SAFETY IN MINES RESEARCH ADVISORY COMMITTEE

Draft final report

The positive identification of asbestos or other fibres in the mining of kimberlite deposits and an evaluation of relevant threshold limit values

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Executive Summary

The primary objective of this project was to determine whether asbestiform fibres were present in kimberlite mines, mining both pipes and fissures. This research work was carried out in conjunction with another SIMRAC project OTH 410.

Dust control by means of water is undesirable due to the fact that blue ground swells and disintegrates when it comes into contact with water, rendering the ground still to be mined unstable and unsafe.

The dust caused by dry drilling is a cause for concern and a research project was undertaken to determine the risk to which this drilling method exposes employees.

A literature study revealed that asbestiform fibres are commonly found in rock formations world-wide, with chrysotile being the most prevalent form of asbestos fibre. It is commonly accepted that a background fibre concentration of 0,0005 f/mℓ would be representative for urban outdoor levels. It was therefore necessary to establish the background levels of fibre content in the atmosphere, which could have an effect on underground sampling.

Fibre counts did not differ much between the two mining methods (pipe and fissure mining) or between wet and dry drilling. However, during dry drilling, there was a tendency for dust to obscure the presence of fibres, resulting in possible inaccuracies during the fibre-counting process.

When the dust load was reduced by means of control measures, more fibres became visible for counting. High fibre counts were noted when samplers were programmed to sample at short intervals (10-minute cycles) during every 60-minute period. Less dust was then sampled and the asbestiform fibres were easily detectable by means of microscopy.

The extent of employee exposure was not established but the results obtained during this project revealed that asbestiform fibres are present in the working environment of kimberlite mines and this means that further monitoring of employees is necessary to determine their risk and personal exposure.

Monitoring of asbestiform fibres should form an integrated part of the monitoring programme for airborne pollutants. Structured routine sampling for airborne fibres should

be conducted at all mines mining kimberlite, irrespective of the type of deposit mined (excluding alluvial deposits).

A cost-effective method of identifying the various asbestiform fibres and other fibres is necessary for the whole mining industry in South Africa.

Acknowledgements

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Table of Contents

List of Figures

List of Tables

Glossary of abbreviations, symbols and terms

Abbreviations

American Conference of Governmental Industrial Hygienists	ACGIH
Asbestos International Association	AIA
Department of Minerals and Energy	DME
Eight-hour time weighted average	TWA
Fibres	f
Fibres/m•	f/m•
Kilotons per month	kton/m
Litres per minute	•/min
Long-running thermal precipitator	LRTP
Man-made mineral fibres	MMMF
Metre	m
Micrometre	µm
Millilitre	m•
National Institute for Occupational Safety and Health	NIOSH
Natural ventilation pressure	NVP
Non-asbestos mineral fibres	NAMF
Phase-contrast microscopy	PCM
Pollutant Index	PI
Recommended Technical Method 1	RTM 1
Recommended Technical Method 2	RTM 2
Return airway	RAW
Safety in Mines Research Advisory Committee	SIMRAC
Scanning electron microscope	SEM
South African Bureau of Standards	SABS
Thermal precipitator	TP
Three-dimensional	3-D
Threshold Limit Value	TLV
Tons per ton (tons of water per ton of rock mined)	t/t
Transmission electron microscope	TEM

1 Background

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 occasionally, a diamond. Characteristics of kimberlite are inclusions, sometimes enormous boulders, of igneous and sedimentary rocks through which pipes erupted.

Owing to 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 rapid decomposition of the kimberlite which can cause drill holes to colapse, thereby preventing charging up with explosives, possibly resulting in loss of production. Decomposition of kimberlite could pose a safety hazard to the workforce. Drilling in kimberlite is a dry operation and, unless dust control measures are effective, and methodically maintained, the possibility of liberating dust (and other pollutants) into the working environment is evident. Development ends are started as late as possible in the mining sequence and the basic method is similar to that used during development in waste or country rock, i.e. non- kimberlite deposits.

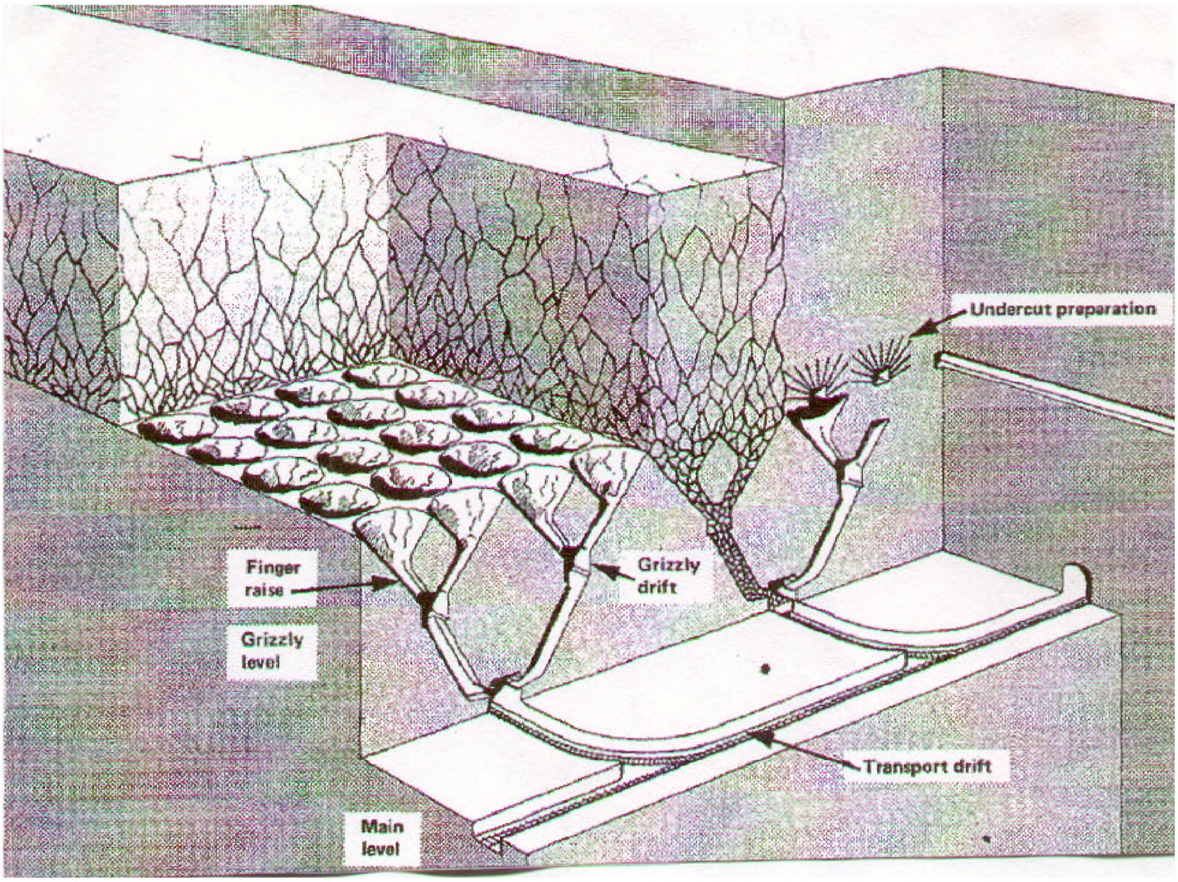
As kimberlite deposits differ from region to region different types of mining methods are used. This project was conducted in different regions and included both pipe and fissure deposits. The geology associated with each site is discussed in this report.

For obvious reasons, 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.

1.1 Block caving

The word "block" refers to the mining plan whereby an ore body is divided into large sections or blocks, with a square section. Each block is completely undercut and a horizontal slot in the lower part of the block is excavated to remove support to the rock above. Gravitational forces, in the order of millions of tons, act on the rock mass causing successive fracturing which affects the entire block. The rock pressure builds up at the bottom of the block, crushing the material into fragments that can be handled in draw-off points.

In block caving the ore fractures and breaks up by itself due to internal stresses and gravity. Only a minimum of drilling and blasting is required for ore production. This method of production is illustrated in Figure 1.1.



1.2 Sub-level caving

The ore is divided into sub-levels with comparatively close vertical spacing. Each sub-level is developed into a regular network of drifts, covering the whole ore section. Long holes are drilled into the ore volume immediately above each sub-level drift in a fan-shaped pattern. The blasting of one fan of holes breaks up a slice of ore. The ore then caves into the drift, where it is loaded and transported to ore passes. Ore extraction normally retreats along an approximately straight front, which means that adjacent drifts are worked simultaneously. A typical sub-level caving method is shown in Figure 1.2.

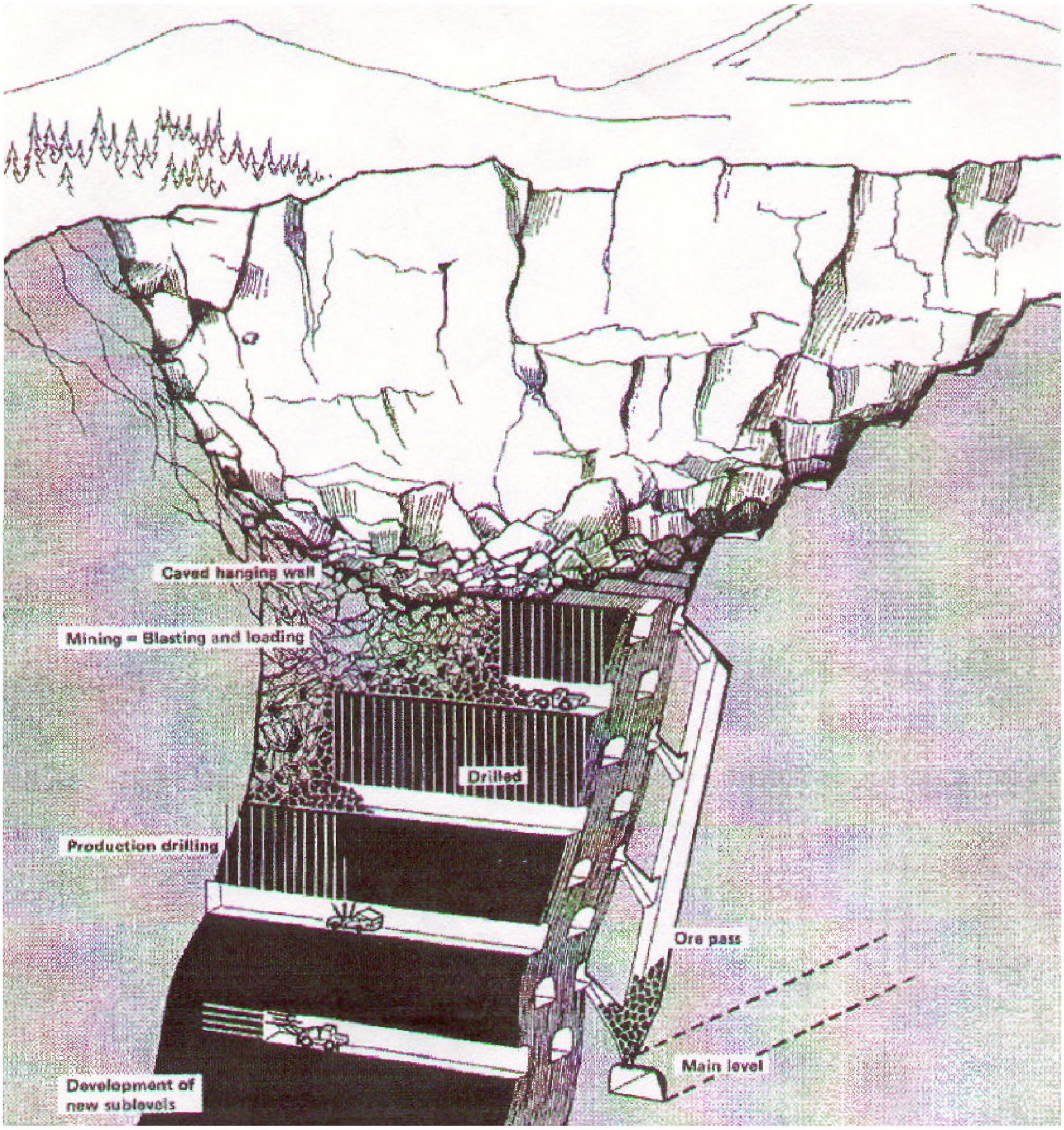


Figure 1.2: Sub-level caving mining method

In mining pipe deposits, large tunnels are used to access the ore body and to transport the ore to tipping points. Because of the size of the tunnels, large and bulky mining equipment can be employed, including those used for dust control. In fissure mining, deposits may be mined in narrow stopes, usually near-vertical in inclination.

1.3 Vertical retreat stoping

This method is used for fissure mining and resembles shrinkage stoping as the ore is excavated horizontally, and stoping starts from below and advances upwards. Broken ore can remain in the stope to support the walls. The ore is recovered at the bottom, or underneath the stope, through a draw-off point resembling that used in sub-level open stoping. This method is normally used for steep dipping ore bodies.

1.4 Modified underhand method

This method is also used for fissure mining. The stope faces are carried "underhand" at an angle of approximately 25° to the horizontal, which permits easy ore handling and safe travelling. Tramming drives are established in country rock approximately 6 m away from the fissure. These drives are developed using a wet drilling operation. No stope safety-pillars are left; instead double-row matpacks are installed above and below the fissure drive. The broken rock is lashed down the face (and in the early stages into the stope raise) to a stope box of the usual type adjacent to the cross-cut from the tramming drive.

Typical fissure and open stope drives of vertical retreat stoping are shown in Figures 1.3 and 1.4 and a typical underhand stoping method in Figure 1.5.

It is obvious that the methods used for dust control in the large pipe deposit excavations, as well as the bulky equipment involved, cannot be employed in narrow, vertical stopes of fissure mining. Because dust control at source in fissure mining is currently found to be much more difficult than dust control in large kimberlite pipes, more emphasis is placed on pollutant dilution and removal, although the technique was found to be ineffective since booster or main fans are not used to ventilate these mines. As a result, personnel working in the fissure deposits tend to be exposed to much higher airborne pollutants than employees working in more controlled environments.

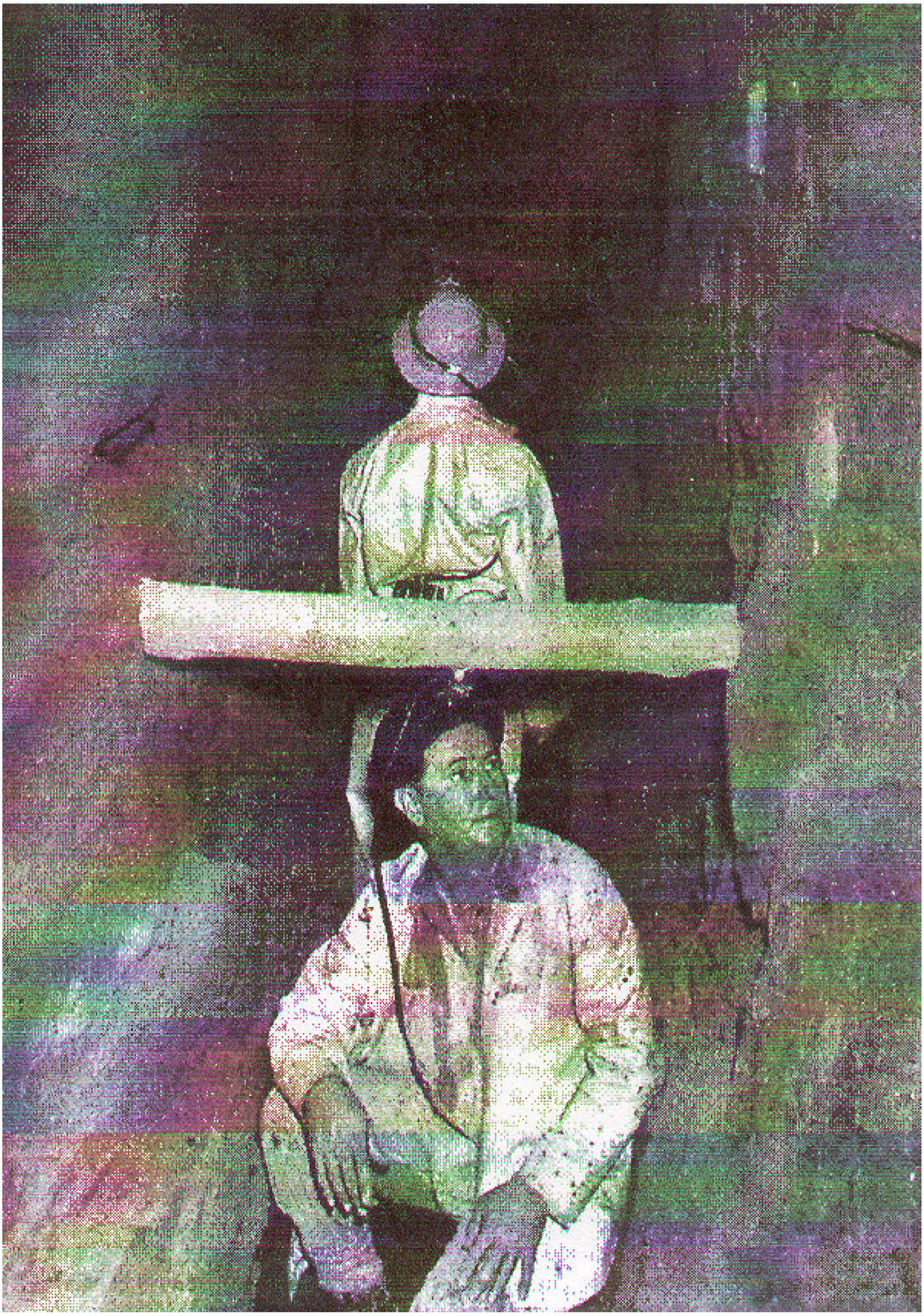
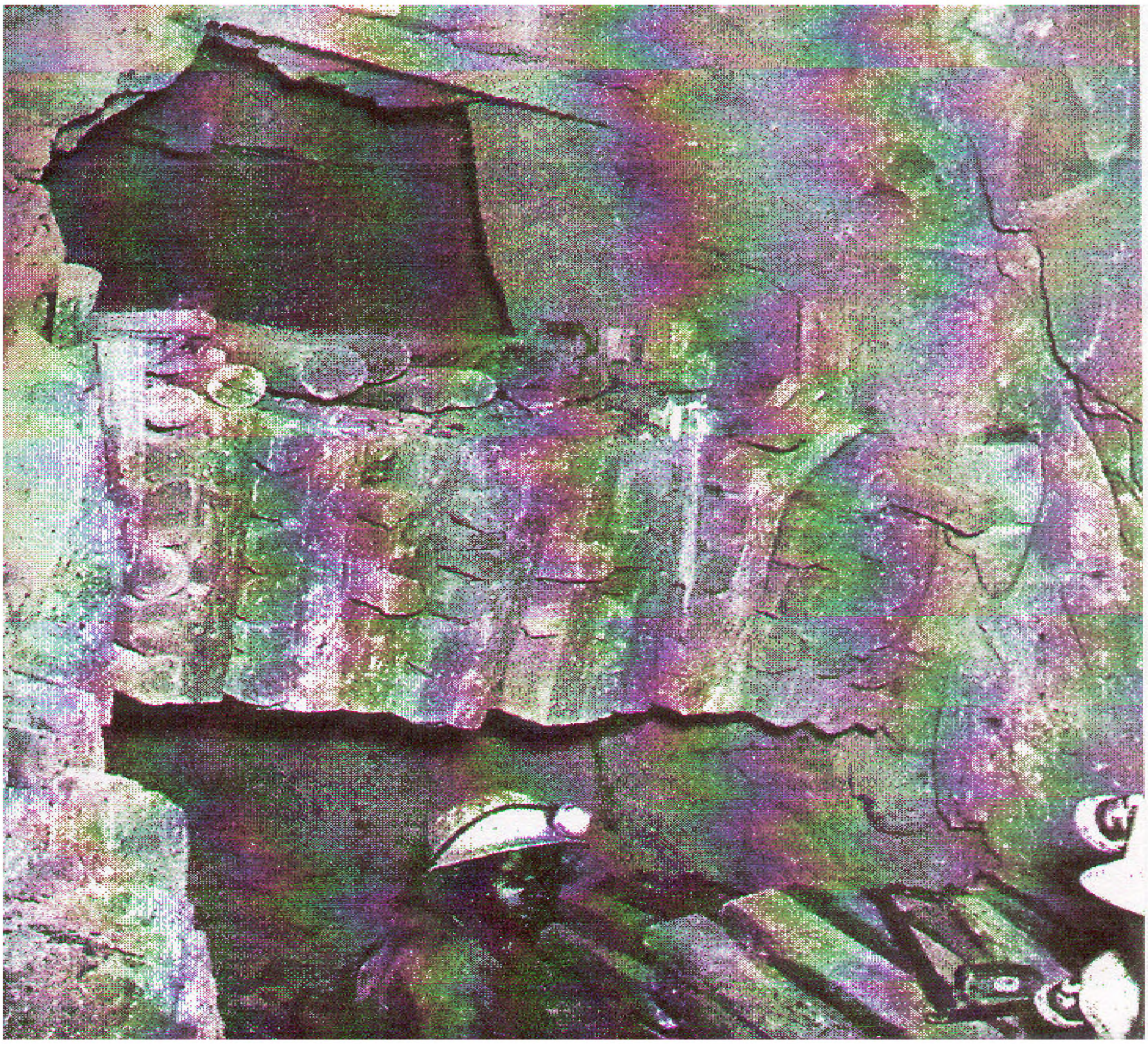
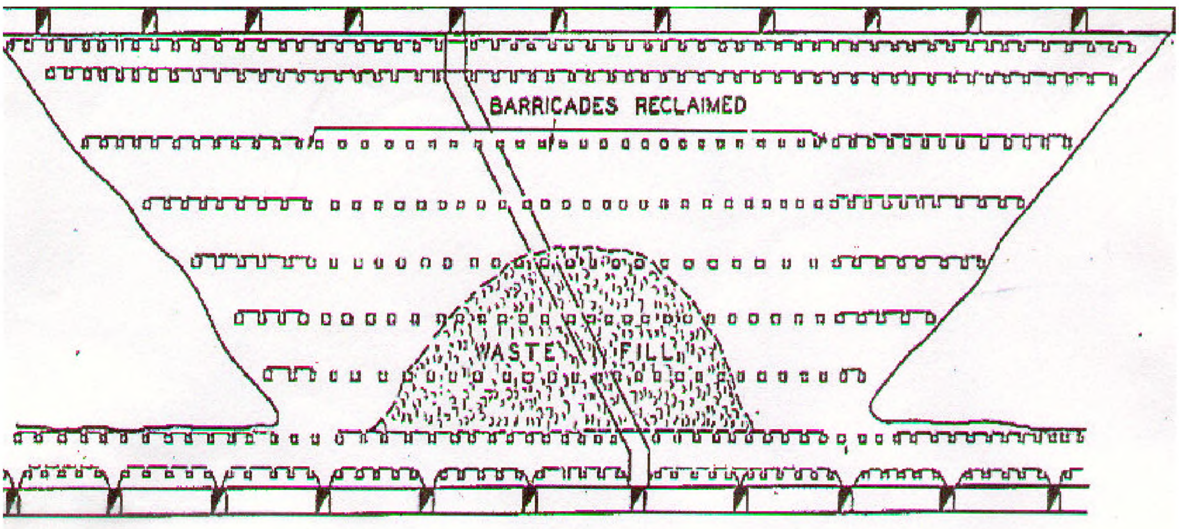


Figure 1.3: Typical fissure drive




BARRICADES RECLAIMED
WASTE
FILL

2 Introduction

A recent report (1995) of the Mine Environmental Control Department of the Department of Minerals and Energy (DME) showed that airborne fibres could be encountered in the workings of mines exploiting not only asbestos but also kimberlite deposits. Awareness of this phenomenon was somewhat dramatically increased with the airing towards the end of 1995 of a documentary television programme in "Carte Blanche", a Sunday night presentation, in which the plight of a person who had contracted mesothelioma, a severe and malignant form of asbestosis, was highlighted. This person claimed never to have worked in an asbestos mine but only in a diamond mine.

At that stage the source and extent of contamination from airborne fibres in non-asbestos mines was unknown. However, an initial literature search indicated that amphiboles such as tremolite and actinolite are common in both igneous and metamorphic rocks.

