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Proceedings of the Symposium on Talc, Washington, D.C., May 8, 1973

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Metal and Nonmetal Mine Health and Safety, Washington, D.C.

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PROCEEDINGS OF THE SYMPOSIUM ON TALC, WASHINGTON, D.C., MAY 8, 1973

compiled by

Aurel Goodwin[1]

ABSTRACT

A symposium on the health hazards of respirable dust in the mining and milling of talc was held on May 8, 1973, in Washington, D.C. The results of medical effects on both human and animal subjects were presented. Methods for identification and classification of talc minerals were also presented. Analytical techniques discussed included X-ray diffraction, scanning electron microscope observation, electron probe, and optical microscopy.

INTRODUCTION

The Secretary of the Interior has the responsibility under the Metal and Nonmetallic Mine Safety Act to develop standards for the purpose of the protection of life and the promotion of health and safety in metal and nonmetal mines. There are approximately 66 different mineral commodities produced by these mines. The multitude of minerals in the ore and host rock present a varied hazard to the health of employees of the mineral industries. It therefore becomes necessary to attempt to evaluate the unique health effects and levels of exposure which can be tolerated for the working lifetime of individuals exposed to these minerals without adverse effect on their health. It also becomes necessary to be able to identify and quantitatively measure the concentration of these minerals in respirable dusts.

This symposium was held to receive data relevant to both the health effects and mineral identification of talc. Talc is a term used for a product having certain physical properties. The mineral composition of talc varies depending on its source and on the uses for which it is intended.

Presentations were given relating to the characterization of airborne dust from mining and milling of talc minerals and medical data from studies of talc workers, asbestos workers, and animal studies.

[1]Chief, Division of Health, Metal and Nonmetal Mine Health and Safety (now Chief, Health Division, Mining Enforcement and Safety Administration (MESA), Washington, D.C.)

OPENING STATEMENT

by

Donald P. Schlick[1]

Ladies and gentlemen, I should like to welcome you to this symposium. My name is Donald P. Schlick and I am Deputy Director--Health and Safety. Until about 30 years ago, occupational chest disease meant primarily diseases related to breathing dust containing free silica. Now, however, we recognize that a number of other dusts also are involved in contributing to occupational diseases such as coal dust and the silicates--asbestos and talc.

This symposium was called to obtain data relating to the characterization of "talc" dust and the adverse affects on persons occupationally exposed to talc dust during their working life. This data is intended to provide at least a partial basis for developing a standard adequate to protect those persons employed in the mining and milling of talc minerals.

As used commercially, the term "talc" refers primarily to physical properties rather than to a specific mineral. Thus, the American Conference of Governmental Industrial Hygienists in their Threshold Limit Values (TLV) refers to "talc" and to "talc (fibrous)." In the documentation of the TLV's they refer to talc (nonasbestiform) and talc (fibrous)--tremolite. Thus, fibrous talc is the talc with the associated amphibole-tremolite. The only reference in the documentation for nonasbestiform talc is dated 1935 and the most recent reference to fibrous talc is dated 1963. Current standards for exposure in mining and milling of talc are the Threshold Limit Values. Because of the difficulties in distinguishing fibrous and nonfibrous talc and because of much recent work on asbestos, particularly on the toxic effects of the different types of "asbestos," we have called this meeting. This meeting is called, however, to consider asbestos only as it relates to so-called fibrous talc.

Our goal is to establish a standard which will assure that persons working in the mining and milling of "talc" will not suffer impaired health due to their employment. We hope that this symposium will result in providing up-to-date information on which to base a standard. As stated in the announcement of the meeting, we shall, however, include written communications received before June 1, 1973, as part of this symposium. I should like to request that all speakers who do not have written statements provide a written copy of their presentation by that time.

I thank you all for coming, and I will now turn the meeting over to Arthur P. Nelson, Acting Assistant Director, Metal and Nonmetal Mine Health and Safety.

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[1]Acting Deputy Administrator, Mining Enforcement and Safety Administration, Washington, D.C.; formerly Deputy Director, Health and Safety, Bureau of Mines.

OPENING REMARKS

by

Arthur P. Nelson[1]

This the first meeting we have had of this type for Metal and Nonmetal Mines. We are gathering data prior to developing new standards and presenting them to our Advisory Committee. As you know, our standards for air quality presently are the American Conference of Governmental Industrial Hygienists Threshold Limit Values. We have found inadequacies in these standards and will probably deviate from them more in the future as better data become available.

The talc industry is composed of approximately 65 operations, employing about 1,200 workers. These operations are distributed throughout the United States; U.S. production in 1972 was about 1.1 million tons with 86 percent produced in five States: California, Montana, New York, Texas, and Vermont. A small amount of talc, about 30,000 tons, is imported annually, mainly from Canada, Italy, and France.

The proceedings of this meeting will be used in part to arrive at standards for exposure of persons working in mining and milling of talc minerals. The Bureau of Mines and the U.S. Department of Health, Education, and Welfare are planning a joint survey of environmental conditions and health status of employees in the talc mining and milling industry.

Data that will be presented here today should be of immense value and will contribute much that in the past has not been available to support the development of improved standards.

I welcome you here today and I hope that you have a good and productive meeting. Thank you.

[1]Acting Assistant Administrator, Metal and Nonmetal Mine Health and Safety, Mining Enforcement and Safety Administration, Washington, D.C.; formerly Acting Assistant Director, Metal and Nonmetal Mine Health and Safety, Bureau of Mines.

MORTALITY EXPERIENCE OF NEW YORK TALC MINERS AND MILLERS

by

Morris Kleinfeld, M.D.[1]

My former colleagues in the Division of Industrial Hygiene of New York State and I have had the opportunity to conduct numerous studies of talc workers in New York State, including clinical, physiological, radiological, and environmental observations (5).[2] In addition, we have also studied the mortality experiences among workers in talc mining and milling. In most instances, we have had the invaluable opportunity to correlate the clinical with the environmental data. In general, we have found that sustained inhalation of significant amounts of commercial talc dust over an extended period of time, or where there was a significant elapsed time from initial exposure, can produce a symptomatic form of pneumoconiosis. The commercial talc to which the talc workers were exposed contained not only the mineral talc, but also other silicates such as serpentine, tremolite, anthophyllite, and other ingredients, predominantly carbonates. Moreover, free silica was often present in the dust in variable amounts, usually not averaging more than 3 percent.

Specifically with regard to our mortality experiences among talc workers, we found in an earlier study of talc workers (miners and millers) who had 15 or more years of exposure to talc dust that the proportional mortality from carcinoma of the lung and pleura among these workers was four times that of the general population. However, the significant increase in incidence of malignancy appears in the older talc workers, namely, those in the 60- to 79-year age group, rather than in the 40- to 59-year age group (3). This observation in the talc workers was at variance with those found in a group of asbestos insulators who had the same duration of exposure covering a similar time period (2). The asbestos insulators showed an increased incidence of mortality from lung cancer in both age categories. The incidence of carcinoma of the gastrointestinal tract and peritoneum among talc workers was not significantly different from that of the general population, whereas among the asbestos insulators the incidence of gastrointestinal malignancy was significantly higher than that of the general population. We postulated that the earlier occurrence of malignancies among the asbestos insulators was due to two factors: The first was the relatively greater carcinogenicity of the chrysotile asbestos as compared to commercial talc; the second was the exposure of the insulators to greater quantities of chrysotile asbestos as compared to the talc workers who were exposed to lesser quantities of commercial talc dust which was admixed with appreciable amounts of tremolite and anthophyllite asbestos. Our observations favored the first factor. The earlier study (3) also showed an increased incidence of deaths due to talc pneumoconiosis and/or its complications.

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[1] Formerly Director, Division of Industrial Hygiene, New York State.

[2] Underlined numbers in parentheses refer to items in the list of references at the end of each chapter.

A followup study was made to bring our mortality data among the talc workers up to date and to provide additional information not reported in the earlier study. The pertinent data is presented in the material that follows.

All the talc workers employed in 1940 who had accumulated 15 or more years of exposure to commercial talc dust as well as those who achieved a minimum of 15 years of such exposure between 1940 and 1969 were included in the followup study. The group totaled 260 workers and it is believed that the overall number constituted the total work force in the worker population under study. The data were obtained from a number of sources. Plant records were examined and the work history of each individual was detailed to include job changes and specific years of employment. Death certificates were studied in all instances where they were available. The records of the physicians who had attended the workers privately were reviewed. Substantial medical information on the majority of the workers was available in the files of the Division of Industrial Hygiene and was used as an additional source of data. Hospital records, including autopsy reports and histological specimens, were examined wherever available. Autopsy or biopsy records were obtained in 38 of the 108 deaths.

A comparison was made of the observed proportional mortality rates from the specific causes with the expected rates among similar population groups and was found satisfactory for a descriptive study of this nature. The proportions of observed mortality attributed to cancer of the lung and pleura and of the gastrointestinal tract and peritoneum and cardiac diseases were compared to the expected mortalities due to the above causes in the various age groups. The expected mortality for the total group represents the proportion of deaths among white men in the United States due to the specific causes in the year 1955. This particular year was chosen as standard because it was the median year of death among the 108 deaths. For each of the 5-year periods, the median years, namely, 1942, 1947, 1952, 1957, and 1962 were selected.

In the group of 260 talc workers studied, there were 108 deaths. There were a total of 25 deaths from malignancies. Of these 25 deaths, 13 were due to lung and pleural malignancies; 9 were due to gastrointestinal and peritoneal malignancies and 3 were due to other malignancies. Thirty deaths resulted from cardiac disease, other than cor pulmonale, and 29 deaths were attributable to pneumoconiosis and its complications. Accidents and suicides accounted for 8 deaths and there were 16 deaths due to other causes (table 1). The average age at death of the 108 talc workers was 60.3 years, with a range of from 38 to 84 years. Environmental exposure data was available in 97 of the 108 death cases. The mean duration of exposure for this group was 24.1 years, with a range of 15 to 47 years. The dust exposure was predominantly to talc, tremolite, anthophyllite, carbonate dusts, and a small amount of free silica. Comparative dust counts at the talc mines and mills prior to 1945 and between 1946 and 1969 were obtained (table 2).

TABLE 1. - Causes of death in 108 talc workers from 1940 to 1969

Cause of death	No.	Percent
Malignancies	25	23.1
Lung and pleura	13	12.0
Gastrointestinal and peritoneal	9	8.3
All other malignancies	3	2.8
Cardiac deaths (other than cor pulmonale)	30	27.8
Pneumoconiosis and complications	29	26.9
Accidents or suicides	8	7.4
All other causes	16	14.8
Total	108	100.0

TABLE 2. - Comparative dust and fiber counts at the various talc mining and milling operations

	Dust count[1]						Dust count[1]		Fiber count[2]
	Average	Median	Average	Median	Average	Median	Average	Median	
	Pre-1945		1946-65		1966-69		1972		
Drilling	818	413	5	3	19	19	7	7	3
Mucking	120	30	5	5	9	9	3	3	2
	Pre-1948		1948-65		1966-69				
Crushing	180	69	42	13	28	20	35	15	62
Screening	69	61	37	37	-	-	-	-	-
Milling	92	75	25	20	40	24	7	7	25
Garnering and separating	278	70	27	27	-	-	13	9	27
Pulverizing	-	-	28	28	-	-	-	-	-
Bagging	151	129	27	23	29	25	27	27	47
Railroad and truck loading	-	-	73	63	43	20	36	28	24
Blow room[3]	1,227	1,196	-	-	-	-	-	-	-
Open chutes[3]	125	83	-	-	-	-	-	-	-

[1] Dust count in mppcf.
[2] Fiber counts in No. fibers/ml >5μ in length.
[3] Operation discontinued after 1948.

With regard to the deaths due to malignancies, 12 of the 13 malignancies of the lung and pleura were carcinomas of the lung and 1 was a fibrosarcoma of the pleura. Of the nine malignancies of the gastrointestinal tract and peritoneum; three were cancers of the stomach, two were cancers of the liver, one of of which was a primary hepatoma of the liver and the other a metastasis from a gastrointestinal malignancy; one was a cancer of the colon; two were cancers of the pancreas; and one was a pertoneal mesothelioma. The three malignancies involving other sites included one retroperitoneal reticulum cell sarcoma; one chronic lymphatic leukemia, and one Hodgkins' disease (table 3). The overall proportional mortality or carcinoma of the lung and the pleura was four times

that expected. Consistent with our previous observation, a significant increase appeared to occur in the 60- to 79-year age group rather than in the 40- to 59-year age group (table 4). As I have already mentioned, this finding among talc workers was at variance with what we had observed among asbestos insulators where the observed values in both the 40- to 59-year and 60- to 79-year age groups were significantly different from the expected values. In the absence of adequate smoking data, one cannot assess the role played by smoking in accounting for the differences in the occurrence of malignancies.

TABLE 3. - Causes of death in 108 talc workers[1] from 1940 to 1969

Cause of death	1940-44	1945-49	1950-54	1955-59	1960-64	1965-69	Total
Malignancies:							
Lung and pleura.....	-	2	1	5	3	2	13
Stomach.....	-	1	-	1	-	1	3
Liver.....	1	-	-	1	-	-	2
Colon.....	-	-	1	-	-	-	1
Pancreas.....	-	-	-	-	1	1	2
Peritoneum.....	-	-	-	1	-	-	1
Other malignancies.....	-	-	2	-	-	1	3
Cardiac diseases.....	3	6	-	6	8	7	30
Pneumoconiosis and complications.....	2	4	2	8	9	4	29
Accidents and suicides.....	1	1	1	2	2	1	8
Others.....	-	3	1	1	5	6	16
Total.....	7	17	8	25	28	23	108

[1]Includes workers having had at least 15 or more years of exposure to talc dust.

TABLE 4. - Deaths and proportional mortality from carcinomas of the respiratory tract, of the gastrointestinal tract, and from cardiac diseases among workers by age group from 1940 to 1969

Age group	Total deaths	Deaths and proportional mortality from respiratory cancers			Deaths and proportional mortality from gastrointestinal cancers			Deaths and proportional mortality from cardiac diseases		
		No.	Observed, percent	Expected, percent	No.	Observed, percent	Expected, percent	No.	Observed, percent	Expected, percent
40	3	0	0	1.6	0	0	2.5	1	33.3	21.1
40-59	47	4	8.5	5.2	3	6.4	5.7	11	24.4	44.2
60-79	54	9	16.6	3.6	4	7.4	7.2	17	31.5	47.8
80-84	4	0	0	1.1	1	25.0	5.3	1	25.0	47.1
Total	108	13	12.0	3.7	8	7.4	6.5	30	2.8	45.8

When carcinoma of the lung and pleura was related to each of the six 5-year periods, namely from 1940 to 1969, it is important to note that the observed proportional mortality from carcinoma of the lung was approximately four times as much as the expected mortality during the period 1945-49 and dropped to approach the expected mortality from 1960 to 1964 and from 1965 to 1969 (table 5). The differences between the observed and expected mortality rates were significant in 1950-54 and insignificant in 1960-64 and in 1965-69. The improved mortality experience between 1960 and 1969 and to 1973 for lung and pleural cancers is particularly pertinent since environmental control have resulted in an appreciable reduction in the dust count in the mines and mills, although the fiber count still exceeds the present threshold limit value for asbestos dust by approximately four to five times (table 2). This finding indicates that the present threshold limit value of

5 fibers/ml with a fiber length greater than 5 microns for fibrous talc, including tremolite and anthophyllite, is basically adequate.

TABLE 5. - Deaths and expected mortality from cancer of the lung and pleura and of the gastrointestinal tract and peritoneum among talc workers from 1940 to 1969

	Lung and pleura				Gastrointestinal tract and peritoneum			
	Deaths	Proportional mortality, percent		P	Deaths	Proportional mortality, percent		P
		Observed	Expected			Observed	Expected	
1940-44	0	0	2.0	-	1	14.3	7.8	NS
1945-49	2	11.7	3.1	S	1	5.8	7.8	NS
1950-54	1	12.5	4.3	S	1	12.5	7.1	NS
1955-59	5	20.0	5.7	S	3	12.0	6.7	NS
1960-64	3	10.7	6.7	NS	1	3.6	6.3	NS
1965-69	2	8.7	7.7	NS	2	9.5	6.1	NS
Total	13	-	-	-	9	-	-	-

P = Probability.
S = Significant.
NS = Not significant.

With regard to cancer of the gastrointestinal tract and peritoneum among the talc workers, we did not find any significant difference between the observed and expected values in the overall and specific age groups studied (table 4) and these findings are consistent with those reported by Kiviluoto and Meurman (1) among anthophyllite workers. These findings differ from those observed in asbestos insulators where a significant increase in the observed incidence of gastrointestinal malignancy was found in the overall and specific age groups studied (3). Our findings among asbestos insulators were similar to those reported by Selikoff, Hammond, and Churg (7).

Of the 29 deaths due to pneumoconiosis and its complications, 20 were due to cor pulmonale, 5 to advanced tuberculosis, and 4 to bronchopneumonia. The lapsed time from the first commercial talc dust exposure to death in this group averaged 30.9 years with a range of 15 to 46 years. All 29 had their initial exposures prior to 1945 at which time more effective engineering controls, including wet drilling in the talc mines, were introduced. The percentage of deaths due to pneumoconiosis and its complications has decreased by more than 50 percent in the last 5-year period studied, namely, 1965-69, as compared to the preceding 5-year period, 1960-64 (table 3). The number of deaths probably reflects the greater exposures which occurred in the earlier years of employment. A longer interval must elapse, however, before the effect of controls on the incidence of pneumoconiosis can be appraised more definitively in the plant studied. It is noteworthy, however, that in another study of a different plant processing a similar mixture of talc, tremolite and anthophyllite, but wherein controls were installed at the inception of operations in 1948, only 1 out of 39 workers had a chest roentgenogram consistent with pneumoconiosis. The mean exposure of the 39 workers was 16.2 years with a range of from 11 to 22 years. The worker whose chest roentgenogram was

consistent with pneumoconiosis was a 75-year old man who had a nonproductive cough, a Grade 1 dyspnea and who worked as a janitor for 11 years. The low incidence of pneumoconiosis was found despite the presence of relatively high fiber count and dust count in this plant (4). The fiber count exceeded by two to six times the present treshold limit value of 5 fibers/ml with a length greater than 5 microns. In terms of time-weighted averages, Murphy and associates (6) found no asbestosis among workers exposed less than 60 million particles per cubic foot (mppcf) years to chrysotile and amosite in ship construction. In the study of the plant having controls since the start of operations (4), it was found that an appreciable number of workers exceed the 60 mppcf-years but did not show any evidence of pneumoconiosis as determined by the criteria of Murphy and associates. The findings from the study of the plant having controls from the start of operations suggest that tremolite and anthophyllite are less fibrogenic than chrysotile or amosite at comparable dust exposures.

Of the 30 cardiac deaths, excluding cor pulmonale, 22 had coronary artery disease, 5 had hypertensive heart disease, and 3 had rheumatic heart disease. Rather surprising was the observation that the observed proportional mortality from cardiac disease was lower than the expected mortality in all 5-year periods except the first, namely, 1940-1944 (table 6). It seems reasonable to state on the basis of the remaining data that the overall observed proportional mortality from cardiac disease among talc workers was lower than the expected mortality. The decreased mortality from cardiac disease among talc workers cannot be attributed to a predisposition to lung cancer which generally results in the death of these workers at earlier ages before they might be expected to succumb to cardiac disease. As demonstrated, the decreased proportional mortality from cardiac disease was present in both the 40- to 59-year as well as the 60- to 79-year age groups (table 4). If malignancy of the lung was a factor, one would have expected a difference in incidence between these two age groups. The true explanation for the lower incidence of cardiac disease is open to conjecture. The rural environment in which the talc workers lived, as well as the possibility that they smoked less, may account for the lower mortality due to cardiac disease as compared to the national rate.

TABLE 6. - Deaths and expected mortality from cardiac disease among talc workers from 1940 to 1969

	Deaths	Proportional mortality, percent	
		Observed	Expected
1940-44	3	42.8	37.4
1945-49	6	35.3	41.0
1950-54	0	0	46.0
1955-59	6	24.0	46.5
1960-64	8	28.6	46.6
1965-69	7	30.4	45.5
Total	30	-	-

I trust that the information I have submitted this morning will provide the Bureau of Mines with essential data relating to the occupational hazards of exposure to talc, fibrous talc, and tremolite dust in order to evaluate the adequacy of the existing threshold limit value for pure talc and talc mixed with tremolite and anthophyllite.

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1. Kiviluoto, R., and L. Meurman. Results of Asbestos Exposure in Finland. Ch. in Pneumoconiosis, ed. by H. A. Shapiro. Proc. of the Internat. Conf., Johannesburg, South Africa, 1969, pp. 180-186; Oxford University Press, Cape Town, 1970.

2. Kleinfeld, M., J. Messite, and O. Kooyman. Mortality Experience in a Group of Asbestos Workers. AMA Archives of Environmental Health, v. 15, 1967, pp. 177-180.

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6. Murphy, R. L. M., Jr., B. G. Ferris, W. A. Burgess, and others. Effects of Low Concentrations of Asbestos. New England J. of Medicine, v. 285, 1971, pp. 1271-1278.

7. Selikoff, I. J., E. C. Hammond, and J. Churg. Mortality Experiences of Asbestos Insulation Workers, 1943-1968. Ch. in Pneumoconiosis, ed by H. A. Shapiro. Proc. of the Internat. Conf., Johannesburg, South Africa, 1969, pp. 180-186; Oxford University Press, Cape Town, 1970.

CHARACTERISTICS OF TALC DUSTS[1]

by

R. S. Lamar[2]

The Nature of Commercial Talcs

It is important to make a clear distinction between commercial talc and talc mineral. Pure talc mineral is a hydrous magnesium silicate having the composition $Mg_6(Si_8O_{20})(OH)_4$.[3] Limited isomorphous substitutions can occur within this structure.[4] Crystal form is generally monoclinic. Individual particles of pure, finely milled talc appear platy or micaceous under the microscope.

Commercial talcs may or may not be pure talc mineral. These products are commonly mixtures of talc mineral with other related minerals that were involved in the paragenesis of the talc mineral.

These associated minerals are in many cases calcite, dolomite, quartz, serpentine, magnetite, magnesite, chlorite, tremolite, anthophyllite, and in some cases chrysotile.[5] These may occur in various amounts and proportions in commercial talcs from different sources or mines. Not all of these associated minerals occur in all commercial talcs. Some products are entirely free from asbestiform minerals, and this distinction is also important.[6]

The so-called "fibrous talcs" appear fibrous because of the presence of asbestiform minerals. Pure talc mineral rarely appears fibrous in crystal habit and is much more commonly platy, lamillar, or micaceous. Specifically, we disagree with the definition of talc (fibrous)--tremolite as it appears in "Documentation of the Threshold Limit Values for Substances in Workroom Air," published by the American Conference of Governmental Industrial Hygienists, 3d edition, 1971, p. 243. It is our opinion that this documentation for talc "fibrous" should be rewritten to eliminate any reference to "fibrous talc" but should refer to the fact that the talc ores can contain fibrous contaminants which are asbestiform minerals. This is important in view of the fact that

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[1] John Wiley & Sons, Inc. Encyclopedia of Chemical Technology. Talc. V. 19, 2d ed., 1969, p. 608.

[2] Research Manager, Celite Division. Johns-Manville Corporation.

[3] Deer, W. A., R. A. Howie, and J. Zussman. Rock-Forming Minerals. V. 3, Sheet Silicates. Longmans, Green and Co., Ltd., London, 1962, p. 121.

[4] Page 124 of work cited in footnote 3.

[5] Pages 126-129 of work cited in footnote 3.

[6] Page, Ben M. Talc Deposits of Steatite Grade, Inyo County, California. Div. of Mines, State of California, Special Rept. 8, August 1951.
Wright, Lauren A. Geology of the Silver Lake Talc Deposits, San Bernardino, California. Div. of Mines, State of California, Special Rept. 38, July 1954.

the definition of the American Conference of Governmental Industrial Hygienists is part of the Federal Mandatory Standard under the Metal and Nonmetallic Mine Safety and Health Act.

In addition to these mineralogical differences, commercial talcs are also supplied in a wide range of particle sizes from 200 mesh, or finer, to less than 5-micron maximum particle size. The end use for the product generally determines the particle size required.[7]

Characterization of Talc Dusts

Talc dusts may be characterized according to mineral composition, chemical composition, particle shape, and particle size. Each of these will be described separately.

Characterization of Mineral Composition

This may be done according to a variety of commonly used and accepted methods.

Petrographic Examination

A highly skilled petrographer, working with a petrographic microscope, can, in many cases, determine various mineral species by measuring such optical properties as index of refraction, extinction angle, birefringence, and crystal habit.[8] As the particle size of a mineral dust is reduced to much below 5 microns these measurements become increasingly difficult and less reliable. Most commercial talcs contain a high proportion of particles smaller than 5 microns and other methods are therefore more reliable.

Electron Probe

The basic principle underlying the identification of materials by X-ray or by electron diffraction is that each crystalline substance has its own characteristic atomic structure which diffracts X-rays or electrons in a particular pattern. The recognition of the pattern establishes uniquely the diffracting substance. Newly developed electron probes, operating through an electron microscope, make possible the identification of individual particles as small as 1 micron by this method. The equipment is very costly and not readily adopted to routine measurements.

X-Ray Diffraction

This is probably the most powerful and useful tool available for the mineral characterization of talc dusts.[9] Using equipment and techniques commonly

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[7] Industrial Minerals. Talc: Micronized Grades Lead the Way. January 1971 p. 9.

[8] Brindley, G. W. Experimental Methods. Ch. 1 in The X-Ray Identification and Crystal Structures of Clay Minerals, ed. by G. Brown. 1961, pp. 35-36.

[9] Page 1 of work cited in footnote 8.

employed in the talc industry, it is possible to identify as little as 1 percent of tremolite in otherwise pure talc mineral. There is evidence that different tremolites respond differently and may show different lower limits of detectability depending on crystal size and perfection.

Differential Thermal Analysis (DTA)

This procedure is useful but not as definitive as X-ray diffraction. Talc, chlorite, serpentine, and the carbonate minerals show characteristic D.T.A. curves but many of the peaks overlap and are not clearly defined in mineral mixtures. Tremolite shows a relatively weak D.T.A. reaction because of its low content of chemically combined water.[10] While D.T.A. is a useful tool for qualitative analysis, it is of limited value for quantitative determinations. Particle size, sample composition, and experimental and instrumental variables are complicating factors.

Characterization by Chemical Composition

Complete chemical analyses are useful in identifying talc dusts but are by no means definitive. Quantitative analyses by conventional wet methods or by X-ray fluorescent methods only help but do not yield the type of positive mineral identification obtainable by X-ray diffraction.

Particle Shape

Partial morphology, shape, and structure are powerful tools for identification of mineral dusts. Measurements made with an ordinary light-microscope can be misleading. For example, a talc platelet observed on edge, or on an angle, may appear to be a fiber. Scanning electron micrographs are far more reliable and revealing because of greater possible magnification and depth of field. When observed in this manner, some talc platelets appear to roll up into a tubular shape not unlike kaolin-halloysite or serpentine-chrysotile. However, in the case of talc, this tubular structure is far more rare and is seldom complete.

Particle Size

Particle size may be determined by direct microscopic measurement using a filar micrometer eyepiece or by measurement of particles in an electron micrograph.[11] Television scanning techniques and equipment are also available. Other procedures involve settling rate determinations in water or other liquids. The Andreasen pipette is commonly used for this purpose.[12]

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[10]Mackenzie, Robert C. (ed.). The Differential Thermal Investigation of Clays. Mineral. Soc., Clay Minerals Group, London, 1957.

[11]Allen, Terence. Particle Size Measurement. Chapman and Hall Ltd., London, 1968, pp. 45-61.

[12]Orr, Clyde, Jr., and J. M. DallaValle. Fine Particle Measurement. The Macmillan Company, New York, 1959, pp. 43-78.

Conclusions

We have attempted to show in the above presentation that the characterization of talc dusts is not simple. No one procedure or method is completely definitive. We believe that mineral composition can best be determined by X-ray diffraction. Particle morphology is best defined by means of scanning electron micrographs and particle size determined by sedimentation involving the Andreasen pipette.

