PB89-187942

FINAL REPORT

CHARACTERIZATION OF SILICA IN THE LUNGS OF AUTOPSIED COAL MINERS

REPORT DOCUMENTATION PAGE	1. REPORT NO.	2.	3. Recipient's Accession No. PB89 187942/AS

4. Title and Subtitle Characterization of Silica in the Lungs of Autopsied Coal Miners	5. Report Date 00/00/00
	6.
7. Author(s) Anonymous	8. Performing Organization Rept. No.
9. Performing Organization Name and Address Final Report, CAN 106	10. Project/Task/Work Unit No.
	11. Contract (C) or Grant(G) No. (C) (G)
12. Sponsoring Organization Name and Address	13. Type of Report & Period Covered
	14.

15. Supplementary Notes

16. Abstract (Limit: 200 words) A two part study was conducted to investigate silica (14808607) in lungs of coal miners at autopsy. The prevalence of silicosis at death in coal miners in relation to mining and job categories was investigated in the first part. Lung tissue sections submitted to the National Coal Workers Autopsy Study (NCWAS) for the period 1971 through 1980 were assessed for the presence of silicotic lesions in the pulmonary parenchyma and tracheobronchial lymph nodes. Examination of the tissue sections for the 3,365 coal miners in the study population indicated that 12.6 percent had silicosis, 45.6 percent had macules, 18.9 percent had nodules, and 5.5 percent had progressive massive fibrosis. Silicosis usually occurred against a background of coal workers pneumoconiosis; only 7.2 percent of lungs without coal workers pneumoconiosis showed silicosis. Transportation workers showed the highest prevalence of silicosis, while workers primarily engaged in surface activities at underground mines have the lowest prevalence. Geographical area affected the prevalence of silicosis, with the highest prevalence in miners from Pennsylvania, West Virginia, Wyoming, and Utah. Years in underground mining was found to be clearly correlated with prevalence and severity of silicosis. The second part studied the particle size distributions and number of particles in coal miners lungs. Particulate burdens were determined for lung specimens from 21 coal miners by scanning electron microscope based automated image analysis. Results were compared with those for urban dwellers. In spite of the specimens being chosen to represent a wide range of exposure and medical history, particle size data were similar. Median circular area equivalent diameters for exogenous particles were found to range from 0.47 to 0.87 micrometers (microm); for silica, median diameters ranged from 0.50 to 0.83microm. For specimens from urban dwellers, more than 70 percent of the median diameters for silica fell between 0.5 and 0.8microm.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms Coal-miners, Silica-dusts, Humans, Postmortem-examination, Respiratory-system-disorders, Mineral-dusts, Epidemiology, Lung-burden, Underground-miners

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages 45
	22. Security Class (This Page)	22. Price PC $13.95 / MF $6.95

(See ANSI-Z39.18) *See Instructions on Reverse* OPTIONAL FORM 272(4-77)

FINAL REPORT: CAN 106 - Characterization of Silica in the Lungs of Autopsied Coal Miners.

1. BACKGROUND

Particulate matter has been recognized as a cause of various lung diseases, the pneumoconiosis, for many years. Specific pneumoconiosis such as coalworkers' pneumoconiosis and silicosis result from the inhalation of particles at the worksite. In many instances, there are simultaneous exposures to many different types of particles. This is particularly true for coal miners where simultaneous exposures to coal dust, silica, and various aluminum silicates are common.

Exposure to silica in coal mining operations is of increasing concern since MSHA data as analyzed by NIOSH indicates that an increasing number of mines are unable to comply with the free silica standard. The extent of the health problem associated with this failure of compliance is difficult to assess as coal workers' pneumoconiosis and silicosis produce similar opacities on the chest radiograph. Morphologically, however, the lesions are distinctive. Part of this study was to examine lungs of autopsied coal miners to assess histologically the prevalence of silicosis in miners. On the assumption that we would find some silicosis among the mining population, we undertook a study to quantitate the size distribution and number of silica particles in the lungs of autopsied miners.

The studies to meet the objectives of this project will be separated in two parts. The first part will describe a study involving the prevalence of silicosis and its relationship with mining and job categories and the second part will describe the study on the particle size distributions and number of particles in autopsied lungs.

2. PREVALENCE OF SILICOSIS AT DEATH IN COAL MINERS

by
Francis Green, Rochelle Althouse, and
Kenneth Weber with the technical assistance of
James Tucker, Lunette Utter, Nadia El-Ayouby and Martha Saab

2.1 APPROACH

Silica exposure has long been recognized as a respiratory hazard in coal mining, and workers in certain job categories within the mines, such as tunnel drillers, roof bolters, and motormen are at high risk for silicosis (1,2,3). Despite these observations and much debate over the years concerning the role of silica in the pathogenesis of pneumoconiosis in coal workers, there is remarkably little information on the prevalence of silicosis in coal miner populations. This can be largely attributed to difficulties in distinguishing silicosis from coal workers' pneumoconiosis (CWP) on the chest radiograph, and to a lesser extent to a paucity of suitable autopsy material.

The United States has a unique autopsy program for former underground coal miners which was initiated under Title 42 of the Federal Coal Mine Health and Safety Act of 1969 (4). This program, called the National Coal Workers' Autopsy Study (NCWAS), is administered by the Division of Respiratory Disease Studies of the National Institute for Occupational Safety and Health (NIOSH), Morgantown, WV.

Each case submitted includes pathologic material and information on the miner's work tenure, primary job, and the most recent mine location. This information forms the basis for this study: to determine the prevalence of silicosis in this population of coal miners and the possible relationships between the previously mentioned factors and silicosis.

2.2 METHODS AND MATERIALS

Lung tissues from 3,365 autopsied coal miners submitted to the NCWAS during the decade 1971-1980 formed the study population. The NCWAS is a voluntary program that is restricted to former coal miners who have worked in an underground mine one day or more. The regulations require that a minimum of three slides and blocks of lung tissue are submitted with the autopsy protocol, together with a questionnaire completed by a close relative of the deceased coal miner. This questionnaire includes information on the number of years of surface and underground coal mining, the location of the most recent mine where the miner worked, the primary job in which the miner was employed, as well as a detailed smoking history. The demographic and occupational data was computer coded into the NCWAS files using NIOSH job classification codes.

Tissue sections from all cases in the NCWAS over the decade 1971 through the end of 1980 were assessed for the presence of silicotic lesions in the pulmonary parenchyma and tracheo-bronchial lymph nodes. There was an average of 4 sections per case with a range of 3 to 22. The degree of silicosis in the pulmonary parenchyma was graded subjectively into three groups of severity - mild, moderate, and severe (Grades I, II and III, respectively) - based upon the profusion and size of the silicotic lesions in the sections. Examples of typical grades of silicosis are illustrated in Figures 1 through 3. Grade 3 included conglomerate lesions measuring more than 1 cm in diameter (PMF). Only classical silicotic nodules were graded: lesions of acute silicosis (silicotic alveolar proteinosis) or accelerated silicosis were not identified in any of the cases. Silicotic nodules were identified by standard histopathological criteria (5). The nodules exhibited central whorled and hyalinized collagen. The periphery of the lesions showed a variable configuration; the majority had irregular stellate mantles of coal dust containing macrophages in a reticulin stroma. Confluence of nodules was frequently seen. The type and severity of coal workers' pneumoconiosis was also assessed by criteria developed by a joint committee of NIOSH and the College of American Pathologists (6). The macular and nodular lesions of simple CWP were further subjectively graded into three grades of severity - mild, moderate, and severe - based upon profusion and size of the lesions in the sections. The data was analyzed using descriptive statistics.

Fig. 1. Low magnification micrograph of coal worker's lung showing a small, discrete, rounded silicotic nodule within the pulmonary interstitium adjacent to a muscular pulmonary artery. This case was classified as Grade I (mild) silicosis. (H & E x 40)

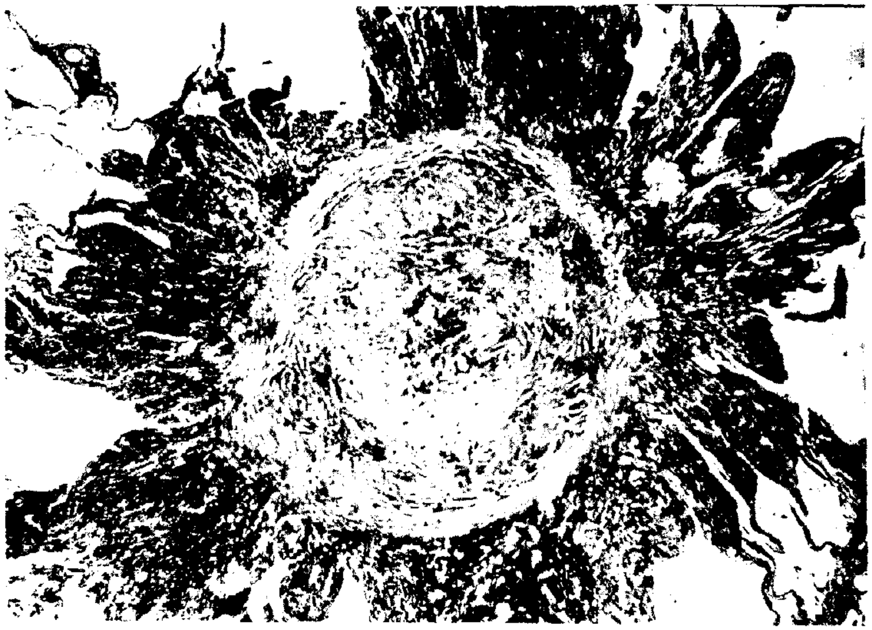


Fig. 2. Larger silicotic nodule from a case classified as Grade II (moderate) silicosis. The lesion shows a hyalinized central area of concentrically arranged collagen fibres surrounded by a stellate mantle of coal dust containing macrophages in a reticulin stroma. This histological pattern is highly characteristic of silicosis in coal workers. (H & E x 20)

