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Title: An Evaluation of Mineral particles at Governeur Talc Company 1975 and 1982: A comparison of Mineralogical Results Between NIOSH an dDGC

Dunn Geoscience Corporation

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An Evaluation of Mineral Particles at Gouverneur Talc Company 1975 and 1982: A Comparison of Mineralogical Results Between NIOSH and DGC

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1.0 CONCLUSIONS

1.1 The best equipment for identifying and counting the mineral species in the Gouverneur Talc Company (GTC) products and dusts is the petrographic microscope and liquids of known index of refraction.

1.2 GTC talc products were found to contain nonasbestiform tremolite, nonasbestiform anthophyllite, talc, serpentine, with trace amounts of quartz, diopside and carbonite. A small percentage of the talc in some grades was present as fibers of the mineral talc (See Section 10.8).

2.0 INTRODUCTION

2.1 Inception

In May, 1981, the R. T. Vanderbilt Company asked Dunn Geoscience Corporation (DGC) to conduct a mineralogic analysis of the commercial talcs and dusts produced at the Vanderbilt mines and mills in the Balmat area of New York State. DGC submitted a proposal to C. S. Thompson of Vanderbilt under a covering letter dated May 24, 1982, and the proposal was formally accepted by Vanderbilt in a letter from T. T. Noland dated July 25, 1982. Based on a telephone conversation from C. S. Thompson in advance of the formal acceptance, actual field work was able to start on June 2 with a visit to Vanderbilt's GTC properties in St. Lawrence County, New York.

2.2 Purposes

The project was designed to: (1) quantify the mineralogy of the current dusts at the GTC mine and mill, (2) determine the mineralogy of certain products and ore produced in the mid-1970's, and (3) compare the results with those published in the National Institute for Occupational Safety and Health's (NIOSH) Technical Report, "Occupational Exposure to Talc Containing Asbestos" (Dement et al: 1980).

2.3 Previous Work

2.3.1 The major rocks of St. Lawrence County, New York, have been extensively studied since the 1800's. The ancient Grenville marbles and associated rocks which dominate the St. Lawrence County exposures occur over a large area of Canada where they have also been studied exhaustively by geologists.

2.3.2 The earliest work referenced in this report is Ebenezer Emmon's 1842 work on the geology of the Second District, which included St. Lawrence County. The geology of the Gouverneur quadrangle, where the Vanderbilt properties are located, was described by Cushing and Newland (1925).

2.3.3 Extensive work in St. Lawrence County was also performed by Professor A. F. Buddington. His writings describe the geology of the Hammond, Antwerp and Lowville quadrangles (1934) and the magnetite deposits of St. Lawrence County in a paper coauthored with B. F. Leonard in 1962.

2.3.4 The most exhaustive recent study of the St. Lawrence talc belt was by A. E. J. Engel (1962), who spent 10 years mapping and analyzing the petrology and mineralogy of the talc ores for the United States Geological Survey. All of the major minerals observed in the present study were described by Engel.

2.3.5 Additional research on specific minerals will be reviewed in Section 4.0 of this report.

2.4 Implementation and Personnel

2.4.1 Work for this project started on June 2, 1982.

2.4.2 Sampling of ore and the initial selecting of air and dust sampling sites were performed by J. R. Dunn on June 2 and 3, 1982. Air sampling in the Balmat area was then performed on June 6, 7 and 8 by K. Dayer (consultant) and J. Behan, P. E., of DGC. Petrographic work on thin sections was performed by J. R. Dunn in July. Grain petrographic and dispersion staining work on products and dusts was done in July, August and September by A. M. Pitaniello. Additional petrographic work on products was done by R. Meade in October. Specific gravity separations and electron microscopy were done in July and August by T. Hare and E. Fullam of Ernest F. Fullam, Inc. Some additional mineralogic observations were made in the spring and summer of 1983. All work was planned, coordinated and reviewed by J. R. Dunn who also did extensive grain analysis under the petrographic microscope. Literature collection and review were performed by J. R. Dunn. Project reviewer was W. E. Cutcliffe, President of DGC.

3.0 DEFINITIONS

3.1 The critical definitions used in this report will follow those used in the recently published American Society for Testing and Materials (ASTM) Designation D4240, "Standard Test Method for Airborne Asbestos Concentration in Workplace Atmosphere".

(1) **asbestos** – a collective mineralogical term that describes a group of naturally occurring, inorganic, highly fibrous, silicate minerals which are easily separated into long, thin, flexible fibers when crushed or processed. Included in the definition are the asbestiform varieties of: serpentine (chrysotile); riebeckite (crocidolite); grunerite (grunerite asbestos); anthophyllite (anthophyllite asbestos); tremolite (tremolite asbestos); and actinolite (actinolite asbestos).

Comment. This is essentially the ASTM definition. It has a commercial sense in that it includes only those minerals which are used commercially for asbestos. The commercial asbestos minerals all consist of flexible, fibrous crystals.

(2) **asbestiform** – a special type of fibrous habit in which the fibers are separable into thinner fibers and ultimately into fibrils. This habit accounts for greater flexibility and higher tensile strength than other habits of the same mineral. The increased flexibility and higher tensile strength are, apparently, the most distinct properties of asbestiform fibers.

(3) **fiber** – an elongated single crystal or similarly elongated polycrystalline aggregate that displays some resemblance to organic fibers.

(4) **fibril** – a single fiber that cannot be separated into smaller components without losing its fibrous properties or appearance.

(5) **fibrous particulate** – a mineral particulate that is composed of parallel, radiating or interlaced aggregates of fibers from which the fibers are sometimes separable. That is, the crystalline aggregate may be referred to as fibrous even if it is not composed of separable fibers but has that distinct appearance. The term fibrous is used in a general mineralogical way to describe aggregates of grains that crystallize in a needle like habit and appear to be composed of fibers. Fibrous has a much more general meaning than asbestos. While it is correct that all asbestos minerals are fibrous, not all minerals having fibrous habit are asbestos.

(6) **asbestos fiber** – forms of any of the six asbestos minerals characterized by properties of flexibility and length to width ratio of the order of 100:1, composed of definite crystalline unit cells oriented with respect to a specific crystal axis.

(7) **aspect ratio** – ratio of a length of a fibrous particulate to its apparent width (equivalent diameter).

3.2 For counting purposes the particles were also divided into the following categories:

(1) **chunks** – particles which vary from equant to particles with a 3:1 aspect ratio.

(2) **elongated particles** – cleavage fragments with greater than 3:1 aspect ratio. These particles may have aspect ratios of 20:1 or more but they are brittle and do not exhibit the characteristics of asbestiform particles (e.g., flexibility, curvature, etc.).

(3) **asbestiform particles** – are essentially those as defined by ASTM. (In work summarized in Sections 10.7 and 10.8, asbestos was defined to include only fiber bundles, frayed or split multiple fibrils, or bent, flexible fibrils.)

3.3 The official Occupational Safety and Health Administration (OSHA) definition of asbestos is as follows: (1) "Asbestos" includes chrysotile, amosite, crocidolite, tremolite, anthophyllite and actinolite. (2) "Asbestos fibers" means asbestos fibers longer than 5 micrometers.

The definition of asbestos which is used by OSHA for regulatory purposes (but not in most of this report) includes all "elongated particles" as defined in this report and all "asbestiform" or "fibrous" particles of this report (provided the particles are of those minerals which have a commercial asbestos form). Effectively, this includes chrysotile and the amphiboles tremolite-actinolite, anthophyllite, grunerite-cummingtonite, and riebeckite. It does not include fibrous variations of such minerals as sepiolite or talc, nor does it include such amphiboles as hornblende or glaucophane even though these latter minerals may have particle shapes which are identical to some particles which are included in the definition of asbestos used by NIOSH. NIOSH also indicates that counted particles must have a minimum length of 5 micrometers and a maximum diameter of 3 micrometers in order to be counted as asbestos.

3.4 "Fibrous Talc"

The expression "fibrous talc" has two meanings, a commercial meaning and a mineralogic meaning.

3.4.1 In commercial usage, New York industrial talcs historically were called "fibrous talc" because the mineral talc was one of the significant constituents and because many of the talc and other mineral particles in the milled products were elongated. Early health researchers wrongly interpreted the expression "fibrous talc" to mean talc containing asbestos. A major purpose of the 1973 Washington, D. C., symposium on talc was to correct misconceptions about the nature of fibrous talc (Goodwin, 1974).

3.4.2 Fibrous talc in a mineralogic or scientific sense is the mineral talc with an asbestiform habit.

4.0 FIBROUS TALC

4.1 *Some questions regarding* fibrous minerals to be answered in this report are (1) does true asbestos occur in the ores, products and dusts of the Vanderbilt properties; (2) does the mineral variation "fibrous talc" occur in GTC products; (3) what are talc's distinguishing characteristics; (4) to what extent has fibrous talc been misidentified as amphibole in the analyses of New York State talc ores and dusts; and (5) could electron diffraction patterns possibly confuse the structural display of talc and anthophyllite?

