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CONTENTS

COMPOSITION AND SIZE OF DUST IN A GOLD MINE ATMOSPHERE

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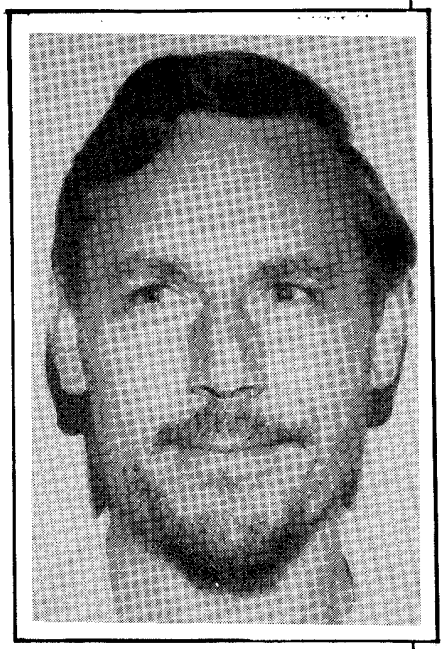

Dust was sampled at various locations in an underground gold mine using stacked filter units (SFUs). This device, consisting of two membrane filters in series, separates the dust aerodynamically into two fractions with a cut-off point at 3,0 μm diameter. Samples were analysed by particle-induced X-ray emission (PIXE). Presented are results on the chemical composition of dust in the form of composition profiles or 'fingerprints' of specific dust-generating localities and processes. In addition to the expected predominance of silica-containing mineral dusts, various other components were identified, including fractions rich in lead, soluble salts, Zinc and Calcium. The possible sources of these components are discussed. The quartz fraction of the dust is calculated using a correction factor based on the composition of sericite (muscovite) and the measured concentrations of alumina and potash. The results are evaluated in terms of implications for the proposed use of a gravimetric method for industrial hygiene monitoring in underground mines.

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1. INTRODUCTION

Over past decades investigations of airborne dust on South African gold mines have focused largely on concentrations of siliceous mineral components. The present paper deals with part of a series of measurements designed to characterize the airborne dust, or aerosol, on a much broader basis, looking at both the major and minor components. By understanding the source materials, dust-generating processes, transport and dust sinks, we hope to arrive at a point where monitoring and control of dust will be placed on a sound technical basis. A particularly compelling need for this more fundamental understanding of all components of dust, as opposed to only the respirable quartz fraction, are the current evaluations of gravimetric sampling to replace the konimeter as the certified method for dust sampling.

Results presented here are from preliminary sampling in a Free State gold mine, where dust samples near specific dust-generating processes, e.g. drilling were collected. Such source samples were needed also to assist in the interpretation of dust samples collected with a streaker sampler in a return airway. These return-airway samples constituted an integration of multiple processes taking place in the mine [1]. The results are preliminary in the sense that only single samples were collected at each site. This work is thus neither a comprehensive survey of the mine, nor necessarily representative of general conditions. Nevertheless, the results do illuminate some of the mine sources of airborne dust. Some of these processes were obvious. Others were unexpected and do not appear to have been reported in the published literature.

2. EXPERIMENTAL

2.1 Sampling Instruments

Sampling was carried out with Stacked Filter Units (SFUs), a two-stage (dichotomous) sampler [2]. The device consists of two Nuclepore polycarbonate membrane filters connected in series (Figure 1). Nuclepore filter membranes are characterized by an extremely uniform pore size, with pore axes aligned vertically to the membrane surface. This results in a comparatively sharp cut-off curve for particle size retention. Such a curve is shown in Figure 2 for an 8-μm pore diameter membrane, at 0,05 m/s face velocity. The first filter, which acted as a coarse, dispersion-particle sieve, was chosen to have 8-μm pore diameter, with effective 50 percent cut-off point diameter of 3,0-μm aerodynamic diameter. The second filter was a 0.4-μm pore diameter membrane, with an essentially 100 percent retention efficiency for all particle sizes.

Stacked Filter Units were connected to sampling trains consisting of a ballast bottle, a Gast DOA320A pump, powered by a 12-V, 40 A-h lead-acid battery, a 1-10 ℓ/min flowmeter and a dry gasmeter. Each assembly, including battery, was packed in a steel carrying-case, and could be transported (with difficulty) by one man. Sampling times ranged between 20 minutes and one hour.

2.2. Sampling Strategy

The intended sampling strategy was to follow the path of airflow through a section of a mine, sampling in the vicinity of, or upstream and down-