Airborne asbestos fibres have been classified internationally as class A1 carcinogens, i.e. they are known to be human carcinogens and the ACGIH has assigned a Threshold Limit Value - Time Weighted Average (TLV-TWA) for airborne asbestos of 0,1 fibres per millilitre (f/m•). The fibre concentration limit in force for surface and underground conditions in South African mines *for all types of asbestos fibres* is 2 f/m•. This limit was set with effect from *1 January 1984* by mutual agreement between the Government Mining Engineer (now the Chief Inspector of Mines) and members of the South African Asbestos Producers Advisory Committee. It is of interest to note that the Department of Labour has set a limit of 1 f/m• for all fibre types. These low limits confirm the seriousness with which exposure to this type of airborne pollutant is regarded by legislators.

Fibrogenic dusts may be considered to be "biologically active" and may become airborne as mining progresses through country rock, intrusions or kimberlite deposits. One of the objectives of this project was to detect low concentrations of fibrogenic dusts with a view to sourcing fibres and formulating control measures.

Because mining operations were essentially dry for most of the time samples were collected, irrespective of the technique used, levels of mineral dust obscured the presence of low fibres, as was anticipated.

In the initial evaluation phase, samples were evaluated in terms of phase contrast microscopy (PCM) as per NIOSH Method 7400 and also the Recommended Technical Method 1 (RTM 1). Although this method was useful for the detection of fibres and in calculating a fibre concentration, it did not help in the identification and classification of fibres. A selected number of samples from all mines investigated was submitted to either the University of the Witwatersrand or the Anglo American Research Laboratories for screening under an electron microscope to identify the fibres. Samples were selected on the basis of the density of background dust and initial fibre concentration. Scanning electron microscopy (SEM) was also used for the identification of non-asbestos mineral fibres (NAMF).

In addition, control samples were collected in a hard-rock mine workshop for a mechanised mining section and at two freeway offramps, for fibres from asbestos brakepads, but no fibres were detected.

Samples were collected in pairs at various test sites to improve the reliability of results. Samples were collected over the duration of the drilling period at drilling sites and continuous samples were also collected at intake and return air positions. Additional, intermittent samples, i.e. samples that are collected for ten minutes in every hour, were collected in return air positions. All sampling pumps were set to operate at 1 ℓ/minute. Air turbulence and, in most areas, copious amounts of dust at the working face positions precluded these positions from sample collection. Furthermore, both thermal precipitator and konimeter samples were collected at the return air positions to increase the database for evaluation and comparison.

Initially, a literature search was done in an effort to obtain references to the presence of airborne asbestos fibres in non-asbestos mines and also techniques used for dust control during dry drilling, since this project was run in parallel with project OTH 410 which concentrated on dust levels during dry drilling. Little information was forthcoming in the dry drilling search but references to asbestos fibres in non-asbestos mines yielded useful information.

3 Geology of asbestos

3.1 Background

Asbestos (translated from the Greek word meaning unquenchable) is a collective term for some of the metamorphic, fibrous, mineral silicates of the serpentine and amphibole groups. They have different physical and chemical properties but share a fibrous form. Mineralogists have generally taken a particle with a length-to-breadth ratio (aspect ratio) of 10:1 or more to be a fibre. In milled asbestos most of the particles have aspect ratios that range from 5:1 to 20:1 or more and, in the case of chrysotile, mostly greater than 50:1. However, for milled non-asbestos amphiboles the ratio of the majority of particles (most of which are cleavage fragments) is less than 3:1. Unfortunately, with the introduction of the membrane filter method of counting, a fibre was arbitrarily defined in the medical and environmental literature as a mineral particle the length of which is at least three times greater than its diameter (regulated fibre). This definition has been the basis of all fibre counting for dose-response studies since 1965, and for this reason has been retained despite general agreement that it is inappropriate. (Browne, 1994).

Among the most valuable characteristics of asbestos are its durability, which unfortunately also causes it to persist in lung tissue, and its fine diameter, which gives it a very high surface-to-weight ratio but also renders it respirable.

A concentration of 0,0005 f/m• is now commonly accepted as a representative outdoor urban level (Browne, 1994).

The Ontario Royal Commission on Asbestos (1984) concluded that there is a linear relationship for dose-response and that a threshold exists so that asbestos will not progress to clinical manifestation at or below lifetime occupational exposures of 25 f/m• years.

Sluis-Cremer *et al.* (1990) published evidence of a threshold for asbestos in South African amphibole mines as assessed at autopsy. The threshold level was estimated at 2 f/m• years with follow-up as long as 45 years, but there are many reasons why exposures were probably underestimated, including the fact that they were based on average fibre concentrations throughout individual mines and on average job rankings, not on individual exposures.

3.2 Origin and occurrence

Over the years the origin of asbestos has been the subject of extensive geological research. There are essentially two major varieties of asbestos, namely serpentine and amphibole (Carman,1949).

Serpentine is a hydrous magnesium silicate with the chemical composition of $3MgO.2SiO_2.2H_2O$, monoclinic, and occurs as a plating variety (antigonite) or as a fibrous variety (chrysotile), which in long fibres is *chrysotile* asbestos. It is normally of secondary origin through the alteration of olivine, pyroxenes or amphiboles, and occurs under widely differing geological conditions. Similarly, the modes of occurrence or manner in which the fibres are physically embedded in the hard rock also differ widely. Current opinion is that chrysotile fibres resulted from two separate metamorphic reactions in ultrabasic rocks of igneous origin. The initial hydrothermal reaction changed the olivines and pyroxenes into serpentine. At a subsequent stage, the serpentine was redissolved and the mineral-rich solution flowed into cracks and crevices in the host rock where fibre was re-precipitated. In this re-precipitation process, asbestos fibre was usually deposited in a cross-vein mode of occurrence, i.e. the fibres lie perpendicular to the wall rock.

In some cases, chrysotile was either deposited or affected by earth movements such that most of the fibres lying parallel to the wall rock. This mode of occurrence is referred to as 'slip fibre'. The third and least usual mode of occurrence of chrysotile is referred to as the 'massive' or 'agglomerated' form in which the fibres were deposited as platelets having no specific fibre orientation.

Chrysotile is found in both igneous and metamorphic rocks. Amphiboles have the general formula $M7(OH)_2.Si_8.O_{22}$ where M is typically Mg or Ca although this may be partially replaced by Na, Fe or Al. These minerals are able to form fibrous structures due to the ease with which their molecular chains can be separated. Table 3.2 shows the species, varieties and chemical compositions.

Table 3.2

Chemical compositions of asbestos

Species	Variety	Chemical Composition
Chrysotile	Serpentine	$3MgO.2SiO_2.2H_2O$
Anthophyllite	Amphibole	$7MgO.8SiO_2.H_2O$
Amosite*	Amphibole	$11FeO.3MgO.16SiO_2.2H_2O$
Actinolite	Amphibole	$2CaO.4MgO.FeO.8SiO_2.H_2O$
Tremolite	Amphibole	$2CaO.MgO.8SiO_2.H_2O$
Crocidolite	Amphibole	$Na_2O.Fe_2O_3.3FeO.8SiO_2.H_2O$

* The name *amosite* is an acronym from Asbestos Mines of South Africa (Carmen, 1949)

Amphiboles are commonly found as a component of igneous and metamorphic rocks of basic or mafic types and comprise about 5 % of the Earth's crust (Encyclopaedia Brittanica, 1992).

The origins of amphibole varieties of asbestos are not as clearly defined as those of chrysotile (Encylodaepia of Chemical Technology, 1994). The two commercially significant fibres, crocidolite and amosite, occur in metamorphosed sedimentary strata known as banded ironstones.

These sedimentary formations vary considerably in composition, which accounts for the compositional variations in the associated amphibole fibres.

Crocidolite and amosite species of asbestos occur in cross-vein modes and anthophyllite and tremolite species often occur in slip modes, although both of the latter can also occur in a massive mode in which fibres are non-orientated. Actinolite, a non-commercial species of amphibole asbestos, is most often found as brittle, acicular, bladed forms in a massive mode.

In its generic connotation, asbestos is a mineral found all over the world. In most cases, asbestos species most easily located are those having limited or no commercial attraction such as actinolite, anthophyllite or tremolite.

Some formations in which asbestos or similar minerals occur are:

1. Limestones in Finland (Juntilla *et al.*).
2. Marbles, pegmatites, serpentines and gneisses – New Jersey.
3. Serpentines in phoscorite at Phalaborwa.
4. Amphiboles and banded ironstones in Black Mountain/Aggenys/Broken Hill deposits.
5. Amphiboles in the Prieska copper deposit.
6. Banded ironstones with iron ore – Postmasburg/Sishen.
7. Todorokite, an asbestiform mineral similar to phrolusite – associated with the Kalahari manganese field.
8. Amphiboles which can occur in diamond pipes and surrounding rock if the rock is mafic and contains carbonatiles.
9. Lizardite, which is known to occur in kimberlites. It forms at temperatures less than 200 •C. Lizardite undergoes a metamorphosis to form lizardite and chrysotile.

3.3 Asbestos and related minerals

Asbestos minerals are natural, hydrated silicates which occur as fibres. Asbestos fibres are classified into two groups: amphiboles and chrysotile. Anthophyllite, amosite, tremolite, actinolite and crocidolite belong to chains of composition $Si_8.O_{22}(OH)_2$. Each fibre of amphibole asbestos tends to form straight edges parallel to the fibre axis and they vary from electron-dense fibres to opaque ones. On the other hand, chrysotile fibrils normally consist of a central capillary and electron-opaque walls.

Chrysotile yields a unique, selected-area, electron-diffraction pattern. Layer lines denoting the periodicity of the fibre axis yield measurements of 5.3.

Amphiboles, however, have quite similar diffraction patterns. It is difficult to distinguish a particular mineral species among amphiboles because the diffraction patterns resemble each other. This technique is effective for differentiating chrysotile from amphibole asbestos.

Chrysotile is the trioctahedral analogue of the kaolin minerals and shows certain morphological similarities to halloysite. Halloysite fibres are generally difficult to distinguish from chrysotile fibrils, but X-ray emission spectra can easily show the difference in chemistry of these minerals. It is clear that asbestiforms can be identified on the basis of their unique analytical characteristics.

3.4 Clay minerals

The sepiolite-palgorskite group is a series of hydrous magnesium minerals. Palgorskite is the aluminium-rich or iron-rich member and sepiolite is the aluminium-poor member. Electron micrographs of these minerals have revealed that the particles consist of elongated fibres, which are axially parallel, sharp-edged and unevenly broken at their ends. The predominant peaks in the energy-dispersive X-ray spectra are magnesium and silicon for the sepiolite fibre, and silicon, aluminium and magnesium from the palgorskite fibre. The chlorites are a group of hydrous silicate minerals whose structure permits extensive isomorphous substitution. The chemical composition of these minerals varies widely indeed. Although four kinds of chlorite having different chemical compositions were examined under a transmission electron microscope, it was difficult to differentiate one species from another on the basis of their morphology or electron-diffraction patterns.

Al-chlorite, Al-Mg-chlorite and Mg-chlorite have similar spectra which differ only with regard to the relative quantities of magnesium, aluminium, silicon and iron they contain. However, these chlorites can be differentiated from each other on the basis of their Mg-Al-Si ratios. Fe-chlorite, on the other hand, differs significantly from the others due to the presence of a magnesium peak and a large iron peak.

3.5 Asbestos bodies (coated asbestos fibres)

Asbestos bodies begin as a fibre normally more than 10 μm long, part or all of which is enclosed in a macrophage or an aggregation of macrophages forming a giant cell. It has been shown that the probability of a fibre becoming coated increases with its length. Bodies less than 10 μm long are rarely encountered, and for fibres longer than 80 μm the probability of coating is virtually 100 %. The dimensional effects on the formation of bodies were also reviewed. Bodies are formed more readily on fibres of greater diameter. About 10 % of fibres visible under a light microscope are coated, irrespective of the fibre type, but the proportion of fibres visible will, in the case of crocidolite, be less than one in ten, so that the true proportion of coated fibres is less than one in ten. With anthophyllite, which has a greater mean diameter, the true proportion is higher. The proportion of coated fibres increases with increasing lapse of time from the last exposure, suggesting that the longer a fibre stays in the lung, the greater the chances that it will be coated. In 1965 it was also shown that the probability of finding asbestos bodies in the lungs of urban dwellers was high and increased with age. Since that time it has become clear that, if searched for with sufficient diligence, bodies can be found in the lungs of all adults living in cities.

3.6 Synthetic (man-made) mineral fibres

Mineral wools are made from "melts" of specific argillaceous limestones and smelter slags, sometimes with the addition of wollastonite or kaolinite. Glass wool (or fibreglass) is made from different types of silicate glass. They are all glassy minerals which, unlike asbestos minerals, are amorphous silicates. The diameters of ordinary glass fibres are usually greater than 3 µm, but may vary down to diameters of less than 1 µm. "Melts" at a temperature of 1 000 to 1 500 °C are "fiberised" by drawing, blowing or centrifugal methods. The diameters and lengths of the fibres differ according to the use for which they are required, and are manufactured to a controlled "nominal" (specified) diameter.

Man-made mineral fibres (MMMF) are commonly coated with a binder, which is usually a biologically inert, fully polymerised, thermosetting resin. They have also been coated with mineral oil to reduce dust emissions and to serve as a lubricant between fibres to improve their handling properties. Unlike asbestos fibres, which split longitudinally into numerous fibrils of much smaller diameter, MMMFs break transversely into shorter fragments with the same diameter (Browne, 1994) (see Figure 3.1).

Slag and rock wools have been produced since the late 1840s, and glass wool since about 1930, yet no clearly authenticated cases of causally related lung disease have been reported, even though fibres of "respirable" dimensions have been present in most products since manufacture began. Epidemiological and radiological studies have not revealed any evidence of pneumoconiosis. Neither long nor short fibres provoked any fibrosis. Nevertheless, on the basis of mixed animal and human evidence, the IARC (1988) has classified rock or slag wool, fibrous glass and ceramic fibres as a "possible human carcinogen" (Group 2B). Continuous glass filaments were found not to be classifiable, and are therefore placed in Group 3.

3.7 Occupational Exposure Limits for Airborne Asbestos

The ACGIH TLV-TWA for asbestos, all forms, adopted in 1998 is 0,1 f/cc.

The UK HSE in 1998 lowered their limits to:

Chrysotile 4 hour TWA 0,3 f/mℓ 10 minute STEL 0,9 f/mℓ

Crocidolite and amosite and mixtures of chrysotile with other types.

4 hour TWA 0,2 f/mℓ 10 minute STEl 0,6 f/mℓ

The EU through:

Council Directive 91/382/EEC of 25 June 1991 amending Directive 83/477/EEC on the protection of workers from the risks related to exposure to asbestos at work (second individual Directive with the meaning of Article 8 of Directive 80/1107/EEC) stipulate:

(a) for chrysolite fibres in the air at the place of work an 8 hour TWA of 0,60 fibres per cm^3, and

(b) concentration in the air at the place of work of all other forms of asbestos firbres, either alone or in mixtures, including mixtures containing chrysolite, 0,30 fibres per cm^3 measured or calculated in relation to an eight-hour reference period.

The DME proposed limit for airborne asbestos (all forms) in the draft Occupational Hygiene Regulations is 1 f/mℓ.

The current DOL Draft Asbestos Regulations stipulate a 4 hour TWA of 0,2 regulated asbestos fibres per millilitre of air averaged over any continuous period of four hours measured in accordance with MDHS 39/4. The 10-min STEL of 0,6 f/mℓ (all forms) should not be exceeded at any time during the working day even if the 4-hour TWA is within the OEL-TWA (Government Gazette 16 August 1999). The new Asbestos Regulations will be promulgated in 2001.

Currently, South African mining regulations set a limit of 2f/m• for regulated fibres. It is known that the DME is considering a change to the present (not the intended) limits as set out by the ACGIH.

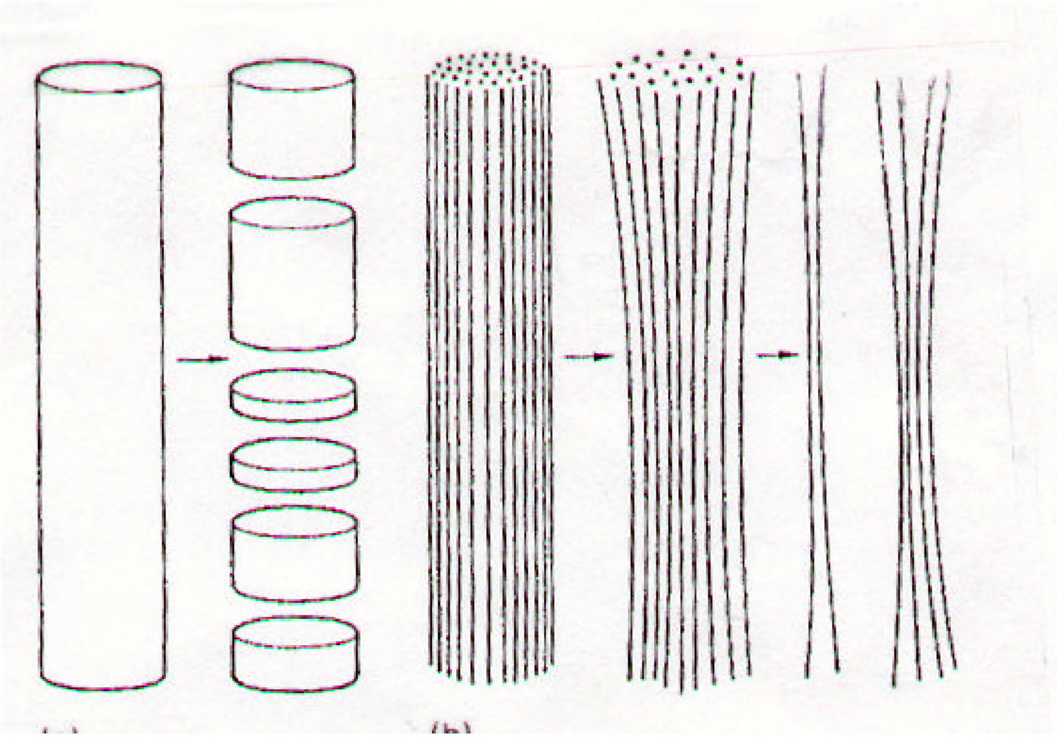


Figure 3.1 Comparison of the modes of fracture of (a) synthetic and (b) asbestos fibres

4 Literature survey

A literature survey was carried out with the aim of establishing the toxicology of mineral fibres, identifying possible sources of mineral fibres in diamond mines from geological considerations, developing a sampling strategy and developing a method for quantifying and identifying fibres.

Many papers have been published on industrial hygiene studies of asbestos workers, miners and others, as well as those exposed to asbestos-containing materials such as insulation, asbestos-cement products and brake linings. Between 1970 and 1982 some 4 000 publications were distributed (Du Toit, 1982). It is obviously not practicable to cover all the published information in this report but a few references which are themselves evaluations of other publications are listed.

4.1 Toxicology

It has been known for centuries (Streib, 1976; Castleman, 1993) that the inhalation of asbestos fibres increases the risk of lung disease. A study of this literature was compiled by Browne (1994). The three diseases associated with asbestos are:

- Asbestosis, a non-malignant fibrotic lung condition
- Bronchogenic carcinoma
- Mesothelioma, a rare cancer of the lining of the lungs, abdomen or heart.

Tobacco smoking was stated to greatly increase the risk of developing bronchogenic cancer amongst people exposed to asbestos. For interest, illustrations of asbestos fibre deposits in lungs are depicted in Figures 4.1a to 4.1d (Browne, 1994).

The influence of fibre type, size and shape on lung tissue and on the retention of fibres in the lungs was studied extensively by Knight (1982) and led to the conventional optical fibre-counting procedure which excludes fibres less than 5 µm long or with a width-to-length ratio greater than 1:3.

Figure 4.1a: Illustration of asbestosis

Asbestosis refers to fibrosis of the lung parenchyma itself. The degree of fibrosis is related to the magnitude and duration of the exposure. Once inhaled, the asbestos fibres are deposited in the respiratory bronchioles and alveolar ducts. It is here in the peribronchiolar area of the lung that fibrosis begins. As the disease progresses, there is involvement of the adjacent alveoli. The fibrosis is limited to the lower half of the lung, does not involve the more central parts of the lobes and cyst formation is absent. Patients are rarely symptomatic before 15 years from the time of initial exposure.

Asbestosis of slight-to-moderate degree involves the posterior and basal zones of the lower lobe, which is reduced in size, and the lingula and lower part of the upper lobe anteriorly spaces in the fibrosis are few and very small. Carcinoma is also present in the lower lobe.

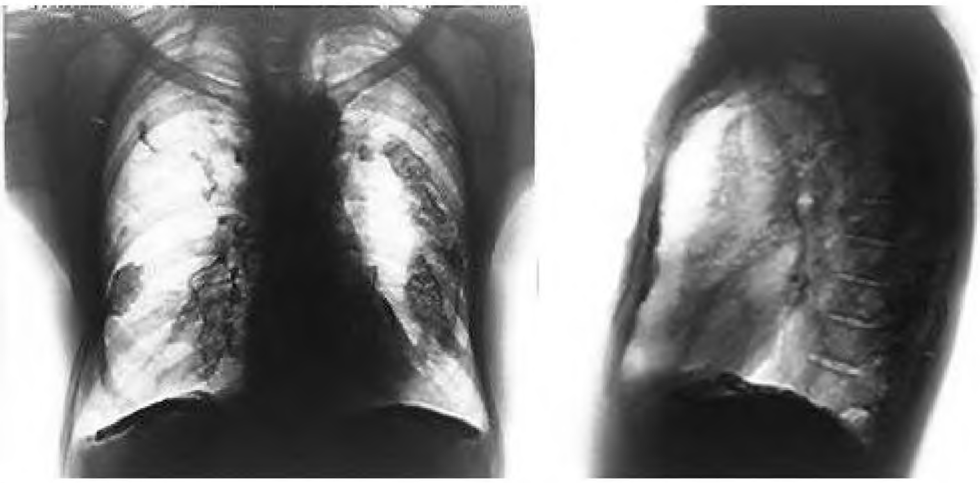


Figure 4.1b: Thorax pulmonary artery and lateral view (X-ray negatives) of 52-year-old asymptomatic patient with asbestosis

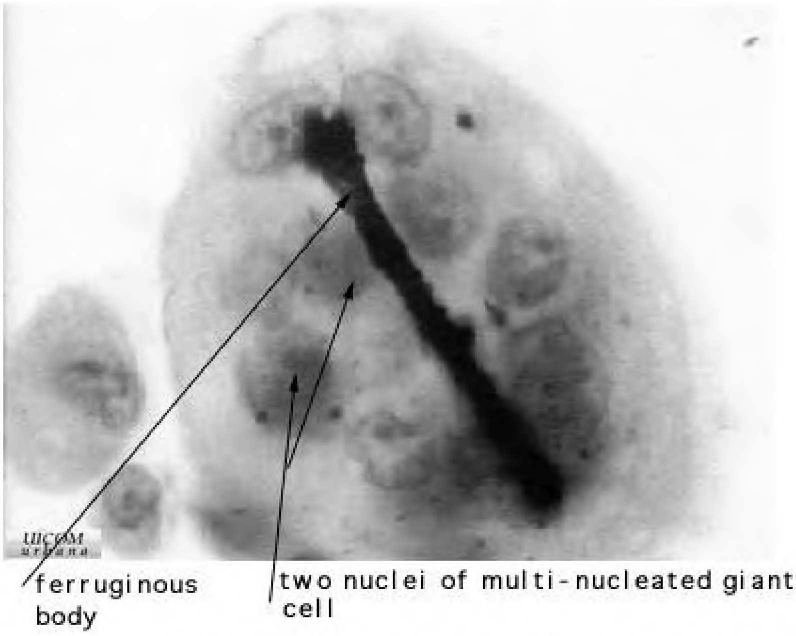


Figure 4.1c: The effect of asbestosis on lung cells showing a foreign body, a giant cell (multi-nucleated macrophages), a fibrogenous body and small alveolar microphages

Figure 4.1c is a slice of lung from a man, a life-long cigarette smoker, employed for 20 years in a factory processing amosite. It shows moderately severe asbestosis (more advanced than that shown in Figure 4.1b) distributed at the periphery of the lower lobe (mostly diffuse) and slight thickening of the pulmonary pleura which are therefore sharply defined. Note that cystic molecular chains can be separated.