4.2 Does Fibrous Talc Occur in GTC Products? – A Literature Check

4.2.1 Fibrous (asbestiform, ASTM) talc of St. Lawrence County has long been described in the geologic literature. Emmons (1842) first described the replacement of silicates by talc in St. Lawrence County (p. 351). Fibrous talc in the ASTM sense is mentioned in the standard mineralogic textbook (Dana, 1905). The only locality for the fibrous talc (agalite) which is referred to in a later Dana and Ford (1932) is St. Lawrence County, New York, where GTC is located. Newland (1909, p. 84) said "Much of the talc has a fibrous texture which is preserved even after fine grinding....". Smyth (1918) described the zinc ores of the Edwards District and described replacement relations involving talc.

4.2.2 Cushing and Newland (1925), briefly described the talc deposits of the Balmat-Edwards District and the occurrences of talc, tremolite, and serpentine as well as the associated minerals observed in the commercial talc ores. They described "secondary" talc as taking on the morphology of the mineral from which it originated, including pre-existent fibers.

4.2.3 Stemple and Brindley (1960) described the structural relations of talc and tremolite and verified the approximately 5.28 angstrom cell spacing in the a-axial direction for talc. They observed that some fibers consisted of both talc and tremolite and, hence, produced mixed diffraction patterns.

4.2.4 Wright (1960) published a description of the optical orientation of fibrous talc. He concluded that the fibrous talc is probably in the shape of laths and is oriented with its axis of elongation the a-axis with the b-axis perpendicular to the long axis and tending to lie flat and the c-axis tending to be perpendicular to flat surfaces of the laths. He found a = gamma, b = beta, and c = alpha. Because the mineral is biaxial negative, the laths tend to lie with the Bxa vertical in sections according to Wright. Beta and gamma refractive indices tend to be very close, 1.582 ± .001 and 1.585 ± .001, respectively, and therefore fibrils should have very little change in refractive index from length to width and should be nearly isotropic with the birefringence in this orientation only .003. If this is true, under crossed polars such grains should be very difficult to see, being almost black.

4.2.5 Engel (1962, p. 300) in his extensive description of the St. Lawrence County talc deposits described the talc as "foliated, massive, and fibrous" and made over 32 x-ray diffraction analyses of the mineral. Engel considered gamma to be about 1.588 and considered beta as very close to the same refractive index.

4.2.6 Kleinfeld, Messite and Langer (1973) discussed the distinctions between talc and amphibole fibers in New York industrial talc and said that there were distinctive differences in the structural array of amphibole fibers versus talc fibers (p.139). The "fiber" of their photomicrograph 3A has the appearance and dimensions of an amphibole cleavage fragment -- a particle which would **not** be defined as asbestiform in the present research, but which appears to fit the NIOSH definition of asbestos in having a greater than 3:1 aspect ratio.

The amphibole structural array which is referred to is what might be anticipated from such a particle. It is probably safe to assume that they did not obtain similar patterns from the more classically asbestiform particles in the same photomicrograph. In addition, they did not show the "structural array" which they mention for the talc fibers for comparison. However, in the two other photomicrograhs on page 139, they showed what they called fibrous talc and chrysotile.

4.2.7 The report by Walter C. McCrone Associates, Inc. (1975) to NIOSH over the signatures of four staff members, concluded that "fibrous" talc occurred (their quotation marks), but did not quantify it. McCrone's identification of fibrous talc was not mentioned in the NIOSH report, although McCrone's work was for the NIOSH report and apparently was done on splits of the same seven samples studied and described by Rohl (1976), see below.

4.2.8 Rohl (op. cit.) of Mt. Sinai did not mention fibrous talc in his report to NIOSH on the GTC talc products.

However, Rohl, et.al. (1976, pages 258 and 279) noted that talc deposits may contain "talc plates and fibers".

4.2.9 Zumwalde and Dement (1977) in their report on the identification of asbestiform minerals include fibrous talc as one of the asbestiform minerals. In addition, they pointed out on page 13 that chrysotile, anthophyllite and fibrous talc "may be difficult to differentiate" under EDS. Dement is one of the authors of the NIOSH report.

4.2.10 Photomicrographs of fibrous talc are included in the present report in section 6.0 (thin section petrography) and section 7 (x-ray diffraction, electron microscopy and polarized light microscopy) contains other data about fibrous talc including x-ray and electron diffraction patterns.

4.2.11 Finally, although fibrous or asbestiform talc was not mentioned in the NIOSH report the title of the report on some early drafts was "Health Aspects Related to Miners and Millers Occupationally Exposed to Asbestiform Talc."

4.3 It is clear from the above that:

4.3.1 The expressions "fibrous talc" and "asbestiform talc" were intentionally eliminated from the NIOSH report.

4.3.2 The occurrence of fibrous talc in St. Lawrence County, New York, has been established in extensive literature dating back at least to the early 1900's.

4.3.3 The three major mineralogic contributors to the NIOSH report (McCrone and Associates, Rohl of Mt. Sinai School of Medicine, and Dement of NIOSH) were aware of the fibrous morphology of some talcs.

4.3.4 The nature of the major asbestiform mineral occurring in the talc mines in St. Lawrence County is controversial because McCrone and Rohl reached different conclusions about the major asbestiform component of splits from what apparently are the same seven products.

4.3.5 The quantities of the various asbestiform minerals -- whatever their identity -- are in doubt because of internally inconsistent particle counts within the McCrone report and within the NIOSH report and because of inconsistencies between McCrone and Rohl.

5.0 SAMPLE COLLECTION

5.1 Introduction

The samples which were collected for this report consisted of (1) hand specimens collected by J. R. Dunn on June 2 and 3, 1982, (2) air filter samples collected by J. Behan (DGC) and K. Dayer on June 6, 7 and 8, 1982, (3) mine dust samples collected by J. Behan and K. Dayer during the above days in June, and (4) product samples reportedly collected in 1975 sent to DGC from the U. S. Bureau of Mines and from R. T. Vanderbilt in June, 1982.

5.2 Hand Specimen Collection

5.2.1 Hand specimens were collected by J. R. Dunn from the underground mine areas (American mine) which were active in 1975, the time of the NIOSH sampling. Samples of ore which were typical so far as possible were collected from the 500, 700 and 900 (see Table 1) levels and the locations noted on nine maps. In addition, samples were collected at or near areas active in 1975 from the Arnold open pit mine which is about three-quarters of a mile south-southeast of Fowler. Samples particularly rich in fibrous talc were collected from dumped material stored on the Anthony property (Number 3 Mine) which is about one-half mile north of Talcville.

5.2.2 The specimens were examined in the DGC laboratory under hand lens and binocular microscope and 27 selected samples of ore as representative as possible were sawed and sent for thin sectioning to D. M. Organist.

TABLE 1

Hand Specimens, Underground Locations

Level and Drift	Collection Point	Thin Section
500 American west footwall	4 area ramp	
500 American west footwall	4 area ramp, 100' west of manway	M3B
500 American west footwall		M2B
500 American west footwall	10 stope area	
500 American west footwall	24 stope area	M1B; MA1
700 American footwall	Northeast end	
700 American footwall	Northeast end	
700 American footwall	Northeast, 95 ramp	
700 American footwall	90 ramp	
700 American footwall	80 ramp	
700 American footwall	70-80 ramp	
700 American footwall	60 ramp	M6
700 American footwall	50 ramp	
700 American footwall	5 draw point	M5A; M5B
700 Main east	8-10 ramp	M9B; M9
700 Main west	7-9 draw point	M10B; M8
900 Main west	M-9	M11A
900 Main west	M-11 ramp	M12A

5.3 Air Sampling

5.3.1 Air filter samples were collected as follows:

TABLE 2

Nuclepore Filter Samples

No. of Sample	Location	Comments
N-1	Mill at Waytrol Pond	Background
N-2	Whitaker Farm	Background
N-3	Waytrol Pond	Overloaded
N-4	Waytrol Pond	Good Sample
N-5	Waytrol Pond	Good Sample

5.3.2 Millipore filter air personnel samples were collected as follows:

TABLE 3

Millipore Filter Samples

No. of Sample	Location and Operator	Comments
M-1	Wheeler operator, M. Mullaney	Cyclone
M-2	Hardinge operator, W. Bickford	No cyclone
M-3	Wheeler operator, M. Mullaney	Cyclone
M-4	Hardinge operator, W. Bickford	No cyclone
M-5	Trammer, E. Therieau	No cyclone
M-6	Crusher operator, G. Hopper	Cyclone
M-7	Trammer operator, E. Therieau	No cyclone
M-8	Crusher operator, G. Hopper	Cyclone

TABLE 4

Mine and Mill Glass Slide Samples

Slide No.	Location and Operator	Comments
S-1	On nuclepore pump at wheeler control pond	Correspond to sample N-1
S-2	Hardinge office	5:20 - 9:25 p.m. January 6
S-3, 4	On steel beams near 10 area, 700 level	Corresponds to bag and ore sample #4 June 7, 8, 24 hrs. 10 a.m. to 10 a.m. (3, 4, 5 and 6)
S-5, 6	On rockwall near 5 draw point 700 Level	Corresponds to bag and ore sample #5
S-7	Wheeler console room	3:15 - 6:26 p.m., June 7
S-8	Hardinge console room	3:10 - 6:27 p.m., June 7
S-9	Wheeler waytrol panel	3:17 - 5:32 p.m., June 7
		Sample 7-9 correspond with N-3 through 5 and M-1 through 5.