CHARACTERIZATION AND OCCURRENCE OF TALC

by

H. T. Mulryan[1]

My name is H. T. Mulryan. I am president of Cyprus Mines Corporation's United Sierra Division. The division is the world's largest producer of talc in terms of product value.

It operates talc mines in the States of Montana, Nevada, California, and Texas and talc processing units in the States of Montana, California, and Nebraska, Belgium, and through an affiliate, Mexico.

The division employs about 180 persons at its talc production units. Approximately half of them work in our Montana mines and mills, the remainder are scatterd among the other eight talc locations. The Montana product approaches the purity of pure talc mineral and its habit is platy or granular, depending on the material source and fineness of grind. Figures 1 and 2 illustrate the nature of the particles by transmission and scanning electron microscope, respectively.

On the other hand, mixtures of minerals from other sources may contain little or no talc mineral and still be correctly known commercially as "talc." Figures 3 and 4 show the particle shapes of "talcs" from the Gouverneur district of New York State. The needles or fibers are mainly tremolite with anthophyllite also commonly present.

This type of commercial talc is not confined to New York State, being extensively mined and processed in California. Table 1 compares the mineral content of talc from New York, California, and Montana. The Silver Lake, Calif., tremolitic talc is similar to a typical New York State talc except for the missing anthophyllite and quartz impurities.

TABLE 1. - Comparison of mineral content of talc from New York, California, and Montana, in percent

Talc type	Talc	Carbonate	Tremolite	Anthophyllite	Quartz	Other
New York.....	62	-	30	5	3	-
Silver Lake, Calif...	54	3	43	-	-	-
Panamint, Calif.....	82	12	-	-	Trace	2 Mont. 4 Mica.
Yellowstone, Mont....	99	1	-	-	<0.5	-
Beaverhead, Mont.....	98	1	-	-	-	1 Chlorite

[1]President, Cyprus Mines Corporation's United Sierra Division.

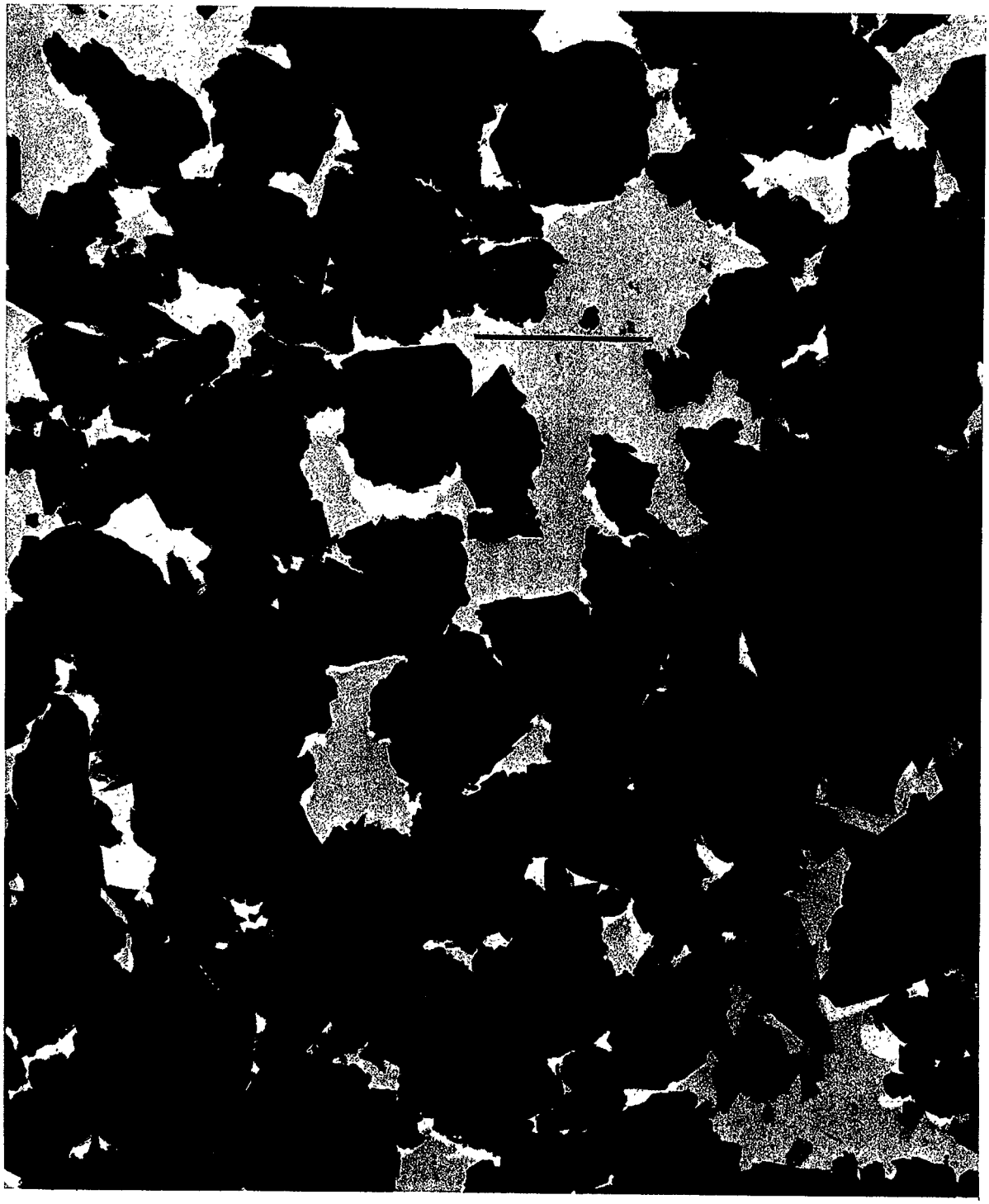

FIGURE 1. - Nature of particles by transmission and scanning electron microscope (X 6,000).

5 micrometers

FIGURE 2. - Nature of particles by transmission and scanning electron microscope (X 4,400).

5 micrometers

FIGURE 3. - Particle shapes of "talcs" from the Gouverneur District of New York State (X 6,000).

5 micrometers

FIGURE 4. - Particle shapes of "talcs" from the Gouverneur District of New York State (X 880).

Another California talc, the Panamint, contains calcite and mica as principal impurities with no asbestos minerals present. The two Montana talcs, Yellowstone and Beaverhead, are high purity and also free of asbestos minerals.

It has been the policy of the Cyprus Mines Corporation to X-ray the production workers at all of our operations annually. This policy has been in effect for 5 years and these examinations have not turned up any lung or pleural cancer among our talc workers, nor have they revealed chronic respiratory disease of any kind.

Seven of the employees were first exposed to talc dust 25 to 44 years ago. All the long service group were California workers who had been exposed to tremolitic talcs as well as tremolite-free materials.

When the threshold limit values for tremolitic talcs were first made public, we became concerned about the possibility that our people had been inadvertently exposed to a health hazard and we took two steps.

First, the division ceased production of all talcs containing detectable amounts of tremolite and established an X-ray diffraction facility at our California mines to assure control.

Second, the seven long-service employees together with four retirees and ex-employees were subjected to exhaustive physical examinations with emphasis on the respiratory system, chest, and abdomen. This group's first exposure to talc dust ranged from 25 to 49 years ago. There are no records to tell us what conditions were like in the talc mines and mills of the 1920's and 1930's, but neither were mining nor milling techniques designed with dust control as a major objective. The oldtime worker was, therefore, exposed to vastly greater amounts of dust than his modern counterpart.

Nevertheless, these exhaustive examinations failed to detect any sign of cancer among any of the long-service group. One of the retirees did reveal signs of possible pneumoconiosis.

Cyprus Mines Corporation's interest in this proceeding is one of concern for the welfare of its workers and for the truth. Although the medical data presented are admittedly limited, they contain no indication that talcs of either the pure Montana type or less pure California varieties are carcinogenic.

We should emphasize that Cyprus' talc operations are in compliance with threshold limit values both as relates to dust from nonasbestiform talc and fiber count. We realized that any dust in excessive amounts cannot be a positive health factor and are making every effort to minimize employee exposure.

DISCUSSION OF THE MINERALOGY OF INDUSTRIAL TALCS

by

C. S. Thompson, Ph. D.[1]

Discussion

The purpose of this presentation is to discuss the mineralogy, crystallography, and morphology of the major constituents of industrial talcs. It is also to present information regarding the nomenclature used to describe these materials with the hope of clarifying the terminology, which is so important in the formulation and understanding of regulations.

Industrial talcs vary greatly in mineralogic composition from relatively pure mineral talc, $Mg_6Si_8O_{20}(OH)_4$, to mixtures containing mineral talc and numerous other minerals, principally: serpentine, $Mg_3Si_2O_5(OH)_4$ (antigorite and/or chrysotile); dolomite, $CaMg(CO_3)_2$; tremolite, $Ca_2Mg_5Si_8O_{22}(OH,F)_2$; anthophyllite, $(MgFe)_7Si_8O_{22}(OH,F)_2$; and chlorite, $(Mg,Al,Fe)_{12}(Si,Al)_8O_{20}(OH)_{16}$. Due to the recent definition of the term "asbestos" in the Federal Register of June 7, 1972, which incorrectly included all forms of anthophyllite, tremolite, and actinolite as "asbestos minerals," many domestic, industrial talc producers have found themselves legislated into being "asbestos" producers as well. It is the purpose of the following discussion to correct this error.

The term "asbestos" (see appendix) is a nonscientific commercial term normally restricted in use to the long, threadlike fibrous varieties of several hydrated silicate minerals, whose fibers can be separated mechanically and pressed, spun, or woven into articles of all types that are resistant to heat and chemical action. Although present usage is generally limited to the commercially available silicate minerals, chrysotile, crocidolite, amosite, anthophyllite asbestos, tremolite asbestos, and actinolite asbestos, other minerals regardless of chemical composition, which possess similar qualities of great elongation, flexibility, high-tensile strength, heat and chemical resistance, spinability, etc., could properly be classified as asbestos. The asbestos minerals mentioned above all have nonasbestos counterparts of the same chemical composition and crystal structure which are far more abundant and widespread than the asbestiform variety. These (see table 1) occur as common rock-forming mineral constituents of many igneous and metamorphic rocks. The crystallization of these normally nonfibrous minerals in fibrous form is a rare occurrence in nature dependent upon unusual combinations of physical and chemical conditions during the metamorphism of preexisting nonasbestiform minerals. As shown in table 1, the asbestiform varieties of the serpentine and amphibole minerals groups have, in part, been given individual names which, in themselves, imply their fibrous nature. In the case of the

[1]Manager of Ceramics, Paper, and Specialties, Research and Development, R. T. Vanderbilt Company, Inc.

three amphiboles, anthophyllite, tremolite, and actinolite, which occur so rarely as the asbestiform variety (all three account for an estimated 1 percent of the total asbestos production), no special name was given to the asbestiform variety, and therefore, a qualifying morphological term such as anthophyllite asbestos, tremolite asbestos, and actinolite asbestos must be used when referring to that particular crystal form. I am convinced that it was this lack of a special name in the mineralogical and other literature which caused, incorrectly, the inclusion of all forms of anthophyllite, tremolite, and actinolite in the Asbestos Dust Standard (29 CFR 1910.93a) instead of only the asbestiform varieties, as was undoubtedly intended by the formulators of the regulation. It is obvious from the studious omission of the nonfibrous varieties of the other asbestos minerals, that is, antigorite, riebeckite, and cummingtonite from the asbestos standard, that if special names had existed for the asbestiform varieties of the remaining amphiboles, they would have been included as well, and anthophyllite, tremolite, and actinolite would also have been omitted.

TABLE 1. - "Asbestos" minerals as listed in Federal Register

Asbestiform variety	Chemical composition	Nonasbestiform variety
Serpentine group: Chrysotile.....	$Mg_3(Si_2O_5)(OH)_4$.....	Antigorite, lizardite.
Amphibole group:		
Crocidolite.....	$Na_2Fe_3Fe_2(Si_8O_{22})(OH)_2$....	Riebeckite.
Amosite.....	$(Mg,Fe)_7(Si_8O_{22})(OH)_2$.....	Cummingtonite.
Anthophyllite asbestos.....	$(Mg,Fe)_7(Si_8O_{22})(OH,F)_2$...	Anthophyllite.
Tremolite asbestos.....	$Ca_2Mg_5(Si_8)_{22})(OH,F)_2$.....	Tremolite.
Actinolite asbestos.....	$Ca_2(Mg,Fe)_5(Si_8O_{22})(OH,F)_2$	Actinolite.

NOTE: Underlined mineral designations are those listed in the Federal Register.

The term "fiber" connotes a greatly elongated particle with threadlike qualities such as high-tensile strength, flexibility, spinability, etc. (see appendix). Asbestos fiber, in particular, refers to a particular crystallization of common nonfibrous rock-forming minerals, resulting in long fiber bundles, which continue to break down during crushing or processing into fibrils of smaller and smaller diameter until near molecular diameters are reached, while still maintaining relatively great elongation. The use of an aspect ratio (length to width) of 3 to 1 as the lower limit of a fiber (as defined in the Federal Register, NIOSH, and so forth), most certainly refers to fragments or pieces of much longer, previously recognizable asbestos fibers, since it is obvious that any other nonasbestos, nonfibrous minerals, such as feldspars, pyroxenes, amphiboles, calcite, gypsum, etc., could not be considered to have become fibrous on the basis that, during processing, they are reduced to particles or fragments which exceed an aspect ratio of 3 to 1. Many such minerals normally occur in elongated prismatic or acicular crystals, which have a tendency to elongate as they are subjected to attritioning but have little tensile strength, tend to be quite brittle, and are therefore not fibrous.

The accompanying sets of photographs and photomicrographs will illustrate the marked morphological difference between the asbestiform and nonasbestiform varieties of the "asbestos" minerals under discussion. We must apologize for the lack of pictures of the asbestiform varieties of tremolite and actinolite. Several specimens so labeled have been examined, but all had been mistakenly identified. A study of these pictures (figs. 1 through 11) will indicate the differences just mentioned as well as the great similarity of the physical forms and grinding characteristics of the nonasbestiform amphibole varieties, riebeckite, cummingtonite, anthophyllite, tremolite, and actinolite. A comparison of these photographs with those of the talc products (figs. 12 through 17) clearly shows that the amphibole minerals, occurring in domestic industrial talcs, are present as the nonasbestiform variety.

It is hoped that this presentation has accomplished the following:

1. Illustrated the differences between asbestiform and nonasbestiform varieties of the same mineral.

2. Helped clarify the nomenclature used in reference to asbestos.

3. Indicated the importance of correct terminology in the formulation of regulations.

4. Presented evidence which shows that the amphibole minerals associated with domestic industrial talc are present as the nonasbestiform variety and are therefore not asbestos.

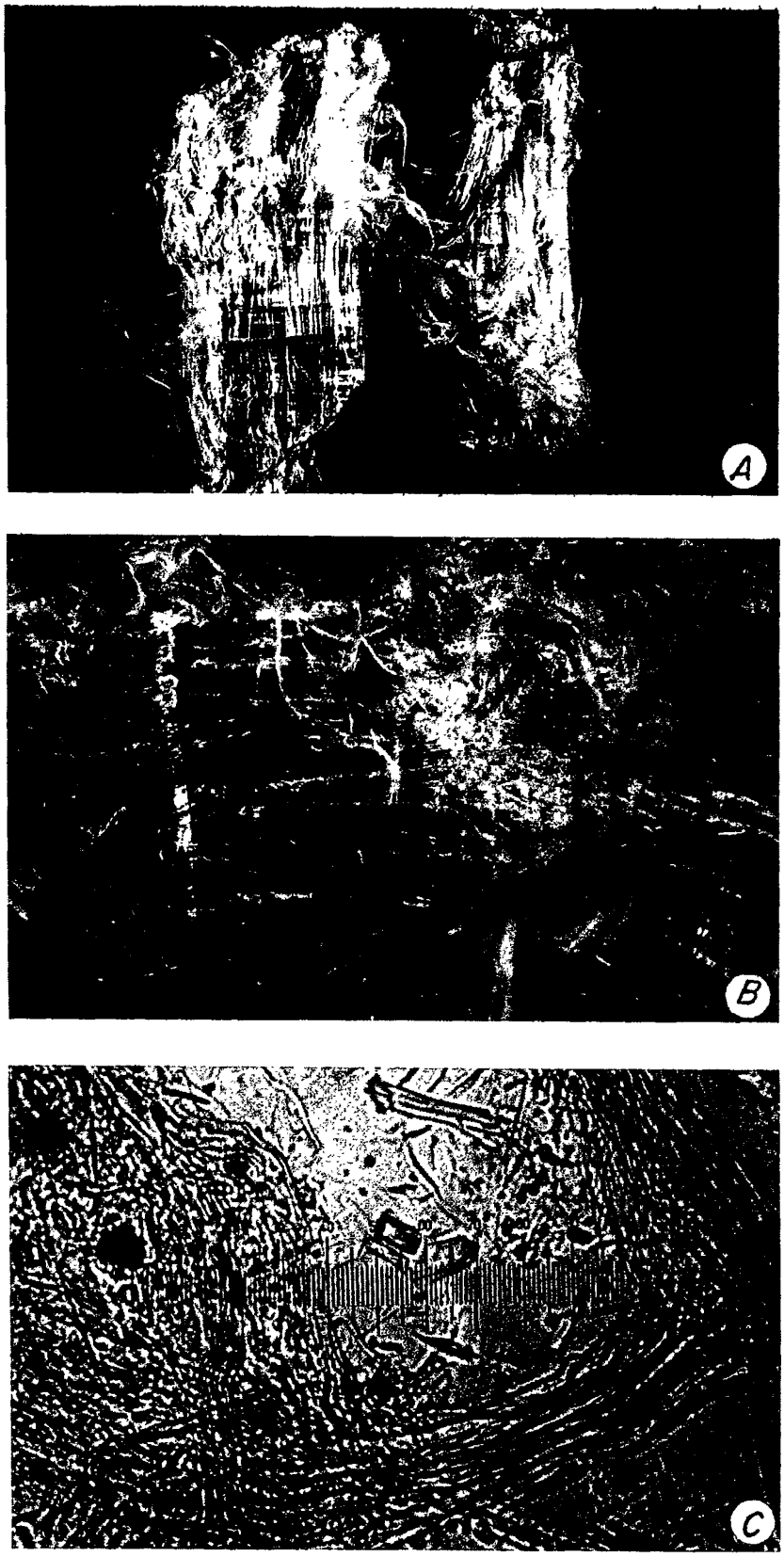

FIGURE 1. - Chrysotile asbestiform variety. *A*, Specimen; *B*, closeup; *C*, photomicrograph (2.75 μm/Div.).

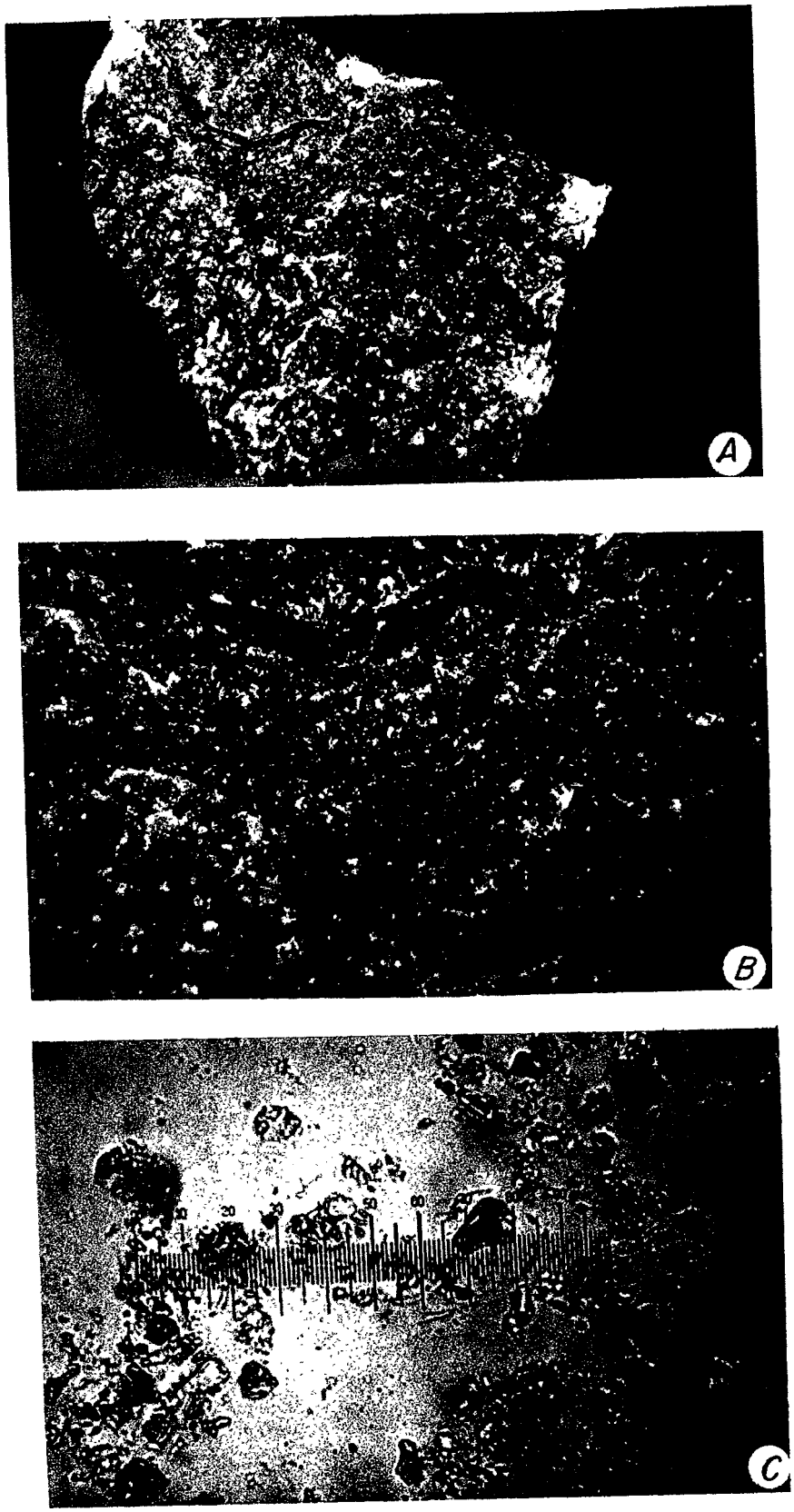

FIGURE 2. - Antigorite nonasbestiform variety. *A*, Specimen; *B*, closeup; *C*, photomicrograph (2.75 μm/Div.).

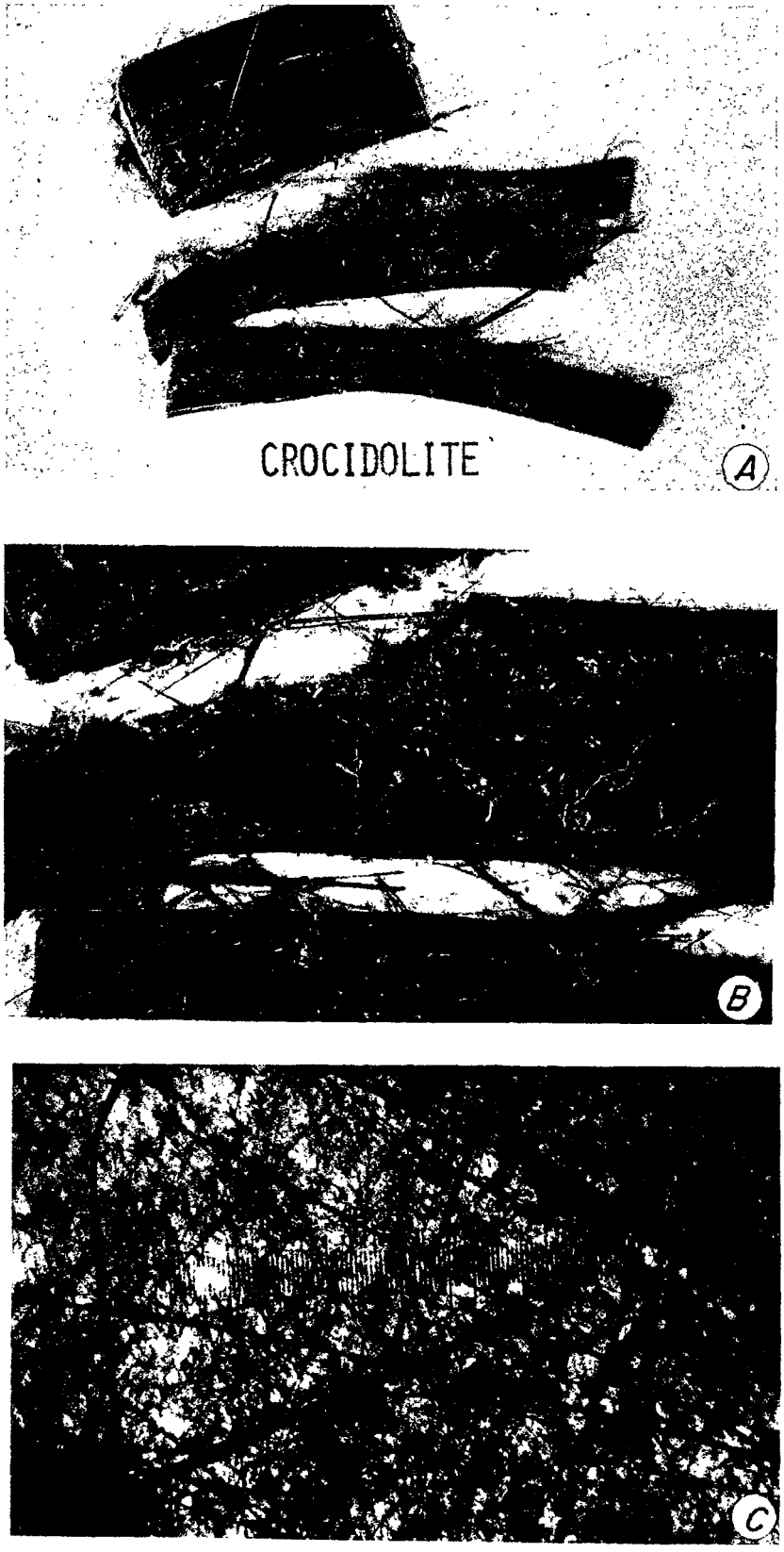

FIGURE 3. - Crocidolite asbestiform variety. *A*, Specimen; *B*, closeup; *C*, photomicrograph (2.75 μm/Div.).