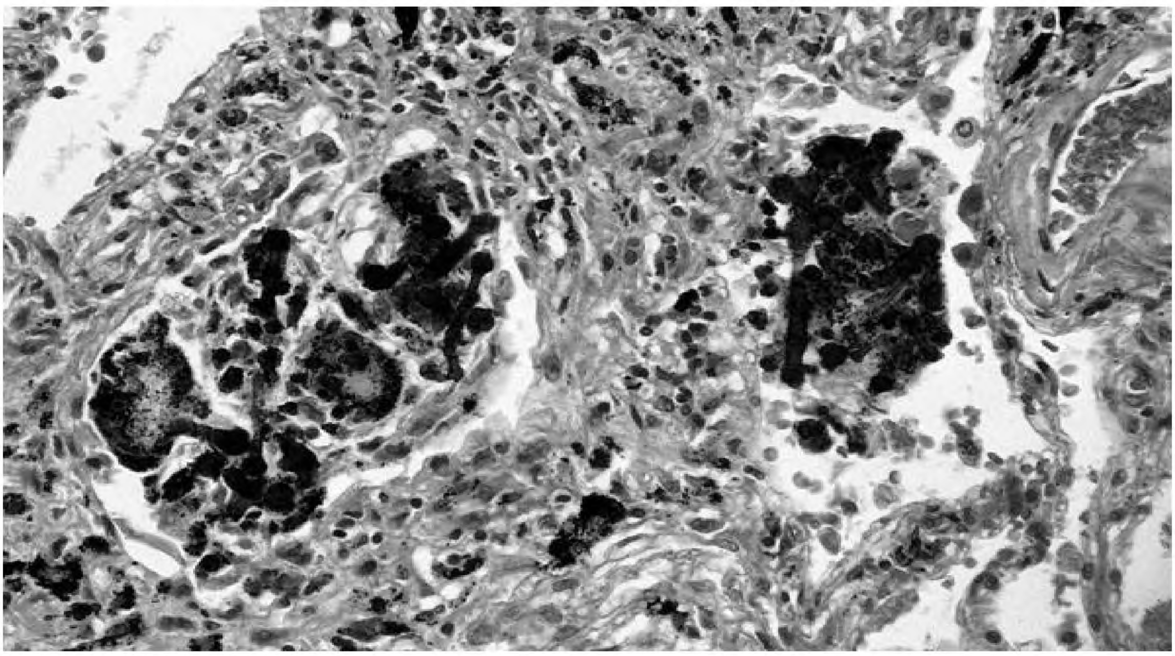


Figure 4.1d: Asbestos bodies in a section of lung with asbestosis

Asbestosis is defined as interstitial pulmonary fibrosis caused by inhaled asbestos dust (fibres). Figure 4.1d shows asbestos bodies with areas of interstitial fibrosis, chronic inflammation and histiocytes. The golden brown structures are encrusted with protein and iron. Some of these beaded structures represent asbestos bodies.

4.2 Sources of asbestos fibres

Two main types of mineral fibre have been known and exploited as asbestos. They are chrysotile, which is a magnesium silicate hydroxide, and the fibrous forms of a range of hydrous silicate minerals containing sodium, calcium, magnesium, iron and aluminium known as amphiboles (Carman, 1949). Chrysotile is a crystalline form of serpentine, which is known as asbestos when it occurs as distinct fibrous bands in massive serpentine. It is less acid-resistant than other forms of asbestos and used to be considered less toxic. Amphiboles have a general formula $M_7(OH)_2\ Si_8\ O_{22}$ where M is typically Mg or Ca although they may be partially replaced by Na, Fe or Al. These minerals can form fibrous structures due to the ease with which their molecular chains can be separated. Common fibrous amphiboles include (Lurie, 1989):

- Tremolite $Ca_2\ Mg_5\ Si_8\ O_{22}(OH)_2$
- Anthophyllite $Mg_7\ Si_8\ O_{22}(OH)_2$
- Actinolite $Mg\ Ca\ Fe\ Si_8\ O_{22}(OH)_2$
- Crocidolite $Na_2\ Fe^{++}_3\ Fe^{+++}_2\ Si_8\ O_{22}(OH)$

Amphiboles are commonly found as a component of igneous and metamorphic rocks of basic or mafic type and comprise about 5 % of the Earth's crust (Encyclopaedia Brittanica, 1992).

Wollastonite ($Ca_3\ Si_3\ O_8$) is a similar fibrous silicate mineral which is used as a substitute for asbestos (Huuskonen, 1983).

Some non-asbestos mines in which asbestos or similar minerals occur in South Africa are listed by Lurie as:

- Serpentines in phoscorite at Phalaborwa
- Amphiboles and banded ironstone in Black Mountain/Aggenys/Broken Hill deposits
- Amphiboles in the Prieska copper deposit
- Banded ironstone with iron ore at Postmasburg/Sishen

- Todorokite, an asbestiform mineral similar to pyrolusite, associated with the Kalahari manganese field.

It appeared from discussions with a geologist (Dr R Boer) that amphiboles can be expected to occur in any mafic rock where the correct temperatures and pressures have been experienced, and that such regions could be in basic country rock adjacent to a volcanic pipe or in kimberlite containing carbonatites. Only two overseas references to fibres in non-asbestos mines were found. One source (Juntilla, *et al.*) discusses the occurrence of fibres in Finnish limestone and dolomite mines, and the other (Germine and Puffer) the distribution of asbestos in the northern New Jersey area of the USA.

Because mineral fibres may occur only in isolated zones of the kimberlite or in the surrounding country rock, it was necessary to sample at as many places as practicable throughout the mine.

From articles in the press and discussions with various people it can be assumed that because of the ubiquitous occurrence of asbestos and similar natural mineral fibres, it is probable that they could be found in various mines. The widespread mining of asbestos in South Africa has resulted in many waste dumps, which were seldom properly covered so that local inhabitants may have been exposed to asbestos fibres from childhood. Moreover, because the demand for asbestos has dropped, it is likely that miners will have moved from asbestos mines to other types of mining. Thus, particularly because of the long latency period for asbestos-related diseases, it would not be reasonable to assume that diagnosed cases amongst miners are the result of exposure in their present employment. Similarly, mine workers could have come into contact with asbestos – cement, thermal insulation, friction linings or other materials incorporating asbestos - during previous employment.

5 Sampling and sample evaluation

Although historically the method for evaluating occupational exposure was visual counts of asbestos dust particles, almost every type of dust-sampling instrument has been used to sample for airborne asbestos fibres. Such instruments have been used to achieve four main objectives: (1) to determine whether an atmosphere is potentially dangerous; (2) to ascertain whether engineering control measures are working effectively; (3) to detect the source of dust; and (4) to determine asbestos zones. In this project the two objectives were: (1) to establish whether airborne asbestos fibres are present during the mining of kimberlite and (2) if so, in what concentrations.

It is not intended to discuss the theories of past and presently available dust-sampling instruments, which can in any case be found in several comprehensive reviews on these instruments. However, for the sake of completeness, it must be stated that three different sampling methods were used for this project. These are: (i) membrane filter samples collected in continuous aire sampling mode and in intermittent mode (i.e. 10 minutes in every 60 minutes, this being the recommended technique when high dust loading is experienced), (ii) thermal precipitator and (iii) konimeter. All the instruments were operated as stationary samplers only.

There are, of course, some points concerning the performance of these instruments that should be noted.

5.1 The konimeter

The konimeter was used for many years to sample for asbestos fibres in air, but was found to have some shortcomings, particularly in situations of varying concentrations such as can be found at dust-generating operations. Counting and sizing under an optical microscope of 100 x magnification can lead to erroneous results. Since the slides are coated with Vaseline, any fibres present tend to be less visible than in samples of other counting instruments. Konimeter slides could not be ignited to remove carbon particles without risking a change in the structure of the fibres.

5.2 The thermal precipitator

In many countries the thermal precipitator is still regarded as the standard method for some atmospheric dust estimations. In this instrument dusty air is drawn at a rate of between 5 and 7mℓ/min through a narrow vertical channel between two circular glass cover slips. A fine wire is centred in the gap between the cover slips and is heated electrically. A steep temperature gradient, perpendicular to the direction of flow, is created between the heated wire and the cold collecting surfaces (cover slips). The movement of particles in the direction of the decreasing temperature causes them to deposit as two strips on the cover slips opposite the heated wire (see Figure 5.1).

In this investigation the sampling head was aspirated by means of a mini sampling pump.

Originally, a 100 % efficiency was claimed for particles less than 10 µm in length. As a consequence, a long-running thermal precipitator (LRTP) was developed to collect fibres greater than 10 µm in length and to take long-term samples. Despite its extensive use as a dust monitor in the asbestos industry, the LRTP suffered from the following disadvantages:

1. It was efficient only at low sampling rates and thus required long periods for reliable fibre counting.
2. It required an appreciable amount of maintenance and checking.
3. There was a possibility of some dust being carried through the precipitators without being deposited on the cover slips.
4. The instrument could not be used as a personal monitor.

In this project only standard thermal precipitators (TPs) with a modified aspiration method, i.e. an electric sampling pump instead of a water aspirator, were used.

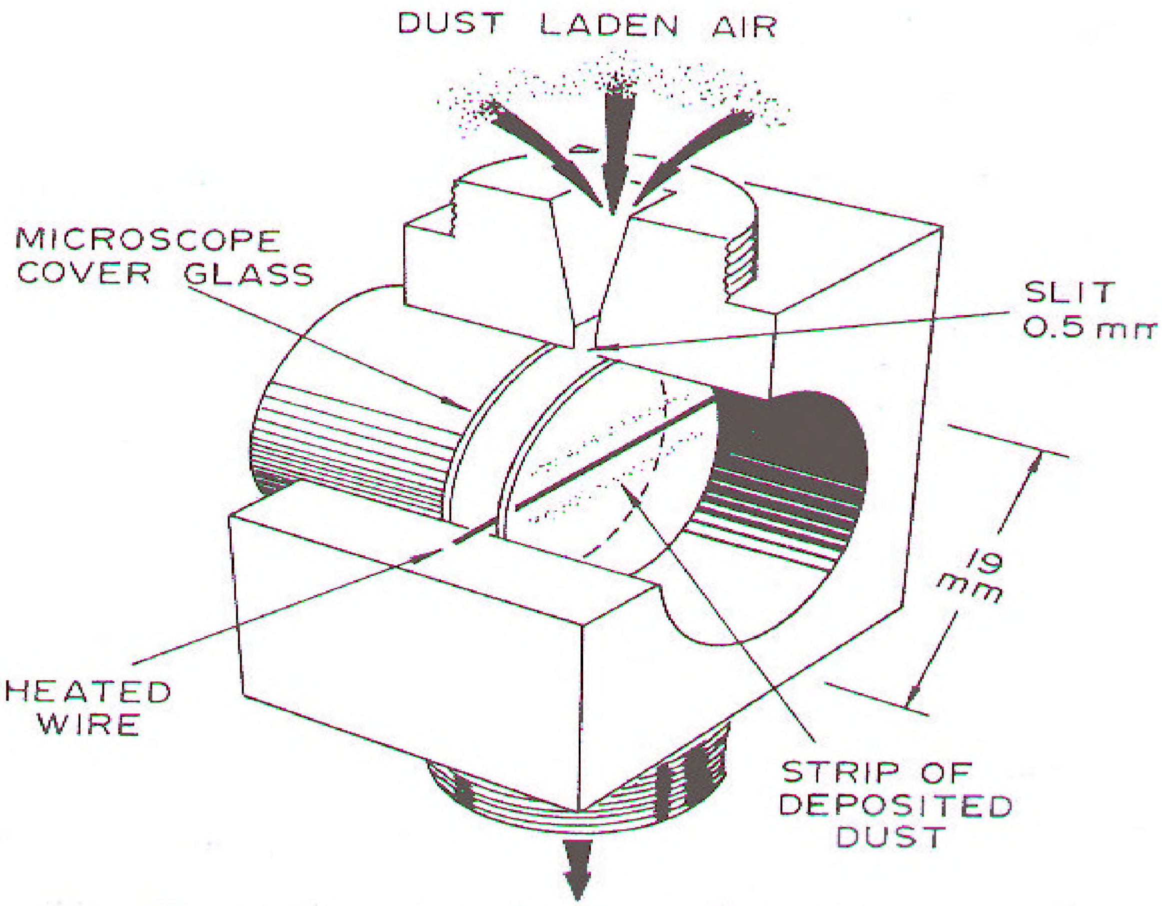


Figure 5.1: Thermal precipitator sampling head

5.3 Sampling with membrane filters

The physical and chemical properties of membrane filters made them outstandingly suitable for the collection of airborne dust. Most membrane filters are made from cellulose ester and this method has the following advantages over other sampling methods:

1. The cellulose ester membrane filters are soluble in ketones and esters, which can be used to make the filters transparent for optical microscope counting. Furthermore, the filters can be cleared by adding an immersion oil having a similar refractive index.

2. Membrane filters having a pore size of between 0,45 and 0,8 µm can be effectively used to trap fibres in the range of 5 to 100 µm.

3. Compared with TPs, it is possible to use higher sampling flow rates and thereby reduce the sampling time.

4. The equipment is small and light enough to be used as a personal sampler.

5.4 Sample evaluation

Sample evaluation for konimeter and TP slides was undertaken with the usual optical microscopes. However, the samples collected on membrane filters required special preparation and counting techniques. The dust-laden sample filter is dissected with a scalpel and the dust deposit on the half to be examined is fixed to the cover slide through the application of triacetin (glycerol triacetate). The second half of the filter is kept for further analysis. The side of the slide with the dust on it is exposed to heated acetone generated from a condensing column, as shown in Figure 5.2.

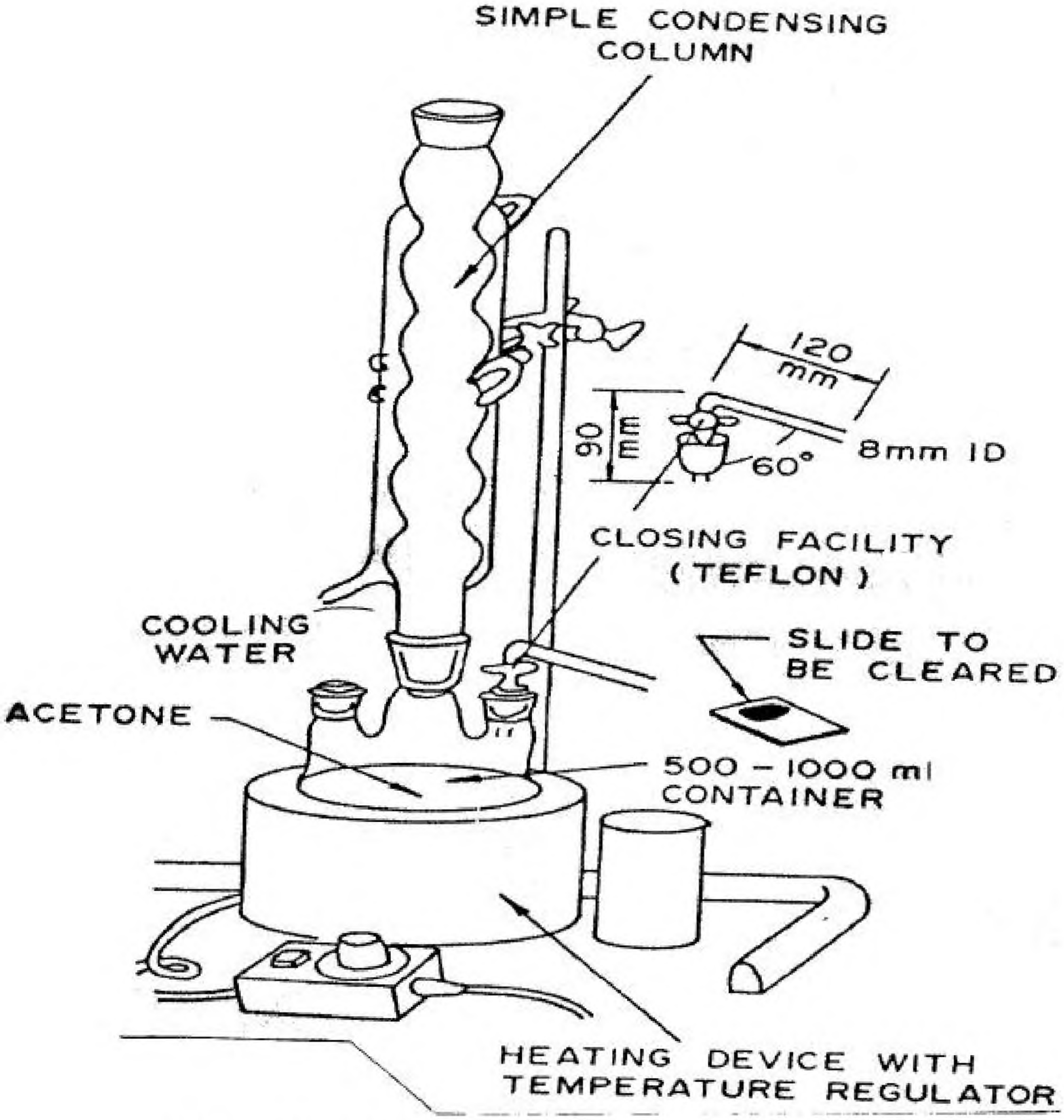


Figure 5.2: Condensing column for acetone treatment

The hot acetone and triacetate clear the filter and leave a clear glass slide, with the dust fixed to it, for evaluation of the fibre concentration under an optical microscope with an enlargement of 500 x. A phase-contrast microscope (PCM) (optical microscope) (Figure 5.3) gives the dust and fibres on the microscope slide a 3-D appearance and assists with the evaluation of the deposit on the slide. Only "regulated fibres" (as per RTM 1) may be counted. A regulated fibre is defined as a particle that has an aspect ratio of at least 3:1, with the length greater than 5 µm and the diameter less than 3 µm. This is shown in Figure 5.4.

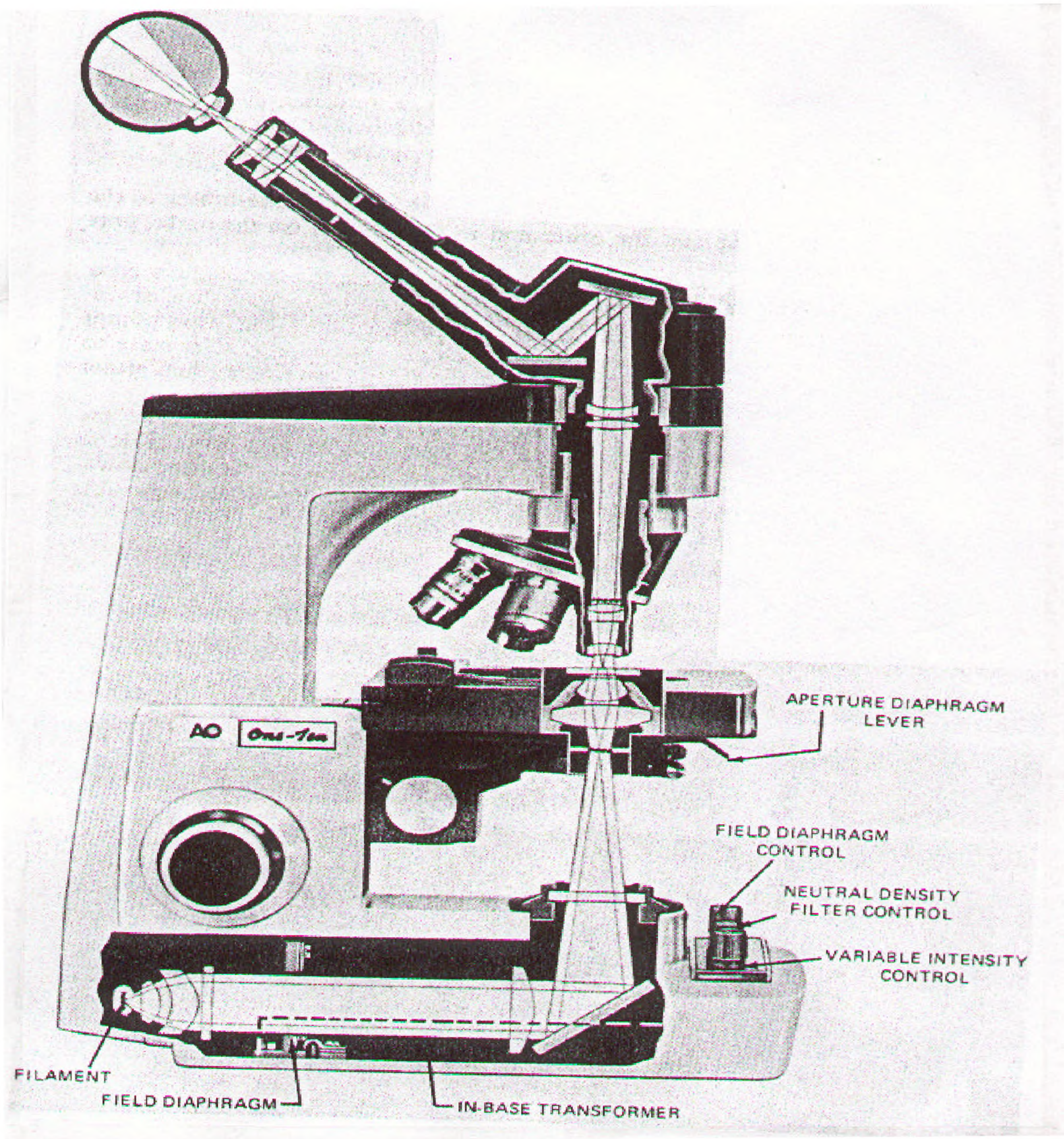


Figure 5.3: Phase-contrast microscope

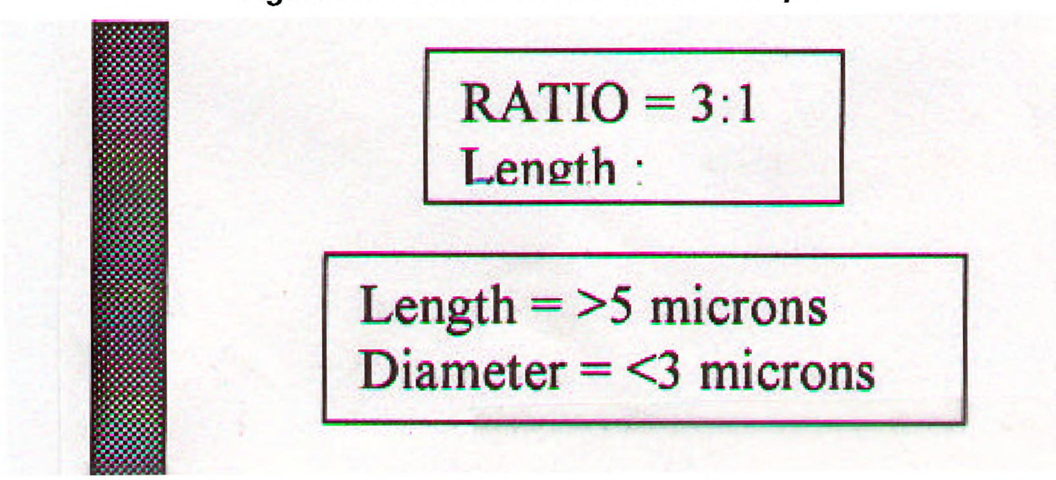
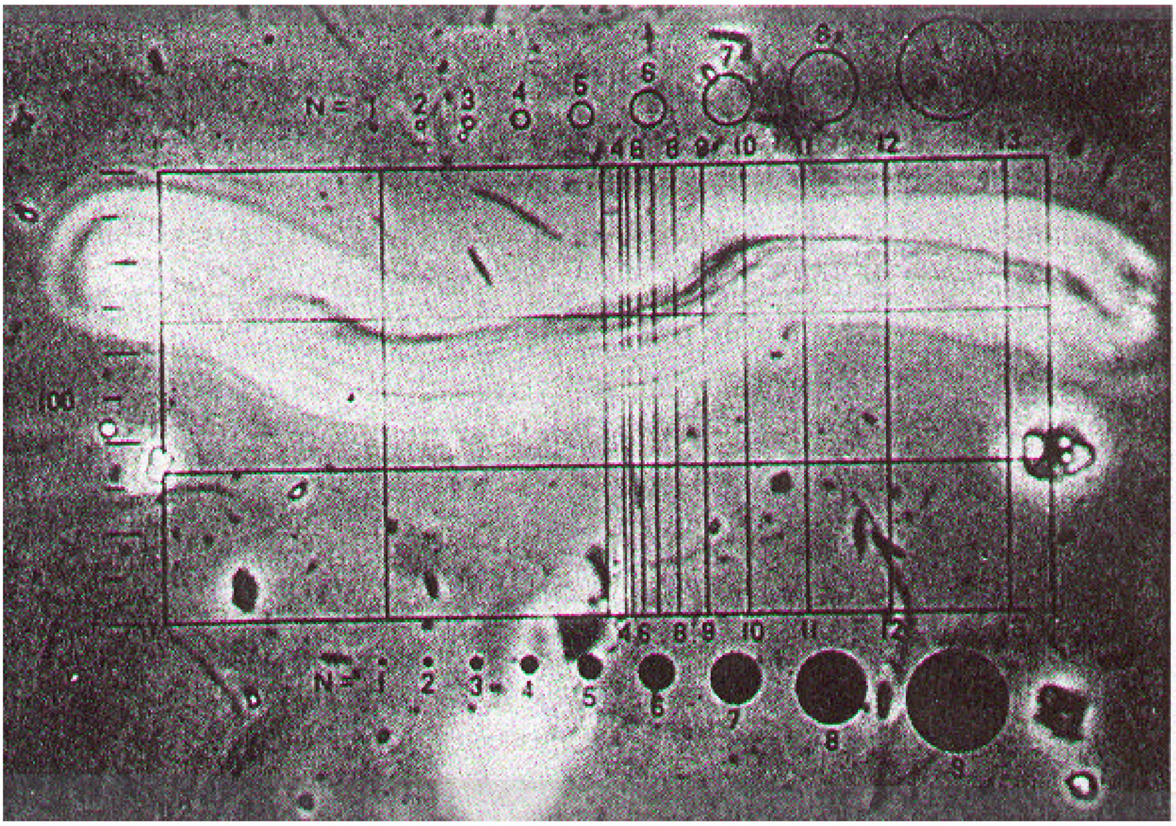


Figure 5.4: Regulated asbestos fibre

Figure 5.5 shows a typical graticule used to evaluate fibre sizes during a fibre count.



