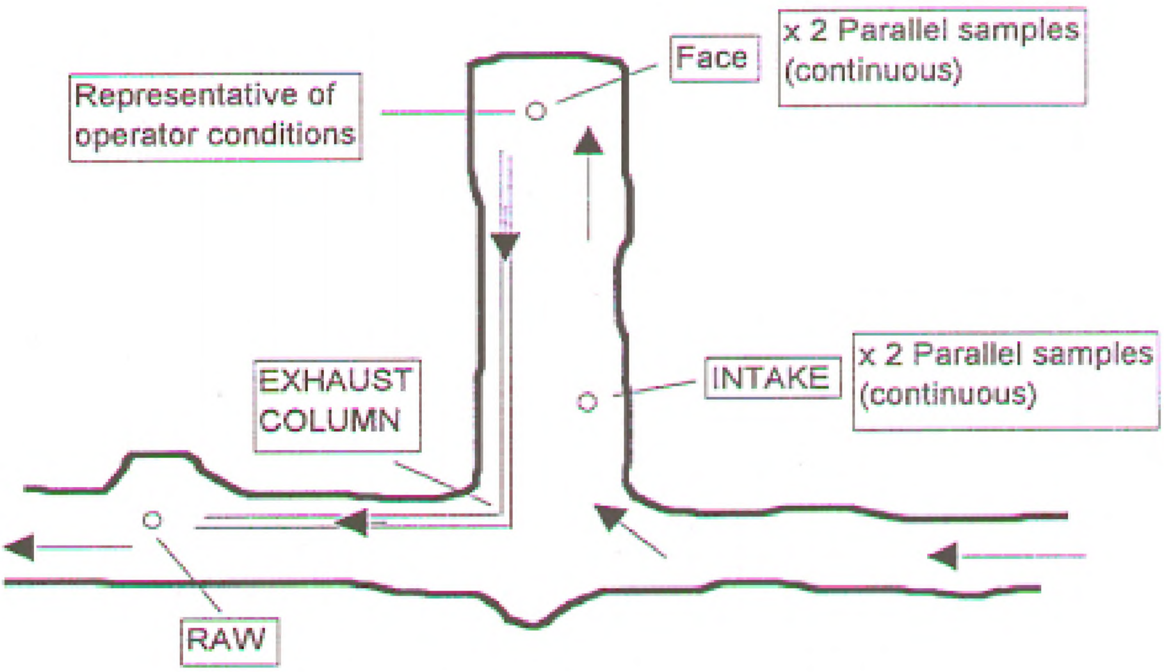

Figure 4: Underground sampling positions

During the drilling operations sampling pumps were strategically placed at representative intake, face and return air positions. Sampling took place over the full duration of the drilling shift, which could vary from 60 to 180 minutes, depending on the monitoring site and the method of drilling. Samples were collected in pairs at each of the localities to provide backup (as well as data on parallel dust sampling). Where possible, sampling at each of the drilling operations was repeated.

Although the samples were collected using personal gravimetric dust samplers, it was not the intention to determine any personal dust exposure levels. Hence, the air quality indices and risks calculated refer to ***workplace conditions*** and not to personal exposures. The results give a measure of the level of dustiness of the workplace.

The return air samples give an indication not only of the amount of settling that could be expected, but also of the amount of dust conveyed to other parts of the mine where air could be reused. It was necessary to carry out intake, face and return air sampling simultaneously although, owing to temporal effects, it was not intended to make any comparison between instantaneous dust levels.

The samples were transported to Miningtek's dust laboratory in special, metal, lockable containers where, after a stabilising period, they were assessed for dust mass and quartz content. The quartz content was determined to establish the toxicity of the underground environment. Quartz analyses were done by Miningtek using the X-ray diffraction method - an approved method - with quality checks performed by the SABS.

The dust concentrations measured from each mine and at each site were categorised as follows:

- wet drilling operations
- dry drilling operations
- quartz concentrations and percentages
- total toxin index.

Apart from quartz, no other analyses were done and therefore 'dust' refers to the concentration of the non-quartz fraction, i.e. the PNOC (particles not otherwise classified) concentration. Average return dust and quartz indices were obtained by dividing the dust or quartz concentration by the respective TLV (threshold limit value). The sum of the PNOC and quartz indices gives the TTI (total toxin index). This is expressed in the following relationship:

$$\frac{C_1}{T} + \frac{C_2}{T_2} + \ldots = TTI$$

It is a commonly held view that for an environment to be "safe", the integrated value of all the pollutant indices, i.e. the TTI, should not exceed unity. However, in this report fibre concentrations have not been included and TTIs can only be used as a general guide to conditions in the workings sampled.

4.1 Sampling method

Sampling was undertaken using a gravimetric sampling arrangement set to sample at a rate of 1,9 P/min. The air sample was drawn through a cyclone, separating the respirable and non-respirable fractions, with the respirable fraction of the sample being deposited on a 37-mm-diameter cellulose nitrate filter with a pore size of 0,8 µm, as shown in Figure 4.1.

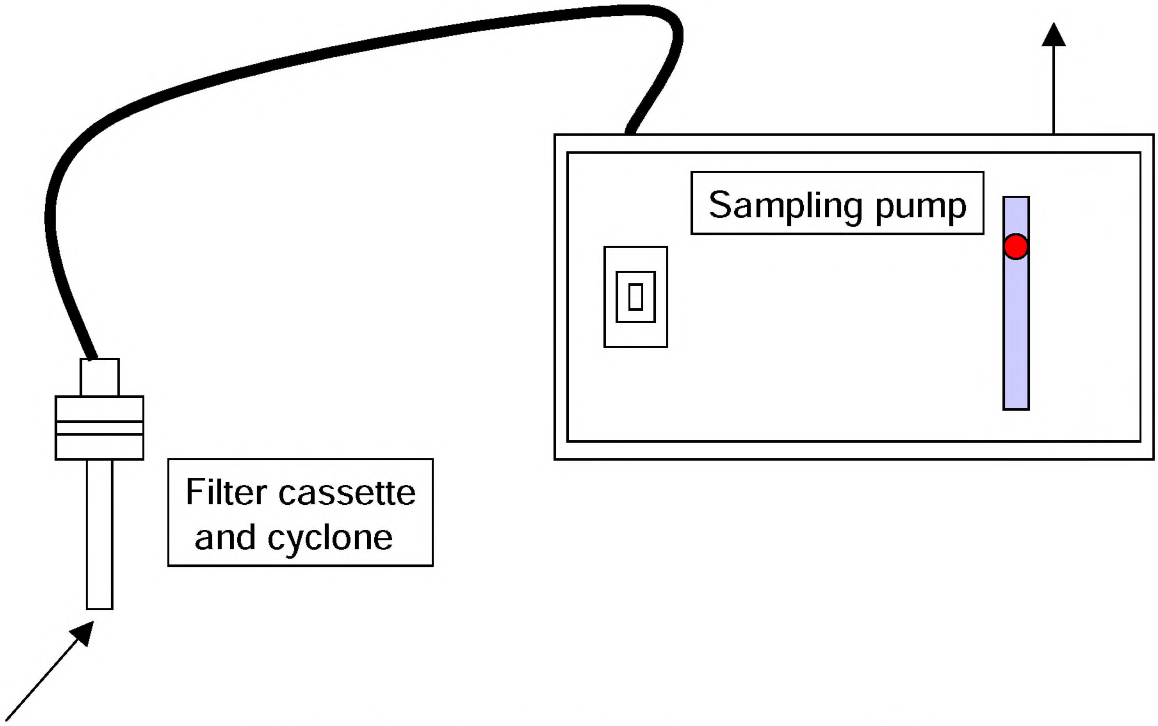

Figure 4.1: Schematic drawing of sampling train

The filter masses, together with reference filter masses, were determined in a climate-controlled room before and after use to ensure accuracy of mass determination on the filter. The sample volume was then calculated from the data obtained during the survey, and consequently a dust concentration was obtained. Intake, face and return air samples could then be compared to establish the quality of the intake air, the liberation of dust during drilling and the quality of the return air. Analysis of the results (with visual observations) indicated the effectiveness of the dust control measures that were in place at the time of the survey.

A tyndallometer, which is a real-time, portable monitoring instrument that uses the light-scattering properties of dust and is capable of measuring total aerosols with concentrations of up to 100 mg/m^3, was used to monitor the conditions at the return air position of the workings. This instrument has an integrated data memory and can provide averaging over random intervals of between five seconds and approximately eight hours, with a data downloading facility. The tyndallometer was used to establish the presence and frequency of dust "spikes" during the drilling operations. The results of the tyndallometer measurements are shown together with the layout of each site and, where possible, remarks are made to explain high readings. Where water is not used for dust control, the aerosol levels indicated by this monitor are likely to be dust levels.

5 Results and discussion

All participating mines gave the assurance that none of the sites sampled had been "prepared" for dust sampling. The underground sampling sites at each mine were not in any specific sequence as they were selected on a day-to-day basis. The emphasis of the study was on evaluating dry drilling practices. The results are discussed in the following categories:

- wet drilling operations (for comparison and possible baseline references)
- dry drilling operations
- quartz concentrations and percentages
- total toxin index.

The quartz index and PNOC were calculated to determine the pollutant risk for each of these components.

Tyndallometer measurements were taken at most of the sites sampled and, where possible, explanations are given for high readings. The tyndallometer observations were thus used to confirm visual observations of dust-generating events.

5.1 Mine 1

Five types of drilling operation were sampled on Mine 1. They represent the various drilling operations combined with the different extraction/dust control methods. Each drilling operation was sampled twice. The following drilling operations were observed:

- main development – wet drilling
- long-hole drilling with dust cassette filtration
- long-hole drilling with on-board dust collection
- development on-board dust collection
- development with hand-held percussion drill.

5.1.1 Wet drilling

5.1.1.1 Dust control

Main development drilling is done in country rock and therefore water is used freely during the drilling process. The water is used for dust suppression as is common in other hard rock mines and therefore the large filtration units are not used for dust control during development.

5.1.1.2 Ventilation systems in use in wet drilling operations

Two types of ventilation system are used for dust removal, viz.

Force/Exhaust System

Air is drawn from the intake (through a ventilation district) into a ventilation duct by a fan and discharged by forcing the air through the duct onto the face. The "used" air flows from the face back to an exhaust column where it is picked up and then discharged into a return airway.

Exhaust Ventilation

Air is drawn into the tunnel by the suction of an exhaust duct, the inlet of which is close to the working face thereby providing ventilation for the operators and machinery at the face. Air returns from the face via this extraction column and exhaust fan, and is discharged directly into the return airway system. Wet drilling is associated only with development operations as they take place in the surrounding or country rock. Although the focus of this project was on dry drilling operations, it is important not to lose sight of drilling operations that do not take place in kimberlite deposits.

5.1.1.3 Results

The results of wet drilling operations are given in Table 5.1.1.3, with a graphical presentation in Figure 5.1.1.3. At both the sites monitored, the results show an individual minimum dust concentration of 0,28 mg/m^3 measured in the intake to the workings, and a maximum dust concentration of 2,44 mg/m^3 measured in the return of the workings. The results from Site 1 show very little make of dust over intake levels. At Site, 2 although the dust levels are almost double those at the face, compared with the intake level, the gain is only equal to the intake level. The dust concentrations at the Site 2 face would not be considered unsatisfactory, especially if evaluated in terms of the PNOC Index.

Table 5.1.1.3

Wet drilling dust concentrations – Mine 1

Site Type of sampling Dust control method	Average dust concentration (mg/m^3)			PNOC index
	Intake	Face	Return	
Site 1 Drill rig	0,29	0,37	0,41	0,08
Site 2 Drill rig	1,18	2,38	2,32	0,46

It is important to realise that the indices indicated refer strictly to working place conditions since the samples were neither personal nor eight-hour TWAs. Although not tabulated, the quartz concentrations were all found to be less than 5 %. In Figure 5.1.1.3a the average dust concentrations of the samples, which were taken in parallel at the two sites, are shown.

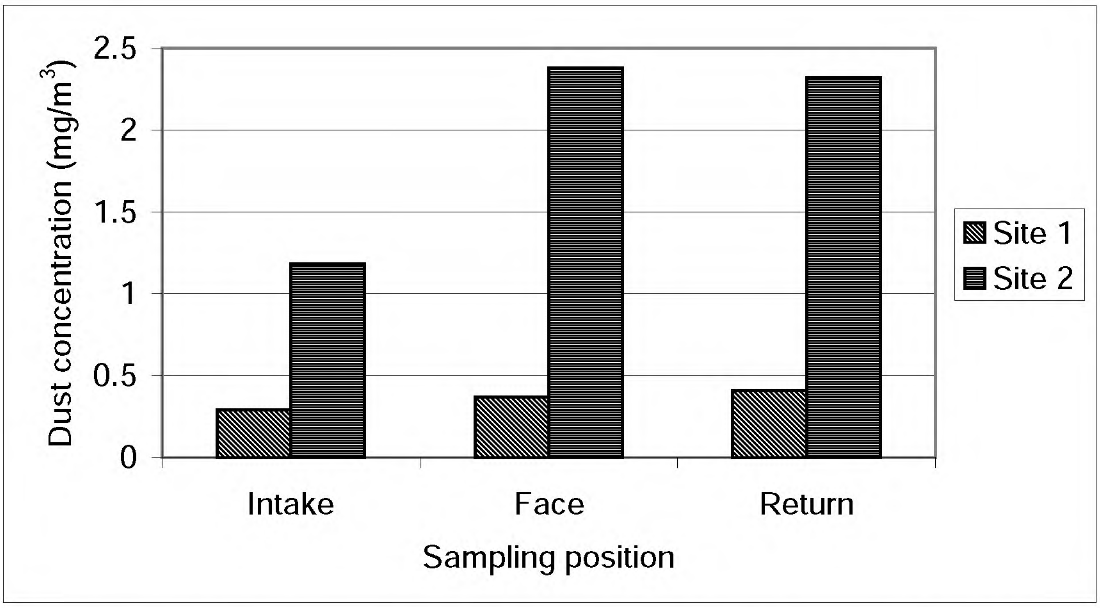

Figure 5.1.1.3: Wet drilling dust concentrations – Mine 1

The site layouts and plots of the tyndallometer measurements in the workplaces that were sampled during wet drilling operations are shown in Appendix B. Drilling at Site 1 started at 11:10 and the relatively high tyndallometer readings recorded are due to the drill rig rubbing against the sidewall during normal drilling activities. The high aerosol concentrations recorded during the sampling at Site 2 are possibly due to the activities when the forcing ventilation column was extended (between 10:00 and 11:00 as shown in Appendix B).

5.1.2 Dry drilling

Long-hole drilling operations were undertaken to drill into the actual kimberlite deposits.

5.1.2.1 Dust control

For this operation a long-hole drill rig is equipped with a fan-driven dust-extraction system with cassette-type filtration. The extraction units are either on-board installations or may be positioned remotely. The results indicate that this system can be effective, providing it is maintained and used correctly. The cowl should fit closely against the face being drilled. Meshing and corners, etc. do prevent a close approach between the cowl and the face, and further development is required for a practical solution. A typical drill rig and dust control system is shown in Figure 5.1.2.1.

