

CURRENT ISSUES WITH PURPORTED “ASBESTOS” CONTENT OF TALC: PART 1, INTRODUCTON AND EXAMPLES IN METAMORPHIC AND ULTRAMAFIC HOSTED TALC ORES

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ABSTRACT

A Google search on *talc asbestos* will yield over 500,000 hits – the reason being the growing number of civil lawsuits in this area. Historically the litigation was centered on amphibole-containing industrial talc. There was no debate these talcs contained amphiboles, but the issue was the definition of asbestos. Ultramafic hosted talcs, however, are formed in such a way as to not favor the formation of amphiboles in the talc; they can occur in the surrounding black-wall, also the serpentinite host rock is in direct contact with the talc. Thus allegations can be made non-asbestiform amphiboles or non-regulated serpentine group minerals can occur in the final products.

INTRODUCTION

Gunter (1994) wrote the following in regard to the question “What is asbestos? *“The question yields different answers depending upon the audience. To a mineralogist, asbestos is a mineral form. To an engineer, it is an industrial material with several useful properties. To a medical doctor, it is an agent that might cause certain diseases. The third answer invokes several more issues: to a lawyer, a possible lawsuit; to a news reporter, a story; to an asbestos abatement worker, a job; and to a public school administrator or a parent, a nightmare.”* The main function of that article was to try and provide background information to be taught at the college level to help students understand some of the issues associated with the use of asbestos in our modern society, and especially its use as a fireproofing agent in schools and public buildings. At that point in time one of the main issues was asbestos abatement as the mining and use of asbestos was waning as its health risks became more clearly known in the occupational setting. Now over 20 years later the current issue we are dealing with herein is “asbestos” occurring naturally in talc. This is a well know concern for those in the talc industry and they have been working on methods to ascertain if their products contained “asbestos” since last century. As such our articles will focus more on issues emerging from recent litigation, and the confusion that occurs, especially in the “asbestos” nomenclature as the mineralogist, engineers, doctors, and lawyers previously mentioned try to communicate. And lastly we need to remain cognizant of the fact that people are still dying of mesothelioma in the US. As a last resort to recoup expenses as they are dying they often respond to the TV advertisements we’ve all no doubt seen.

“ASBESTOS” NOMENCLATURE – MORPHOLOGY MATTERS

As noted above, the words we use to describe asbestos often differ between different groups; however, what is agreed on by most is that asbestos is a commercial term (Van Gosen et al., 2004). More precisely asbestos is defined herein as one of six minerals occurring in an asbestiform habit (Gunter et al., 2007). These minerals are serpentine, riebeckite, grunerite, anthophyllite, tremolite, and actinolite, note the last five minerals belong to the amphibole group. Also, note the first three of these minerals have special names when they occur in the asbestiform habit: chrysotile, crocidolite, and amosite, respectively. As implied in the last sentence, asbestiform is a descriptive term used in mineralogy and simply means “lengthwise separable into fibers,” and while all asbestos minerals are asbestiform, not all minerals that occur in an asbestiform habit are asbestos – more

on this later as it sounds confusing, and does indeed create confusion especially in the legal arena. Even more confusing is the meaning of “fiber” as it can differ between the regulatory and mineralogical communities. In common, everyday use everyone knows what a fiber is (e.g., based on its physical properties it would be flexible much like thread); this is the definition used in the mineralogical community. However, in the regulatory community, and for historical reasons explained in more detail in Gunter et al. (2007), Gunter (2010), and Thompson et al. (2011) a fiber is defined based on its so-called aspect ratio (i.e., its length divided by its width). Depending on the method used, a particle would be defined as a fiber if it had an aspect ratio greater than three or five to one, and while this would encompass such things as thread, as the example given above, it would also encompass a needle as well.

Figures 1-4 will help illustrate the points made in the previous paragraph. Figure 1 shows three mineral samples obtained from the Smithsonian Institute; two of them – showing asbestiform morphology - - are “woven” around a third. These are all amphiboles with the woven white one and the straight one in the center being tremolite, the dark-blue one is the asbestos mineral crocidolite. Clearly the tremolite particle in the center is not asbestos, but it would meet the counting criteria (i.e., aspect ratio) to be considered a fiber. Often once a particle is deemed a fiber, that designation makes it synonymous to asbestos.