Figures 5.6 to 5.9 show single fibres, split fibres, grouped fibres and fibres with other particles respectively. In reality, the situation is much more complex because not only one fibre at a time appears as an image and it is compounded by a high mineral dust background. This will be clearly seen in a later illustration.

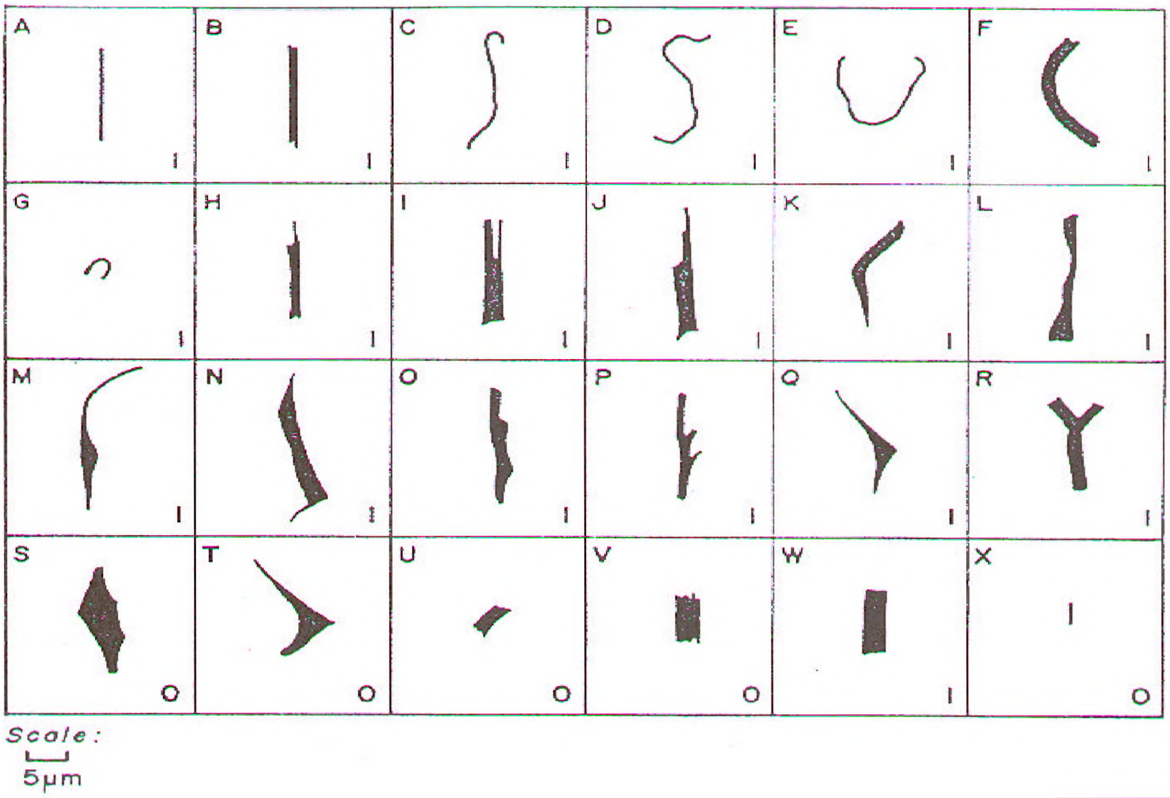
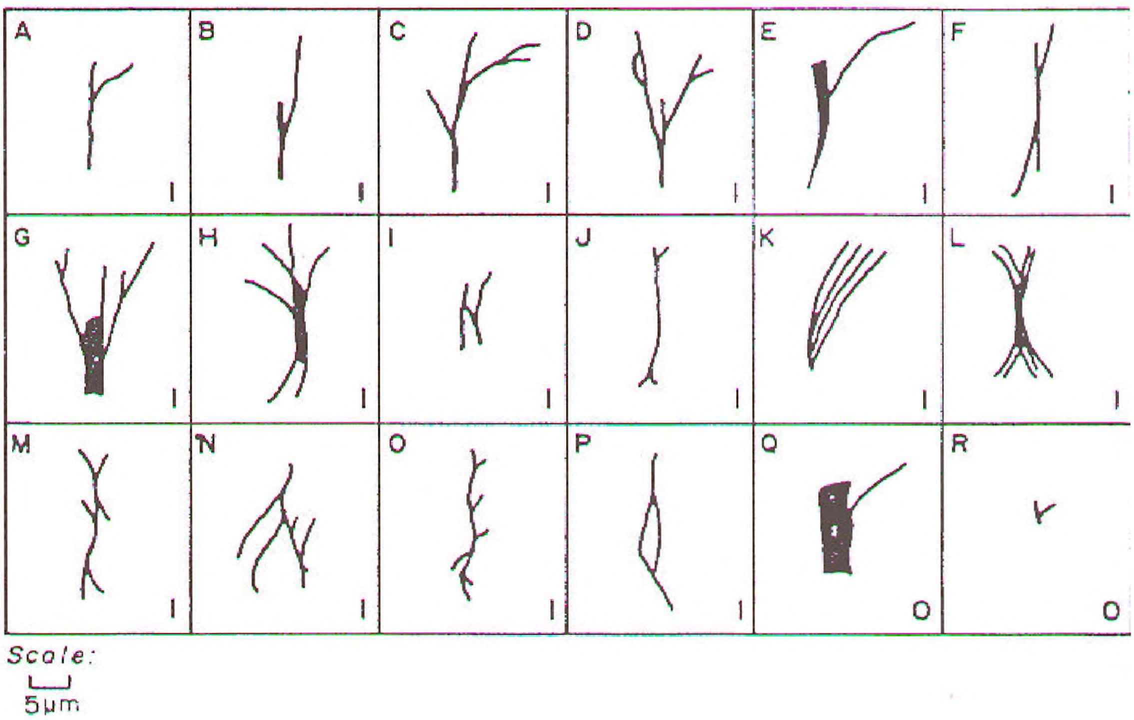


Figure 5.6: Single fibres



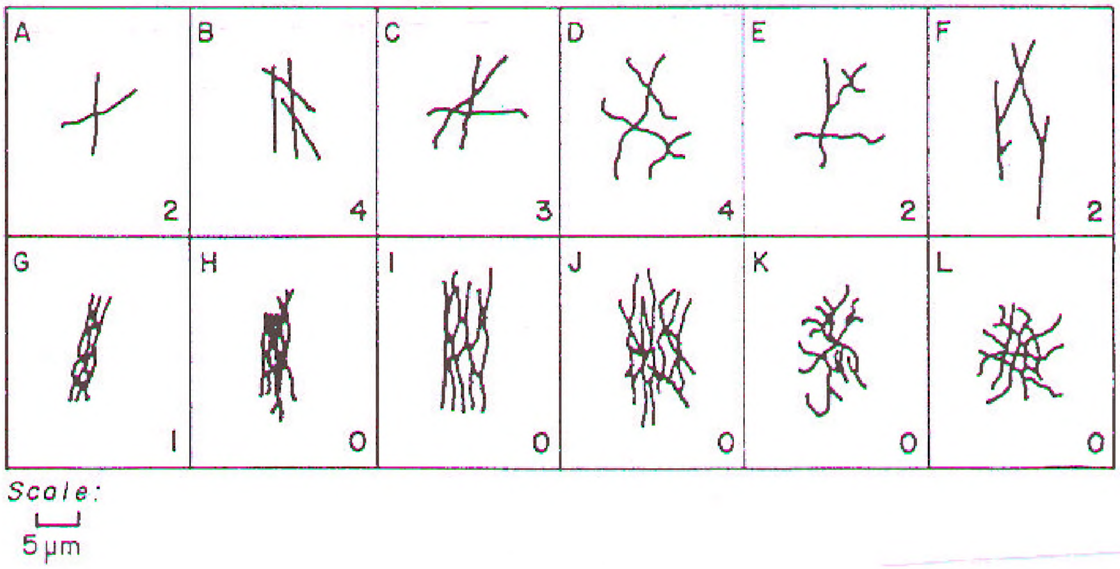


Figure 5.8: Grouped fibres

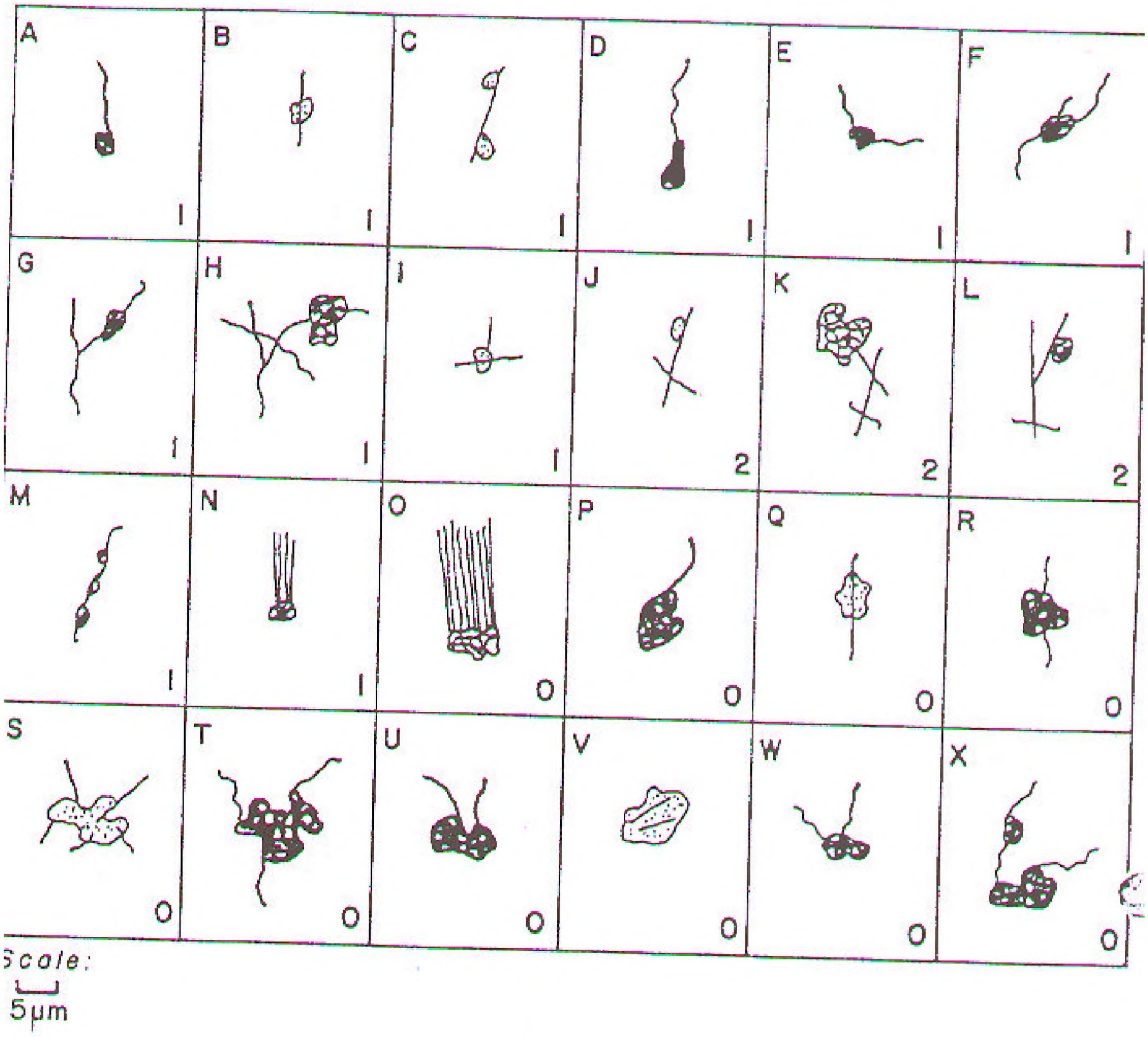


Figure 5.9: Fibres with other particles

5.5 Fibre counting

Once the sample has been prepared, there is a specified technique to be used for fibre counting. This is done using a PCM. The cleared filter on the slide is traversed along five separate radii and fibre counts are made in at least five fields along each radius. The number of regulated fibres found in each field, taking into account the imagery portrayed in Figures 5.6 to 5.9, is recorded. Since only a fraction of the filter is being evaluated, it is necessary to extrapolate the fibre count to the full filter. This is done as follows:

$$f/m\bullet = \frac{A^2}{a^2} \times \frac{N}{n} \times \frac{1}{V}$$

where:
A = the sampling area of the filter, mm^2
a = the area of the counting graticule, mm^2
N = the number of fibres counted
n = the number of fields counted
V = the volume of the sample, m•

Since so few fibres were present, this deviation from the recommended counting technique, i.e. determining the number of fields in which 100 fibres are counted and then extrapolating to the full filter area, was considered to be justified. The recommended counting technique was developed for samples collected in known asbestos-producing operations where high concentrations are anticipated.

5.6 Identification of asbestiform and mineral fibres

Although PCM can be successfully used for fibre counting, this method has limitations with regard to actually identifying the different fibres. Fibre identification is considered to be necessary because different fibre types are considered by some authorities to possess different toxicities. Hence, a method for positively identifying the different fibre types could be regarded as important. Although the various types of asbestos fibres have characteristics that allow recognition under an optical microscope, this identification is not always certain. Identification can be improved by "staining" with fluids of various refractive indices so that the fibres are seen in characteristic colours (Grabar, 1962). Where a number of liquids are required to cope with a range of unknown fibres, however, this method is laborious.

Where relatively pure forms of asbestos only occur, X-ray diffraction has been used (Goodhead and Martindale, 1969) but this method is unlikely to be practicable where a large number of different materials constitute the dust.

Instead of depending on physical characteristics alone to identify fibres, a scanning electron microscope (SEM) may be used to scan the sample and form electro-optical images. A SEM provides what can be described as a "chemical fingerprint" or elemental analysis of the fibres, an example of which is given in Figure 5.10. Figure 5.11 shows electron micrographs of the characteristics of four important asbestos fibre types, namely chrysotile, crocidolite, amosite and anthophyllite. These images should be compared with those shown in Figure 5.10 to gauge the reliability of positive identification.

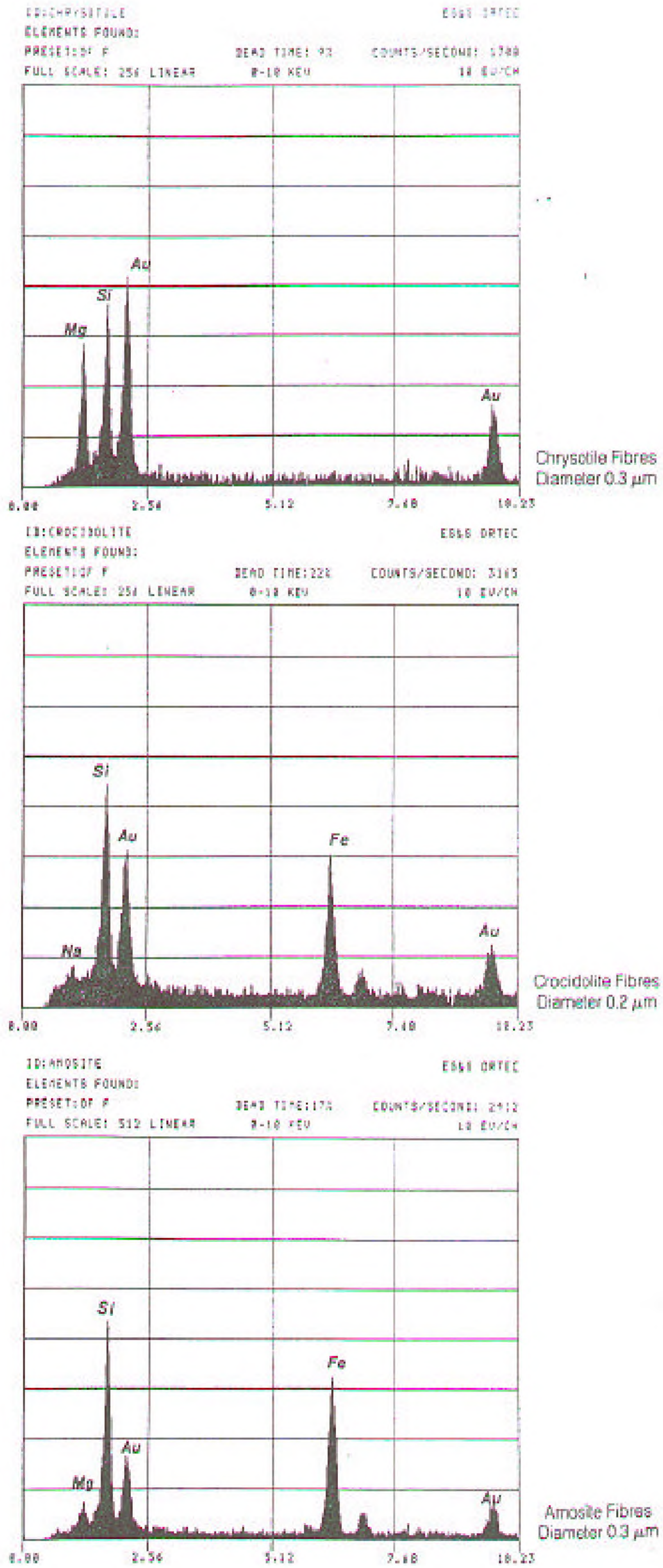


Figure 5.10: X-ray spectra of asbestos on gold-coated nuclepore filters

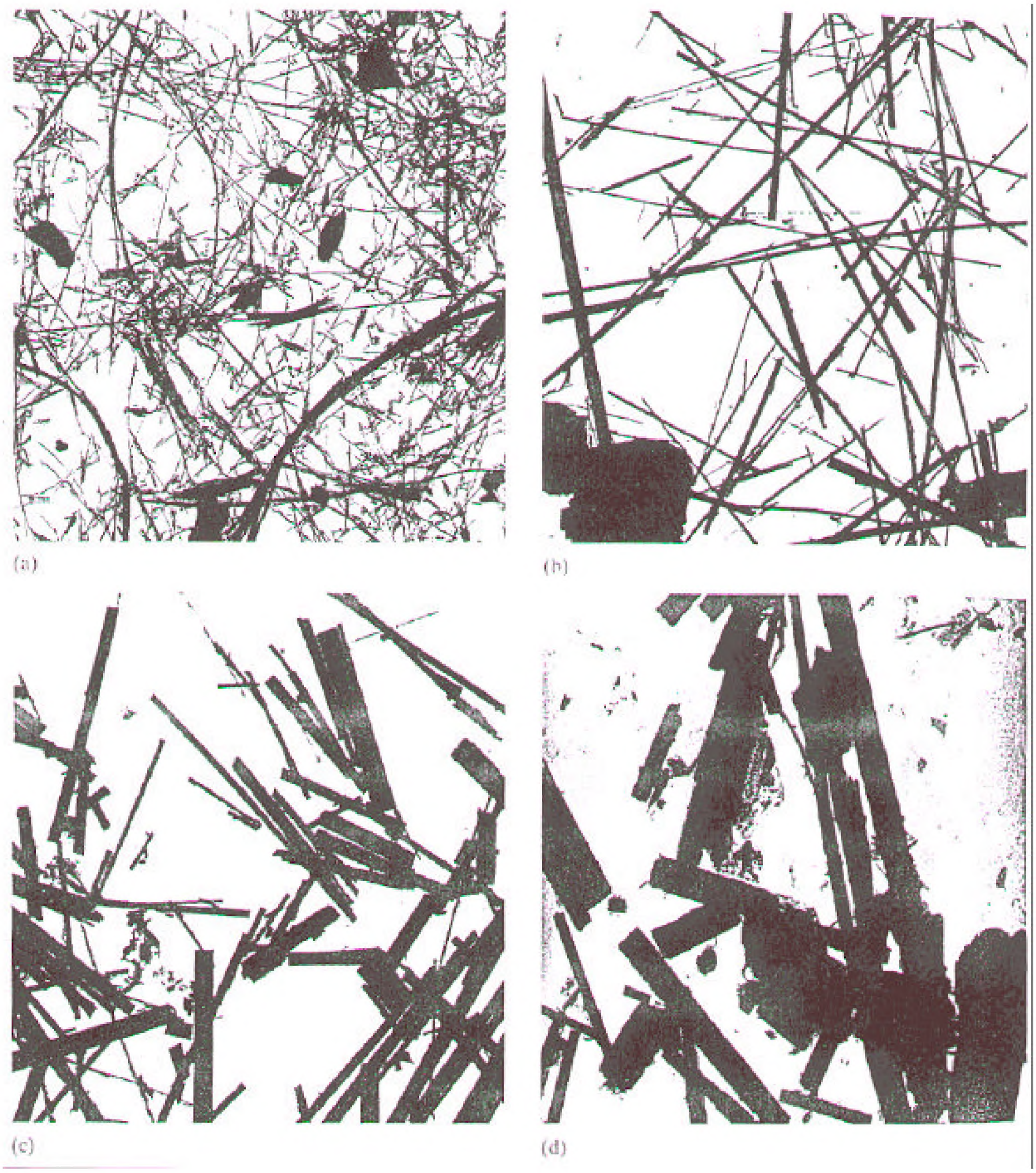


Figure 5.11: Electron micrographs showing the characteristics of four asbestos fibre types (a) chrysotile, (b) crocidolite, (c) amosite, and (d) anthophyllite (magnification x 4 500)

5.7 Sampling method

Sampling was undertaken as prescribed by the AIA and in accordance with RTM 1, using a sampling pump set to sample at a rate of 1,0 ℓ/min, drawing air through a 25-mm-diameter cellulose nitrate filter. The filter holders are open-ended, electrically conductive tubes in order to minimise fibre loss due to electrostatic attachment to the holder.

Figure 5.12 shows the layout of a typical sampling train as required by the AIA.