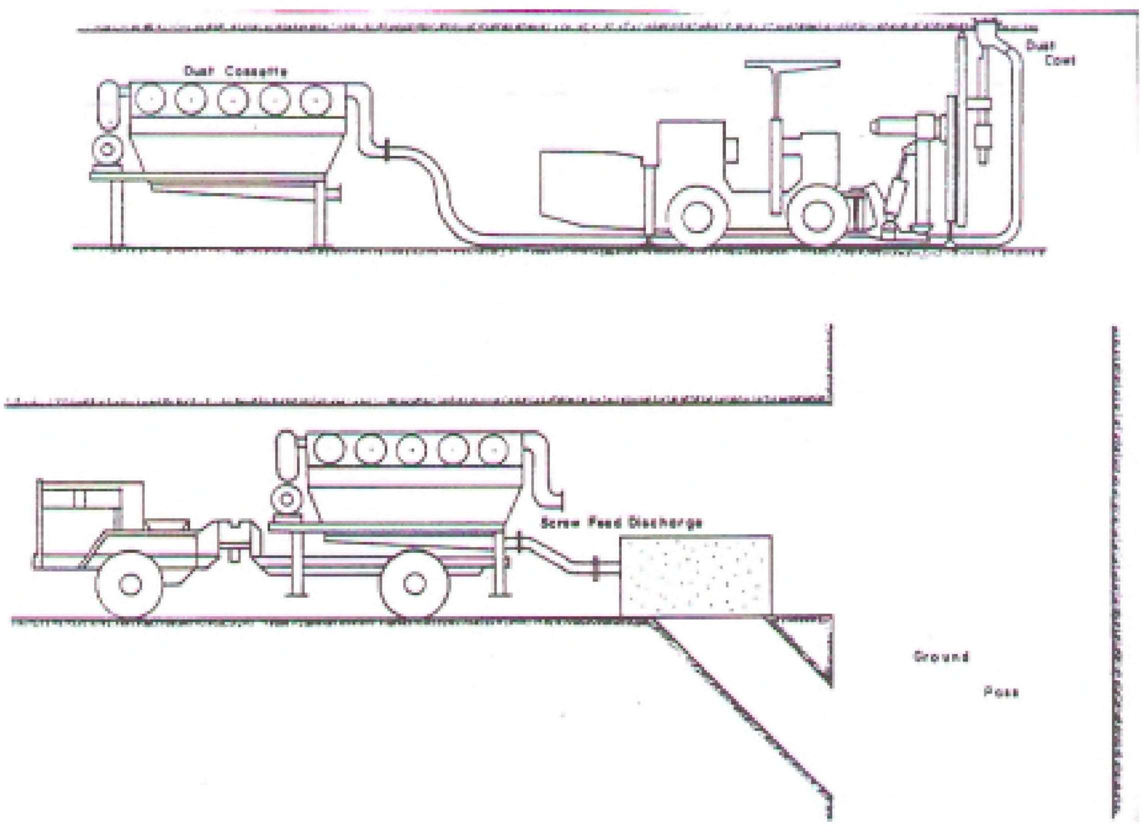

Figure 5.1.2.1: Typical drill rig and cassette-type dust control system

The filters are cleaned by reverse air pulses and the dust discharged via flap valves onto the footwall. The high-pressure blowers or fans are equipped with filter panels. These require daily, manual removal, de-dusting by blowing out on site and reinstallation, which can also cause high dust levels. The piles of dust on the footwall from the cassette discharge provide a source of dust re-entrainment if disturbed or if high air velocities occur over the footwall. This is prevented to some extent by the manual scattering of calcium chloride ($CaCl_2$) flakes over the dust to absorb moisture from the air and bind the dust. This method of application does not ensure full covering of the dust, however, and lumps of moistened dust form within the piles of dry dust, still permitting re-entrainment.

Different drilling techniques are applied, all of which are dry operations. Consequently, various dust control measures are implemented, some with greater success than others. The mining methods used also influence the type of dust control measure applied. The way in which these measures are applied and how the equipment is maintained determines the effectiveness of all control measures.

5.1.2.2 Results

Table 5.1.2.2 gives the results that were obtained during different drilling operations using various dust control measures. Once again, although not tabulated, the quartz concentrations were all found to be less than 5 %. The results shows dust concentrations arising from the different drilling operations and dust control techniques.

Table 5.1.2.2

Dry drilling dust concentrations – Mine 1

Site Type of sampling Dust control method	Average dust concentration (mg/m^3)			PNOC index
	Intake	Face	Return	
Site 3 Long-hole drill rig with remote dust control	0,50	0,82	0,73	0,15
Site 4 Long-hole drill rig with remote dust control	0,06	0,39	0,59	0,12

Table 5.1.2.2 – continued

Site 5 Percussion drill with ventilation	1,04	19,83		
Site 6 Percussion drill with ventilation	1,75	53,87		
Site 7 Long-hole drill rig with on-board dust control	0,61	0,76	1,19	0,24
Site 8 Long-hole drill rig with remote dust control Malfunctioning	4,99	8,05	9,41	1,88
Site 9 Drill rig with on-board dust control	0,67	1,89	1,57	0,31
Site 10 Drill rig with on-board dust control	1,35	5,11	4,61	0,92

Dust concentrations ranged from 0,02 mg/m^3 (individual intake) to 53,87 mg/m^3 (average face concentration) and although the concentration of 53,87 mg/m^3 may be a "once off" contamination due to the malfunctioning of control equipment, i.e. the ventilation fan, it is an indication that high dust concentrations can occur, posing an occupational health risk with this dust control technique. The results from Sites 5 and 6 clearly indicate that ventilation (force or exhaust system) on its own is not very effective in controlling the exposure of personnel to high dust concentrations. Site 8 was equipped with the same type of dust control equipment as Sites 3, 4, 7, 9 and 10 but it was malfunctioning on the day of sampling. This gives an idea of the effectiveness of the dust control equipment used.

Figure 5.1.2.2 shows the average results of the different types of drilling operations and dust control measures taken at the intake, face and return positions for all the test sites.

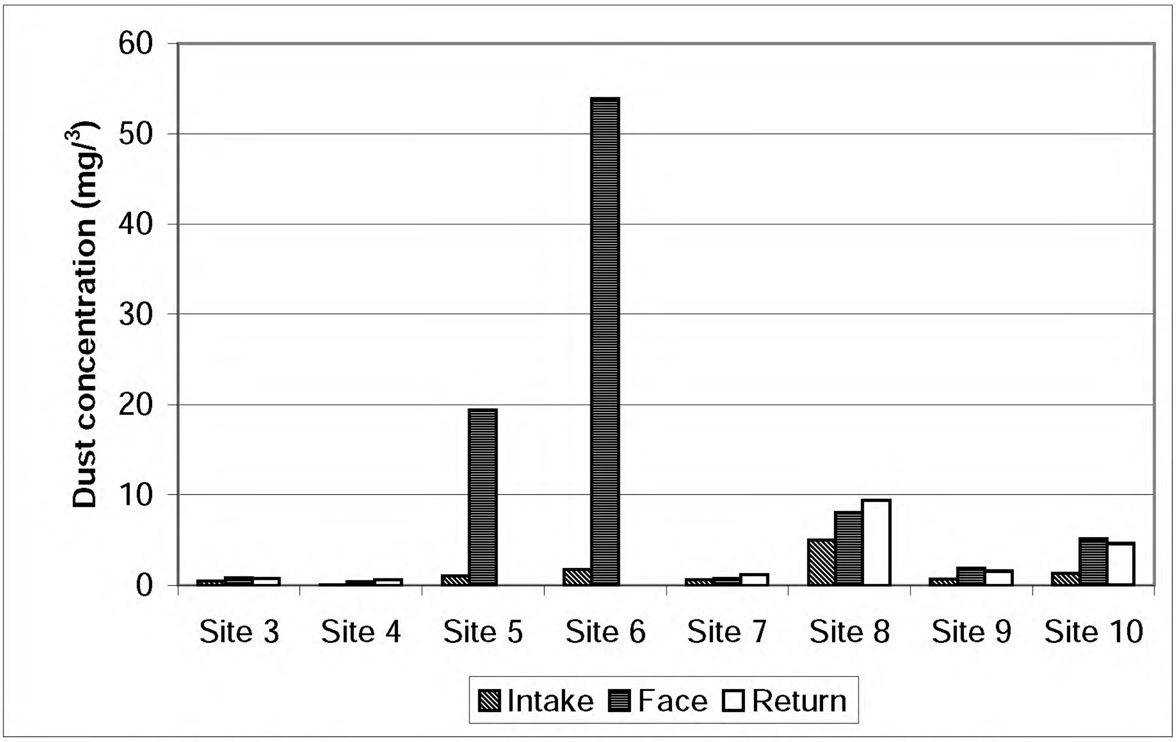

Figure 5.1.2.2: Dry drilling dust concentrations – Mine 1

The dust concentrations measured at Sites 3 and 4 show very little make of dust. Furthermore, with the dust control equipment in use, the dust concentrations can be considered acceptable. For purposes of clarity, the results from the two sites where percussion drills were used, viz. Sites 5 and 6, are shown on the left of Figure 5.1.2.2. Similarly, the results for Site 8 have been placed to the right on Figure 5.1.2.2. The individual site layouts, sampling positions and traces of tyndallometer measurements for Sites 5 and 6 are shown in Appendix B. At these sites percussion drilling took place and the dilution and removal of dust was the method used for dust control. At Site 6 it is also of interest to note that dry lashing resulted in high dust concentrations. It is reasonable to assume that other ore-handling processes such as loading, tramming and tipping would also liberate dust when the ore being handled is dry. The effects of lashing dry ore were also seen at Site 10 (see Appendix B). As it was not one of the objectives of this project, techniques for handling the dry ore without liberating dust into the environment were not monitored in depth although, from the results obtained, this appeared to require further research. During the sampling operation at Site 8, malfunctioning or improperly deployed dust control equipment resulted in high dust concentrations at this monitoring site (see Appendix B). The main reason for the high dust concentrations was that the extraction cowl was not kept close to face, thereby allowing dust to escape. The high intake dust levels are probably due to intake air from the pit being contaminated by dusty surfaces and rock slides. The pollutant index or, in this case, the TTI of unity was only exceeded at

Mine 1 where dust liberation was not properly controlled, viz. at test Sites 5, 6 and 8.

5.1.3 Overall results

Figure 5.1.3 shows the overall results based on actual dust concentrations for all the test sites. The results have been grouped into wet drilling sites and dry drilling sites. It is evident that if dry drilling controls are applied correctly and function correctly, dust emissions can be as well controlled as at wet drilling operations. This can be seen by comparing the results from Sites 1 and 3 with those from Sites 9, 3, 4 and 7. However, the dust levels where control measures are not functioning correctly may be very high, as can be seen from the results at Sites 5, 6 and 8.

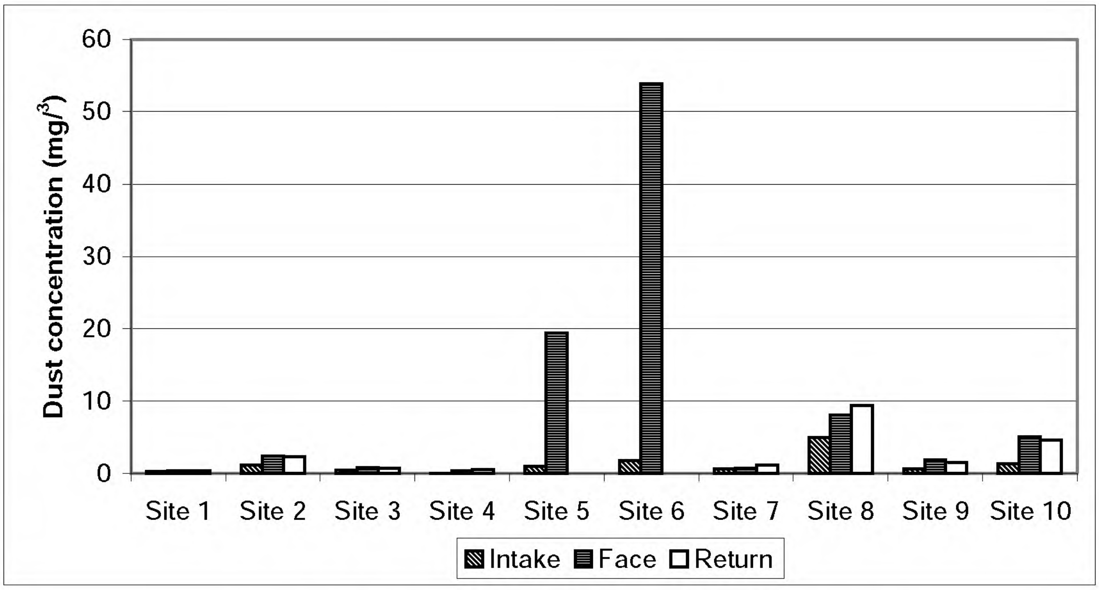

Figure 5.1.3 Dust concentrations – Mine 1

5.2 Mine 2

Drilling is done with hand-held percussion drills for both production and development drilling. Ten sites were sampled of which one, namely Site 8, was development in waste rock and the remaining nine sites were production. However, in some instances fissure water was present during production drilling and this impacted on the results.

5.2.1 Wet drilling

5.2.1.1 Dust control

A "venturi blower" is used to ventilate the 4-m^2-area single tunnels. These units, fitted to a steel column, are 150 mm in diameter and are connected to a compressed air supply. When turned on, the compressed air is discharged through a nozzle embedded in the venturi head and facing the direction of the required air flow and thus creates a venturi effect, causing the entrainment of air from the surroundings, forcing it through the steel column, and then discharging it onto the face. This method dilutes the air at the face and eventually displaces it to mix with the through ventilation.

5.2.1.2 Results

Table 5.2.1.2 shows the dust monitoring results for the wet drilling operations at Mine 2. Unfortunately, only one site was available and therefore no comparison can be made with other wet drilling operations on this mine. The results show that wet drilling operations produce dust concentration levels below the required personal exposure levels.

Table 5.2.1.2

Wet drilling dust concentrations – Mine 2

Site Type of sampling Dust control method	Average dust concentration (mg/m^3)			PNOC index
	Intake	Face	Return	
Site 8 Percussion drill		4,43	3,74	0,75

Figure 5.2.1.2 is a graphical representation of the data obtained during wet drilling. Due to the site layout, it was impractical to sample the intake air. Only one airborne dust sample had a quartz concentration in excess of 5 %, the remaining concentrations being well below 5 % with an average quartz concentration also well below 5 %. The dust at this test site was therefore regarded as PNOC and the PNOC index as the TTI. The pollutant index (PNOC index) was less than unity and could therefore be regarded as acceptable.

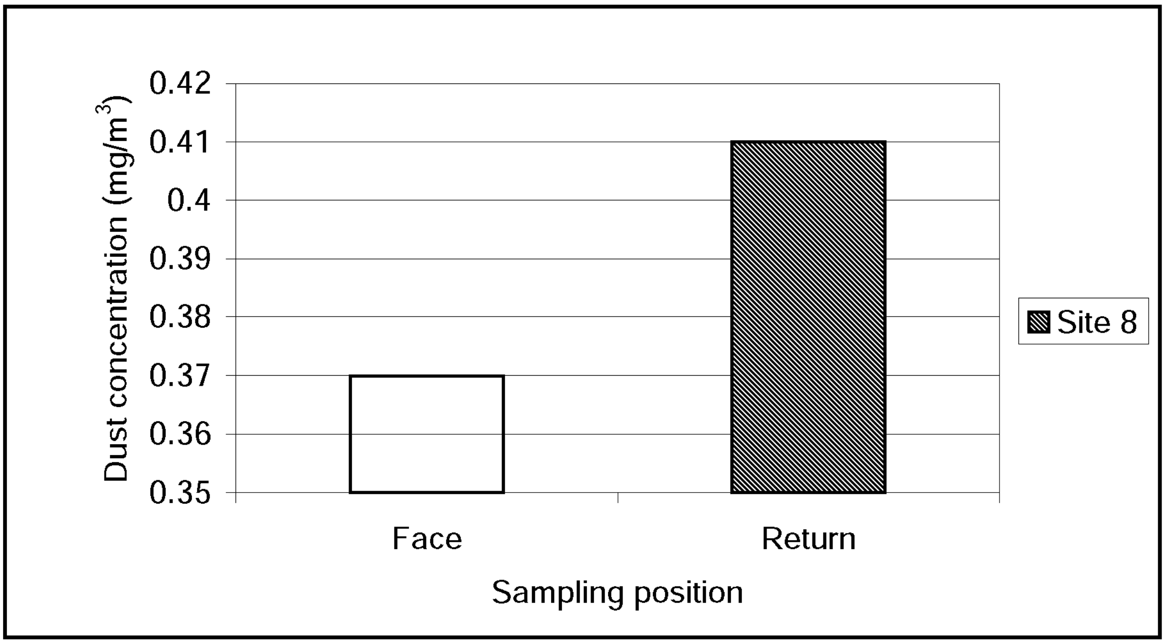

Figure 5.2.1.2: Wet drilling dust concentrations – Mine 2

The site layouts and tyndallometer measurements obtained during the survey are shown in Appendix C. During the measurements at Site 8, blasting at the bottom of the stope occurred at 11:55 and drilling started at 12:04. Furthermore, there was ventilation reversal at 12:47. The dust created during drilling operations was removed mainly through the flow of natural ventilation and/or by the main exhaust fans situated on surface.