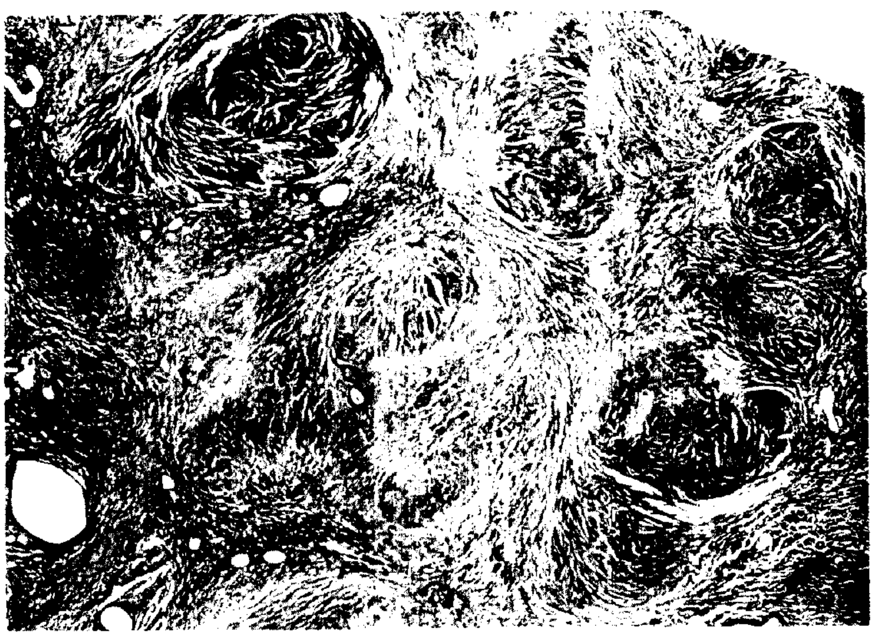


Fig. 3. Silicotic massive fibrosis. Discrete fused nodules are apparent. This case was classified as Grade III (severe) silicosis. (H & E x 20)

2.3 RESULTS

Table 1 shows the demographic characteristics and smoking histories of the NCWAS population (1971-1980).

TABLE 1. - Characteristics of NCWAS Population - 1971-1980

NUMBER	3,365
MEAN AGE AT DEATH	62 ± 12 (SD) years
AVERAGE YEARS WORKED IN UNDERGROUND MINES	26 ± 14 (SD) years
RACE/SEX	94% white males
CIGARETTE SMOKERS (EVER)	74%
AVERAGE PACK YEAR CONSUMPTION FOR SMOKERS	24 ± 20

Table 2 shows the NCWAS submissions by state for the same years. The majority of submissions were received from the Appalachian states of Pennsylvania and West Virginia.

TABLE 2. - NCWAS Population by State

STATE *	NUMBER	PERCENT
Pennsylvania	1460	46
West Virginia	948	30
Kentucky	214	7
Virginia	159	5
Ohio	114	4
Illinois	95	3
Wyoming	45	1
Colorado	42	1

* Only states with 1% or more of the total submission are included.

The prevalences of the various pneumoconiotic lesions in the NCWAS population are shown in Table 3. Pulmonary parenchymal silicosis is seen in 12.6%, and silicotic nodules were seen in the lymph nodes of 52.9% of cases. Of cases with parenchymal silicosis, 89% showed silicotic nodules in the lymph nodes. Macular lesions were seen in 45.6% of cases, and macules with focal emphysema (corresponding to a diagnosis of simple CWP) were present in 35.8% of miners. Nodular lesions of simple CWP and progressive massive fibrosis occurred less frequently, 18.9% and 5.5%, respectively.

TABLE 3. - Prevalence of Silicosis and Coal Workers' Pneumoconiosis using Histopathology in NCWAS (1971-1980)

SILICOSIS	12.6%
SILICOTIC NODULES IN LYMPH NODES	52.9% *
MACULES	45.6%
MACULES AND FOCAL EMPHYSEMA	35.8%
NODULES	18.9%
PROGRESSIVE MASSIVE FIBROSIS	5.5%

* Based on 1,675 cases where lymph node sections were present.

Silicosis was rarely encountered as an isolated type of pneumoconiosis, usually occurring against a background of simple CWP. Table 4 presents the percentage of miners with silicosis by CWP grouping. This shows that only 7.2% of lungs without any form of CWP showed lesions of silicosis, whereas with increasing category of CWP there is a corresponding increase in the prevalence and severity of silicosis. The mean tenure of each CWP grouping showed a very slight increasing trend with CWP severity varying over a three year range.

TABLE 4. - Grade of Silicosis by Coal Workers' Pneumoconiosis

PNEUMOCONIOSIS CLASSIFICATION (Highest Category)	MEAN TENURE YEARS	% WITH SILICOSIS	% WITH GRADE I	% WITH GRADE II/III
No CWP	32	7.2%	4.2%	3.0%
Macules plus Focal Emphysema	33	22%	12%	10%
Nodules	34	32%	15%	17%
PMF	35	51%	11%	39%

The relationship between prevalence of silicosis and principal job within the mine is shown in Tables 5 and 6. Table 5 shows that the highest prevalence of silicosis was observed in transportation workers, a rate almost twice that seen in face workers. As would be expected, maintenance workers and other miners primarily employed in surface activities at underground mines, had the lowest prevalence of silicosis (8.4% and 6.4%, respectively). A more detailed tabulation of job category rank by severity of silicosis is shown in Table 6. Motormen have the highest overall prevalence of silicosis (25.0%) as well as the highest prevalence of severe disease (16.2%). Electricians have the lowest overall prevalence of silicosis (7.6%), as well as the lowest overall prevalence of severe disease (3.6%). The prevalence of silicosis in roof bolters was similar to that seen in face workers, although the proportion of severe disease was higher in the roof bolters.

TABLE 5. - Silicosis Prevalence by Major Job Classification

JOB GROUPING	TOTAL # IN JOB GROUP	% SILICOSIS IN JOB GROUP
Transportation	821	24.2
Face Activities	1490	12.5
Miscellaneous (Foremen, Section Boss)	410	12.2
Maintenance	439	8.4
Surface Activities (at Underground Mines)	249	6.4

TABLE 6. - Prevalence of Silicosis by Job* Ranked by Severity

JOB	N	TENURE MEAN	GRADE I (%)	GRADE II/III (%)	OVERALL %
Motormen	320	32.2	8.8	16.2	25.0
Bonders & Trackmen	54	31.7	5.6	9.3	14.4
Cutting Machine	140	33.5	4.0	8.9	12.8
Foremen	144	33.1	8.3	6.9	15.3
Loaders & Diggers	770	27.3	5.8	6.6	12.4
Continuous Mine Oper.	136	28.7	6.6	5.8	12.5
Roof Bolters	97	26.7	7.2	5.5	12.3
Misc. Drillers	75	29.9	9.3	5.4	14.7
General Face	122	28.5	5.7	4.9	10.6
Shuttle Car Oper.	105	29.3	7.6	4.8	12.4
Loading Machine Oper.	111	29.9	6.3	4.5	10.8
Electricians	198	31.3	4.0	3.6	7.6

* Jobs with > 50 cases in this study.

Table 7 shows the prevalence of silicosis by primary state in which the miner worked. The highest prevalence of silicosis was seen in miners from the Appalachian states of Pennsylvania (14.8%), West Virginia (13.7%), and the Rocky Mountain states of Wyoming and Utah (14.2%). Low prevalences of silicosis were seen from miners working in Virginia, Kentucky, Illinois, and Ohio. Eighteen miners were identified whose last place of employment was at a Pennsylvania anthracite mine. In this group, approximately one-fourth had evidence of silicosis.

TABLE 7. - Prevalence of Silicosis by Primary State of Mining

STATE	# IN NCWAS	TENURE MEAN	PREVALENCE OF SILICOSIS (By Grade) I	II	III	TOTAL
Pennsylvania	1476	30.0	6.6	5.4	2.8	14.8
Pennsylvania (Anth.)	18	33.4	22.2	0.0	5.6	27.8
Wyoming & Utah	56	25.1	7.1	5.3	1.8	14.2
West Virginia	936	28.5	6.9	4.3	2.5	13.7
Colorado	42	31.0	9.5	0.0	0.0	9.5
Virginia	123	24.6	4.9	1.6	0.0	6.5
Illinois	95	27.8	1.0	3.2	1.0	5.2
Kentucky	202	25.5	3.5	1.0	0.0	4.5
Ohio	122	28.9	2.5	1.6	0.0	4.1

Table 8 shows the relationship between the years in underground mining and severity of silicosis. Mean tenure for all miners with silicosis was 34 ± 12 years. Tenure was grouped into low (0-20 years), medium (20-40 years), and high (40+ years). There is a clear and consistent relationship between length of underground mining with prevalence and severity of silicosis indicating a dose response effect.

TABLE 8. - Silicosis by Years in Underground Mining

YEARS IN MINING	NUMBER OF CASES	SILICOSIS GRADE 0	I	II	III
0-20 YRS	799	94.6%	2.4%	2.4%	1.0%
20-40 YRS	1658	85.9%	7.6%	4.5%	1.9%
Over 40 YRS	846	82.9%	7.6%	5.6%	3.8%

2.4 DISCUSSION

The data presented here indicates that a significant proportion of U.S. underground coal miners have received high enough concentrations of free silica in the respirable fraction of coal mine dust to produce silicosis. The 12.6% prevalence noted in this study is remarkably similar to the 13% prevalence noted by Laqueur in a series of autopsied coal miners from southern West Virginia (7). We have been unable to identify prevalence data from other countries. The paucity of data on prevalence of silicosis in coal workers is related in part to the difficulty in distinguishing between the opacities produced by silicosis from those produced by simple CWP on the chest radiograph. The radiographic sign of eggshell calcification (8), although indicative of a reaction to silica in the tracheo-bronchial lymph nodes, is not specific for this disease, and data presented in this paper, showing a high proportion of silicotic nodules in the tracheo-bronchial lymph nodes in the absence of parenchymal lesions, would also indicate that the sign has little diagnostic usefulness for parenchymal silicosis. Correlative studies from the Institute of Occupational Medicine in Edinbrough have shown that the r-type small opacities of simple pneumoconiosis seen on the chest x-ray correlate with silicotic nodules on histopathologic examination (9, 10).