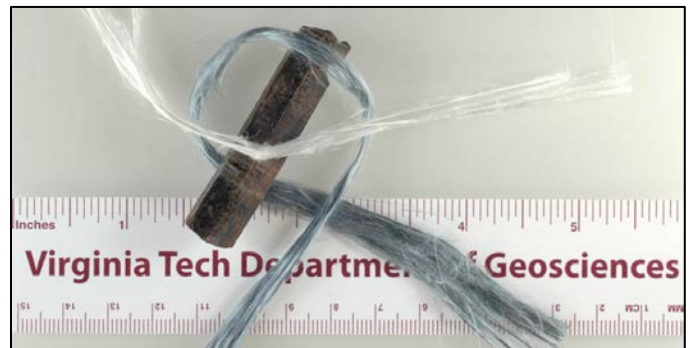


Figure 1. A large dark-colored single crystal of tremolite (center) surrounded by two long pieces of asbestiform amphiboles; the white sample is tremolite and the dark-blue is crocidolite. (Samples from the Smithsonian Institute, modified from Gunter et al., 2007.)

To determine if a mineral possesses cleavage, it must be broken, also a good test for the asbestiform habit is to apply a force to check to make sure the mineral separates lengthwise into fibers. And while this is easy at larger scales, it is impossible at the scale of samples obtained from the air. Figure 2 shows pieces of the tremolite from Figure 1 that have been broken. Note how in Figure 2a the sample breaks along its cleavage planes, while in Figure 2b it separates lengthwise into fibers. Figures 2c and 2d are photos taken in the polarized light microscope (PLM) and show differences in the morphology of the non-asbestiform (Figure 2c) and asbestiform (Figure 2d) tremolite. However the non-asbestiform sample would have aspect ratios that would make it a countable fiber even though they are

non-asbestiform. One final point here is the regulatory definitions of a fiber all assume the particles come from an asbestos source, such as was used in the occupational setting. However these “rules” often fail in the natural setting as discussed in more detail in Gunter (2010) and Thompson et al. (2011).

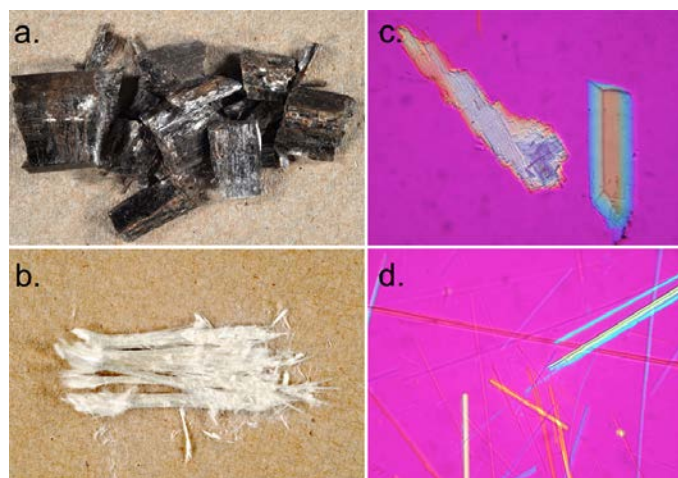


Figure 2. Broken pieces of the non-asbestiform (a.) and asbestiform tremolite (b.) from Figure 1 (field of view is approximately one inch). PLM images of non-asbestiform (c.) and asbestiform tremolite (d.) from a. and b. respectively (field of view approximately 500 microns). (Modified from Gunter, 2010.)

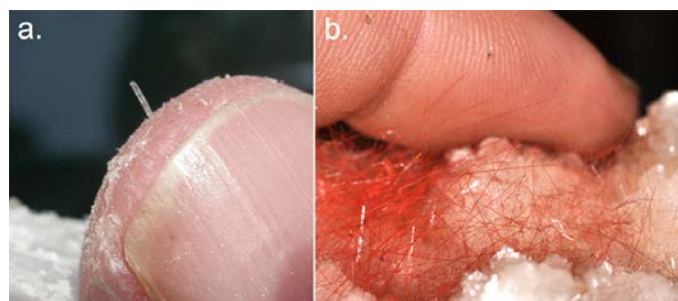


Figure 3. (a.) An example of an acicular mineral sticking in a thumb, opposed to (b.) which shows an index finger pushing down on a flexible mineral fibers.



