CHAPTER 19

KAOLIN PNEUMOCONIOSIS IN A GEORGIA MILL

Martin-José Sepulveda, MD, MPH, Val Vallyathan, PhD, Lloyd E. Stettler, PhD, Laurie Piacitelli and James H. Tucker

National Institute for Occupational Safety and Health
Morgantown, West Virginia

INTRODUCTION

Kaolin is a general term used to describe a group of clays whose principal component is the aluminum silicate kaolinite. In the United States, deposits are primarily concentrated in a belt extending from central Georgia to west central South Carolina. Kaolin is used in the manufacture of paper products, refractory materials and ceramics, and as a filler in plastics, rubber and paints.

In 1981 a hazard evaluation was conducted by the National Institute for Occupational Safety and Health (NIOSH) at a kaolin operation in Georgia. The facility under study was small by industry standards and included both an open pit mine and an adjacent mill. This chapter presents the results of medical, environmental and pathological studies performed in this evaluation and discusses the findings in relation to previously published data.

METHODS

Environmental

Exposure assessment included measurements of respirable dust, total dust, crystalline silica, fiber and trace metal content, and particle size distribution. Respirable dust and crystalline silica were measured in all job categories using personal sampling pumps that contained a cyclone preseparator. Total dust samples were collected with sampling pumps in designated work areas. Samples were obtained over full shifts, and tared filters were analyzed gravimetrically. Respirable crystalline silica content was determined by NIOSH Physical and Chemical Analytical Method 259 [1]. Aerodynamic particle sizing was performed with Andersen particle fractionators* that were stationed in four mill areas and in the baghouse. Air samples for fiber content were analyzed by electron microscopy [2], and elemental composition was determined by energy-dispersive X-ray spectrometry (XES).

Medical

The study population was defined to include all current workers. Former workers with a minimum of five years kaolin employment since January 1970 were also invited to participate. All workers were identified by the company from personnel records. The study population was composed entirely of males.

A modified British Medical Research Council (BMRC) questionnaire on respiratory disease was administered and a complete occupational history obtained on each worker. Lung function testing was performed on each worker consisting of forced expiratory maneuvers into an Ohio 840 waterless spirometer. Each worker performed at least five maneuvers, which were recorded electronically as flow-volume curves. From a minimum of three maneuvers meeting American Thoracic Society criteria [3], the highest FEV_1 (forced expiratory volume in one second) and FVC (forced vital capacity) values were selected. These were corrected to body temperature and pressure saturated with water vapor (BTPS).

Standard 14 X 17 inch posteroanterior roentgenograms of the chest were submitted by NIOSH for independent readings by three certified pneumoconiosis ("B") readers utilizing the 1971 ILO/UC Classification of Radiographs of the Pneumoconioses [4]. Radiographs were interpreted without knowledge of worker occupation or exposures. Pneumoconiosis was considered present if at least two of three readers categorized small opacity profusion as 1/0 or greater.

Pathology

Two workers in the study group had diagnostic lung biopsies available at the time of the study, and tissue blocks were obtained from each. Serial

*Mention of product names does not constitute endorsement by the U.S. Public Health Service (USPHS).

5-μ sections were prepared from the blocks and were stained with hematoxylin and eosin, Masson's trichrome (collagen), elastin, reticulin and Perl's iron stains. For analysis of particles in lung tissue, adjacent serial sections were mounted on carbon planchets and examined by scanning electron microscopy (SEM) with backscattered electron imaging. Elemental composition of particles was then determined by XES [5]. An ETEC Autoscan SEM equipped with a solid state backscattered electron detector and a Tracor Northern XES were employed for these studies.

Definitive identification of mineral inclusions was made in one biopsy, which had an adequate quantity of tissue. Particles were isolated from lung tissue sections by sodium hypochlorite digestion and low-temperature plasma ashing [5,6]. Mineral inclusions obtained by plasma ashing were analyzed for elemental composition by image analysis and XES. Randomly selected views at a magnification of 1000X were examined using the ISI Super III scanning electron microscope with a Kevex 7000 X-ray energy spectrometer and a LeMont Scientific DA-10 image analyzer. Morphologic, crystallographic and electron diffraction features of particles remaining after sodium hypochlorite digestion were studied by transmission electron microscopy and selected area electron diffraction using a JEOL 100CX electron microscope.

RESULTS

Environmental

Analysis of airborne dust for elemental composition, aluminum to silicon ratio and morphologic features demonstrated a composition of 96% kaolinite and 4% titanium dioxide. Airborne particle fractionation for five mill work stations adjacent to pulverizers and the baghouse showed respirable dust fractions (below 10 μ) exceeding 50%. Other locations sampled had 10–20% respirable dust fractions.