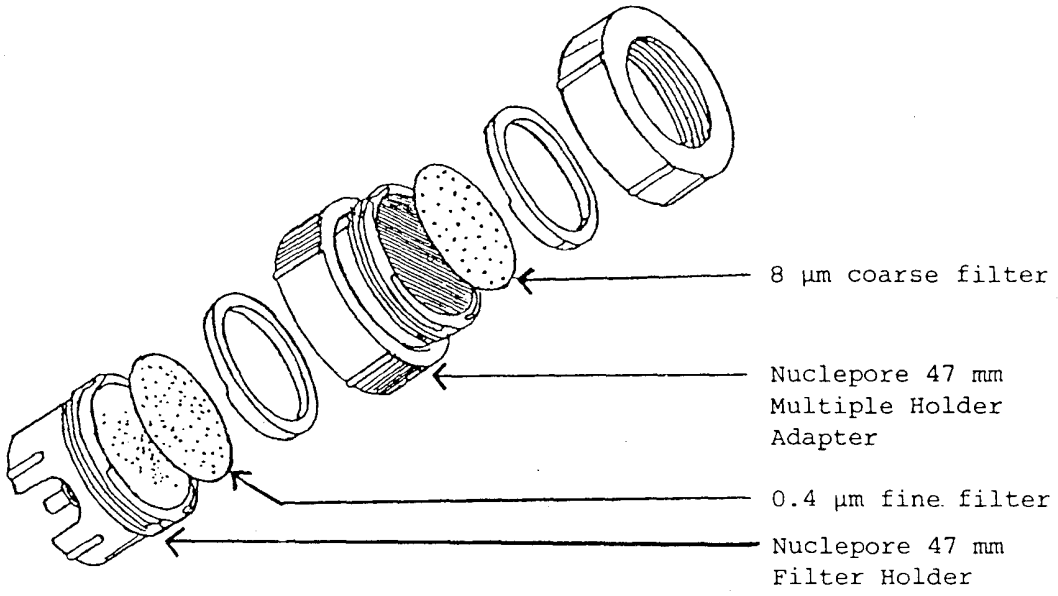

Figure 1. Components of the Stacked Filter Unit dichotomous aerosol sampler

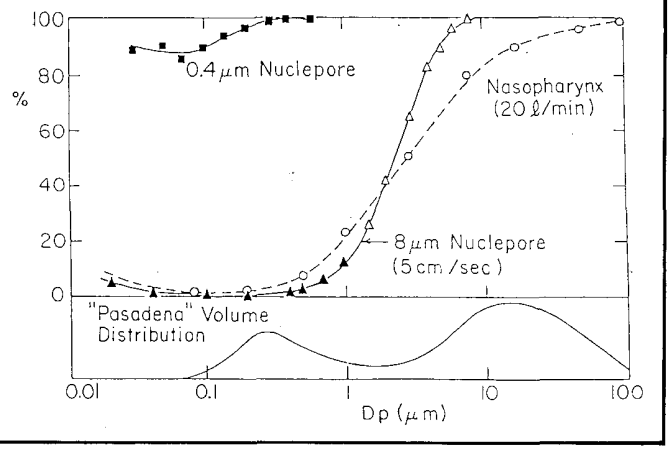

Figure 2. Aerosol collection efficiencies for 0.4 and 8.0 μm pore diameter Nuclepore membrane filters. X axis scale is in units of particle aerodynamic diameter. Particle deposition in the human nasopharynx region is superimposed. The 8.0 μm filter 50% cutpoint occurs at the minimum in the natural bimodal aerosol mass distribution

stream of localities or processes generating dust. Limitations of time and resources prevented complete sampling at all identified processes. Sites sampled are described with the results in Section 3. In several instances physical layout of the mine and ventilation systems prevented upstream sampling.

A particular feature of the section of mine sampled was that industrial-grade water used for dust suppression was drawn from the brackish local ground water. This brackish water is typical of the region and is used extensively as industrial-grade water by the mines.

2.3 Analysis

Particle-induced X-ray Emission (PIXE) can be used to determine concentrations of elements Al and heavier with minimum detection limits of a few nanograms per cubic metre. The following elements were routinely observed in mine-dust samples: Al, Si, S, Cl, K, Ca, Ti, Cr, Mn, Fe, Cu, Zn and Pb, with integrated beam currents of 0,5 μC and irradiation times of approximately 2 minutes. Na was on occasion observed in the X-ray spectra at high concentrations (>300 ng/m^3), but peak-fitting and absorption-corrections made its absolute determination difficult. Analyses of SFU samples were performed using 4,5 MeV protons at the Crocker Nuclear Laboratory[3]. Streaker samples were analysed at the Schonland Research Centre with 3 MeV protons, with other parameters similar to those in the SFU analyses.

2.4. Composition Profiles

Composition profiles or 'fingerprints' are used as the major interpretive technique in this paper. From PIXE the elemental concentrations are derived. By means of standard X-ray fluorescence analysis procedures used in mineralogy, elemental concentrations were converted to standard oxide forms, with the exceptions of Cl. As chlorides in the mine atmosphere are derived from soluble salts, rather than from mineral oxides, it was converted to NaCl. As Na was not measured quantitatively, this approximation accounts also for the Na mass. Sulphur in the airborne particles may have been derived from reduced forms (FeS), or in the oxidized state, as conversion sulphate (SO_4). It was calculated as the latter.

The calculated oxide or compound concentrations were then summed for each sample stage, coarse or fine, and the percentage concentration of each component was calculated. The histogram of these fractional concentrations constitutes the profile. Comparison of ratios of concentrations of pairs of elements in the dust with the corresponding ratios from source materials provided further useful information.

Sampled processes (or areas encompassing a number of processes) were examined from three aspects:

(i) Profiles were constructed from the differences between upstream and downstream samples. By such differencing the downstream sample was corrected for amounts present in the upstream air, thereby characterizing dust-generating or removal processes in the intervening zone. In the absence of an upstream sample, a downstream sample from a strong source was assumed to provide a good approximation for a source profile.

(ii) Increases in absolute concentrations relative to those in the upstream air gave an indication of the source strength in the locality.

(iii) Comparison of the ratio of elemental quantities in fine and coarse dust on the filters provided an indication of the size distribution of individual elemental components.

For the sake of brevity in the discussion, concentrations of components on either the coarse or fine filters will be designated by subscripts C or F, respectively, Hence Si_F=70 percent refers to the fractional concentration of SiO_2 on the fine filter stage. Unless specified otherwise, all references are to **oxide** masses or mass fractions.

3. RESULTS AND DISCUSSION

Results from five localities or processes where dust was generated have been selected for discussion. Selection was made partly on the intrinsic interest of the process itself and partly on the ability to characterize the dust composition in relation to the processes. The samples selected were from:

(i) drilling in a blind development end;

(ii) drilling and whitewashing in a haulage way;

(iii) blasting;

(iv) return air from the stopes; and

(v) air from disused workings.