Figure 4. Photographs of other minerals that occur in the asbestiform habit: (a. & b.) sepiolite and (c. & d.) brucite (photos taken at the Smithsonian Institute.)

Figure 4 will hopefully bring some clarity to the statement above that not all asbestiform minerals are asbestos. Two separate minerals are photographed from the Smithsonian collection are; in Figures 4a and 4b is sepiolite – shown at two separate scales, while

Figures 4c and 4d are brucite – likewise shown at two separate scales. Note that “asbestiform” [sic] actually appears on the label for sepiolite. Clearly both of these samples are occurring in the asbestiform habit, but are not asbestos. Also, these minerals can both occur associated with talc deposits.

Another physical property of a fiber – in the mineralogical sense – is that it is flexible. Figure 3 shows examples of this. In Figure 3a a non-fibrous amphibole particle is seen stuck into a thumb – this was not planned but occurred while handling ore samples in the Gouverneur talc mining district. Observing Figure 3b closely, note the red fibers are being pushed down, and are not sticking in the finger; this sample is mesolite – a zeolite mineral that often occurs in a fibrous habit. Just to be clear, there is a distinction between fibrous and asbestiform, in that asbestiform would be a subset of fibrous. For example individual strands of human hair are fibrous, but not asbestiform. However, if they were glued together then they would be asbestiform. This is important, as often a countable fiber will also become synonymous with fibrous, and sometimes even asbestiform.

The last illustration in this section is pertinent to the discussion of “asbestos” in talc. Figure 5 shows two scanning electron microscope (SEM) images of asbestiform particles removed from crayons, and assumed to be from the Gouverneur talc mining district. Mineral names have been added to these images based on compositional data obtained from EDS by Van Gosen et al. (2004). Note in Figures 5a and 5b they label both asbestiform and play talc particles. However, in Figure 5b they also label a portion of the particle anthophyllite. As McNamee and Gunter (2013, 2014) and especially McNamee et al. (2015) show, and discussed later in this paper, these particles are actually non-asbestiform anthophyllite altering into asbestiform talc.

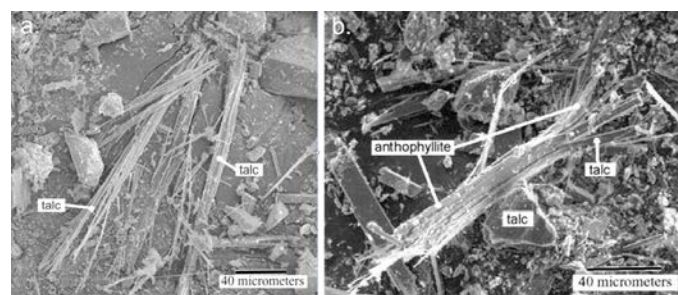


Figure 5. SEM images of asbestiform talc and anthophyllite removed from crayons (modified from Van Gosen et al., 2004).

To reiterate, just because a mineral particle is a countable fiber does not make it asbestos, and all minerals that occur in an asbestiform habit are not asbestos; it is both important to identify the mineral and its morphology. And this leads to one of the complicating factors of how “fibers” have been historically measured in air samples. First fibers were defined with a 3:1 aspect ratio and being longer than 5 microns. Next air samples were collected and particles counted by use of a phase contrast microscope (PCM) at 450x. In this method no attempt is made to identify the particle.

Finally asbestiform is used in mineralogy as a modifier for a mineral’s habit, and while it might seem like a silly analogy, a cherry tomato remains a tomato and is not a cherry. Thus just because a mineral occurs in an asbestiform habit does not make it asbestos, or worse yet, just because a 3:1 aspect ratio particle is counted by PCM does not make it asbestos.

MINERAL IDENTIFICATION

Minerals are identified based on their crystal structure and chemical composition; thus, for positive identification it is best to obtain both (for details see Chapter 19, Dyar and Gunter, 2008). Correctly operated a transmission electron microscope (TEM) can provide both diffraction data (i.e., electron diffraction) and compositional data – if capable of energy dispersive spectroscopy (EDS) – on the same particle. However EDS spectra are often used, in combination with morphologic characteristics, for routine identification of minerals in a known asbestos-exposed individual. Often EDS data cannot provide

sufficient quantification of the mineral compositions, to distinguish between minerals with similar compositions. While it might seem obvious, the correct identification of minerals is central to resolving legal disputes; however, based on our experience minerals are often misidentified for several reasons: 1) similarities in composition, 2) similarities in structure, 3) misuse of regulatory definitions, 4) relying on method developed for different purposes, 5) only using one characteristic of a mineral for identification, and 6) there can be inherent biases.