The tyndallometer measurement did not correlate well with the visual observations. This was most probably the result of external contamination, although the gravimetric sampling results in the return air position do not support such an assumption.

5.2.2 Dry drilling

Dry drilling at Mine 2 was done with hand-held percussion drills only. The mining method is the same as at Mine 3 but differs from the mining methods used at Mines 1, 4 and 5. Table 5.2.2 gives the results obtained at Sites 1 to 7. The dust concentrations at Sites 9 and 10 were measured to establish those associated with the intake air. No dust-extraction equipment was in use during the survey, and the only form of dust control was by dilution of the ventilation. The results shown in Table 5.2.2 and Figure 5.2.2 indicate that there were high dust concentrations during dry drilling operations and that all the pollutant indices were above the limit for personal exposure, although these were workplace levels.

Table 5.2.2

Dry drilling dust concentrations – Mine 2

Site Type of sampling Dust control method	Average dust concentration (mg/m^3)		
	Intake	Face	Return
Site 1 Percussion drill	12,98	32,22	32,67
Site 2 Percussion drill	8,08	31,13	17,32
Site 3 Percussion drill	26,92	62,92	9,54
Site 4 Percussion drill	3,43	149,57	8,45
Site 5 Percussion drill		184,69	
Site 6 Percussion drill	29,72	94,34	
Site 7 Percussion drill	35,0	99,51	30,50
Site 9		0,42	
Site 10		1,26	

Site 5 was a development heading with venturi ventilation, where samples were taken at positions on the face, and at 10 m and 20 m away from the face. The results here show the effect of dust settling and are most likely due to a combination of larger particles in the respirable range and low air velocities. There was also a possibility of air recirculation at the face.

Figure 5.2.2a shows a maximum average dust concentration of 149,57 mg/m^3 measured at Site 4. It also compares only drilling operations and therefore excludes Sites 9 and 10. Site 5 was excluded because it was a development heading and not a stope. The average face dust concentration for Site 5 was even higher than that recorded for Site 4. Site 5 was ventilated by means of a venturi driven by compressed air. Although this type of device may meet the present requirements for the ventilation of development ends based on a volume flow rate per unit area, namely 0,15 m^3/s per m^2, it is unlikely to have provided the tunnel velocity of at least 0,5 m/s needed to remove pollutants. As a consequence, the high dust levels measured at the face were also observed in the return air in the tunnel.

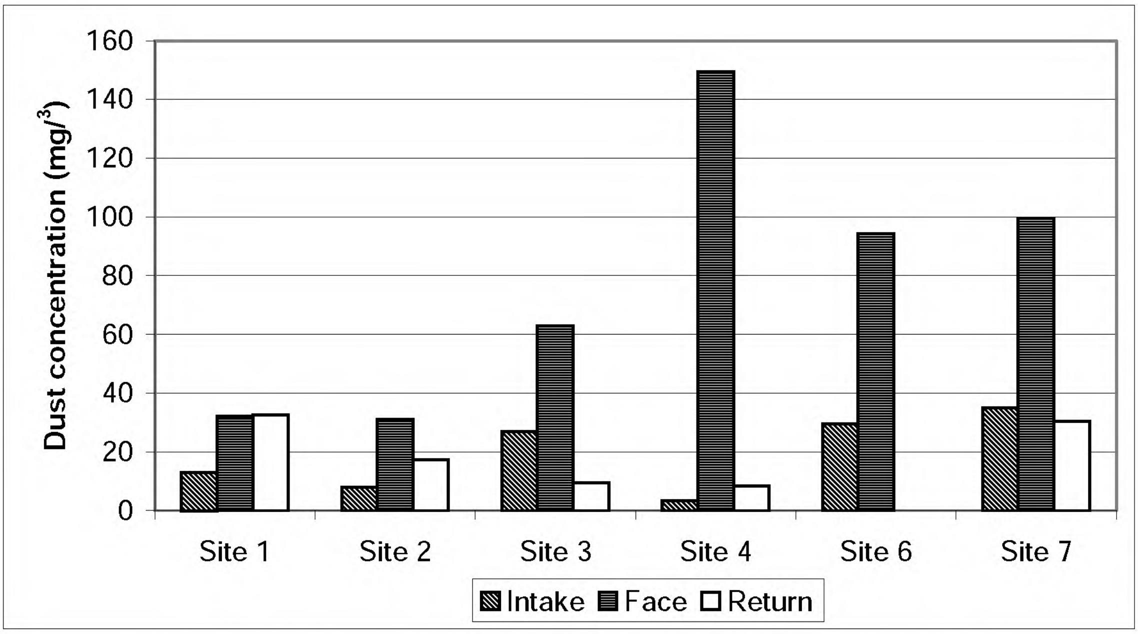

Figure 5.2.2a: Dry drilling dust concentrations – Mine 2

With the exception of the two intake air samples at Sites 9 and 10, all other pollutant indices exceeded the acceptable reference level of 1,0. These results are indicative of high dust concentrations pervading the workings and should be viewed with concern.

People travelling through or working in these areas would be exposed to high dust concentrations which could result in high eight-hour exposure levels. Furthermore, the personnel could be exposed to high "peak" concentrations, which play an important role in the development of lung disease.

Even though the intake dust levels may be high, owing to ineffective dust control measures, throughout this mine the dust levels at the face and in most returns are seen to be considerably elevated. A higher and better controlled ventilation supply rate could significantly dilute face dust concentrations and remove the dust at a faster rate. However, higher ventilation supply rates alone are unlikely to reduce dust concentrations to acceptable levels.

Figures 5.2.2b and c show the layout of Site 6 and the tyndallometer measurements taken at this site during the survey. This result was selected to illustrate how high dust levels can be sustained throughout a shift. It is also important to note that the air, now highly polluted, would be coursed to other workings. Because of the nature of the terrain and the remoteness of the return sampling positions, the high tyndallometer recordings could not be correlated with face activities. The site layouts, sampling positions and tyndallometer traces for the remaining test sites are shown as Figures C1 to C9 in Appendix C.

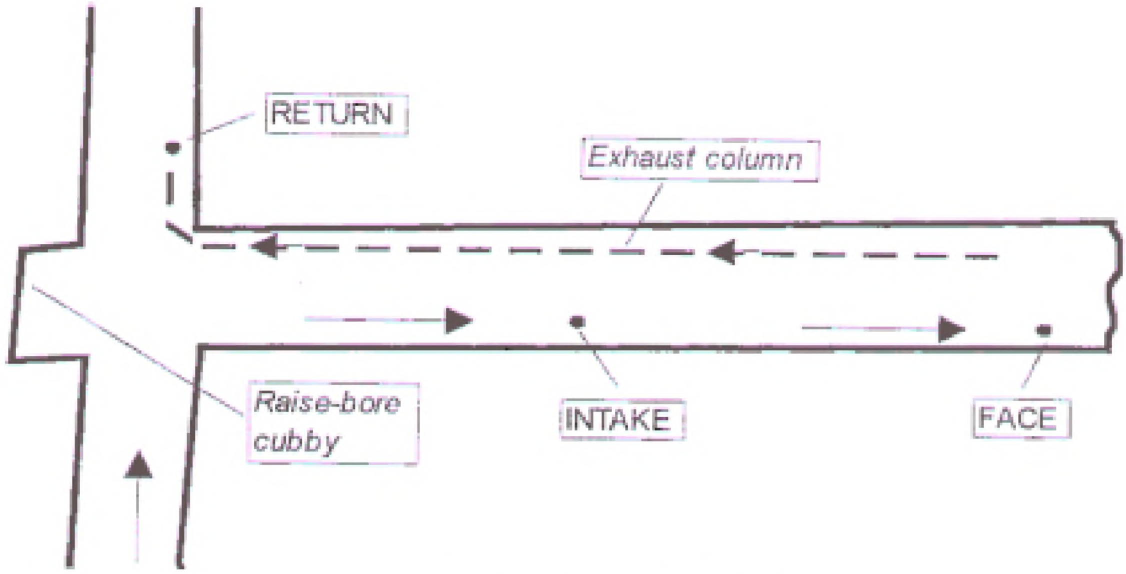

Figure 5.2.2b: Layout of Site 6

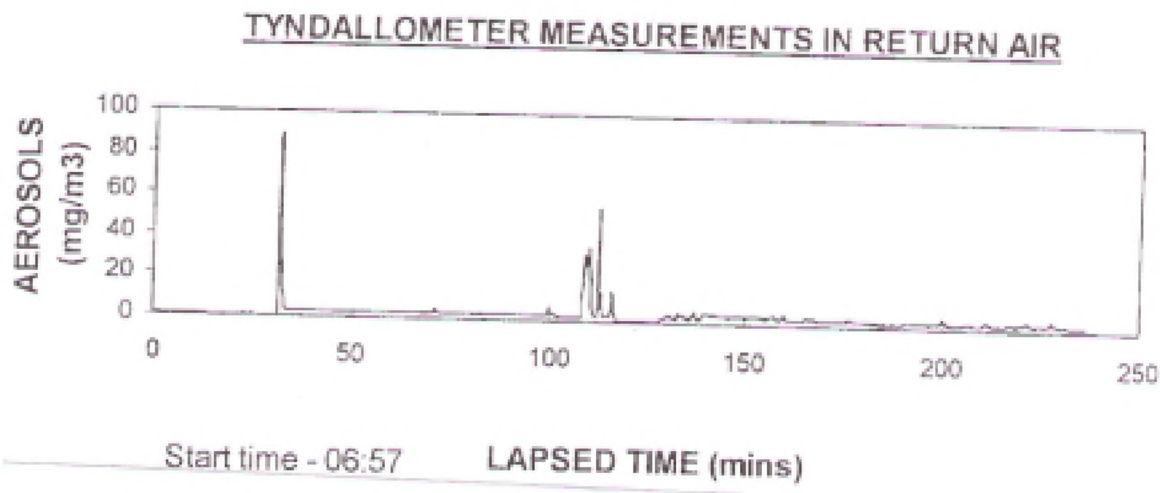

Figure 5.2.2c: Tyndallometer measurements at Site 6

5.2.3 Total toxin index

Most of the dust samples collected in the return air at the test sites were analysed for quartz content. The quartz indices were then calculated and added to the PNOC index to give the overall TTI. Where the quartz concentrations were found to be less than 5 %, the TTIs remained unchanged and were equal to the PNOC indices. However, where the quartz content was found to exceed 5 %, namely at Sites 3, 4 and 5, the pollutant indices were found to increase significantly from 1,91, 1,69 and 8,04 to 11,31, 8,69 and 70,74 respectively for the three sites (see Table 5.2.3 and Figure 5.2.3). The only satisfactory TTI was measured at Site 8 where wet drilling took place and the quartz content was less than 5 %.

Table 5.2.3

Toxin indices – Mine 2

Work-place	PNOC conc. mg/m^3	TLV	PNOC index	Quartz conc. mg/m^3	TLV	Quartz index	Toxin index
1	32,67	5	6,53	1,06	5	0,21	6,53
2	17,32	5	3,46	0,33	5	0,07	3,46
3	9,54	5	1,91	0,94	0,1	9,40	11,31
4	8,45	5	1,69	0,70	0,1	7,00	8,69
5	40,22	5	8,04	6,27	0,1	62,70	70,74
6	-	5	-		-	-	-
7	30,5	5	6,10		-	-	6,10
8	3,73	5	0,75		-	-	0,75

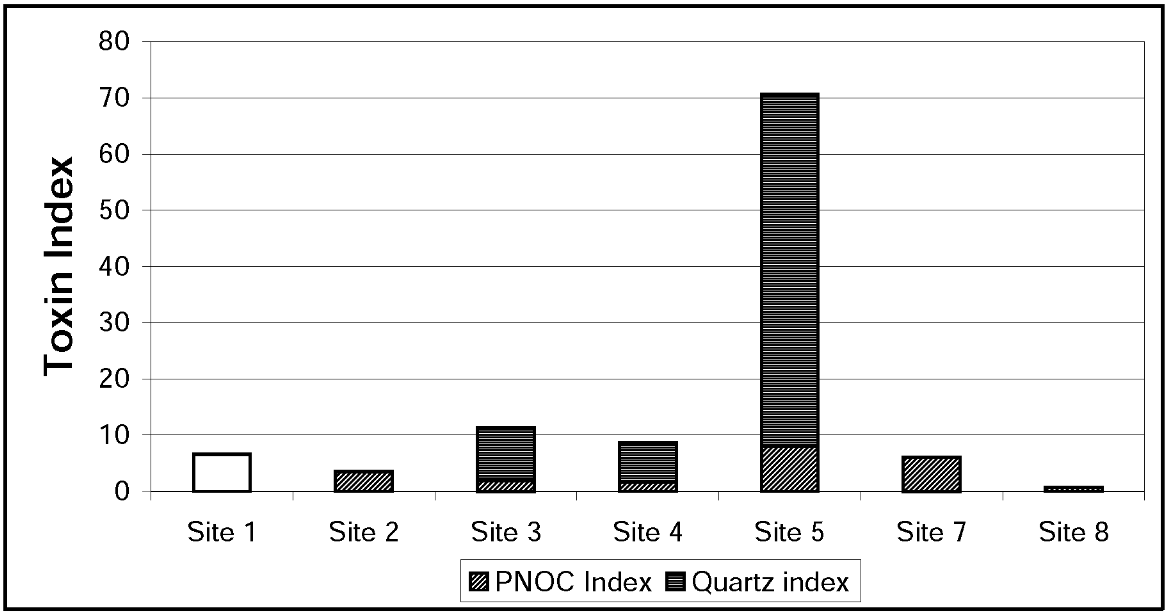

Figure 5.2.3: Total toxin index – Mine 2

Since mines cannot exercise control over quartz concentrations, they need to aim for greater control over dust liberation into the working environment. With the exception of Site 8, the TTIs indicate very high levels of dust throughout the mine. This is also evident in the high intake air dust levels. When intake dust levels are high, this dust is superimposed on the dust already in the workings thereby leading to even higher dust levels, which exacerbates the whole situation because workings are series-ventilated.

It is obvious that dust suppression in the mining of narrow fissure kimberlite deposits needs to be addressed as a matter of urgency, not only in the stopes but also in the development headings.

5.2.4 Overall results

Figure 5.2.4 shows the overall dust sampling results in terms of actual dust concentrations. The sites have been grouped into wet drilling operations and dry drilling operations. Intake levels are high, with the exception of Site 4, indicating general pollution throughout the mine. Whether or not water is used, the dust concentrations may be equally good or equally bad as can be seen from Figure 5.2.4.