3.1. Drilling in a Blind Development end (DDE)

This sample, code DDE, was taken 15 m from the face of a blind development end of a 4 m diameter haulage way. Five pneumatic drills were operating intermittently during sampling. Forced ventilation ducts conveyed air to within 5 m of the face. The sampler was positioned sufficiently far away from the face so that the coarser water droplets would settle and to allow some degree of mixing of intake air and dust and vapours generated at the face. The incoming air was not sampled at this site.

The composition profile, shown in Figure 3, is dominated by the mineral components, comprising the oxides of Si, Al, K and Fe. On the assumption that all the ancillary silicate minerals are in the form of muscovite (sericite)[4] with composition $H_2.K.Al_3.(SiO_4)_3=2H_2O.K_2O.3Al_2O_3.6SiO_2$[5] the fraction of silica (SiO_2) present in the form of muscovite was estimated. This was done twice, once using alumina (Al_2O_3) as the tracer and once using potash (K_2O). If all the alumina and potash in the

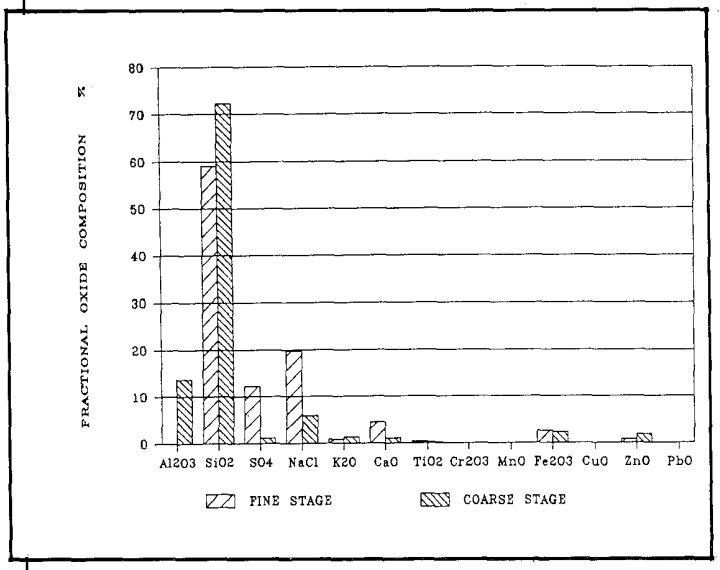

Figure 3. Dust composition profile from drilling in a blind development end, 5 drills operating, 15 m from the face. Sample code DDE.

dust is due to muscovite only, the two calculations should yield a similar result. The remaining silica is then attributed to pure quartz mineral (SiO_2).

For the coarse filter, silica in all forms accounted for 72 percent of the total mass. On the basis of alumina and potash contents, silica in the form of muscovite accounted for 16 percent and 5 percent respectively of the coarse stage mass. The balances of 56 percent and 67 percent, respectively, were assumed to be in the form of quartz. The disagreement between the two values may indicate that, in this sample, the ancillary silicate minerals are richer in alumina than was assumed for pure muscovite. On the fine filter, alumina, surprisingly, was below the detection limit. When potash was used as a tracer, silica in the form of muscovite accounted for 4 percent of the mass and silica in the quartz for 55 percent. Ratios of fine to coarse concentrations are presented in Table 1. The fine, inhalable, mineral fraction consituted only 4 percent of the coarse fraction at this site.

Table 1 RATIO OF FINE TO COARSE CONCENTRATIONS IN AIRBORNE DUST SAMPLES AT VARIOUS LOCALITIES

Code Locality	DDE Drilling develop-ment	DMH Drilling main haulage	BLST Filtered blasting fumes	RAS-1 Return air from stopes	MRB Refuge Bay (Disused workings)
Al_2O_3	—	—	0,15	0,40	0,64
SiO_2	0,04	—	0,33	0,37	0,45
SO_4	0,48	0,32	—	2,42	1,97
NaCl	0,17	0,05	4,90	—	—
K_2O	0,04	0,05	2,51	0,55	0,38
CaO	0,19	0,05	1,02	0,41	0,25
TiO_2	—	—		—	
Cr_2O_3	—	—	—	—	—
MnO	—		—	—	—
Fe_2O_3	0,06	0,08	0,44	0,48	1,16
CuO	—	—		—	0,03
ZnO	0,02	0,48	0,43	0,40	—
PbO	—	—	3,13	—	1,17

The Sodium and Chloride elements which were observed in the underground dust came from the brackish service water

Next, in order of decreasing concentration in the profile, were the soluble ions Cl, Na and SO_4. In a previous report[6] the presented evidence showed that the elements Cl and Na, and a portion of S concentrations observed in underground dust, arose from brackish ground water which is used as industrial-grade water and which is aerosolized by pneumatic drills and dust suppression sprays. Calcium hypo-chlorite, $Ca(OCl)_2$ is added to the water as a disinfectant. The amount of Cl from this source is likely to be small compared with that in the natural components, as can be seen from the amount of dissolved solids in the fissure water (Table 2, Sample D). The presence of these elements in these samples is further confirmation of this observation. Table 2 shows the concentrations of soluble ions in water collected at various points in the mine.

Sample C was taken from an industrial-water pipe in the development end during the dust-sampling interval. Chloride, sodium, sulphate and calcium were the dominant ions in the water, in that order. The fractions of sodium chloride in the airborne dust collected on the course and fine filter was 5,9 percent and 19,7 percent respectively. These values were lower than expected from previous measurements[6] especially since a visible cloud of spray was present during the sampling. The higher value of NaCl in the fine fraction indicates that the size distribution of salty droplets has a maximum at a smaller diameter than the mineral particles (see Table 1). In this case, since the sampling was close to the source, the droplets had not had sufficient time (15 to 30 s at approx. 1 m/s air speed) for significant evaporation to occur which would lead to a smaller particles. This may indicate that many of the water droplets were generated in the sub-3 μm aerodynamic diameter size range.