A relationship was noted between severity of coal workers' pneumoconiosis and the presence of silicotic lesions in the lung. This was most marked in miners with PMF in whom over 50% showed silicotic lesions in the pulmonary parenchyma. Although this is an interesting finding, it does not necessarily imply a role of silica in the pathogenesis of PMF (11, 12). We feel that the association can best be explained in terms of dose response with both silicosis and PMF occurring in miners with long work tenures and high cumulative exposures to coal mine dust.

The study also showed a relationship between length of underground mining with prevalence and severity of silicosis. Unfortunately, exposure data were not available for these mines during the decades when exposures most likely occurred. Therefore, true dose response data cannot be obtained from this study. It is of interest to note that, although longer tenures of work correlated with increasing prevalence and severity of silicosis, there were miners with short work histories who also developed silicosis. This indicates that acute high exposures or individual susceptibility may also play a role in the development of silicosis in U.S. coal miners.

Exposure to quartz at underground and surface coal mines depends on a number of factors. The quartz dust itself is largely derived from the rock strata adjacent to the coal seams, as the latter contains relatively small concentrations of quartz. Quartz exposures, therefore, may depend upon a number of factors including the geology of the coal deposit and adjacent rock strata, the height of the coal seam, faults and undulations, the method of mining, and the specific job of the miner. It is, therefore, not surprising that there are regional and occupational variations in the prevalence of silicosis. Although the numbers are small, the very high prevalence of silicosis in the Pennsylvania anthracite miners is in keeping with previously published epidemiologic studies documenting high pneumoconiosis prevalence in anthracite miners (13). Pennsylvania anthracite mines have low undulating seams requiring the use of sand on the tracks to improve traction and removal of large amounts of overburden in order to extract the coal.

Operations such as roof bolting, tunnel and surface drilling, and transportation are associated with high silica exposures, and miners employed in these jobs are more likely to develop silicosis (2, 14). This study generally supports these observations. An exception to this may be the moderate prevalence of silicosis noted in the roof bolters. However, our data may underestimate the true risk for silicosis in roof bolters as they had the lowest work tenures of any job category (26.7 years). Moreover, the proportion with severe disease, categories 2 or 3, was higher in the roof bolters than in the face workers. Motormen who had the highest overall prevalence of silicosis as well as the highest prevalence of severe disease are known to be at high risk for silicosis due to the use of traction material containing up to 81% free silica on the tram car tracks (15).

Several considerations should be noted in generalizing from these data to the entire population of miners. The NCWAS population is a biased sample and includes only a relative small proportion of all miners who die. Estimates based on the expected death rates amongst retired and active underground coal miners during the decade of 1970-1980 indicate that slightly less than 10% of coal miners who die are entered into the NCWAS program. It is likely that miners submitted to the NCWAS have less occupational disease than miners that are not included, as more severely affected miners may be already receiving compensation at death, and thus, their families would be less likely to request an autopsy. If this interpretation is true, we expect that in the overall population of miners at death, a greater proportion would have silicosis; thus, data based on the NCWAS would give a relative underestimate. Studies of working bituminous coal miners from western Pennsylvania and with long tenures (20-30 years) in the early 1960's showed prevalences of ≃ 5% PMF (16), whereas for retired miners of less than 30 years mining the prevalence was 7.5%. Although these studies were based on radiographic examination, there is a good correlation between radiographic and pathologic diagnosis of PMF (17). Based on these findings, the underestimate of severe CWP appears small.

In conclusion, the data presented here indicates that a significant portion of U.S. underground coal miners have received high enough doses of silica in the respirable fraction of the coal mine dust to produce silicosis. The disease observed in this study represents the effects of exposures received more than ten years prior to death due to the known long latency period of silicosis. Respirable dust levels during the decades in which most of these miners received their exposures were certainly much greater than miners are receiving today. It is likely, therefore, that the prevalence of silicosis will decrease in coming decades. The NCWAS population can serve a useful purpose in monitoring disease prevalence in the future.

2.5 SUMMARY AND CONCLUSIONS

This study was initiated in order to determine the prevalence and pathological features of silicosis in coal miners. The population base was 3,365 autopsied miners submitted to the U.S. National Coal Workers' Autopsy Study between 1971 and 1980. This program is voluntary and covers an estimated 10% of all coal workers who die. The mean age at death of the population was 62 years of whom 75% were current or ex-smokers at the time of death. The average work tenure was 26 years. Lung sections from all cases were reviewed and the type and severity of pneumoconiosis documented. These findings were correlated with years of mining, job history, and geographic location of mine. Classical silicotic nodules were found in 12.6% of the population. There was a significant relationship between length of underground mining and prevalence and severity of silicosis, indicating a dose response effect. The study also showed that job category and geographic location of the mine were important determinants of silicosis prevalence, and that silicosis was strongly associated with higher categories of coal workers' pneumoconiosis (CWP).

3. SILICA LUNG PARTICLE SIZE DETERMINATION IN COAL MINER LUNGS

by

Lloyd E. Stettler, James H. Tucker, Robert D. Riley
S. Frank Platek, J. Pat Mastin, Frank H.Y. Green
and Edward Zuchelkowski with technical
assistance of Diane Schwegler-Berry

3.1 APPROACH

In order to develop the technologies to control silica exposure in mines, it is clearly important to quantify the size fractions of inhaled silica particles which are preferentially retained by the lung. SEM-based automated image analysis has been routinely used to characterize particles extracted from lung tissues (18-20). Large numbers of particles may be quickly sized and chemically characterized using this instrumentation.

In the work being reported here, the particulate burdens of tissues from 22 coal miners were determined using SEM-based automated image analysis and contrasted with the particulate burdens of Cincinnati, Ohio urban residents who had no overt pneumoconioses. For the coal miner lungs, particle size data for the total dust as well as the component of this dust, which was considered to be silica, will be presented.

3.2 METHODS AND MATERIALS

Lung Specimens

Selection of lung specimens for use in this study was based primarily on two factors; 1) The availability of both slides and wet-formalin fixed tissues for analysis and 2) that selected cases represent the various gradients of disease (i.e., stages of CWP and/or silicosis) and/or dust exposure as related to the miner's job and/or tenure. Fixed wet lung tissues and slides were available for approximately 260 of the 3,365 autopsied miners submitted to the U.S. National Coal Workers' Autopsy Study (NCWAS) from 1971 to 1980. Additional cases were reviewed and selected from mine accident cases submitted to this laboratory since 1980.

Based on the review of the subjects' work and medical histories, histopathology, and/or examination by polarizing light microscopy, tissues from 21 of these subjects were selected for particulate analysis. Both paraffin-embedded and wet, formalin-fixed tissues were available for all of the subjects selected.

Two mm thick sections of whole freeze-dried lung specimens from coal miners were also available for analysis. Portions of a whole lung section from one subject (lung #22) were analyzed to provide some information on particle distributions within the lung. A total of 24 circular sections were taken from the whole lung section using a 4 mm diameter cork borer. Twelve sections were taken from the upper and lower lobes. Of these 12 sections, 6 were taken from areas of heavy particle deposition and 6 were taken from adjacent (control) areas with no visible particles. The six sections from the adjacent areas for the upper or lower lobes were pooled for particle analysis.

Subject data for all of the analyzed lungs in terms of age, job setting, etc. is summarized in Table 9.

Tissue Processing

Processing of tissue for image analysis consisted of taking 1-2 grams of wet tissue from each of the bulk pieces of formalin-fixed lungs and mincing into 1 mm^3 pieces using a clean, stainless steel razor blade and then freeze-drying to constant weight. Approximately 0.1-0.2 g of the freeze-dried tissue was placed in a clean glass vial and then ashed in a low temperature asher at 90 watts using an oxygen pressure of 2 torr. An empty glass vial was also placed in the asher at this time and was processed similarly throughout the sample preparation steps as a blank for the lung sample(s) being ashed. At the end of this period, the vials were removed from the asher and placed on a vortex mixer for one minute to disperse the ash. If large pieces of unashed material remained after this process, the sample was re-ashed for an additional 7 hours. Each 4 mm diameter section taken from the whole lung section was weighed and ashed in similar fashion.

A suspension of the ash from each sample was made using 50 ml of a 0.05% solution of Aerosol OT in filtered, de-ionized water. The resulting suspensions were sonicated in an ultrasonic bath for 15 minutes. The suspensions were made up to a final volume of 100 ml with filtered, de-ionized water to which 1 ml of glacial acetic acid had been added and allowed to sit overnight. Aliquots of the suspensions for sample and blank were then filtered onto 25 mm diameter, 0.1 um pore size Nuclepore[1] filters.

For *in situ* evaluation, five micron sections were cut from the paraffin-embedded tissue from selected lungs for both light and scanning electron microscopy (SEM). Conventional H&E, Masson's trichrome, Wilder's reticulum and Movats pentachrome stained slides were prepared for histopathology examination. Polarizing light microscopy (PLM) was used for the detection of birefringent material in areas of particulate accumulation and within lesions in the lung (Fig. 4, A-D). In selected cases, adjacent sections to those examined by light microscopy were mounted on a carbon planchet and deparaffinized for SEM-EDXA analysis of the particles (Fig. 5, A-E). The carbon planchet mounted 5. micron sections were examined in a Etec SEM using an accelerating voltage of 20 kV and backscattered electron image (BEI). Individual particles were analyzed using an EG&G Ortec EEDS II energy dispersive X-ray analysis system.

Automated Particle Analysis

Particles found on the filter preparation for each lung and blank were analyzed using a scanning electron microscope (Hitachi S-570 or ISI Super IIIA) equipped with a Kevex 7000 energy dispersive x-ray analysis system and a LeMont Scientific DA-10 image analysis system using the backscattered electron image. For each lung filter preparation, all of the particles (a minimum of

1000) in a minimum of twenty randomly selected fields of view at a magnification of 1000X were sized and analyzed for 31 elements using an x-ray spectrum acquire time of 5 seconds (Fig. 6, A-D). Particles found in a minimum of 20 randomly selected fields of view for the blanks were similarly analyzed. The image analysis particle recognition parameter (off particle searching point density) used at the 1000X magnification was such that all particles 0.2 um and greater in diameter should be found and analyzed. For these analyses, net x-ray intensities for each element were determined using the pre-selected peak and background windows shown in Table 10. An element was defined as present according to the relationship

$$I_P = I_B + 3\ I_B^{\ 1/2}, \qquad (1)$$

where I_P is the peak elemental intensity and I_B is the average background intensity for each element.