5.4 Product Samples

5.4.1 Product samples were received from R. T. Vanderbilt and the U. S. Bureau of Mines (USBM). The historic samples were selected to be representative of the products which were being manufactured in 1975 and as close to splits of the samples tested by NIOSH and their consultants as possible.

5.4.2 R. T. Vanderbilt sent samples from Vanderbilt's Norwalk offices by Purolator Sky Courier on June 18, 1982, which were received on June 21, 1982, in a 10" x 12" x 12" cardboard box. The inventory of the contained samples is as follows:

TABLE 5

Vanderbilt Product Samples

Sample (1) CPS-364. Fibrous talc. In 3" x 6" plastic bag. Has a warning on label.

The following were in 3-5/8" x 6" yellow cardboard containers with metal (gold colored) ends with a circular pressure sealing metal top.

Sample	Description	Lot
(2)	IT 5X	S-137
(3)	IT 325	S-159
(4)	NYTAL 300	S-197
(5)	IT X	S-173
(6)	CERAMITALC NO. 1	S-107
(7)	IT 3X	S-154
(8)	CERAMITALC HDT	S-108
(9)	NYTAL 100	S-181
(10)	CERAMITALC 10-A	S-174
(11)	NYTAL* 400	S-141

According to Vanderbilt personnel the CPS samples received from the USBM (Table 6) are the same as those of Table 1, of the NIOSH report. However, Table 1 products are lettered A, B, C, etc., and summarizes data from six samples. The CPS-251 series listed below consists of seven samples and they are numbered. Table 7 is a summary of the samples reportedly checked by NIOSH, McCrone and Rohl.

TABLE 6

U.S.B.M. SAMPLE INVENTORY

(Samples 1-7 Collected 11/4/75 by A. Harvey Alongside NIOSH)

Sample No.	Product	CPS Nos.	Their No.	Comments	Time Collected
(1)	NYTAL 200	CPS-251-4	26	Packer Sta. 3 3/8 cut	8:45 a.m.
(2)	NYTAL 99	CPS-251-5	27	Packer Sta. 2 3/8 cut	2:05 p.m.
(3)	NYTAL 300	CPS-251-7	29	Packer #3 3/8 cut Second Shift	8:00 p.m.
(4)	HDT-Talc	CPS-251-1	23	#2 Packer 3/8 cut	11:25 a.m.
(5)	NYTAL 200	CPS-251-6	28	#3 Packer 3/8 cut	7:00 p.m.
(6)	FT Talc	CPS-251-3	25	Packer Sta. 3 3/8 cut	11:30 a.m.
(7)	NYTAL 100 HR	CPS-251-2	24	#2 Packer 3/8 cut	9:01 a.m.
(8)	NYTAL 200	In 3-5/8" x 6" container as in case of set 1.			

All samples were in a 6" x 12" open ended plastic bags wrapped in buff-colored paper towels, Scotch taped. Except for sample 8, each sample in a 4-1/4" x 7" "locked top" plastic bag. Labeling was with a black marker.

TABLE 7

Samples Checked by NIOSH, Rohl and McCrone

	NIOSH REPORT (DEMENT)		
Product	**Table #3 (p. 37)**	**Table #1 (p. 35)**	**Rohl and McCrone No.**
NYTAL 400	1	-	83756
NYTAL 300	2	E	83755
IT-5X	3	-	83757
IT-X	4	-	83759
IT-3X	5	-	83761
IT-FT	6	A	83760
IT-325	7	-	83758
NYTAL 100	-	B	-
NYTAL 200	-	D	-
NYTAL 200	-	F	-
CERAMITALC HDT	-	C	-

6.0 THIN SECTION MINERALOGIC AND PETROGRAPHIC ANALYSIS

6.1 Introduction

As a check of the Engel (1962) report and other previous work: (1) Samples of various types of ores were collected by J. R. Dunn. (2) Typical samples from this collection were sawed and slabs were then sent for thin sectioning to D. M. Organist. Thirteen thin sections were from samples from underground at Balmat; seven were from the Arnold pit and seven were from the Anthony property (No. 3 Mine.). (3) Petrographic and mineralogic work on the thin sections were done by J. R. Dunn in July, 1982.

6.2 Mineralogy

6.2.1 The minerals identified were tremolite, talc, anthophyllite, serpentine (lizardite or antigorite), titaniferous pyroxene (probably diopside), quartz, carbonate (probably either calcite or dolomite), probable chlorite, and probable epidote. The first four minerals are by far the most common judging from thin sections and appear to comprise over 90% of the ore. Tourmaline, which was described by Engel (1962), was not observed.

6.2.2 The anthophyllite is tannish in thin section (whereas tremolite is colorless), is in somewhat larger and longer crystals than tremolite, and has a prominent cross fracture. The anthophyllite has parallel extinction in all orientations in contrast to tremolite which has inclined extinction in most orientations. The distinction between tremolite and anthophyllite in thin section is not difficult.

6.2.3 McCrone (op.cit.) considered the serpentine as probably a mixture of lizardite and antigorite; and Rohl (op.cit.) stated that its x-ray patterns most closely resembled lizardite. DGC made no attempt to identify the type of serpentine, although the textures are similar to lizardite from similar rocks in Canada as described by Wicks and Whittaker (1977). Serpentine-rich rocks appear to be most common from the Arnold pit. No serpentine was observed in thin sections from the Anthony property.

6.2.4 Fibrous talc is very common at the Anthony property where it replaces amphiboles. Platy talc occurs with the fibrous talc, although in the thin sections of ore from the Anthony property, fibrous talc was far more common than platy talc. Platy talc occurs throughout the properties. The best evidence that the predominant fibrous mineral is talc is: the matching of refractive indices of adjacent grains combined with fibers of talc frequently growing out from plates of talc with the same optic orientation as the plates. In addition, the fibrous mineral in Photograph 2 has refractive indices perpendicular to the fiber length which are often lower than the omega refractive index of quartz, a property consistent with talc but not with amphibole.

6.2.5 The rock types are basically amphibole-talc rocks with varying amounts of serpentine. Locally, quartz may occur in patches and some marble was observed. Biotite was not seen in thin sections, but was observed in one hand specimen from the mine and was observed by Engel (1962).

6.2.6 The mineralogy and also the replacement relations are similar to those exhaustively described by Engel (1962). The only mineral which was not observed by Engel is what appears to be epidote which was seen in some thin sections from the Anthony property. Considering the mineral assemblages and chemistry of the rocks, the occurrence of some epidote is not surprising.

6.2.7 The mineral assemblage is a complex relationship of replacement textures and disequilibrium mineralogy. Tremolite, anthophyllite, carbonate and, perhaps, quartz appear to have been originally in equilibrium. Later, with decreasing metamorphic temperature, talc replaced the amphiboles in part. Some of the replacement talc is fibrous. Some fibrous talc such as that growing from talc plates and that growing within quartz crystals does not appear to have replaced amphibole. After that, serpentine replaced both some of the talc and some of the amphiboles. The observations from Engel (1962) were verified. Photos 1 to 6 are examples of some of the mineral textures seen in thin sections.

7.0 MINERALOGIC CHECK - THE FIBROUS TALC QUESTION

7.1 Introduction

The issue of whether or not fibrous talc is present in GTC products needs to be discussed. DGC conducted research using common identification techniques to try to determine to whatever extent possible whether or not fibrous talc occurs in the GTC ores, products and dusts.

7.2 How Are Minerals Identified?

7.2.1 Geologists and mineralogists can identify most common minerals with the unaided eye or with a hand lens and little else. For the practiced observer most recognition of minerals is done in a manner similar to the way in which one identifies another human being. The brain instantly summarizes a group of observations and arrives at a name. If such identification of minerals were not usually possible, much work done by geologists could not be done, because more elaborate techniques are too expensive.

7.2.2 In addition, a mineral tends to be found in common associations, with certain minerals occurring very commonly together, and with other minerals incompatible together. Association is also a factor in recognizing other human beings. One may feel very comfortable recognizing someone in a context in which that person is expected, but may have moments of uncertainty if the same person is seen in an unexpected environment, i.e., out of context or association.

7.2.3 Geologists in all such identifications summarize a series of characteristics such as luster, fracture, cleavage, color and association and may check their identifications with other characteristics such as hardness or solubility in acid. These techniques are sufficient for virtually all work commonly done by professional geologists.

7.2.4 A most critical thing about such work is that identifications are rarely based on a single characteristic; trying to use a single characteristic might be like trying to identify people based only on their weight. However under some circumstances a single characteristic may be sufficient for identification of other humans — for example finger prints or dental x-rays.

7.2.5 Similarly, the x-ray powder diffraction pattern of a mineral comes the closest to the single characteristic sufficient for identification. Some minerals are isostructural and therefore have very similar diffraction patterns, which might be confusing to the inexperienced analyst.