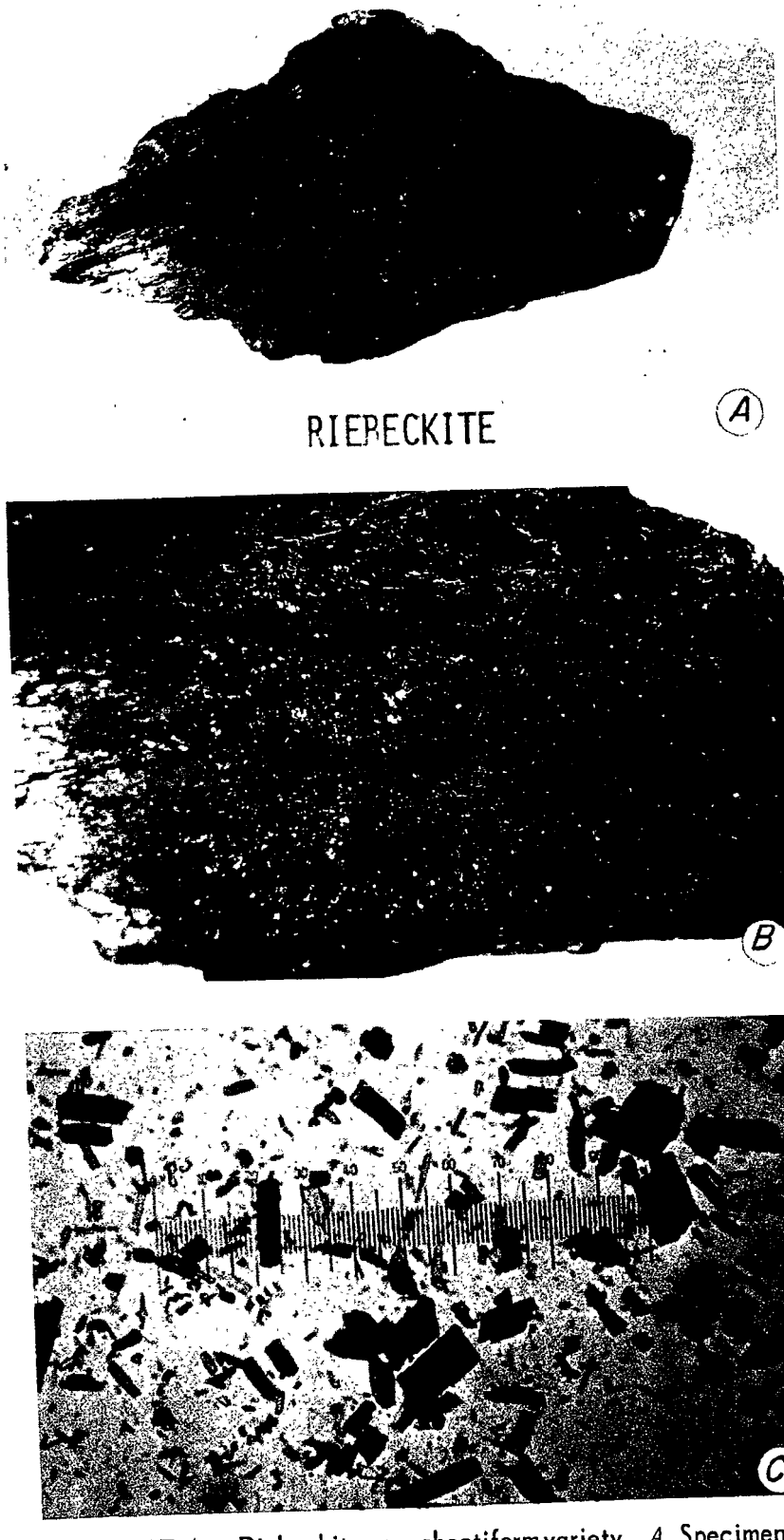

FIGURE 4. - Riebeckite nonasbestiform variety. *A*, Specimen; *B*, closeup; *C*, photomicrograph (2.75 μm/Div.).

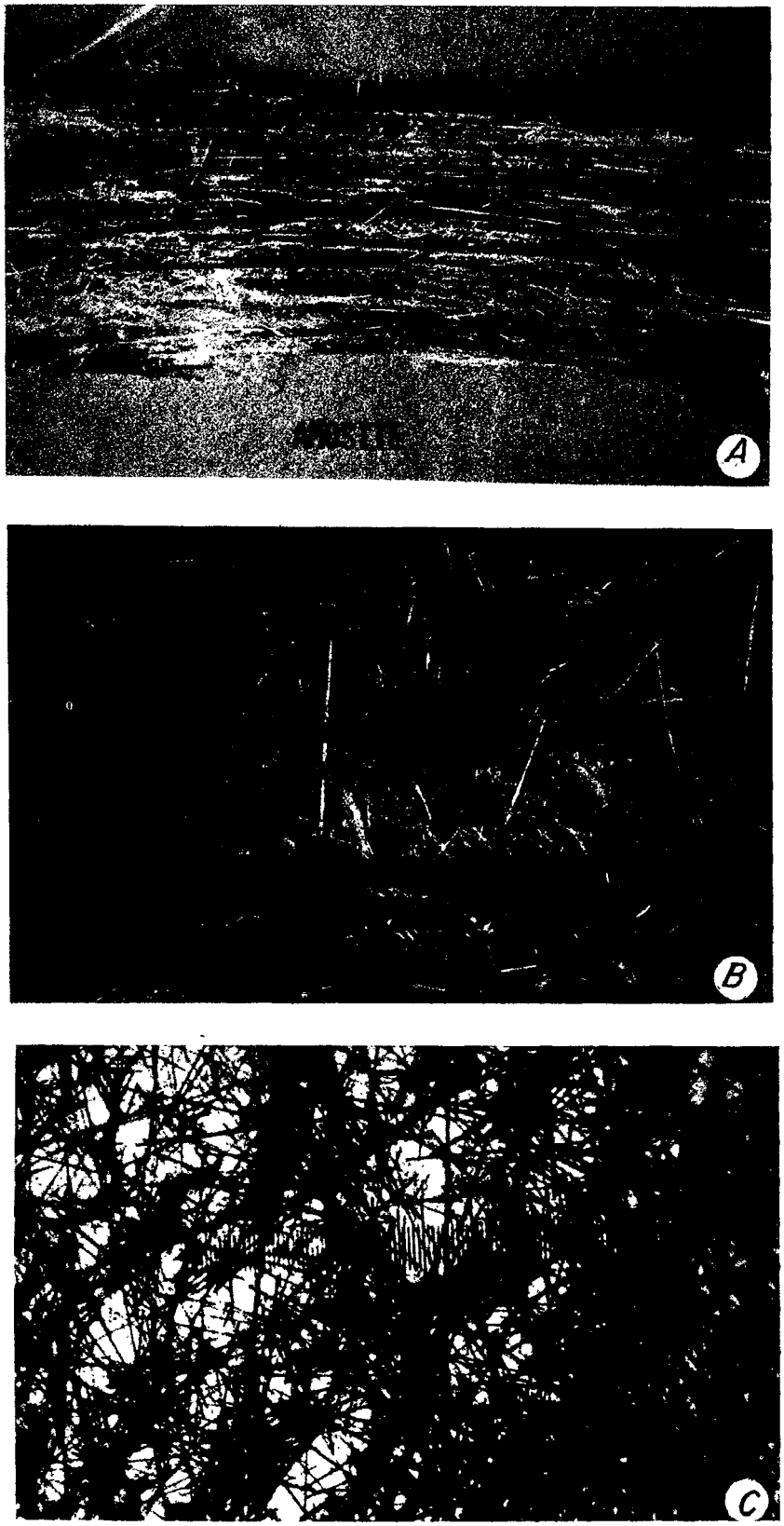

FIGURE 5. - Amosite asbestiform variety. *A*, Specimen; *B*, closeup; *C*, photomicrograph (2.75 μm/Div.).

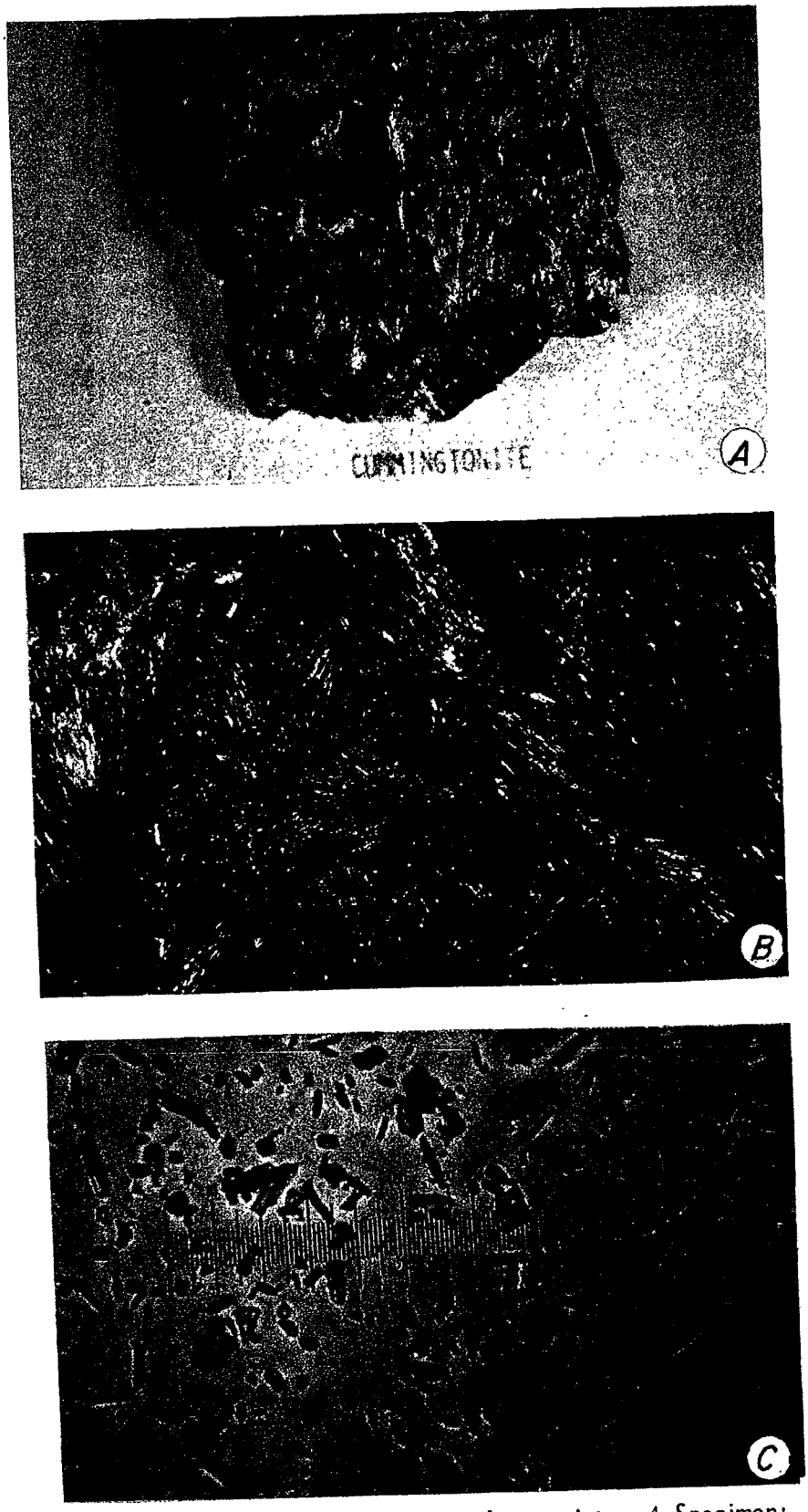

FIGURE 6. - Cummingtonite asbestiform variety. *A*, Specimen; *B*, closeup; *C*, photomicrograph (2.75 μm/Div.).

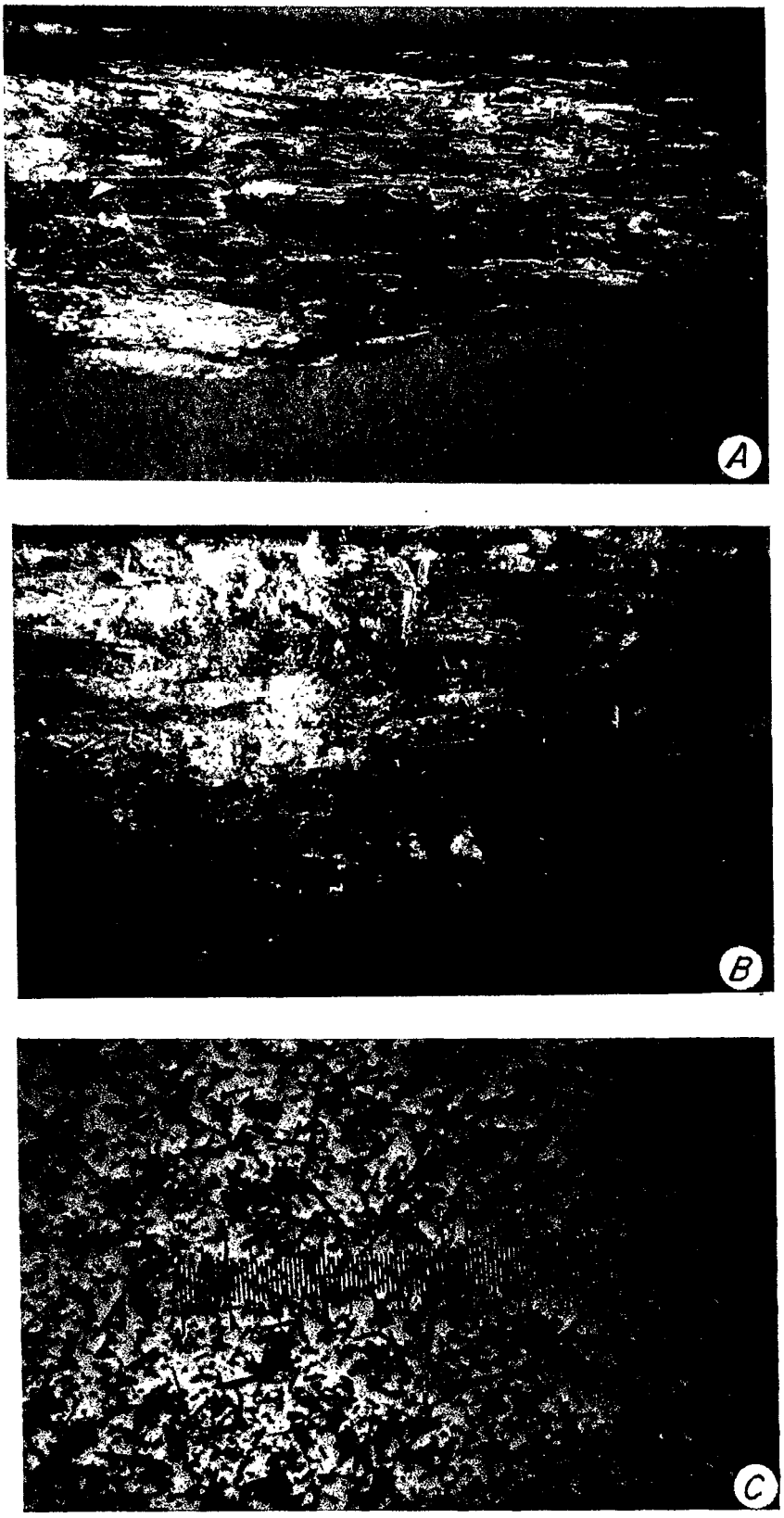

FIGURE 7. - Anthophyllite asbestos asbestiform variety. *A*, Specimen; *B*, closeup; *C*, photomicrograph (2.75 μm/Div.).

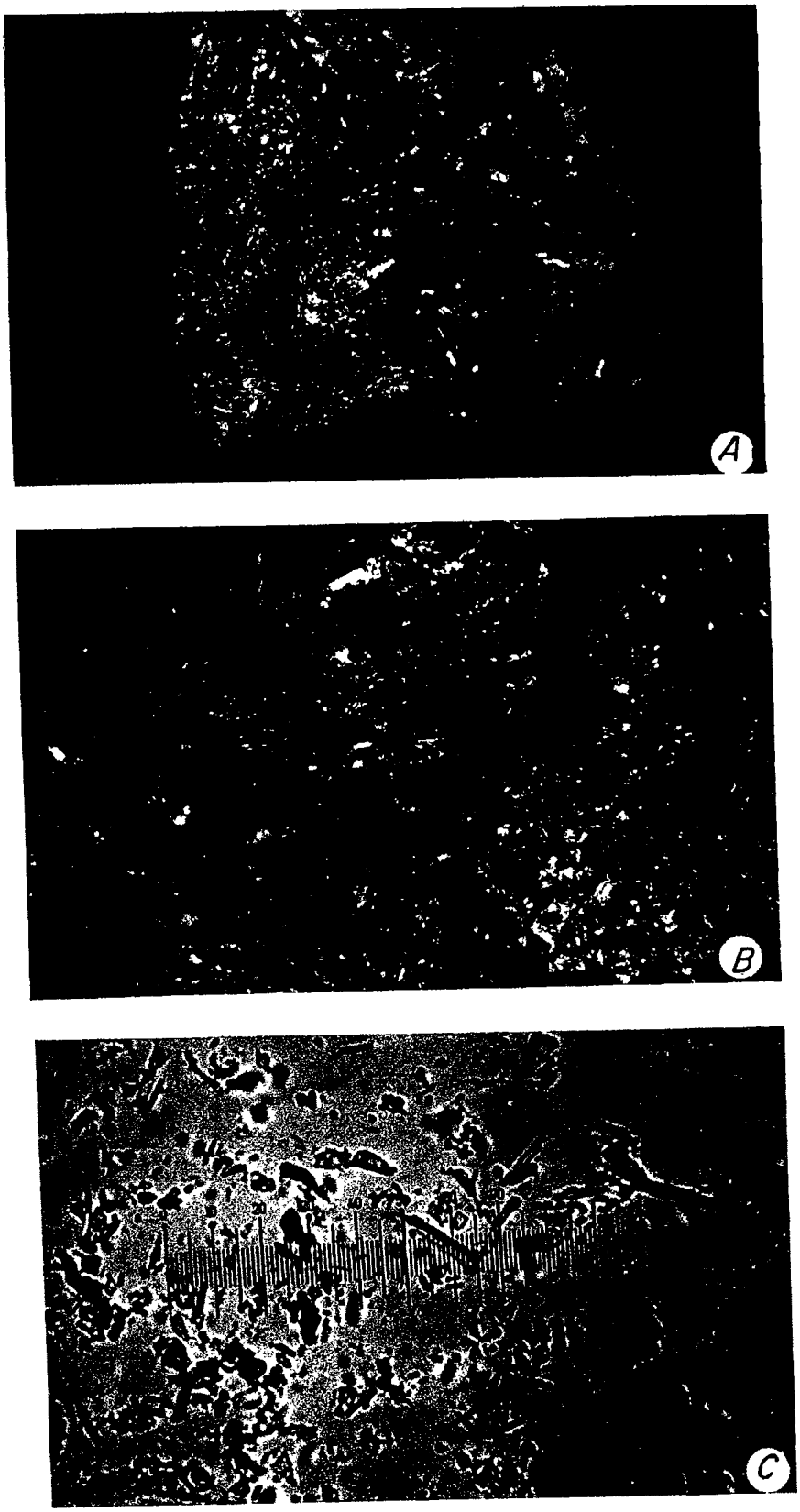

FIGURE 8. - Anthophyllite nonasbestiform variety. *A*, Specimen; *B*, closeup; *C*, photomicrograph (2.75 μm/Div.).

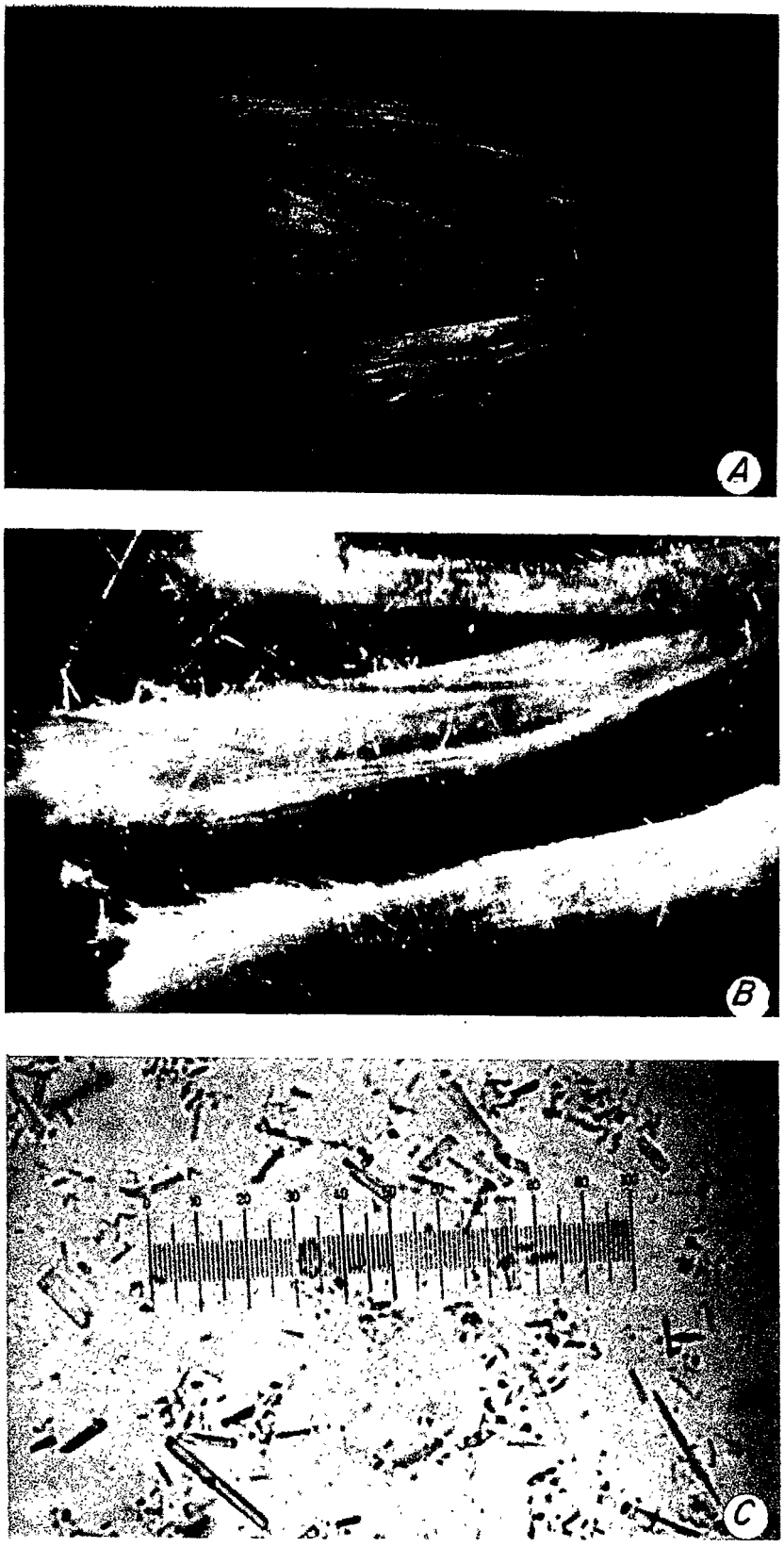

FIGURE 9. - Tremolite asbestos asbestiform variety. *A*, Specimen; *B*, closeup; *C*, photomicrograph (2.75 μm/Div.).

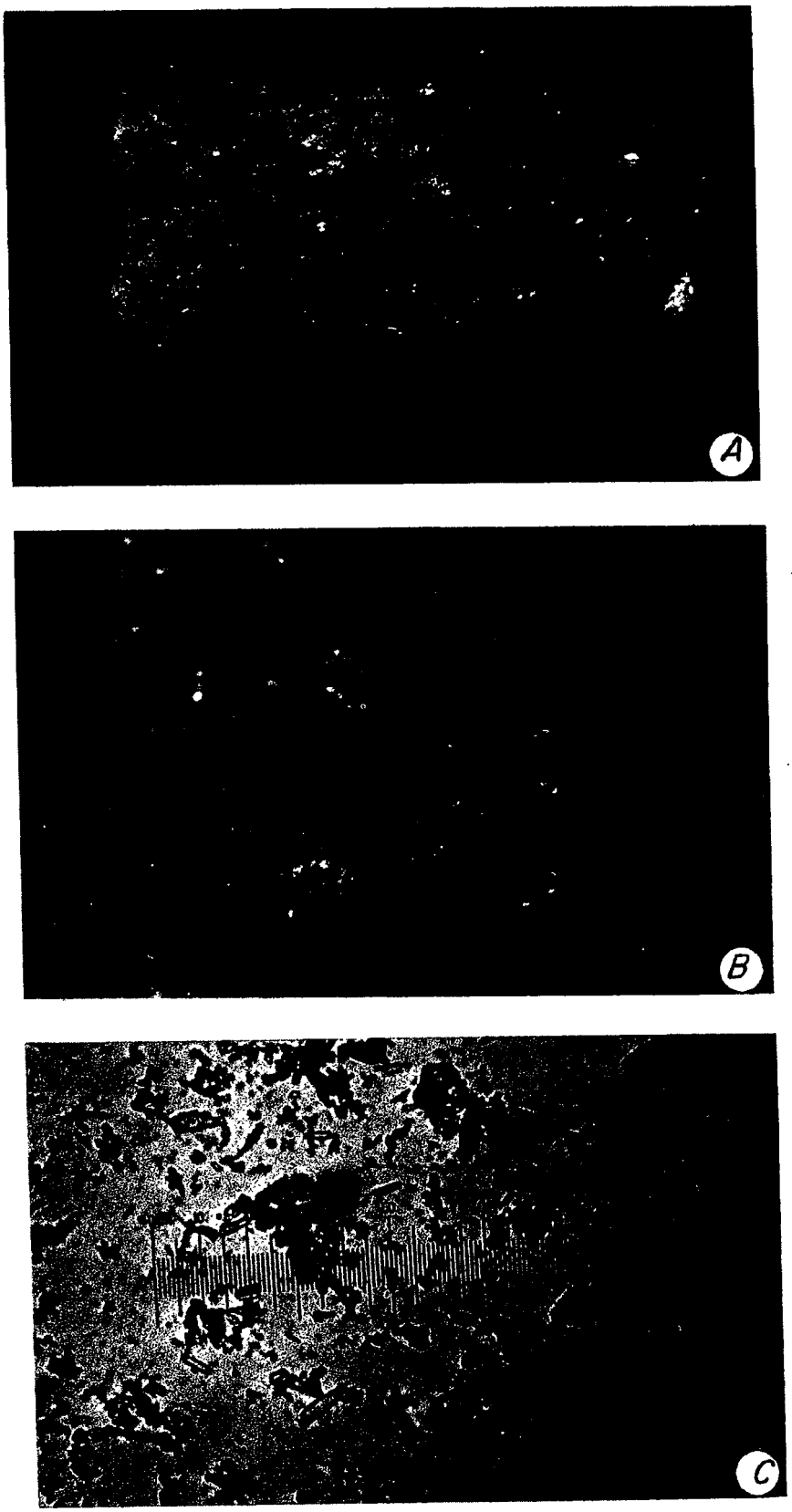

FIGURE 10. - Tremolite nonasbestiform variety. *A*, Specimen; *B*, closeup; *C*, photomicrograph (2.75 μm/Div.).

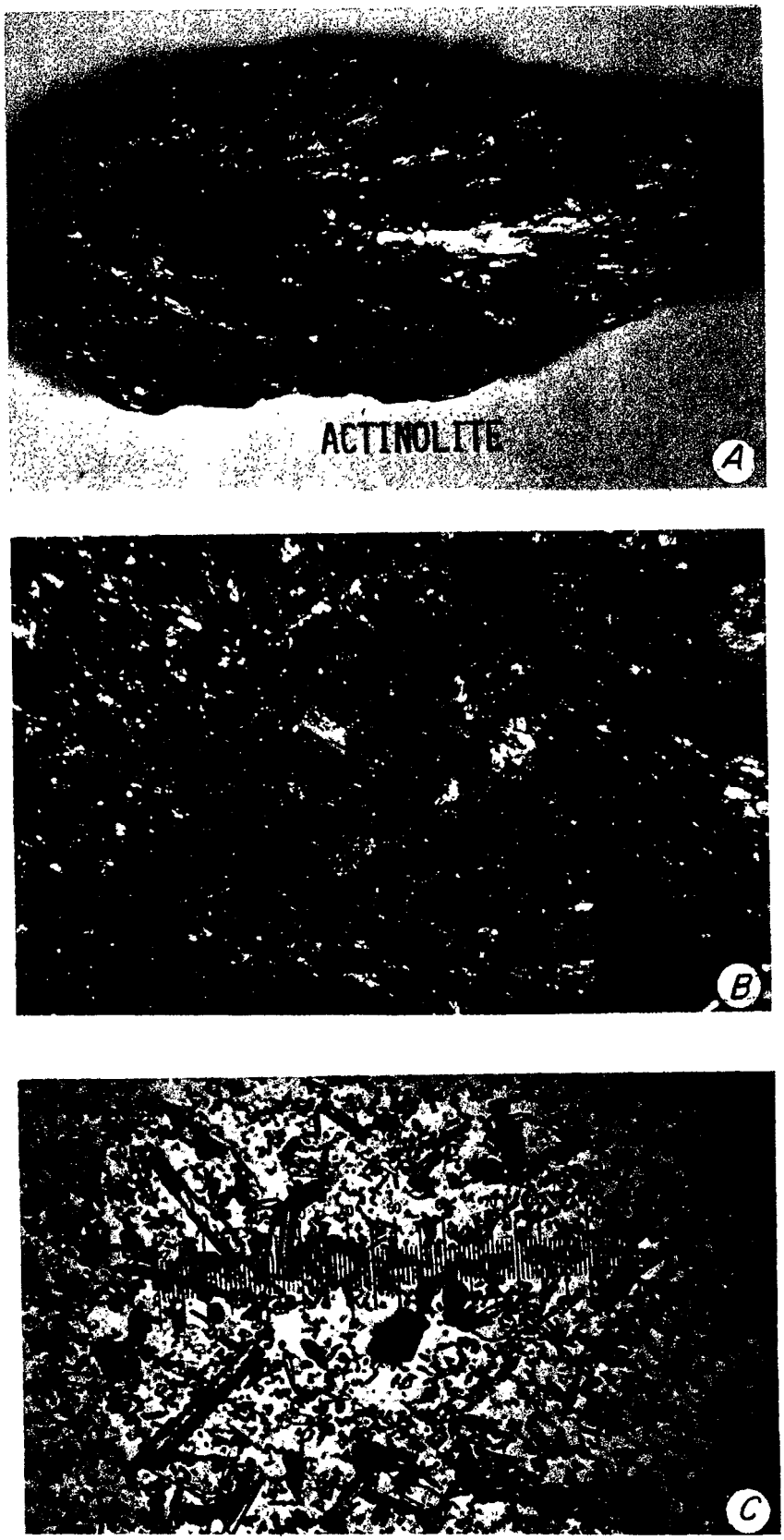

FIGURE 11. - Actinolite nonasbestiform variety. *A*, Specimen; *B*, closeup; *C*, photomicrograph (2.75 μm/Div.).