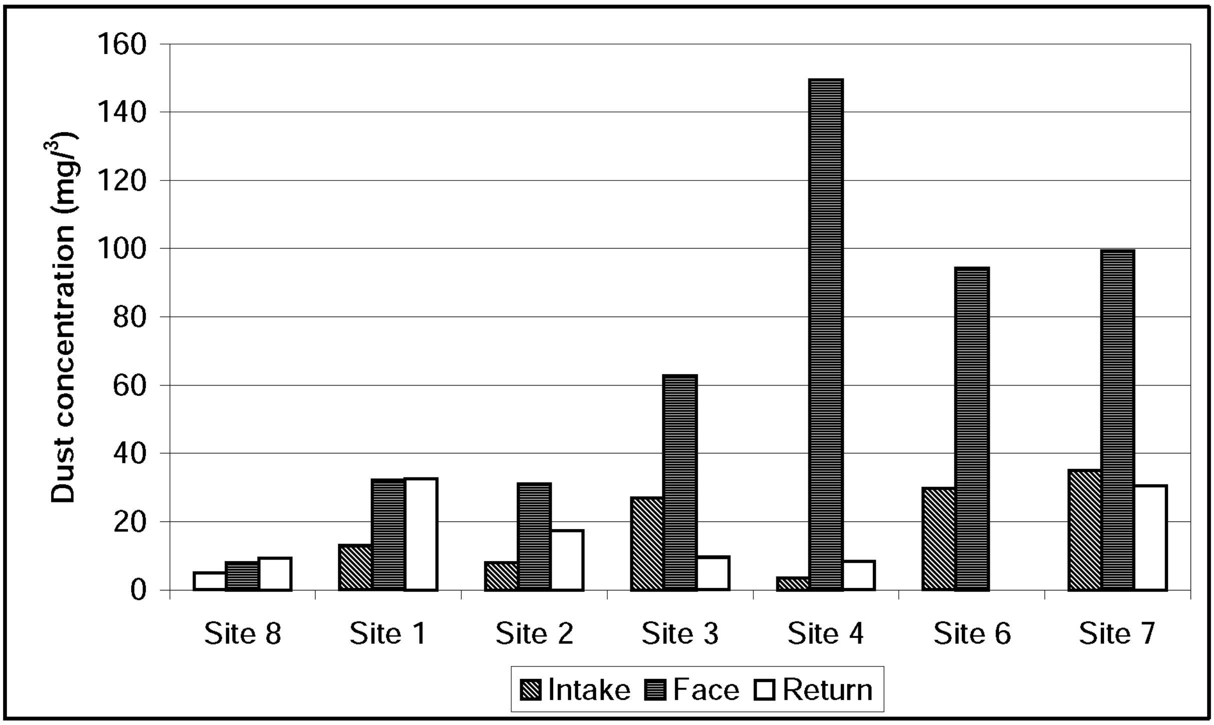

Figure 5.2.4: Dust concentrations of intake, face and return samples – Mine 2

5.3 Mine 3

As in the case of Mine 2, all mining operations are done by means of hand-held percussion drills. The development and stoping methods are therefore the same as those described for Mine 2. Ventilation flow through the mine relies solely on natural ventilation pressure (NVP), which is uncontrollable, unpredictable and can, under certain conditions, even reverse direction.

5.3.1 Wet drilling

Table 5.3.1 shows the results obtained at Mine 3 and Figure 5.3.1 gives a graphical representation. Again it is evident that wet drilling operations yield acceptable results, with indices well below 1,0.

Table 5.3.1

Wet drilling dust concentrations – Mine 3

Site Type of sampling Dust control method	Average dust concentration (mg/m^3)		
	Intake	Face	Return
Site 1 Percussion drill	12,98	32,22	32,67
Site 2 Percussion drill	8,08	31,13	17,32
Site 3 Percussion drill	26,92	62,92	9,54
Site 4 Percussion drill	3,43	149,57	8,45
Site 5 Percussion drill		184,69	
Site 6 Percussion drill	29,72	94,34	
Site 7 Percussion drill	35,0	99,51	30,50
Site 9		0,42	
Site 10		1,26	

At Site 1 it is evident that drilling operations did increase the dust levels. This may be due to the quality of the water used, which was unfortunately not tested. At Site 6 although the intake air already had a high dust concentration, it is apparent that wet drilling and limited ventilation did not worsen conditions.

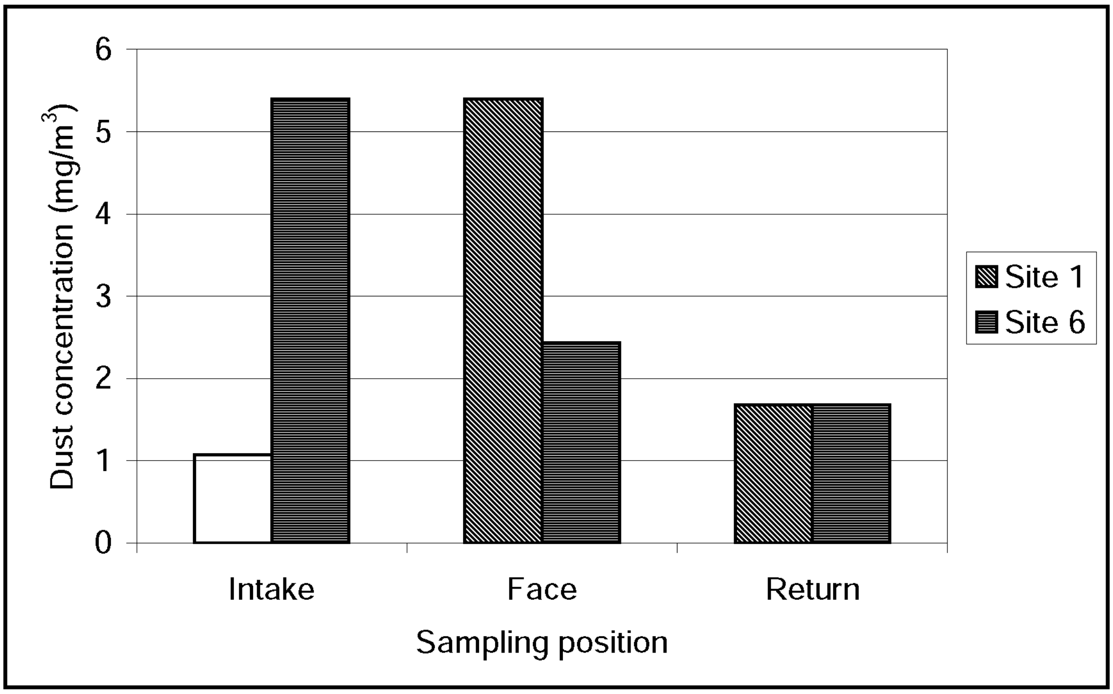

Figure 5.3.1: Wet drilling dust concentrations – Mine 3

The individual site layouts and tyndallometer measurements are shown in Appendix D.

When sampling at Site 6, due to the remoteness of the return air monitoring stations from the face and the nature of the site layout, it was unfortunately not possible to correlate the high tyndallometer readings with face activities.

5.3.2 Dry drilling

Table 5.3.2 sets out the sampling results obtained at four sites during dry drilling operations and Figure 5.3.2 is the graphical representation. The results for Sites 2, 3 and 4 clearly indicate the lack of dust control measures. Very poor ventilation and "stagnant" air at the drilling operation at Site 2 resulted in unacceptably high face dust concentrations as well as very high return air dust concentrations. The Site 5 results indicate the effect of water on the drilling operation, as the site was drenched in water on the day of sampling. Once again dry drilling is seen to be a prolific generator of respirable dust at the face, irrespective of the intake dust conditions. The effect of water at the face was not seen at Site 5, which displayed a very high dust concentration. The effect of the water at this site was evident mainly in the return air samples, on which the pollutant indices were based. The high face dust concentrations were probably due to compressed air from the drill expelling air, water, dust and rock chips into the atmosphere from the hole in an uncontrolled manner. The water obviously provided some form of scrubbing action but did not control the dust liberated at the drill holes. However, the PNOC index at this site was the lowest and the only one less than unity.

Table 5.3.2

Dry drilling dust concentrations – Mine 3

Site Type of sampling Dust control method	Average dust concentration (mg/m^3)		
	Intake	Face	Return
Site 2 Percussion drill	30,49	328,26	135,97
Site 3 Percussion drill	1,11	9,36	12,00
Site 4 Percussion drill	85,02	23,85	15,32
Site 5 Percussion drill	4,28	172,19	4,47

It is of interest to note that the abundance of water at Site 5 did not appear to affect production adversely, nor did it appear to have any effect on the kimberlite. The water did, however, make the surfaces slippery and dangerous for travelling, but no more so than in other mines that mine vertical or near-vertical deposits.

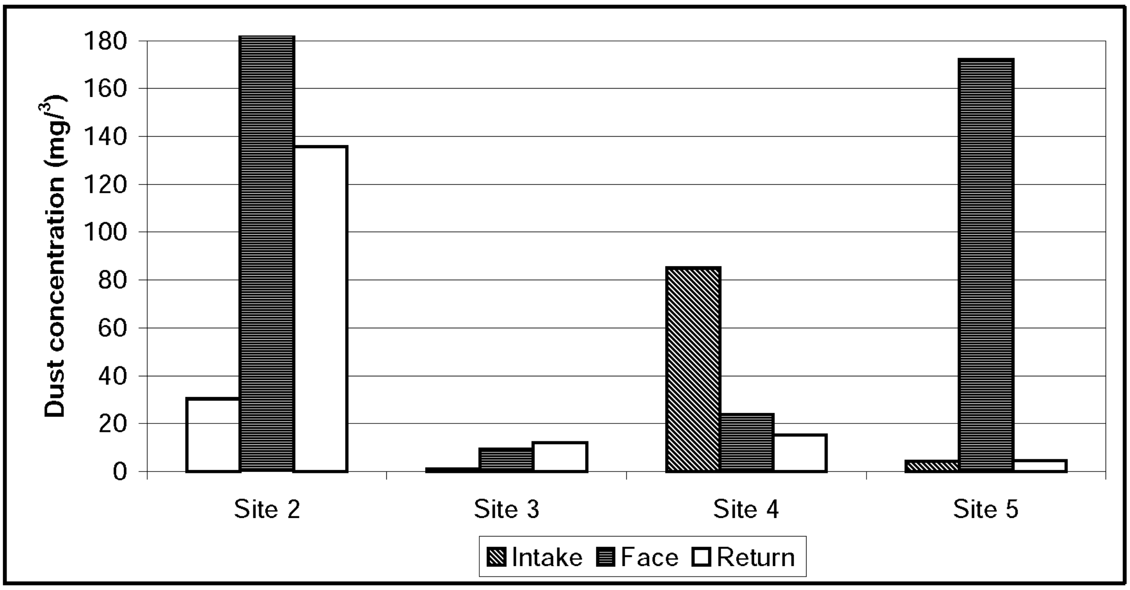

Figure 5.3.2: Dry drilling dust concentrations – Mine 3

5.3.3 Additional test sites

Apart from the working face measurements, two sets of gravimetric dust samples were collected, from an upcast shaft and a downcast shaft. These sites were annotated as follows:

Site 7 upcast shaft	Site 9 repeat of upcast shaft samples
Site 8 downcast shaft	Site 10 repeat of downcast shaft samples.

5.3.4 Quartz concentrations

The samples collected in the return air positions, together with the upcast and downcast air samples, were analysed for quartz content using the X-ray diffraction method, as already explained.

The results are set out in Table 5.3.4 and depicted in Figure 5.3.4, as well as in Appendix D. The high toxin index for Site 2 was due to the combination of a very high dust concentration with a relatively low quartz content. This reinforces the need to control dust levels in order to ensure acceptable environmental conditions, since mines have no control at all over quartz levels.

The actual dust concentrations for the upcast and downcast shafts proved to be low but the quartz concentrations recorded, apart from those from test Site 1, were the highest recorded in the mine with the quartz concentration at Site 10, a downcast shaft, rising to 64,5 % (the first sample yielded 22,2 % quartz). No explanation can be offered for this phenomenon, which is after all a measure of the quality of the intake air. It is possible that some recirculation of air exiting the mine was taking place.

Table 5.3.4

Quartz concentrations and percentages – Mine 3

	Average		
Work-place	**Dust concentration (mg/m^3)**	**SiO_2 (%)**	**Quartz concentration (mg/m^3)**
Site1	1,10	20,9	0,23
Site 2	109,95	5,5	6,05
Site 3	5,89	4,3	0,25
Site 4	10,77	2,9	0,31
Site 5	4,53	11,6	0,53
Site 6	0,92	10,3	0,09
Site 7	0,77	28,6	0,22
Site 8	0,21	22,2	0,05
Site 9	0,01	ND	-
Site 10	0,09	64,5	0,06

ND = Below the detectable limit of 20 µg.

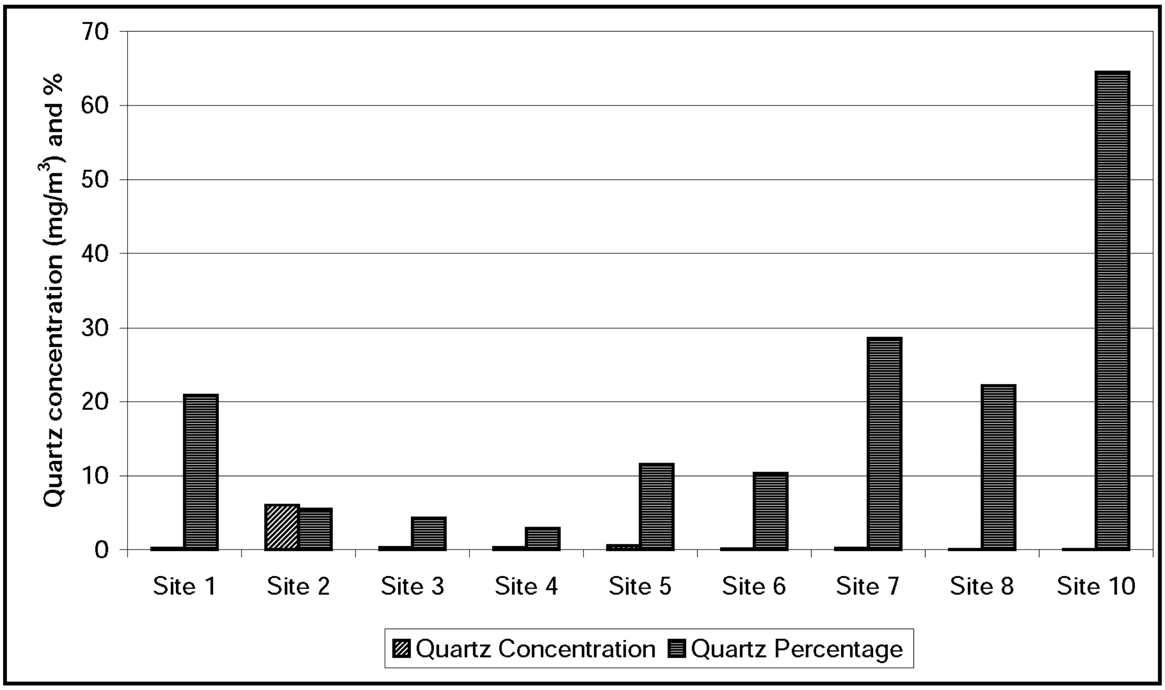

Figure 5.3.4: Quartz concentrations and percentages – Mine 3

5.3.5 Total toxin index

All the measured data and calculated data were used to compile the TTIs. These results are presented in Table 5.3.5 and shown graphically in Figure 5.3.5. As can be seen, the only TTIs less than unity were found at Sites 8 and 10 (the downcast shaft), and at Site 9, the upcast test site (repeat sample). The moderate quartz contents found at Sites 2 and 5, coupled with the very high dust concentration for Site 2 for the day and the high dust concentration for Site 5, resulted in very high and unacceptable TTIs for these particular sites.