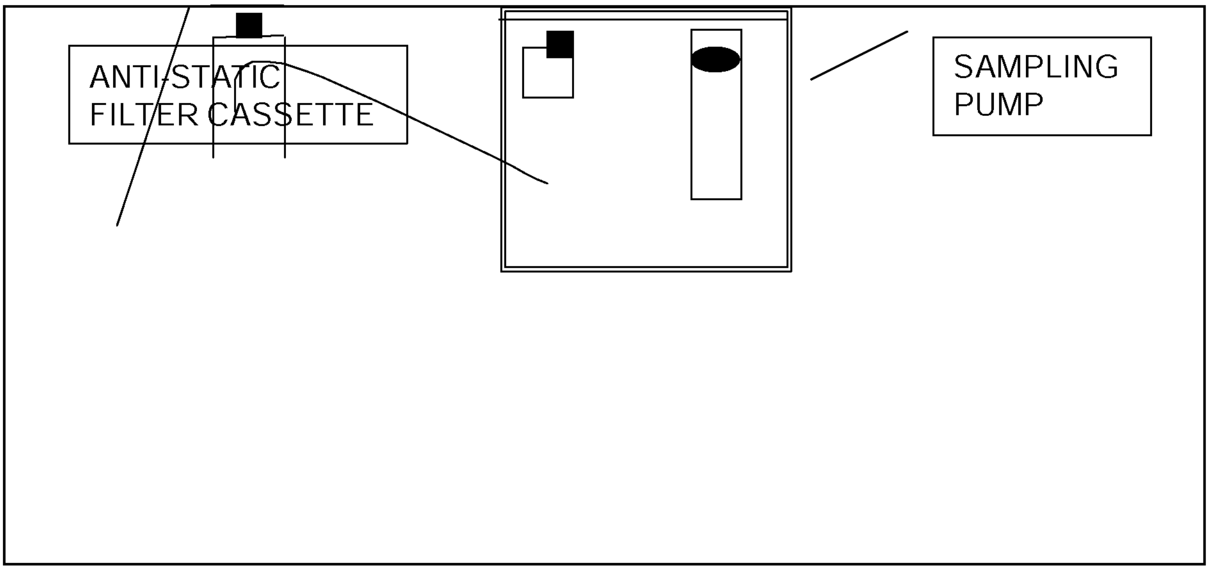


Figure 5.12: Schematic drawing of a sampling train for airborne asbestos fibres

RTM 1 prescribes that in the event of high dust concentrations, samples should be taken for only 10 minutes in every 60 minutes to eliminate the possibility of spoiled samples. High dust concentrations complicate the counting and identification of fibres.

Sampling pumps were placed in the intake and return airways of the workings. No samples were taken at the face where drilling operations took place due to high dust concentrations. All sampling pumps were set up as stationary monitoring stations. The aim of this study was to establish the presence of fibres in the working environment and personal exposure was not considered.

A typical underground sampling arrangement is shown in Figure 5.13.

Once the samples had been collected, they were returned to Miningtek's dust laboratory where they were stabilised before being prepared for fibre counting. After fibres had been counted, filters were selected for fibre identification processing.

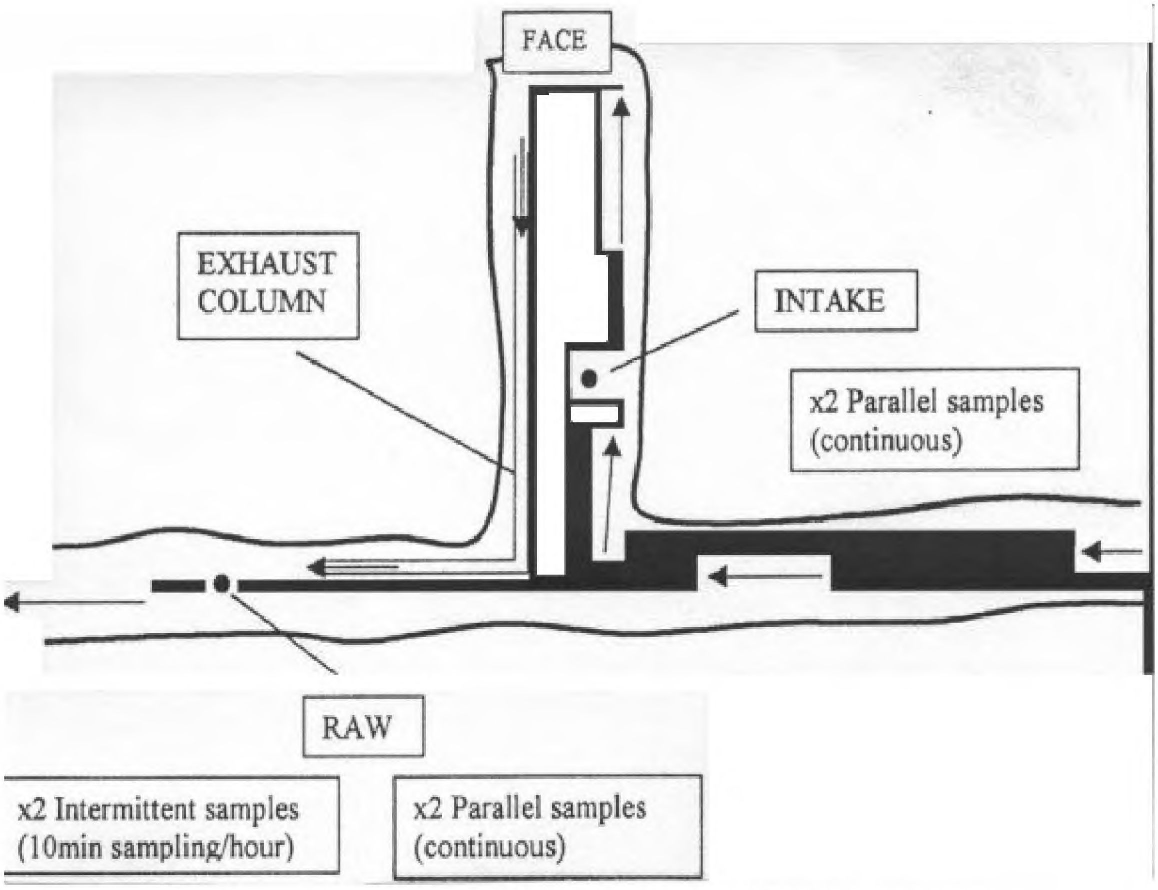


Figure 5.13: Typical underground sampling arrangement

6 Mine test sites

6.1 Mine 1

This is a diamond mine exploiting a kimberlite pipe deposit that intrudes Bushveld Complex rocks and is one of eleven known kimberlite occurrences in the area. Several 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 main shift.

Although most of the mining operations involve dry drilling, water is pumped to surface at a rate of 3300 kilolitres per day (0,4 t/t). The volume of air flow through the mine is 780 m^3/s.

The drilling methods applied 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 operations.

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

6.2 Mines 2 and 3

These mines are situated in the Beaufort Sediments, which are dyke-like bodies of kimberlite and are sometimes 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 example of a typical fissure drive is shown in Figure 1.3.

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 varies from underhand stoping to typical conventional open stoping. Examples of these are shown in Figure 1.4 and Figure 1.5.

6.3 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 kℓ/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. Although a reversal would introduce fresh air into the tunnel, it would also carry contaminated air to other parts of the workings and therefore it must be countered.

Two types of mining methods are practised:

- Sub-level caving as shown in Figure 1.2
- Block caving with long-hole drilling as shown in Figure 1.1.

6.4 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 amount of water pumped to surface is 3 900 k• /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 and is shown in Figure 5.1.

7 Results

This section deals with the results that were obtained during surveys. All participating mines gave the assurance that none of the sites sampled had been "staged" or 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 aim of the study was first to establish the presence of fibres, and then to identify the fibres found. The investigation into dry drilling was carried out simultaneously with this study.

As stated earlier in the report, the initial intention was to sample drilling operations. Later there was a request to extend sampling to other mining operations such as tipping and loading because of the high dust concentrations present during those operations. The feeling was that where there were higher dust concentrations, fibres might well also be present.

Sketches of all the test sites used at each mine are shown in Appendices A to E.

Although the mines were sampled in order from Mine 1 to Mine 5, results have been grouped differently. Results from the pipe deposits, Mines 1, 4 and 5, have been grouped together and those from the fissure deposits, Mines 2 and 3, have also been grouped together. This was done to facilitate the comparison of results from mining of the different types of deposits. A further separation of results was made between dry mining and wet mining operations at all test sites

7.1 Airborne fibre concentrations

7.1.1 Pipe deposits

7.1.1.1 Mine 1

In all, samples were collected at 11 different test sites including a tip. At all monitoring stations samples were collected in pairs and personal samples, continuous and intermittent, were collected together with konimeter and TP samples.

The results have been tabulated and those from completely dry activities have been separated from those where water was either used or was present. The results for each pair of samples have been averaged and are shown in Tables 7.1 and 7.1.1 and Figures 7.1 and 7.2. The fibre concentrations from the TP and konimeter samples were found to be an order of magnitude lower than those from asbestos sampling. The highest individual fibre concentration, 2,99 f/m•, was found at an intermittent sampling position during dry drilling operations.

The second-highest individual fibre concentration was 2,35 f/m• at a wet drilling operation. The individual high concentrations are not reflected in the figures because they were one of a pair of samples and the averages of the pairs of samples have been used in the comparisons. A point that must be noted is that although all the *average* fibre concentrations were less than 1 f/m•, there were individual concentrations that exceeded 2 f/m• and averages of pairs of samples (the recommended sampling method according to the AIA) that exceeded 1f/m•. The results also indicate that, irrespective of whether mining operations were wet or dry, the intermittent sampling method yielded higher average fibre concentrations than the other techniques. This type of result will impact on both sampling methods and exposure limits.

At dry mining sites, intake air samples measured with konimeters showed similar values to return air samples. The intake air samples collected as continuous samples actually showed higher values than the continuous return air samples, but the values were not as high as those from intermittent sampling.

Table 7.1

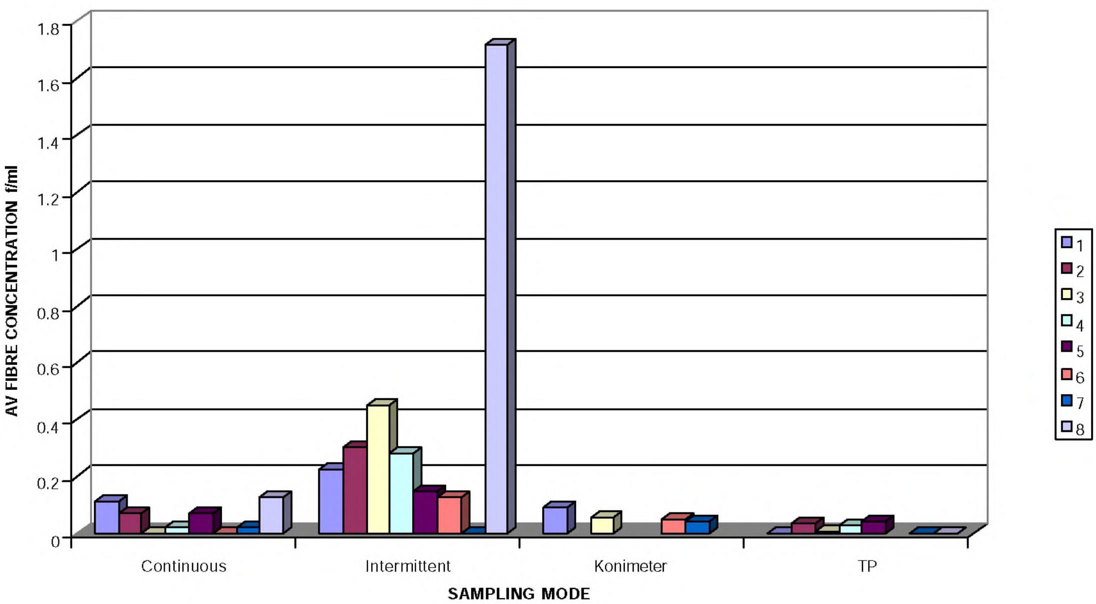
Fibre sampling results for Mine 1: pipe deposit

	Filter No.	**Konimeter samples Fibre conc. f/mℓ**	**Thermal precipatator Fibre conc. f/mℓ**
Site 10 Development drilling (on-board filtration)	576 PR20 572	0,10 0,07	 0,003
Site 9 Development drilling (on-board cassette)	PR30	-	0,035
Site 8 17 Level west Dry drilling	PR25 PR26 PR21	0,05 0,06	 0,008
Site 7 732 L Long-hole drilling	590	-	0,030
Site 6 Tunnel 55 north	599	-	0,039
Site 5 615 Level 55 tunnel	594	0,05	
Site 4 615 Level 38 tunnel	591 592	 0,04	0,001
Site 3 615 Level 38 tunnel	PR6	-	0,003
Site 2 C-cut 732 east access (wet drilling)	PR4 605 PR3	 0,35 0,12	0,030
Site 1 Cross-cut development West axis (wet drilling) Country rock	PR1	-	0,002

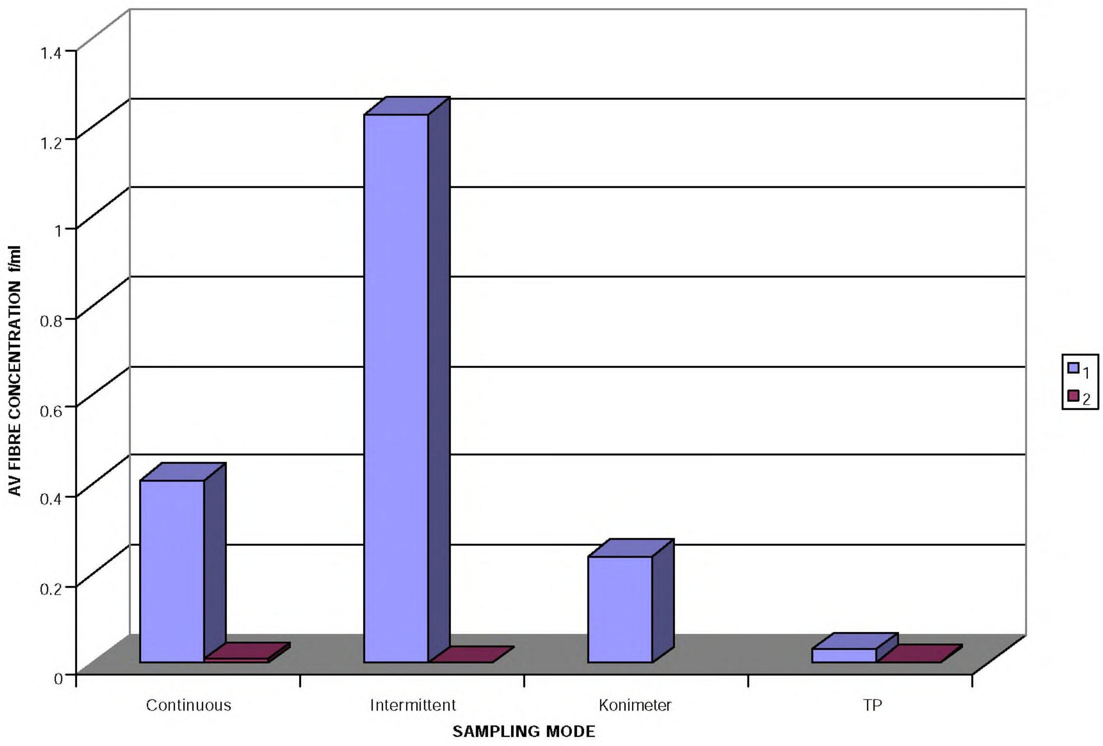
Table 7.1.1

Summary of fibre sampling results for Mine 1

Sampling position	Conc. f/mℓ
Dry intake	0,12
Dry konimeter intake	0,08
Dry return (cont.)	0,07
Dry return (intermit.)	0,41
Dry konimeter return	0,06
Dry tip return	0,02
Wet intake	0,03
Wet return (cont.)	0,14
Wet return (intermit.)	0,62
Wet konimet. return	0
Wet tip return	0,02



Mine 1 (dry)



At wet drilling operations the intake air fibre levels as determined by membrane filter sampling were only about 25 % of the intake air levels for dry operations and only approximately 20 % of the return air levels measured on a continuous basis. The intermittent return air samples were about 20 times higher than the intake samples and about 450 times higher than the results indicated by continuous sampling.

It is considered that intermittent sampling results are probably the most representative of conditions where airborne fibres are encountered. Under high-power magnification it was obvious that the background dust levels are very high, as can be expected from dry drilling operations, and can obscure the presence of a low fibre count. This is especially true where dry mining is practised. In many instances fibre counts could not be done at all and the results had to be reported as too contaminated for assessment. This does not mean that there were no fibres present, but only that the high background dust levels obscured any fibres present. Alternatively, any fibres present may not have fitted the definition of a "regulated fibre" and were ignored. In other cases the background dust level was so high and rendered the sample unusable from a fibre analysis aspect but not from a dust concentration point of view. In this report only usable results are reported.

At this particular mine, no usable results were obtained from the return air sampling position at a tip and some samples were too contaminated to analyse for identification.

7.1.1.2 Mine 4

As stated previously, this was also a pipe deposit mine. Only one wet operating site was monitored and the only meaningful result was obtained from the pair of continuous monitors at the return air position – 0,2 f/m• average. Individual fibre concentrations were found to exceed 1 f/m• at three sites, two of which occurred in intermittent samples and one in a continuous sample in a return air position.

Results are depicted in Tables 7.2 and 7.2.1 and in Figure 7.3. When judged against the intake conditions monitored on a continuous basis, namely 0,04 f/m•, an increase in fibre concentrations was detected in the return air position – 0,13 f/m• for continuous monitoring and 0,46 f/m• for intermittent samples. Once again results for the konimeter and TP samples collected in the return air were considerably lower than for the return air samples collected in other modes.

The highest individual fibre concentration was measured as an intermittent sample in the return air, with a level of 4,87 f/m• being recorded. The second-highest individual fibre concentration, namely 1,4 f/m•, was recorded from a continuous return air sample and the third-highest concentration, 1,25 f/m•, was recorded from an intermittent return air sample.

Measurements from this mine continued the trend of intermittent sampling results being higher than continuous sampling results in return air positions. The reasons for this were discussed above.

The results of sampling at a crushing plant and ramp fan show very low fibre concentrations.

7.1.1.3 Mine 5

This was the last pipe deposit mine that was sampled for airborne fibres.

Results of the sampling at Mine 5 are set out in Tables 7.3 and 7.3.1 and are summarised pictorially in Figures 7.4 and 7.5.

With regard to the dry mining operations, the average intermittent sampling result of 0,57 f/mℓ was almost twice as high as the average result obtained for continuous return air sampling (0,29 f/mℓ). The average dry intake air fibre concentration of 0,1 f/mℓ was higher than for the other two pipe deposit operations. The highest individual fibre concentration was measured from an intermittent return air sample and was determined as 3,29 f/mℓ. This concentration was, however, exceeded by one sample collected in the upcast shaft. It was also an intermittent sample and the concentration was found to be 5,2 f/mℓ.

Table 7.2

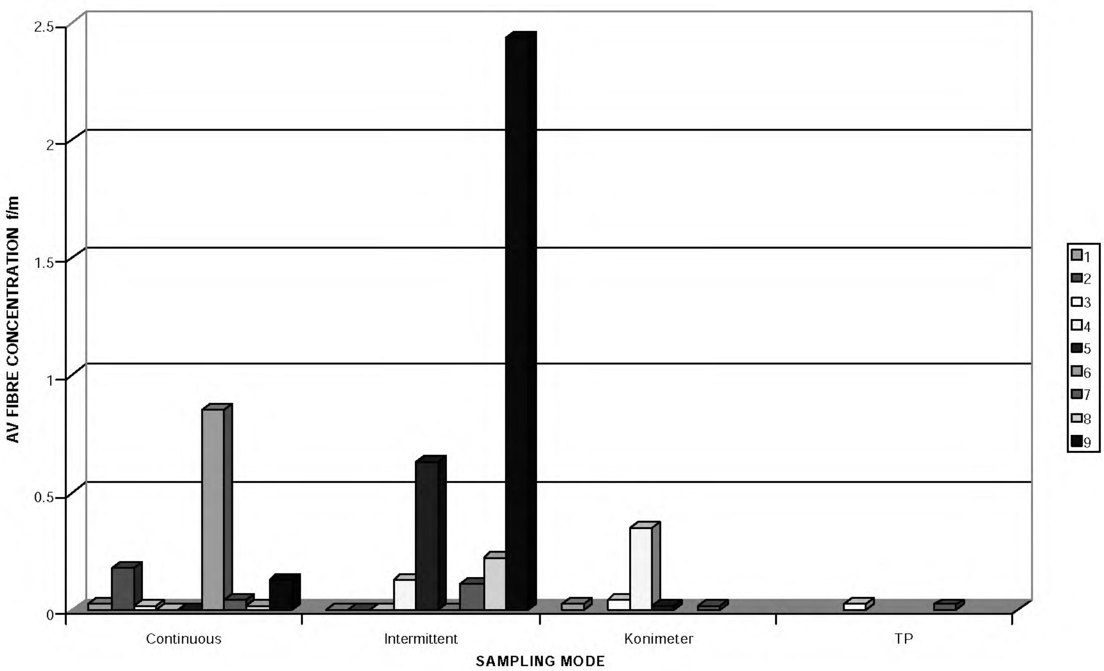
Fibre sampling results for Mine 4: pipe deposit

	Filter No.	**Konimeter samples Fibre conc. f/mℓ**	**Thermal precipitator Fibre conc. f/mℓ**
48 Level Tunnel 13	KF3	0,03	-
48 Level, Tunnel 11 Development drilling (dry)	LF8	-	0,030
48 Level, Tunnel 9 Development drilling (dry)	KF11	0,35	-
48 Level, Tunnel 29 Long-hole drilling (down)	KF40	0,02	-
37 Level, Tunnel 6 Dry drilling (Up holes)	KF20	-	0,022
Crushing plant	KF22	-	0,003
29 Level, Ramp fan Station	KF49	-	0,008

Table 7.2.1

Summary of fibre sampling results for Mine 4

Sampling position	Conc. f/mℓ
Dry intake	0,04
Dry return (cont.)	0,13
Dry return (intermit.)	0,44
Dry konimeter return	0,09
Dry tip return	0,03
Wet intake	0,00
Wet return (cont.)	0,35
Wet return (intermit.)	0,00



Mine 4 (dry)

Table 7.3

Fibre sampling results for Mine 5: pipe deposit

	Filter No.	Konimeter samples Fibre conc. f/mℓ	Thermal precipitator Fibre conc. f/mℓ
Site 1A Long-hole drilling	KF57 KF69	-	0,025 0,022
Site 3 No. 9 drill drive	1KF22	-	0,009
RAW RAW hand-held drilling	1KF2 1KF20	-	0,011 0,005
RAW percussion drilling	1KG18	-	0,000
No. 8 ground pass Wet drilling (dolomite)	1KF59	-	0,003

Table 7.3.1

Summary of fibre sampling results for Mine 5

Sampling position	Conc. f/mℓ
Dry intake	0,10
Dry return (cont.)	0,29
Dry return (intermit.)	0,57
Dry return (TP)	0,012
Dry konimeter return	0,09
Wet intake	0,04
Wet return (cont.)	0,20
Wet return (intermit.)	0,04
Wet return (TP)	0,003
Tips	0,14
Downcast shaft	0,00
Main intake	0,02
Upcast shaft	2,82
Main return	0,43

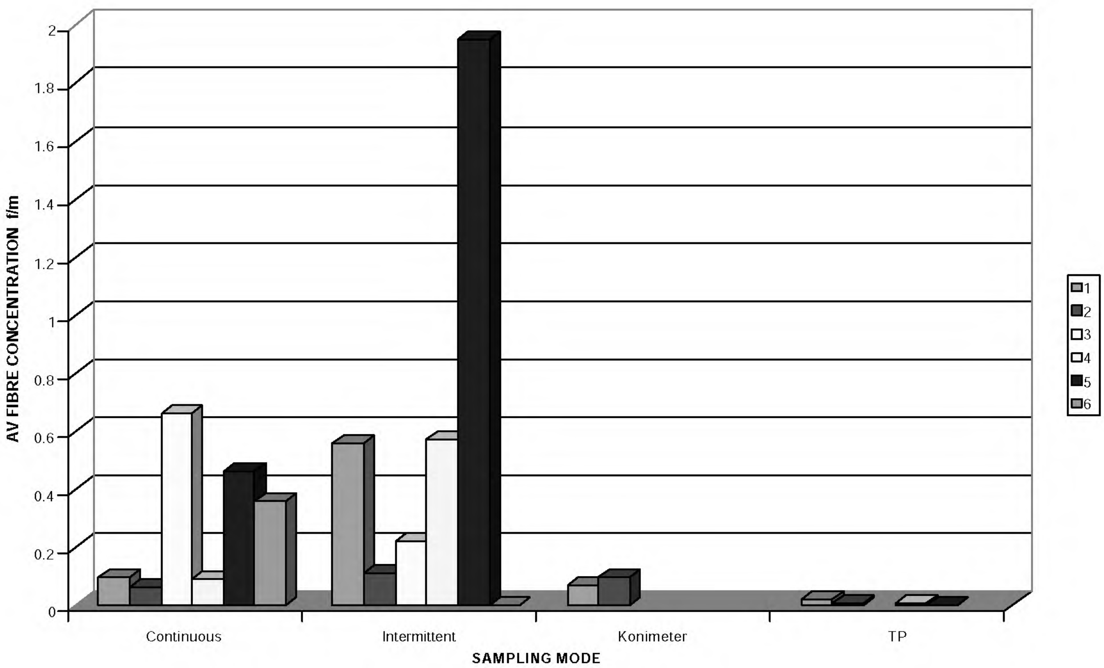
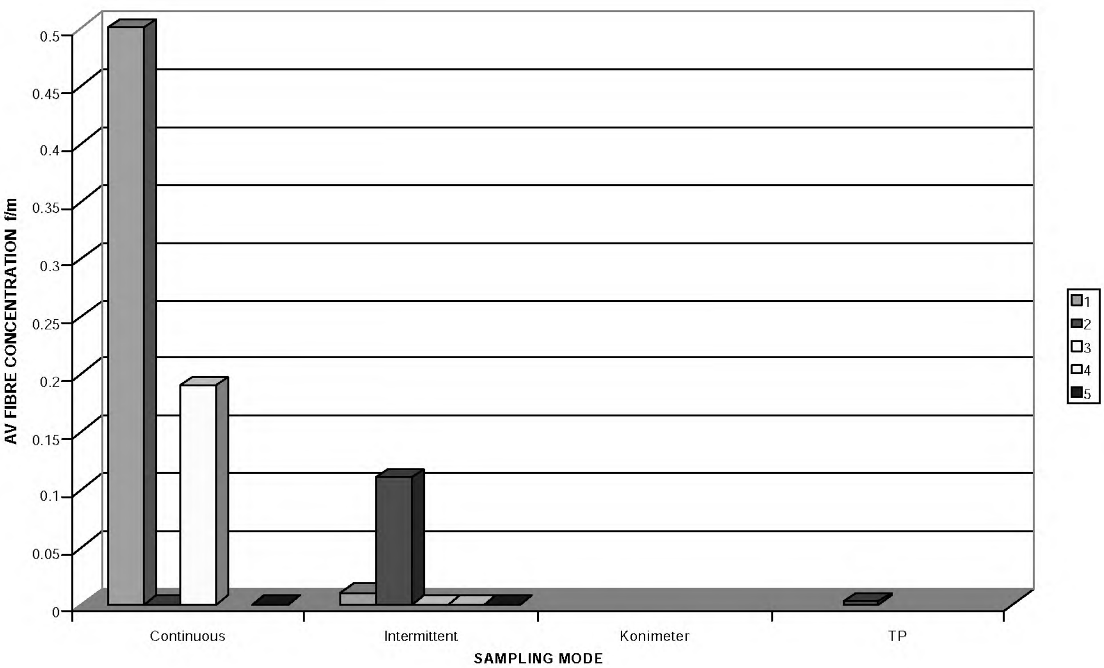


Figure 7.4: Comparison of sampling results for different techniques - Mine 5 (dry)



As far as the wet mining results (basically in country rock) are concerned, the continuous return air sampling results were five times higher than those found for the intermittent samples, i.e. 0,2 f/m• compared with 0,04 f/m•. This is considered to be due to the fact that with wet drilling operations the general level of background dust was lower than for dry drilling operations and therefore the obscuring effect was reduced considerably, thereby increasing the visibility of airborne fibres in the counting field. This was probably the case for the filters that could be assessed, but examination of Table 7.3 shows that several samples were too contaminated for meaningful assessment. For this reason, not too much should be read into the apparent anomaly in these results.