FIGURE 12. - New York talcs, Nytal 99 (~50 percent tremolite), 5.5 μm/Div.

FIGURE 13. - New York talcs, Nytal 200 (~45 percent tremolite), 5.5 μm/Div.

FIGURE 14. - New York talcs, Nytal 400 (~40 percent tremolite), 5.5 μm/Div.

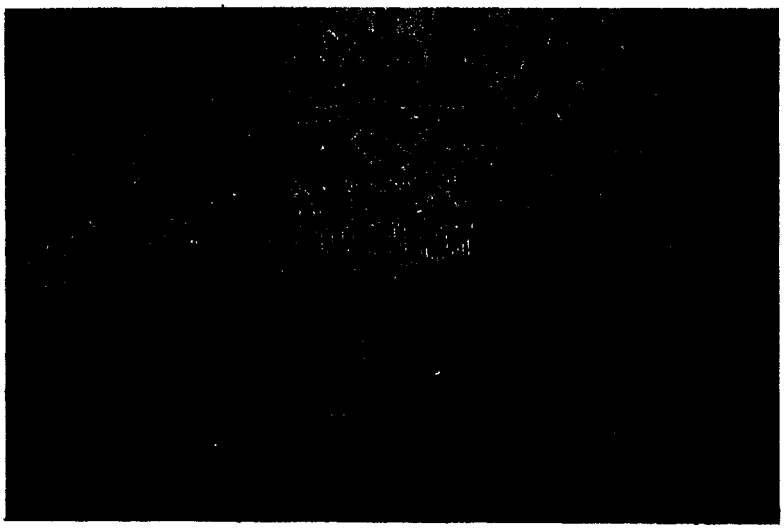

FIGURE 15. - California talcs, Western hard ore (~35 percent tremolite), 5.50 μm/Div.

FIGURE 16. - California talcs, Westal 301 (~30 percent tremolite), 5.50 μm/Div.

FIGURE 17. - California talcs, Westal 404 (~20 percent tremolite), 5.50 μm/Div.

Appendix

Bibliography of Asbestos Terms

Source 1: Berger, Hans (translated by Ralph E. Osper). Asbestos Fundamentals--Origins, Properties, Mining, Processing, Utilization. Chemical Publishing Company, Inc., New York, 1963.

> In the mineralogical sense the term asbestos is extended in part also to other fibrous minerals, without reference to composition, structural constitution, properties, and technical-industrial significance. Two main groups are differentiated with respect to origin, mode of formation, mineralogical relationships, structure, composition, and properties of the asbestoses: namely, the serpentine asbestoses (chrysotiles) and the amphibole asbestoses. The fibrous crystalline variants of the minerals have in part been given individual names to which, in the interest of a precise terminology, the word asbestos must not be appended. For example, the fibrous form of serpentine is called chrysotile, serpentine-asbestos, or fibrous serpentine--but not chrysotile asbestos. The accepted names of the five asbestoses used commercially are given as follows:

Group	Designation of mineral	Designation of asbestos
Serpentine asbestos	Serpentine.....	Chrysotile.
Amphibole asbestos.	Riebeckite.....	Crocidolite, blue asbestos
Do.....	Gruenerite.....	Amosite.
Do.....	Anthophyllite.....	Anthophyllite asbestos.[1]
Do.....	Tremolite.....	Tremolite asbestos.[1]

[1] These varieties have no special designation.

Source 2: HM Factory Inspectorate, United Kingdom. Asbestos Health Precautions in Industry Department of Employment. Health and Safety at Work, No. 44. 1971.

> Asbestos is the common name given to a number of inorganic, fibrous, silicate minerals that possess a crystalline structure. Chrysotile, the most abundant of the fibrous silicates and the one most extensively used in industry, belongs to the serpentine group of rock-forming minerals and is mined mainly in Canada, Russia, and Rhodesia. The other forms of asbestos belong to the amphibole group. They are crocidolite, commonly known as 'blue asbestos' which is found in South Africa; Western Australia and Bolivia; amosite which occurs only in South Africa; anthophyllite, the fibrous form of which is found in Finland and Africa; and the fibrous forms of tremolite (available in Italy) and actinolite, which has been found in South Africa.
>
> 'Asbestos' means any of the following minerals, that is to say, crocidolite, amosite, chrysotile, fibrous anthophyllite and any mixture containing any of the said minerals.

Source 3: Ladoo, Raymond Bardeen. Non-Metallic Minerals. McGraw-Hill, New York, 1st ed., 1925.

> Asbestos, 'amphibole' asbestos, 'hornblende' asbestos, and 'Italian' asbestos are various terms given to the monoclinic amphiboles, tremolite $Ca_2Mg_5(Si_8O_{22})(OH,F)_2$ and actinolite, $Ca(Mg,Fe)_2(SiO_3)_4$, when they occur in fine silky fibers.

Source 4: Dana, Edward Salisbury. A Textbook of Mineralogy. With an Extended Treatise on Crystallography and Physical Mineralogy. John Wiley & Sons, Inc., New York, 1947.

> Actinolite. Calcium-magnesium-iron amphibole.....In crystals, either short- or long-bladed, as in tremolite; columnar or fibrous; granular massive....The fibrous and radiated kinds are often called asbestiform actinolite and radiated actinolite.....ASBESTOS.
> Asbestos. Tremolite, actinolite, and other varieties of amphibole, excepting those containing much alumina, pass into fibrous varieties, the fibers of which are sometimes very long, fine, flexible, and easily separable by the fingers, and look like flax. These kinds are called asbestos (from the Greek for incombustible).....
> CROCIDOLITE. Blue Asbestos--Probably to be considered as a fibrous variety of riebeckite. Fibrous, asbestos-like; fibers long bur delicate and easily separable.

Source 5: Hurbut, Cornelious S., Jr. Dana's Manual of Mineralogy. John Wiley & Sons, Inc., New York, 18th ed., 1971.

> Serpentine occurs in two distinct forms: (1) a platy variety, antigorite, which conforms in its properties to those of the phyllosilicates, and (2) a fibrous variety, chrysotile. ...The variety chrysotile is the chief source of asbestos. The uses of asbestos depend upon its fibrous, flexible nature, which allows it to be made into felt and woven into cloth and other fabrics, and upon its incombustibility and slow conductivity of heat. Asbestos products, therefore, are used for fireproofing and as an insulation material against heat and electricity. Massive serpentine, which is translucent and of a light to dark green color, is often used as an ornamental stone and may be valuable as building material.

Source 6: Gary, Margaret, R. McAfee, Jr., and C. L. Wolf. Glossary of Geology. American Geological Institute, Washington, D.C., 1972.

> Amosite: A commercial term for an iron-rich, asbestiform variety of amphibole occurring in long fibers. It may consist of an orthorhombic amphibole (anthophyllite and gedrite) or of a monoclinic amphibole (commingtonite or grunerite).
>
> Asbestos: A commercial term applied to a group of highly fibrous silicate minerals that readily separate into long, thin, strong fibers of sufficient flexibility to be woven,...certain fibrous varieties of amphibole...

Crocidolite: A lavender-blue, indigo-blue, or leak-green asbestiform variety of riebeckite, occurring in silky fibers and in massive and earthy forms. Syn: Blue asbestos: Krokidolite.

Source 7: Deer, W. A., R. A. Howie, and J. Zussman. Rock Forming Minerals. V. 2, Longman Group Ltd., London, 1963.

Riebeckite also occurs as an extremely fibrous mineral, when it is known as blue asbestos or crocidolite. The best known occurrences of blue asbestos are in South Africa where it occurs in bedded ironstones, the seams of crocidolite conforming to the bedding of the ironstones. The composition of the crocidolite is remarkably similar to that of the ironstone and the crystallization of the amphibole, initially in the form of massive riebeckite, occurred with little or no addition of material under conditions of moderate temperature and pressure consequent on the burial of the ironstones to moderate depth. ....Both Peacock (1928) and Hall (1930) favor the hypothesis that Na_2O was originally uniformly distributed throughout the ironstone and subsequently concentrated in certain bands. The later transformation of the massive riebeckite to the fibrous crocidolite may result from the instability of the riebeckite during a period when the ironstones were subjected to shearing stress. .....The members of the cummingtonite-grunerite series are typically found in both regionally and contact metamorphosed rocks. The more magnesian members are found also in some igneous rocks, including those of hybrid origin. The asbestiform varieties amosite and montasite are of economic importance. ....The characteristic habit of the members of the cummingtonite-grunerite series is acicular or fibrous. The asbestiform variety, amosite, when fresh is ash-grey in color; the mineral, however, is frequently coated with iron oxides, when the color is brown to yellow. The fibers of the montasite variety are less harsh than amosite and are often soft and silky in texture. ....The habits of the anthophyllite minerals vary from fibrous and asbestiform to bladed and prismatic. The fibers of anthophyllite asbestos generally do not have any great tensile strength and are of less economic importance than the amosite and crocidolite fibers. .....Mass-fiber anthophyllite asbestos occurs as a replacement mineral in ultrabasic rocks at Kamiah, Idaho (Anderson, 1931). .....Laudermilk and Woodford (1930) have described an asbestiform anthophyllite in veins in serpentinite at Coffe Creek, Carvill, California.

Source 8: Deer, W. A., R. A. Howie, and J. Zussman. Rock Forming Minerals. V. 3, Longmans, Green and Company, Ltd., London, 1962.

The principal minerals of the serpentine group all have the approximate composition $H_4Mg_3Si_2O_9$, and comparatively little substitution of other irons is found to occur in natural specimens. The most well known serpentine mineral, chrysotile, often occurs in veins of silky fibers and is the most important source of commercial asbestos.

Source 9: Read, H. H. Rutley's Elements of Mineralogy. Thomas Murby & Company, London, 25th ed., 1953.

> Mineralogically, asbestos includes the fibrous forms of amphibole; the fibers are generally very long, fine, flexible, and easily separated by the fingers; the color.....The term asbestos in the strictest sense is confined to the fibrous forms of actinolite, but the asbestos of commerce includes fibrous varieties of a number of silicates....

Source 10: Huggins, Charles W. Electron Micrographs of Asbestiform Minerals. BuMines RI 5551, 1959, 14 pp.

> Tremolite does not break down into fibers that approach a uniform rectangular cross section, as crocidolite does. Two samples (figures 9 and 10) indicate that the fibers break into fragments. Some of the fragments are quite thin, while others are rather thick. The fragments are composed of thin sheets. Some of the small sheets (figure 9) are so thin that they are almost translucent to the electron beam. Dark streaks are again noticeable in the thin sheets of tremolite, as they are slightly wrinkled for Bragg reflections. The thin sheets are probably less than 100 A. in thickness.
>
> Actinolite is generally considered the basic amphibole asbestos member. The fibers of actinolite are quite poor; and, because it rarely has commercial value, it is not very well known. The sample examined was splintery and very brittle. It was not expected that the mineral would break down into fibers for electron microscopic study, but we felt it worth the effort to try, since it is the basic member of the amphibole group. Figure 11 reveals that it did not break into single fibers. Low magnification was used, as the material broke into large, opaque pieces.

Source 11: Gaze, Richard. The Physical and Molecular Structure of Asbestos. Ann. New York Academy of Science, article 1, v. 132, 1965, pp. 23-30.

> The name 'asbestos' is used to describe any mineral that breaks down into fibers when it is crushed or processed.

Source 12: Kingery, W. D. Introduction to Ceramics. John Wiley & Sons, Inc., New York, 1963.

> Asbestos: 'Asbestos' is the name given to a group of hydrous magnesium silicate minerals which have a fibrous texture. The crystal structure of these minerals is characterized by the presence of long chains of silicate tetrahedra which can be readily cleaved in directions parallel to the silicate chains but not in directions that cut the chains, with the result that these minerals can be shredded into fibers...

Source 13: McGraw-Hill Book Company, Inc. Mineral Raw Materials, by the Foreign Minerals Division, U.S. Bureau of Mines, 1937, p. 16.

> Asbestos is not a distinct material but a commercial term used to express the fibrous nature of several minerals.

Source 14: Colliers Publishing Co. Colliers Encyclopedia, 1972.

> Asbestos, any of several varieties of fibrous minerals whose fibers may be spun or felted to make fabrics, panels, or coatings that are resistant to heat and chemical action. Asbestos is also valued for its electrical insulating properties.

Source 15: Encyclopedia Americana--International Edition, 1969.

> Asbestos, general name for a group of silicate minerals that occur as fibers or fibrous masses and that can be woven into heat resistant materials. The fibers are separated mechanically and pressed, spun, or woven, often with cotton, wire, rubber, or cement, to produce fireproof articles of all types: clothing, curtains, electric cable insulation, brake linings and clutch facings, insulating boards, sheets, shingles and talcs.
>
> Asbestos is a fibrous mineral substance...In its natural state, asbestos is found encased in rocks. Its fibrous quality makes it a remarkable mineral. Asbestos is as dense as the rock in which it is encased, but it is a mass of tiny fibers that become as fluffy and light as thistledown when separated mechanically from rock.

Source 16: Encyclopedia Britannica, 1971.

> Fibre--A fibre may be defined as a unit of matter of hair-like dimensions whose length is at least 200 times greater than its width.

EXPERIMENTAL STUDIES ON BIOLOGICAL EFFECTS OF TREMOLITE TALC ON HAMSTERS

by

William E. Smith, M.D.[1]

My name is William E. Smith. I am director of Health Research Institute at Fairleigh Dickinson University, Madison, N.J. I am a doctor of medicine. Over the past 25 years, I have studied more than 200 chemical materials for carcinogenicity in animals and have reported results of these tests in scientific journals. In the past 8 years my associates and I exposed animals to various mineral dusts, maintained them over their natural life spans, and studied them for pathologic changes by gross and microscopic examination of their tissues and organs.

The principal purpose of these latter studies has been to develop information on possible fibrogenic and/or carcinogenic properties of various preparations of mineral dusts. The principal support for this work was provided by Research Grant EC 00226 from the Bureau of Occupational Safety and Health, U.S. Public Health Service. Thus far, we have published five papers (listed in the bibliography section of this paper) describing some of our findings in animals exposed to various preparations of asbestos. Today, I would like to offer a brief summary of our experiments with asbestos and describe as yet unpublished data from studies we have made with a sample of talc containing a large amount of tremolite.

From our work, we identified the Golden Syrian hamster as a species that was capable of developing pulmonary fibrosis resembling asbestosis seen in man. Those experiments were done by repeated intratracheal injections of chrysotile or amosite asbestos.

The method used for those experiments, weekly intratracheal injections, is technically tedious and time consuming. We found that we could compare the relative fibrogenicity and carcinogencity of mineral dusts more conveniently by depositing the dusts by a single injection into the pleural space of hamsters.

After single intrapleural injection of preparations of the chrysotile, amosite, anthophyllite, or crocidolite types of asbestos, we found that hamsters developed extensive pleural adhesions. These adhesions were composed mainly of round cells and multinucleated giant cells in the first few months after injection. Within 5 months, these adhesions became densely fibrotic. Adhesions induced by the chrysotile, amosite, anthophyllite, or crocidolite types of asbestos tended to extend over large areas of the surfaces of the lungs.

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In contrast, we saw very little reaction when we gave hamsters intrapleural injections of a sample of tremolite talc, which I shall identify by our sample number, FD-14. After intrapleural injection of this tremolite talc, the particles were gathered into small depots on the lung surface. These depots contained round cells and multinucleated giant cells, but there was very little formation of fibrous tissue. The experiments thus show that fibrogenic activity of tremolite talc is very much less than the fibrogenic action of the four principal types of asbestos.

Also, in hamsters that had been given intrapleural injections of the four principal types of asbestos, we found intrathoracic tumors that we designate as mesotheliomas (table 1).

TABLE 1. - Number of mesotheliomas in groups of 50 hamsters

Dose, mg	Chrysotile	Amosite	Anthophyllite	Crocidolite
25	9	-	-	-
10	4	3	3	10
1	0	0	-	2

From the data in table 1, it can be seen that the yield of mesotheliomas, in groups of 50 hamsters per sample, was related to dose. In response to a large dose (25 mg) of chrysotile, nine hamsters developed mesotheliomas. In response to a smaller dose (10 mg) of chrysotile, four hamsters developed mesotheliomas. In response to a still smaller dose (1 mg), there were no mesotheliomas. This experiment provides evidence to show that the carcinogenic action of chrysotile is related to dose, hence should be controllable by appropriate industrial hygiene measures to control dose.

At the 10 mg dose level, amosite and anthophyllite gave about the same yield of mesotheliomas as did chrysotile, but crocidolite induced more than double the number of mesotheliomas gotten with the other types of asbestos.

Also, crocidolite induced mesotheliomas in two hamsters treated with the lowest dose level (1 mg) whereas no mesotheliomas occurred in animals treated with that dose of chrysotile or amosite.

Table 2 shows results of tests for carcinogencity of six preparations of chrysotile in groups of 50 hamsters each. Each of these preparations was tested at our highest dose level (25 mg per injection). The table gives data on the mean fiber length and mean fiber diameter of these samples. It can be seen that 8 to 10 mesotheliomas were induced by three of these samples: harsh chrysotile, soft chrysotile, and the same sample of soft chrysotile heat-treated to achieve some of the properties of harsh chrysotile. These three samples that proved carcinogenic had mean fiber length of 5.3 to 6.9 micrometers and mean fiber diameter of 0.2 to 0.8 micrometer.

These three active preparations of chrysotile were subjected to further milling to reduce the majority of particles to submicroscopic dimensions. The

table shows that this reduction in particle size eliminated the carcinogenic effect of these samples. It also greatly reduced their fibrogenic action.

TABLE 2. - Tests for carcinogenicity of six preparations of chrysotile in groups of 50 hamsters each

Chrysotile preparation	Mean fiber length		Mean fiber diameter		No. of mesotheliomas
	OM, micrometers	EM, micrometers	OM, micrometers	EM, micrometers	
Soft.....	32.5	6.9	2.2	0.18	8
Soft (heated).	-	-	-	-	10
Harsh.....	38.9	5.3	2.9	.2	9
Soft.....	-	.9	-	.03	0
Soft (heated).	-	-	-	-	0
Harsh.....	-	.4	-	.07	0

OM Optical microscope.
EM Electron microscope.

Now, we have tested a sample of tremolite talc for carcinogenicity in hamsters. Electron diffraction studies of this sample showed it to contain 50 percent fibrous tremolite and 35 percent talc (table 3). A majority of the talc particles were platy, but some were rolled or fibrous.

TABLE 3. - FD-14 (tremolite talc): Composition

	Percent
Selected area electron diffraction:	
Fibrous tremolite.....	50
Antigorite.....	10
Talc[1].....	35
Chlorite.....	5

[1]Of this about 75 percent is platy and 25 percent is rolled or fibrous.

In this sample, the fibrous particles had an average length of 5.7 micrometers and an average diameter of 1.6 micrometers (table 4). They are therefore in a size range that might be carcinogenic in our experiments with chrysotile. However, this sample of tremolite talc induced no mesotheliomas after intrapleural injection into hamsters.

TABLE 4. - FD-14 (tremolite talc): Size measurement[1]

(Phase microscopy 10x ocular, 100x objective)

	Length, micrometers		Diameter, micrometers	
	Range	Average	Range	Average
Fibrous particles.....	2.5-16.5	5.7	1- 5	1.6
Platy particles.....	-	-	1-10	2.0

[1]Ratio fibrous to platy particles: 3 to 1.

Table 5 gives detailed data on these tests which were conducted at our highest dose level (25 mg). In view of the long latent period before development of tumors, if we wish to compare relative carcinogenicity of different samples, validity of the comparisons depends on the number of animals surviving into the later periods of the tests. In table 5, the number of survivors in each group at each time period is shown as the denominator. The cumulative number of animals bearing mesotheliomas is shown as the numerator.

TABLE 5. - Yields of mesotheliomas in hamsters after intrapleural injection at 25-mg dose level[1] [2]

Sample	151 days	340 days	372 days	450 days	500 days	550 days	600 days	650 days	700 days
Soft chrysotile.....	0/44	0/33	1/30	1/20	4/11	4/9	7/3	8/1	([3])
Harsh chrysotile.....	1/41	4/26	4/21	7/16	7/13	7/9	8/5	9/2	([3])
Heat-treated soft chrysotile.....	0/37	1/35	1/32	1/27	4/17	5/15	8/4	10/1	([3])
Tremolite talc.....	0/52	0/35	0/34	0/29	0/27	0/23	0/20	0/15	0/7

[1] Numerator: Cumulative number of hamsters with mesotheliomas.
[2] Denominator: Number of hamsters surviving on stated day.
[3] Survivors at 650 days in chrysotile groups were killed on that day. Pleural adhesions, but no tumors, were found in them.

We started with about 50 hamsters in each group. The first tumor was found at 151 days in an animal that had been treated with harsh chrysotile.

Now let us look at the situation as it was 500 days after start of tests. At that time, 4 mesotheliomas had occurred in the group treated with soft chrysotile and only 11 animals survived.

In the group treated with harsh chrysotile, 7 mesotheliomas had occurred and 13 hamsters were still living.

In the group given heat-treated soft chrysotile, there were 4 mesotheliomas and 17 survivors.

By comparison, no mesotheliomas had occurred in the group treated with tremolite talc, and there were 27 survivors.

The group on tremolite talc thus had many more animals at risk in the late stages of the tests, yet no mesotheliomas developed in them.

In the three groups on preparations of chrysotile, all of the animals had died or were killed to close out those groups by 650 days. At that time, the final yield of mesotheliomas in those groups was 8, 9, and 10, respectively.

By comparison, the group on tremolite talc had developed no mesotheliomas by 650 days, and there were still 15 animals living and at risk in that group at that time.

Eight of these survivors died of various causes between 650 and 700 days. No mesotheliomas were found in them.

The remaining seven survivors on tremolite talc were killed for examination at 700 days. No mesotheliomas were found in them.

Throughout the tests, animals treated with the preparations of chrysotile in table 5 were found to have thick fibrous pleural adhesions extending over large areas of the lung surfaces, whereas animals treated with tremolite talc never showed more than small depots of the mineral particles with relatively little tissue reaction.

In summary, our experiments show profound differences between the biologic effects of tremolite talc, in respect to both fibrogenicity and carcinogenicity, as compared with the biologic effects of the four principal types of asbestos: chrysotile, amosite, anthophyllite, and crocidolite.

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THE BIOLOGICAL ACTION OF TALC AND OTHER SILICATE MINERALS

by

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Introduction

The recent revelation that prolonged human inhalation of certain fibrous minerals (for example, crocidolite) may be associated with excess prevalence of malignant neoplasia of the lung, and even of other organs such as the stomach or colon, has focussed attention on the biological potentials of all the fibrous minerals. For reasons not quite clear to this author, talc has somehow and probably quite unjustifiably become embroiled in the issue of the carcinogenicity of asbestiform minerals. Talc, though a silicate, is by no means a fibrous mineral.

It is quite important, however, to thoroughly review biological reactivity to talcs because their industrial uses are so diversified. Direct human exposure is considerable, involving all elements of humanity, practically from cradle to grave. There also is a contradiction between the stringent rules for dust suppression in mining or milling of talc and the almost total lack of controls over talc when released for private use.

The crucial issue is whether all silicate minerals are equally pathogenic. To resolve this question it is necessary to review what is on record concerning the biological action of talc and compare this with what is known about the adverse properties of other silicates and especially the asbestiform minerals.

The biological potentials of a variety of natural and synthetic silicates have been personally researched over the past 3 decades. These studies have included investigation of human subjects, experimental animals, and a review of the literature. Human studies include observations on crocidolite and amosite miners and millers in Africa, chrysotile, tremolite, and talc miners, millers, and industrial workers in the United States and Canada, and textile workers in fiberglass and synthetic fiber industries. The number of human subjects studied exceeds 10,000. These studies are evaluated against a background of familiarity through personal clinical experience and research of the pathogenic action of a variety of other natural and synthetic siliceous, non-siliceous, and chemical and synthetic substances. The clinical subjects exceed 100,000 and necropsies have been performed on over 10,000 deceased industrial workers.

Animal studies have recently been reviewed in a publication on Tumors of Primates and Rodents (7). These included researches on the biological properties of 407 industrially important materials through experimental exposures of 7,906 animals.

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The published literature is vast and ever increasing. In excess of 4,000 papers have been reviewed. If these do not include all that has been written on this subject of pneumoconiosis, any omissions would be unintentional.

For practical purposes all references cannot be cited nor will it be reasonable in a paper of the intended scope of this presentation to recapitulate all that is known about the biological actions of talc and fibrous environmental agents. It will be feasible only to summarize pertinent highlights.

Fibrous and Nonfibrous Dusts

There appears to be considerable difficulty in differentiating between respiratory inhalants which may be called "fibrous" as compared with "nonfibrous" substances. There is no problem when we consider substances such as crocidolite, amosite, chrysotile, anthophyllite, fiberglass, rockwool, or natural or synthetic textiles (wool, cotton, nylon, rayon, dacron, orlon, etc.). These materials are predominantly composed of elongated delicate component elements which are indisputably "fibers."

There appears to be no absolute definition of what constitutes a fiber--neither with mineralogists nor with textile experts. Review of discordant terminologies almost leads one to the conclusion that a fiber is a fiber when it is obviously so. Physicochemically speaking, however, a fibrous mineral would be a substance with a propensity for cleavage in two planes of space. Some mineral fibers can, however, also form when aluminosiloxane sheets are "rolled" to form tubules.

Sporadic and possible spurious attempts have been made to classify minerals such as talc or tremolite as fibrous dusts. This is apparently on the basis of three properties:

1. There is the fact that talc and tremolite are mineralogically classifiable as silicates, as are most fibrous minerals such as the asbestos series.

2. Some samples of talc and tremolite contain a minority of oblong particles which are considerably longer than they are thick. These elongated particles are only very rarely true "fibers" in the conventional sense and are more properly designated spicules, rods, or needles.

3. It is a fact that some talc or tremolite deposits occur geologically in close juxtaposition to chrysotile or other ore bodies so that some contamination of talc with serpentine, dolomite, magnetite, pyrophyllites, and clays may occur.