Total dust levels by work area are illustrated in Figure 1 and revealed prevalent exposure in excess of 10 mg/m^3 in three mill work stations. Personal respirable dust levels were obtained for the various occupations and the results are shown in Figure 2. Occupations of highest exposure for which more than two samples were collected were baghouse and bin-related work. No job-specific mean concentration was above the respirable dust threshold limit value (TLV) of 5 mg/m^3 recommended for nuisance particulates by the American Conference of Governmental Industrial Hygienists (ACGIH) [7]. Crystalline silica in respirable dust samples (n = 44) was examined and none was detected (limit of quantitation greater than or equal to 30 μg) [1].

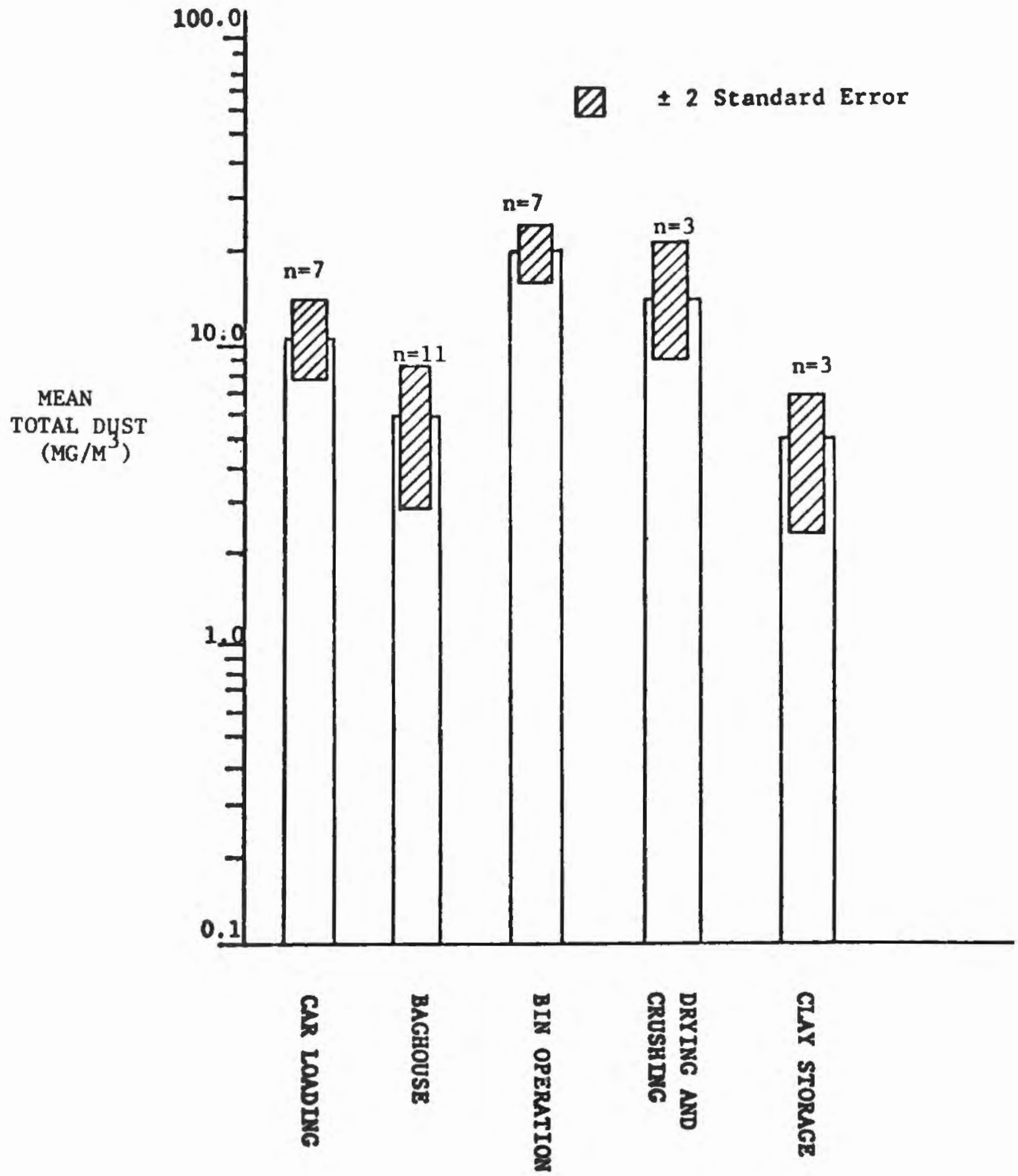

Figure 1. A histogram of the mean and standard error of area total dust measurements obtained during the days of health testing.

Medical

All current workers (n = 49) participated in the study (Table I), and 16 (76%) of 21 ex-workers with at least five years of kaolin exposure were also examined. Former workers were principally retirees, which is reflected in greater mean age and mean exposure-years compared to current workers.