The main minerals at concern in dealing with purported asbestos concern of talc are: chrysotile ($Mg_3Si_2O_5(OH)_4$), anthophyllite ($Mg_7Si_8O_{22}(OH)_2$), and tremolite ($Ca_2Mg_5Si_8O_{22}(OH)_2$), note how two of these have similar compositions to talc ($Mg_3Si_4O_{10}(OH)_2$), with the main difference being the ratio of Mg/Si. Thus semi-quantitative compositional data, as often obtained by EDS, may lead to misidentification. All of these minerals are composed of polymerized chains of silicate tetrahedrons. For anthophyllite and tremolite two chains are joined together (i.e., forming the so-called double chain silicates) and for chrysotile and talc an infinite number are joined together (i.e., forming the so-called sheet silicates). One important point here is crystallographic repeats along these chains is approximately 5.3Å for each. And it is often this repeat that is used in methods developed to determine the asbestos content in air samples to identify a particle as asbestos or not.

TALC FORMATION

Talc generally forms from alteration of other minerals. There are four general talc-forming environments for economically important talc deposits based on the starting minerals and their conditions of alteration. McCarthy et al. (2006) summarizes them as: Type 1, which form from low-temperature alteration of peridotite; Type 2, which form from low-temperature alteration of gabbro; Type 3, which form from low-grade metamorphism of dolomite; and Type 4, which form from high grade metamorphism of dolomite. Geologists have given the name serpentinization to the low-temperature process that occurs in Type 1 and Type 2 deposits. This is the same process that was mentioned above to explain the formation of the serpentinite belt in Vermont. As is common in geological settings, other minerals are associated with talc in these deposits as a function of how the talc formed. In Type 1 and 2 deposits the main accessory minerals are serpentine (i.e., antigorite), magnesite, and chlorite. For Type 3 formation, the accessory minerals are: dolomite, chlorite, quartz, and feldspar. Because Type 4 formations reach higher temperatures than Type 3, they have a different set of accessory minerals: tremolite, serpentine, actinolite, carbonates, and quartz. Note the first three minerals listed in Type 4 deposit could be asbestos if they occurred with an asbestiform habit, while the only potentially asbestiform mineral for the other three types of formations is serpentine. McCarthy et al. (Table 1, 2006) noted that Vermont talc contained trace amounts of serpentine and no tremolite. Van Gosen et al. (2004) also gives a summary of talc formation and likewise points out that amphiboles only occur at higher temperatures of formation.

Example of metamorphic hosted talc

Talc has been mined in the Gouverneur talc mining district since the turn of last century. The geology of the area consists primarily of metasediments and other metamorphic units of the Adirondack Lowlands, part of the Mesoproterozoic Grenville Province (Chiarenzelli et al., 2010). The host rocks to the talc ore consist of Mg- and Ca-bearing silicates such as tremolite, anthophyllite, talc, and serpentine (Ross et al., 1968). These minerals are products of metamorphosed dolomites and quartzites, deformed by regional metamorphism and igneous intrusions (Engel, 1965; Ross et al., 1968). Ross et al. (1968) provides more details of the mineral alterations that have occurred in this deposit. Talcs produced from this area are often referred to as tremolitic talc as the tremolite content of the finished products can approach 50%.

In fall of 2009 attorneys representing a company that produced talc from this area approached MEG. He was asked to answer the question "Is there asbestos in talc produced from this talc mining district?" The company provided him with samples of all of their

different products for his characterization work. Again, there is no question these products contain amphibole, and as every Geol 101 student learns, amphiboles are elongate and most would meet the 3:1 counting criteria to be considered a fiber (Gunter, 2010; Thompson et al., 2011 and references therein). Also, when non-asbestiform single crystals of amphibole are crushed, cleavage fragments are produced that will also meet the 3:1 counting criteria (for example Figure 2c).

An even more complicating issue occurs with talc produced from this area as already shown in Figure 5; some of the talc is asbestiform. Figure 6 shows SEM images and associated EDS spectra of both platy and asbestiform talc particles from the same commercial product. Recall the ratio of Mg/Si for talc is 3/4 and anthophyllite is 7/8 thus making these particles hard to differentiate based solely on EDS spectra as discussed above. Thus other analytical methods must be used to differentiate them.