Table 2 DISSOLVED SOLIDS CONTENT (mg/ℓ) OF INDUSTRIAL-GRADE AND FISSURE WATER FROM A FREE STATE GOLD MINE

Sample No. Site	A Drill Feed Water	B Industrial Water Dam	C Drill Feed Water, Development End	D Fissure Water
pH	6,25	6,05	5,9	7,1
Total dissolved solids	4576	4650	5050	4610
Calcium, Ca	374	419	400	375
Magnesium, Mg	28,5	28,8	26,6	12,5
Sodium, Na	1150	1160	1280	1300
Potassium, K	29,1	29,0	25,2	10,5
Bicarbonate, HCO3	24,4	31,7	24,4	51,2
Chloride, Cl	1660	1675	2090	2190
Sulphate, SO4	1055	1460	900	465
Iron, Fe	0,04	0,04	0,01	0,02
Manganese, Mn	0,99	1,00	1,40	0,07
Copper, Cu	0,02	0,02	0,01	<0,01
Zinc, Zn	0,64	0,40	0,50	0,03

The ratios of SO_4, NaCl and Ca in the water and in the coarse and fine sample fractions are given in Table 3. The relative compositions of the three components in the coarse dust is seen to be similar to that in the water. On the fine filter, however, SO_4 is enriched by a factor of 2,8 relative to NaCl and Ca. The excess SO_4, after the amount attributable to the industrial water contribution has been substracted, amounts to 8 percent of the fine mass. This excess sulphur could be derived from pyrite (FeS), an ancillary mineral which forms 3 percent of typical reef[4]. If all the fine Fe were in the form of pyrite (as opposed to Fe_2O_3) it would account for only a further 3 percent of the mass attributed to SO_4, leaving a balance of 5 percent. As high $(SO_4)_F$ fractions also occur in the **intake** air to this section of the mine (SO_{4F} = 18 percent) the most likely source of excess fine SO_4 is sulphate derived from SO_2 in the surface atmosphere, and carried into the mine with the intake air.

Table 3 RELATIVE COMPOSITION OF SOLUBLE SALTS IN INDUSTRIAL QUALITY WATER; COARSE AND FINE DUST AT A BLIND DEVELOPMENT END (SAMPLE CODE DDE)

Component	SO_4	NaCl	Ca
Water, sample D	1,00	3,74	0,44
Dust, coarse	1,00	4,54	0,66
Dust, fine	2,82	4,54	0,73

Zinc concentrations had time variations different from the other element . . . The lubricating oil is a possible source

The zinc oxide coarse and fine fractional concentrations at this site are 1,9 percent and 0,8 percent respectively, which were among the highest values measured. Zn concentrations had time variations very different from those of many of the other elements measured[1,7,8], peaking during the drilling shift. This would appear to eliminate both the reef and water as major sources of this element, since both of these show peak concentrations during blasting. Furthermore, although Zn concentrations in the industrial water are increased by a factor of 20 relative to that in fissure water (Table 2), the water concentration of Zn would still be two orders of magnitude too low to account for the observed levels in dust, when Cl is used as a tracer for water-derived components. The Zn content of lubricating oil in the pneumatic drills is one possible source, which seems to be confirmed by the high fractional concentrations in this sample which was taken close to operating drills. This possibility remains to be investigated.

3.2. Drilling and Whitewashing in a Main Haulageway (DMH)

Several operations were being conducted in this locality: intermittent drilling of the hangingwall; attachment of galvanized steel-mesh bratticing; and spraying of the hangingwall with a coarse slurry of slaked lime ($Ca(OH)_2$). Air movement through this zone was slow (1 m/s) which allowed accumulation of relatively high dust concentrations.

Simultaneous upstream and downstream samples were collected over 30-minute intervals.

Composition profiles, code DMH, for coarse and fine fractions corrected for dust in the upstream air, are presented in Figure 4. Two major components are present: first, mineral dust, from drilling into the hangingwall, which is present in the coarse profile only. The absolute mineral concentration

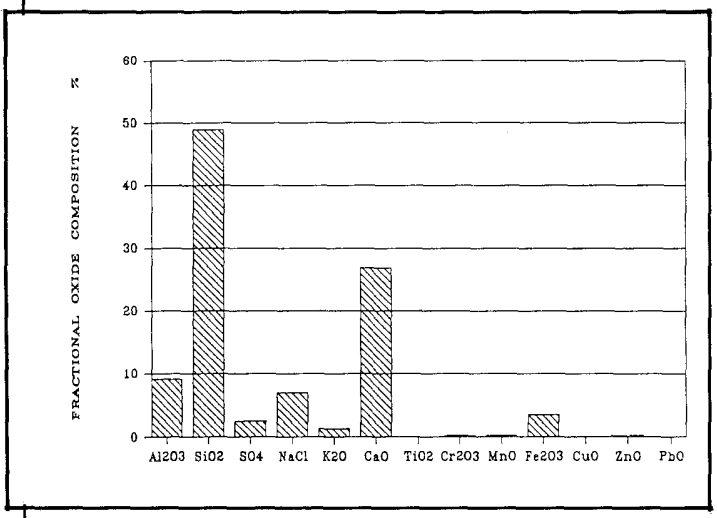

Figure 4(a). Composition profile obtained by subtracting up from down-stream dust concentrations in a haulage way where drilling and white-washing were taking place. Coarse stage