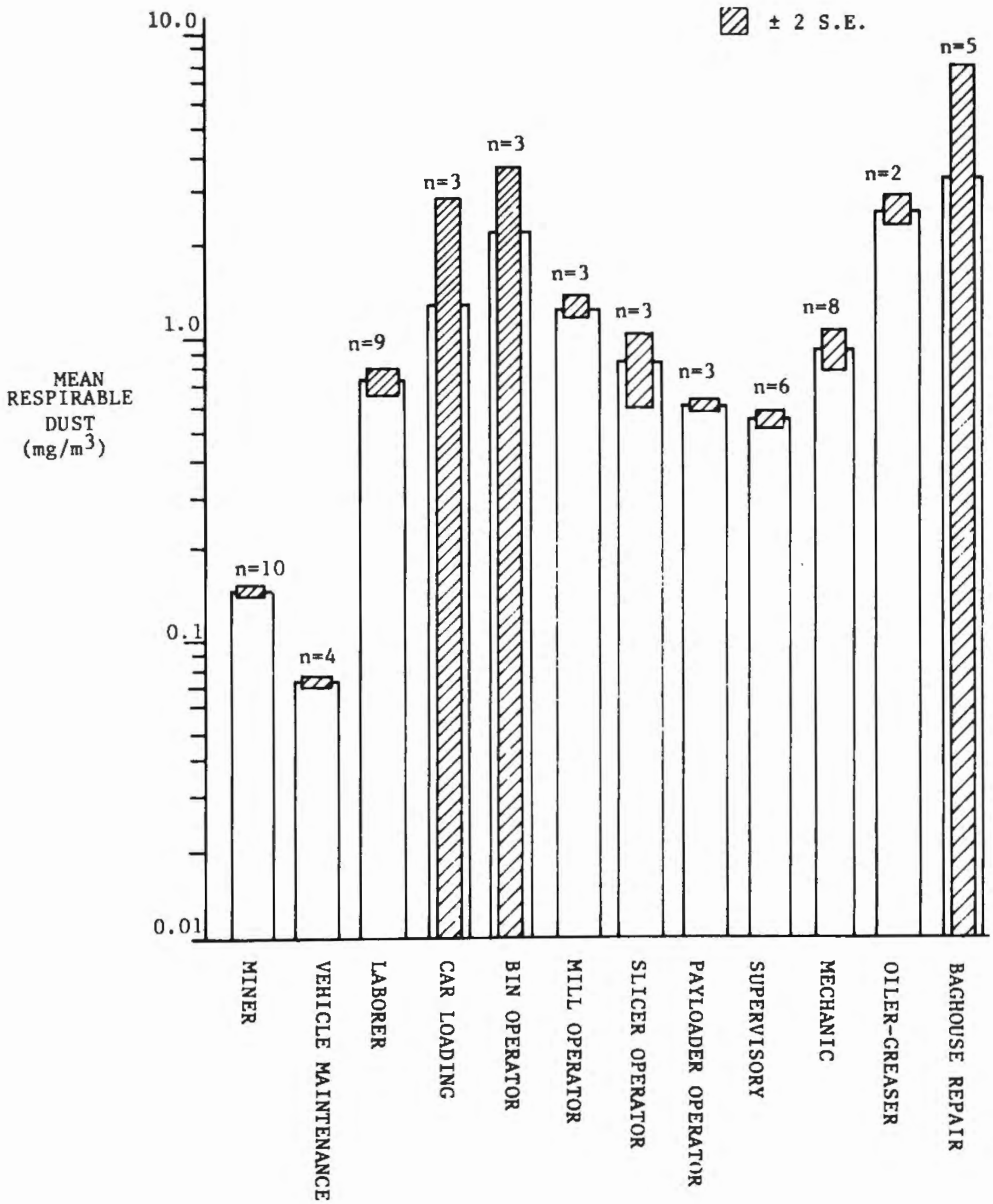

Figure 2. A histogram of the mean and standard error of respirable dust measurements by occupation.

The prevalence of pneumoconiosis by chest roentgenogram is shown for the study group in Table II. Pneumoconiosis was present in 11% of the current workers. Four workers had simple, and one had complicated, pneumoconiosis. Former workers with five or more years of kaolin exposure demonstrated a 19% prevalence rate of pneumoconiosis. All former workers

Table I. Demographic Characteristics of Participants

	Current Workers	Ex-workers–5 Years Tenure
Number	49	16
Percent participation	100	76
Mean age ± SE	44±2	61±3
Race		
Percent black	51	56
Mean exposure years ± SE	16±2	28±4
Smoking		
Percent current smokers	55	44
Mean pack-years ± SE	29±3	34±9

Table II. Prevalence of Pneumoconiosis by Chest Roentgenogram

	Number	Simple[a] Pneumoconiosis	Complicated[b] Pneumoconiosis	Total
Current Workers[c]	47	4	1	5 (11%)
Ex-workers ⩾ 5 Years Tenure	16	0	3	3 (19%)
Ex-workers ⩾ 5 Years Tenure + Current Workers	63	4 (6%)	4 (6%)	8 (13%)

[a]Category 1/0 or greater; ILO/UC 1971 Classification [4].
[b]Large opacities (greater than 1 cm) present in addition to small opacity profusion 1/0 or greater.
[c]Radiographs for two workers were not available.

with pneumoconiosis had conglomerate upper lobe lesions. None had past exposure to other environmental respiratory hazards.