Table 5.3.5

Toxin indices – Mine 3

Work-place	PNOC conc. mg/m^3	TLV	PNOC index	Quartz conc. mg/m^3	TLV	Quartz index	Toxin index
Site 1	1,68	5	0,34	0,23	0,1	2,30	2,64
Site 2	135,97	5	45,32`	6,05	0,1	60,50	105,82
Site 3	12,00	5	2,40	0,25	5	0,05	2,40
Site 4	15,32	5	3,06	0,31	5	0,06	3,06
Site 5	4,47	5	0,89	0,53	0,1	5,30	6,19
Site 6	1,68	5	0,37	0,09	0,1	0,90	1,27
Site 7	0,55	5	10,11	0,22	0,1	2,20	2,31
Site 8	0,16	5	0,03	0,05	0,1	0,50	0,53
Site 9	0,01	5	0,002	-	-	-	0,002
Site 10	0,03	5	0,006	0,06	0,1	0,60	0,61

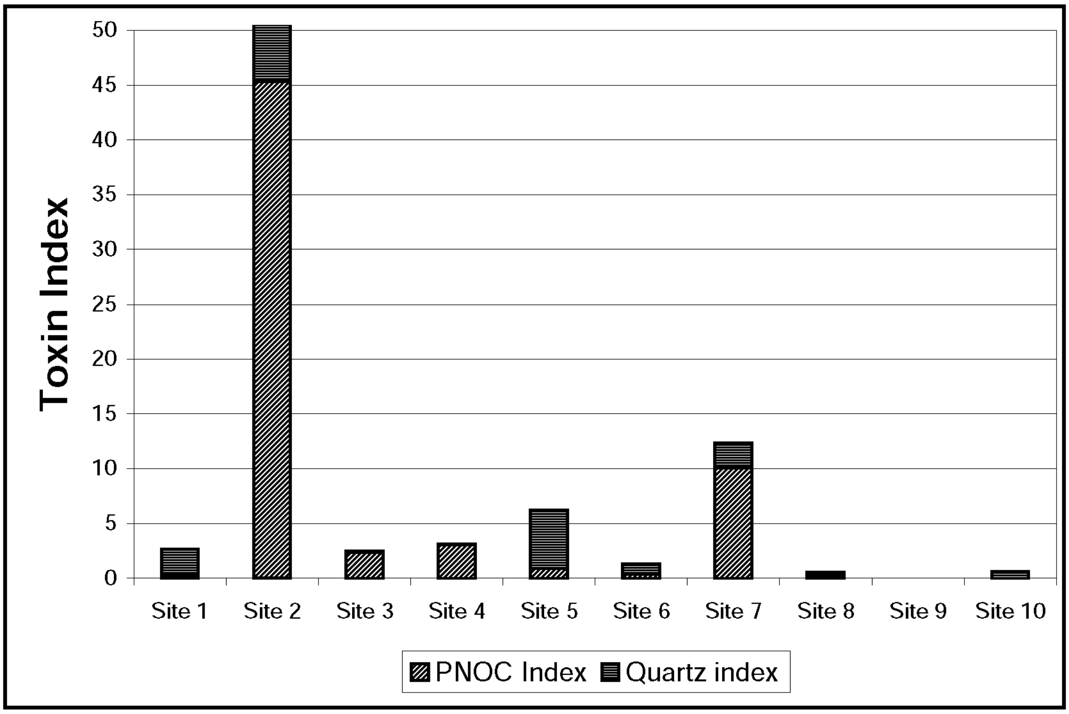

Figure 5.3.5: Total toxin index – Mine 3

The high TTIs in the workings and the high PNOCs in the intake air to the workings, because of series ventilation, are again indicative of widespread, high pollutant levels throughout the mine.

Once again the absence of controlled, positive ventilation and dust control measures led to high worker exposure levels.

Although the installation of ventilating fans, both main fans and booster fans, may prove to be difficult because of the extensively mined-out and honeycombed areas, this course of action should nevertheless be pursued. In addition, other dust-suppression measures, including the possible use of water in the stopes, should also be investigated and implemented where possible.

5.3.6 Overall results

The overall average dust concentrations for Mine 3 are presented graphically in Figure 5.3.6. The results clearly show the advantage that water has as a dust control measure over dry drilling control methods. Some exceptionally high dust concentrations were recorded at dry drilling sites. However, judging from what was found at similar dry drilling sites at other mines, this does not have to be the case.

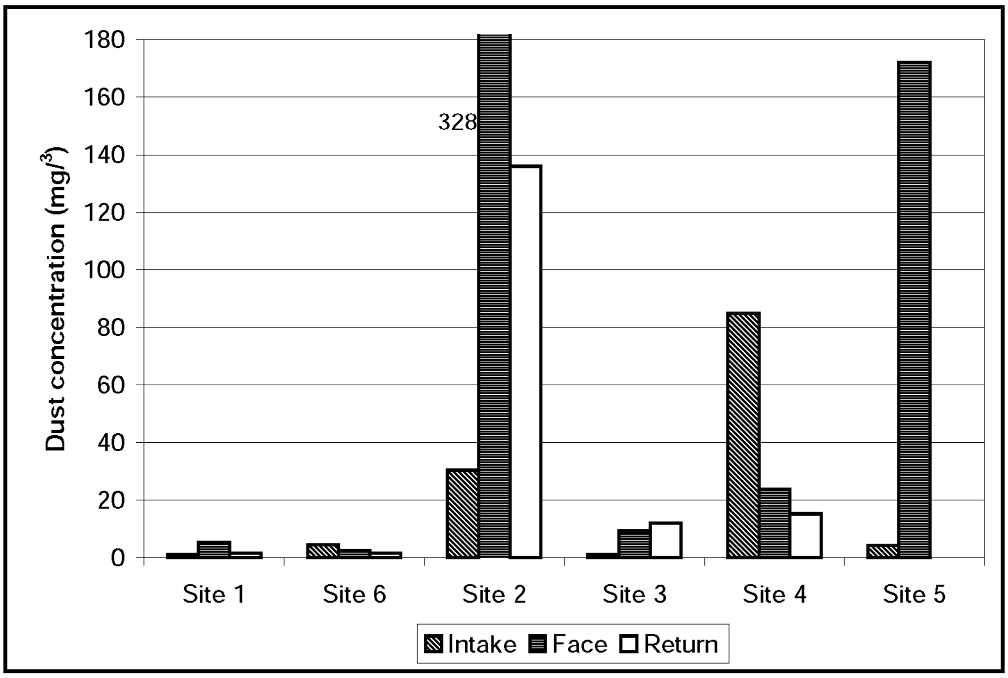

Figure 5.3.6: Dust concentrations of intake, face and return samples – Mine 3

5.4 Mine 4

Nine sites were sampled during the survey of which one represented a wet drilling operation and the remaining eight sites dry drilling operations.

5.4.1 Wet drilling

5.4.1.1 Ventilation and dust control

A centralised exhaust dust filtration system is used, based on the concept of capturing the dust-laden air in the vicinity of the drilling faces at several localities simultaneously and conveying it to a common filtration unit. An excavation relatively central to the tunnels being mined is equipped with suitable dust-filtering arrangements. All exhaust columns serving the tunnels are connected to the common filter chamber. Filtered air is discharged into the return airway by means of a centrifugal fan.

When the development holes connect with the open pit, the air very often tends to enter the development end from the open hole and pass into the workings. This happens when the underground booster fans do not provide sufficient positive pressure to prevent this type of occurrence and the neutral point in the push-pull fan system is incorrectly located. Under such conditions the exhaust dust-extraction duct concerned is unable to induce the dust-laden air to enter the duct and the ingress of air from the open hole pushes the dust-laden air into the workings.

5.4.1.2 Results

The results of the wet drilling operation are shown in Table 5.4.1.2 with a graphical representation in Figure 5.4.1.2a. The PNOC index is below the target value of 1,0.

Table 5.4.1.2

Wet drilling dust concentrations – Mine 4

Site Type of sampling Dust control method	Average dust concentration (mg/m^3)		
	Intake	Face	Return
Site 3 Drill rig	2,36	5,31	2,33

The drilling operation increased the average face dust concentrations. This may be a function of the quality of the water used for drilling (this aspect was unfortunately not checked). The drilling process does not appear to have added to the overall dust levels.

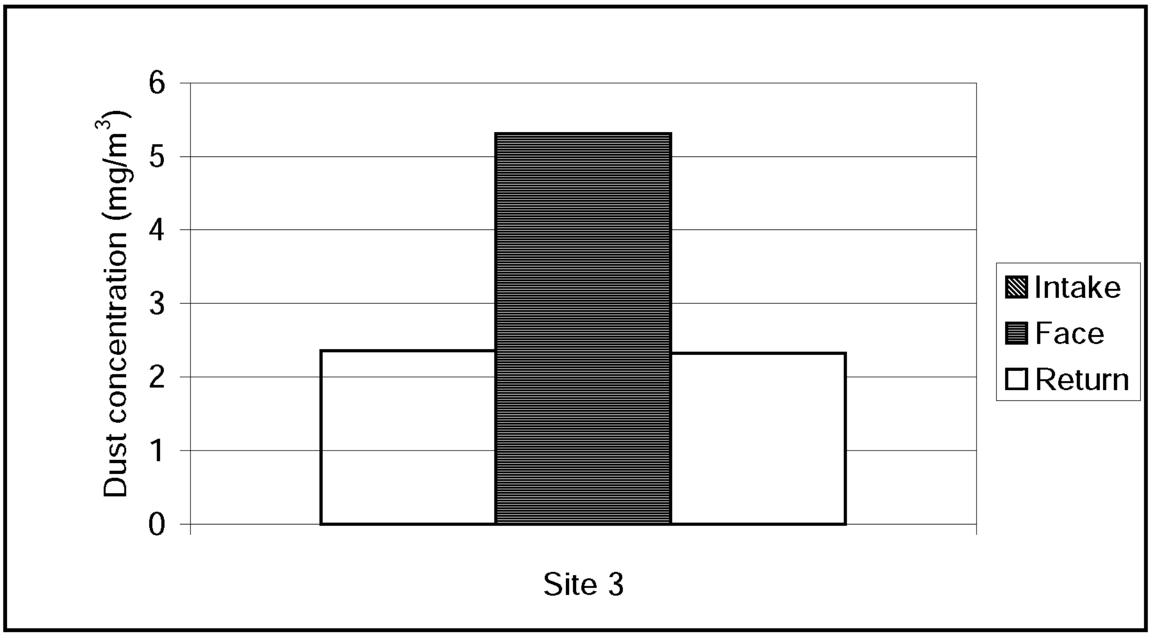

Figure 5.4.1.2: Wet drilling dust concentrations – Mine 4

5.4.2 Dry drilling

5.4.2.1 Ventilation and dust control

The machines used in long-hole drilling operations are equipped with a cassette-type dust-extraction filtration unit similar to the system described for Mine 1, except that these filters do not use fans, but high-pressure blower units instead.

5.4.2.2 Results

The PNOC indices are shown in Table 5.4.2.2 and the results indicate that proper dust control measures can be effective. Eight sites were sampled, with only two of the sites exceeding a PNOC index of 1,0. The results are also depicted graphically in Figure 5.4.2.2.

Table 5.4.2.2

Dry drilling dust concentrations – Mine 4

Site Type of sampling dust control method	Average dust concentration (mg/m^3)		
	Intake	Face	Return
Site 1 Drill rig with dust-extraction system	1,85	-	13,41
Site 2 Drill rig with dust-extraction system	4,10	297,78	3,57
Site 4 Drill rig with dust-extraction system	2,09	93,61	17,23
Site 5 Long-hole drill rig with remote dust control	4,18	1,64	4,48
Site 6 Long-hole drill rig with remote dust control	0,10	1,44	3,26
Site 7 Long-hole drill rig with remote dust control	0,24	0,86	1,38
Site 8 Long-hole drill rig with remote dust control	1,50	3,89	1,19
Site 9 Long-hole drill rig with jet fan	0,30	0,03	3,99

Due to activities on the upstream side of the test sites, the intake dust levels at Sites 1, 2, 4 and 5 were higher than expected. As judged against the return air dust levels, there were appreciable increases in dust levels over the intake dust levels for test Sites 1, 4, 6 and 9. The face conditions at Sites 2 and 4 to which the equipment operators were exposed were totally unacceptable. Both the control systems happen to have been on-board extraction systems, and both were either faulty or not correctly positioned against the working face. This again emphasises the importance of correctly functioning, correctly deployed dust control equipment for capturing the dust at source and thereby controlling the airborne emissions.

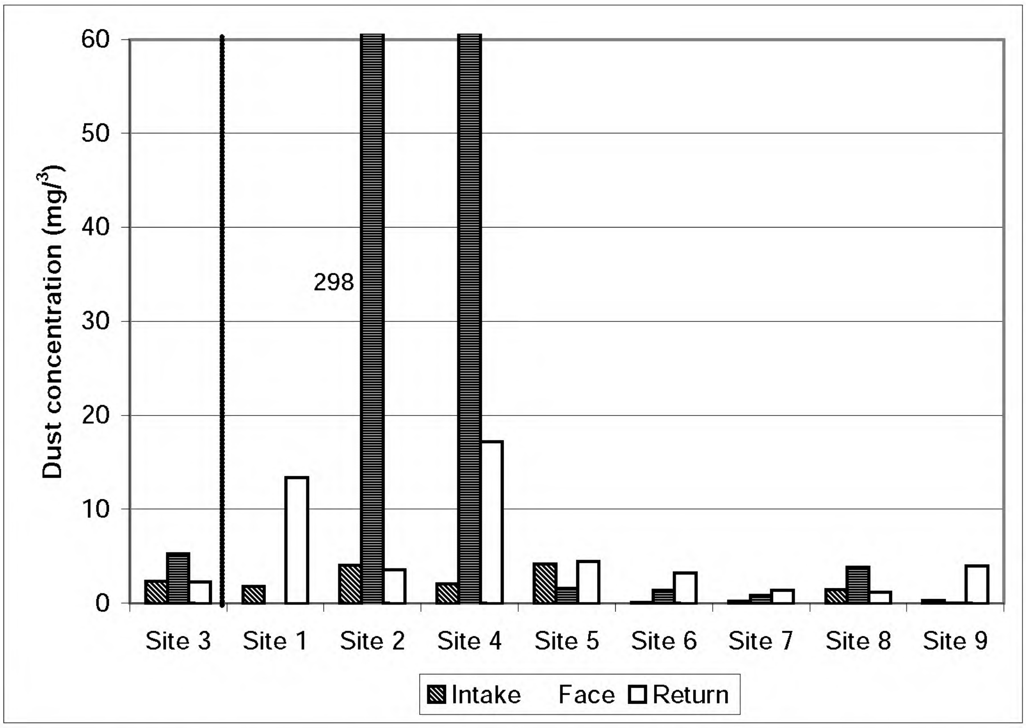

Figure 5.4.2.2: Dry drilling dust concentrations – Mine 4

Appendix E gives the individual sampling positions and tyndallometer measurements.

5.4.3 Quartz concentrations

The results of the quartz analyses are shown in Table 5.4.3 as well as in Appendix E. A maximum quartz index of 6,80 was obtained, with a minimum of 0,01 at Site 1. Figure 5.4.3 shows the quartz concentrations and percentages for the sites sampled.