The logic in designating any nonfibrous silicate as fibrous, for the latter two reasons, somehow evades this author. If this principle were applied to other substances, there would be no sensible way to classify minerals or environmental contaminants. For example, hematitite or magnesite ores are often "contaminated" with siliceous materials, both fibrous and crystalline. Coal often contains mica, clays, asbestos, silica, etc. Do these admixtures justify classifying hematite as anything other than hematite;

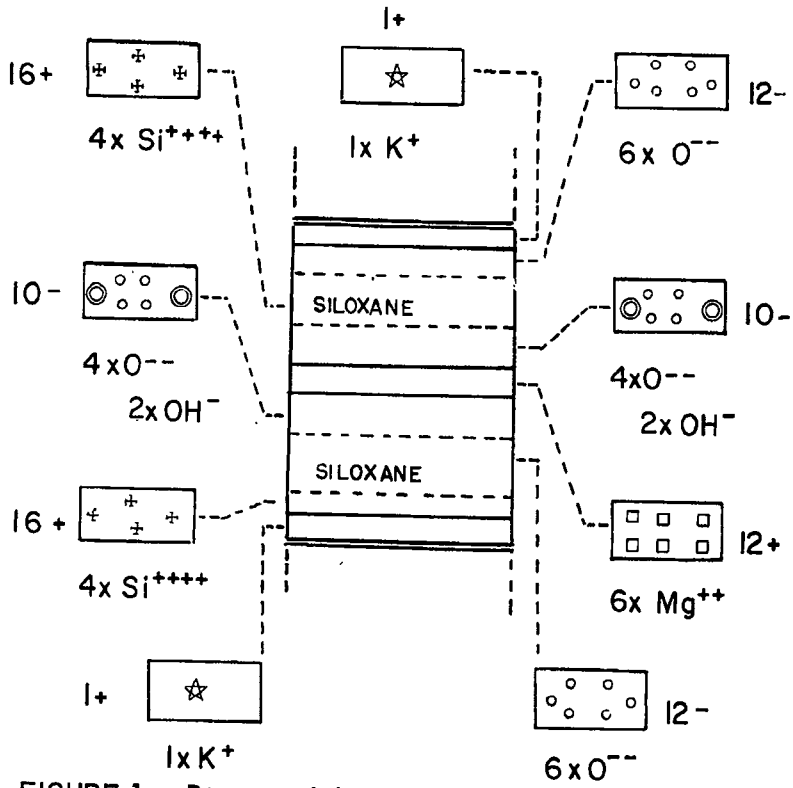

FIGURE 1. - Diagram of the alumina-siloxane templates of silicates.

magnetite as anything but magnetite; coal as anything except coal; and so forth?

Perhaps the solution lies in subclassifying the silicate materials (table 1) as those which belong to an asbestiform group and those that are not primarily asbestiform in nature. This may make mineralogical sense and may agree with some of the biological propensities of these materials. Such a classification may also be extended to embrace minerals and textiles, whether natural or synthetic.

To resolve these issues it is necessary to take a closer look at the physicochemical relationships of the various silicate minerals. These substances were all formed in nature because of certain highly characteristic coordinative properties of silicon, oxygen, and aluminum atoms. When the earth's crust was formed, these atoms sought one another to form the "substrate" for varieties of silicates. This substrate is the alumina-siloxane moiety formed in all silicates (fig. 1). Individual silicates differ from one another according to whether and how certain other elements such as iron, magnesium, manganese, sodium, and calcium become interposed in the "micropores" of the siloxane frame work and the degree to which and the manner in which these siloxanes are hydrated. This is a highly complicated although virtually fully decoded science. Indeed, because of the advanced state of the science of silicate chemistry, it already is industrially possible to synthesize a number of these multibillion-year-old natural silicate minerals--though not yet at sufficiently low cost to be competitive with mineral silicates. For our present purposes it is pertinent to summarize that, based on the alumina-siloxane template concept, there is a precise physicochemical explanation why silicate minerals are present in nature as microporous crystalline substances, or sheetlike tubular, ribbon or lathlike, oblongate, acicular, or fibrous minerals. A classification of the silicates on the basis of this principle is presented in table 2.

TABLE 1. - Fibrous respirable aerosols

Natural	Synthetic
MINERAL	
Silicate:	Silicate:
Asbestiform	Fiberglass
Crocidolite	Rockwool
Amosite	
Anthophyllite	Nonsilicate: Potassium titanite
Chrysotile	
Nonasbestiform	
Talc	
Tremolite	
Nonsilicate: Brucite	
TEXTILE	
Cotton	Nylon
Wool	Dacron
Hair	Orlon
Silk	Rayon

TABLE 2. - Silicate minerals

Microporous crystalline	Tubular or hollow
Laminar:	Hydrated:
Analcite	Chrysotile
Chabazite	Endellite
Heulandite	
Fibrous: Natrolite	Anhydrous: Halloysite
Sheetlike	Ribbonlike
Aluminous:	Attapulgite
Montmorillonites	Sepiolite
Montmorillonite	Paligorskite
Nontronite	Oblong particulate
Hectorite	Tremolite
Saponite	Acicular
Micaceous	Sericite
Biotite	Antigorite
Illite	Sillimanite
Muscovite	Fibrous
Phlogopite	Actinolite
Vermiculite	Anthophyllite
Pyrophyllite	Amosite
Kaolinites	Crocidolite
Kaolin	
Actinolite	
Nonaluminous: Talc	

It is to be noted that talc is here classified as a sheetlike silicate which is in a group quite separate from other laminar silicates or from tremolite which is often also called talc. Because talc ($Mg_3Si_4O_{10}(OH)_2$) lacks the aluminum atoms which have such a strongly bonding effect between the siloxane

polymeric layers, the talc silicate readily splits primarily and predominantly along one plane of space to form fine lamina. However, cleavage along the two other planes of space occurs secondarily. This provides for the fine divisibility of talc. The nonadherence of the flat particle surfaces to one another furnished the "greasy" or "slippery" property of talc. Scanning electron microscopy has well demonstrated this flaky character of the talc particle (fig. 2).

Tremolite also is often classified as talc, perhaps because it also lacks the aluminum atom. Since two calcium atoms substitute for aluminum, tremolite belongs mineralogically with the amphiboles (which all have achieved comparable substitutions). It has the empirical formula: $Ca_2Mg_5Si_8O_{22}(OH)_2$. From the point of view of its siloxane structure, tremolite differs from talc in that it cleaves almost equally readily in two planes of space whereas cleavage in the third plane is a secondary feature. For this reason the classical tremolite particle is cuboidal to oblongate instead of platelike (fig. 3). A minority of tremolite "crystals" cleave less well in the third dimension than they do in the other two. These particles then manifest as stiff rods or needles. For this reason the appropriate location of tremolite in table 3 lies between the sheetlike silicates and the acicular silicates (sericite, antigorite, and sillimanite). The latter habitually cleave in such a manner that their natural format is a short needle or rod.

The amphibole minerals, as mentioned above, have substituted other elements for aluminum. Thus in actinolyte and anthophyllite both magnesium and

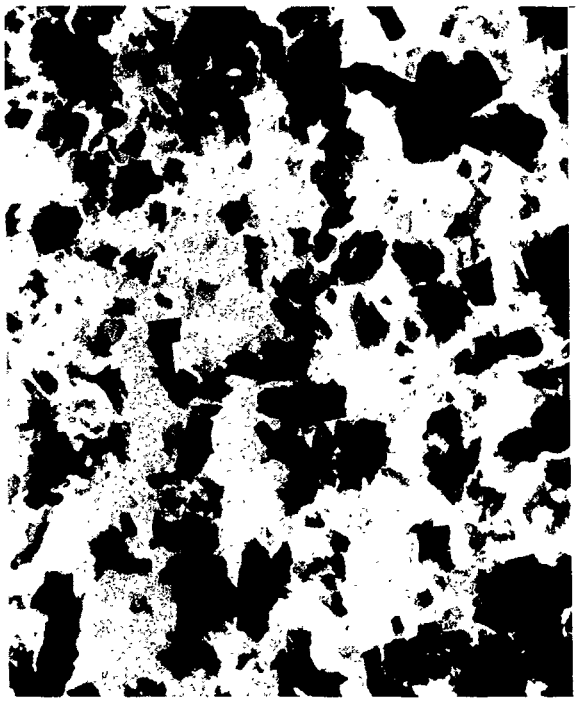

FIGURE 2. - Electron microphotogram of talc showing its laminar character (X 7,500).

FIGURE 3. - Microphotograph of typical oblong tremolite crystals. (Magnification unknown.)

iron are present $(MgFe)_7Si_8O_{22}(OH)_2$. In crocidolite there are both sodium and bivalent and trivalent iron ($Na_2Fe^{+2}_3Fe^{+3}_2Si_8O_{22}(OH)_2$). Amosite is a mixture of actinolite and anthophyllite. Aluminum is absent from all of these. Their cleavage in relation to the siloxane substrate is predominantly and equally in two parallel planes. For this reason, they occur in nature as elongated fibers, which will bend rather than break in the third spatial plane. Consequently, these fibers have high tensile strength and flexibility which is why they are so industrially important.

TABLE 3. - Pathogenicity of silicates

Rating	Minerals
0	Montmorillonite, kaolinite, talc, tremolite.
1	Talc + antigorite, magnesite, dolomite, and spinell.
2	Tremolite with many rods or needles.
3	Sericite, antigorite, sellimanite, mica.
4	Chrysotile.
5	Actinolite.
6	Anthophyllite.
7	Amosite.
8	Crocidolite.
9	Asbestos + silica or other minerals.

Chrysotile is unique among the nonaluminum-containing silicates. Its empirical formula is $Mg_6Si_4O_{10}(OH)_8$. It is classifiable as a tubular or hollow silicate. Its siloxane template, however, is basically a sheet which becomes rolled upon itself to form a tube. For this reason chrysotile is classifiable with endellite which is rolled in the opposite direction. When dehydrated to form halloysite the prior endellite tube splits lengthwise to assume a ribbonlike or lathlike form. It then resembles the silicates, attapulgite, sapiolite, and paligorskite.

What does all this have to do with the biological properties of talc? Probably a great deal. These physicochemical characteristics of the various silicates are the bases for their particulate size, their ease of entry into the respiratory system, their penetration into cellular and intercellular tissue elements, their retention in or elimination from tissues, their solubilization, their chelation or interaction with other elements within the biological system, and their acceptance or rejection by living matter. These biological counterparts may now be examined.

Differential Biological Properties of Silicate Minerals

There are marked differences between the capacities of the individual classes of silicate minerals to provoke responses in human and animal tissues. There also are major misconceptions as to what these substances can do when inhaled by man or other mammals. Two of the most extreme of these are (1) that all siliceous minerals are equally pathogenic and (2) that there is even the least semblance between the effects of the asbestiform and the nonasbestiform silicates.

To express these differences in a practical manner one may accord a percentile value of pathogenicity to each substance. Since it is not really possible to discriminate biological responses with complete precision, a scale of zero to 10 may suffice. My appraisal of the differential pathogenicity of the silicate minerals is recorded in table 3.

Since there are in the medical literature disease categories such as talc lung or talc pneumonconiosis, many explanations are needed to clarify why talc and tremolite (as pure substances) have been given a zero rating and why chrysotile asbestos is classified at the lower end of the pathogenic spectrum whereas crocidolite and amosite asbestos are at the opposite end. Since it is extremely difficult to disprove a Jack and the Bean Stalk myth, multiple facets of the problem need be explored.

It is necessary to examine more closely the origins and the erroneous premise that all silicate minerals are equally injurious. The loose use of the terms asbestos or asbestosis and the facile identification of other amphiboles with "asbestos" may be a factor. How did this come about?

Part of the problem originates in the manner in which physicians make diagnoses of conditions such as "asbestosis" or the techniques used in dramatizing a description of newly identified disease entity. Often the diagnosis is not based on precise and painstaking verification of the pertinent issues. Not uncommly, loose association and coincidence are the guiding criteria. Careful work histories are not always taken, so that a lung lesion found in an employee of a certain industry may become identified with the final occupation, whereas it might have had its origin in nocuous dust exposures encountered in a prior unrelated decade. Far too often the isolated rare exotic example is the sole basis for the generic concept of a "new" pneumoconiosis. The exception becomes the rule. Even unrelated disease, such as tuberculosis or mycosis or sarcoidosis have been misidentified as new pneumoconioses, merely because they occurred in an employee of the suspected occupation. This problem has been discussed more fully elsewhere (2-3, 8).

Pneumoconiosis usually is identified during life through radiography. The radiologist who expertly examines "shadows" of lesions must rely on the pathologist who has studied necropsy specimens. The latter often is quite uncritical of the source of his material and not uncommonly quite poorly informed in the field of pneumoconiology. In the entire United States with its thousands of excellent pathologists, there are probably not more than a half a dozen true connoisseurs of this eclectic branch of forensic medicine. This may be true also in other countries. To make a reliable identification, the pathologist must not only have had years of experience in decoding this type of man-made disease, but must also have access to appropriate microscopy, chemistry, and petrographic equipment and skills.

It also is quite unusual to encounter "pure" cases of a particular disease. Industrial workers, especially in America, tend to be quite mobile. They shift from one trade to another and potentially receive multiple exposures so that the pneumoconiosis which ultimately emerges often is a manifestation of a prior dust or chemical exposure or a composite of many

successive exposures to diverse agents, some of which may not even be separately pathogenic, but which may produce disease through the principle of potentiation. The phenomenon of individual susceptibility often also is overlooked and disease, which develops in an unusual isolated case among many unaffected employees, is seized upon as a "typical" example of how dangerous the suspected silicate may be. Sometimes insufficient heed is paid to the question of dosage. Almost any substance is harmful in overwhelming amounts. Even substances which are biological necessities can be harmful in excessive concentration. We all need oxygen but cannot survive perpetually in an all oxygen environment without adverse results. Our bodies need water, but our tissues can "drown" therein. So it is with "inert" minerals. If a worker is grossly, recklessly, and long exposed to almost any dust, the pulmonary defenses will be overcome and harm will result. This point is well illustrated in experiments for instance with fiberglass utilizing the intratracheal versus the inhalation techniques. If a quantity of glass fibers is injected into the lungs of animals, gross pulmonary lesions swiftly follow (fig. 4). When, however, the same glass particles are inhaled in smaller daily dosage for periods of up to 2 years, no disease is induced even though the total amount of glass inhaled may greatly exceed the amount introduced as a single "slug" (fig. 5).

FIGURE 4. - Pulmonary lesion induced within 4 months in a guinea pig by intratracheal injestion of 1 mg of glass fibers in successive doses (X 40).

FIGURE 5. - Lack of pulmonary response to glass fibers inhaled daily by guinea pig for 18 months in an aerosol concentration of 1 mg per cubic foot of air (X 40).

Careful analysis of the mineralogic composition of the lungs and the work histories of deceased industrial workers with various grades of silicate-induced disease has shown that "pure" examples of specific silicatoses are extremely rare. It is almost axiomatic that if any advanced grades of disease are found among workers in silicate industries, the causative agents are multiple and likely to have potentiated each other's adverse propensities. For this reason the worst examples of severe pulmonary fibrosis or other lesions generally fall in category 9 as shown in table 3. A typical example of such a severe mixed silicatosis is illustrated in figure 6.

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Pure crocidolite or amosite pneumoconioses are rarely found in America today. They used to be common in England 30 or more years ago and of course are specifically associated with South Africa. The severe disease (category 8 or 7) which these intensely and relentlessly fibrogenic silicates cause (figs. 7 and 8) has strongly influenced the image of "asbestosis." For decades crocidolite pneumoconiosis was asbestosis. The problem is that when the word "asbestosis" is today used in relation to other fibrous silicates such as chrysotile, the horrible image of crocidolite pneumoconiosis is conjured up.

Indeed, it is extremely difficult to find examples of pure chrysotile asbestosis. Most workers with advanced pulmonary disease who are said to have chrysotile asbestosis usually have had prior or secondary exposure to other silicates, silica, and other minerals or chemicals.

The few rare cases of pure chrysotile asbestosis are <u>not</u> characterized by gross pathology such as is found with amosite or crocidolite asbestosis (fig. 9). Chrysotile pathogenicity is, therefore, given a value of 4 on the scale of 0 through 9.

The only human examples of tremolite or talc pneumoconiosis which have been placed on record were caused by tremolite which contained a high proportion of needles or rods or talc which was significantly adulterated with other minerals such as tremolite ($Ca_2Mg_5(OH)_2Si_8O_{22}$), dolomite ($CaMg(CO_3)_2$), spinell ($MgAl_2O_4$), magnesite ($MgCO_3$), magnetite (Fe_2O_3), antigorite ($Mg(OH)_8Si_4O_{10}$), chromite ($FeCr_2O_4$), etc. The amount of disease seen in these cases even after prolonged exposure is minimal (fig. 10). Pathogenicity ratings of 2 and 1 have been accorded these aberrant variants of tremolite and talc.

Pure talc, $Mg_3Si_4O_{10}(OH)_2$, appears to be biologically inert. It is true that the mineral can be found in the lungs after significant prolonged exposure, but it is simply here as a stored material. Histologically this is a thesaurosis only without any thesaurismosis (for example, cytogenic, cytotoxic, or fibrogenic reaction to the talc particles).

For this reason talc is accorded a zero pathogenicity rating along with the clays and kaolin. Tremolite also belongs here when it occurs as oblong crystals with a minority of rods or needles.

FIGURE 6. - Dense pulmonary carnification in a human subject occupationally exposed to successive aerosols containing quartz, flux calcined diatomite, crocidolite, amosite, and chrysotile (X 1).

FIGURE 7. - Dense interstitial fibrosis caused in human lung by exposure to crocidolite dust (X 1).

FIGURE 8. - Subpleural and interstitial pulmonary fibrosis caused in man through exposure to crocidolite and amosite (X 1).

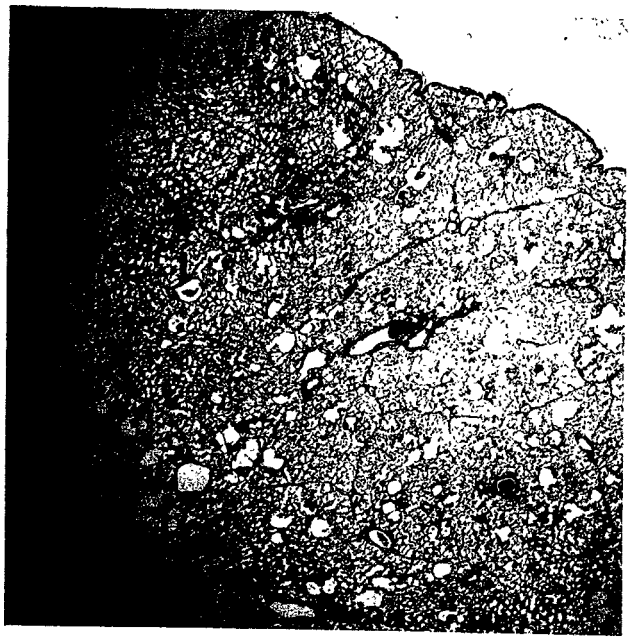

FIGURE 9. - Limited reaction of the human lung to the inhalation of chrysotile dust for 22 years as a miner and mill worker (X 1).

FIGURE 10. - Limited human pathology characterizing exposure to impure tremolite dust for 18 years (X 1).

Histological Gradation

The differential biological potentialities of the silicates are also recognizable on histological review of "pure" examples of human exposure.

Starting with talc the examples of tissue reaction shown in figures 11 to 13 clearly demonstrate the inert nature of this mineral. The close crowding of the myriads of talc particles, which are brilliantly revealed by polarized light microscopy, is typical. The individual represented in the X-ray had worked in an automobile tire manufacturing factory for 2 decades and during all of this time he was regularly and heavily exposed to talc dust. He then left this industry to take employment for 11 years in a nondusty trade. He never developed symptoms during life. He died following an automobile accident. The talc lesions were discovered on routine review of the tissues and the work history as described was reconstructed retrospectively. The lack of tissue reaction, particularly the lack of fibrogenesis, correlates well with the symptomless state during life. There is no damage to the bronchial or vascular elements and alveolar space, pleura, and regional lymph nodes remained unaffected despite the abundant presence of talc particles around or in these lung components. The number of talc particles per unit square area of lung tissue at standard magnification is inversely proportional to the tissue reactivity to silicates. The excessive dysratio of particles to cellular or interstitial tissue is about as great as one may ever observe and serves as an index of biological inertness of talc. By subsequent petrographic and X-ray diffraction techniques the talc retained in the lung tissue

FIGURE 11. - Microphotograph of talc particles in the alveolar wall of the human lung, rendered visible by polarization of transmitted light grade 0 thesaurosis (X 1,000).

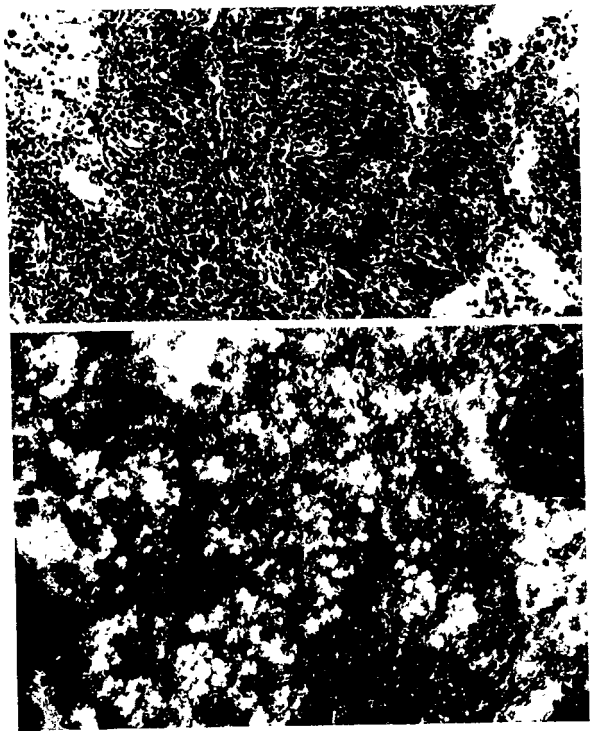

FIGURE 12. - Microphotograph of talc particles in the human bronchial lymph node, visualized by polarization microscopy, grade 0 thesaurosis (X 1,000).

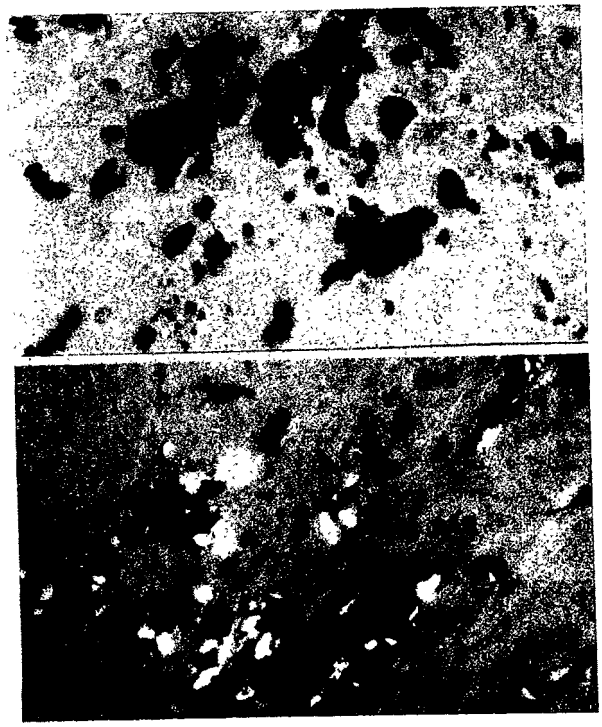

FIGURE 13. - Transmitted light microphotograph of the alveolar wall in a man who had been occupationally exposed to talc dust for 20 years, grade 2 thesaurosis (X 100).

of this case was shown to be an approximately 70 percent talc and 30 percent tremolite mixture. This case, therefore, further demonstrated the inertness of tremolite and proves that tremolite does not potentiate any latent pathogenicity which talc may have or vice versa.

The next example shows that tissue reaction in a talc worker who had been exposed for a protracted period to talc which contained a variety of impurities including tremolite rods, clays, and silica. The worker remained essentially sympton free during approximately 24 years of exposure to this dust. His death was due to a myocardial infarction about 7 years after retirement. Three features are evident by contrast with the first case (fig. 14). First there is patchy or minimal interstitial fibrosis of alveolar walls. Second, collars of dust-filled cells may be observed in the lymph channels around small blood vessels and bronchiles. Third, occasional ferruginous bodies can be seen in the areas of fibrosis (fig. 15). There is minimal distortion of the air spaces and some focal pleural sclerosis. This grade of tissue pathology is, therefore, no longer a thesaurosis or mere storage response, such as was seen in the case of pure talc exposure. We are now dealing with an example of early thesaurismosis or true tissue reaction to stored dust but without physiologically discernable adverse effect. This class of response typifies mineral or grade 1 reaction to the silicate dust.

The stage 2 pneumoconiotic reaction is characterized by a quantitatively greater prevalence of the abnormalities seen with stage 1. There are about twice as many fibrotic plaques in the alveolar walls (fig. 16). There is

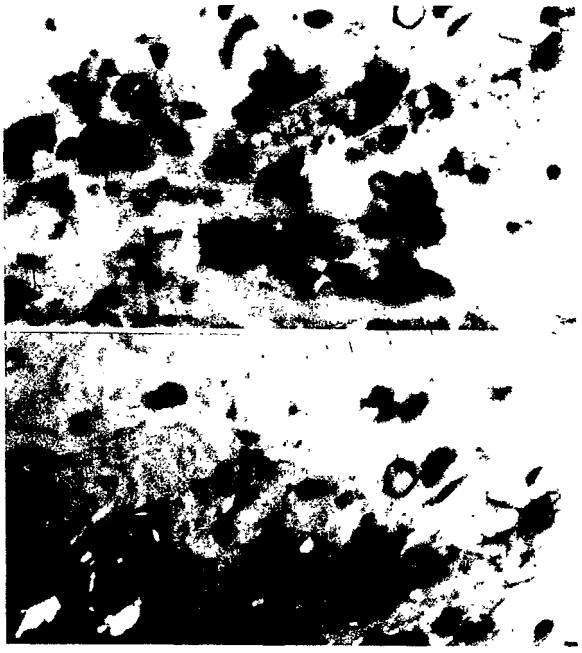

FIGURE 14. - Focal lesions in human lung of an employee who had been exposed to dust containing talc, tremolite, clay, and silica. Grade 1 silicatosis (X 100).

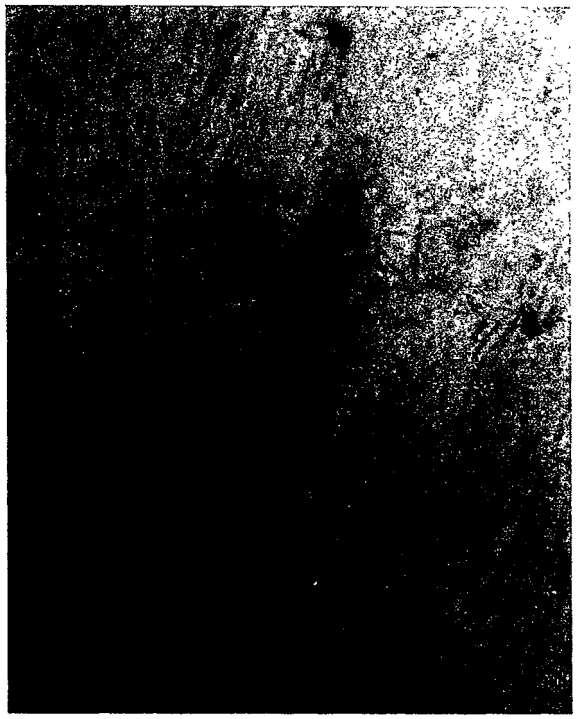

FIGURE 15. - Ferruginous bodies revealed by Perl's stain in case 15 (X 1,000).

FIGURE 16. - Grade 2 silicatosis in a human lung after prolonged occupational exposure to tremolite containing a high proportion of rods or needles (X 100).

FIGURE 17. - Typical focal lesion caused by prolonged inhalation of chrysotile fibers, grade 4 silicatosis (X 100).

FIGURE 18. - Chrysotile body as visualized by transmitted light. Note the splintered clublike ends of the body (X 400).

FIGURE 19. - Chrysotile body showing the ferroproteinaceous matter in the capsule around the chrysotile fiber, Perl's stain (X 400).

minimal alveoloar space and bronchilar distortion. The patient had, however, displayed no symptoms during life despite his known prolonged exposure to tremolite which contained about 20 percent rods and needles.