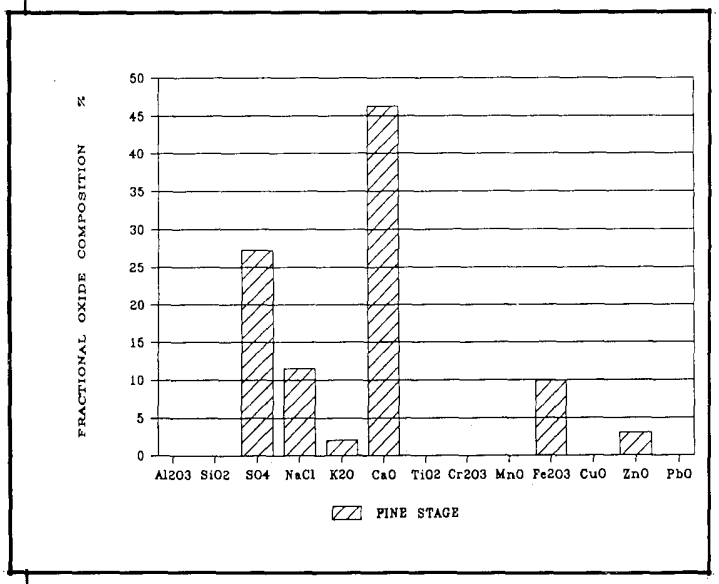

Figure 4(b). As above, fine stage

increased sevenfold in the coarse stage (Table 4), while in the fine stage it decreased slightly, indicating that the sampled locality was a net sink of fine mineral dust. The composition of the coarse fraction in the DMH sample, Si:Al:K=28:5:1, was close to the mineral composition of dust in the upstream air, Si;Al:K=28:5:1ℓ. Of the 65 percent silica in the coarse stage, 21 percent and 27 percent were present in the form of muscovite, calculated on the alumina and potash contents, respectively. The agreement between these results is better than that for samples taken at the previous locality. The fraction of silica as quartz was therefore between 38 percent and 44 percent.

Table 4 RATIOS OF DOWNSTREAM TO UPSTREAM CONCENTRATIONS OF DUST COMPONENTS AT A LOCALITY IN A MAIN HAULAGEWAY WHERE ROCK DRILLING AND WHITEWASHING OF THE HANGINGWALL WERE OCCURING (CODE DMH)

Oxide Composition	Al_2O_3	SiO_2	SO_4	NaCl	K_2O	CaO	Fe_2O_3	ZnO
Fine fraction	#	0,97	1,6	2,9	1,3	4,0	1,4	*
Coarse fraction	7,3	6,8	2,7	2,0	7,4	23,4	5,8	4,8

Downstream Al below detection limit. Ratio = 0,0
* Upstream Zn below detection limit. Ratio not defined.

Secondly the measured CaO components in the coarse and fine fractions were 27 percent and 46 percent respectively. This represented a substantial twenty three fold increase in the coarse and a four-fold increase in the fine CaO concentrations compared with the intake air (Table 4). Spraying of the hangingwall with slaked lime was the obvious source of this CaO. As was to be expected, the low-pressure spraying of a concentrated slurry produced predominantly coarse particles. Associated with the fine Ca was a substantial amount of SO_4 ($(SO_4)_F$ = 27 percent). Since this profile has been corrected again for the upstream air excess $(SO_4)_F$ cannot be attributed to the intake air since $(SO_4)_F$ is 2,5 fold greater than $NaCl_F$; sources of $(SO_4)_F$ additional to the grade water are required. It is not apparent why, if the two elements were indeed both from the slaked lime slurry, SO_4 and Ca should fractionate differently between coarse and fine particles. Electron microscope examination of mine aerosol particles, showed Ca to be associated with S in evaporated crystals, sometimes abutting chloride salt crystals but often also as pure Ca-S crystals[6]. The extent to which SO_4 is generated from industrial-grade water, slaked lime, pyrite and other possible sources remains to be determined.

Three minor components warrant brief mention. Increases in the Cl content, indicative of the effect of the spray water, were moderate at three fold and two fold for the coarse and fine stages, respectively, compared with a seven fold increase of Cl in the coarse mineral dust (Table 4). Additional spray points or more rapid settling of mineral components relative to that of the salt components may account for the higher concentrations of NaCl in slightly aged aerosols, that is, several minutes downstream of the drilling operations.

The absence of other mineral components from the fine dust profile rules out the likelikhood that FeS_2 is the source of the observed $(Fe_2O_3)_F$ = 10 percent, which may have been derived from abrasion of steel drill bits. However, the presence, in the coarse dust, of Mn and Cr together with an iron component (4 percent), in the ratio Fe:Mn:Cr = 36:3:2, is more indicative of hardened tool steel as the source.

The absolute amount of Zn in the coarse fraction (640 ng/m^3) exceeded that in the fine fraction by a factor of two. However, the large coarse-fraction mineral component reduced the fractional concentration of Zn_C to 0,2 percent, compared with Zn_F = 3,0 percent. The increase in Zn between upstream and downstream was fivefold in the coase fraction, while no Zn was present in the upstream fine fraction (Table 5). The lack of correlation between increases in CaO and ZnO in the coarse and fine fractions appears to rule out a common source. If Zn were derived from the galvanized steel mesh, one would expect mechanical dispersion, for example abrasion, to produce Zn-particles in the coarse fraction. Pneumatic drills are a common factor between this and the previous locality, each of which had high ZnO concentrations. As mentioned above, lubricating oils used in the drills were a possible source of airborne zinc.

3.3. Blasting (BLST)

Air samples were taken downstream of a horizontal tunnel which was being developed on a two-blast-per-day cycle. Air and blasting fumes from this development end were extracted through a series of filters, comprising a water-spray bank, a $KMnO_4$-impregnated vermiculite filter bed and bag filters. The sampler was located downstream of the bag filters after which it was ducted to an upcast exhaust shaft. Sampling started 10 minutes before the blast and continued for 40 minutes afterwards.