7.2.6 Another single characteristic which is often sufficient for identification is chemical composition. But many natural chemicals are multimorphous; for example, FeS_2 may be marcasite or pyrite and SiO_2 may be quartz, tridymite, cristobolite or chalcedony. At least one other piece of information is often required for absolute identification.

7.2.7 In the case of fibrous talc, a knowledgeable geologist or mineralogist considering association, hardness, soapy feel, lustre, and color would identify the fibrous mineral at the No. 3 Mine as probable talc. The thin section identification of talc fibers would remove any uncertainties as would a determination of refractive index in media of known index of refraction. The x-ray diffraction powder pattern would also remove uncertainties, provided a pure fibrous powder could be obtained. Any of these three techniques **alone** could be sufficient for certain identification. In the context of association plus the characteristics observed in the hand specimen, the electron diffraction pattern might be sufficient evidence to verify the presence of talc in a fibrous form. But the electron diffraction pattern **alone** may not be sufficient for proof, just as hardness, color, chemical composition, or specific gravity alone are usually not sufficient for proof. Multiple fibers and poor orientation may make identification difficult. The nature of the problem can be seen in part in the NIOSH report's Table 7 in which almost 40% of the "fibers" were not identified to their satisfaction with TEM.

7.2.8 Mineral identification nearly always is based on measuring multiple characteristics. It is simplistic to assume that any single measurement, no matter how sophisticated the equipment used for the measurement, will always be sufficient for identification.

7.3 Selection of Material

A single specimen (An 6 from the No. 3 Mine) of what is considered to be largely fibrous talc was selected for study. This fairly pure material was investigated because such relatively pure material gave the best assurance that all techniques would be employed on the same mineral. The thin section of An 6 contains fibrous talc plus non-fibrous tremolite, anthophyllite and probable epidote. Most thin sections of other samples from the No. 3 Mine had similar fibrous material but platy talc, amphiboles and quartz were relatively abundant impurities and there was no simple way to concentrate the fibers for study purposes. The sample was studied with the hand lens, zoom binocular microscope, under PLM in thin section and grain section, and under TEM/EDS and XRD. The latter two methods were employed at Ernest F. Fullam Incorporated, the remaining at DGC.

7.4 Description of Material

7.4.1 Hand Specimen

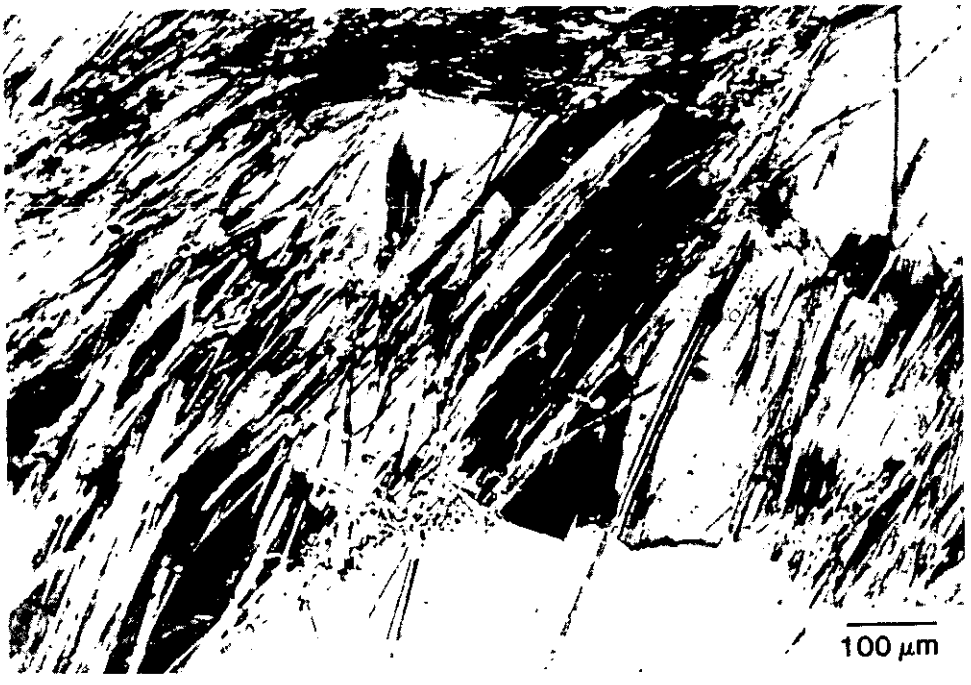
In hand specimen the rock is a gray-white, locally greenish material. Under 10X hand lens and binocular microscope the mineral particles were observed to be mostly acicular or fibrous. Much of the specimen is readily scratched with a finger nail and is slippery or soapy to the touch, i.e., the specimen has the criteria of hardness and slippery feel of talc (soapstone). These latter characteristics are compatible with historic criteria for identification of talc and without additional criteria the major mineral would be called "probable talc".

Note: Talc is the standard mineral in elementary student hardness sets representing the hardness of one, the lowest hardness on the Moh scale in which calcite is three, feldspar is six, quartz is seven and diamond is ten.

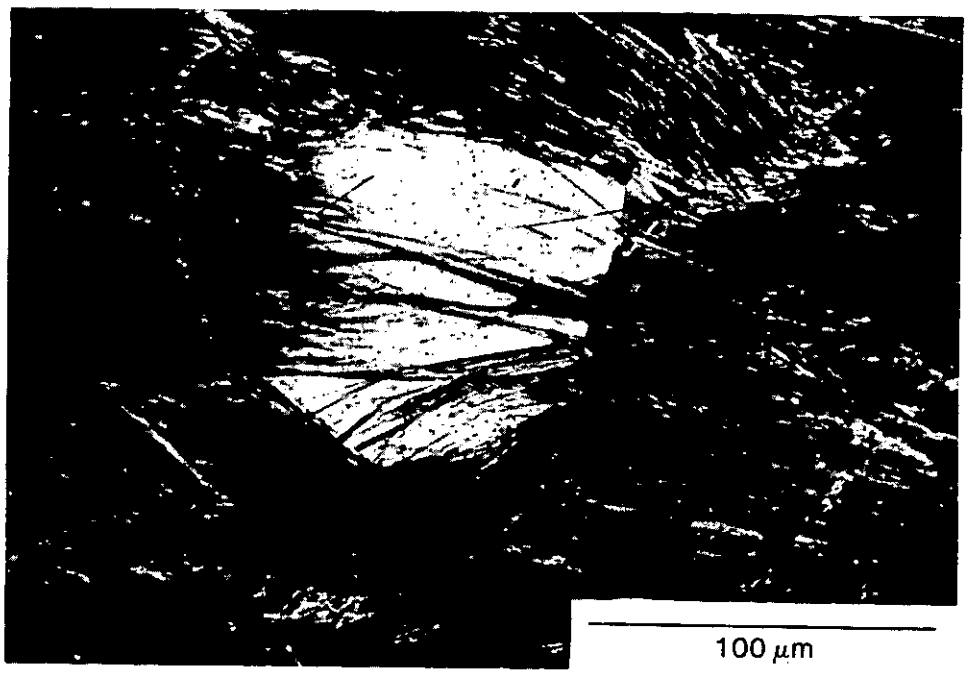
7.4.2 Thin Section

As previously noted, thin section An 6 consists primarily of a fibrous mineral plus tremolite, quartz, probable epidote and some anthophyllite. The predominant fibrous mineral in An 6 has a high birefringence with a length-slow optic orientation (see Photograph 7). Fibers which have high interference colors change relief significantly on rotation. The predominant fibrous mineral has a lower refractive index than the amphiboles and therefore is not amphibole. A thin section of

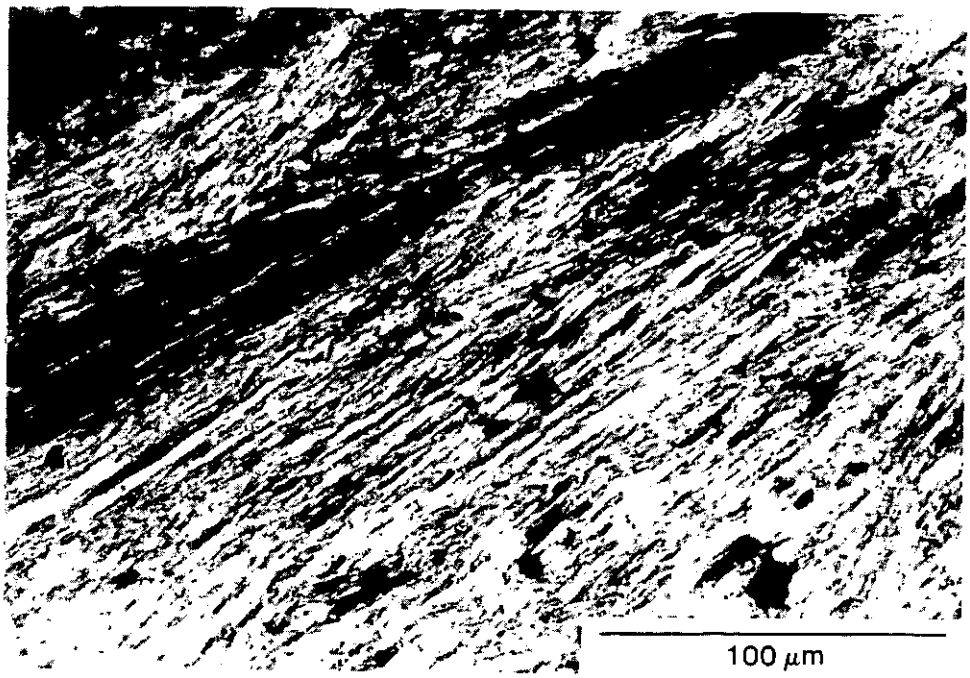
Photograph 1. Talc rock with talc occurring as "books" largely set on edge. Basal plate of talc (centered dark patch) traversed by talc fibers. Fibers often in optic continuity and growing from books. (No. 3 Mine; UXN)