Table 5.4.3

Quartz concentrations and percentages – Mine 4

	Average		
Work-place	**Dust concentration (mg/m^3)**	**SiO_2 (%)**	**Quartz concentration (mg/m^3)**
Site 1	13,47	0,5	0,07
Site 2	*63,89*	*0,5*	*0,32*
Site 3	*1,53*	*16,6*	*0,25*
Site 4	*32,87*	*1,2*	*0,39*
Site 5	1,30	46,4	0,60
Site 6	2,64	25,7	0,68
Site 7	1,61	18,1	0,29
Site 8	2,42	9,7	0,23
Site 9	*15,22*	*2,1*	*0,32*
Site 10	*0,84*	*14,8*	*0,12*

The quartz analyses confirm the findings of a previous research project, SIMGAP 046,: (Unsted, 1996) that the quartz concentration of airborne dust can vary from sample to sample, site to site and shift to shift. Low dust concentrations with a high quartz content can lead to a poor pollutant index just as high dust concentrations with a low quartz content can. This varying quartz content makes comparisons of conditions between one workplace and another very difficult. The decision to use parallel samplers was therefore vindicated in that at least two samples could then be averaged when comparisons were made. It is felt that this reduced the errors in the comparison.

The quartz content was found to be less than 5 % at only four of the test sites, namely Sites 1, 2, 4 and 9. Mine personnel were somewhat surprised at the high quartz contents.

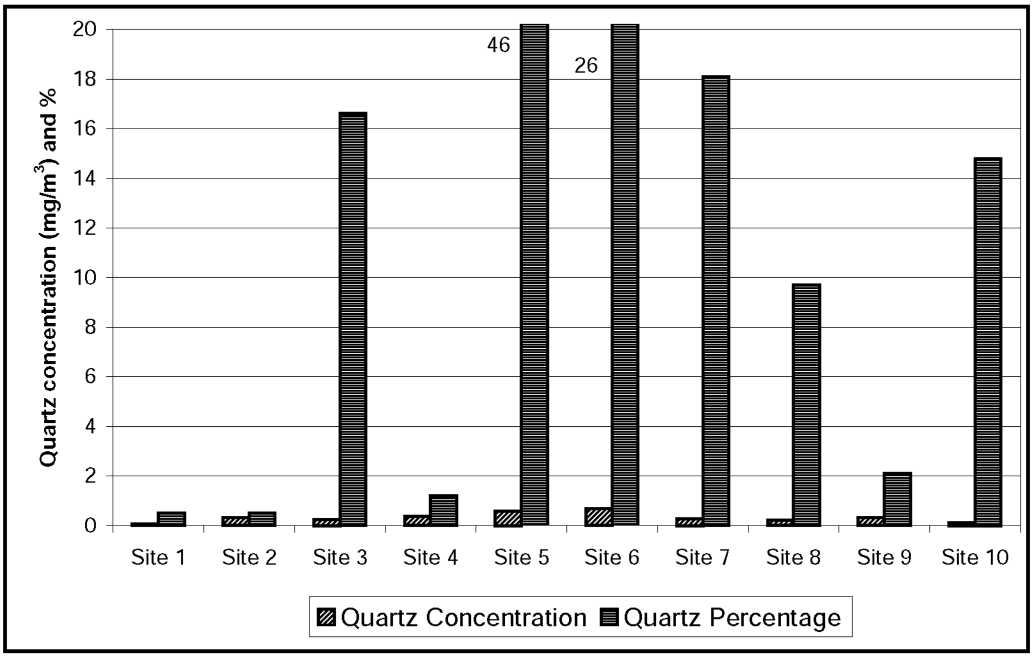

Figure 5.4.3: Quartz concentrations and percentages – Mine 4

5.4.4 Total toxin index

The total toxin indices are given in Table 5.4.4. The quartz and PNOC indices are graphically presented in Figure 5.4.4.

Table 5.4.4

Toxin indices – Mine 4

Work-place	PNOC conc.	TLV	PNOC index	Quartz conc.	TLV	Quartz index	Toxin index
Site 1	13,41	5	2,68	0,07	5	0,01	2,68
Site 2	3,57	5	0,71	0,32	5	0,06	0,71
Site 3	2,33	5	0,47	0,25	0,1	2,50	2,97
Site 4	17,23	5	3,47	0,39	5	0,08	3,47
Site 5	4,48	5	0,90	0,60	0,1	6,00	6,60
Site 6	3,26	5	0,65	0,68	0,1	6,80	7,45
Site 7	1,38	5	0,28	0,29	0,1	2,90	3,18
Site 8	1,19	5	0,24	0,23	0,1	2,30	2,54
Site 9	3,99	5	0,80	0,32	5	0,06	0,80
Site 10	0,72	5	0,14	0,12	0,1	1,20	0,26

As can be seen, the TTIs were less than unity at only three test sites, viz. Sites 2, 9 and 10. The high TTIs tend to indicate the liberation of dust into the environment or else the superimposition of dust on elevated intake dust levels because of inadequate dust control elsewhere in the mine. Once again it is seen how the presence of quartz in concentrations greater than 5 % can substantially increase the toxin index.

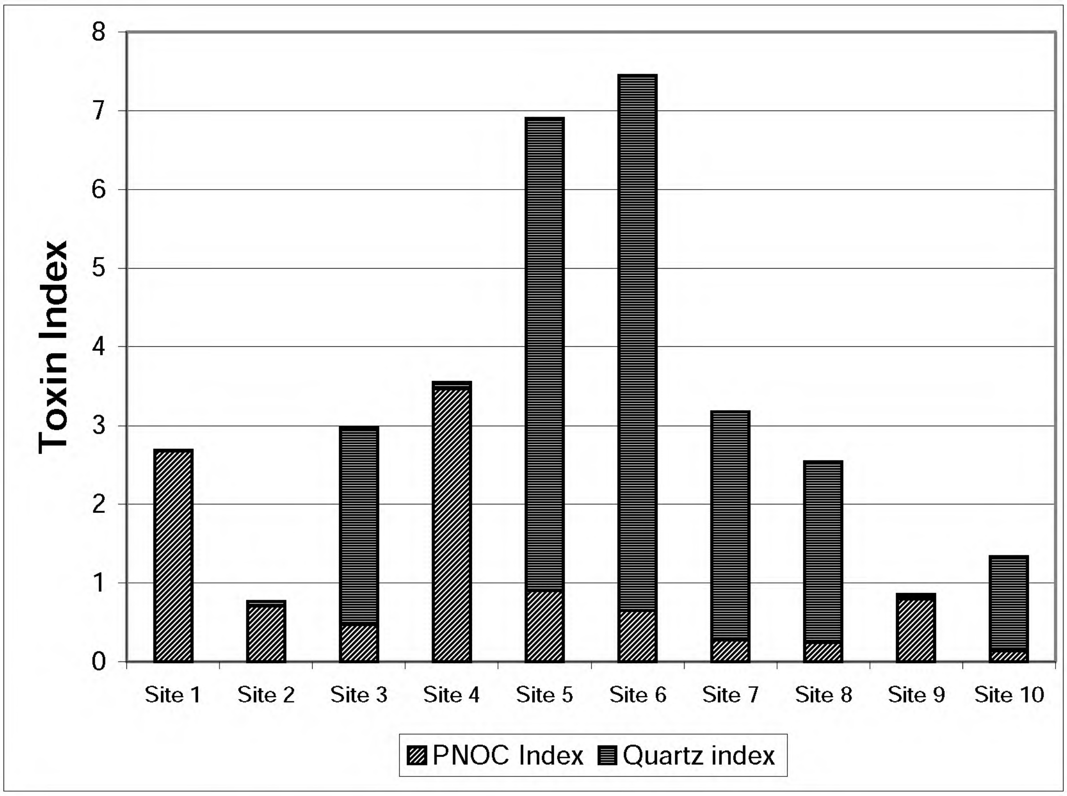

Figure 5.4.4: Total toxin index – Mine 4

5.4.5 Overall results

The overall results for Mine 4 are presented in Figure 5.4.5. The dry drilling results show even lower dust concentrations, when control measures are properly applied, than the wet drilling concentrations. At two dry drilling sites, namely Sites 2 and 4, where ventilation rates were inadequate, the dust concentrations were found to be excessively high.

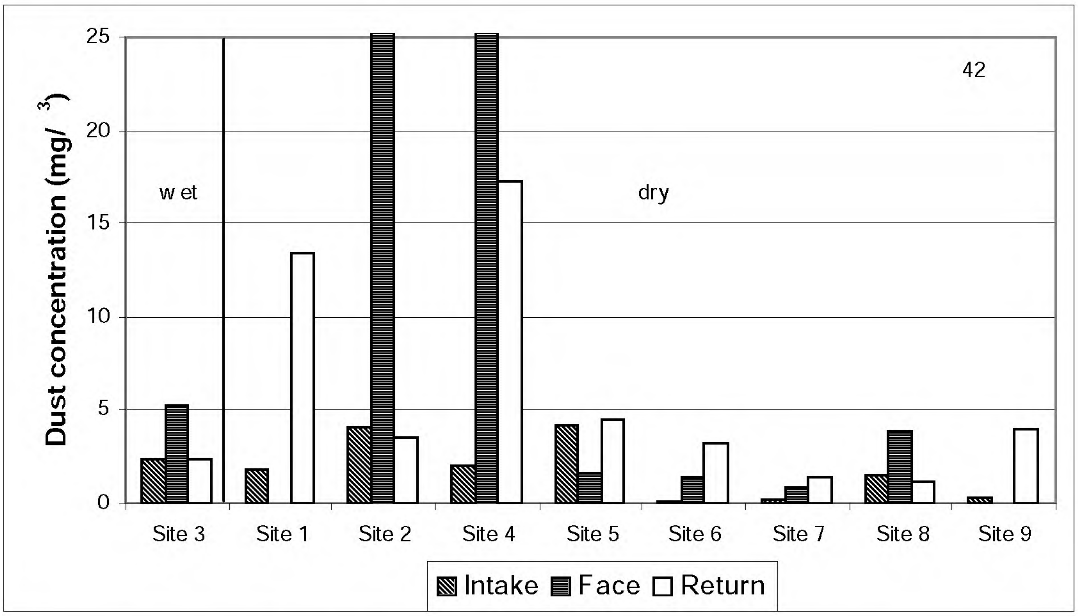

Figure 5.4.5: Dust concentrations of intake, face and return samples – Mine 4

5.5 Mine 5

Ten sites were sampled at Mine 5, of which four were wet drilling operations and the remaining six sites dry drilling operations.

5.5.1 Wet drilling

5.5.1.1 Ventilation and dust control

A system of wet drilling in country rock using a drill rig, similar to that used at both Mines 1 and 4, is in operation.

An additional method is also employed in which an exhaust overlap system is used for dust control at the main tunnels developed with either hand-held percussion drills or drill rigs (wet drilling). Developing tunnels are ventilated and the return dust-laden air is exhausted via an extraction column. The exhaust column may discharge directly into the return airway, or be connected to a centralised filter chamber.

In some instances only a forcing ventilation system is in place, allowing the return air to flow in a cross-cut connected to a dedicated ventilation column plugged into the return airway. Air may also be directed back to the return airway (RAW).

Four sites were sampled, with the dust levels at only one site exceeding a PNOC index of 1,0. The results are shown in Table 5.5.1.1. Figure 5.5.1.1a shows graphically the results of the intake, face and return air samples.

Table 5.5.1.1

Wet drilling dust concentrations – Mine 5

Site Type of sampling Dust control method	Average dust concentration (mg/m^3)		
	Intake	Face	Return
Site 5 Drill rig with exhaust column	0,74	1,51	1,04
Site 7 Percussion drill with exhaust column	2,46	0,15	0,43
Site 9 Percussion drill with exhaust column	5,04	2,61	3,51
Site 10 Drill rig with exhaust column	7,15	6,82	5,21

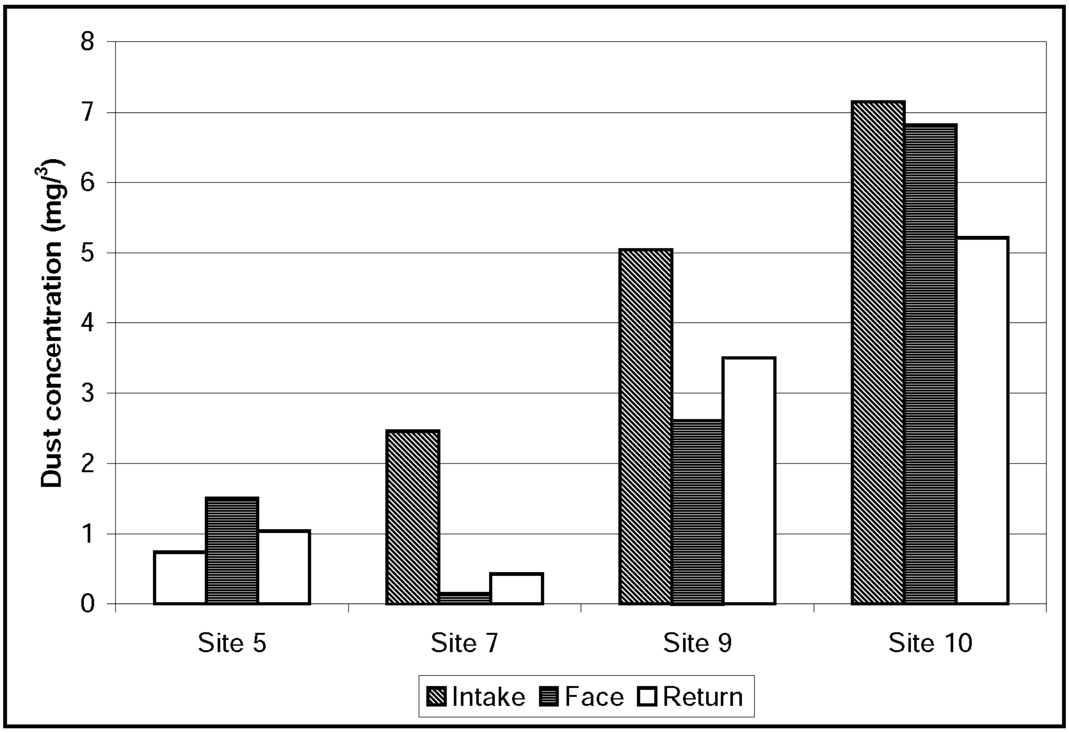

Figure 5.5.1.1: Wet drilling dust concentrations – Mine 5

The individual site layouts and tyndallometer graphs can be found in Appendix F.

5.5.2 Dry drilling

5.5.2.1 Dust control

Dust control during drilling in the kimberlite consists of cassette-type filtration, operated remotely from the drill rig, similar to that used in Mine 1. A portable dust-extraction unit (ejector cyclone extraction) is also used to filter air during dry drilling in a confined space that permits only two hand-held percussion drills.

5.5.2.2 Results

The results for the six sites are shown in Table 5.5.2.2. A minimum PNOC index of 0,02 was calculated for Site 3 where drilling was done with a long-hole drill rig. In the instances where hand-held percussion drills were used, the indices were all above 1,0 indicating the need to implement effective dust control. Figure 5.5.2.2 shows the average dust concentrations of the intake, face and return air samples and clearly highlights the effectiveness of the two different dust control techniques.

Table 5.5.2.2

Dry drilling dust concentrations – Mine 5

Site Type of sampling Dust control method	Average dust concentration (mg/m^3)		
	Intake	Face	Return
Site 1 Long-hole drill rig with remote dust control	1,79	1,58	2,41
Site 2 Long-hole drill rig with remote dust control	1,29	0,37	1,72
Site 3 Long-hole drill rig with remote dust control	1,00	0,85	0,12
Site 4 Hand-held percussion drill with force column	1,55	24,17	15,01
Site 6 Hand-held percussion drill with force column	0,06	22,58	22,32
Site 8 Hand-held percussion drill with force column	0,43	40,42	17,11

NB: Three additional samples were collected for purposes of comparison/control.