The profiles of sample code BLST are shown in Figure 5. Two important noteworthy features of this profile are:

(i) the high Pb concentrations, especially in the fine stage, for which Pb_F = 33 percent exceeds Si_F = 25 percent;

and

(ii) correspondingly high K fractions, $K_{C,F}$ = 18 percent and 6 percent, respectively.

The ratios $(Si:Al:K)_F$ = 2,1 : 0,17 : 1,0 indicate a composition markedly different from that of other samples of mineral dust containing these three elements or from the composition of sericite.

A considerable enrichment in the fine K fraction had occurred. Since this was not associated with any other mineral elements, another source must be identified. The presence of $KMnO_4$ in the vermiculite filter bed is an obvious possibility, even though the Mn concentration did not increase significantly, this may be discarded by examing the evidence from streaker sampling results on a neighbouring mine. The streaker sampling encompassed blasts which occurred as part of regular mining operations, with air being exhausted along airways without passing through $KMnO_4$-impregnated vermiculite beds, or any other filters. In these samples the K concentrations were increased considerably. As these K levels which were high relative to other mineral components, notably Si and Al, did not occur during drilling or clearing of the same ore bodies, it must be concluded that the K is aerosolized during the blast.

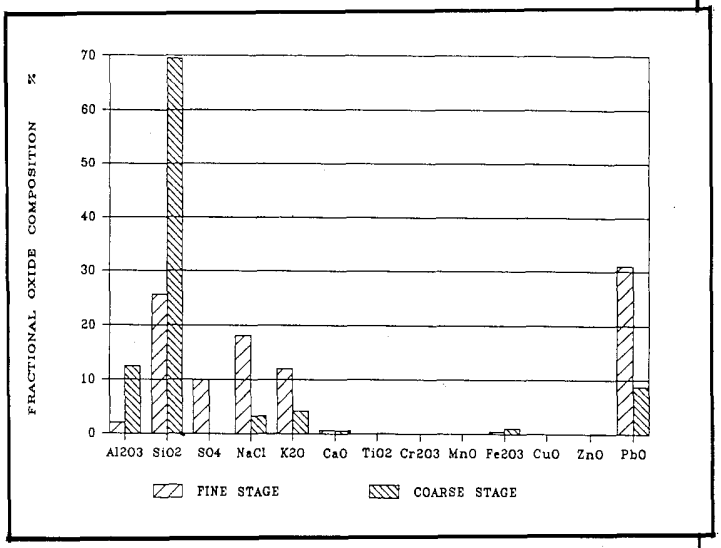

Figure 5. Composition profile of filtered blast fumes

The materials present during the blast are the explosives, detonator caps, safety fuse, igniter cord and the ore. The temperatures reached during the blast (up to 5000 °C) are such as to vaporize the oxides formed as part of the explosion, as well as the casing of the explosives and caps. In addition, in the area immediately surrounding the explosive, chemical as well as physical effects may occur, in which case K components of the ancillary minerals (sericite) may be liberated selectively into the vapour phase. Further investigations are needed to elucidate these high K concentrations.

3.4. Return Air From Stopes (RAS-1, RAS-2)

Two samples are considered under this heading, both collected towards the end of the drilling shift (13h00). The first sample, RAS-1 was taken at the top of an inclined shaft equipped with a chair lift.

The air velocity from the lower stoping was over 3 m/s which resulted in the transit time of the air between the drilling site and the sampling point being several minutes. Furthermore, since sampling took place towards the end of the shift, most drilling would have been completed. The second sample, RAS-2, was taken closer to the working faces, where the air from a stope entered the return airway.

Composition profiles for the two samples are presented in Figures 6 and 7. Mineral components dominate. The ratios of the mineral elements for the two samples are $(Si:Al:K)_F$ = 17:4:1 and 34:0:15,3 and (Si:Al:K)c = 26:5:1 and 32:6:1. The quartz components, calculated from total silica corrected for alumina and potash contents, are shown in Table 5. Agreement between pairs of quartz values is, in each case, better than 15 percent. This agreement renders the reasonable assumption that the auxilliary minerals have the same composition as muscovite.

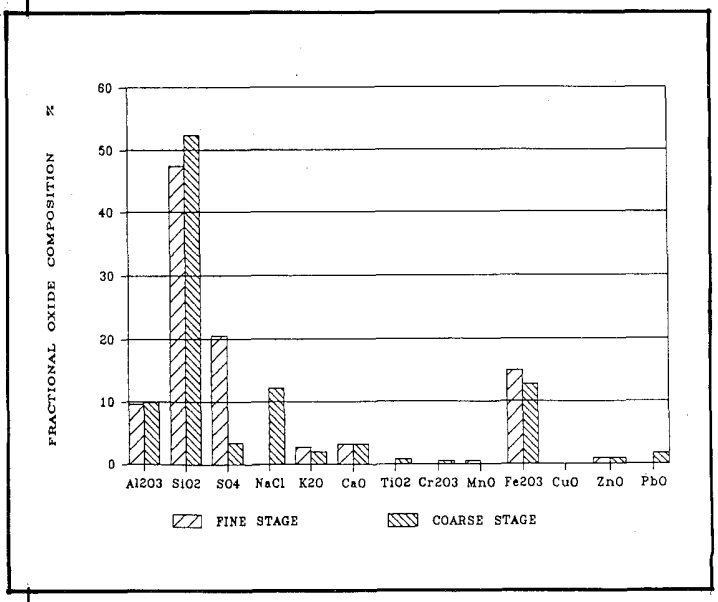

Figure 6. Composition profile of dust in return air from stopes. Sample code RAS-1.