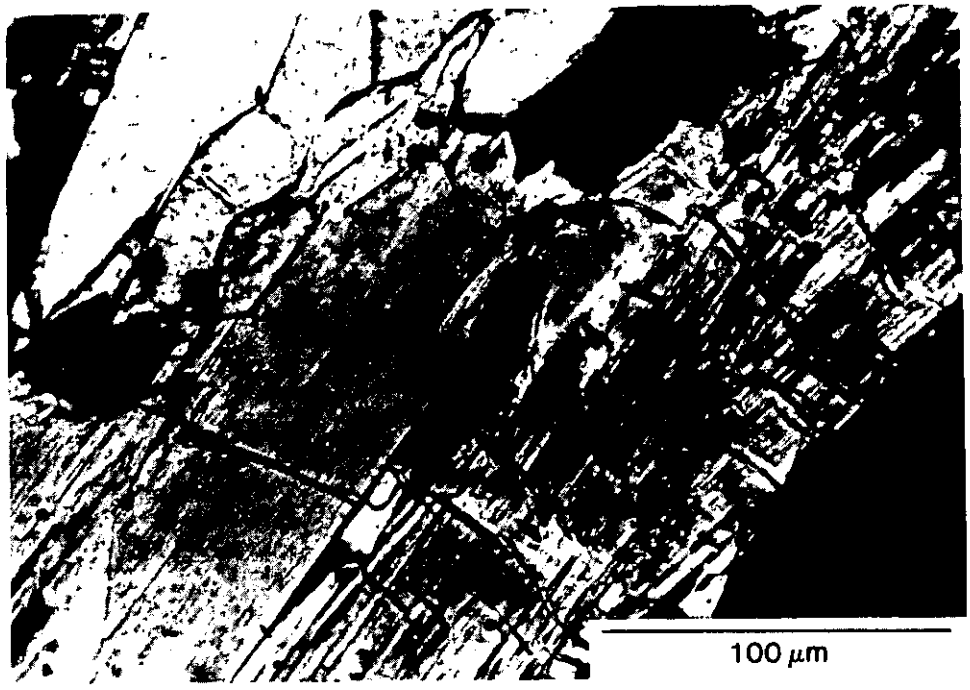
Photograph 2. Fibrous talc in quartz. Lower refractive index of talc lower than omega refractive index (1.544) of quartz. (No. 3 Mine, UXN)



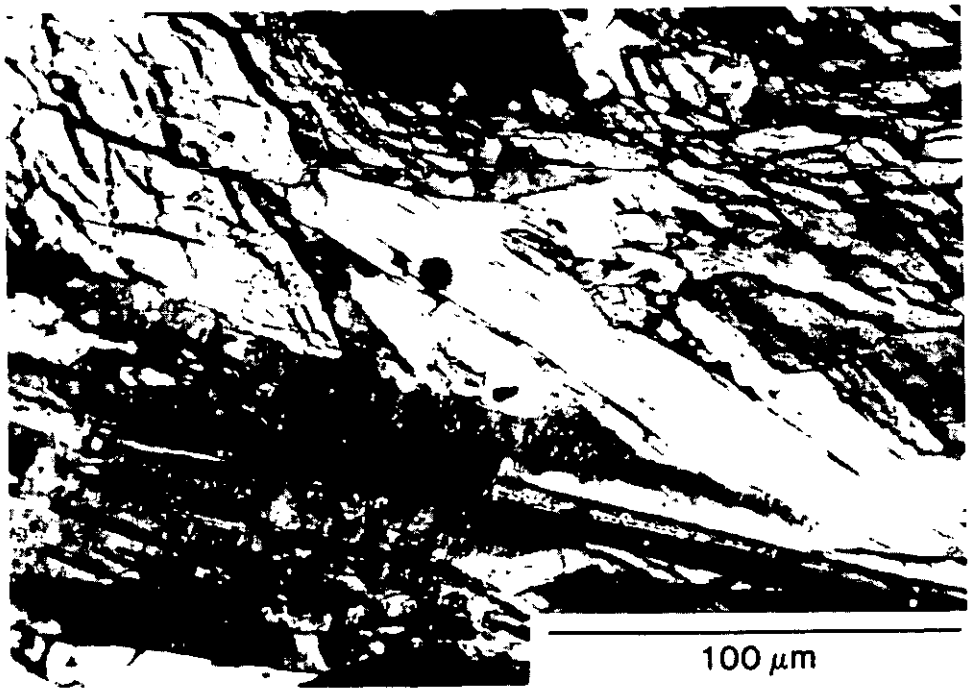
Photograph 3. Fibrous talc in quartz. (No. 3 Mine; UXN)



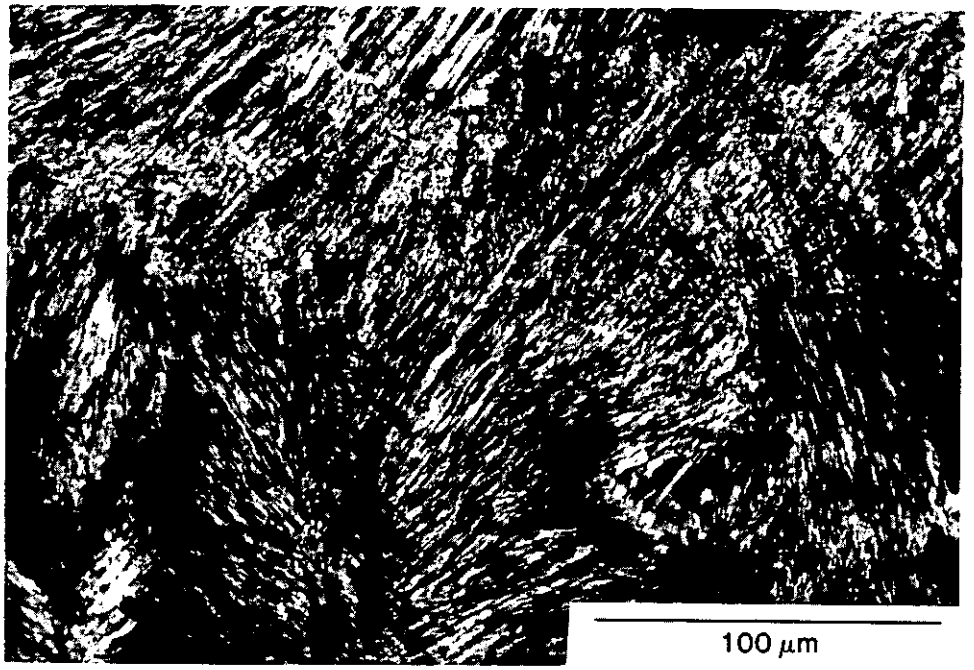
Photograph 4. Fibrous talc. (No. 3 Mine; UXN)



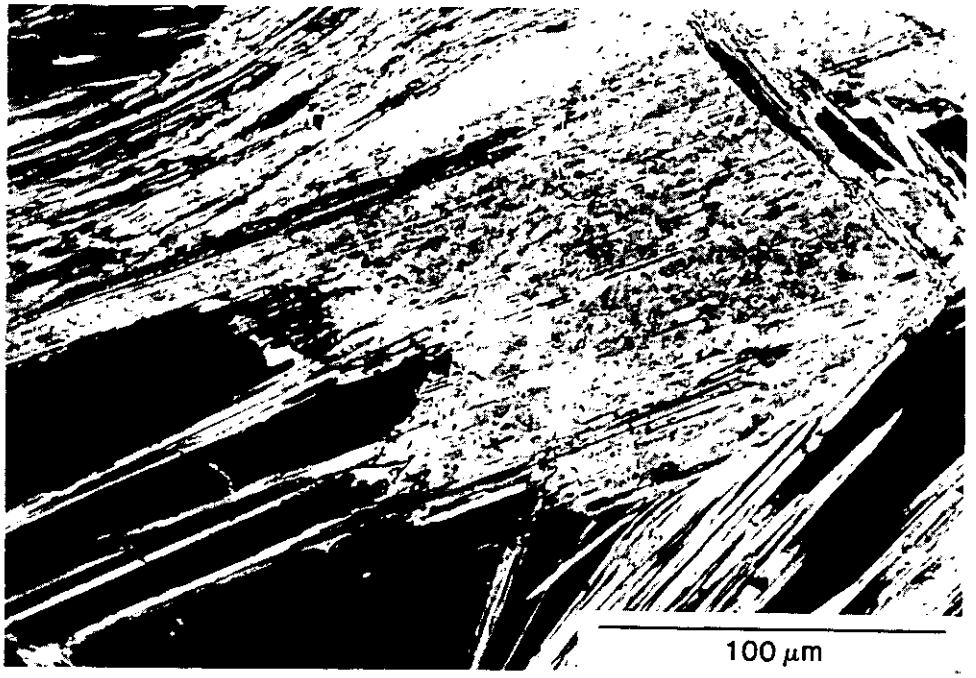
Photograph 5. Tremolite (tr) – anthophyllite (a) rock. Anthophyllite recognizable by prominent cross fracture. (Balmat, underground, 900 Level; UXN)