Chrysotile dust inhalation, when unaccompanied by other exposures, causes slightly more reaction than that just described. This is grade 4 biological reactivity. There now is more involvement of alveolar walls and characteristic spiderlike or octopuslike lesions are found (fig. 17). The chrysotile fibers are quite characteristic and may be found as chrysotile bodies (fig. 18) which also stain vividly blue and in typical dumbbell fashion with Perl's stain (fig. 19). Under oil immersion X 1,000 magnification bare chrysotile fibers of great delicacy may also be visualized (fig. 20). There is fairly diffuse pleural thickening and slight perivascular, and peribronchiolar fibrosis is discernable throughout. Slight airspace distortion is evident even though there was no macroscopically or physiologically detectable emphysema. This man had worked as a chrysotile miller for approximately 23 years and had never been exposed to any other dust, having formerly been a farmer in Quebec Province. Detailed physiological analyses were inconclusive for functional deficits. No diffusion defect was revealed. The reason for this is readily evident when the relationship of the alveolar fibrosis to the alveolar fibrosis to the alveolar capillaries is analyzed (fig. 21). Since the capillaries remain intact on the alveolar surfaces, no physiological impairment has resulted except for minimal stiffening of the lungs with sequential minimally increased breathing effort. Gas exchange has remained unaffected.

Such cases of pure chrysotile exposure are extremely rare. More usually the disease is the culmination of dust exposures which occurred during a mixed career of mining and participation on other dusty occupations. Depending on the variety in the mixture of dusts and the intensity and duration of exposure,

FIGURE 20. - Bare chrysotile fibrils imbedded in fibrous tissue within an alveolar wall of a chrysotile miller, Masson trichrome stain (X 1,200).

FIGURE 21. - Alveolar wall of chrysotile miller showing integrity of capillaries despite underlying fibrosis, Masson stain (X 1,200).

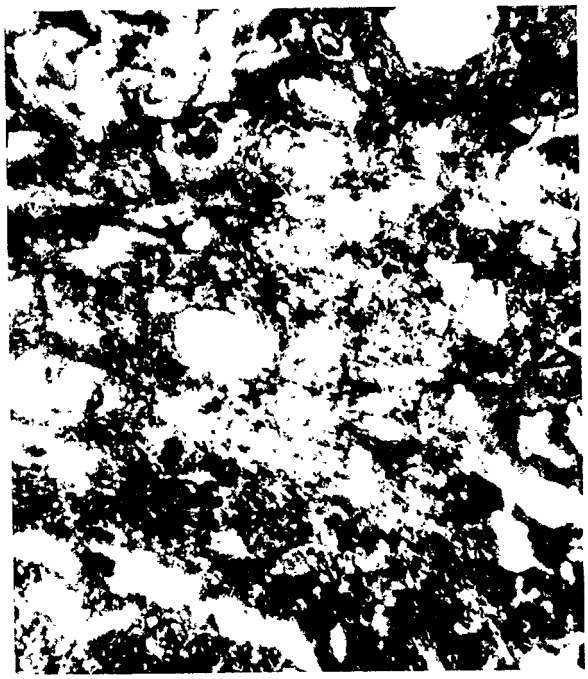

FIGURE 22. - Interstitial lesion representative of grade 6 silicatosis. Prolonged occupational exposure to anthophyllite dust (X 10).

FIGURE 23. - Interstitial pulmonary lesion produced by prolonged exposure to crocidolite. Grade 8 silicatosis (X 10).

FIGURE 24. - Interstitial reaction to mixed silica and chrysotile dust exposure. Grade 9 silicatosis (X 10).

all gradations of tissue reaction from 5 through 9 may be found (figs. 22-24). Strongest potentiation is between silica (quartz) and chrysotile, as happens in the transit pipe industry. The lung tissue becomes diffusely and densely carnified leaving very little viable and functional lung. This happens relatively swiftly and the tragedy is that the fibrogenic process goes on relentlessly long after exposure to dust has ceased. This silica destroys what chrysotile avoids and vice versa.

The lesions produced by amosite or crocidolite acting alone are very severe (grades 7 and 8). Characteristically the fibrous amosite or crocidolite fibers seek out perivenous, perilobular, and pleural lymph and tissues (fig. 25). Dense sclerosis results in a weblike manner, thus producing severe pulmonary restrictive damage. There is so much fibrous tissue that the causative crocidolite fibers are relatively scarce and difficult to detect, especially since these fibers are less ferrophilic than the less harmful chrysotile fibers (fig. 26). Proliferation of pleural mesothelium is a classical sequel to crocidolite exposure which leads to neoplasis (mesothelioma) in a high proportion of cases (fig. 27).

Experimental Evidence

The differential pathogenicity of silicates has been experimentally probed by this author and several others. Some results of personal researches have been published (9), but much additional data remain to be reported.

One of the principle experiments was to explore the comparative effects of fibrous and nonfibrous types of silicates and to evaluate the pathogenicity of long versus short fibers and ball-milled fiberless silicates. The intratracheal, intravenous, intracardiac, intracerebral, intraocular subcutaneous and inhalation routes were utilized by this author. Others have experimented additionally with the intrapleural and intraperitoneal routes. Rats, guinea pigs, rabbits, and monkeys were the principal experimental subjects of this author. Others have also conducted experiments on mice, cats, dogs, and hamsters.

Talc has consistently stood out in all experiments as an inert material. It could be injected into diverse tissues in relatively large quantities without evoking the least reaction. When introduced into the bloodstream, talc was still found cirulating freely after 18 months. In this respect talc differs radically from silica (as quartz) which vanished from the bloodstream within hours after intravenous or intracardiac introduction.

The experiment with talc was limited to a study of the nonfibrous form of the silicate. No fibrous talc was obtainable and by the aformentioned physicochemical definition probably does not exist.

Tremolite could be studied in both its particulate and rod or needle form. As a particulate variant (even when there were up to 5 percent rods) tremolite proved wholly inert. As the proportion of rods was increased, about 20 percent of focal lesions were demonstrable in the experimental aminals. Intratracheal

FIGURE 25. - Proliferation of perivenous tissues in person occupationally exposed to amosite dust (X 100).

FIGURE 26. - Typical crocidolite fiber in pulmonary lesion (X 400).

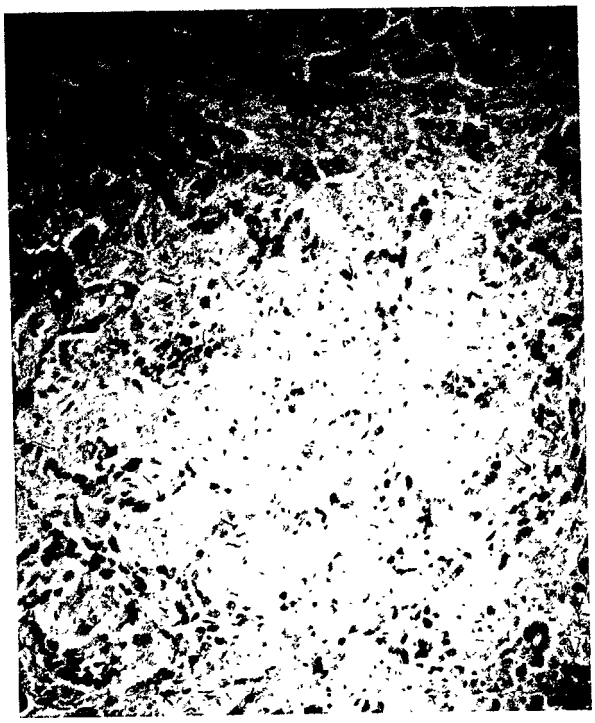

FIGURE 27. - Pleural mesothelioma which developed after prolonged exposure to crocidolite (X 100).

injection induced significant pulmonary pathology. By inhalation, however, the tremolite proved relatively innocuous, even though some fibers were trapped in alveolar phagocytes and converted to "tremolite" bodies (fig. 28). Although these bodies resemble those of asbestos, the tremolite bodies do not have the ominous significance of the asbestos bodies. When the effects of short tremolite rods (less than 5 microns) were compared with long rods (20 to 50 micrometers) an interesting result was obtained. The short needles proved inert. The long tremolite rods induced tissue reaction. This emphasized the fact that it is not the chemical composition which is the basis for biological reactivity to the silicate but only the elongated shape of particles which furnishes a pathogenic stimulus.

Comparable results were obtained with anthophyllite and chrysotile. Long fibers (20 to 50 micrometers) consistently induced pulmonary lesions in all experiments. These varied in severity according to dose or duration. When fibers were milled to less than 5 micron length neither of these silicates produced significant pathological responses in experimental animals. This reaffirmed the principle that it is the length of the anthophyllite or chrysotile fiber particles and not their chemical composition which serves as the pathogenic stimulus.

This author has not had comprehensive personal experience with the effects of amosite or crocidolite on experimental animals. The few experiments personally performed and review of the sparse literature on this subject confirms, however, that these two silicates are significantly more pathogenic to diverse animal species than is either anthophyllite or chrysotile. This reaffirms the high pathogenicity classification offered in table 3.

FIGURE 28. - Tremolite body located within alveolar space of guinea pig following prolonged daily inhalation exposure at concentration of 1 mg per cubic foot of air (X 400).

A further principle was brought out in parallel experiments with fiberglass. Inhalation by guinea pigs of long and short fibers did not result in interstitial fibrosis. These glass fibers were 5 microns or more in caliber. An experiment performed with fibers less than one-twentieth of this diameter (average 0.2 micron) resulted in significant pulmonary fibrogenesis. This result suggests that the biological activity of glass in particular and perhaps other fibrous silicates may be a product of either the particle length or particle diameter. It is not known at this stage if this principle would truly apply to all fibrous silicates. Nor is it known whether length and fineness of fiber caliber can potentiate each other in producing tissue responses. The latter experiment still needs to be performed. There is, however, some human evidence that this may be the case. The electron microscope has in recent years been applied to the study of pneumoconiotic lesions. Through this instrumental modality it has been possible to demonstrate large numbers of extremely fine asbestos fibers within pulmonary fibrotic lesions which appeared almost devoid of "asbestos bodies" as visualized by conventional optical microscopy. Electron microscopy has also revealed that there are many delicate fibers among conventional-sized fibers normally discernable in asbestos dusts as viewed by maximum magnification optical microscopy. Similar fine submicron fibrils have not been observed in specimens of talc or tremolite. The presence of these ultramicroscopic components in asbestos minerals, therefore, constitutes a further explanation for the great differences between the biological actions of the talcs and asbestiform silicates.

Carcinogenicity

The controversy over the carcinogenicity of some asbestos minerals and the applicability of this to the talcs now requires closer examination.

The propensity of crocidolite and amosite to evoke neoplastic responses in man has been a well-documented phenomenon for more than half a century, requiring almost no further elaboration except the following comments: (1) There is today less lung cancer in crocidolite workers than formerly because of improved dust control; (2) pleural mesotheliomatosis has recently emerged as an important neoplastic sequel to crocidolite exposure; (3) there is an enhanced prevalence of cancer of nonpulmonary tissues in employees of crocidolite industries; (4) cigarette smoking and urban air pollution have in recent years surfaced as a complicating issue, so that there may now be some doubt whether all crocidolite-associated neoplasia is exclusively due to the crocidolite; (5) inhalation experiments with crocidolite have not been convincing in demonstrating neoplasiogenesis; (6) implantation studies, especially pleural space deposition of large quantities of crocidolite, have shown a positive correlation between oncogenesis and crocidolite dosage; (7) the latter observation is mitigated by the experimental demonstration that ordinarily noncarcinogenic substances, such as quartz dust, can also produce pleural mesotheliomatosis, so that the pleural response is in a sense nonspecific.

Amosite probably also is carcinogenic though perhaps not as decisively as is crocidolite. There also is some question whether the crocidolite or amosite are in themselves carcinogenic or whether other chemicals, with which

these fibers are impregnated or mineralogically associated are the oncogenic agents. Benzpyrenes and cancer-producing metal salts (arsenic, nickel, beryllium) have been demonstrated in crocidolite and amosite ores.

Nothing comparable has been demonstrated for talc or tremolite. Because the latter has been classified as an amphibole mineral, it has naturally come under suspicion as a theoretical carcinogen. Theory and fact, however, have never matched up in either human experience or animal experimentation. For decades workmen have been engaged in talc and tremolite mining or milling or have been exposed to talc products in secondary industries employing talc and tremolite as slippage agents or fillers or for insulating purposes, etc. Excess prevalence of lung cancer, which could not equally reasonably have been accounted for in terms of exposure to cigarette smoke, urban pollution or to prior, concurrent, or sequential exposure to true asbestos, has been convincingly recorded.

One of the earlier epidemiological surveys of tremolite miners in New York State did hint at an enhanced incidence of lung cancer among relatively young, 45- to 55-year-old, employees of selected mines. This was a disturbing observation. However, subsequent surveys of the same miners have shown a distinctly lower incidence of neoplasia even though the miners now were an average of 1 decade older with commensurately longer tremolite exposure and, of course, with longer periods of cigarette smoking. Two explanations may clarify this change. The first is that the average level of dustiness in the tremolite miners had been appreciably reduced during the past 2 decades. Prior to the institution of vigorous dust control, it was not uncommon to find mine and mill workers smothered in clouds of tremolite dust--particle counts probably having been 100 to 1,000 times greater than has recently been permitted. The second feature uncovered by detailed analyses of the work histories of the tremolite industry employees of the prior era (that is before 1955) showed that with rare exceptions all these employees had spent a large part of their working lives in industries other than talc mining. Many had been exposed to asbestos or to rock and metal ore dusts. Analysis of the lung tissue of a representative number of these employees confirmed the presence of quartz, asbestos, metals, and other substances. This clearly created doubt whether the earlier epidemiological findings have true validity with respect to tremolite.

The alleged carcinogenicity of chrysotile, which is mined in the vicinity of one of the major tremolite deposits in North America, has been an additional confusing factor. Persons who are not thoroughly familiar with the rather major mineralogical and biological differences between tremolite and chrysotile may have been confused by the geological close association of these ore bodies and the erroneous assumption that both tremolite and chrysotile are asbestos minerals. The latter issue has already been discussed and it has been established that, although tremolite may be an amphibolelike substance such as anthophyllite, amosite, or crocidolite, there are no premises for assuming that tremolite is likely to behave biologically as do the other three amphiboles.

Is chrysotile a carcinogen? This is a very perplexing question. A crescendo of popular opinion has sought to incriminate chrysotile. This author remains unconvinced. The main premise for carcinogenicity stems from epidemiological observation of employees of the insulation and shipbuilding industries. In both these industries there has been in the past considerable exposure of pipe laggers to asbestos dust. Only in recent decades, however, have these insulation bats been composed predominantly of chrysotile. In former years crocidolite and amosite were important components. Studies of lung tissues of deceased laggers have verified the presence of amphibole as well of serpentine asbestos. Which then was the carcinogen? It is a known fact also that in recent years fiberglass has to an increasing extent begun to substitute for asbestos in this industry. The increasing demonstration of lung cancer in insulation workers coincides with the latter event. Which agent then is the carcinogen? It is further known that insulation workers have during decades become heavily exposed to methylethyl ketone-type solvents in the synthetic glues presently used to bond the bats of asbestos or fiberglass to the pipes or ducts which are being insulated. Formerly the glues did not contain such highly volatile solvents. Indeed, one of the occupational diseases of significance in this industry now is polyneuropathy due to the inhaled solvent vapors. These solvents come in direct contact with respiratory epithelial surfaces, whose lipid surface membranes and organelles are highly vulnerable since they are readily solubilized into methylethyl ketones or similar solvents. Which then is the true carcinogenic substance?

Finally, it should be pointed out that the role of cigarette smoking has not been satisfactorily discounted in the referenced epidemiological studies of lung cancer among insulation workers. In some groups reported an excess prevalence of lung cancer was not demonstrable when cigarette smoking was taken into consideration. Epidemiological surveys of chrysotile workers in Quebec showed no excess of lung cancer. A review of pleural mesothiliomatosis in Canada also failed to focus attention on Quebec or any other center where chrysotile industries are concentrated.

There also is conflicting experimental evidence about chrysotile. In one personally conducted study the theoretical carcinogenicity of chrysotile asbestos was probed by an inhalation study in which tumor induction in rats exposed to beryllium sulfate (a potent carcinogen) was compared with tumor rates in rats similarly exposed to chrysotile dust and to chrysotile following beryllium sulfate and also to chrysotile dust exposure preceding exposure to $BeSO_4$. The results were striking (2, 7). In the beryllium group the mean incidence of lung cancers was 15.4 percent. In rats exposed to both chrysotile and $BeSO_4$, the malignant tumors totaled only 8.5 percent. No tumors developed in rats which were exposed only to chrysotile and there were none in undosed controls observed for 24 months. This clearly shows that so far from chrysotile acting as a carcinogen or as a cocarcinogen with a known potent carcinogen, the chrysotile behaved like an anticarcinogen with respect to the beryllium.

Mention may also be made of an experiment conducted with natural versus synthetic chrysotile deposited into the pleural space. The latter was associated with some tumor production. The synthetic chrysotile had the contrary

effect (1). The difference between the two is that natural chrysotile sometimes is contaminated with metallic salts absorbed by the serpentine fiber surfaces or perhaps trapped within the chrysotile tubules. Some of these metals include known carcinogens such as nickel, chromium, and arsenic. Since these metals are not universally present in equal degree in all samples of chrysotile, caution must be used in stigmatizing this mineral unnecessarily as a carcinogen. It should also be stressed that the intrapleural experiment is highly artificial so that cancer production by this technique may be expected with true carcinogens as well as with substances which are not ordinarily carcinogenic for man (for example silica). The demonstration, therefore, that synthetic chrysotile, natural tremolite, and talc are incapable of evoking pleural mesotheliosis may be highly significant testimony that these substances may not possess latent carcinogenic properties for man.

Sequelae and Complications

Carcinogenesis has been separately discussed since it is not established whether it is an independent property of carcinogenic minerals or a sequel or complication of the pneumoconiotic pathology induced by these silicates.

It is necessary to review several principle sequelae and complications of exposure to dusts.

The first is tuberculosis. The close association between pulmonary tuberculosis and silica inhalation has been convincingly established through epidemiological studies and experimental inquiry and the pathogenic principles for tuberculogenesis by siliceous minerals has probably been fully clarified (5). Do the silicates also promote the development of pulmonary tuberculosis? There is no real epidemiological evidence for this and no laboratory proof. The relatively closed communities in South Africa where crocidolite and amosite are mined and processed and the comparably closed community in Quebec where chrysotile is produced constitute excellent epidemiological models. No significant excess of tuberculosis has been demonstrated for these occupational groups whose life careers could be followed to a satisfactory degree. A large number of these miners and mill workers were personally studied by this author and a number of necropsy specimens were likewise examined. By contrast with silica workers, tuberculosis was consistently conspicuous by its absence or infrequency.

Since the pathogenic asbestiform silicates proved nontuberculogenic, it is no surprise that tuberculosis has not been associated with talc and tremolite mining. Of 300 mine and mill workers who have been followed over the past 25 years not a single individual developed tuberculosis. This is an amazing record, which speaks for itself since tuberculosis is by no means a conquered disease, especially among industrial workers.

Heart Disease

There are no indications that arteriosclerotic heart disease is any more prevalent in asbestos workers than in the general population. The incidence indeed appears to be lower. This may be due to the excess prevalence of cor

FIGURE 29. - Partly destroyed blood vessel in lung of asbestos worker (X 10).

FIGURE 30. - Perivascular fibrosis showing stenosis of pulmonary blood vessels. Silica and asbestos exposure (X 10).

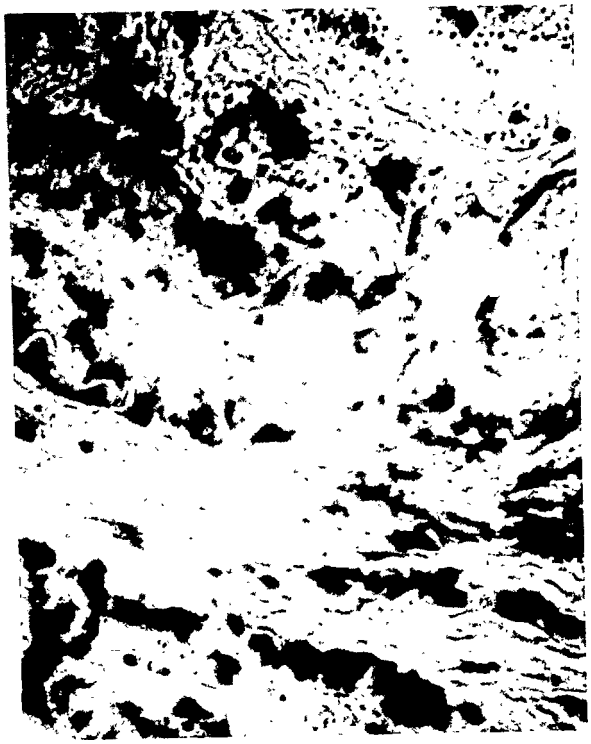

FIGURE 31. - Asbestos bodies in wall of blood vessel as demonstrated by Perl's stain. Mixed amosite and chrysotile exposure (X 10).

pulmonale. The latter constitutes a significant problem and has a direct explanation in the perivenous pulmonary fibrosis and elastosis and the consequent destruction of the vascular system (figs. 29 to 31).

In tremolite workers some cor pulmonale does occur. This is usually traceable to prior, concurrent, or subsequent exposure to asbestos dust. Review of the life histories of 300 tremolite employees shows an incidence of 8.3 percent of the fatal cardiac disease. This is not significantly different from the occurrence of arteriosclerotic heart disease among age-matched control groups that never were exposed to tremolite. Less is know about pure talc industrial groups. The lack of epidemiological data at least established that thus far no problem has surfaced.

Emphysema, Bronchitis, and Bronchiectasis

So many industrial agents cause emphysema and/or bronchitis (4) that an inquiry about this matter seems pertinent.

There are no indications that either emphysema or bronchitis are selectively more prevalent among asbestos workers than with the general public. The underlying pathology induced by asbestos is not of such a nature as to foster either of these conditions. There is no primary bronchopathy and consequently no alveolar distension induced by obstruction. Nor is there alveolar mural destruction. The very nature of asbestosis protects the lungs against this, since the fibrous and elastic tissue in the alveolar walls strengthens rather than weakens these structures (fig. 23). At a later stage there may be some compensatory emphysema as areas of the lung collapse. This is, however, limited and regional only.

Bronchiectasia is another matter. It is quite a common sequel of progressive interstitial pulmonary fibrosis in asbestosis. The bronchi and bronchioles are distended by the contraction of fibrous tissue in the pulmonary parenchyma between them. This form of lung pathology may be seen as a late sequel of crocidolite, amosite, or chrysotile asbestosis. Unlike bronchiectasis in nonoccupational groups, the asbestotic form of the disease is initially nonsymptomatic because there is little or no associated infection. However, the latter may occur later.

None of this is seen with pure talc workers. There has been no excess prevalence of either emphysema, bronchitis, or bronchiectasis unless there has been prior or concurrent or subsequent asbestos exposure. Precise epidemiological data are available for tremolite workers. Thus, of 264 employees followed since 1948 only four developed emphysema. This reflects an incidence of approximately 1.51 percent. This is far below the incidence of emphysema in the general population. Bronchitis without emphysema was observed in seven individuals. No bronchiectasis was found among these workers. This clearly shows that talc and tremolite not only behave differently from chrysotile, amosite, or crocidolite but may even be associated with a lower incidence of these disorders which now are among the most prevalent and disabling illnesses in North America. Whether talc or tremolite protect the lungs against

emphysema and perhaps bronchitis seems a fair question to pose and can be answered affirmatively on the basis of the above evidence.

Conclusion

World production of talc and tremolite currently exceeds 3 million tons per annum. These clearly are useful mineral products which play an important part as fillers of asphalt, rubber and roofing materials, as components of ceramics, paints, insecticides, paper, textiles, wall tiles, cement, stucco, wire and cable coverings, or as foundry parting compounds. A small proportion of talc enters into the toiletry and food processing industries. Through these multitudinous uses thousands of human subjects come into contact with talc and tremolite for every employee contributing to their production. America produces and uses more than one-third of the world production. It is difficult to imagine how modern civilization can be sustained without these useful and relatively inexpensive minerals.

It seems fortunate, therefore, that talc and tremolite are so biologically inert. There is a mood in the United States today to eliminate all environmental hazards. No one can quarrel with the humanitarian ideology inspiring such enthusiasms. Too many hazardous materials have been haphazardly released into the human environment and it would be better to control all industrial substances equally to achieve maximum security. Not only does this seem logical, but it seems reasonable to counsel against restraints which will unnecessarily increase the cost of living for everyone or which may gum up the works somewhere along the line. After all, the human body, and particularly the lungs, have some defenses. The lung constantly replaces itself as part of normal existence. It would seem that, although these defenses can be overwhelmed through long exposure to asbestos minerals, this is not established for talc or tremolite in modest concentration. This fact should be taken into consideration in formulating regulations for dust control in the talc industry.

Summary

1. The physicochemical relationships of silicates are reviewed. Although there are superficial resemblances between the empirical formulas of talc, tremolite, chrysotile, amosite, and crocidolite, there are significant physicochemical structural differences between their respective molecules.

2. Mineral silicates may be best classified in terms of their capacity to be formed as sheets, tubules, ribbons, oblong crystals, needles, or fibers instead of using the conventional mineralogical classifications of serpentines or amphiboles or of asbestiform minerals.

3. Talc and tremolite are biolgocally relatively inert substances and this contrasts sharply with the marked pathogenicity of amosite and crocidolite. Chrysotile occupies an intermediate position, but its biological propensities are closer to those of talc and tremolite.

4. Experimental and epidemiological studies provide closely confirmatory data with respect to the points just mentioned. It is extremely difficult to identify large numbers of employees who have been exposed exclusively to one or another mineral. Many pulmonary lesions in silicate-industry employees are composites of multiple-dust and chemical exposures and many of the nocuous agents derive from sources other than the silicate industry in question.

5. Lung cancer has been definitely associated epidemiologically with exposure to crocidolite. There is no evidence that talc or tremolite possess the biological propensity to induce neoplastic lesions. There also is some doubt as to the role of chrysotile in carcinogenesis. Even though some studies suggest that chrysotile may foster the development of lung cancer under certain circumstances, other studies flatly contradict this evidence so that the issue still seems unresolved.

6. The sequelae and complications of exposure to asbestos include bronchiectasis and cor pulmonale. Obstructive bronchopathy and emphysema do not normally occur as a consequence of exposure to asbestos. Talc and tremolite exposure are devoid of any of these pathological responses.

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APPLICABILITY OF ASBESTOS STANDARD TO FIBROUS TALC

by

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I would like to speak about the application of the current asbestos standard to fibrous talcs, to tremolite, and to the variety of fibrous minerals that are found in several of the talc deposits, especially those talc deposits that have widespread industrial use in the United States. Specifically, I would like to demonstrate here that health data indicate that all fibrous mineral material should be considered equally for the purpose of standard setting, that the current asbestos standard is limited in its provisions and represents a bare minimum standard for all fibrous minerals, and, finally, that control measures exist that would reduce dust concentrations in mines and mills below those required by the current asbestos standard.

Let me briefly go into some of the background of the asbestos standard and the data that led to the specification of a current standard of five fibers per milliliter of air and a later standard in 1976 of two fibers. The standard specifically includes the six asbestiform minerals--amosite, crocidolite, chrysotile, tremolite, anthophyllite, and actinolite--and it is applicable to all industries covered by the Department of Labor in the United States. The equality of consideration of the various minerals has a background in several studies. For example, crocidolite and its severe problems have been documented in work that has come out of South Africa and Great Britain in studies by Dr. Wagner and Dr. Newhouse. In the United States, data have been developed by Dr. Selikoff of the Mount Sinai School of Medicine on the mortality experience of factory workers exposed only to amosite. Here, one finds that roughly half of those individuals who died, died either of cancer or asbestosis.