At Mine 5, in addition to workplace samples, samples were also collected at tips, in the downcast and upcast shafts and in the main intake and return airways. As could be anticipated, the downcast shaft (0 f/m•) and main intake air sampling results (0,02 f/m•) yielded very low airborne fibre concentrations.

The airborne fibre concentrations at tips were comparable to the return air sampling results at workplaces. Also, as anticipated, if fibres are liberated during mining operations, airborne fibre concentrations at main returns and in the upcast shaft will be higher than those in intake routes. In fact, as already discussed, the airborne fibre concentrations in the upcast shaft were the highest encountered at the mine, as shown, during this investigation.

The konimeter and TP samples again showed the lowest results for the different sampling modes.

7.1.2 Fissure deposits

7.1.2.1 Mine 2

Mining operations were conducted completely dry in the fissure stopes. Reduction in dust levels was almost entirely dependent on dilution through unreliable natural ventilation pressure. Ventilation of the workings, and thus dust dilution, was dependent on ambient air conditions which could alter the effective air density, resulting in air flowing in alternating directions and not effecting dilution or removing airborne pollutants.

The results of the airborne fibre measurements are shown in Table 7.4 and Figures 7.6 and 7.7. These results indicate that the average airborne fibre levels were higher than those found in the pipe deposit mines. The highest individual fibre concentration measured was 3,59 f/mℓ. This was an intermittent sample collected in a stope where fissure water had substantially wetted the workings. An examination of Table 7.4 will show that statistics were greatly influenced by the number of contaminated samples in the results. Since values could not be assigned to contaminated results, they were omitted from any statistical determinations.

As was found in the three mines already discussed, the intermittent sampling results show higher values than the other sampling modes. This was found to be the case for both dry and wet mining operations. The konimeter and TP sampling results continued to return lower results than either of the two sampling modes.

Although individual pairs of samples for dry operations were noticeably higher than for wet operations, the overall wet operation sampling averages for airborne fibre concentrations were higher than for dry mining operations. The reasons for this have already been discussed.

Table 7.4

Fibre sampling results for Mine 2: fissure deposit

	Filter No.	**Konimeter samples Fibre conc. f/mℓ**	**Thermal precipitator Fibre conc. f/mℓ**
16 Level, Rock drilling north, dolerite (wet)	SK16 SK 17	 0,009	0,008
16 Level, Fissure drilling, north (dry)	SK19 SK18	 0,04	0,008
17 Level, north drilling (dry) (wet kimberlite)	SK9	0,04	-
18 Level, Stope	SK28 SK27	 0,05	0,000
17 Level, Stope Fissure water in stope	SK31	-	0,010
18 Level, Development south Wet drilling	SK41	-	0,022

Table 7.4.1

Summary of fibre sampling results for Mine 2

Sampling position	Conc. f/mℓ
Dry intake	0,02
Dry return (cont.)	0,19
Dry return (intermit.)	0,66
Dry konimeter return	0,04
Dry tip return	0,004
Wet intake	0,14
Wet return (cont.)	0,40
Wet return (intermit.)	0,77
Wet konimet. return	0,005
Wet tip return	0,014

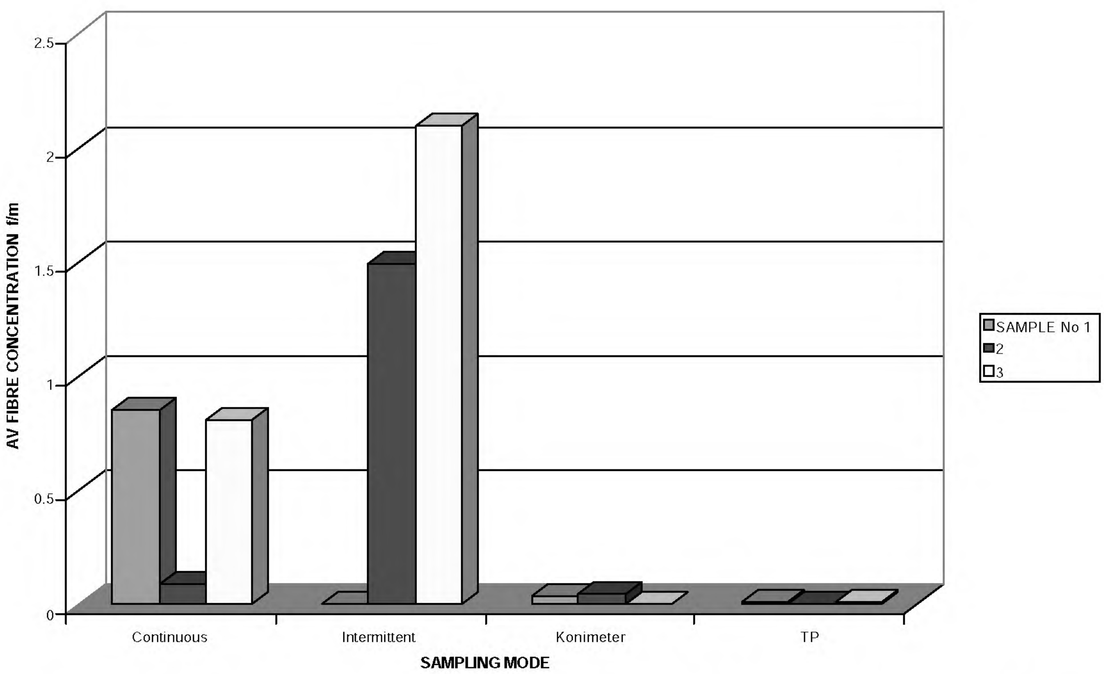


Figure 7.6: Comparison of results for different techniques - Mine 2 (dry)

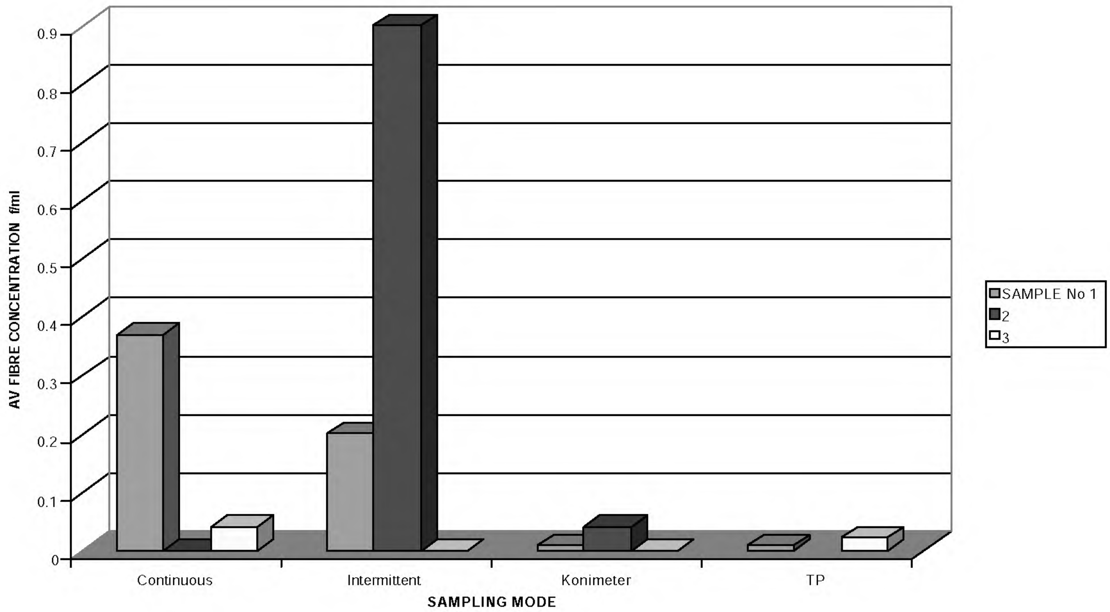


Figure 7.7: Comparison of results for different techniques - Mine 2 (wet)

7.1.2.2 Mine 3

This was the second fissure deposit mine at which monitoring for airborne fibre was conducted. No wet operations were monitored. Once again, intermittent sampling results yielded the highest fibre concentrations and konimeter and TP samples displayed the lowest fibre concentrations. The highest individual airborne fibre concentration was measured at 1,63 f/m•for an intermittent sample. As in previous results, the true statistics are obscured by a number of contaminated samples and other samples that were unusable. The results for this mine have been tabulated in Tables 7.5 and 7.5.1 and are shown pictorially in Figure 7.8.

7.2 Overall sampling results

The average intake and return air fibre concentrations, for both wet and dry conditions and for both continuous and intermittent samples, were summarised and are presented graphically in Figure 7.9. The results for the intermittent sampling mode are clearly higher than those for the continuous mode owing to the reasons already discussed. It is also apparent that the return air sample fibre concentrations, especially those from the intermittent samples, are at a higher level than the intake air concentrations. This indicates and confirms the release of airborne fibres into the atmosphere during mining operations. It is not always obvious whether return air fibre concentrations were found to be higher at dry drilling sites or at wet drilling sites. This comparison is difficult to make because the use of water would control pollutant levels and make the assessment of fibre levels easier since the background dust levels would be lower.

A comparison of the average intake and return air fibre concentrations for wet and dry conditions is shown in Figure 7.10. The general trend indicates higher fibre concentrations for return air samples. In turn, this implies the release of asbestiform fibres into the working environment during mining operations.

Return air fibre concentrations in fissure mines were found to be much higher than intake air fibre concentrations, irrespective of whether water was present or not. It is also clear that the average fibre concentrations, regardless of the sampling mode, were much lower than the present allowable concentration of 2 f/m • for asbestiform fibres.

A comparison of the average fibre concentrations for continuous and intermittent samples for both wet and dry operations for all mines monitored is presented in Figure 7.11. Although too few points are available to establish a mathematical relationship, the figure does confirm that intermittent sampling results were found to be higher than continuous sampling results.

7.3 Fibre identification

As has been noted by the AIA, optical methods are a good means for fibre counting but are less ideal techniques for fibre identification. Referring to Figure 5.10, it can be seen that identification of the different asbestos fibres can be extremely difficult, especially by inexperienced or not fully qualified Technicians. Micrographs in Figure 5.11 illustrate how chemical fingerprints of fibres can assist with the process and improve the reliability of fibre identification and analyses. Figures 7.12 to 7.22 show SEM images of a series of filters analysed for fibre identification. The images show varying degrees of particle density and different types of fibres. It is obvious that the sampling technique is most important to ensure that filters are not overloaded, thereby presenting too dense a background which will obscure the presence of any fibres. However, in many cases the background loadings will not be known or cannot be accurately estimated, so that it is difficult to decide what would be the correct sampling technique to use.

Table 7.5

Fibre sampling results for Mine 3: fissure deposit

	Filter No.	**Konimeter samples Fibre conc. f/mℓ**	**Thermal precipitator Fibre conc. f/mℓ**
10 east stoop 10 Level development	PR53	-	0,004
Dry drilling	PR56	0,22	0,013
12 West 7 cross-cut Dry drilling (dolerite)	PR59	-	0,016
11 West 7 cross-cut Dry drilling (dolerite)	PR61 PR62	 0,20	0,004
10 Level development west Drilling (dry) (shale)	PR65	-	0,013
11 Level 3 cross-cut raise Drilling (dry) (shale)	PR48 PR69	 0,05	0,003
11 Level east 3 cross-cut Drilling (dry) (shale)	PR71 PR70	 0,03	0,001
10 Level 10 east development Drilling (dry) (dolerite)	PR51 PR74	 0,13	0,016

Table 7.5.1

Summary of fibre sampling results for Mine 3

Sampling position	Conc. f/mℓ
Dry intake	0,04
Dry return (cont.)	0,08
Dry return (intermit.)	0,37
Dry konimeter return	0,07
Dry tip return	0,008

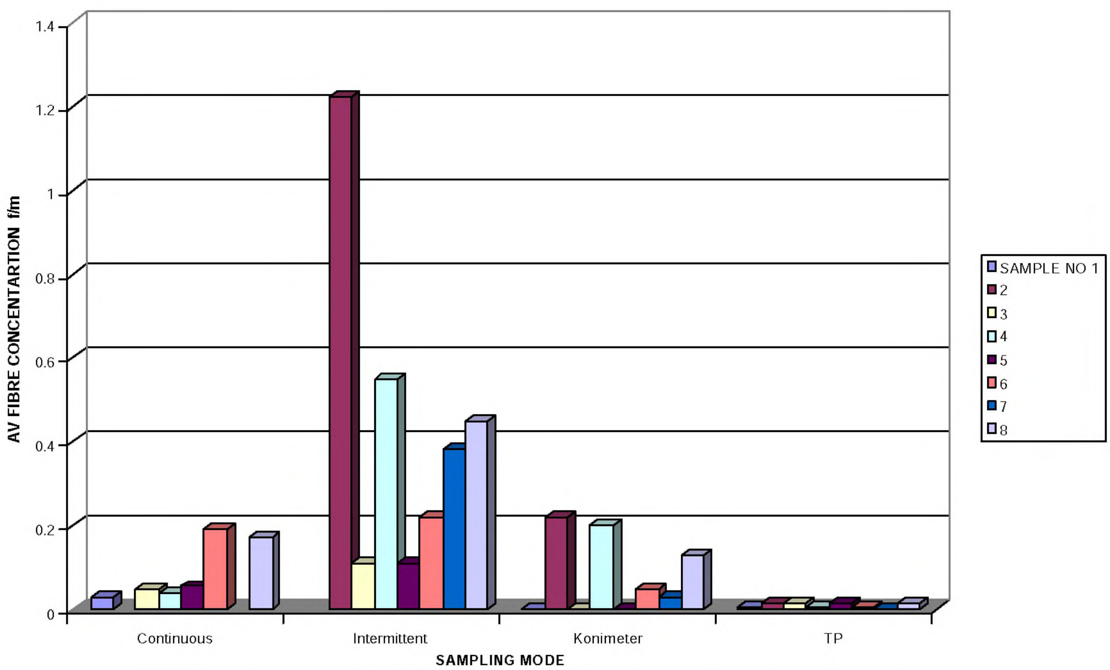


Figure 7.8: Comparison of results for different techniques - Mine 3 (dry)

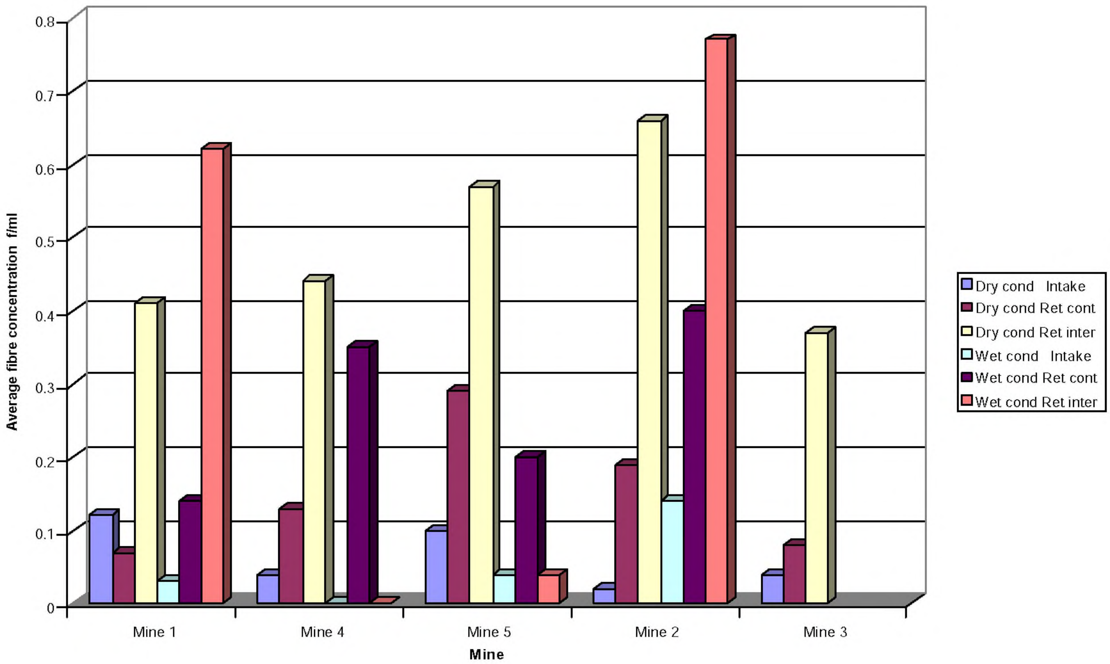


Figure 7.9: Comparison of average fibre concentrations for all mines

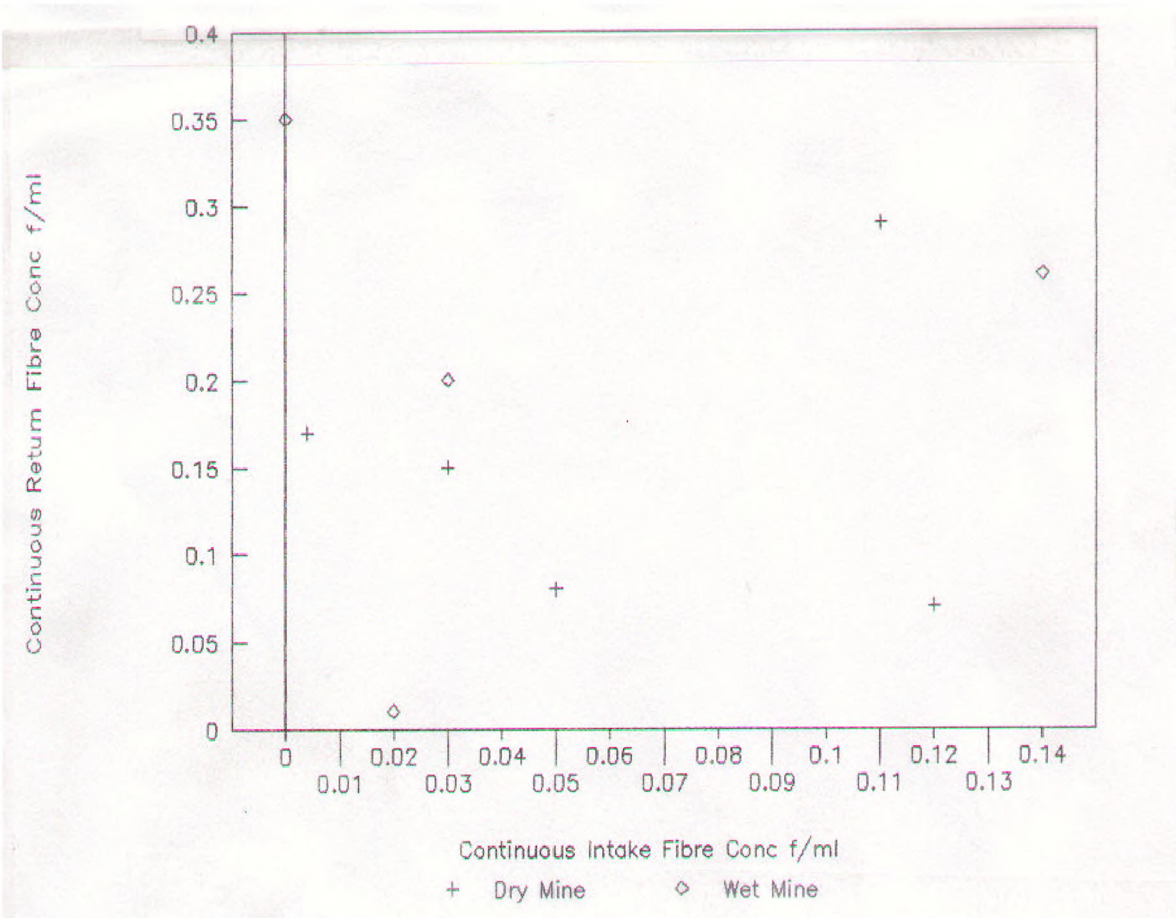


Figure 7.10: Comparison of average intake and return fibre concentrations

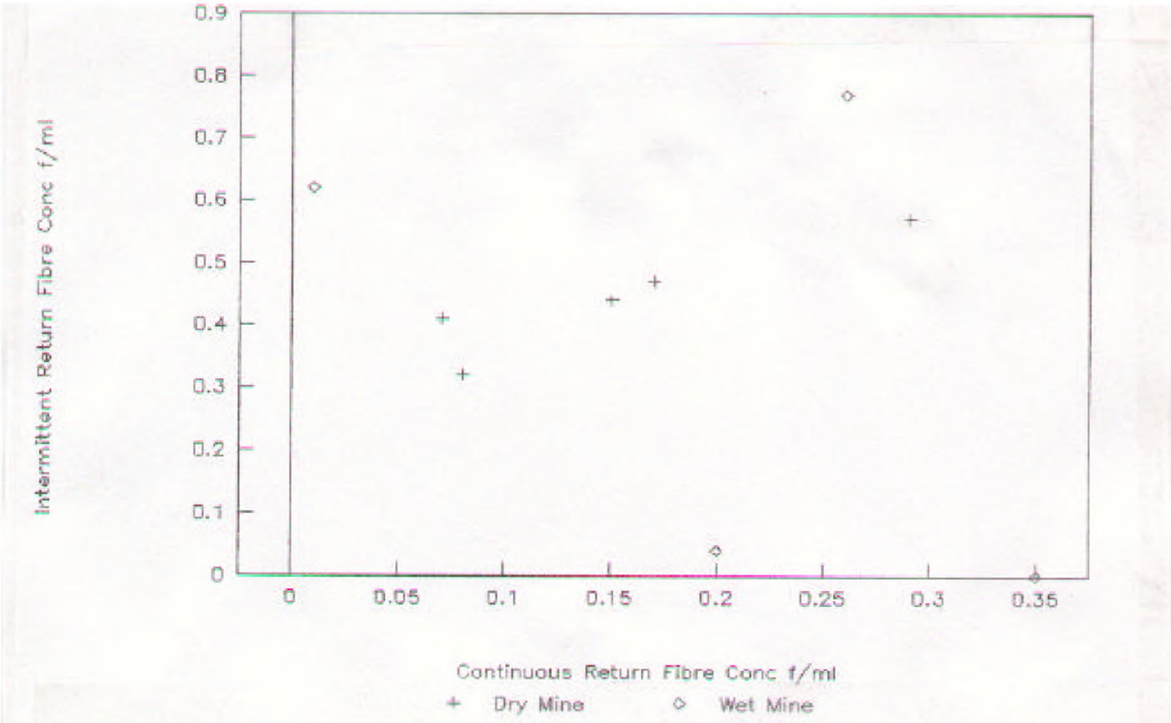


Figure 7. 11: Comparison of average continuous and intermittent fibre concentrations