Each analyzed particle was categorized using a chemistry definition file which classified the particles based on their major elemental components and the net fractional x-ray intensities for these components. A single chemistry file was found to be suitable for all lungs analyzed in this study. The major definition characteristics for each of the 14 major chemical classes in this file are given in Table 11. These definitions range from the very tightly defined one element classes such as silica, rutile-like, and alumina-like to very broadly defined classes which allow a wide variation in elemental x-ray intensities. Major classes can be subclassified by further restricting the elemental limits within a class.

3.3 RESULTS

Particle size data for both particles classified as silica as well as the total exogenous particulate burden for each of the 22 lungs analyzed in this study are summarized in Tables 12-15. Individual sample number median diameters for silica are plotted in Figure 7 for those lungs which had a single piece of tissue analyzed (lungs 1-21).

The LeMont mass median diameters shown in Tables 12 and 13 were calculated from the individual particle size data (circular area equivalent diameters) generated by the LeMont image analyzer. Individual particle volumes were calculated from each particle's circular area equivalent diameter assuming that all particles were spherical. Individual particle masses were then calculated from these volumes using bulk particle densities. The LeMont generated mass median aerodynamic diameters for the total exogenous and silica categories given were calculated from the equation

$$MMAD=MMD \times \rho^{1/2}, \qquad (2)$$

where MMAD is the mass median aerodynamic diameter, MMD is the mass median diameter, and ρ is the bulk particle density.

The data in Tables 14 and 15 were derived from the log-probability plots of the LeMont-generated circular area equivalent diameter data for each lung.

For lungs in which the individual circular area equivalent diameters were log-normally distributed and at least 250 particles were sized, a second set of mass median diameters were calculated using the Hatch-Choate equation (21).

$$\log MMD = \log d_n + 6.908 \log^2 \sigma_g \qquad (3)$$

where d_n is the number median diameter and σ_g is the geometric standard deviation determined from the log-probability plots of the size data. A second set of mass median aerodynamic diameters were then calculated using equation 2 with the second set of MMD values determined by equation 3.

Particle composition/concentration data for each of the 22 lungs analyzed in this study are summarized in Tables 16-21. The particle composition/ concentration data shown in Tables 16-19 for the 21 lungs for which single pieces of lung tissue were analyzed are summarized in Table 22.

3.4 DISCUSSION

A major goal of this work was to determine the size range of silica particles retained within the lung. This information could then be used to develop the appropriate technology to control silica exposure in the mines. As is shown in Figure 7, the silica number median diameter distribution for the 21 lungs for which a single piece of tissue was analyzed is relatively narrow, ranging from 0.50 to 0.83 micrometers. The data from lung 22 for which different sites were sampled and analyzed further indicate that the differences in sizes retained vary little (0.50-0.66) within an individual lung.

One might question whether there is something unique about this set of 22 lungs and whether the distribution of number median diameters shown in Figure 7 is atypical. To answer this question, the number median diameters for the silica particles found in the analyses of 87 lungs from subjects from the Cincinnati, Ohio urban area is shown in Figure 8. The instrumentation and procedures used to generate the data in Figure 8 were the same as used for the coal miner lungs. As is shown by this data, the number median diameter distribution for silica in the 87 urban lungs is quite comparable to that seen in the coal miners. Greater than 70% of the silica number median diameters for both lung sets fall between 0.5 and 0.8 micrometers. It is clear from this data that the lung is an excellent size selector and that all lungsoperate similarly in this size retention process. Thus in the mines, it is silica particles less than 1 micrometer in physical diameter which must be controlled since these particles form the bulk of the particles retained by the lung.

In addition to number median diameters, size data is also presented in Tables 12-15 in terms of mass median and mass median aerodynamic diameters (MMD and MMAD). The LeMont mass median diameter data (Tables 12 and 13) must be considered <u>gross</u> approximations since the assumption of spherical shape used in the calculation of the data is obviously poor. Furthermore, this calculated MMD is drastically and unrealistically affected by the presence of one or two large particles. For example, the calculated silica MMD for lung 19 is 11.68 (Table 12). However, one large particle classified as silica accounted for almost 78% of the total mass of all 250 silica particles analyzed. Whether this one particle is statistically significant is very questionable. Much more reliable mass median diameters may be determined for log-normally distributed particle size data through application of the Hatch-Choate equation (Equation 3). Thus, the second set of mass median diameter data (Tables 14 and 15) should be used in any future applications of the data presented in this report.

Conversion of particle number/size data to aerodynamic particle data is very tenuous since size, shape, and density affect aerodynamic behavior (21). Thus all mass median aerodynamic diameter data shown in Tables 12-15 must be considered approximate at best with the LeMont data (Tables 12 and 13) being the poorer of the two sets since these data are so susceptible to small numbers of large particles as discussed earlier. While the mass median aerodynamic diameter data for silica shown in Table 14 must be regarded as fairly crude approximations, these data do imply that silica particles having aerodynamic diameters less than about seven micrometers must be controlled in the mining environment since in only three of the 35 specimens shown in Table 14 were the mass median aerodynamic diameters greater than seven micrometers.

The particle concentration data for the 21 lungs as summarized in Table 22 show considerable variation with a maximum of over a 38-fold difference in total exogenous particle concentrations seen. The range of silica concentrations was even larger with the maximum difference being over 92-fold. Similarly, large variations (Tables 20-21) were also seen within an individual lung (lung 22) for total exogenous particle concentration with over a six-fold range seen between the pigmented areas and over a 39-fold range seen between the pigmented areas and the adjacent non-pigmented areas. The range of silica concentrations seen within the same lung varied almost six-fold between pigmented areas and over 83-fold between the pigmented and non-pigmented areas.

The large variations in particle concentration between very small samples of tissue taken from the same lung illustrate the fact that the particle concentration data are representative <u>only</u> of the volume analyzed and are, most likely, not representative of the entire lung. One would expect, however, that larger pieces of tissue would be more representative than smaller pieces, i.e., there would be less overall variation in particle concentration between larger pieces than smaller pieces.

In general, one would expect much higher particle concentrations in coal miners' lungs than in the lungs of the general populace. Furthermore, if the particulate burden of "normal" lungs can be assumed to arise from the earth's crust, one would expect the types of inorganic particles found in the miners' lungs to be similar in composition to those in normal lungs. To this end, particle concentration data from the 87 Cincinnati, Ohio subjects is presented in Table 23. The data in Table 23 is representative of the <u>average lung particle concentrations</u> since aliquots of whole lung homogenates were analyzed in this study. While the particle concentration data for the 21 miner lungs as summarized in Table 22 may not be representative of the entire lungs for these subjects, it is readily apparent that the individual pieces of tissue from these lungs which were analyzed in this study generally contain much higher average total exogenous (six-fold), silica (eight-fold), and aluminum silicate (nine-fold) particle concentrations than the urban lungs. Moreover, beyond these apparent differences in various particle concentrations, there is a close similarity between the miners' lungs and the urban lungs in terms of the type of particles found with aluminum silicates, silica, and rutile-like particles being the top three particle types in both lung sets.

One final point of interest in the coal miners' lungs is the correlation, if any, between overall silica concentration level and the incidence of silicosis. Bearing in mind the potential for wide concentration variations within the lung and the fact that the light microscopic silicosis evaluations may have been made on sections of tissue far removed from the area where the tissue for particle analysis was taken, there does seem to be a general correlation between silica concentration and the silicosis diagnosis. Lungs 1, 6-10, and 16 were diagnosed as having silicosis. Of these, lungs 8, 9, 1, 16, and 7 had, in order, the highest silica concentrations seen in the 21-lung set. Lungs 6 and 10 were ranked ninth and sixteenth respectively in silica concentration.

3.5 SUMMARY AND CONCLUSION

The particulate burdens of lung tissue from 21 coal miners were determined using SEM-based automated image analysis. The selected subjects represented varied medical histories and mining experience, both in terms of job setting and tenure. Particle size data for the 21 coal miner lungs were quite similar despite the varied medical and work histories. The median circular area equivalent diameters for the exogenous particles in the 21 lungs ranged from 0.47 to 0.87 µm. Median diameters for silica ranged from 0.50 to 0.83 µm while the aluminum silicate median diameters ranged from 0.6 to 0.95 µm.. The number median diameter distribution for silica in urban lungs is quite comparable to that seen in coal miners with greater than 70% of silica median diameters for both lung sets falling between 0.5 and 0.8 µm.

TABLE 9. - Coal Miner Specimen Information

Lung	Age at Death	Years in Mining	Job Classification	Cause of Death	Silicosis
1	57	14	Motorman	Cardiac	Yes
2	53	16	Coal loader	Cardiac	No
3	38	11	Coal loader	Cardiac	No
4	41	8	Miner operator	Accident	No
5	43	23	Roof bolter	Cardiac	No
6	53	32	Motorman	Cardiac	Yes
7	60	35	Coal loader	Renal Insufficiency	Yes
8	52	23	Buggy operator	Tuberculosis	Yes
9	53	32	Brakeman	Drowning	Yes
10	66	30	Coal loader	Chronic lung Disease	Yes
11	23	NA*	Longwall faceman	Accident	No
12	31	NA	Longwall mechanic	Accident	No
13	28	NA	Loading machine operator	Accident	No
14	28	NA	Beltman	Accident	No
15	32	NA	Longwall cornerman	Accident	No
16	58	39	Foreman	Accident	Yes
17	37	17	Miner operator	Accident	No
18	26	6	Jack setter	Accident	No
19	30	8	Electrician/mechanic	Accident	No
20	45	26	Miner operator	Accident	No
21	56	17	Shuttle car operator	Accident	No