Photograph 6. Talc-amphibole rock, amphibole (am) showing intersecting cleavages. Anthophyllite (a) amphibole with cross fractures lower 1/3 with adjacent talc (ta) plates. Talc has "birdseye" structure. (Balmat, underground, 900 Level; UXN)



Photograph 7. Fibrous talc, relatively pure. Specimen is subject of research of Section 7.0 of this report. Epidote, anthophyllite and tremolite were also observed in this thin section. (No. 3 Mine; UXN)



Photograph 8. Talc rock with talc fibers growing in optic orientation from talc books. Fibers cross local basal sections of talc (black). Refractive index of fibers less than to equal to that of talc base (1.588) (No. 3 Mine; UXN)

specimen An 5 (Photographs 1 and 8) from the same locality is also rich in the fibrous mineral and has large talc plates or "books" from which typical, nearly uniaxial negative interference figures were obtained. Additionally, the books of talc have a typical "birdseye maple" appearance under crossed polars, a characteristic of most micaceous minerals with high birefringence. Several apparent fibrous crystals grow from talc books and have the same optic orientation as talc books (see Photograph 8). The refractive indices of the fibers are less than those of the basal plates of talc perpendicular to the fiber length and have less than to about equal refractive indices as the basal plates parallel to the fiber lengths, i.e., their refractive indices match those of the coarse talc. At 430X no change in refractive indices was observed at the junction of the talc books and the apparent fibers with the same optic orientation, i.e., the apparent fibers are definitely talc. The lower refractive index of the fibers in Photographs 2 and 3 (of specimen An 4, from the same locality) is less than the omega refractive index (1.5442) for quartz, again consistent with the described refractive indices for talc. From these measured characteristics, the major fibrous mineral in thin sections An 4, An 5 and An 6 is clearly talc.

7.4.3 Grain Section

Powder from An 6 was scraped off the sawed surface from which the thin section was made. Some of it was put in a 1.592 immersion medium and observed under PLM. Bundles of fibers were the predominant material and under crossed polars were found to have a length-slow orientation. The fiber bundles had refractive indices which approached but were less than 1.592 with the fibers set north-south. On rotation a change to higher relief was distinct. The predominant fibrous mineral which was observed in every grain section investigated in this project has similar optical characteristics. These optics are compatible with talc fibers as described by Wright (1960) but not compatible with amphibole or serpentine minerals. Additionally, McCrone (1983) notes that talc fibers have refractive indices which are about 1.59 parallel to the length and that its refractive indices are distinctly different than those of asbestos minerals.

7.4.4 X-Ray Diffraction

Some of the powder from An 6 was mounted in a 0.3 mm capillary tube, placed in a Phillips powder diffractometer and subjected to copper K alpha radiation for four hours to obtain a Debye-Scherrer XRD pattern.

The diffractometer pattern shows that the material is predominantly talc, but some quartz and tremolite lines were also observed. Some lines may be from anthophyllite, but the identity is uncertain. No lines consistent with epidote were observed.

7.4.5 TEM/ED

A "clamshell" type specimen grid supported representative powder from specimen An 6 for TEM microscopy. The equipment used was a Joel JEM 12 KV transmission electron microscope. Photograph 9 is of typical fibers as viewed under TEM at 10,000X.

Electron diffraction patterns were taken of seven different fibers. The fibers were rotated slightly on a horizontal axis about parallel to their axes of elongation to clarify the patterns. All of the diffraction patterns were consistent with what would be expected from talc, and four had hexagonal (or pseudohexagonal) symmetry.

Points on some patterns suggested the possibility of anthophyllite or tremolite also being present (perhaps as minor intergrowths or biopyroboles).

7.4.6 The Relationship Between Talc and Amphiboles

According to various authors talc may alter from tremolite or anthophyllite under certain chemical and physical conditions. In thin section talc may be seen cross-cutting and replacing amphibole, with such replacements along anthophyllite's cross fractures very common.

Talc may be seen in contact with unaltered tremolite with no apparent replacement relationship. Additionally, some talc fibers do not seem to have replaced amphiboles. For instance, it is difficult to envisage a mechanism whereby talc fibers in quartz replaced amphibole fibers in quartz. Additionally, talc fibers growing from talc books in optical continuity are more readily explained if there were no original amphibole phase.

From the above, one might expect some talc fibers to be quite pure; but also some fibers may contain remnants of amphiboles as layers or relict patches or zones and some amphibole particles may include talcose zones.

How much of the fibrous talc is pure talc? At this time this question cannot be answered with certainty. However, a fiber with all refractive indices less than 1.592 and with strong variable relief must be called talc. This does not preclude the possibility that under TEM with very high magnification and with ED some indication of amphibole might be seen. But the refractive index is a mass effect averaging the bending of light by the various silicate molecules to give averaged values. With such averaged values indicating that a fiber is talc, it is reasonable to call the fiber talc.

7.5 Summary and Discussion

7.5.1 All information obtained using the megascopic, optical, structural, morphological, and compositional nature of the primary fibrous mineral indicate that it is mostly fibrous talc. The mineral is similar to the fibrous talc described by Stemple and Brindley (1960), by Wright (1960) and by Ross (1968). Additionally, a paper by Virta (1983) of the USBM Particulate Unit has described fibrous talc from the No. 3 mine at Talcville using similar techniques to those used in the present report. He verified the mineral variation fibrous talc. He also was able to find some amphiboles apparently in transition to fibrous talc. Occasional weak "amphibole points" obtained by Fullam with TEM/ED may indicate that some residual or unreplaced amphibole zones may occur within some talc fibers. Ross (1968) found some talc with inclined extinction and considered it to be a talc-tremolite mineral. Two fibers of a mineral with inclined extinction and refractive indices compatible with talc were observed and noted in Table 12, Section 10.8.2, of the present report. Their indentities were classified as unknown and not included in the talc count. Barr (1978) noted similar inclined extinction for some talc particles from the GTC properties and also observed a gradation in upper refractive indices so that some fibers had maximum R.I.'s as high as 1.600 (to as low as 1.582). In every single case the talc fibers checked had far lower refractive indices than 1.592 perpendicular to the direction of elongation -- expected of talc but not typical of anthophyllite which should be greater than 1.592. McCrone (1983) also points out that fibrous talc is readily distinguished from the amphiboles because its maximum refractive index is about 1.59. Most structural, optical and other characteristics are not compatible with the predominant fibrous mineral being any form of serpentine or amphibole.

Photograph 9. TEM, talc from sample An 6. 10,000X.

7.5.2 Given the knowledge that the products, ores and dusts at the GTC properties consist largely of talc, tremolite, anthophyllite and serpentine the best way to distinguish the minerals for particle counting purposes is through the use of the petrographic microscope and immersion media. A procedure for counting such particles is outlined in Section 10.0 of this report.

7.5.3 The conclusions which we must reach regarding fibrous talc are: (1) It exists and is present in ores mined by the GTC. (2) Electron microscopy often yields ambiguous results. (3) Distinctions between anthophyllite and talc particles using electron microscopy are not as valid as distinctions based on refractive indices.

8.0 MINERAL PARTICLE IDENTIFICATION AND COUNTING PROCEDURES -- PRELIMINARY ANALYSIS

8.1 Introduction

Table 8 is a summary of certain critical characteristics which are useful in distinguishing the most common minerals which are known to occur (or may occur) in the GTC ores.

TABLE 8

Summary of certain characteristics of minerals which were looked for in the talc deposits in St. Lawrence County, New York

MINERAL	REFRACTIVE INDICES[1]	SPECIFIC GRAVITY	EXTINCTION ANGLE	MAJOR METALLIC ELEMENTS	PARTICLE MORPHOLOGY, ORIENTATION
talc					
(platy, fibrous)	1.588 (1.539)[2]	2.7-2.8	---	Mg,Si	irregular to fibrous
anthophyllite	1.596-1.623[3]	2.85-3.2	parallel	Mg,Si	elongated fragment
tremolite-actinolite	1.599-1.629	2.9-3.2	10-18	Mg,Si,Ca	elongated fragment
serpentines	1.540-1.554[3]	---	---	Mg,Si	
lizardite	---	2.50-2.65	---		equant particles
antigorite	---	2.50-2.65	---		equant particles
chrysotile	1.542-1.555	2.22	parallel	Mg,Si	asbestiform (ASTM)
diopside	1.665-1.692	3.2-3.28	38	Si,Ca,Mg	equant particles
carbonates					
dolomite	1.682-1.503	2.8-2.9	---	Mg,Ca,C	rhombohedrons
calcite	1.658-1.486	2.71	---	Ca,C	rhombohedrons
chlorite	1.57 ± .07	2.6-3.0	---	Mg,Si	plates
epidote	1.72-1.77	3.25-3.5	---	Si,Ca,Al,Fe	equant particles

[1] Refractive indices from the minerology literature vary somewhat for each mineral. The refractive indices tabulated are those which appear to be most reasonable.