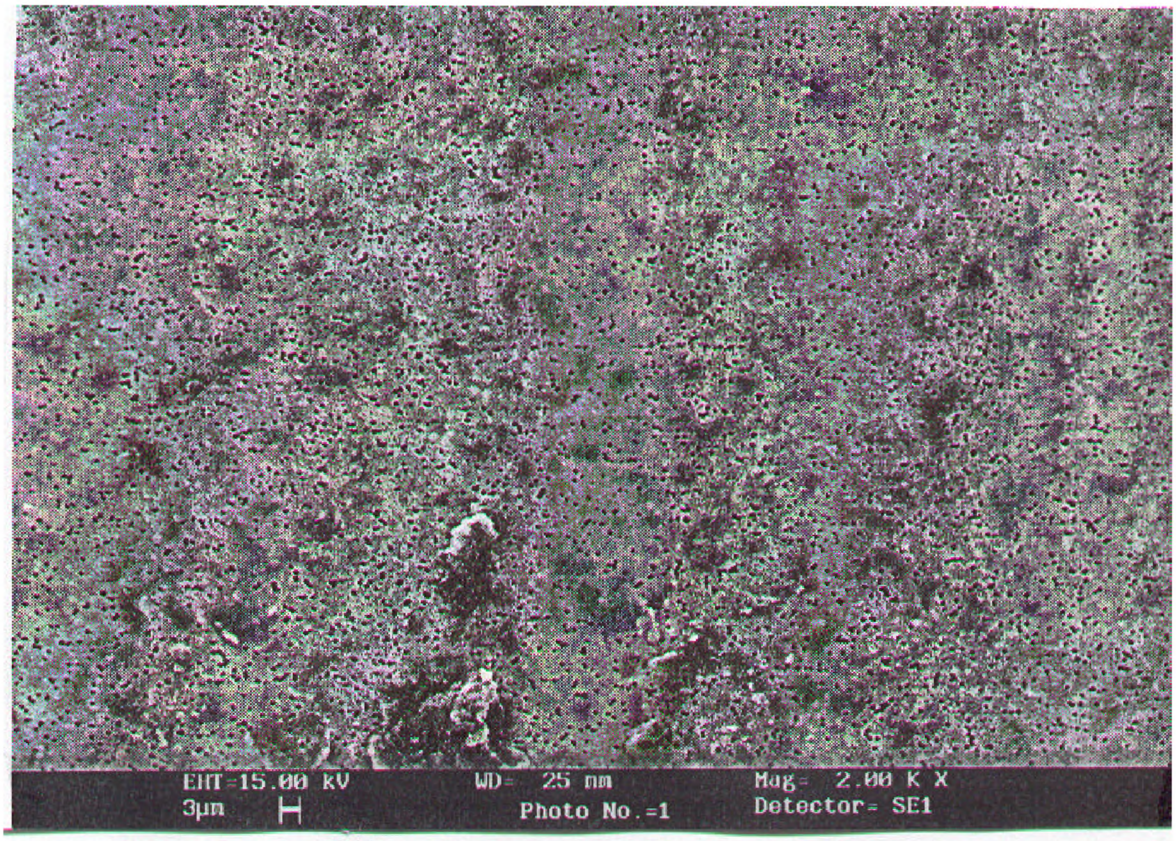


Figure 7.12: SEM image of sample KF2

Note: The low density of trapped particles is seen. The tiny black dots represent porosity of the filter.

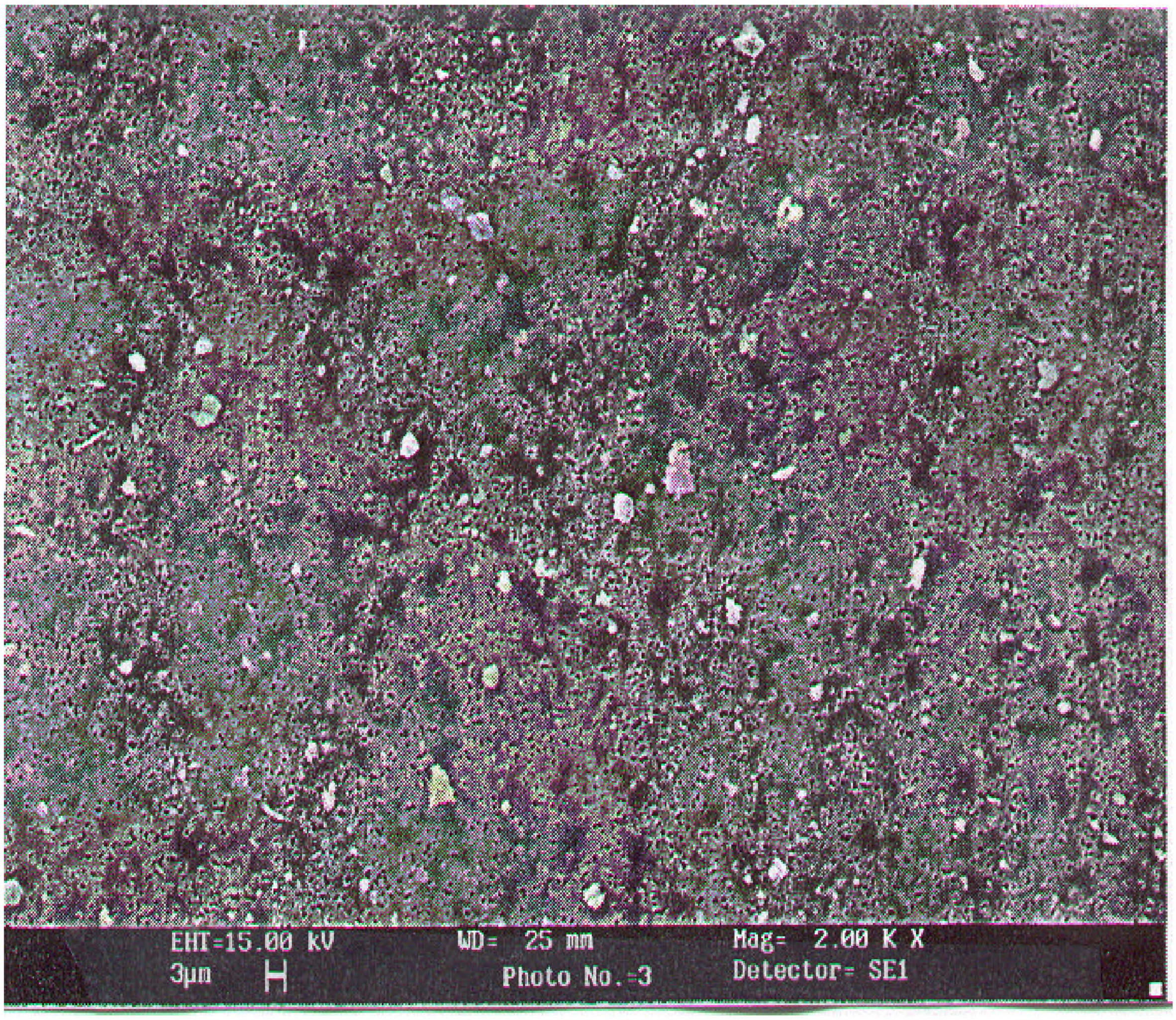
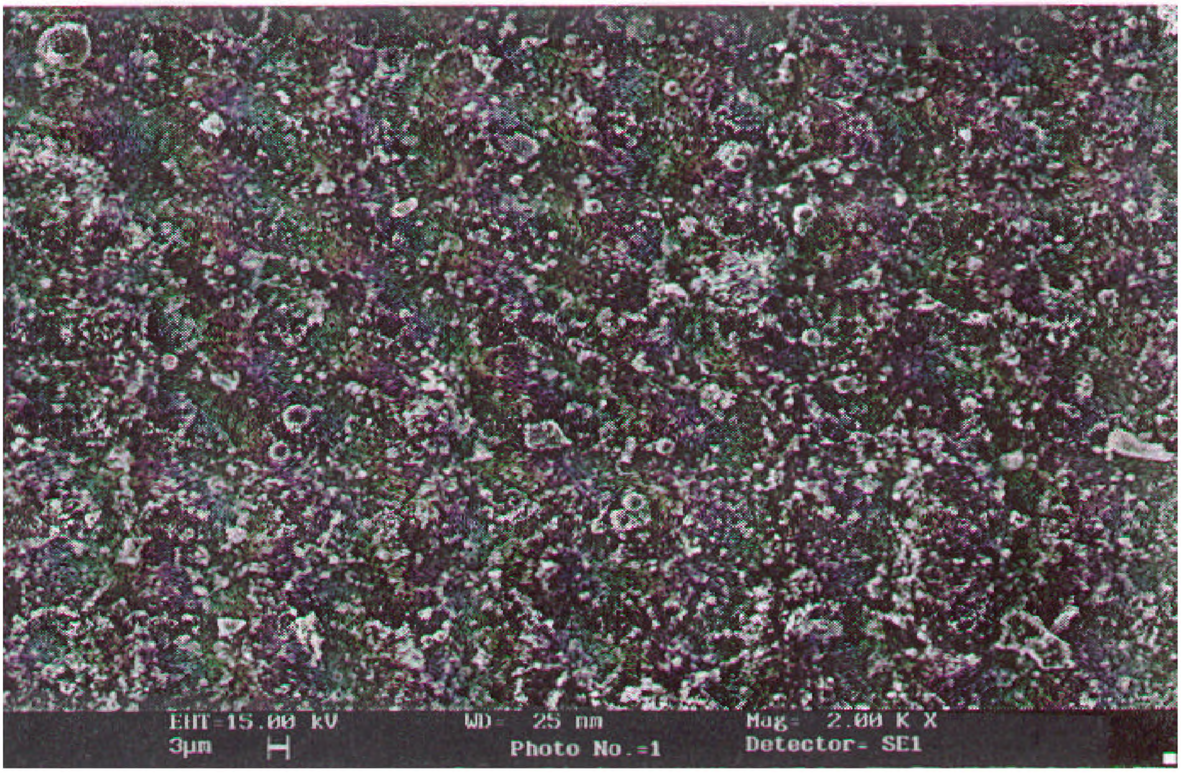
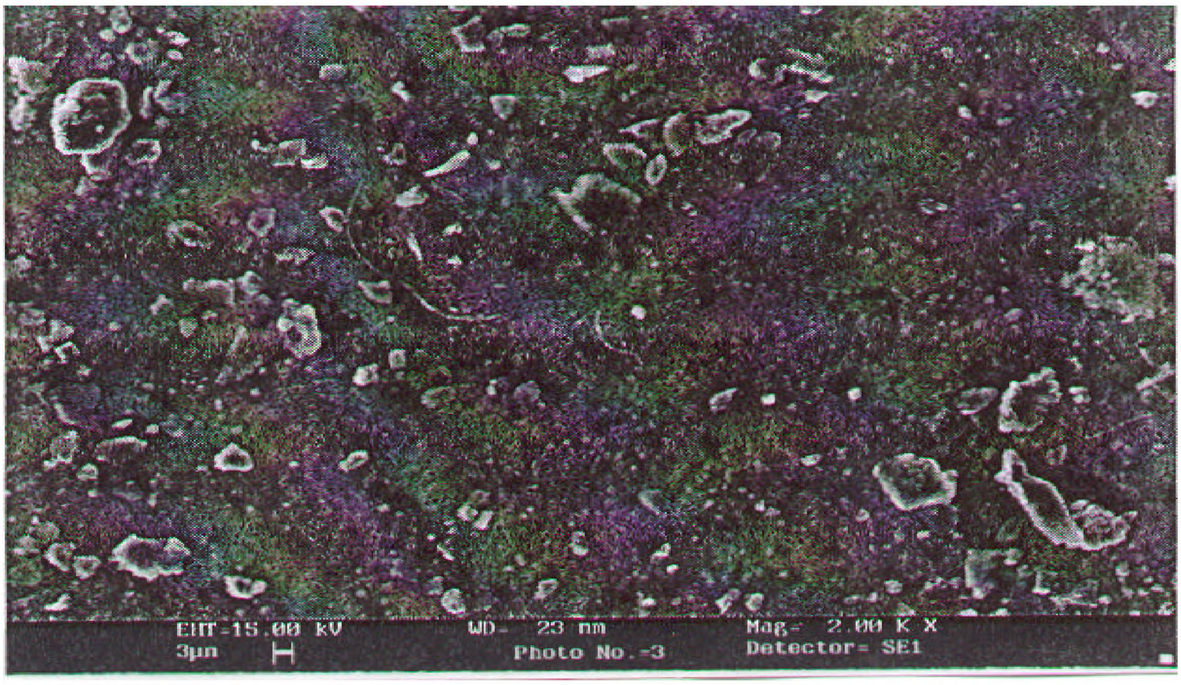


Figure 7.13: SEM image illustrating the sample loading for filter KF3

Note: Scattered particle loading with an even distribution can be seen, indicating a good sampling rate and technique. The fibres noted have been tabulated. No asbestos fibres were identified.



Note: The small round objects are pollen, possibly from grass seeds. Only three particles, which met fibre definition were noted, but these consist of iron oxide. The dense cover of dust particles may indicate that the sampling period was too long.



Note: The distribution of particles is seen and the thin fibres in the centre and left of centre are chrysotile (field 51).

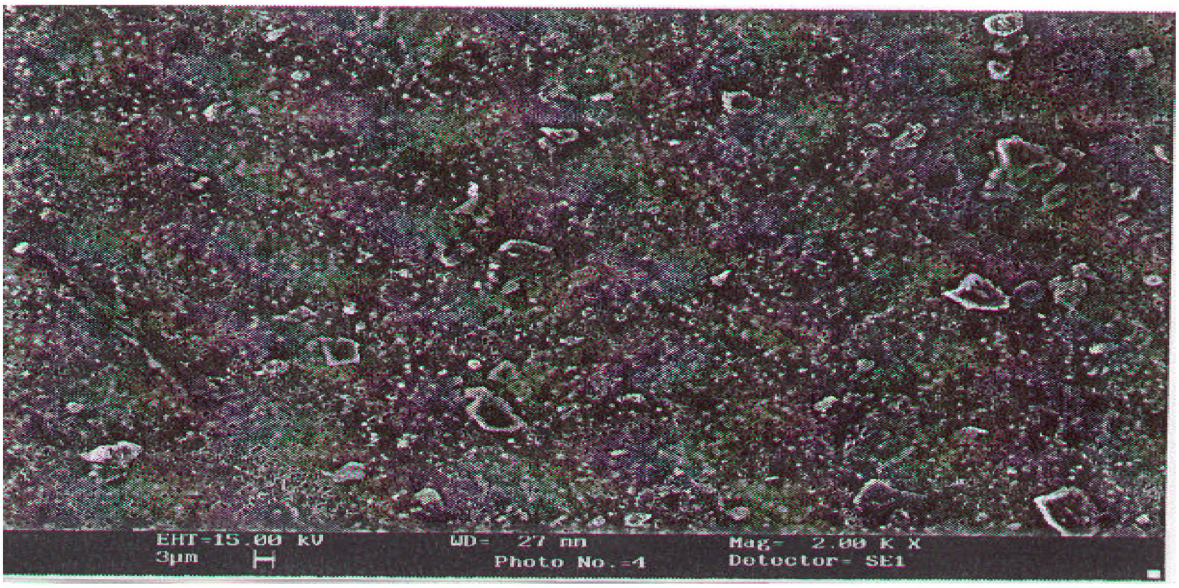


Figure 7.16: SEM image of particle distribution on filter KF23

Note: The fibre on the left is an anthropyllite fibre.

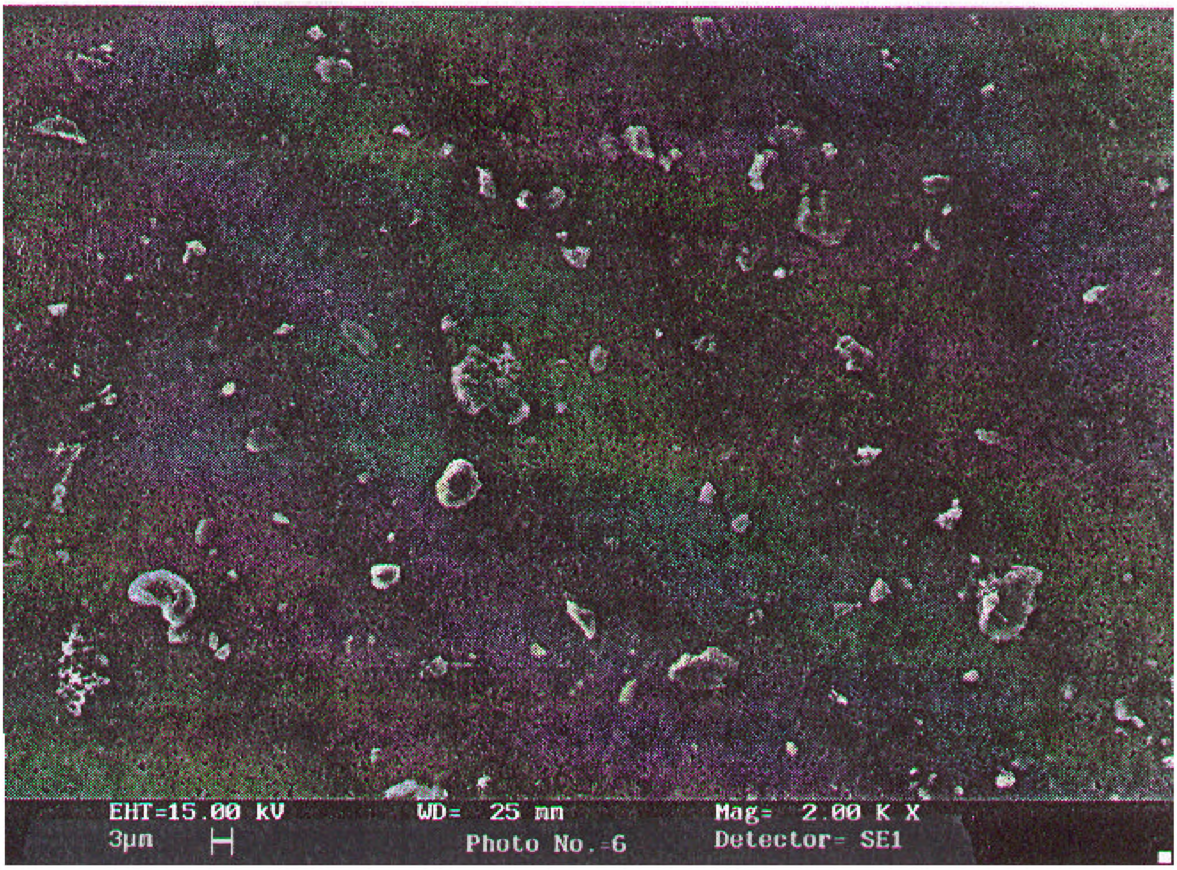


Figure 7.17: SEM image of scattered particles together with organic fibres as noted on filter KF43

Note: The distribution of particles is seen and the thin fibres in the centre and left of centre are chrysotile (field 51).

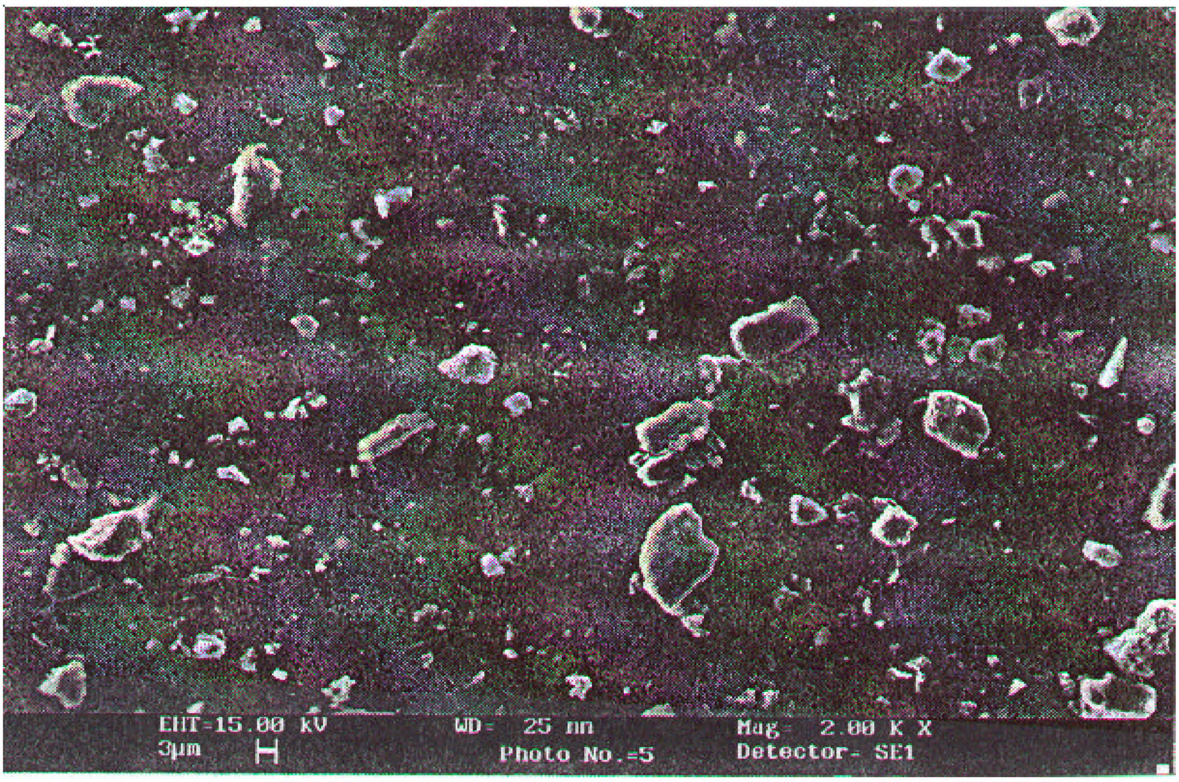


Figure 7.18: SEM image showing typical particle distribution on filter KF55 at 200 x magnification

Note: Thin chrysotile fibres are seen left of centre and directly below towards the base of the image. An uneven but not very dense particle loading can be seen. Organic material is present in small amounts. Chrysotile fibres are present in small amounts and seem to have broken up into numerous small fibres. Very small, thin fibres are visible in all fields under high magnification.