The youngest and oldest workers with pneumoconiosis were 38 and 69 years old, respectively (Table III). Cumulative years of kaolin exposure exceeded 19 years in all but one worker with pneumoconiosis (15 years). Seven of eight workers with pneumoconiosis had dust exposure limited to mill work, and mill tenure was largely in the dustier occupations (bin operation, bulk loading and bagging). Pneumoconiosis was present in one worker who had been employed primarily as an open pit miner.

Seven of eight workers with pneumoconiosis performed lung function testing (Table IV). Three of four workers with simple pneumoconiosis had normal spirometry, and two of three workers with complicated disease had abnormal pulmonary function. The three workers with pneumoconiosis and abnormal lung function exhibited restrictive, obstructive and mixed deficits. All had prominent smoking histories.

Table III. Lung Function[a] and Related Data in Workers with Pneumoconiosis

						Lung Function		
Patient No.	Age (yr)	Smoking Status	Pack-Years	Tenure (yr)	Mill Jobs[b] (yr)	% Predicted FEV_1	% Predicted FVC	FEV_1/FVC
1[c]	69	SM	28	34	34	R[d]	R	R
2[c]	62	SM	22	26	26	32	56	45
3[c]	60	ES	21	35	18	89	91	77
4	61	ES	31	39	0	75	79	73
5	38	SM	22	15	15	98	93	86
6	44	ES	23	22	16	101	98	83
7[c]	56	ES	20	35	16	82	100	64
8	43	ES	2	20	7	87	91	78

[a]Knudson [8]; blacks 0.9 predicted values.
[b]Mill jobs: total years in bin, bagging, car loading and screen work.
[c]Complicated pneumoconiosis.
[d]Refused spirometry.

Table IV. Lung Function by Chest Roentgenogram Among Pneumoconiosis Cases

	Pneumoconiosis	
	Simple[a]	Complicated
Lung Function		
Normal	3	1
Obstructed[b]	–	1
Restricted[c]	1	–
Combined obstructed and restricted	–	1
Spirometry refused	–	1

[a]Simple pneumoconiosis = small opacities profusion 1/0.
[b]Obstructed: FEV_1/FVC less than 0.70.
[c]Restricted: % predicted FVC less than 80%.

Pathology

Lung biopsies in two participants with pneumoconiosis were examined by the previously described histologic and electron microscopic methods. Chest roentgenograms of the two workers showed category 2 disease in one (worker 8, Table III) and complicated pneumoconiosis in the other (worker 2, Figures 3 and 4). The biopsy specimens of both workers exhibited nodular lesions and diffuse fibrosis, with loose collagen and reticulin fibers