*NA = not available

TABLE 10. - Analyzed Elements and X-ray Windows

Element	Left Background Window keV	Peak Window keV	Right Background Window kev
Na	0.92-0.94	1.00-1.08	1.14-1.16
Mg	1.14-1.16	1.22-1.30	1.36-1.38
Al	1.36-1.38	1.44-1.52	1.58-1.60
Si	1.58-1.60	1.70-1.78	1.88-1.90
P	1.88-1.90	1.98-2.06	2.16-2.18
S	2.16-2.18	2.26-2.34	2.48-2.50
Cl	2.48-2.50	2.58-2.66	2.78-2.80
Cd	2.92-2.98	3.10-3.16	3.18-3.18
K	3.18-3.18	3.26-3.34	3.40-3.40
Sn	3.40-3.40	3.42-3.46	3.52-3.54
Ca	3.52-3.54	3.66-3.74	3.84-3.86
Sc	3.84-3.86	4.06-4.14	4.32-4.34
Ti	4.32-4.34	4.48-4.56	4.72-4.74
V	4.72-4.74	4.92-5.00	5.20-5.22
Cr	5.20-5.22	5.38-5.46	5.66-5.68
Mn	5.66-5.68	5.86-5.94	6.14-6.16
Fe	6.14-6.16	6.36-6.44	6.62-6.64
Co	6.74-6.76	6.90-6.98	7.04-7.08
Ni	7.24-7.26	7.44-7.52	7.68-7.70
Cu	7.84-7.86	8.00-8.08	8.22-8.24

TABLE 10 (continued) - Analyzed Elements and X-Ray Windows

Element	Left Background Window keV	Peak Window keV	Right Background Window keV
W	8.22-8.24	8.34-8.44	8.56-8.56
Zn	8.56-8.56	8.60-8.68	8.84-8.90
Hg	9.66-9.74	9.94-10.02	10.22-10.30
Pb	10.22-10.30	10.50-10.60	10.82-10.90
Se	10.82-10.90	11.20-11.28	11.48-11.56
Br	11.48-11.56	11.88-11.96	12.38-12.46
Sr	13.68-13.76	14.14-14.22	14.46-14.54
Y	14.46-14.54	14.90-14.98	15.30-15.38
Zr	15.30-15.38	15.70-15.78	16.14-16.22
Nb	16.14-16.22	16.54-16.62	17.02-17.10
Mo	17.02-17.10	17.40-17.48	17.70-17.78

TABLE 11. - Chemistry Definition File - Major Particle Classes

Major Class	Allowable Net Fractional X-ray Intensity
Silica	$0.90 \le Si \le 1.00$
	$0.00 \le Df^{a} \le 0.10$
Aluminum Silicate	$0.10 \le Al \le 0.50$
	$0.50 \le Si \le 0.90$
	$0.00 \le Df \le 0.50$
Magnesium Silicate	$0.05 \le Mg \le 0.50$
	$0.00 \le Fe \le 0.50$
	$0.50 \le Si \le 0.90$
	$0.00 \le Al \le 0.05$
	$0.00 \le Df \le 0.001$
Iron Oxide-like	$0.90 \le Fe \le 1.00$
	$0.00 \le P \le 0.001$
	$0.00 \le Df \le 0.10$
Rutile-like	$0.90 \le Ti \le 1.00$
	$0.00 \le Df \le 0.10$
Alumina-like	$0.90 \le Al \le 1.00$
	$0.00 \le Df \le 0.10$
Combination-Endogenous	$0.01 \le P \le 1.00$
	$0.00 \le Zr \le 0.001$
	$0.00 \le Y \le 0.001$
	$0.00 \le Df \le 0.99$
Silicon Rich	$0.50 \le Si \le 0.90$
	$0.00 \le Zr \le 0.001$
	$0.00 \le Df \le 0.50$
Iron Rich	$0.50 \le Fe \le 0.90$
	$0.00 \le Df \le 0.50$
Titanium Rich	$0.50 \le Ti \le 0.90$
	$0.00 \le Df \le 0.50$

[a] Df refers to the fractional x-ray contribution of all remaining elements not previously specified in a class.

TABLE 11 (continued). - Chemistry Definition File - Major Particle Classes

Major Class	Allowable Net Fractional X-ray Intensity
Other Aluminum Silicates	$0.10 \leq Al \leq 0.50$ $0.10 \leq Si \leq 0.50$ $0.00 \leq Df \leq 0.70$
No X-rays	$0.00 \leq Df \leq 0.001$
Aluminum Rich	$0.50 \leq Al \leq 0.90$ $0.00 \leq Df \leq 0.50$
Miscellaneous	No requirements. All remaining particles are placed in this class.

TABLE 12. - Silica Particle Size Data for Lungs 1-22 (LeMont)

Lung	Number of Particles Analyzed	Number Median Diameter (um)	Mass Median Diameter (um)	Mass Median Aerodynamic Diameter (um)
1	397	0.66	2.01	3.28
2	89	0.81	2.55	4.17
3	62	0.76	1.51	2.46
4	312	0.82	2.15	3.51
5	226	0.63	2.34	3.82
6	451	0.62	2.35	3.84
7	436	0.58	2.62	4.28
8	608	0.74	2.27	3.70
9	705	0.53	2.24	3.65
10	483	0.62	2.97	4.85
11	403	0.54	2.17	3.54
12	349	0.62	2.39	3.89
13	705	0.50	1.91	3.11
14	391	0.60	3.54	5.78
15	466	0.59	1.88	3.07
16	385	0.60	1.74	2.84
17	392	0.83	2.48	4.04
18	480	0.77	2.01	3.28
19	250	0.67	11.68	19.04
20	193	0.71	2.52	4.10
21	270	0.73	3.17	5.17
Lung 22				
U-1	456	0.54	2.47	4.03
U-2	428	0.58	3.36	5.48
U-3	531	0.59	6.46	10.54
U-4	442	0.51	3.56	5.81
U-5	449	0.54	3.28	5.34
U-6	523	0.66	2.14	3.48
Control 1-6	610	0.54	4.13	6.74
L-1	659	0.53	2.25	3.66
L-2	438	0.50	2.24	3.65
L-3	489	0.51	1.90	3.10
L-4	375	0.51	2.63	4.29
L-5	391	0.56	2.30	3.76
L-6	325	0.55	3.82	6.23
Control 1-6	261	0.50	1.65	2.69

TABLE 13. - Total Exogenous Particle Size Data for Lungs 1-22 (LeMont)

Lung	Number of Particles Analyzed	Number Median Diameter (um)	Mass Median Diameter (um)	Mass Median Aerodynamic Diameter (um)
1	1382	0.70	4.19	7.25
2	1063	0.76	3.86	6.69
3	536	0.87	6.90	11.96
4	1727	0.71	2.93	5.07
5	1086	0.61	2.99	5.18
6	1334	0.72	3.78	6.54
7	1469	0.70	2.97	5.14
8	2449	0.80	3.60	6.23
9	2069	0.65	3.83	6.64
10	1087	0.70	4.89	8.47
11	1048	0.55	2.71	4.69
12	1049	0.61	3.45	5.97
13	1342	0.54	2.50	4.33
14	1164	0.61	4.03	6.97
15	1134	0.47	2.66	4.60
16	1102	0.60	3.61	6.25
17	1624	0.86	5.10	8.83
18	2148	0.78	3.82	6.62
19	1091	0.73	5.96	10.33
20	1123	0.72	4.13	7.14
21	1110	0.67	3.77	6.53
Lung 22				
U-1	1093	0.54	2.77	4.80
U-2	1024	0.56	3.40	5.89
U-3	1035	0.56	16.66	28.85
U-4	1094	0.53	4.51	7.81
U-5	1021	0.51	5.43	9.41
U-6	1125	0.63	2.98	5.17
Control 1-6	1099	0.50	7.31	12.66
L-1	1467	0.53	2.52	4.36
L-2	1098	0.50	2.44	4.23
L-3	1098	0.51	3.34	5.79
L-4	1120	0.52	3.22	5.58
L-5	1157	0.59	2.86	4.95
L-6	1053	0.57	2.88	4.99
Control 1-6	1167	0.51	4.75	8.15

TABLE 14. - Silica Particle Size Data for Lungs 1-21 (Graphical/Hatch-Choate)

Lung	Number of Particles Analyzed	Number Median Diameter (um)	Geometric Standard Deviation	Mass Median Diameter (um)	Mass Median Aerodynamic Diameter (um)
1	397	0.66	2.03	2.94	4.82
2	89	----	----	----	----
3	62	----	----	----	----
4	312	0.80	2.04	3.62	5.95
5	226	----	----	----	----
6	451	0.65	2.13	3.60	5.91
7	436	0.60	2.00	2.55	4.19
8	608	0.75	2.05	3.51	5.77
9	705	0.55	1.87	1.79	2.94
10	483	0.62	2.35	5.58	9.16
11	403	0.54	2.05	2.53	4.15
12	349	0.63	2.23	4.34	7.14
13	705	0.50	2.07	2.45	4.02
14	391	0.60	2.17	3.61	5.94
15	466	0.58	2.05	2.71	4.45
16	385	0.59	1.95	2.26	3.72
17	392	0.84	1.95	3.18	5.23
18	480	0.74	1.92	2.65	4.35
19	250	0.66	1.97	2.66	4.38
20	193	----	----	----	----
21	270	0.69	2.12	3.74	6.14
Lung 22					
U-1	456	0.55	1.93	2.01	3.31
U-2	428	0.61	2.32	5.12	8.42
U-3	531	0.61	2.03	2.74	4.50
U-4	442	0.49	2.12	2.68	4.40
U-5	449	0.54	2.26	3.93	6.45
U-6	523	0.63	2.02	2.78	4.57
Control 1-6	610	0.53	2.23	3.65	6.00
L-1	659	0.55	2.14	3.13	5.15
L-2	438	0.51	2.20	3.32	5.45
L-3	489	0.52	2.07	2.55	4.19
L-4	375	0.49	2.10	2.57	4.21
L-5	391	0.53	2.19	3.37	5.54
L-6	325	0.53	2.18	3.27	5.38
Control 1-6	261	0.48	2.12	2.64	4.34

TABLE 15. - Total Exogenous Particle Size Data for Lungs 1-21 (Graphical/Hatch-Choate)