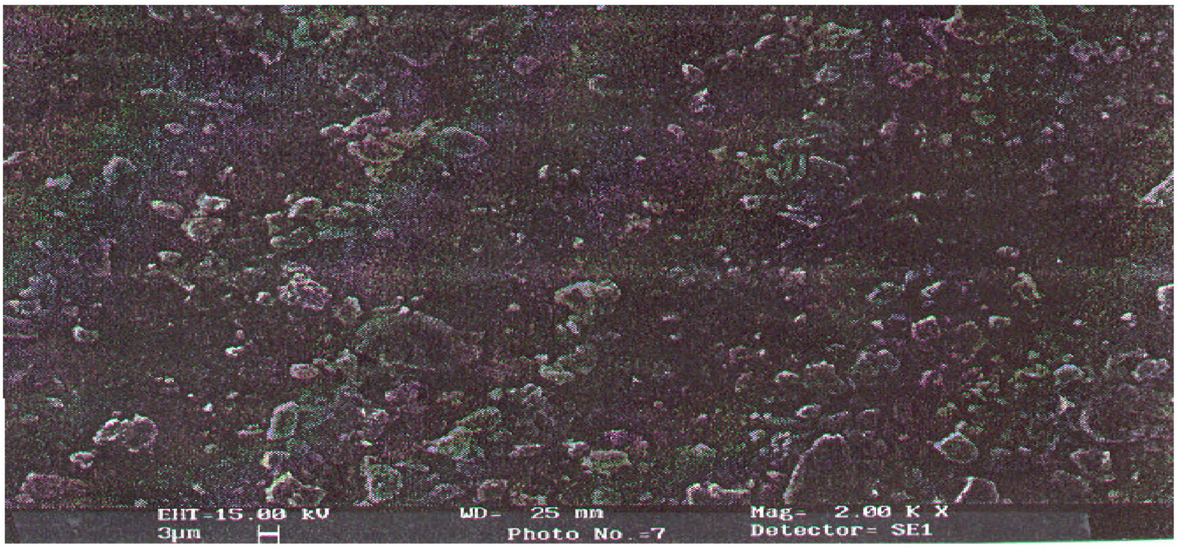


Figure 7.19: SEM image showing moderately dense loading of particles for filter IKF15

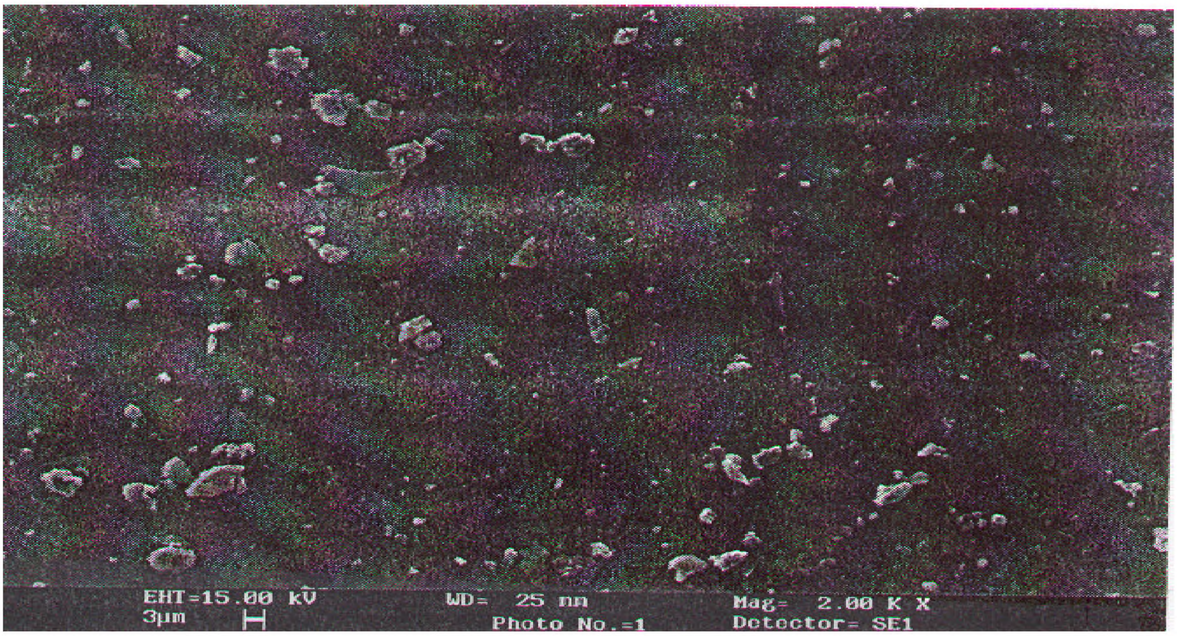


Figure 7.20: SEM image of sample IKF30 illustrating the loading on the filter

Note: The loading is not dense. Only a few countable fibres were noted but fibrous particles with a length < 5 μm are present.

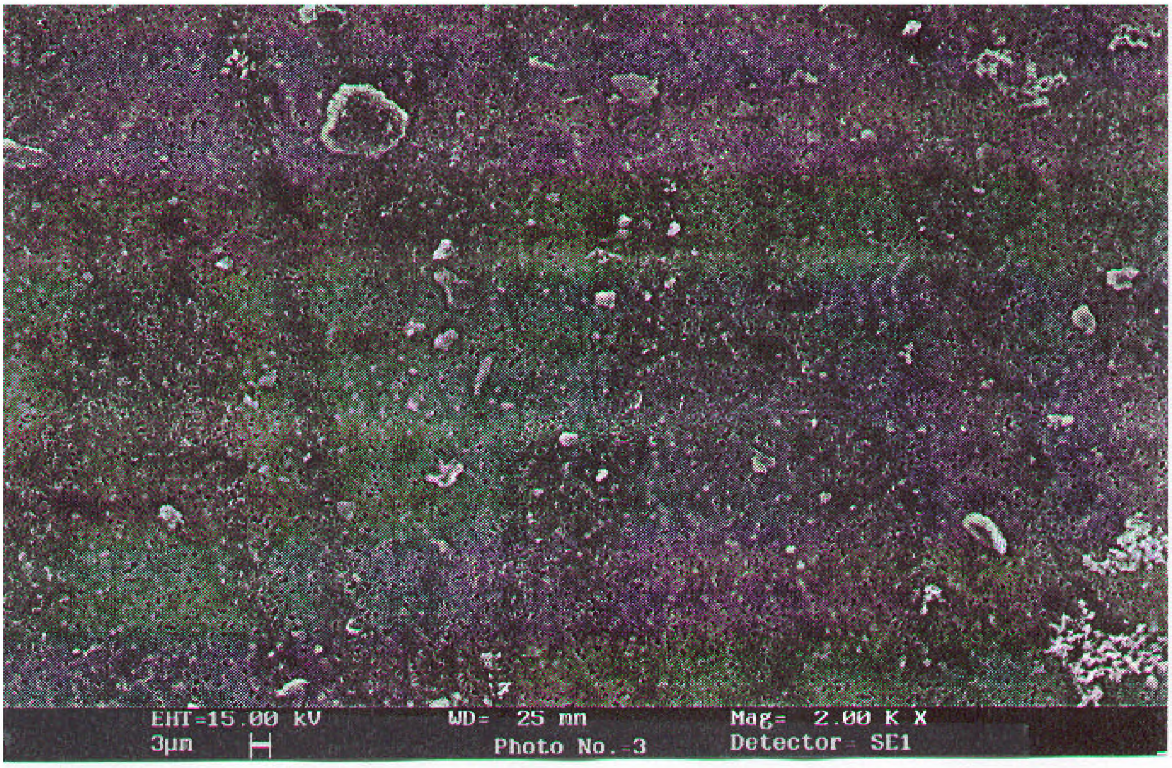


Figure 7.21: Sparse particle distribution of sample IKF36 seen at 200 x magnification

Note: Organic bundles can be seen in the right corner. In fact, a lot of organic material is present in bundles, the individual fibres of which are not always identifiable because of very dense spacing.

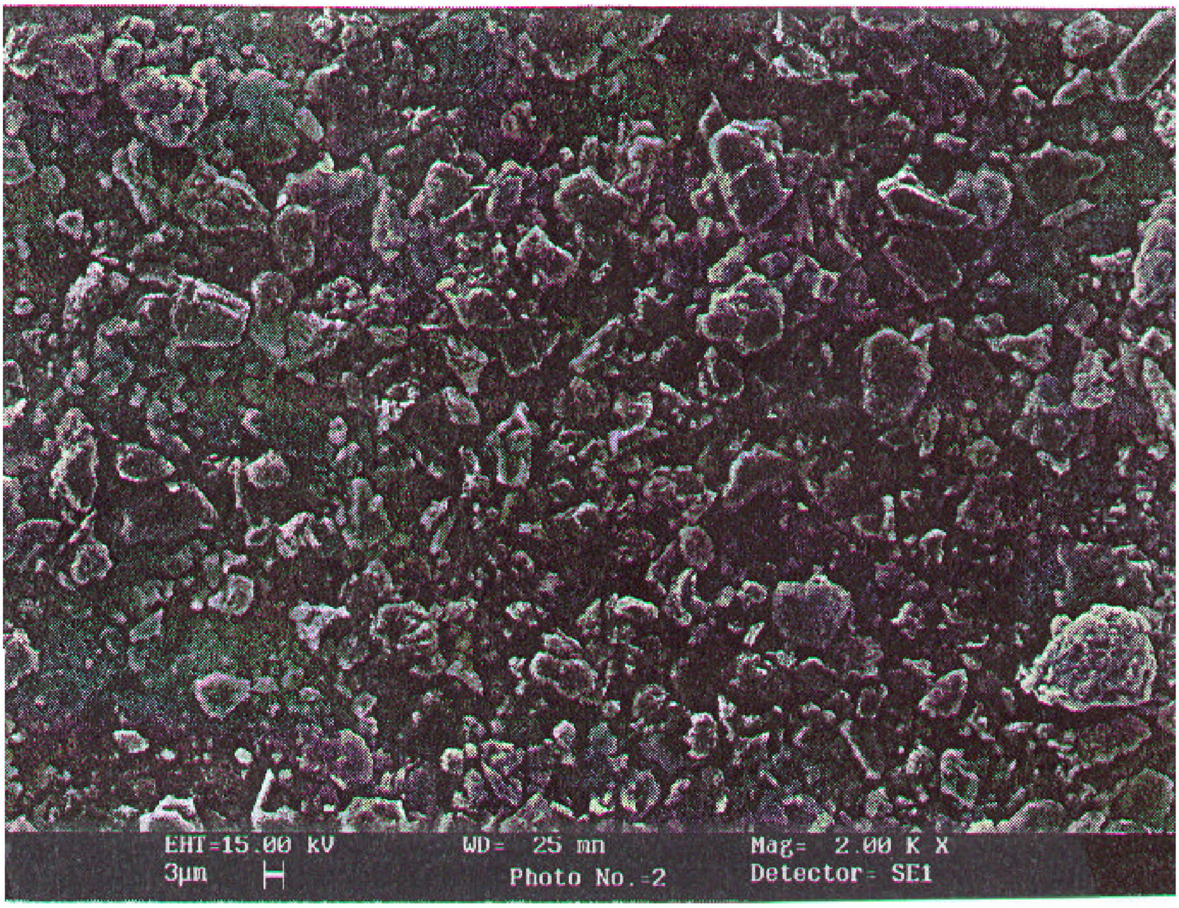


Figure 7.22: SEM image at 200 x magnification of sample IKF49 showing a fairly dense loading of particles

Results of all the fibre analyses, for pipe deposit mines and non-drilling operations, have been set out in Table 7.6. The results are also presented graphically in Figures 7.23 to 7.25.

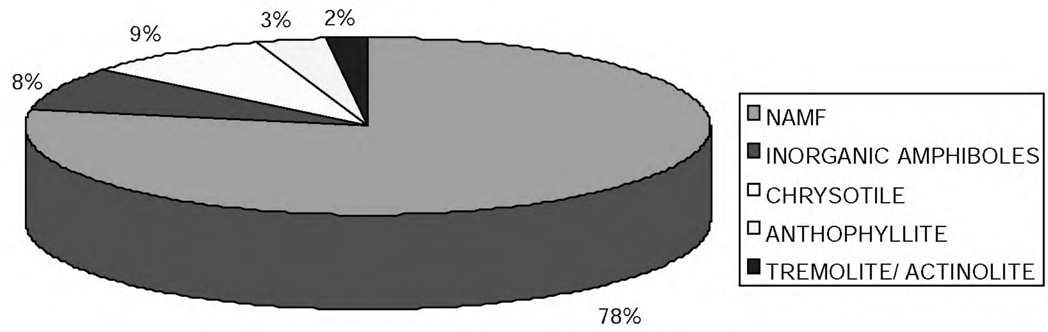


Figure 7.23: Fibre identification at drilling operations for pipe deposit mines

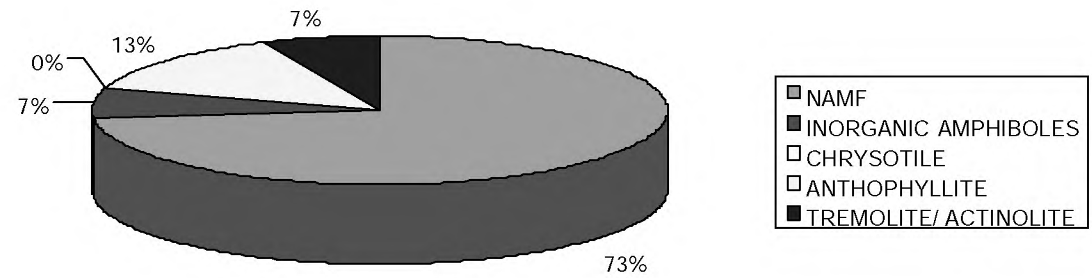


Figure 7.24 Fibre identification at drilling operations at fissure deposit mines

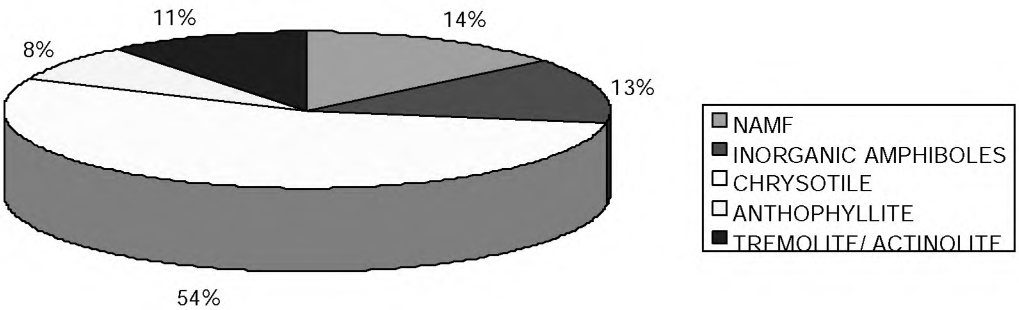
Table 7.6

Results of fibre identification analyses

Mine	Filter No.	Sampling position	Total fibre count	Name	Inorganic amphiboles	Chrysotile	Antho-phyllite	Tremolite/ Actinolite
1	PR4	Return air	1	1				
	PR7	Return air	5	3			1	1
4	KF2	Return air	1		1			
	KF3	Return air	5		5			
	KF14	Return air	39			37	2	
	KF43	Return air	27	15	7		4	1
	KF30	Return air	10		7		1	2
5	1KF36	Return air	308	299	4		4	1
	KF58	Intake air	4	2	1			1
	1KF30	Return air	10		7		1	2
		Total	410	320	32	37	13	8
		% of Total		78,0	7,8	9,0	3,2	2,0
		Total sample vol. (1)	960					
		Overall fibre conc f/mℓ	**0,207**	**0,162**	**0,016**	**0,019**	**0,007**	**0,004**
2	SK2	Return air	6	4	1		1	
	SK38	Return air	1	1				
3	PR50	Return air	3	2				1
	PR52	Return air	5	4			1	
		Total	15	11	1	0	2	1
		% of total		73,3	6,7	0,0	13,3	6,7
		Total sample vol (1)	323					
		Overall fibre conc f/mℓ	**0,023**	**0,017**	**0,002**	**0,000**	**0,003**	**0,002**
4	KF23	Crusher return	8	1	3		2	2
	KF55	Jet fan return air	186	33	2	144	2	5

Mine	Filter No.	Sampling position	Total fibre count	Name	Inorganic amphiboles	Chrysotile	Antho-Phyllite	Tremolite/ Actinolite
5	1KF15 1KF49	Upcast Main raw	24 48	 4	14 16		3 13	7 15
		Total	266	38	35	144	20	29
		% of total		14,3	13,2	54,1	7,5	10,9
		Total sample vol (1)	396					
		Overall fibre conc f/mℓ	**0.326**	**0,047**	**0,043**	**0,176**	**0,025**	**0,036**

NAMF =Non-Asbestos Mineral Fibre



Samples selected for fibre analysis were not randomly chosen. These samples had been subjected to fibre counting and, based on the criteria of the number of fibres (not too few) and the background particle density (not too high), filters were selected for further analysis. The selection was not always successful when optical analysis was used. In some instances the background particle density was too high for acceptable analysis and different filters had to be selected.

The number of usable samples for fibre analyses was seriously limited, mainly due to high background particle density. This situation arose primarily because dry mining operations were evaluated.

It is important to note that fibres were found in samples from both dry and wet operations and also in pipe and fissure deposits. Irrespective of where the samples were collected, fibres were found. However, it must be noted that most fibres found in the samples were non-asbestos mineral fibres (NAMF) (78 % in pipe deposits, 73 % in fissure deposits and 54 % at non-drilling operations). In terms of the present limit of 2 f/m• for all asbestos fibres, it can be anticipated that at a fibre concentration of 2 f/m• it is likely that the asbestos content would range between 0,4 f/m• and 1 f/m•.

The highest fibre concentration measured was found in an upcast shaft, namely 2,82 f/m• (a non-drilling operation). Based on the analyses of fibres found in this investigation, the highest asbestos fibre concentration would have been 54 % and thus the actual asbestos fibre concentration is likely to have been 1,52 f/m•, which is less than the present limit of 2 f/m•. In the workings the highest average fibre concentration for a pair of samples was found to be 4,87 f/m•. Again based on the above analyses, it is likely that only 24,5 % of this sample average would be asbestos fibres and this then equates to an asbestos fibre concentration of 1,19 f/m•, which is again well below the present limit of 2 f/m•.

It is also important to note that fibres were found in both the country rock and in kimberlite deposits. Finding of fibres in blue ground was probably due to inclusions and intrusions of country rock material.

Also of great significance is the fact that NAMF were found together with chrysotile, anthophyllite and tremolite/actinolite fibres in all the mines sampled.

7.4 Control samples

In addition to underground sampling, samples were also collected at three other sites, i.e. in an underground workshop area in a highly mechanised section of a gold mine and at two freeway offramps. These samples were collected to establish whether background fibre levels could also be found due to other activities such as braking or the cleaning out of brakes where asbestos liners are used. The only fibres found, at one of the offramps, were not asbestiform but appeared to be flora, e.g. grass seed.

7.5 Sampling and analytical errors (after RTM 2)

7.5.1 General

The errors introduced into the estimation of airborne asbestos dust are either sampling or analytical errors, each of which has a systematic and a random component. The application of standard procedures and interlaboratory comparisons is the only way of controlling most of the many sources of error inherent in the SEM method. The following subsection lists some of the common sources of error.

7.5.2 Systematic errors

7.5.2.1 Sampling

- Flow rate
- Sampling time
- Non-representative or biased sampling
- Contamination – deliberate or accidental
- Disruption or loss during transportation.

7.5.2.2 Analytical

- Effective filter area
- Counting area
- Filter mounting
- Microscope and observers
- Contamination
- Calibration of magnification
- Loss of fibres during preparation
- False identification of other mineral species of similar composition
- Misidentification due to inadequate or false X-ray emissions from neighbouring particles.

7.5.3 Random errors

7.5.3.1 Sampling

- Flow rate variability
- Random fluctuations of the airborne dust cloud.

7.5.3.2 Analytical

- Fibre distribution on the filter
  Non-random deposition of dust on the filter leads to gross errors, the magnitude of which cannot be estimated. Fifty or more fields must be counted to ensure that minor divergence from randomness does not bias the result.

- Poisson distribution errors
  As only small samples of the fibres deposited on the filter are counted, errors can arise in estimating the total number of fibres on the entire filter face. Theoretically, the Poisson distribution defines the variation in fibre counts resulting from viewing randomly selected counting fields on the filter. If a minimum of 50 fibres is counted, and if a Poisson distribution were appropriate to the counting results, the relative standard deviation of the fibre counts would be ±14. It has been shown experimentally that the actual distribution of fibre counts can depart significantly from that of Poisson, in which case the standard deviation will be greater.

8 Conclusions and recommendations

8.1 Conclusions

Although conclusions and recommendations for dust control during the dry drilling of kimberlite were set out in the companion research report (Unsted, 2000), they are repeated here for convenience. It should be noted that whenever the release or generation of dust is discussed, the release or generation of airborne fibres should also be considered.

Kimberlite pipe mines feature large excavations, with large and heavy equipment and, generally, bulky items of dust control equipment. However, this dust control equipment, whether on-board or remote, did not prove successful and requires further research. Malfunctioning of this equipment revealed that the dust levels were even higher than had originally been thought.

Kimberlite is mined in deposits known to contain asbestos formations in one form or another due to intrusions. Investigations were conducted in mines practising both pipe mining and fissure mining.

The asbestos fibre sampling results for pipe and fissure mining, and also those for wet and dry drilling, were kept separate for purposes of comparison. The main difference in the results was found to be due to the ventilation methods applied with the various mining and drilling methods. Fibre counts did not differ much between the two mining methods (pipe and fissure mining) or between wet and dry drilling. However, during dry drilling, there was a tendency for dust to obscure the presence of fibres, resulting in possible inaccuracies during the fibre-counting process.

Intermittent sampling, using 10-minute sampling cycles per 60-minute sampling period, yielded higher fibre concentrations mainly due to the low background dust level in the atmosphere making fibres more visible.

Membrane filter samples were collected in pairs and considerable differences were found between the individual samples in the pairs, highlighting the necessity to collect samples in pairs.

One of the mandates of this project was to determine whether airborne fibres were present during kimberlite mining and then to identify the fibres detected. For this purpose stationary samples were collected. From the results obtained it is clear that employees may be exposed to some form of asbestos fibres and personal exposure monitoring should be investigated.

Background samples were necessary to determine the rate of fibre release in kimberlite mines. Samples were therefore taken on surface, in downcast shafts and in the main intake airways, and the results were almost negative. However, samples collected in the return airways and upcast shafts revealed reasonably high levels of asbestos fibres, namely 0,43 f/mℓ and 2,25 f/mℓ respectively. These results indicated that fibres are indeed released during the mining process.

Several types of asbestiform fibres were found in all the mines sampled, in both country rock and kimberlite excavations. From the literature study it appears that there may be a similar problem with other minerals, and this aspect needs to be investigated as well.

Distinguishing between asbestos and other fibres proved not only difficult but almost impossible, even for experienced technicians. No fibres at all were reported in some cases, as reflected in the tables, not because no fibres were present, but because those outside the selection criteria were disregarded.

8.2 Recommendations

8.2.1 Dry drilling

8.2.1.1 Consideration should be given to effective dust control measures in all drilling operations in country rock.

8.2.1.2 Polycrystalline rotary drill bits appear to be effective in reducing dust emissions and further experiments need to be done with them as a possible cost-effective means of dust control.

8.2.1.3 The ventilation flow rate in headings should be increased to at least 0,5 m/s, irrespective of their cross-sectional dimensions, to adequately dilute and remove air contaminants.

8.2.1.4 Means of controlling dust at source should be investigated, even if a combination of different techniques is required (similar to the quiet rock drill).

8.2.1.5 The feasibility of using bonding materials on footwall/haul roads to combat dust should be investigated. Mines other than kimberlite mines should be surveyed to determine whether fibre, in whatever form, are being released during mining operations.

8.2.2 Fibres and fibre monitoring

8.2.2.1 Mines in which fibres are present should invest in a fully equipped laboratory, or obtain the services of such laboratory. A sampling programme to monitor for asbestiform fibres should be drawn up, and a qualified person will be required to perform this task on a part-time or full-time basis, depending on the risk rating of the mining operation.

8.2.2.2 Personal sampling for asbestiform fibres should form part of the monitoring programme for airborne pollutants for mines known to have asbestiform fibres in the minerals being mined.

8.2.2.3 The RTM 1 method should be used for evaluating personal exposure samples and cognisance must be taken of airborne dust in the sampling area. All kimberlite mines should conduct such sampling programmes.

8.2.2.4 If other mines wish to determine the prevalence of asbestiform fibres in their operations, samples should be taken in pairs, as was demonstrated during this research project.

8.2.2.5 The exposure level for all forms of fibres should be set at 1 f/mℓ for uniformity in the mining industry and to avoid confusion.

8.2.2.6 Other mines not covered during this research project should be subjected to a research/survey project to determine whether asbestiform fibres, which could have a detrimental effect on workers' health, are present in their working places.

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