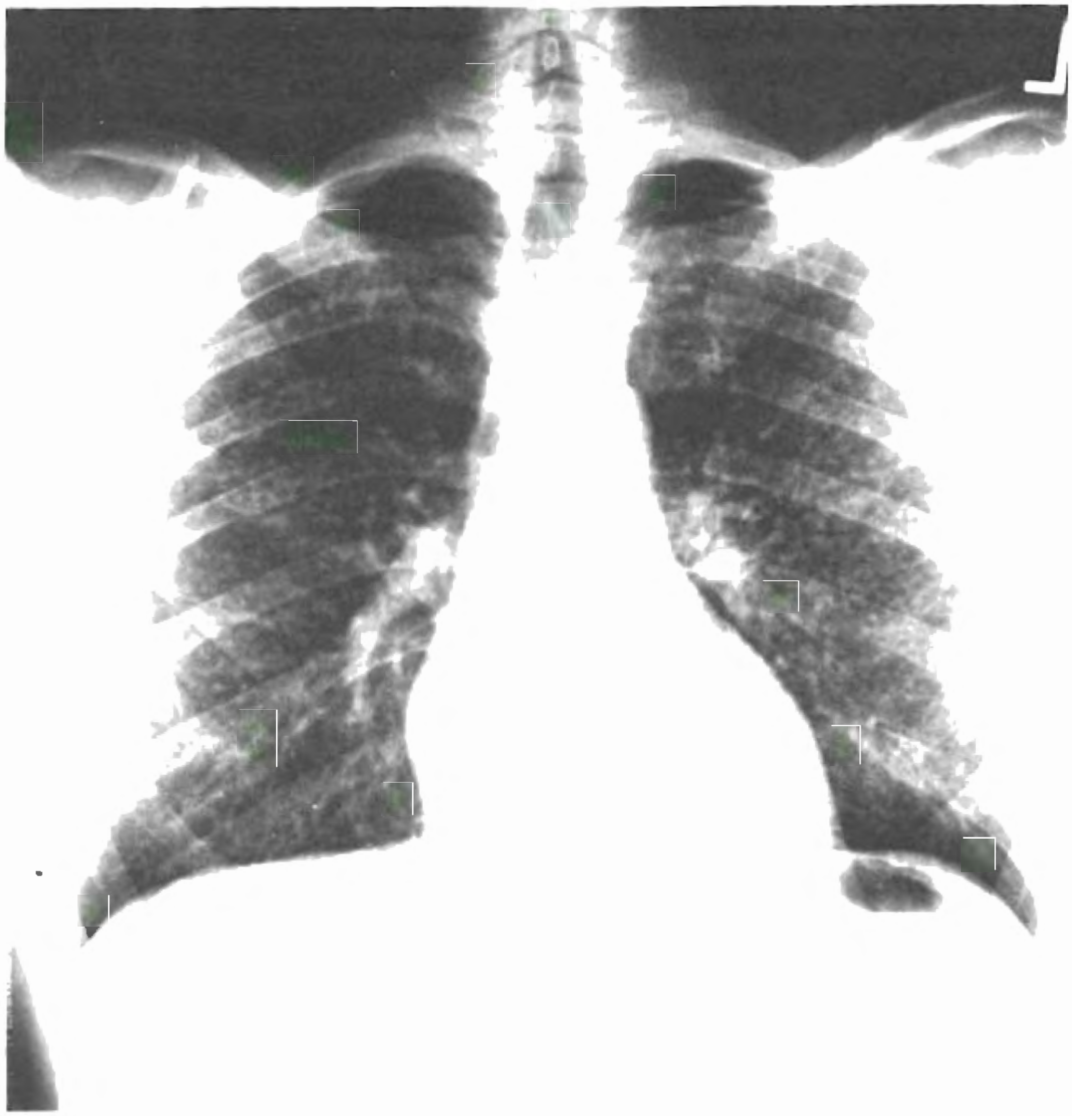

Figure 3. Chest roentgenogram of worker 8 (Table III) showing diffuse, bilateral small rounded opacities.

arranged in a haphazard pattern (Figure 5). Large numbers of weakly birefringent dust particles were embedded in the fibrous meshwork and in macrophages. SEM studies, with the aid of backscattered electron imaging, demonstrated numerous dust particles in the fibrotic lesions, and XES revealed inclusions to be composed primarily of aluminum and silicon (Figure 6).

Additional analysis of lung dust was performed on the biopsy of worker 2. After low-temperature plasma ashing, 1896 randomly selected lung particles were characterized by elemental composition using SEM with image analysis

Figure 4. Chest roentgenogram of worker 2 (Table III) showing complicated pneumoconiosis with conglomerate upper lobe lesions.

and XES. Of these, 85% were aluminum silicates, 5% aluminum iron silicates, 9% endogenous iron and less than 1% crystalline silica. Adjacent tissue sections were digested with sodium hypochlorite, and resulting particles were examined by transmission electron microscopy (TEM). Mineral inclusions were found to have morphologic and crystallographic features of kaolinite. Selected area electron diffraction of these particles confirmed the TEM findings by demonstrating characteristic kaolinite diffraction patterns (Figure 7) [9].

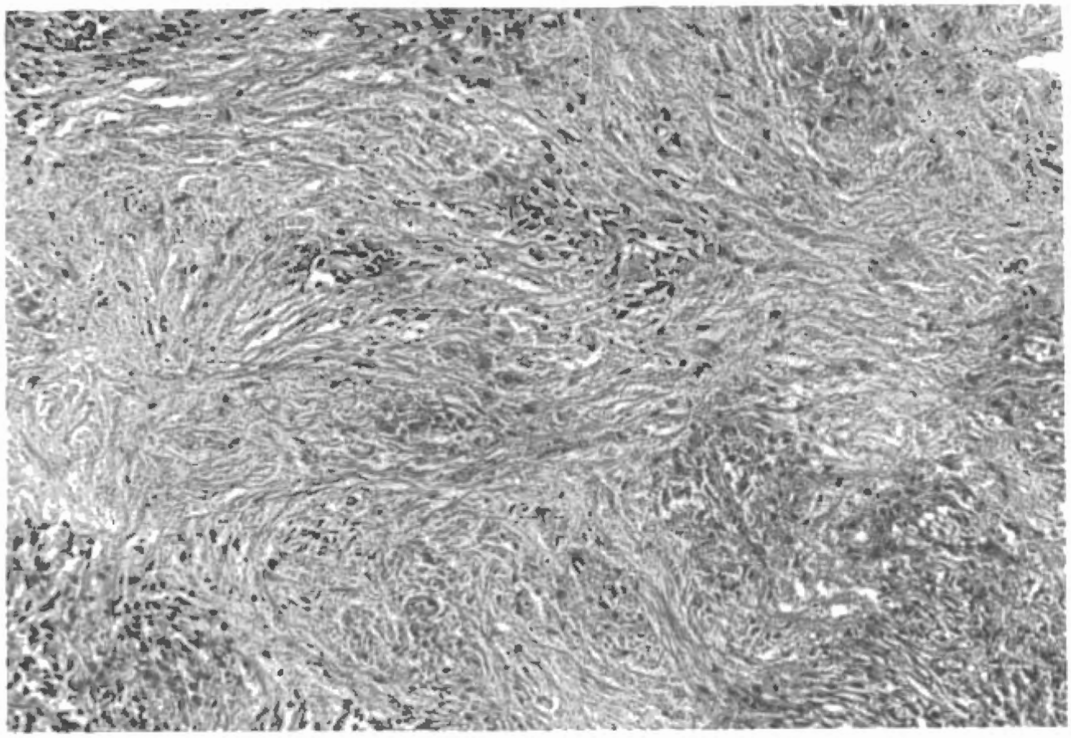

Figure 5. Photomicrograph of lung biopsy from worker 2 (Figure 4) showing diffuse fibrosis and an abundance of dust (haematoxylin and eosin stain, original magnification X163).