Lung	Number of Particles Analyzed	Number Median Diameter (um)	Geometric Standard Deviation	Mass Median Diameter (um)	Mass Median Aerodynamic Diameter (um)
1	1382	0.71	2.14	4.07	7.04
2	1063	0.74	2.50	9.17	15.88
3	536	0.90	2.40	9.04	15.65
4	1727	0.72	2.05	3.39	5.87
5	1086	0.62	2.09	3.18	5.51
6	1334	0.73	2.22	4.90	8.48
7	1469	0.70	2.16	4.14	7.17
8	2449	0.80	2.12	4.33	7.50
9	2069	0.67	2.07	3.31	5.72
10	1087	0.70	2.52	9.12	15.79
11	1048	0.55	2.12	3.02	5.24
12	1049	0.63	2.33	5.37	9.30
13	1342	0.54	2.18	3.35	5.80
14	1164	0.62	2.32	5.25	9.10
15	1134	0.50	2.05	2.34	4.06
16	1102	0.61	2.08	3.04	5.27
17	1624	0.89	2.17	5.35	9.27
18	2148	0.78	2.08	3.87	6.71
19	1091	0.80	2.41	8.18	14.17
20	1123	0.72	2.26	5.32	9.22
21	1110	0.67	2.20	4.35	7.54
Lung 22					
U-1	1093	0.56	2.12	3.00	5.19
U-2	1024	0.59	2.31	4.81	8.34
U-3	1035	0.58	2.17	3.51	6.08
U-4	1094	0.54	2.15	3.13	5.41
U-5	1021	0.53	2.22	3.61	6.25
U-6	1125	0.60	2.12	3.32	5.76
Control 1-6	1099	0.50	2.32	4.23	7.33
L-1	1467	0.55	2.19	3.49	6.05
L-2	1098	0.50	2.16	2.95	5.12
L-3	1098	0.52	2.16	3.09	5.35
L-4	1120	0.52	2.22	3.49	6.04
L-5	1157	0.57	2.14	3.24	5.62
L-6	1053	0.57	2.31	4.63	8.03
Control 1-6	1167	0.52	2.41	5.28	9.15

TABLE 16. - Particle Concentration/Composition Data for Lungs 1-5

Particle Type	Particle Concentration (millions/g of dry lung)				
	Lung 1	Lung 2	Lung 3	Lung 4	Lung 5
Total Exogenous	4997	1644	257	5972	2736
Silica	1440	135	27	1078	567
Aluminum Silicate	2923	488	138	3962	1942
Magnesium Silicate	62	13	9	63	8
Rutile-like	207	39	0	195	53
Alumina-like	11	8	1	132	3
Exog.-Endog. Comb.[a]	50	743	72	60	25
Silicon Rich	120	41	3	17	35
Iron Rich	37	35	2	198	5
Titanium Rich	69	30	6	167	51
Other Aluminum Silicates	25	20	1	21	5
Aluminum Rich	36	6	0	38	10
Miscellaneous	18	87	3	42	33

[a] Exog.-Endog. Comb. is a subclass of "Combination Endogenous" (Table 3). Particles in this subclass have a major exogenous component in addition to an endogenous component and are considered to be of exogenous origin.

TABLE 17. - Particle Concentration/Composition Data for Lungs 6-10

Particle Type	Particle Concentration (millions/g of dry lung)				
	Lung 6	Lung 7	Lung 8	Lung 9	Lung 10
Total Exogenous	2788	3703	9991	5239	1097
Silica	946	1100	2484	1795	489
Aluminum Silicate	1178	2248	6943	3100	400
Magnesium Silicate	29	8	12	36	59
Rutile-like	38	149	257	122	56
Alumina-like	11	0	20	0	1
Exog.-Endog. Comb.	459	50	70	45	21
Silicon Rich	44	28	29	28	27
Iron Rich	4	20	4	23	5
Titanium Rich	27	88	94	59	8
Other Aluminum Silicates	11	5	37	10	7
Aluminum Rich	8	3	25	25	14
Miscellaneous	33	5	16	0	11

TABLE 18. - Particle Concentration/Composition Data for Lungs 11-15

	Particle Concentration (millions/g of dry lung)				
Particle Type	Lung 11	Lung 12	Lung 13	Lung 14	Lung 15
Total Exogenous	1261	1455	1039	1083	2592
Silica	494	484	548	362	1070
Aluminum Silicate	469	796	344	471	541
Magnesium Silicate	5	4	6	4	30
Rutile-like	93	45	44	65	679
Alumina-like	2	4	2	3	2
Exog.-Endog. Comb.	2	4	5	6	29
Silicon Rich	69	39	50	86	64
Iron Rich	10	8	6	9	21
Titanium Rich	75	42	13	50	55
Other Aluminum Silicates	2	4	2	1	12
Aluminum Rich	7	4	3	0	7
Miscellaneous	32	18	14	27	81

TABLE 19. - Particle Concentration/Composition Date for Lungs 16-21

	Particle Concentration (millions/g of dry lung)					
Particle Type	Lung 16	Lung 17	Lung 18	Lung 19	Lung 20	Lung 21
Total Exogenous	3868	2576	2376	509	3748	4129
Silica	1351	626	533	116	636	1005
Aluminum Silicate	2130	1629	1437	219	2512	2536
Magnesium Silicate	4	30	20	37	13	37
Rutile-like	113	51	45	7	44	216
Alumina-like	14	13	0	1	7	22
Exog.-Endog. Comb.	70	79	90	100	201	26
Silicon Rich	39	22	57	4	104	138
Iron Rich	35	10	42	7	67	34
Titanium Rich	60	18	27	3	57	48
Other Aluminum Silicates	0	35	38	1	67	15
Aluminum Rich	18	19	7	2	10	26
Miscellaneous	35	43	81	13	30	26

TABLE 20. - Particle Concentration/Composition Data for Lung 22 - Upper Lobe Specimens

Particle Type	Particle Concentration (millions/g of dry lung)						
	Upper Lobe Sample Identification						
	U-1	U-2	U-3	U-4	U-5	U-6	Control 1-6
Total Exogenous	12252	15243	4133	14784	12007	6376	1123
Silica	5090	6345	2125	5941	5250	2952	600
Aluminum Silicate	5217	6957	1352	6808	5009	2650	154
Magnesium Silicate	22	45	8	81	35	28	20
Rutile -like	382	433	129	393	366	182	69
Alumina -like	135	45	20	122	95	34	28
Exog. -Endog. Comb.	68	104	24	162	94	62	2
Silicon Rich	225	388	129	393	284	85	64
Iron Rich	292	224	129	353	366	108	91
Titanium Rich	157	194	93	122	130	74	40
Other Aluminum Silicates	67	105	16	149	47	57	7
Aluminum Rich	247	134	20	41	95	63	5
Misc.	349	269	89	217	236	80	42

TABLE 21. - Particle Concentration/Composition Data for Lung 22 - Lower Lobe Specimens

Particle Type	Particle Concentration (millions/g of dry lung)						
	LOWER Lobe Sample Identification						
	L-1	L-2	L-3	L-4	L-5	L-6	Control 1-6
Total Exogenous	27895	27674	25979	15944	18327	20788	710
Silica	12528	11033	11563	5330	6187	6394	150
Aluminum Silicate	12374	12593	11077	9218	10788	13380	161
Magnesium Silicate	75	50	378	70	0	18	1
Rutile -like	833	878	1058	508	377	364	24
Alumina -like	0	24	46	56	0	0	14
Exog. -Endog. Comb.	153	581	190	143	95	19	250
Silicon Rich	171	252	261	86	79	119	13
Iron Rich	357	373	512	94	139	146	37
Titanium Rich	284	276	353	155	316	174	8
Other Aluminum Silicates	209	151	24	57	111	40	4
Aluminum Rich	190	353	237	100	143	60	4
Misc.	722	1109	281	127	94	75	44

TABLE 22. - Summary Particle Data for 21 Coal Miner Lungs

	Particle Concentration (millions/g of dry lung)				
Particle Type	Mean	Standard Deviation	Minimum	Median	Maximum
Total Exogenous	3003	2267	257	2592	9991
Silica	823	594	27	626	2484
Aluminum Silicate	1734	1629	138	1437	6943
Magnesium Silicate	23	20	4	13	63
Rutile-like	120	147	0	56	679
Alumina-like	12	28	0	3	132
Exog.-Endog. Comb.	105	177	2	50	743
Silicon Rich	50	36	3	39	138
Iron Rich	28	42	2	10	198
Titanium Rich	50	38	3	50	167
Other Al Silicates	15	17	0	10	67
Aluminum Rich	13	11	0	8	38
Miscellaneous	31	25	0	27	87

TABLE 23. - Summary Particle Data for 87 Urban Lungs

	Particle Concentration (millions/g of dry lung)				
Particle Type	Mean	Standard Deviation	Minimum	Median	Maximum
Total Exogenous	477	380	71	374	1862
Silica	94	70	11	72	337
Aluminum Silicate	179	144	21	127	762
Magnesium Silicate	9	8	0	6	34
Rutile-like	55	115	2	29	942
Alumina-like	3	6	0	1	53
Exog.-Endog. Comb.	44	80	1	17	561
Silicon Rich	12	9	2	10	55
Iron Rich	22	23	1	15	145
Titanium Rich	14	12	1	10	67
Other Al Silicates	7	7	0	5	33
Aluminum Rich	22	22	1	13	115
Miscellaneous	15	13	1	11	63

FIGURE LEGENDS

Fig. 4a. Section of coal worker's lung (Case #16) illustrating a small silicotic nodule within the pulmonary interstitium. (Wilders X70)

Fig. 4b. Same lung as in Fig. 4a taken with cross polarizing filter. Area shown lies adjacent to a small silicotic nodule (not shown) and shows proliferating coal dust laden macrophages enmeshed in a connective tissue stroma. Note the distribution of birefringent particles. (H&E X180)

Fig. 4c. Regional lymphatic tissue from same case as Fig. 4a showing phagocytic cells containing dust (arrows). (H&E X450)

Fig. 4d. Same field as in Fig. 4c taken with cross polarizing filters showing birefringent particles. (H&E X450)