Site 11: Operator was in the vicinity of a ground pass at the tipping area.

Site 12: Same as above.

Site 13: Main return.

The results of the additional sampling are shown in Tables 5.5.3 and 5.5.4.

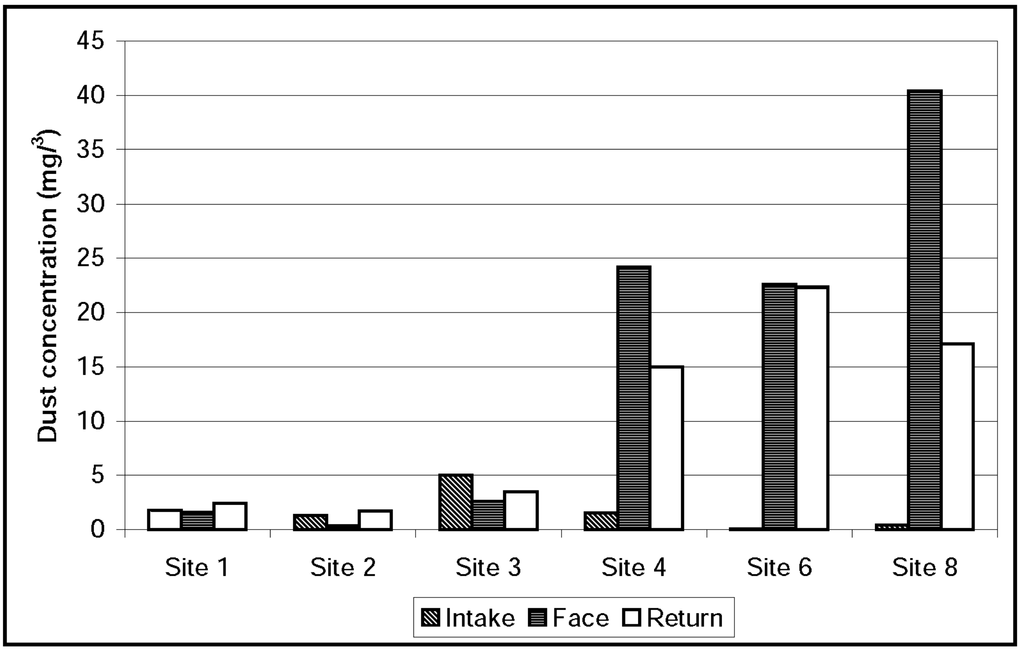

Figure 5.5.2.2: Dry drilling dust concentrations – Mine 5

It is clear from these results that where dust extraction and monitoring are properly implemented, both the face and return air dust concentrations can be controlled and kept to acceptable levels. The ventilation system used for dust control with hand-held percussion drills did not provide an effective solution to dust emission, and the face and return air samples were unacceptably high, especially when compared with the intake dust levels. In Appendix F the site layouts, sampling positions and tyndallometer readings obtained are shown.

5.5.3 Quartz concentrations

The results are given in Table 5.5.3. With the exception of Site 5, for which an index of 2,60 was calculated, all the quartz indices are below 1,0. The quartz concentrations exceeded 5 % at three sites, viz. Sites 3, 5 and 13. Figure 5.5.3 shows the quartz concentrations and percentages.

Table 5.5.3

Quartz concentrations and percentages – Mine 5

Work-place	Dust conc. (mg/m^3)	SiO_2 (%)	Quartz conc. (mg/m^3)	Quartz index
Site 1	*3,01*	*2,95*	*0,09*	0,02
Site 3	0,43	16,10	0,07	0,70
Site 4	14,29	1,0	0,14	0,03
Site 5	1,74	12,40	0,26	2,60
Site 6	14,04	0,80	0,11	0,02
Site 7	0,60	-		-
Site 8	20,07	1,0	0,20	0,04
Site 9	5,12	2,10	0,11	0,02
Site 10	*6,54*	*1,25*	*0,08*	0,02
Site 11 (Operator)	4,10	2,60	0,11	0,02
Site 12 (Operator)	14,36	0,80	0,11	0,02
Site 13 (Main return)	0,77	9,30	0,07	0,70

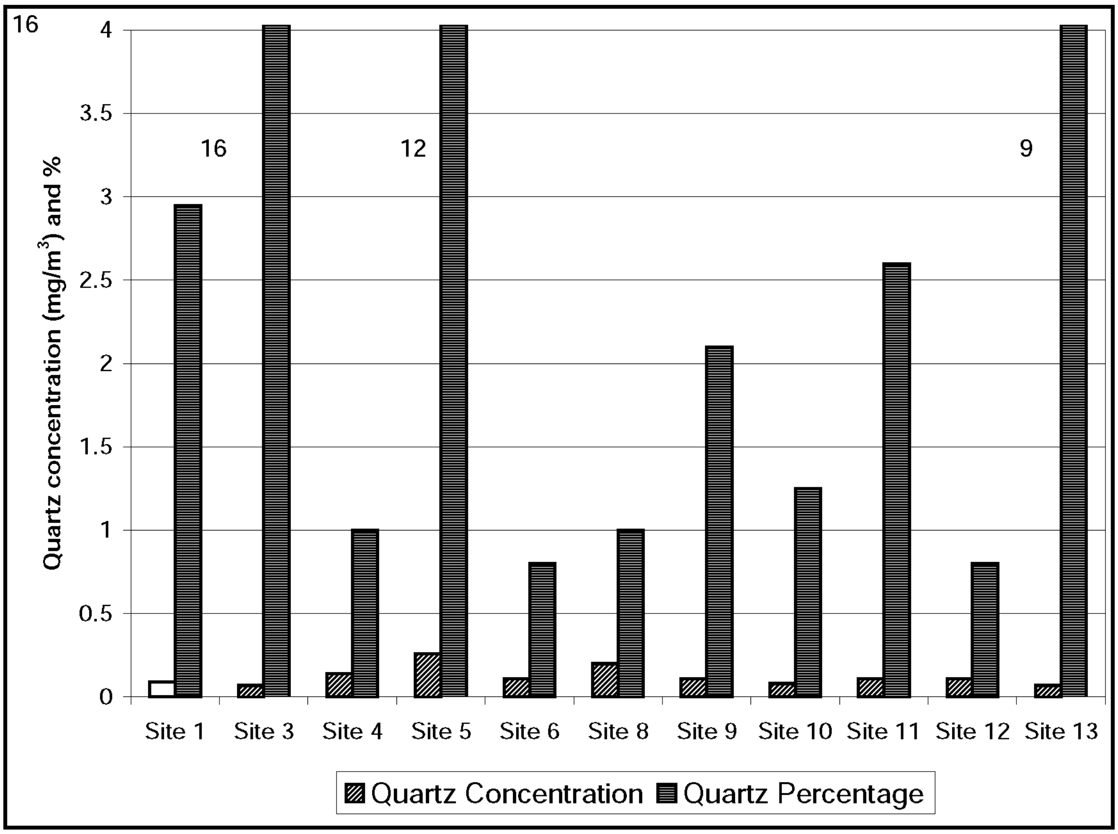

Figure 5.5.3: Quartz concentrations and percentages – Mine 5

5.5.4 Total toxin index

Total toxin indices are shown in Table 5.5.4 and Figure 5.5.4, and emphasise the necessity for strict dust control. Five of the 13 sites exceeded an index of 1,0. In terms of dust exposure, these sites would be deemed unhealthy.

Table 5.5.4

Toxin indices – Mine 5

Work-place	PNOC conc.	TLV	PNOC index	Quartz conc.	TLV	Quartz index	Toxin index
Site 1	2,41	5	0,48	0,09	5	0,02	0,48
Site 2	1,72	5	0,34	-*	-	-	0,34
Site 3	0,12	5	0,02	0,07	0,1	0,70	0,79
Site 4	16,01	5	3,20	0,14	5	0,03	3,20
Site 5	1,04	5	0,21	0,26	0,1	2,60	2,81
Site 6	22,32	5	4,46	0,11	5	0,02	4,46
Site 7	0,43	5	0,09	-*	-	-	0,09
Site 8	17,11	5	3,42	0,20	5	0,04	3,42
Site 9	3,51	5	0,70	0,11	5	0,02	0,70
Site 10	5,21	5	1,04	0,08	5	0,02	1,04
Site 11	0,11	5	0,02	0,003	5	0,001	0,02
Site 12	0,11	5	0,02	0,001	5	0,0001	0,02
Site 13	0,77	5	0,14	0,07	0,1	0,72	0,86

* Below detectable limit of 20 :g.

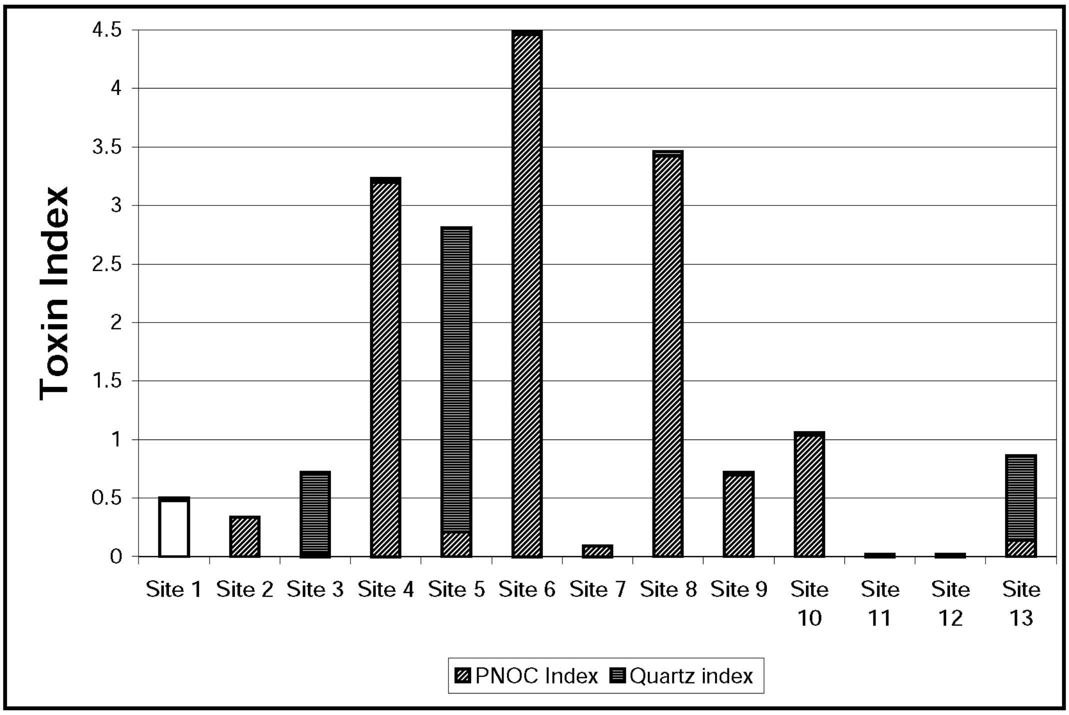

Figure 5.5.4: Total toxin index – Mine 5

5.5.5 Overall results

The overall results are presented graphically in Figure 5.5.5.

Again, it is obvious that the use of water offers good dust suppression capabilities. Where drill rigs are equipped with dust control measures such as at Sites 1, 2 and 3 dust emissions are seen to be in check, whereas the ventilation system for dust control used at Sites 4, 6 and 8 proved to be largely ineffective.

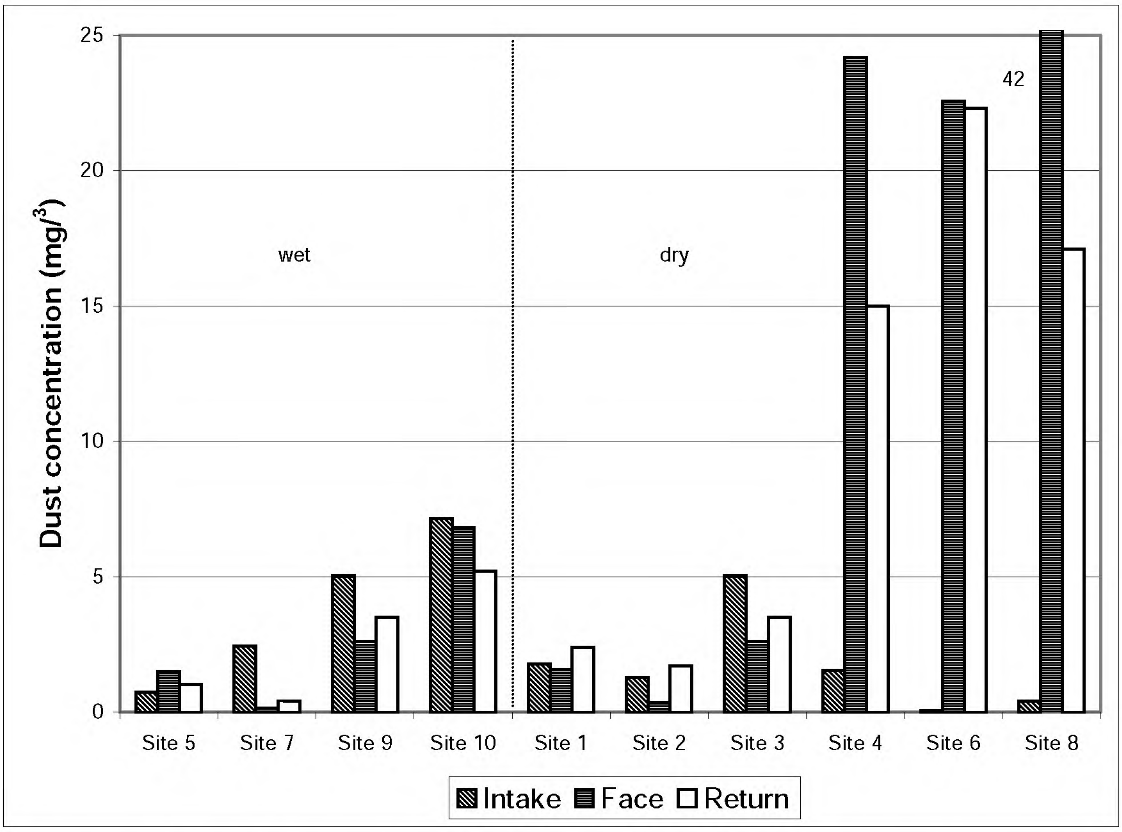

Figure 5.5.5: Dust concentrations of intake, face and return samples – Mine 5

6 Comparison of all mines

The quality of a work environment can be evaluated in terms of the actual dust concentrations or a dust index, in which a common conversion factor would be used. This would seem to be a logical approach for testing the effectiveness of dust control measures. The dust indices would not be equated in any way with eight-hour TWA exposures, which are really personal exposure levels against which the health hazard is assessed. Even the conversion of dust concentrations to total toxin indices is of limited value when using samples of short duration to assess the health hazard due to the malfunctioning or absence of equipment. If changes are made to a dust control device, the effects are likely to be noticed in the actual dust concentrations and only to a lesser extent in the dust (PNOC) index. The effects of changes would also readily be seen on tyndallometer readings.

However, the quartz content of the dust could cloud the evaluation and when judging the dustiness of workplaces, the results may even be re-ordered when quartz contents are taken into consideration. This may give the correct ranking in terms of health hazard but not in terms of effective control. The health hazard is determined by taking into account the quartz content of the dust and since the quartz content is variable and non-repeatable and the mines have no control over it, it should not be used for evaluating engineering controls.