DISCUSSION

Radiographic evidence for pulmonary disease in china clay (kaolin) workers was reported by Middleton [10] in 1936. Pathologic findings in the pneumoconiosis of kaolin workers were subsequently described by Lynch and McIver [11] and Hale and co-workers [12]. Cross-sectional respiratory surveys of selected kaolin workers have been conducted and are summarized in Table V. The characteristic radiographic lesion appears to be diffuse, bilateral, fine discrete nodulation, which may be accompanied by massive conglomerate upper lobe lesions.

The present study reveals a prevalence rate of pneumoconiosis of 11% among current workers and 19% among 16 of 21 former workers with a minimum exposure to kaolin of 5 years. The radiographic spectrum of disease seen is consistent with previous observations (Table V) and includes pneumoconiosis of simple and complicated varieties. Cumulative years of kaolin exposure in the 8 workers with pneumoconiosis (mean = 28 years) supports the general notion of long exposure and latency period in this disease (Table V).

The environmental survey characterized dust exposure as pure kaolinite.

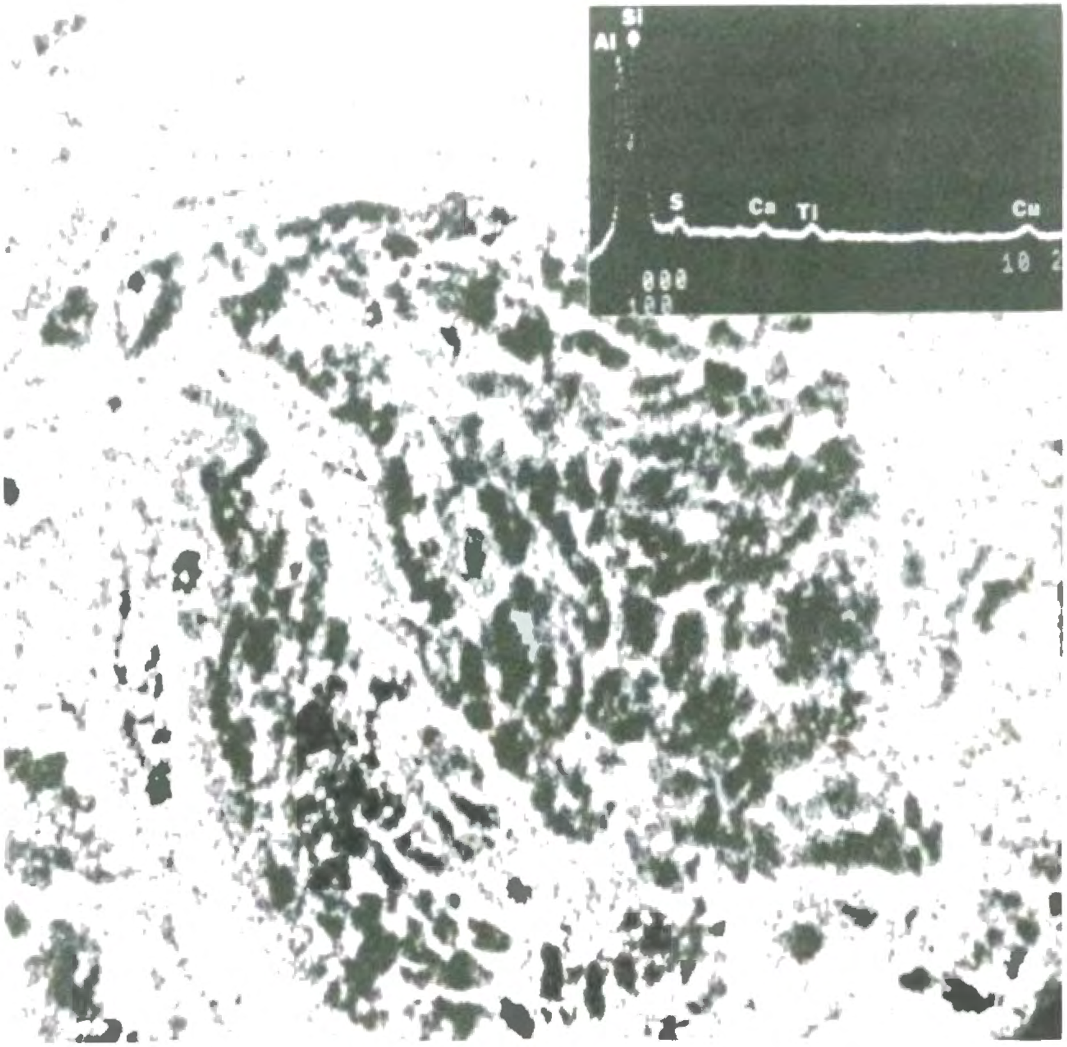

Figure 6. Back-scattered electron micrograph from the lung biopsy of worker 8 (Figure 3), illustrating numerous dust particles in the fibrous tissue meshwork (BEI mode of SEM; magnification ×285). *Insert*: Elemental profile of lung mineral inclusions observed by energy-dispersive X-ray spectrometry. Particles are seen to contain primarily aluminum and silicon.

Table V. Summary of Kaolin Pneumoconiosis Case Studies

Author	Country	Number of Workers	Prevalence of Pneumoconiosis (%)	Cumulative Years Exposure (cases)
Edenfield [13]	U.S.	1,130	3.7	42/44 >10
Warraki et al. [14]	U.A.R.	914	0.7	6/6 >15
Sheers [15]	Britain	553	9.0	34/48 >15
Rawlings et al. [16]	U.S.	404	8.9	NA[a]