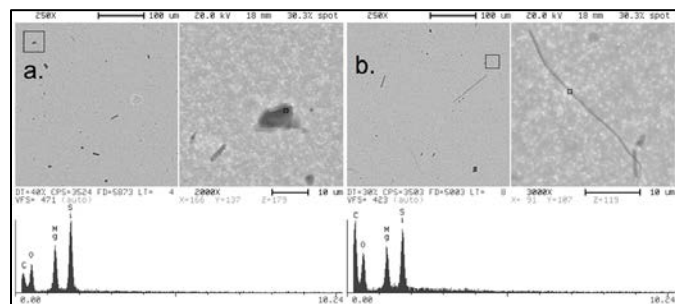


Figure 6. SEM images and EDS spectra of talc: (a.) platy and (b.) asbestiform. (Note the lower magnification image on the left for each particle contains a small box that is the imaged area on the right.)

Fortunately the refractive indices of the minerals in these talcs differ, with the amphiboles being the highest then followed by talc and finally serpentine. Thus when one makes a grain mount by immersing the particles in a near-matching refractive index liquid for talc, the talc will "disappear." This can be seen in Figure 7; also note that some of the talc particles are asbestiform. Figure 8 is a more quantitative use of refractive indices to aid in the identification of particles found in these products. In this example one particle each of tremolite, talc, and serpentine are shown immersed in a refractive index liquid. Then each particle is orientated until one of its principal refractive index directions is brought parallel to the lower polarizer as shown in the insets. Next the temperate, and thus the refractive index of the liquid is changed (cooled to increase it and heated to decrease it) until a match is found for each of the particles. Also note that the only asbestiform mineral in the Figure 8 is talc; however, the single crystal of tremolite would meet the counting criteria to be a fiber, but it is clearly not tremolite-asbestos.

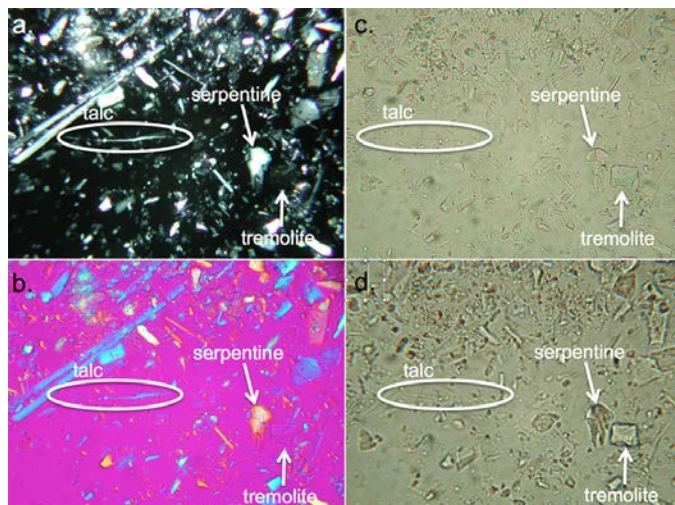


Figure 7. Four PLM images of a talc product from the Gouverneur talc mining district in a near-index matching fluid for talc: (a.) cross-

polarized light, (b.) cross-polarized light with full-wave plate inserted, (c.) plane polarized light, and (d.) plane polarized light with the stage slightly lowered. (Field of view about 500 microns.)

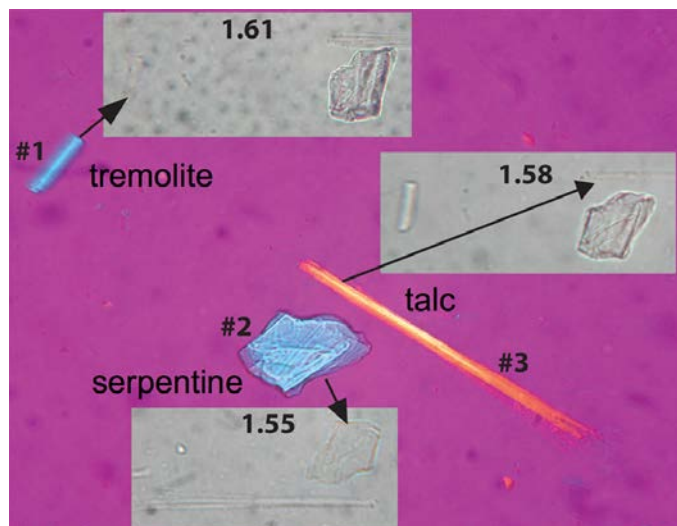


Figure 8. PLM image of tremolite, talc, and serpentine in cross-polarized light with full-wave plate inserted. Insets are in plane-polarized with the refractive index of the liquid adjusted to a near-match for each mineral (Modified from Gunter, 2010.)