It is also noted that an observation made on one day could yield a certain TTI for a given quartz concentration. Due to the variability of the airborne quartz, a test on another day may yield exactly the same dust loading but a different quartz content which, in turn, may either lower or raise the TTI and if the assessment is based on the TTIs, different conclusions may be drawn for the two sets of results.

It also follows that if emission levels are controlled, the exposure levels will be controlled. If dust levels are minimised, the quartz index will also be minimised.

In the light of the above, the overall comparison of all mines was therefore based on actual dust concentrations.

The results have been re-ordered so that the mines exploiting pipe deposits, namely Mines 1, 4 and 5, have been grouped together, and those exploiting fissure deposits, namely Mines 2 and 3, have been grouped together.

Figure 6a shows the results of average dust concentrations in wet drilling operations. Irrespective of the type of deposit mined, the dust levels all appear to be similar.

However, the picture alters radically when the results of dry drilling are compared for the five mines. As seen in Figure 6b, where pipe deposits are mined, i.e. in Mines 1, 4 and 5, and dust control measures are properly implemented (Mines 1 and 5), the average dust levels are significantly lower than those in the dry mines of fissure deposits, i.e. Mines 2 and 3, where inadequate (and ineffective) ventilation is the main method of combating dust liberation into the working environment. The high face dust conditions found at Mine 4 were also due largely to inadequate ventilation in development ends where hand-held percussion machines were used.

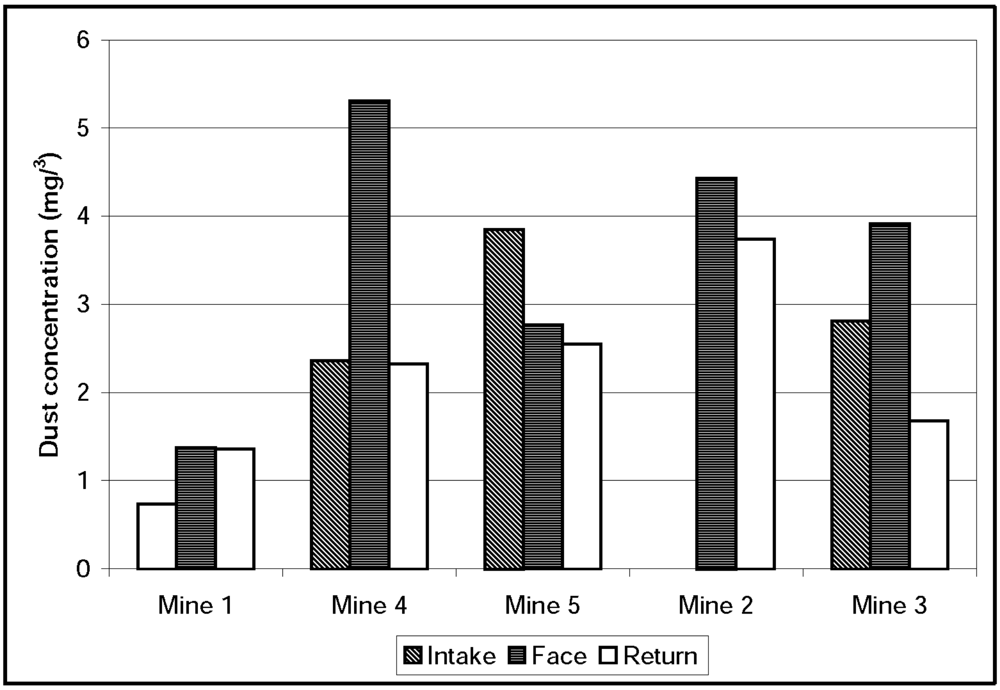

Figure 6a: Wet drilling dust concentrations on Mines 1 to 5

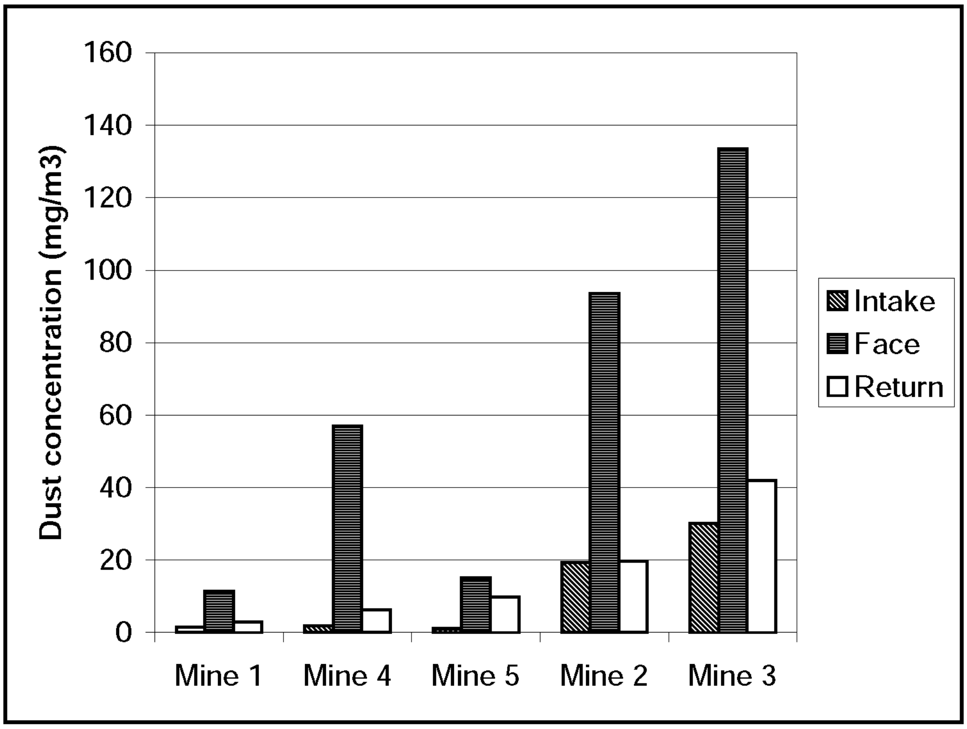

Figure 6b: Dry drilling dust concentrations on Mines 1 to 5

7 Discussion and conclusions

Research was conducted at mines representative both of the geological occurrences of kimberlite and of mining methods.

The conclusions reached with regard to dry drilling can be classified in terms of findings for kimberlite pipe mines, for fissure mines and for those common to both types of mining. Accordingly, the conclusions are set out along these lines.

Kimberlite pipe mines feature large excavations, large pieces of mining equipment and, generally, large items of dust control equipment. Although one set of results for on-board dust control equipment showed high dust concentrations, there was generally little to choose between on-board or remotely located dust filtration units. These dust control measures capture the dust at source through the deployment of a cowl at the rock face through which the drill passes. However, dust can escape the influence of the cowl where the fit against the face is poor due to an uneven surface area, drilling on or near a bend, or through interference from the safety mesh. This problem needs researching together with the problem caused when dust is discharged from the filter units onto the footwall and then is later disturbed and becomes airborne.

It was not possible to determine the effectiveness of the dust control equipment by monitoring atmospheric conditions with and without the equipment in use, but some idea of the probable dust levels, all very high, without dust control equipment was gained when measurements were taken during the malfunctioning of control equipment (see results for Mine 1, Site 8).

It is obvious that for the dust control equipment to remain effective, it needs scheduled maintenance and must be correctly deployed.

Although the project was aimed mainly at determining the effect of dry drilling and the effectiveness of control measures, certain other sources and causes of pollution were noted. In the first instance, dust on the haul roads was identified as a problem. In some instances, the haul roads are paved and swept and in others a chemical binder is used. These measures appear to be effective but the dust levels were not specifically evaluated. Nevertheless, where uncontrolled, this source of dust could have been responsible for elevating certain intake dust levels, which could not otherwise be explained. Scheduled and regular sweeping of paving and the regular application of binder are therefore also important to ensure that the general dust levels, which could become intake air dust levels, are not elevated and thereby adversely affect worker exposure. The control of haul road dust also requires research.

Another dust-generating problem identified was dry lashing. It follows that other aspects of handling dry ore, such as loading, tramming and tipping, could also be expected to be problematic. The handling of dry ore should also be researched.

Finally, a problem was identified where the underground workings hole into the open pit. Under the influence of the surface exhaust fans, air tends to be drawn into the workings at these holings. This has the effect of introducing high dust levels from rock slides, etc. or else keeping the polluted air in suspension in the headings and then pushing it into the workings. Jet fan-type ventilation aimed at pressurising headings locally to prevent the ingress of air and to cause an airflow into the open pit was, in many cases, not successful. Personnel were therefore exposed to high dust levels under such circumstances and research into effective push-pull ventilation for this type of mining can be seen to be justified.

With regard to the mining of fissure deposits, it was found that no dust control measures were implemented in the stopes other than ventilation for the dilution and removal of dust. However, the ventilation was only brought about through natural ventilation pressure, which, as is well known, can be erratic, reversible, dependent on weather conditions and unreliable. As a consequence, the dust generated at the drills was neither diluted nor removed effectively, leading to very high dust concentrations at the operators' positions as well as for all personnel in the vicinity and downstream thereof. Very slow air movement resulted in high dust concentrations for very long periods in the workings and for all people in the path of the slow-moving, highly polluted air. The situation is exacerbated when workplaces are ventilated in series. Large numbers of personnel were thus being exposed to high dust concentrations. The extensively honeycombed workings would make effective ventilation difficult but not totally impossible. To compound the problem, it should also be noted that ventilation or environmental engineering officers are not employed by these mines.

Stopes were found to be highly contaminated by dust. At times visibility was bad enough to be considered a safety hazard, especially in the near-vertical stopes.

Although no water is used to mine the blue ground because it is claimed that water has a detrimental effect on kimberlite, no adverse effects on production were observed in a stope that was very wet from natural causes and the water did appear to have a scrubbing action on the dust generated by drilling. However, the slippery surfaces made travelling in the stope very dangerous.

This is only one instance where water was encountered in the kimberlite but, nevertheless, the controlled use of water for drilling in fissure mining operations should be re-examined.

Improved ventilation, even vastly improved ventilation, on its own is unlikely to reduce the dust generated from dry drilling to acceptable levels and additional measures will need to be introduced.

Although the literature search did not turn up any direct references to dry mining, this does not really mean that it is not practised elsewhere in the world. Drilling methods are often described but no reference is made to whether or not water is used and dust control methods are generally not discussed. In a similar way, references to noise levels are not reported. Just because dry drilling or noise levels are not specifically mentioned is no guarantee that dry drilling was not practised or that the drill was not particularly noisy.

Different mining methods are used to mine the different types of kimberlite deposit and dust control methods also vary with the type of deposit mined. Whatever the deposit, no water is used in mining blue ground.

No single or uniform solution to the dust-generation problem in the mining of kimberlite appears feasible. A satisfactory solution to dust control in pipe deposits would not necessarily be relevant to fissure mining since it would not be practical, for instance, to introduce suction pipes and filters into vertical or near-vertical stopes. However, a satisfactory and practical solution to dry drilling in vertical fissure deposits could well have application in the mining of blue-ground pipes.

Irrespective of the type of deposit, where ventilation was poor, in the stopes or development headings ventilated by venturis the dust levels were found to be high. This poor ventilation coincided with the use of percussion drills.

Serious consideration should be given to using water for all drilling operations in country rock.

As reported, the use of polycrystalline rotary drill bits was found to dramatically reduce dust emissions in controlled conditions. This aspect should be investigated in experiments aimed at testing, first, just the drill bits and then the drill bits in addition to the use of water or other dust control measures such as improved ventilation.

It would appear that a ventilation flow rate based on the cross-section of a development heading is inadequate to provide a healthy working environment under the conditions encountered in these mines. Although the ventilation provided by a venturi driven by compressed air may meet the legal requirements for ventilation, the heading may nevertheless be inadequately ventilated. Serious consideration should be given to providing a minimum air speed of at least 0,5 m/s, regardless of the size of the heading, to dilute and remove contaminants.

It is further recommended that controlled tests be conducted on surfactants, wetting agents, mist injection and foam for controlling dust liberation into the working environment. The possibility of coupling dust control measures to a rock drill that is totally enclosed, a feature of a machine being developed for noise control, should be explored. Whatever approach is adopted to control dust effectively in dry drilling operations, it is unlikely that a single technique will succeed since a combination of techniques appears to be necessary.

Work on binding agents such as calcium chloride to control footwall and haul road dust is also indicated.

A spin-off of the successful development of a dust control technique for dry mining in kimberlite mines will be that such a technique can also be used in opencast mines and quarries.

It is also apparent that no single mining company, particularly those exploiting fissure deposits, is likely to be able to fund the necessary research and that research on an industry-wide basis is indicated.

It is clear that the mining of different geological deposits of kimberlite requires different mining techniques. Different equipment will be needed for fissure deposits and pipe techniques. In addition, the scale of operations is different and the problems encountered are different. This also holds true for the dust control measures in use.

Whereas in pipe deposits where there are large excavations and bulky dust control equipment in the form of extractor fans, filters, ducting and capture cowls is used, mostly to good effect, in the narrow confines of the kimberlite fissure stopes the use of such equipment would not be feasible.

This project did not set out to prove that where dry drilling takes place, copious amounts of dust are liberated into the working environment (although this would have been easy to do). Rather, the different approaches to controlling dust where dry drilling is practised were monitored. The prime recommendation is that wherever drilling is not taking place in kimberlite, i.e. in country rock, water should be used to reduce dust emissions. Steps should be taken to implement this recommendation without delay.

In the mining of **pipe deposits**, adequate dust capture at source by means of drilling cowls, ducting, fans and filters is favoured, with the fans and filters either centrally mounted on the drill rigs or else mounted on-board. The on-board units appeared to be more effective whatever the favoured system, with the success and effectiveness of the dust capture depending on the quality of maintenance and the conscientious application of the devices. Several problems were encountered in the mining of pipe deposits with regard to dust control:

i) When a holing takes place into the open pit, reversals of airflow can occur. This leads polluted air being conveyed into the workings. The problem can be overcome by ventilation planning and the deployment of strategically sized and sited underground booster fans. This is a mine-specific problem.

ii) Dust collected by the extraction systems is deposited on the footwall and, after disturbance, becomes re-entrained in the ventilating air. Once again, this is a mine-specific problem.

iii) Dusty footwalls lead to the widespread dispersion of dust in the workings. This problem has received little attention and needs to be addressed on an industry-wide basis. Any effective solution could also be employed in other mining sectors.

iv) The large excavations in use generally result in low air velocities even if the flow rates are acceptable for dilution purposes. This leads to inadequate pollutant-removal rates and consequently personnel may be exposed to unacceptable conditions. It should be ensured that air velocities are such that pollutants are removed from the workings as quickly as possible, as well as being diluted. A minimum velocity of 0,5 m/s is strongly recommended.

v) Throughout the project, the escape of dust from the drilling cowl arising from inadequate sealing against the working face was observed. This should be addressed on an industry-wide basis.

As far as **fissure mines** are concerned:

i) A top priority should be to ensure a positive, controlled ventilation system to remove dependence on the vagaries of natural ventilation pressure. This would in the first instance assist with the dilution and removal of airborne dust. It would not in itself be sufficient to deal with all the problems of dry drilling in fissure mining, but would certainly assist in alleviating them. This type of problem is mine-specific.

ii) The problem of controlling dust in steeply inclined, narrow fissures is unlikely to be solved by a single mine and should therefore be addressed on an industry-wide basis.

iii) The use of polycrystalline drill bits to reduce the liberation of dust into the working environment should be addressed on an industry-wide basis.

iv) Efforts to control dust in fissure mining are likely to culminate in the application of several techniques, e.g. positive ventilation and polycrystalline drill bits.

The possible benefits of using surfactants to limit dust emissions into the working environment should be researched on an industry-wide basis.

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