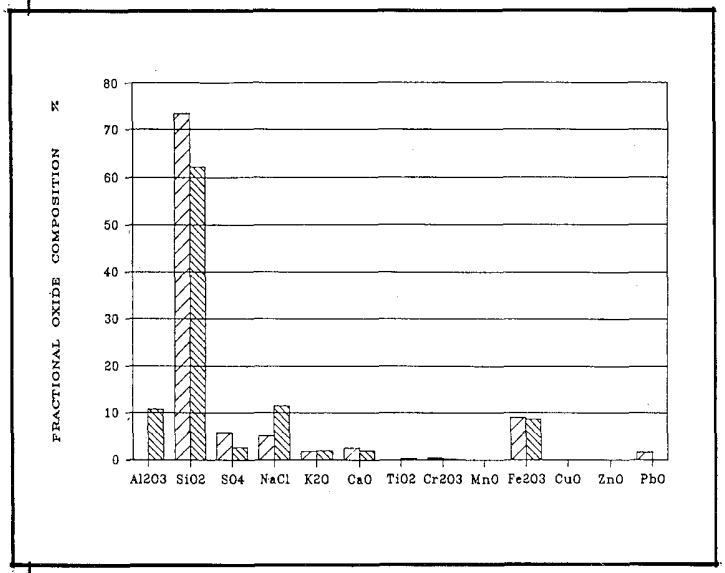

Figure 7. Composition profile of dust in return air from stopes, as air first rejoins a haulage way. Sample code RAS-2.

The Fe and SO_4 components were the next most abundant in the return air. The Fe fraction is somewhat higher than in previous samples. The sources of these components would be similar to those discussed above. In sample RAS-1 the Zn fractions of the course and fire samples 0,9; 1,0 percent respectively which were relatively large. Zn was entirely absent from sample RAS-2. The only other feature of note was a small Pb_C fraction of 1,8 percent in RAS-1. This may be due either to Pb, from a previous blasting cycle, resuspended as a coating on coarse mineral dust, or to a blast that had been set off before the scheduled time. In the latter case, a predominantly fine rather than only a coarse Pb component would have been expected. The absolute concentration of PbO_2 was 1,4 $\mu g/m^3$, a value typical of daytime values in the atmosphere in the centre of Johannesburg or other major cities. This level is thus within values currently tolerated for environmental health purposes.

Table 5 QUARTZ COMPONENT OF DUST IN RETURN AIR FROM STOPES, CALCULATED FROM ALUMINA AND POTASH CONTENTS OF DUST, BASED ON MUSCOVITE (SERICITE) COMPOSITION*

Sample code	Fine Stage			Coarse Stage		
	Total Measured SiO_2	Quartz SiO_2 Calculated from Al_2O_3	K_2O	Total Measured SiO_2	Quartz SiO_2 Calculated from Al_2O_3	K_2O
RAS-1	47	36	37	52	41	45
RAS-2	73	#	66	62	50	55
MRB	39	28	33	38	31	30

* Muscovite composition: $SiO_2:Al_2O_3:K_2O = 3,83 : 3,26 : 1,00$
\# Al below detenction limit.

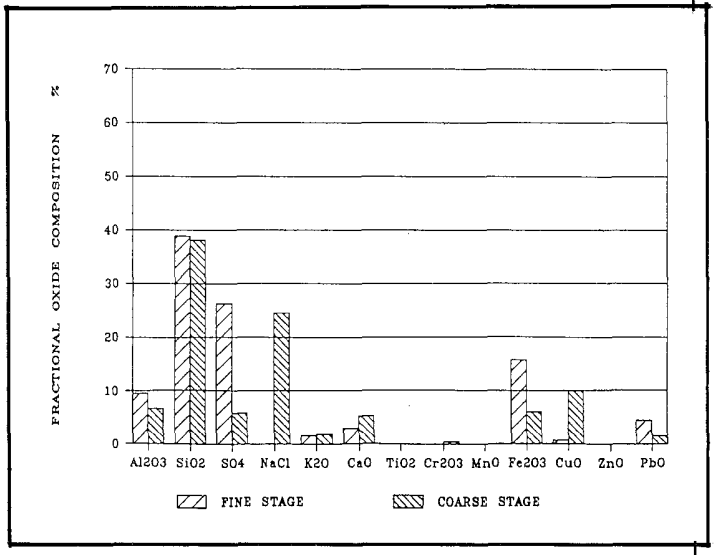

Figure 8. Composition profile of dust in air flowing from a section of disused workings sealed off from the main ventilation system. Sample code MRB.

3.5. Air From Disused Workings (MAN-REFUGE BAY) (MRB)

This man-refuge bay was a blocked-off length of tunnel, 20 m long, leading off a haulageway. The dead-end of the bay was sealed off from disused workings by a concrete wall. A perceptible current of warm air entered the refuge bay through a 150 mm diameter opening in the wall. The sampler was located close to this inlet. This sample, code MRB, was considered to be representative of the air in the disused workings, after it had passed through with an unknown residence time.

The concentration profiles from the refuge bay are shown in Figure 8. Striking features are relatively low mineral concentrations of $Si_{C,F}$ = 38 percent; 39 percent respectively and high fine sulphate; SO_4 = 26 percent. If air moved slowly through the disused workings then it would be expected that the coarser particles would settle out. This would lead to a larger ratio of fine to coarse particles, which is, in fact, observed. Table 1 shows that these fine-to-coarse ratios for the mineral components were ten times higher than for samples close to the drilling in the development end. The proportion of silica present as quartz is shown in Table 5.