More extensive data have developed among the insulation workers. These workers have been exposed predominantly to chrysotile, also to a little amosite during World War II and since World War II, especially in shipyards. Of that group of workers, one in five who died, died of lung cancer, nearly one in 10 of mesothelioma, one in 10 of gastrointestinal cancer, three times the expected amount, and almost 10 percent died of other forms of cancer. Another 7 percent of the deaths are from asbestosis--scarring of the lungs. All told 53 percent of the deaths of a group of New York and New Jersey insulation workers are from one of these two sources--asbestosis or cancer. Nearly 40 percent of their total deaths can be related to their occupational exposure to asbestos.

We can also consider a major asbestos manufacturing facility, one which uses extensive amounts of chrysotile. In fact, 95 percent of the manufactured products (asbestos used in manufacturing) in the United States utilize

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chrysotile asbestos. Again the same statistics are obtained, with one exception, and that is in the textile department. Here, the percentage of deaths due to cancer were relatively low, about 20 percent. This came about because the deaths due to pneumoconiosis in the textile department resulting from the extremely high dust concentrations exceeded 40 percent. So we have the grim data that pneumoconiosis can, in one sense, protect against cancer. These persons die before they reach the time of onset of lung cancer or any of the other cancers. In fact, the period of time from onset of exposure to death due to either mesothelioma or lung cancer among asbestos insulation workers is about 35 years. Very few deaths occur prior to 30 years, virtually none prior to 20 years since onset of exposure. The cancers we are speaking about, those associated with occupational exposure to asbestos, are a long time in coming. If any cause gives rise to death prior to that, then the cancers will not be seen.

If we look now at the very limited data available on the mortality of talc miners and millers, we see that asbestos exposure results in similar causes of death. In the early data of Kleinfeld, for example, we have information on 91 workers and the causes of their death, which were as follows: 20.9 percent, malignancies; 27.5 percent, cardiac deaths (other than cor pulmonale); 30.7 percent, pneumoconiosis; and the remaining 20.9 percent, other causes. Approximately half the deaths attributed to malignancy were due to cancers of the lung and pleura.

While we have only limited data on what happens to humans exposed to talc mine dust containing the wide variety of minerals Dr. Langer has described for you, the mortality data we do have indicates that the mining and use of such minerals should be treated with extreme caution. In fact, as an aside, if one compares the mining and milling of talc with the mining and milling of Canadian chrysotile as reported by McDonald, one would postulate that talc is a material that is far more dangerous than chrysotile. However, I do not think that this is necessarily an appropriate assumption to make. From the data we have I do think it can be said at this time that there is no reason for saying that any one of the asbestos varieties or a fibrous talc is more carcinogenic or less carcinogenic or more fibrogenic or less fibrogenic than another.

Some animal data have been referred to previously in this symposium. Virtually all such data must be considered with caution. They can be used to indicate potential problems and, indeed, problems have been suggested by animal experiments. For instance, recent data from the National Cancer Institute (NCI) indicate that all durable fibrous material, irrespectively of their chemical composition, when implanted on the pleura of animals, act as a carcinogen with equal intensity. For example, fibrous glass, fibrous aluminim oxide, and the various forms of asbestos in these NCI experiments induced mesothelioma at approximately the same frequency. Similar experiments in Germany, in which fibrous glass, several varieties of asbestos, and fibrous nemolite were injected into the peritoneum of animals also produced mesothelioma, roughly of equal intensity. I think in this case nemolite was the most carcinogenic. Thus, two separate experiments with animals indicate that a wide variety of fibrous materials are equally potentially dangerous.

A technical reason also indicates that all fibrous mineral material should be treated equally in a standard. It is impossible for an individual technician, counting fibers in an industrial air sample, to distinguish whether it is a fibrous talc, an asbestos mineral, or any other mineral fiber. All one can determine, using a phase contrast microscope, is the presence of a fiber, determined by its length and width. Without the very sophisticated instrumentation that you have already heard about, it is inappropriate to require that a dust counter, either in the Bureau of Mines or in industry, distinguish between fibrous minerals. Currently, in a mixed exposure with asbestos, no such discrimination is made by the U.S. Department of Labor in assessing exposure.

The data we have just discussed, the evidence Dr. Langer has presented of asbestos in talc deposits, the finding of severe health problems in one group of talc mines and mills, the similarity in toxicity of all fibrous minerals in animals, and the inability of a technician to distinguish one fiber from another using a phase contrast microscope, all these indicators show that the standard for asbestos should be applied to all fibrous minerals in talc mines and mills.

When one suggests that the asbestos standard be equally applicable to the fibrous minerals associated with talc, let us briefly consider the background that led to that standard to get an appreciation of its adequacy here. Information on dust levels associated with disease is limited. Six studies have documented asbestos dust levels in insulation work. All of them give average exposures ranging from 10 to 15 fibers per milliliter of air, but none were done 20 to 30 years ago directly on the groups of workers whose mortality has been documented. In a recent group of workers that were examined by Dr. Selikoff much lower exposure levels were associated with radiographic evidence of asbestosis. These were workmen who sand the taping compound, the spackly that is applied to the joints of wallboard. In the past they did this no more than 20 percent of their time and now, even less. Dust counts here showed average exposures on the order of five fibers per milliliter or less <u>when sanding</u>. These data give no comfort with a standard of five fibers per milliliter.

When one speaks of dust count in terms of fibers per milliliter of air, it should be recognized that one is looking only at the tip of an iceberg. The standard specifies that only fibers longer than five microns be counted, because these fibers are readily seen in an optical microscope. In the electron microscope, myriads of shorter fibers can be seen. This would not be a problem if the fraction counted were the same in all exposures. Unfortunately, it is not. In chrysotile exposures we have seen the fraction counted to be 1 in 250, or 1 in 50, or even 1 in 20. When other asbestos minerals were counted, such as amosite, the fraction could be as great as 1 in 3. So, what we have is a standard that specifies determining an asbestos exposure with what is really a rubber yardstick. We are looking at tips of icebergs, but the icebergs, unfortunately, have variable densities. What we have, really, is only a very qualitative estimate of exposure in any occupational circumstances where fibers are determined by this standard. One should exercise extreme caution in certifying that a work place is safe to a workman who may

have to spend 8 hours per day, 5 days per week, 50 weeks per year in such an environment.

Moreover, in considering this standard, little weight was given to a safety factor that would be appropriate for cancer. No data exist on the possibility for a threshold for asbestos-induced cancer and there is no indication that the five fibers per milliliter currently specified, as badly defined as it is, provides adequate protection against cancer for U.S. workmen using asbestos and other fibers.

Finally, the data on the incidence of asbestosis which went into the current standard and which received great weight are now in doubt. The data were concerned with the prevalence of asbestosis in men who worked only after the application of dust control measures from 1931 to 1933 in a British asbestos factory. The men were examined in 1966. All were still at work and only 13 individuals in the study group had more than 30 years of exposure. That same group now has been reexamined 5 years later and the data have been published. There is considerably more evidence of asbestosis among the workers than was first published, perhaps 10 times as much.

Thus, we see that the asbestos standard that I suggest be applied here, as it has been in the past, to the fibrous forms of talc and tremolite is a standard that is really a very inadequate one. It represents an absolute minimum standard. We do not have the luxury of relaxing it whatsoever. Moreover, the full scope of that standard should be applied to the fibrous minerals considered here. Mandatory monitoring and surveillance, the application of engineering controls, the use of personnel protection equipment, the availability of change rooms for workmen, and periodic medical examinations are important parts of that standard.

Along with such protection for the workmen, it is necessary that labeling provisions similar to those in the asbestos standard apply to the fibrous talc and the fibrous minerals that may be present in talc. Much of these materials are later used in industry. The rubber industry is one extensive user that has already been mentioned. Similarly, concern for exposure extends into the consumer area. For instance, last summer the Board of Education of New York City found that they had in their stockrooms modeling material that contained 50 percent asbestos. This was used by children who mixed the dry powder with water to form a paste that could be used for shaping various models and art works. The Board of Education went to the supplier and told him that this material was unsafe and they did not want to use it. He said, "We'll change our formulation." The formulation that came back substituted fibrous talc from the Gouverneur deposit in New York for the asbestos. The material displayed on the slides by Dr. Langer was the material that was substituted for this modeling material. Again, the City of New York did not allow its use because of the concern for health. Caution labels as applied in the current asbestos standard are certainly applicable to all such fibrous mineral material that can be disseminated into the air.

The concern for surveillance and maintaining a safe environment in the mines extends into the community and here the currently proposed standard of

the Environmental Protection Agency (EPA) places a special burden on those concerned with the monitoring of mines. The EPA standard for asbestos emissions does not consider mines and mills with the assumption that emissions from such sources will be controlled by the maintenance of appropriate control measures in the work place. I only hope this confidence of the EPA is justified.

Control is feasible. I was recently in an asbestos mill in California where average fiber levels, determined by the Bureau of Mines and the State Department of Health, ranged from two to five fibers per milliliter. With pure asbestos ore, levels were achieved that were in compliance with the standard I am suggesting be applied to ore bodies containing only a small fraction of fibrous material.

In summary, I would strongly urge that the procedure which was followed in the past be continued. The existing standard for asbestos should be applied to fibrous talc and the various asbestos minerals present in the talc. Equal application of the standard to all fibrous minerals is dictated by health and technical reasons. The standard to be applied is, in fact, a relatively weak one and no relaxation of it should be considered. Finally, the application of such a standard is appropriate because engineering controls exist that will allow it to be met.

ASPECTS OF MINERALOGY OF TALC

by

Arthur M. Langer[1]

My name is Arthur M. Langer. I am an Associate Professor of Mineralogy at the Mount Sinai School of Medicine. For the last 8 years I have been professionally associated with the Environmental Sciences Laboratory in that institution. I serve as Head of the Physical Sciences Section. My research has concentrated in the environmental and occupational health areas. My field of specialization is mineralogy, and I concern myself with the identification of biologically important mineral particles in the environment, identification, and characterization of mineral particles in human tissues, and in various types of consumer products. I have written many papers in these areas, and they are available upon request.

I am going to apologize because I was not present at the symposium this morning. I think that some of my statement might be a review of what has previously been covered. However, some of these points are important and worth stressing again.

I would like to emphasize, first, the complex nature of the term "talc." Talc is a mineral species. However, the word talc, as often used in industry, refers to a property rather than a true mineral entity. Finely ground-up material with a resultant high surface area is often called "talc." The similarity ends here between the mineral talc and "talc" as used in the industrial experience. The same word, therefore, means different things to different people.

One must define mineralogically the "talc" in question. Talc geologically forms, generally, from an altered ultramafic rock, one which is composed mainly of magnesium silicates. Anthophyllite and serpentine asbestos (chrysotile) may form during this process as well. Talc may also originate through the metamorphism of a carbonate rock with the introduction of silica. In this latter rock type the introduction of silica would produce calcium magnesium silicates which may include the asbestos mineral tremolite. There are 10 States in the continental United States that are major producers of talc. In each of these States there is generally a different geologic material responsible for the talc production. The nature of these deposits may be extremely complex. For example, at the Gouverneur, New York, talc deposit, several of the asbestos fiber types occur with the talc. The senior author of a paper on that deposit is here in the audience, Dr. Malcolm Ross of the U.S. Geological Survey. He and his colleagues published their findings in the "American Mineralogist." I would recommend this paper to anyone wishing to learn about the complexities of the talc deposits. Talc deposits are complex and almost always include asbestos as a natural contaminant.

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Dr. Kleinfeld spoke this morning about the health experiences of some miners and millers who were exposed to aerosols generated from this rock. They suffer significant disease, much of which may be related to the asbestos in the rock. The talcs from New York State are peculiar, yet they might be representative of many talc deposits. Talc minerals may vary themselves. For example, in New York State there are fine talcs that are associated with the asbestos mineral, tremolite. These talc plates tend to be intergrown with other mineral particles, present in the sublight, microscopic size range. These talc grains, incidentally, are specifically selected for the ore because they mill well. They tend to reduce in size along these intergrain boundaries.

There are four representative amphibole asbestos minerals--tremolite, anthophyllite, crocidolite, and amosite. Crocidolite and amosite do not enter into consideration because they do not commonly occur in talc deposits. The other fiber types do. In the aforementioned New York State talc deposit there are two tremolite varieties alone: common tremolite, the calcium magnesium silicate phase, and hexagonite, which is a manganese-rich species of tremolite (manganese substitutes in the octahedral site for magnesium and iron). An amphibole called tirodite, a calcium manganese, with iron-rich fiber occurs as well. Another common amphibole occurs in this deposit, anthophyllite. Here, in this one deposit, we also have two structural varieties of the mineral talc. Platy talc, the true mineral, occurs here with monoclinic and triclinic symmetries, so there are possibly two different physical and chemical responses in the biological environment. One more thing, in New York State talc deposit, in addition to the amphibole asbestos, serpentine minerals occur. Within the serpentine phase some chrysotile asbestos fibers occur in trace amounts. Three asbestos fiber types, from trace to major amounts, may occur naturally in talc deposits. These are anthophyllite, tremolite, and chrysotile.

How does one mineralogically characterize talc samples? We prefer to rely on electron beam instrumentation to differentiate talc from asbestos. For example, any elongated object observed on a transmission electron microscope screen may be characterized and identified by morphological characteristics, selected area electron diffraction pattern (which gives you structural information concerning the particle), and microchemical analysis (with an electron probe-type instrument). We are able to, in this manner, characterize mineral fibers and identify them. We can routinely separate fibrous talc minerals from asbestos. True talc fibers tend to occur with more curvilinear edges with pyramid truncations, a termination common for platy minerals. Talc plates yield characteristic hexagonal electron diffraction patterns. Fibers in talc may be characterized, identified, and in some cases quantified.

Let met describe some of my talc work to you. This is what the fibrous talc from New York State looks like as viewed with a transmission electron microscope (fig. 1). Some of these fibers are anthophyllite; others are fibers of tremolite. These mineral phases were identified by just about all available techniques, including X-ray diffraction and light microscopy. I have analyzed 16 talcs from the New York State Gouverneur deposit and found that in 16 of the 16 samples, talc, the true mineral talc, constituted only

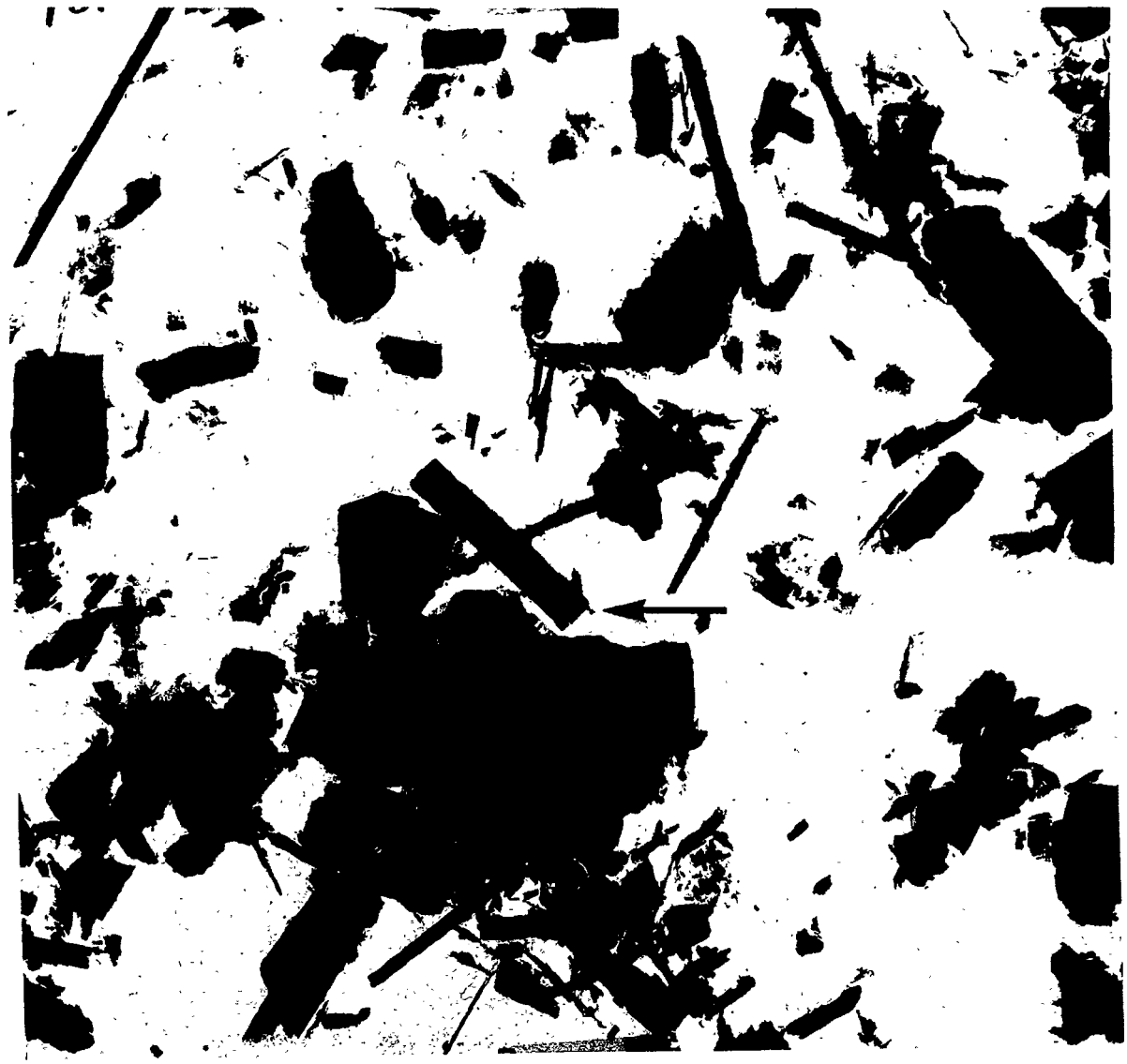

FIGURE 1. - Transmission electron micrograph of a typical fibrous talc sample from the Gouverneur deposit, New York State. Fibers constitute a significant proportion of the sample. The fiber population is made up of talc fibers, tremolite, and anthophyllite. Arrow in center of photograph indicates a 2- by 10-micrometer fiber of tremolite. (Magnification unknown.)

one of the major mineral phases within the sample (table 1). Major constituents in all cases were also anthophyllite and tremolite. Again, other analytical techniques supported this observation as well. With high-resolution transmission electron microscopy, one sees that talc plates may contain many different mineral entities with a single grain. Intergrowths of talc with asbestos minerals are common (fig. 2). What the biological consequences are, incumbent upon the inhalation of large quantities of such minerals, which may be retained on a cellular level for a very long time period, is presently unknown. We do know, from our experience with microchemical analysis of

asbestos fibers, that particles are chemically degraded while residing in vivo. They also have an extremely long period of residence in the biological systems. talc particles themselves may be intergrowths of many mineral phases, some of which may be asbestos.

TABLE 1. - Minerals identified in the New York State fibrous talc deposit by X-ray diffraction[1] [2] [3]

Sample	TALC	TREM	ANTH	SERP	CHLOR	Sample	TALC	TREM	ANTH	SERP	CHLOR
1.....	MAJ	MAJ	MAJ	MAJ	TR	9.....	MAJ	MAJ	MAJ	MAJ	TR
2.....	MIN	MAJ	MAJ	MIN	TR	10.....	MAJ	MAJ	MAJ	MAJ	TR
3.....	MAJ	MAJ	MAJ	MAJ	TR	11.....	MAJ	MAJ	MAJ	MAJ	TR
4.....	MAJ	MAJ	MAJ	MAJ	TR	12.....	MAJ	MAJ	MAJ	MIN	TR
5.....	MAJ	MAJ	MAJ	MAJ	NIL	13.....	MAJ	MAJ	MAJ	MAJ	TR
6.....	MAJ	MAJ	MAJ	MAJ	TR	14.....	MAJ	MAJ	MAJ	MAJ	NIL
7.....	MAJ	MAJ	MAJ	MAJ	NIL	15.....	MIN	MAJ	MIN	MAJ	NIL
8.....	MAJ	MAJ	MAJ	MAJ	TR	16.....	MAJ	MAJ	MIN	MAJ	TR

MAJ Major phase.
MIN Minor phase (only most intense reflections are visible).
TR Trace (major peaks discernible but just above background).
NIL No peaks observed.
[1] Prominent mineral phases: TALC = the mineral talc; TREM = tremolite; ANTH = anthophyllite; SERP = serpentine minerals; CHLOR = chlorite.
[2] Other phases observed: Mg-rich calcite; phlogopite (?); pyrophyllite; pyroxene, various diopside.
[3] The number of peaks observed in the scans 3° to 70° 2 θ (theta) averaged about 60 with intensities 5 times greater than background. All visible reflections numbered about 90. Many of the overlapping peaks were counted as single reflections. The above phases account for more than 85 percent of each sample analyzed.

I will now discuss some of our experience in human case material. This illustration is an electron micrograph of a tissue obtained from a workman who worked in a rubber factory for 30 years (fig. 3). He worked with talc; the talcs used in this factory were fibrous talc. Those particles that you see are both amphibole and chrysotile asbestos fibers. It is possible to examine tissues of workmen exposed to talc dust and determine, with a high degree of certainty, what the mineral particles are which were retained in the lung tissues. Examination of lung tissues of individuals who have worked with talc shows, invariably, that inhalation of talc dust means inhalation of asbestos as well.

I think that the major points stressed indicate that there are talcs, and there are talcs. Some mineral deposits are extremely complex and the mineralogy reflects this. The methods recommended for proper characterization of talc would be polarized light microscopy, X-ray diffraction (using step scanning mode), transmission electron microscopy with selected area electron diffraction, and microchemical analysis. Asbestos minerals may be distinguished from talc in this manner.

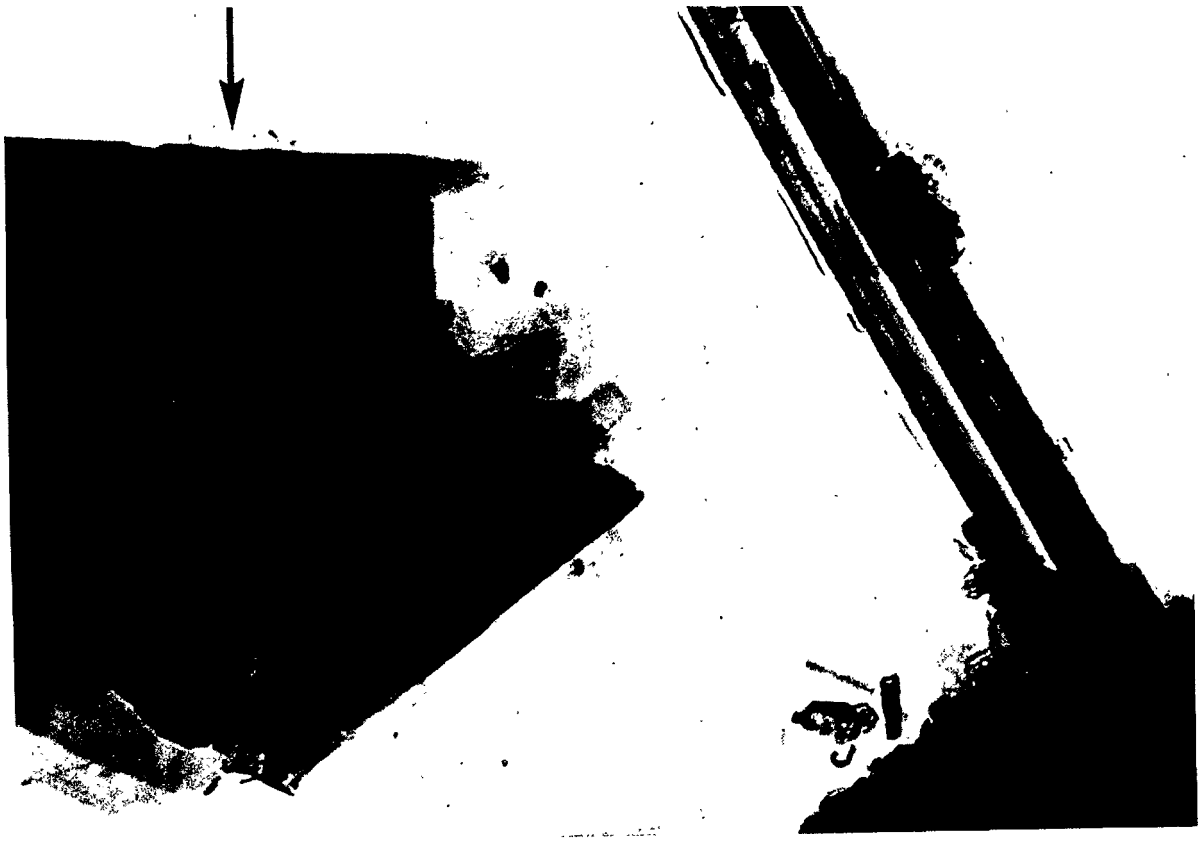

FIGURE 2. - Transmission electron micrograph of a talc "composite grain" from the Gouverneur deposit (arrow). The amphibole asbestos fiber to the right of the grain is about 0.2 micrometer thick. The amphibole fibers intergrown in the talc host are only several hundred angstroms in thickness. (Magnification unknown.)

FIGURE 3. - Transmission electron micrograph of a carbon extracted lung tissue specimen from a workman exposed to talc dust in a rubber factory. This individual died of talcosis and lung cancer as primary causes. Autopsy revealed the presence of a primary cancer of the sigmoid colon. Most fibers shown in this photograph are chrysotile. Talc plates are also visible. (Magnification unknown.)

We would feel, and I think I am speaking for the rest of my group, that it would be prudent at this time for the Bureau of Mines not to change the present restrictions on fibrous talc. We feel that talc is a mixture of many different components, including asbestos, and that talc deposits themselves are extremely complex and zoned, so that any one mine cannot be counted upon to yield the same kind of dust by the month or even by the day.

Thank you. This is the end of my formal presentation. I would like to add some pertinent remarks: I do not know whether this was discussed this morning, but I would like to comment on a group of men studied by Kleinfeld and colleagues (3), who were exposed to talc dust at the mines and mills of Gouverneur, New York. None of the cohort of 39 men had X-ray evidence of pneumoconiosis. However, 25 percent showed clinical signs of shortness of breath, dyspnea, and cough, which could be correlated with early stages of pneumoconiosis. We have reported these observations in that paper. These men, exposed only some 16 years on the average, were apparently exposed to extremely high concentrations of talc dust so that on a comparative scale we would consider that talc contaminated with asbestos would be somewhat less fibrogenic than comparable dust exposures to pure asbestos. But there are several nuances here of which everyone should be aware. It takes an extremely long time for the clinical symptoms of disease related to asbestos exposure to manifest themselves. Generally, it takes 20 to 30 years from onset of exposure to asbestos dust to bring about either lung scarring (asbestosis) or the various malignancies associated with the exposure. Therefore, in our report, we were very cautious. We indicated that the time period of observation of this small group of men was too short to really make any dramatic statement that tremolite talc, anthophyllite talc, or talc itself is a biologically less harmful material than pure asbestos. We feel that this group of men has to be followed for a much longer time period, and that malignancies, if they do occur, certainly would not appear for another 10 years at least.

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MINERALOGY, IDENTIFICATION, AND QUANTIFICATION OF AIRBORNE TALC DUST

by

T. D. Oulton[1]

Introduction

As representatives of the Engelhard Minerals & Chemicals Corporation organization which mines and processes mineral talc of the platy variety at Johnston, Vt., I, together with Mr. E. J. Triglia and Mr. D. A. Jacobs, attended the symposium. We had not intended to make any formal presentation to the meeting, but certain things that were said and much that was left unsaid persuade Engelhard Minerals & Chemicals Corporation to present additional remarks, which we feel will be relevant and appropriate. The points which we intend to make, and which will be expanded in part in a supplementary discussion section, may be summarized briefly as follows:

1. The mineralogy of talc as compared to that of the asbestos minerals discussed by Dr. C. S. Thompson, while interesting and correct so far as it went, was in our opinion quite insufficient. A more complete exposition of the composition and crystallography of the fibrous amphiboles together with the significant distinctions between these and the crystallographic control which enforces the elongate tubular structure of chrysotile may provide a rational basis for correlating and understanding the observed great range in variability of these materials with respect to biological activity (for example, physiological toxicity, carcinogenicity, industrial hazardousness), as so ably reviewed in the discussions by Drs. Kleinfeld, Schepers, and Smith.