[a]NA = not available.

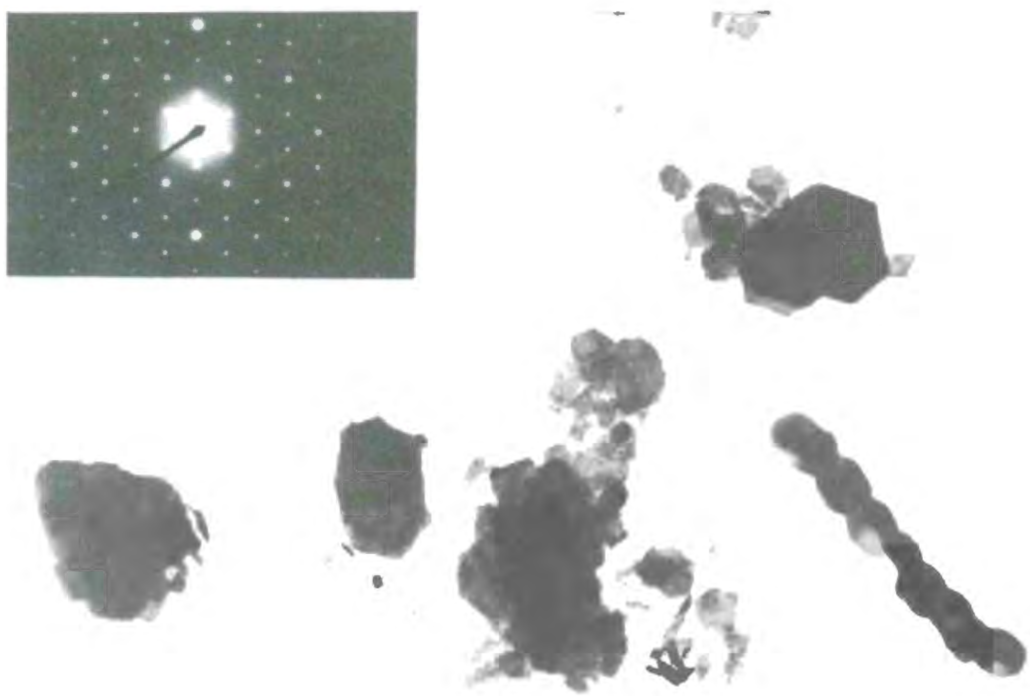

Figure 7. Transmission electron micrograph of lung particles isolated from tissue sections of worker 2's lung biopsy. Aggregates of pseudohexagonal plates typical of kaolinite are observed. (Original magnification ×6500). *Insert*: Selected area electron diffraction pattern seen in isolated lung particulates. Measurements made on the photomicrograph indicate that interplanetary distances are characteristic of kaolinite [9].

While crystalline silica exposure has been described in Missouri kaolin firebrick workers [17], none was detected by X-ray diffraction in numerous respirable dust samples at the present facility. As the workplace under study has historically exploited the same local kaolin seam, it is unlikely that crystalline silica has been present in higher concentrations in the past. Analytical electron microscopy studies of lung tissues in two cases supports this exposure assessment, particularly as regards the biopsy, where isolation of lung particulates and electron diffraction analyses were performed.

The absence of historical environmental data prohibits reliable estimation of past exposure. Whereas work conditions prior to 1970 were reported as considerably dustier, the addition of several pulverizers at that time raises the possibility of lower, but more respirable, exposures in recent years. It is not possible, therefore, to assess the relative contribution of dust exposure in the two time periods to observed cases of pneumoconiosis. In contrast to the levels of past exposure, the handling of milled kaolin in bagging and bulk loading operations was identified as a hazardous task. Seven of the eight workers with pneumoconiosis had substantial work experiences in these occupations. Similar observations have been made in kaolin workers with pneumoconiosis [13,15].