This sample had a 4,1 percent Pb component. The presence of Pb in this sample taken approximately 20 hours after the previous blast, indicates that blasting fumes penetrated into the disused workings and were being flushed out with a considerably longer time constant (minimum 20 hours) than the average ventilation air. The ratio Pb_F:Pb_C = 1,17 is close to the BLAST ratio which indicates that some of the fine Pb is primary blast fume, as opposed to Pb on resuspended coarse mineral dust. Absolute concentrations of $(PbO_2)_{C,F}$ = 680 and 800 µg/m³ respectively were again within common urban environmental levels and not a matter for immediate concern.

The presence of lead in the ventilation air indicated that blasting fumes penetrated into the discused workings

Copper at this site, Cu_C = 10 percent, was the highest Cu fraction measured. Underground equipment which could have released Cu aerosol included electric motors and switchgear contacts (minor) and brazing of copper or bronze with gas or electric arcs. The specific source of Cu in this sample was not obvious. Clearly it was not associated with blasting.

4. CONCLUSIONS

Composition profiles demonstrate that aerosols, while dominated by silica mineral components in almost all cases, showed considerable variation in different localities of the mine. Major secondary components have been identified. This is believed to be the first time that some of them have been reported in the open literature. Specifically, high lead and Potasium particle concentrations were measured and associated with blasting. Residual amount of lead observed with the exception of those in the exhaust blast fumes, were not at concentrations that would give rise for concern. Standard practice for ventilation of mines for the exhaust of noxious gases appears to be adequate for removing Pb fumes as well.

Spraying to suppress dust produced a secondary aerosol of chloride and calcium sulphate salts, derived from dissolved solids in the water. High concentrations of coarse calcium-rich particles were identified during the spraying of hangingwalls with slaked lime. Zn-rich particles were associated with pneumatic drilling. However, the exact source of the zinc has not been positively identified. A portion of fine sulphate can be attributed to secondary-conversion sulphate, present in the surface air and drawn into the mine by the ventilation system.

The presence of these various secondary aerosol components has a significant bearing on current investigations into the suitability of gravimetric sampling for industrial hygiene monitoring in underground mines in South Africa. Proposals presently being considered, include the use of a cyclone preseparator, and allowing a filter to collect the respirable fraction below some defined cut-off point. If one assumes that quartz is still the major hazardous component in underground dust and if compliance with standards and compensation levies are to be based on the proposed gravimetric standards, then the present results show that such an approach could lead to several anomalies:

The silica content of dust is highly variable from 25% to 70%

(1) The silica content of the dust is highly variable, from 25 percent to 70 percent of the fine fraction. Part of the fine respirable particles were sulphates brought in with the intake air, which can constitute up to 30 percent of the mass for particles with an aerodynamic diameter less than 3 µm. The sulphate content of the intake air is highly variable and the inclusion of sulphate in a measurement of air quality underground (by gravimetric sampling) would introduce an arbitrary and significant variable.

(2) Regional differences, both within and between mines, in the dissolved solids content of water, will lead to large differences in the salt content of the aerosol. The anomalous situation may arise whereby the more extensive the use of dust suppression sprays, the higher the gravimetric concentration of dust might be. While quality and source of water are within the control of mines, the situation as sketched does not lead to a sound base for air quality measurements.

Clearly, desirable characteristics of a monitoring technique are that it should be sensitive and yield a direct measurement by a rapid and inexpensive method. Gravimetric determinations satisfy these three criteria but give only an indirect measurement of the desired quantity, quartz. The argument above attempts to show that the gravimetric method is in fact so poorly correlated with quartz content as to be inappropriate. X-ray diffraction has the virtue of providing a direct measure of

quartz. It was, however, until recently, not sensitive enough for routine analysis of the small sample masses obtainable by personal-type samples. (Recent improvements in X-ray diffraction instrumentation have made it possible to obtain diffraction measurements, within a few minutes, of the quartz content of personal filter samples of mine dust, collected over the time of a single shift[9].

In this work it has been shown that the measurement of the elemental concentrations in dust samples by energy dispersive X-ray analysis (PIXE) may be used to calculate the portion of silica present as quartz. While considerable further work is required to validate an approach for use in industrial hygiene monitoring, the feasibility has been established of using an assumed composition of secondary silicate minerals (muscovite) to calculate the quartz component of the silica. PIXE measurements are also rapid and sensitive. Preliminary calculations have shown that if PIXE is set up in a central specialized laboratory for the gold mining industry, similar to the present arrangement for konimeter sample analysis, the unit cost per sample analysis could be reduced to acceptable values.

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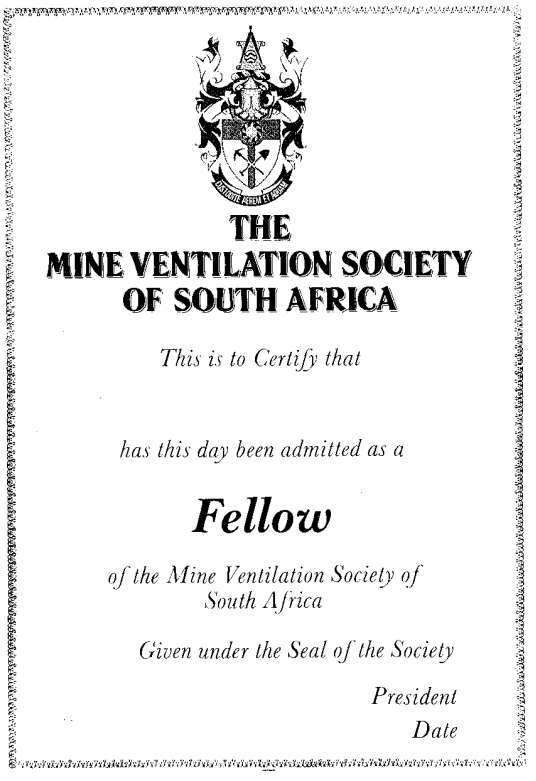

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