Along with the products we also made multiple collecting trips to the former mines and obtained museum samples for our research. Ironically the sample shown in Figure 9 was from one such trip in which we accompanied a plaintiff's expert. Preliminary negotiations allowed for him to collect 10 samples and we would split the samples at the mine. However, they wanted to collect 12, which was deemed ok.

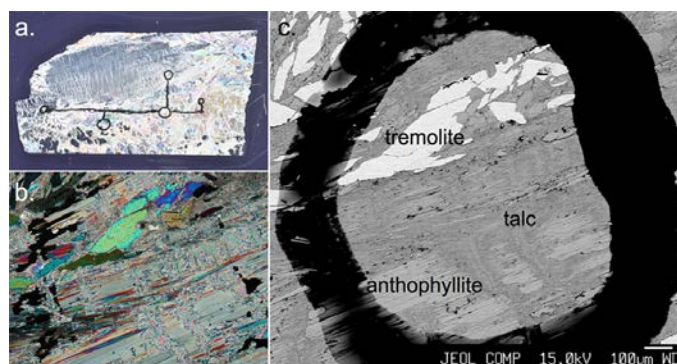


Figure 9. Three images of a rock sample collected at a former talc mine near Talcville, New York: (a.) polished thin section in cross-polarized light with circles added, (b.) PLM image of upper-most circle in (a.), and (c.) a BSE image of the same area as in (b.) with mineral names added (Modified from McNamee et al., 2015.)

Figure 9 shows images at different scales of sample number 12 from that collecting trip. Figure 9a is a photograph taken in cross-polarized light of a polished thin section of a talc-amphibole schist. Note in the upper left portion of the image (just above the horizontal black line) is a large single crystal of anthophyllite. Figures 9b and 9c are close-up images of the circle on the right end of the anthophyllite grain. In Figure 9b the different minerals can be seen as a function of their retardation. Figure 9c is a back-scattered electron (BSE) image taken in the electron microprobe. Note the different shades of grey are related to the different minerals as a function of their mean atomic number; thus, tremolite is the brightest, anthophyllite intermediate, and talc the least. Talc and anthophyllite were also clearly differentiated on the basis of wavelength dispersive spectroscopy (WDS), which provides quantitative data, as compared to semi-quantitative data from EDS. Recall Van Gosen et al. (2004) used EDS to differentiate

anthophyllite from talc in samples from this same area. However, we question those results as they were: 1) obtained with EDS and 2) the talc and anthophyllite are intergrown on such a fine scale the excitation volume in the SEM may have included areas of both minerals. (See McNamee et al. (2015) for more details of our compositional analysis.)

Returning to the products, Figure 10 shows a polished grain mount of a very acicular (i.e., non-asbestiform) anthophyllite grain altering on its edges to an asbestiform talc as seen by the differing shades of grey. Needless to say, if we had not first observed this in polished thin sections, we would have thought the different shades of grey resulted from a different polish or the talc being covered with epoxy.

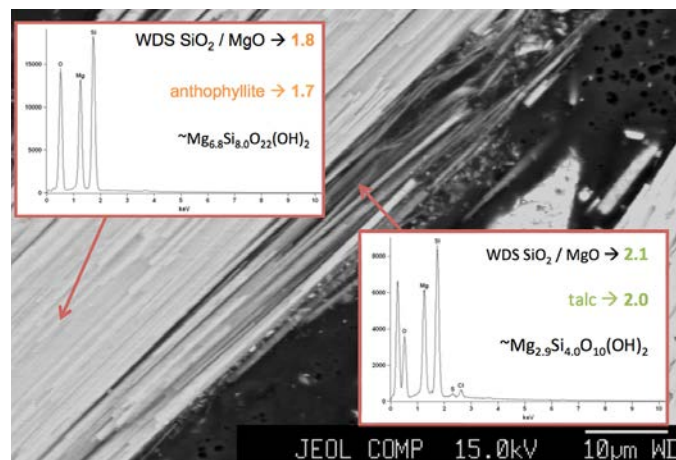


Figure 10. BSE images and associated EDS spectra from the Gouverneur talc mining district showing the alteration of non-asbestiform anthophyllite to asbestiform talc. (Modified from McNamee and Gunter, 2014.)