2. The crystallographic structural control of "talc mineral," which has been determined as a symmetrical three-layer phyllosilicate provides a strong argument against even the possibility of talc existing in a "fibrous" form. Therefore, we object to terminology in any official document which implies in any way the existence of "fibrous talc" or "talc, fibrous," and support instead an expression such as "talc <u>in association with</u> fibrous and/or elongate and/or asbestiform mineralogical particulates."

3. We urge the use of a more precise descriptive mineralogical terminology in any official document and deplore the mixed descriptive mineralogical identifications such as are used in the Occupational Safety and Health Administration (OSHA), 29 CFR 1910.93a, wherein a trivial or trade name such as "amosite" is given equal weight with the systematically correct nomenclature for some of the other amphiboles. We also object to the strained interpretation of the term "fiber" as used in the same document. Although there can be little doubt about what is actually meant in the context, the term "fiber" in

[1]Engelhard Minerals & Chemicals Corporation, Johnston, Vt.

general English usage certainly implies a whole set of functional properties quite distinct and different from the so-called "fibrous" character assigned to at least some of the amphiboles.

4. We regard the blanket identification arbitrarily as "asbestos" or as "asbestiform" or any particulate matter with a projected area length to diameter ratio of 3 to 1 when observed at X 450 magnification by phase contrast microscopy as a completely unacceptable technical oversimplification, and we hold that the burden of proof that such an observed particulate can indeed be demonstrated or proven to be "asbestos" or an asbestos-related particulate lies wholly with the observer.

5. In furtherance of the preceding remarks, we fully support the contentions advanced by Dr. Stanley and others, as well as by Dr. Thompson, that it is necessary to bring the most sophisticated analytical and observational techniques available to the correct identification and classification of these materials. However, we must take issue with Stanley of Pfizer Inc. that transmission electron microscopy is the "only" acceptable technique for such final decision-making. In our experience the scanning electron microscope (SEM) techniques, combined with energy-dispersive electronanalysis is every bit as powerful and in some cases even less ambiguous than is transmission electron microscopy combined with selected area electron diffraction. The fact is, of course, that all of these available techniques serve to complement and supplement one another and that no single simple test or limited group of tests can provide the necessary information for reliable and complete identification of these complexly interrelated minerals.

6. We object to the very transparent attempt of the Mt. Sinai group (Drs. Langer, Nicholson, and Rohl) to arbitrarily include "talc" into the broad group of asbestos minerals. One cannot diminish the importance of the work of the Mt. Sinai group in developing full awareness of the pathology of asbestos and the related physiological activity of certain asbestos minerals. But it does not follow from this that there is necessarily an identifiable pathological response to talc that can be labeled "talcosis," or even (following the discussion and evidence presented by Drs. Kleinfeld, Shepers, and Smith, as well as the vital personnel records of talc miners and workers reviewed by Lamar, Mylryan, and Bacon) that there is necessarily an identifiable pathological response to tremolite that can be labeled as "tremolitosis." The Mt. Sinai group had no new evidence to offer and merely restated the old asbestos data extended only by implication and hypothesis to "talc, fibrous" while the other speakers presented rational discussion and hard new evidence quite contradictory to the position taken by the Mt. Sinai group.

7. We endorse the moderate position taken by Dr. Sykes representing Ralph Nader Associates; namely, that much research still needs to be done and many questions still need to be answered before fully rational decisions regarding the "talc question" can be resolved. No one, for example, can expect a paraprofessional field inspection to have ready access to all the highly complex diagnostic instrumentation that has been mentioned above. On the other hand, there is evident widespread dissatisfaction and incredibility associated with the present standard OSHA phase contrast microscopic method

for fiber identification and counting. There is a clear requirement for a new field method that is both more reliable and accurate, but no such method seems to be presently at hand. This would seem to be an appropriate problem for reference to a concensus-forming organization for the development of consensus definitions and consensus standard test methods such as the newly formed ASTM Committee E-34. We therefore urge that this problem be presented to the Executive Subcommittee of E-34 with a request that the assignment be accepted and referred to the appropriate working subcommittee for resolution.

8. Nothing in the foregoing remarks should be taken as an objection to the standard limitations in concentrations of airborne "nuisance" dusts. Certainly every employer should be sensitive to his responsibility for the health and safety of his employees in the workplace. But we wish to emphasize that an oversimplistic and ill-considered regulatory document for the talc mining and milling industry could easily result in such severe economic dislocations that an important American industrial mineral material supply could be reduced to a point from which recovery would be extremely difficult.

Structural (Crystallographic) and Compositional Characteristics Which Distinguish the Amphibole and Serpentine Minerals From Talc

The technical discussion which makes up the following sections is based mainly on standard mineralogical and crystallographic reference sources.[2] [3]

Classification of the Silicate Minerals
Based on Grouping of SiO_4 Tetrahedra

Class	Grouping of SiO_4 tetrahedra	Linkages of SiO_4 tetrahedra	Oxygen atoms per 4 Si
I. Nesosilicates.....	Singles.....	0	16
II. Sorosilicates.....	Groups (sisters)....	1	14
III. Cyclosilicates....	Rings.....	2	12
IV. Inosilicates.....	Chains.....	2	12
V. Phyllosilicates...	Sheets.....	3	10
VI. Tectosilicates....	Frameworks.....	4	8

Of these classes we are concerned only with the inosilcates (IV), of which the amphiboles are a subgroup based on a double chain of silica tetrahedra extending infinitely (linearly) in one direction, and with the phyllosilicates (V, sheets) in which the linkages of silica tetrahedra extend infinitely in two directions (for example, planar), and of which the kaolinite-antigorite and the pyrophyllite structures are subgroups.

[2]Winchell, A. N. Elements of Optical Mineralogy. Pt. 2, Description of Minerals. John Wiley & Sons, New York, 1951.
[3]Pavarennykh, A. S. Crystal Chemical Classifications of Minerals. Plenum Press, New York, 1972.

Inosilicates (IV)

The amphiboles in the subgroup of inosilicates (IV) are common rock-forming minerals which make up a substantial fraction of the earth's crust; any of the amphiboles may be but are not necessarily fibrous in morphology, and in fact, the commercially useful fibrous amphiboles are relatively rare.

Following the notation suggested by Pavarennykh, the amphibole group can be represented by the formula:

$$R_2R_5[Si_4O_{11}]_2(OH)_2^{1}{}_{\infty},$$

where R_2R_5 combined are basic cations supplying a total of 14 plus charges, and $^{1}_{\infty}$ indicates that the silica double chain structure is linear and can extend infinitely in only one direction.

Another common system of nomenclature groups all of the amphiboles, except anthophyllite (cummingtonite), under the generic name "hornblende," which is further divided into the common hornblendes, the oxyhornblends (which may be partially or totally dehydroxylated), and the soda-hornblendes in which sodium plays a prominent role in the basic cation R_2R_5 (+14 charge) complement. In some of these varieties there may also be some ionic proxying for Si in the $[Si_4O_{11}]$ double chain silica tetrahedral (amphibole characteristic) portion of the structures.

According to Pavarennykh's systematic classification:

Anthophyllite subgroup, orthorhombic monoclinic, Z = 4, 2 (not all members included):

Name	Chemical formula	Space group	a	b	c
Anthophyllite.....	$Mg_7[Si_4O_{11}]_2(OH)_2^{1}{}_{\infty}$	D_{2h}^{16} - Pnma	18.56	18.08	5.28
Cummingtonite.....	$(Mg,Fe)_7[Si_4O_{11}]_2(OH)_2^{1}{}_{\infty}$	C_{2h}^{3} - C2/m	9.56	18.45	5.34
Amosite (magnesian grunerite).	$(MgFe)[Si_4O_{11}]_2(OH)_2^{1}{}_{\infty}$	C_{2h}^{3} - C2/m	9.56	18.45	5.34

Tremolite subgroup, monoclinic, Z = 2 (not all members included):

Name	Chemical formula	Space group	a	b	c	B
Tremolite.....	$(Ca_2Mg_5)[Si_4O_{11}]_2(OH)_2^{1}{}_{\infty}$	C_{2h}^{3} - C2/m	9.64	18.05	5.27	104°42'
Actinolite.....	$Na(Ca_2MG_5)[Si_4O_{11}]_2(OH)_2^{1}{}_{\infty}$	C_{2h}^{3} - C2/m	9.89	18.14	5.27	105°48'
Ferroactinolite.	$(Ca_2Fe_5)[Si_4O_{11}]_2(OH)_2^{1}{}_{\infty}$	C_{2h}^{3} - C2/m	9.87	18.34	5.30	104°30'

NOTE.--Actinole is partially "dehydroxylated" approaching oxyhornblende composition with Na^+ furnishing the 15th + charge required for negative lattice charge compensation.

The structural analogy between tremolite and actinolite can be perhaps better recognized by rewriting the formulation in the preceding tabulation to show the substitution of Na^+ for H^+ in the hydroxyl grouping, thus:

$$(Ca_2Mg_5)[Si_4O_{11}]_2(ONa)(OH)^{1}_{\infty}.$$

Glaucophane subgroup, monoclinic, Z = 2:

Name	Chemical formula	Space group	a	b	c	B
Glaucophane (a soda-hornblende).	$Na_2(Mg,Fe)_3(Al,Fe)_2[Si_4O_{11}]_2(OH)_2^{1}_{\infty}$	C^3_{2h} - C2/m	9.74 9.90	18.02 18.14	5.34 5.32	104°10' 103°30'

NOTE.--Glaucophane has perfect $Mg\text{-}Fe^{2+}$ isomorphism and somewhat less complete $Al\text{-}Fe^{3+}$ isomorphism, so that under this classification the name "glaucophane" acquires a more generalized meaning while the old species glaucophane and riebeckite become the subspecies magnesio-alumoglaucophane and ferro-ferri-glaucophane. The fibrous form of the latter is commonly called crocidolite which thus has the ideal crystallographic formula:

$$(Na_2Fe^{+++}_2)[Si_4O_{11}]_2(OH)_2^{1}_{\infty}.$$

It may also be noted at this point that the mineral name amosite cannot be found in any standard mineralogical reference or classification and that the nomenclature is not recognized by mineralogists. Amosite is, in fact, a trade name based on the acronym for Asbestos Mines of South Africa and is applied to the production of these mines in which the major mineral constituent approaches the ideal structure of magnesian grunerite, that is, $(MgFe_6)^{+14}$ which in turn is the ferrous end-member of the cummingtonite subspecies of anthophyllite.

At this point it is now possible to compare the crystallographic structure of all the prescribed (fibrous) amphiboles; representing the "amphibole part" of the structure, that is $[Si_4O_{11}]_2(OH)_2^{1}_{\infty}$ as "R," it is evident that all of these species belong to the same space group, have substantially identical lattice parameters, and differ only in the composition of the charge-balancing (14+) divalent cations, thus:

Anthophyllite	(Mg_7) R
Amosite	$(MgFe_6)$ R
Tremolite	(Ca_2Mg_5) R
Actinolite	(Ca_2Mg_5) R, where R is $[Si_4O_{11}]_2(ONa)(OH)$
"Ferroactinolite"	(Ca_2Fe_5) R
Crocidolite	$(Na_2Fe^{++}{}_3Fe^{+++}{}_2)$ R

There seems to be at hand substantial evidence that the biological activity of these structures may vary over a relatively wide range of intensity; if so, the cause for this may most reasonably be sought in the cation complex compositions with already some suggestions that those species highest in iron are relatively more carcinogenic than those from which iron is absent.

Phyllosilicates

The phyllosilicates are the sheet or layer structures in which the silica tetrahedra are arrayed (extended) infinitely in two directions (that is, planar). The group relevant to this discussion is the kaolinite-antigorite group. These are

1 to 1 layer lattice silicates consisting of parallel sheets of silica tetrahedra and basic cations in octahedral coordination. Quoting Pavarennykh:

> The minerals assigned here are structurally identical but represent polytypes and products of isomorphism. The kaolinite subgroup minerals have 2/3 of the positions in the octahedral layer filled (the di-octahedral subgroup) whereas all positions are filled in the antigorite subgroup (the trioctahedral subgroup). Both may have a tubular chrysotile structure, which is more common in the antigorite subgroup.

Again following the Pavarennykh classification, the aluminian (dioctahedral) and the magnesian (trioctahedral) structural analogues can be represented:

1. Kaolinite subgroup, triclinic monoclinic (not all members included):

Name	Chemical formula	Space group	a	b	c	B
Kaolinite.....	$Al_4[Si_4O_{10}](OH)_8^{\infty\infty}$	C_1^1 - P1	5.14	8.93	7.37	104°30'
Metahalloysite...	$Al_4[Si_4O_{10}](OH)_8^{\infty\infty}$	C_s^3 - Cm	5.15	8.9	7.9-7.5	105°

2. Antigorite subgroup, monoclinic serpentines:

Name	Chemical formula	Space group	a	b	c	B
Antigorite.....	$Mg_6[Si_4O_{10}](OH)_8^{\infty\infty}$	Cm	5.30	9.20	7.46	91°24'
Lizardite.....	$Mg_6[Si_4O_{10}](OH)_8^{\infty\infty}$	C2	5.31	9.20	7.31	90°
Chrysotile.....	$Mg_6[Si_4O_{10}](OH)_8^{\infty\infty}$	C2/m	5.34	9.25	14.65	93°16'

Of these minerals, both metahalloysite and chrysotile are tubular while kaolinite, antigorite, and lizardite are planar or "platy." A possible explanation acceptable to many mineralogists was suggested by Bates[4] by which the tubulation was due to the slight dimensional misfit between the tetrahedral and octahedral layers due to the different ionic sizes and bond lengths of the dioctahedral $(Al^{+++})_2$ and the trioctahedral $(Mg^{++})_3$ layers. Such misfits set up a strained lattice structure which can be relieved by a rolling of the structure into a tubule with the SiO_4 lattice layer on the outside, as in metahalloysite but with the magnesian octahedral lattice layer on the outside as in chrysotile. Many of the special properties of these minerals can be accounted for on such a basis.

No such strain relief is permitted to the planar or platy varieties (kaolinite, antigorite, or lizardite) so that the tetrahedral (SiO_4) sheet structure fit must be adjusted by distortions in bond angles and bond length. The point to be emphasized here is that chrysotile is a tubular (fibrous)

[4]Bates, T. F. Morphology of Layer Lattice Silicates. Dennison Univ., J. Sci. Labs., v. 42, 1951, pp. 83-92.

1 to 1 layer lattice (phyllosilicate) structure totally unrelated to that of any of the amphiboles. The possibility of lattice strain relief by tubulation available to the 1 to 1 layer lattice structure is also not available to the 3-layer lattice structures considered in the next section.

3. Pyrophyllite subgroup, monoclinic:

Name	Chemical formula	Space group	a	b	c	B
Pyrophyllite.....	$Al_2[Si_4O_{10}](OH)_2$	C_{2h}^6 - C2/c	5.15	8.92	18.95	99°55'
Talc.....	$Mg_3[Si_4O_{10}](OH)_2$	C_s^4 - Cc; Z=4	5.27	9.12	18.85	100°00'

The pyrophyllite group structure is that of two nets of SiO_4 tetrahedra parallel to (001) with the free vertices facing each other, and between these nets, a net of Al (Mg) octahedra. Talc is therefore the trioctahedral structural analogue of pyrophyllite, and because the magnesia layer is spatially symmetrical with respect to the silica layers on each side, no curling or tubulation is in any way possible. The physical form of talc is therefore platy, foliated, with highly perfect cleavage on (001).

In all of our electron micrographic studies, we have never seen any evidence of curled, rolled, tubulated, or elongated talc structures, and it is suggested that those who have reported observations of such particulate forms were actually looking at some other mineral species, and that such could be demonstrated by structural or chemical analysis as by, for example, selected area electron diffraction or by selected area energy dispersive electron analysis.

The preceding structural elucidation and the comparison of the amphiboles, serpentines, and talc is the technical basis for our remarks in paragraphs 1, 2, 3, 4, and 5. Based on the same considerations it also becomes clear why no analytical procedure based on X-ray diffraction alone can yield any reliable estimate of the concentration of any of these prescribed (asbestos or asbestiform) minerals when they are admixed with any other material. Any and all of the amphiboles as well as the serpentine (antigorite subgroup) minerals can and do occur intimately admixed with both the platy and fibrous varieties, and X-ray diffraction alone simply cannot discriminate between the two morphologies.

Finally, we would like to make an additional comment relative to the definition of "fiber." We have searched the encyclopedic and lexiconographic sources and can find nothing that bears any etymological relation to the word as used by OSHA. One essential characteristic of a "fiber" is that it can be spun into a thread and woven into a cloth, a characteristic of only a few of the varieties of "asbestos" included in the OSHA list. ASTM does have a consensus definition (see ASTM D 2946-71) wherein a fiber is defined as follows:

> Fiber--any material in a form such that it has a minimum length to average maximum traverse dimension of 10 to 1, and a maximum transverse dimension of 0.255 mm.

We wish to thank the Bureau of Mines for organizing the Talc Symposium and we also wish to thank the organizers for the opportunity to make these supplementary remarks for the record.

MEDICAL ASPECTS OF TALC

by

Richard M. Spiegel, M.D.[1]

Pneumoconiosis

The literature contains several studies over the past 3 or 4 decades concerned with the incidence of talc pneumoconiosis (3-4, 6, 9, 11-12, 16, 21-22) or talcosis and with its pathogenesis (19-20), in addition to numerous case reports and autopsy evaluations (1, 5, 8, 14, 17-18). The bulk of the workers investigated have been involved in mining and milling although various usage areas have also been examined.

One short summary statement that nearly all of author findings would support is that talc exposure can produce a clinical picture virtually indistinguishable from asbestosis; but at a lower rate than with comparable asbestos exposure. The pulmonary function alterations (decreased vital capacity and diffusion capacity), the often thin and "chronically ill" appearance of the subjects, the "ferruginous" bodies found on lung sections, the pleural plaques and calcifications, and the roentgenographic picture of interstitial fibrosis predominantly in the lower lung fields, with diffuse, "reticular," irregular small opacities are all findings in common with talcosis and asbestosis. Importantly, they are special in each person, quite different from those usually seen in silicosis. Many cases with silicosislike signs are reported, but these are invariably in workers exposed to talc with high free-silica content and undoubtedly represent silicotalcosis.

This brings up the major problem in establishing the toxic potential of talc--defining what we mean by "talc." The term is used in industry to refer to certain physical properties rather than chemical composition. "Commercial talc," with which all of the studies are concerned, can contain a great variety of related and unrelated constituents in an even greater variety of proportions, mixed with "pure talc," a hydrous magnesium silicate, often to the point where "pure talc" is a minor component (2, 20, 24). The still unresolved question is how much damage, if any, is caused in the lungs by true talc and how much by the contaminants?

The major suspects, because of their well-established pathogenicity, are free silica and the asbestiform materials such as tremolite, anthophyllite, and serpentine. The role of the former, however, can easily be separated, as previously mentioned, by different clinical manifestations and simple environmental assaying. The role of the latter substances, on the other hand, including also hydrous magnesium silicates, is very hard to determine. True talc is to a great extent formed in nature by hydrothermal alteration of asbestiform

[1]Medical Investigations Branch, Division of Field Studies and Clinical Investigations, National Institute for Occupational Safety and Health, Cincinnati, Ohio.

deposits and, therefore, the mined material is not only usually a mixture of the two but can also vary in percentage markedly, even in samples taken in relative close proximity. This compounds the problem because differentiation even in the laboratory is extremely difficult and entails generally electron microscopy.

Because asbestos fibers generally form a part of "talc" exposure and the resultant talcosis is fairly identical with asbestosis, some authors conclude that talc pneumoconiosis is actually being caused by the tremolite or other asbestos contaminants and that true talc plays no role. Supporting this is one study (19), which suggests that talc and tremolite produce different responses in animal tissue, the former cytotoxic and the latter fibrogenic and cytotoxic.

However, intuitively it would seem likely that talc particles, as seen in fibrous talc, with similar structure and chemistry to asbestos particles should produce similar diseases. Also, as differentiation of these particles is often unfeasible and fibrous talc is invariably contaminated with asbestos, there is no practical reason at this time to prove their relative toxicities. The present American Conference of Governmental Industrial Hygienists' standard, reflecting this view, is set for fibrous talc at 5 fibers/ml>5μ in length (the same as asbestos) without reference to type of fiber and is in a combined standard for "talc (fibrous) - tremolite."

The differentiation implied just described between fibrous (or "tremolitic") talc and nonfibrous (granular or nonasbestiform) talc creates another source of disagreement. The distinction is based on the geologic composition of the mined deposit rather than on any filtering process, with the two types lying at opposite ends of a continuum, rather than being separate entities. In any occupational "talc" exposure, both fibrous talc and granular talc standards must be met; that is, if the fiber content is lower than the fibrous TLV, the exposure can be considered strictly granular and must then meet the present American Conference of Governmental Industrial Hygienists' granular talc limit of 20 mppcf. This standard is apparently based for some reason on Dreessen's study (3) of Georgia talc miners and millers, which included a group of workers exposed to levels of approximately 17 mppcf, none of whom had evidence of pneumoconiosis. However, not only was the talc involved 10 percent tremolite (certainly not granular) but no attempt was made to establish duration of exposure. Hogue and Mallette's study (4), sponsored by the Firestone Tire and Rubber Company, might be better suited for this purpose. They examined 20 company employees with exposures of 10 to 36 years (only 4 employees less than 20 years) and levels at the time of the study ranging from 15 to 35 mppcf, with allegedly higher levels in the past, and they found no evidence of pneumoconiosis. The talc used was reportedly "pure talc" containing "no free silica, tremolite, chrysolite, chrysotile, or actinolite," although no evidence was presented to support this statement. Opposing this would be some studies of Kleinfeld and Messite (9, 16), which concluded that while the fibrous type was more pathogenic, both talcs can produce pulmonary fibrosis. Their identification of the granular talc is not substantial, however. One study involved workers in two milling plants, one allegedly using fibrous, the other granular talc, but no evidence is offered

to confirm this classification. In the other study they compared two mining areas in New York State, one fibrous and the other granular, examining only a single sample to establish the nature of the latter area. In a different study Weiss (24) mentions this same region as producing, on the contrary, a very fine tremolite (fibrous) talc. Essentially then, the toxicity of true granular talc has not been well documented, probably in some measure because of its rare use.

Carcinogenesis

There has been only one mortality study in the literature on talc workers, but fortunately it was a good study. The New York State Department of Labor has followed a group of fibrous talc miners and millers since 1940 and has published over 10 articles concerning their health status, among which was Kleinfeld's mortality study (12) of workers who had at least 15 years of talc exposure prior to 1940 or who achieved 15 years of exposure between 1940 and 1965. Of the 220 subjects in the cohort, there were 91 deaths. In addition to the high rate of deaths due to pneumoconiosis and its complications, the overall death rate from lung and pleural malignancies (10 deaths) was three to four times that predicted on the basis of age and sex.

Much attention is given to analyzing this rate and contrasting it with that seen in asbestos workers (2, 12). The only generalization that can be drawn from such a comparison, however, is that for a given exposure, asbestos has probably a greater carcinogenic potential. It is quite possible that this nevertheless high risk of lung and pleural malignancy seen in exposure to fibrous talc is a result of the asbestiform components, but there is no definite evidence either way.

Summary

The potential pathologic sequela of talc exposure depends on the constituents of the talc in question. If free silica is present, the worker risks developing silicotic lesions. With the fibrous variety of talc, including a variable amount of asbestiform contaminants, talcosis may develop, clinically almost identical with asbestosis. The role of the pure talc fibers in this disease has not been established. It also has not been established clearly if granular talc, without asbestiform contaminants, can produce talcosis.

Fibrous talc exposure has shown to yield a significantly high risk of lung and pleural malignancies, though probably not as high as with asbestos exposure. Whether pure talc is carcinogenic has not been studied.

Annotated Bibliography

NOTE.--Chronologically, references 21 and 22 report the initial morbidity study in 1940 of 221 fibrous talc workers. Thirty percent of those with over 10 years of exposure demonstrated advanced fibrous. References 6 and 16 present results of a followup study in the mid-50's. New cases appeared less severe, attributed to improved mining techniques. In reference 16 a comparison was made between the original group and miners in another area where talc was less fibrous and comparably less disease was seen.

1. Alivisatos, G. P., and others. Talcosis of Unusual Rapid Development. British J. of Industrial Medicine, v. 12, 1955, pp. 43-49.
Eight case reports from Greece of "talcosis" after very short, but very heavy exposure. From description, silicosis probably played a role.

2. Blejer, A. P., and R. Arlon. Talc: A Possible Occupational and Environmental Carcinogen. J. of Occupational Medicine, v. 15, February 1973, pp. 92-97.
Good recent summary of talc toxicity compared to asbestos experience. Only new information concerns consumer exposure in food.

3. Dreesen, W., and J. M. Dalla Valle. The Effects of Exposure to Dust in Two Georgia Talc Mills and Mines. Public Health Repts., v. 50, February 1935, pp. 131-141.
One of the first, well-documented surveys of talc workers showing high incidence of pneumoconiosis (half of the heavily exposed subjects).

4. Hogue, W. L., and F. S. Mallette. A Study of Workers Exposed to Talc and Other Dusting Compounds in the Rubber Industry. J. of Industrial Hygiene and Toxicology, v. 31, November 1949, p. 359.
Industry study of 20 workers with long exposure to allegedly pure talc yielded no pneumoconiosis.

5. Hunt, A. C. Massive Pulmonary Fibrosis From the Inhalation of Talc. Thorax, v. 11, 1956, pp. 287-294.
Case report and discussion. Attributes massive pulmonary fibrosis to talc alone, disregarding silica because of lung ash findings.

6. Kleinfeld, M., J. Messite, and others. Talc Pneumoconiosis. AMA Archives of Ind. Health, v. 12, July 1955, pp. 66-72.
References 6-13, 16, and 21-22 are all from the New York State Department of Labor and are concerned with longitudinal study of talc miners and millers.

7. _____. Problem Areas in Pneumoconiosis. AMA Archives of Environmental Health, v. 5, November 1960, p. 498.
A general discussion of the state of the art. See also reference 6.

8. _____. Talc Pneumoconiosis. AMA Archives of Environmental Health, v. 7, July 1963, pp. 101-115.
Post-mortem reports on six subjects with talcosis. Findings compared to asbestosis and silicosis. See also reference 6.

9. _____. Lung Function in Talc Workers. AMA Archives of Environmental Health, v. 9, November 1964, pp. 559-566.
A comparative morbidity study of workers exposed to fibrous and granular talc dusts using a different from that above population, all millers in two separate facilities. Those allegedly exposed to only granular talc had significantly less signs and symptoms of disease. See also reference 6.

10. _____. Pulmonary Ventilation Function and Talcosis of the Lung. Diseases of the Chest. AMA Archives of Environmental Health, v. 42, November 1964, p. 592.
Intensive pulmonary function evaluation of 20 men with clinical and radiologic diagnosis of talcosis. See also reference 6.

11. _____. Effect of Talc Dust Inhalation on Lung Function. AMA Archives of Environmental Health, v. 10, March 1965, pp. 431-437.
Study population from 9 as a whole compared with a group of matched controls in morbidity study showing significant differences. See reference 6.

12. _____. Mortality Among Talc Miners and Millers in New York State. AMA Archives of Environmental Health, v. 14, May 1967, pp. 663-667.
Mortality study of original population. See reference 6.

13. _____. Mortality Experience in a Group of Asbestos Workers. AMA Archives of Environmental Health, v. 15, August 1967, pp. 177-180.
Similarly designed mortality study of asbestos workers, apparently set up primarily to compare with study 12. See reference 6.

14. McLaughlin, A. I G., and others. Talc Pneumoconiosis. British J. of Ind. Medicine, v. 6, 1949, pp. 184-194.
Discussion and literature review of case report.

15. _____. Dust Diseases in Great Britain. AMA Archives of Ind. Health, v. 12, 1955, p. 83.
General discussion.

16. Messite, J., M. Kleinfeld, and others. Pulmonary Talcosis, Clinical and Environmental Study. AMA Archives of Ind. Health, v. 20, 1959, pp. 408-413.
See reference 6.

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