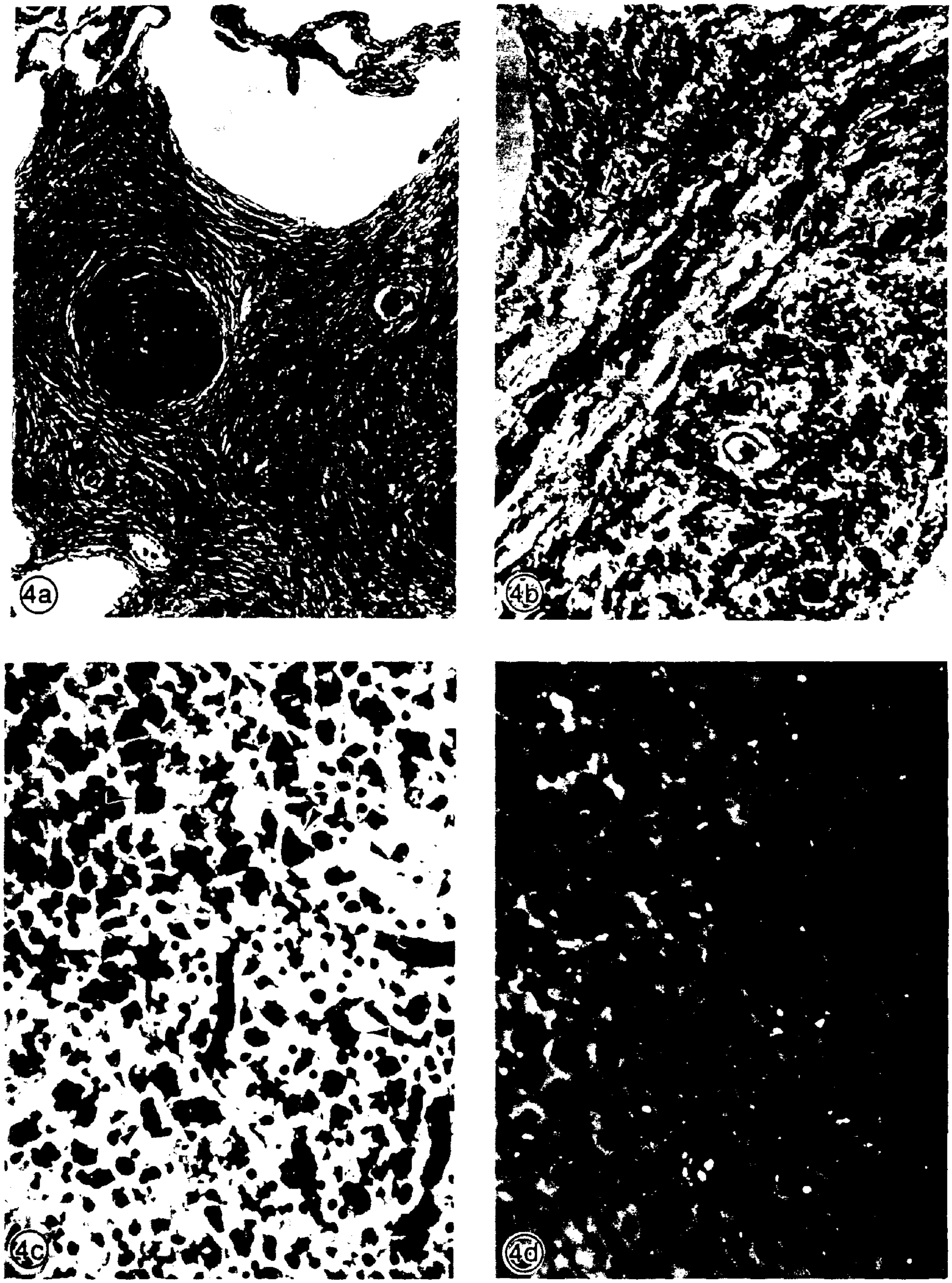
Fig. 5a. Secondary Electron Image (SEI) of lesion in silicotic lung of coal miner (Case 16). Particulate material is faintly apparent against the organic tissue matrix. (uncoated tissue section X2000)

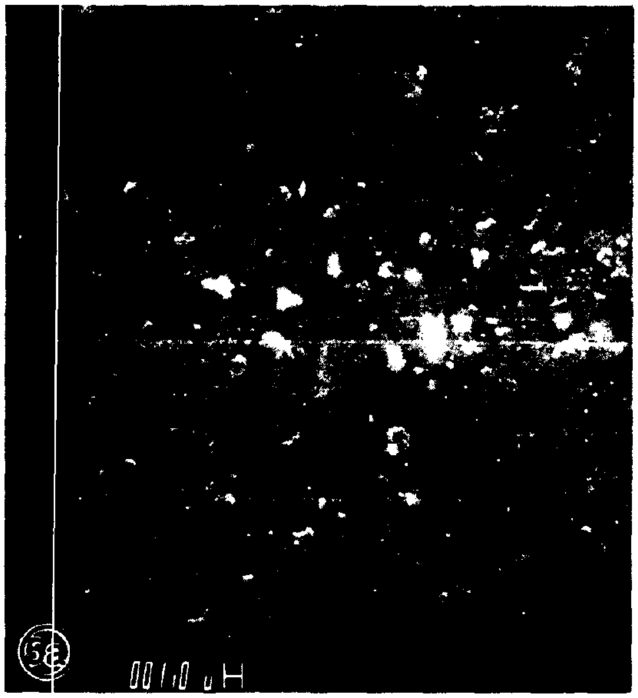
Fig. 5b. Same field using Backscattered Electron Imaging (BSI). Mineral particulate stands out against the organic matrix. (uncoated tissue section X2000)

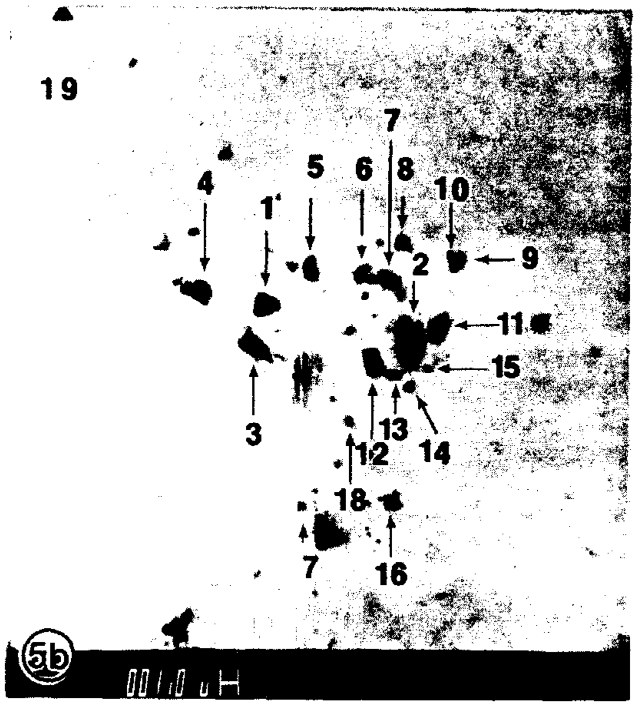
Fig. 5c–e Energy Dispersive Spectra of numbered particles in 5b. Fig. 5c Particles 1, 2, 5, 6, 7, 8, 9, 10, 12, 13, 14, 17, 18, 19. Fig. 5d Particle 11 and Fig. 5e Particles 3, 4, 16.

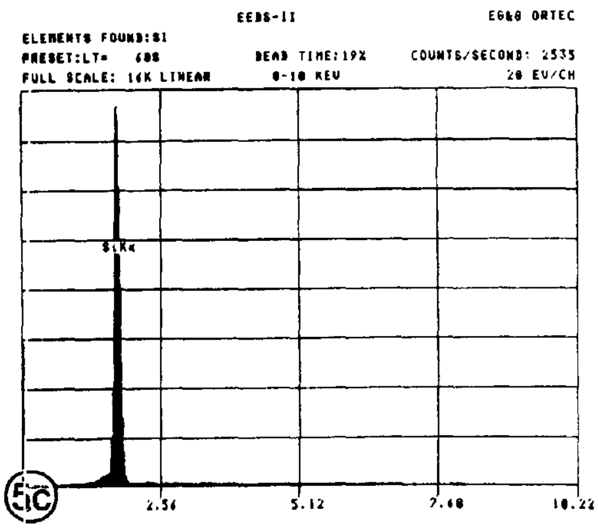
Fig. 6a. A Backscattered Electron Image (BEI) of a typical field of view from one of the ashed lung preparations.

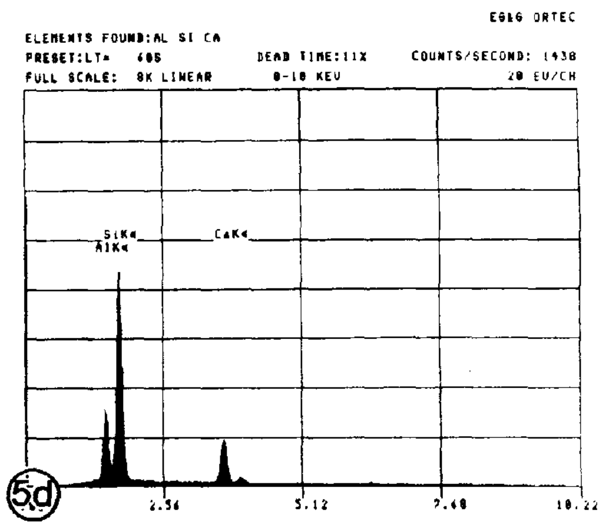
Fig. 6b–d Energy Dispersive Spectra of the indicated particles in 3a.