[2] The 1.539 R.I. is rarely measurable in plates because this refractive index direction is perpendicular to the basal cleavage.

1.588 is the refractive index along the length when in the fibrous form. Engel (1962) gave gamma as 1.588; Wright (1960) considered gamma to be 1.585; McCrone (1983) 1.59

[3] Engel (1962).

8.2 Procedures Commonly Used

8.2.1 For counting procedures the ideal is to identify every particle, which means **every orientation of every particle**. Each method of particle identification which is commonly in use has shortcomings for such particle counting, because in some cases distinctions simply cannot be made and in some cases the costs or time required are prohibitive. For example:

(1) Energy dispersive x-ray techniques for determining elemental composition (EDS) may not be capable of distinguishing among the five magnesium silicates which may occur in the ores. There is a tendency for serpentines to have an EDS peak for Mg about 0.9 as high as that for Si. Anthophyllite's Mg peak is about 0.4 as high as Si and talc's about 0.3 as high. However, in counting particles, ratios vary from the ideal, often making anthophyllite and fibrous talc difficult to distinguish. Mixed mineralogy in a single particle (biopyrobole) may be a further complication.

(2) The carbonates calcite and dolomite are almost impossible to distinguish from each other in thin section but readily distinguished with EDS. Virta (1985), for instance, refers only to "carbonate", not calcite or dolomite.

(3) Because of similarities in refractive indices, the dispersion staining techique alone is not effective for making distinctions between anthophyllite and tremolite or between lizardite and antigorite. Combining dispersion staining with extinction angles allows the distinction between anthophyllite and tremolite to be made. For extremely thin fibers the dispersion staining colors may be very difficult to see.

(4) The transmission electron microscope using electron diffraction techniques can be used to make most distinctions, but it is expensive to use in routine analyses especially if the patterns must be fully indexed. Additionally, the electron diffraction patterns may not always be "sufficient for identification" (see NIOSH, op.cit., p. 41) because of similarities of patterns for minerals of the same group. For instance, amphiboles are nearly isostructural and, therefore, the distinction between anthophyllite and tremolite is very difficult. In addition, the 5.3 angstrom "repeat" may occur in both amphiboles and fibrous talc. It is noteworthy that for three of the four most common minerals in the Balmat talc deposits, electron diffraction patterns may give equivocal results.

(5) Bulk x-ray analysis is only semiquantitative and cannot ordinarily detect minerals which are less than two to three percent of the total material. In addition, with many lines observed because of the occurrence of several minerals together some confusion about the source of some lines may occur.

8.2.2 Because of the various limitations of each method, many studies of mineral particles involve the use of a combination of techniques, as in the case of the NIOSH report.

9.0 PROCEDURES AND PARTICLE COUNTS, FIRST PHASE

9.1 Introduction

The description of the primary data gathering component of work for this report is divided into two phases. The first phase consists of dispersion staining microscopy work using more or less standard and routine techniques.

9.2 Air Testing Program

Air sampling was done at Vanderbilt's Gouverneur Talc mine on June 6, 7 and 8, 1982. The sampling was of three types: Millipore personnel samplers, nuclepore ambient air sampling, and sedimentation slides. Nuclepore samples were not examined and only two of the dust sedimentation slides were examined. These have been kept for examination at some later date if needed. The millipore samples were all checked. The sample locations are summarized in Table 9.

9.2.1 The procedures used were as follows:

A fiber was defined in the NIOSH sense, i.e., as a particulate with a length greater than 5 micrometers, a width less than 3 micrometers, and a length to diameter ratio of 3:1 or greater. What is called fibrous in this procedure includes all elongated particles in the above category, i.e., no attempt was made to subtract any amphibole cleavage fragments or talc fibers from the totals (Table 10).

9.2.2 Equipment:

The following equipment was utilized for fiber counting:

(1) Leitz-Wetzlar binocular microscope with Koehler illumination;

(2) 10X eyepiece fitted with a Porton Reticle;

(3) Phase contrast condenser;

(4) 40-X Phase contrast objective;

(5) Stage micrometer (for calibration);

(6) Immersion oils.

TABLE 9
GOUVERNEUR TALC AIR SAMPLES
MILLIPORE (PERSONNEL) SAMPLES

Sample	Date	Total Liters	Comments	Time	Pumping Rate
M-1	6/7	288	Wheeler Operator Michael Mullaney, cyclone attached, respirable dust sample	2:51 p.m. - 5:21 p.m.	2.0 LPM
M-3	6/7	120	Same as M-1	5:23 p.m. - 6:23 p.m.	2.0 LPM
M-2	6/7	272	Hardings Operator 1,2,3, Wilson Bickford, fiber sample (no cyclone)	3:01 p.m. - 5:24 p.m.	1.9 LPM
M-4	6/7	116	Same as M-2	5:24 p.m. - 6:25 p.m.	1.9 LPM
M-5	6/8	288	Trammer (slusher hoist 700-11 AW), 10 Area Ed Therieau, fiber sample (no cyclone)	6:58 a.m. - 9:22 a.m.	2.0 LPM
M-7	6/8	146	Same as M-5	9:22 a.m. - 10:35 a.m.	2.0 LPM
M-6	6/8	328	700 Level crusher operator Gary Hopper, respirable dust sample (cyclone)	5:59 a.m. - 9:43 a.m.	2.0 LPM
M-8	6/8	126	Same as M-6	9:43 a.m. - 10:46 a.m.	2.0 LPM

9.2.3 Procedure:

Separate the middle and bottom sections of the field monitor to expose the filter. Place filter, sample side up, in the mounting solution and cover it with a #1-1/2 coverslip. The filter will become "water-white" transparent in approximately 15 minutes.

Using 400 X phase contrast illumination scan over a range of focal planes of the filter surface. At least 300 fibers were counted in a maximum of 50 fields. Criteria used in counting fibers include, counting any fibers 5 micrometers or longer with an aspect ratio 3:1 or greater which lies entirely within the counting area. Count as 1/2 a fiber which lies with one end in the field of view.

9.2.4 Calculations:

The following equation was used:

$$\text{Fibers} = \frac{(\text{Counted fibers})}{(\text{Total fields scanned})} \cdot \frac{(\text{Total filter area})}{(\text{Total area of field})} \cdot \frac{}{(\text{Volume Sampled})}$$

$$\text{Volume}$$

9.2.5 Results

TABLE 10

FIBERS PER MILLILITER,

NUCLIPORE PERSONNEL SAMPLES

Sample	Fibers*/ml	% Error
M-1	.322	5.4
M-2	.668	4.7
M-3	.028	9.8
M-4	1.38	5.0
M-5	.226	5.6
M-6	.616	4.4
M-7	.975	5.3
M-8	.988	5.7

*For the purpose of being able to compare our results with those of NIOSH, fiber is defined in the regulatory sense and taken as 5 micrometers or more in length, less than 3 micrometers in width, and with an aspect ratio of 3:1 or more. Fibrous and elongated talc particles are included along with amphibole and any serpentine minerals. The fibrous or elongated talc particles counted should be subtracted from the above count because talc is not officially recognized as an asbestos mineral.

9.3 Dispersion Staining Counts – Evaluation

Using methods and optical equipment pioneered by McCrone, dispersion staining particle identifications and counts were made on the gravity separations. However, the gravity separations were found to be unsatisfactory. In addition, the truly asbestiform particles—in the mineralogic or ASTM sense — were difficult to work with for these reasons: (1) the particle definition was not as sharp as with a petrographic microscope at comparable magnifications; and (2) the dispersion colors for very thin fibers were very difficult to see. Because of these difficulties, a procedure was devised using the more standard refractive index techniques with immersion media as described below.

10.0 PETROGRAPHIC PARTICLE PROCEDURE, SECOND PHASE

10.1 Introduction

Dispersion staining counts were routinely checked by J. R. Dunn using the petrographic microscope, immersion media and the Becke line, and because it appeared to be faster and better for measuring some definitive properties, a counting procedure was devised using the petrographic microscope. This procedure is specific for the mineralogy of the Balmat area and is considered to be valid for all of the major asbestiform and non-asbestiform minerals which occur. Any exotic minerals (minerals usually less than 1%) may be missed or confused with the major minerals under some conditions.