The current study documents the occurrence of pneumoconiosis in a group of kaolin workers. The findings cannot be extrapolated to other kaolin operations owing to potential differences in overburden, kaolin seams, crystalline silica and asbestos content, industrial process, dust control and levels of exposure. The pathogenic potential of crystalline silica-free kaolinite is supported, however, and the need for representative, controlled epidemiological studies in this industry is indicated. These may better characterize exposures, assess the effect of dust on lung function and generate reliable data on the occurrence of pneumoconiosis.

REFERENCES

1. National Institute for Occupational Safety and Health. Free silica in airborne dust. Washington, DC: Department of Health, Education and Welfare, National Institute for Occupational Safety and Health, 1977. (NIOSH manual of analytical methods) (DHEW publication no. (NIOSH) 77-157-A-1977).
2. National Institute for Occupational Safety and Health. Review and evaluation of analytical methods for environmental studies of fibrous particulate exposures. Washington, DC: Department of Health, Education and Welfare, National Institute for Occupational Safety and Health, 1977. (DHEW publication no. (NIOSH) 77-204).
3. American Thoracic Society. Standardization of spirometry. Am Rev Respir Dis 119:2–11, 1979.
4. International Labour Organization. International classification of radiographs of the pneumoconioses. Geneva: International Labour Organization, 1971.
5. Vallyatham NV, Green FHY, Craighead JE: Recent advantages in the study of mineral pneumoconiosis. In: Summers SC, Rosen PP, eds. Pathology annual part 2, vol. 15. New York: Appleton-Century-Crofts, 1980, pp. 79–82.
6. Thomas RS: Use of chemically reactive gaseous plasmas in preparation of specimens for microscopy. In: Hollahan JR, Ball AT, eds. Techniques and application of plasma chemistry. New York: Wiley-Interscience, 1974, p. 255.
7. American Conference of Governmental Industrial Hygienists. Threshold limit values 1981. Cincinnati, Ohio: American Conference of Governmental Industrial Hygienists.
8. Knudson RJ, Slatin RC, Lebowitz MD, Burrows B: The maximal expiratory flow-volume curve: normal standards, variability, and effects of age. Am Rev Respir Dis 113:587–600, 1976.
9. Brown G, ed.: Mineralogical Society of London Clay Minerals Group. X-ray identification and crystal structure of clay minerals. Norwick: Jerold & Sons Ltd, 1969, pp. 51–131.
10. Middleton EL: Industrial pulmonary disease due to inhalation of dust. Lancet 2:136, 1959.

11. Lynch KM, McIver FA: Pneumoconiosis from exposure to kaolin dust, kaolinosis. Am J Pathol 30:1117, 1954.
12. Hale LW, Gough J, King EJ, Nagelschmidt G: Pneumoconiosis in kaolin workers. Br J Ind Med 13:251, 1956.
13. Edenfield RW: A clinical and roentgenologic study of kaolin workers. Arch Environ Health 5:392–403, 1960.
14. Warraki S, Herant Y: Pneumoconiosis in china clay workers. Br J Ind Med 20:225, 1963.
15. Sheers G: Prevalence of pneumoconiosis in Cornish kaolin workers. Br J Ind Med 21:218–225, 1964.
16. Rawlings W, Kennedy T, Menkes H, Morgan R: Pulmonary function and respiratory symptoms in a population of Georgia kaolin workers. Am Rev Respir Dis 4:146, 1981.
17. Lesser M, Zia M, Kilburn KH: Silicosis in Kaolin workers and firebrick makers. S Med J 10:1242, 1978.

DISCUSSION

Question: In your presentation, your case definition for pneumoconiosis was a classification of 1/0. If you were to change that to a more definite definition of pneumoconiosis, say a 1/1, would that put you more in line with previous studies? And if you were to use a different comparison group or set of standards than Knudson, which some people consider to be supernormal, what would happen to the level of significance of your pulmonary function decrement?

Response: In regard to the first question, only one of the eight workers was categorized as having small opacity profusion of 1/0. The remaining workers all had at least category 1/2 or greater. In regard to the analysis of lung function, Knudson was only employed to illustrate the clinical classification of the eight workers with pneumoconiosis. The lung function of the 189 workers was compared with workers in hazard-free environments that we have studied ourselves. Your comments regarding the Knudson so-called normal population are entirely appropriate.

HEALTH ISSUES RELATED TO METAL AND NONMETALLIC MINING

Edited by
WILLIAM L. WAGNER
WILLIAM N. ROM
JAMES A. MERCHANT

BUTTERWORTH PUBLISHERS
Boston • London
Sydney • Wellington • Durban • Toronto

An Ann Arbor Science Book

Ann Arbor Science is an imprint of Butterworth Publishers

Library of Congress Catalog Card Number 82-48649
ISBN 0-250-40610-1

10 9 8 7 6 5 4 3 2 1

Butterworth Publishers
10 Tower Office Park
Woburn, MA 01801

Printed in the United States of America