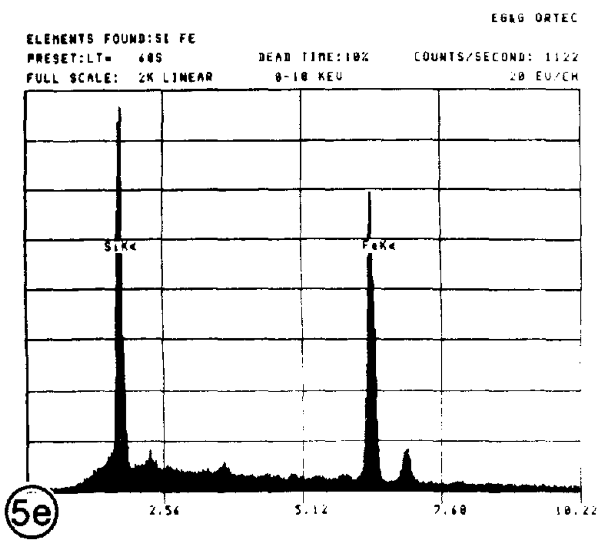

4a
4b
4c
4d

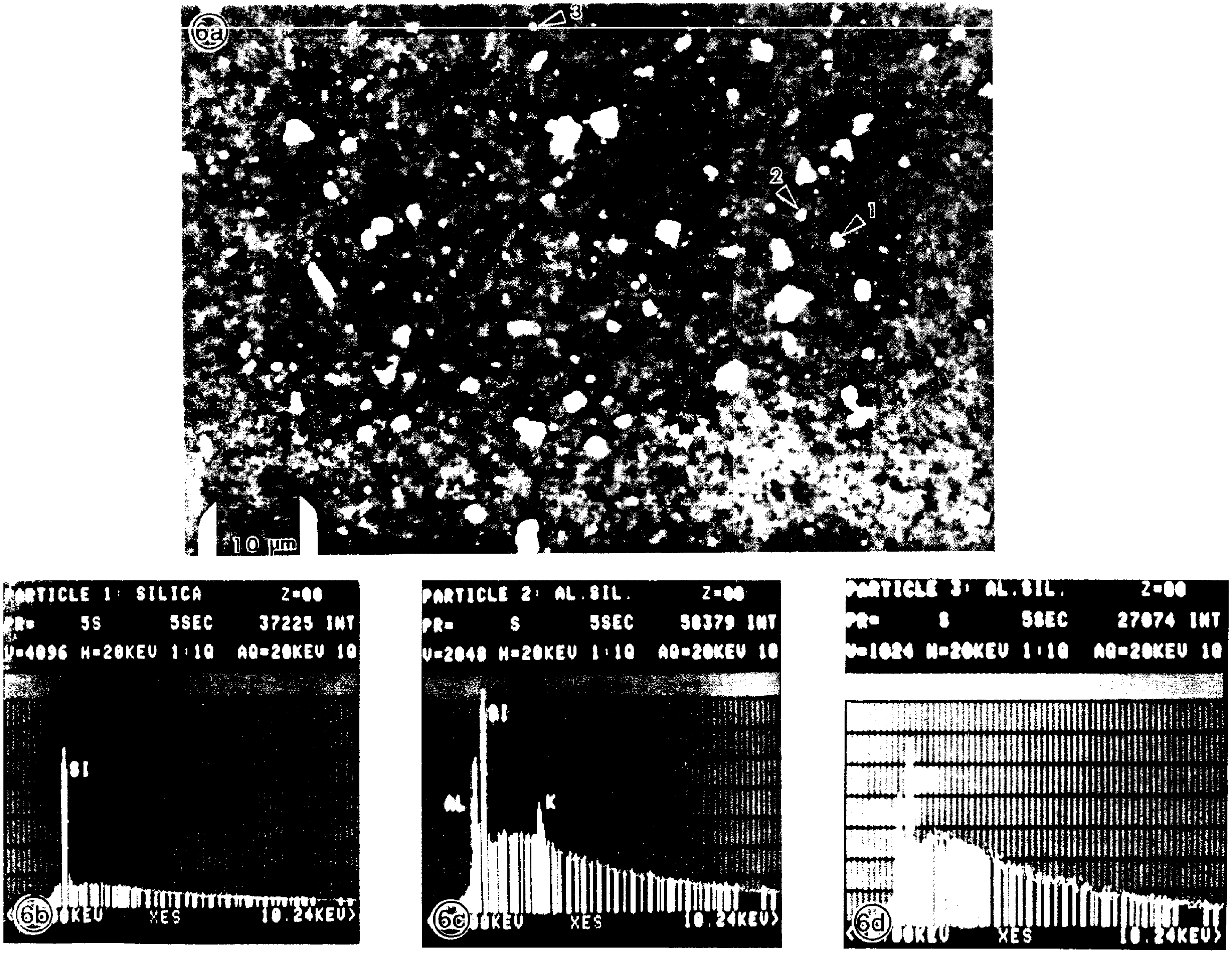

5a
001.0 uH


19
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
18
7
5b
001.0 uH


EEDS-II
EG&G ORTEC
ELEMENTS FOUND:SI
PRESET:LT= 60S
DEAD TIME:19%
COUNTS/SECOND: 2535
FULL SCALE: 16K LINEAR
0-10 KEV
20 EV/CH
SiKα
2.56
5.12
7.68
10.22
5c


EG&G ORTEC
ELEMENTS FOUND:AL SI CA
PRESET:LT= 60S
DEAD TIME:11%
COUNTS/SECOND: 1438
FULL SCALE: 8K LINEAR
0-10 KEV
20 EV/CH
SiKα
AlKα
CaKα
2.56
5.12
7.68
10.22
5d


EG&G ORTEC
ELEMENTS FOUND:SI FE
PRESET:LT= 60S
DEAD TIME:10%
COUNTS/SECOND: 1122
FULL SCALE: 2K LINEAR
0-10 KEV
20 EV/CH
SiKα
FeKα
2.56
5.12
7.68
10.22
5e


6a
3
2
1
10 µm
6b
PARTICLE 1: SILICA Z=00
PR= 5S 5SEC 37225 INT
V=4096 H=20KEV 1:10 AQ=20KEV 10
SI
0KEU XES 10.24KEV
6c
PARTICLE 2: AL.SIL. Z=00
PR= S 5SEC 50379 INT
V=2048 H=20KEV 1:10 AQ=20KEV 10
AL
SI
K
0KEU XES 10.24KEV
6d
PARTICLE 3: AL.SIL. Z=00
PR= S 5SEC 27074 INT
V=1024 H=20KEV 1:10 AQ=20KEV 10
XES 10.24KEV

REFERENCES

1. Banks, D. E., M. A. Bauer, R. M. Castellan, and N. L. Lapp. Silicosis in Surface Coal Mine Drillers. Thorax 38:275-278, 1983.

2. Seaton, A., J. A. Dick, J. Dodgson, and M. Jacobsen. Quartz and Pneumoconiosis in Coal Miners. Lancet Vol. 2 (8258):1272-1275, 1981.

3. Walton, W. H., J. Dodgson, G. G. Haddon, and M. Jacobsen. The Effect of Quartz and Other Non-coal Dusts on Coal Workers' Pneumoconiosis. In: Inhaled Particles IV edited by Walton W. H., Oxford, Pergammon, Vol. 2:669-690, 1977.

4. Cassidy, E. P. The National Coal Workers' Autopsy Study. Arch Pathol 94:133, 1972. Federal Coal Mine Health and Safety Act, Public Law 91-173, December 30, 1969.

5. Craighead, J. E., et al. Diseases Associated with Exposure to Silica and Non-fibrous Silicate Minerals. Report of Joint NIOSH/Silicosis and Silicate Disease Committee. Arch. Path. Lab. Med. 112:673-720, 1988.

6. Kleinerman, J., F. H. Y. Green, R. Harley, et al. Pathology Standards for Coal Workers' Pneumoconiosis. Arch. Path. Lab. Med. 103:375-431, 1979.

7. Laqueur, W. A. Final Report on the Pathology of Coal Workers' Pneumoconiosis and Related Investigations (PHS Grant #65-65-9), Beckley, WV, Appalachian Regional Hospital, 1966.

8. Parkes, W. R. Occupational Lung Disorders. Second Edition, Butterworth's, London, 7:146-151, 1982.

9. Ruckley, V. A., J. M. Fernie, J. S. Champman, et al. Comparison of Radiographic Appearances with Associated Pathology and Lung Dust Content in a Group of Coal Workers. Br. J. Indus. Med. 41:459-467, 1982.

10. Davis, J. M. G., J. Chapman, P. Collings, et al. Variations in the Histological Patterns of the Lesions of Coal Workers in Britain and their Relationship to Lung Dust Content. Am. Rev. Resp. Dis. Vol. 128:118-124, 1983.

11. Jacobsen, M., W. M. Maclaren. Unusual Pulmonary Observations and Exposure to Coal Mine Dust: A Case Control Study. Ann. Occup. Hyg. 26:753-765, 1982.

12. Green, F. H. Y, W. A. Laqueur. Coal Workers' Pneumooconisis. Path. Ann. 15:333-410, 1980.

13. Morgan, W.K.C., D. B. Burgess, G. Jacobson, et al. The Prevalence of Coal Workers' Pneumoconiosis in U.S. Coal Miners. Arch. Environ. Health 27:221-226, 1973.

14. Morgan, W. K. C., A. Seaton. Occupational Lung Diseases. Second Edition, W. B. Saunders Company, Philadelphia, 7:83-86, 1984.

15. Baier, E. J. Comparison of Dust Exposure in Pennsylvania Anthracite and Bituminous Coal Mines. Am. Indus. Hyg. Assoc. 25:476-480, 1964.

16. McBride, W. W., E. Pendergrass, and J. Lieben. Pneumoconiosis Study of Western Pennsylvania Bituminous Coal Miners. J. Occup. Med. 5:376-388, 1963.

17. Rossiter, C. E. Relation Between Content and Composition of Coal Worker's Lung and Radiological Appearances. Br. J. Ind. Med. 29:31-44, 1972.

18. Stettler, L. E., D. H. Groth, and S. F. Platek. Automated Characterization of Particulates Extracted from Human Lungs: Three Cases of Tungsten Carbide Exposure. Scan. Elect. Micros. I: 439-448, 1983.

19. Gylseth, B., L. E. Stettler, G. Mowe, V. Skaug, and B. Lexow. A Striking Deposition of Mineral Particles in the Lungs of a Farmer - A Case Report. Am. J. Ind. Med. 6: 231-240, 1984.

20. Stettler, L. E., S. F. Platek, R. D. Riley, D. H. Groth, and J. P. Mastin. Particle Contents of Urban Lungs - An Update, In "Microbeam Analysis"--1986, A. D. Romig and W. F. Chambers, Eds., San Francisco Press, San Francisco, 1986, pp. 547-550.

21. Stockham, J. D., E. G. Fochtman, Eds., Particle Size Analysis. Ann Arbor Science, Ann Arbor, 1977, pp. 1-12.