10.2 Procedure: Immersion Medium - 1.592, 430 X.

Step 1 Number of Non-Asbestiform Particles Above and Below 1.592 RI

Count all non-asbestiform particles in 1/4, 1/2 or full field as to whether they have less than or greater than 1.592 R.I. This is done with the converger out and the diaphragm partially closed to accentuate the Becke line. This step separates nonasbestiform particles into two groups, one containing primarily amphiboles and pyroxenes and the other containing primarily talc, serpentine, and quartz. Calcite straddles the R. I. of the liquid. For this step **make no mineral identifications.**

Step 2 Tremolite-Anthophyllite-Pyroxene Determination

Under crossed polars measure extinction angles of particles which have R. I.'s greater than 1.592. Particles with parallel extinction are counted as anthophyllite; particles with up to about 17° are counted as tremolite; 18° to about 30° are counted as pyroxene. (Pyroxene also has significantly higher relief than the amphiboles.) For particles with low first order colors put the converger in to sharpen the extinction position. For very small particles the 1-lambda wave plate may be useful to help see the extinction position.

Step 3 Asbestiform Mineral Determination, First Phase

With the converger in locate asbestiform particles (ASTM). For each particle remove converger, stop light down if necessary to sharpen Becke line. For particles with R. I. greater than 1.592 determine extinction angles. Such particles with parallel extinction are called anthophyllite: with inclined are called tremolite*. Particles which have R.I.'s less than 1.592 are counted as talc.

When the Becke line is difficult to see, it is often useful to turn elongated particles east-west to further sharpen the Becke line.

Note 1 The assumption is made here that for particles with R. I. above 1.592 which are too small to identify, the ratio of minerals will be the same as for those which are identifiable.

Note 2 These procedures should be followed for at least 200 particles.

10.3 Immersion Medium: 1.570, 430X

Step 4 Count the number of nonasbestiform particles which have refractive indices above and those below 1.570. For best results the converger should be out, the light stopped down. Make no mineral identifications at this step.

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*Note: Asbestiform tremolite may have parallel extinction.

Step 5 The microscope should be set up as in Step 4. For non-asbestiform particles, all particles which have all refractive indices less than 1.570 and are irregularly birefringent, show some straight edges, have tendency to cleave, or have a wispy, irregular appearance, are classified as serpentine. More or less equant particles which are clear and conchoidally fractured are classified as quartz.

Step 6 With the converger in, polars crossed, diaphragm open wide, locate asbestiform particles. For each particle, remove converger, stop light down. Particles with refractive indices slightly above 1.570 parallel to the length and less than, equal to or slightly greater than 1.570 perpendicular to the length are counted as talc.

Asbestiform particles with refractive indices distinctly lower in all orientations are counted as chrysotile; particles distinctly higher in all orientations are counted as amphibole asbestos. Amphibole grains with inclined extinction are tremolite; those with parallel extinction are asbestiform anthophyllite.

Note 3 Count at least 200 particles in Steps 4 and 5.

10.4 Calculations:

10.4.1 Anthophyllite, tremolite and diopside are determined by taking the ratio of the three minerals of Step 2 and assuming that the particles with R. I. greater than 1.592 found in Step 1 contain the three minerals in the same ratio.

10.4.2 The serpentine and quartz contents are determined by making the same sort of calculation as in 10.4.1 above but using data from Step 4 and Step 5 for serpentine and quartz.

10.4.3 Asbestiform mineral percentages are found by taking the data from Step 3 for anthophyllite and tremolite; chrysotile and asbestiform talc are taken from Step 6.

10.4.4 The nonasbestiform talc content is calculated by adding the percent of all other constituents (anthophyllite, tremolite, diopside, serpentine, quartz, and asbestiform particles) and subtracting from 100%. Talc may also be determined by subtracting the total particle percent greater than 1.592 material from the total particle percent greater than 1.570. Fibrous talc, which was determined separately, is added to the total talc.

10.5 Advantages of Above Technique

The major advantage to the above procedure is in Steps 1 and 4 where by counting only particles with refractive indices above or below either 1.592 R. I. or 1.570 R. I., the operator is relieved of the problem of identification of some individual particles, particularly talc. The number of talc particles is taken only as a difference in percents of particles. The other advantage is that in Steps 3 and 6 asbestiform particles are counted separately allowing the optics to be set up to maximize the ability to locate very thin asbestiform fibers. The distinction between tremolite and anthophyllite is also readily made when in cleavage fragments.

10.6 Dispersal Procedures

10.6.1 A dispersal problem was encountered with one slide. The particles which were removed from the product container were those which adhered to metal tweezers. That material was placed on a slide in 1.592 R. I. medium and covered. The powder was observed to form a regular, mesh-like pattern at first. This pattern was destroyed by pushing down on and sliding the cover plate. Counting the particles disclosed that the total amphibole was only 31% for 279 particles which

were counted. These aberrant results are possibly caused by static forces in which platy minerals tend to adhere to the metal surfaces of the tweezers to a greater extent than elongated particles. That the static forces remained was indicated by the regular mesh-like pattern of the particles on the slides. The possibility of a problem with static electrical forces was not further studied. However, they apparently can cause preferential concentrations of various minerals which could contribute to erratic particle counts.

10.6.2 Particles to be counted henceforth were piled on top of the instrument used to remove the dust and no more obviously aberrant results were obtained.

10.7 Petrographic Counting Results

10.7.1 Table 11 summarizes the petrographic particle counts.

10.8 Petrographic Asbestos Check

10.8.1 Because of the considerable confusion about the definition and nature of asbestos and because in normal counting procedures true asbestos particles (ASTM sense) are always a minor component, seven products were checked for asbestiform particles alone. The only particles which were considered to be asbestiform were those which were bent, frayed or in obvious bundles, i.e., in the classic mineralogic or ASTM sense. Apparent single fibers which were not bent were not considered. The 1.592 and 1.570 immersion media were used and the following products were checked: IT-FT, IT-5X, NYTAL 200, NYTAL 100, NYTAL 99, NYTAL 300 and CERAMITALC HDT (CPS 251 series). At least 25 particles from each of these products were checked in the 1.592 immersion medium for a total of 196. This is far more asbestiform particles than would be seen in normal counting of all particles. (If all particles were counted and if the total asbestiform particles were 5%, almost 4000 particles would have to be counted to see 196 asbestiform particles.) The results are summarized in Table 12.

TABLE 11

PETROGRAPHIC PARTICLE COUNTS, PERCENT PARTICLES

NYTAL 200

	Percentage		
Mineral	**Chunks**	**Elongated**	**Asbestiform**
Tremolite*	21	13	tr*
Anthophyllite*	3	4	tr*
Talc	35		5
Serpentine	13		
Quartz	4		
Diopside	2		
Calcite	tr		
Unknown	tr		tr

Particles counted: 1059

NYTAL 300

	Percentage		
Mineral	**Chunks**	**Elongated**	**Asbestiform**
Tremolite*	22	17	tr*
Anthophyllite*	5	5	tr*
Talc	35		4
Serpentine	8		
Quartz	2		
Diopside	1		
Calcite	tr		
Unknown	tr		

Particles counted: 621

*Possible Biopyriboles

10.8.2 The results are:

TABLE 12

Fibrous Particle Count of Bulk Products Using PLM
(percentages are relative to the total asbestiform particles)

Particle Category	Total Number of Asbestiform Particles
Particles with R. I. less than 1.592, parallel extinction	188 (95.9%)
Particles with R. I. greater than 1.592, parallel extinction (anthophyllite ? see 10.8.3)	3 (1.5%)
Particles with R. I. greater than 1.592, inclined extinction (tremolite see 10.8.3)	3 (1.5%)
Unknown, R. I. less than 1.592 inclined extinction (triclinic talc?)	2 (1.0%)

FT, 5X and 200 were checked in 1.570 R. I. liquid. The asbestiform particles had refractive indices predominantly less than 1.570 perpendicular to the length, close to or slightly more than 1.570 parallel to the length. A strong change in relief was usually observed on rotation. The optics were about as expected but with the higher refractive index a little lower than expected. This information taken with the observation that asbestiform particles under SEM have low Mg relative to Si means that the overwhelming majority of asbestiform particles are asbestiform talc. No serpentine asbestos (chrysotile) was observed.

Asbestiform particles in FT and 5X were investigated in a 1.540 immersion medium. The lower refractive index (perpendicular to the fiber length) was found to be around 1.540. The birefringence, thus, appears to be over 0.030. These characteristics are typical of talc.

10.8.3 Most asbestiform particles summarized in Table 12 cannot be tremolite or anthophyllite because the refractive indices are mostly lower than 1.592. Chrysotile is eliminated because of the upper refractive index, the strong change in relief and high birefringence. Those particles listed as tremolite and anthophyllite could possibly be transitional alteration minerals such as the biopyriboles, since their determination was made using only their index of refraction and extinction angles.

10.8.4 The most obviously asbestiform mineral is not tremolite as indicated by McCrone or anthophyllite as indicated by Rohl and NIOSH. By far the best mineralogic fit is for the major asbestiform mineral being talc.

10.8.5 From calculations from Tables 11 and 12 the total percent of asbestiform amphibole (or amphibole-talc intermediate) in the talc product is probably less than 0.2%.

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