McNamee and Gunter (2014) provide full quantitative data for the particles shown in Figure 10, but herein we show the associated EDS spectra for each, and the similar peak ratios of Mg and Si, even for these polished thin sections. The inset in Figure 10 are the chemical formulas for each mineral which are stoichiometrically correct as well as the MgO/SiO₂ ratios obtained by WDS.

The above illustrated discussion of our analytical work from this former talc mining district is described in much more detail in McNamee and Gunter (2013, 2014) and McNamee et al. (2015). Our most recent article also explains, at the atomic scale how asbestiform talc forms from non-asbestiform anthophyllite. Basically (001) layers of talc form on the {210} planes of the anthophyllite; thus, the talc layers are in four different orientations combining at the atomic scale into asbestiform fibers.

Example of ultramafic hosted talc

In Vermont there is a near north-south band of talc-producing rocks in the approximate middle of the state. These talc ores are part of an ophiolite sequence occurring in New England (Doolan, 1996). Briefly peridotites were sutured onto eastern North America then during uplift they underwent serpentinization. Locally some of these serpentinized peridotites underwent steatitization (i.e., turned into nearly monomineralic talc bodies) by mineralized fluids moving mostly along fault boundaries. Details of the local geology and various Vermont talc deposits are provided by Chidester et al. (1951), Chidester (1962), and by Van Gosen et al. (2004).

These ultramafic hosted talc deposits are also referred to as blackwall talc deposits in reference to one of the rock types associated with the talc ore. The blackwall rocks form a boundary between the talc and the country rock; it is also worth noting that there is often unsteatitized serpentinite in the core of the talc ore. Simply one could think of deposits as ellipsoidal in shape with three pseudo-concentric zones: serpentinite in the interior, followed by talc with a rind of blackwall all included in the surrounding country rock. Robinson et al. (2006) discuss this type of talc deposit and the minerals associated

with the differing rocks types. Figure 11 is a photo of four rocks collected from this type of deposit showing distinct differences in color. Figure 12 is a series of powder X-ray diffraction (XRD) patterns yielding similar minerals for each sample as those found by Robinson et al. (2006).



Figure 11. Four rock samples collected from an ultramafic-hosted talc body in Vermont.

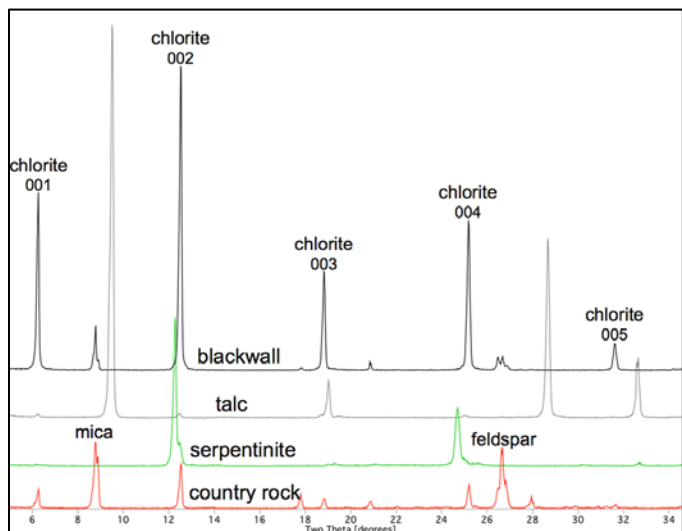


Figure 12. Powder XRD patterns of the four samples shown in Figure 11, with peaks of major phases labeled.

Even though Van Gosen et al. (2004) note the lack of amphiboles in Vermont-style talc deposits, some clarification of his section on "Vermont talc" is needed in regard to both amphibole and asbestos content of Vermont talc. Phillips and Hess (1936) describe in more detail how these small bodies of serpentinite form, and the associated minerals occurring with them, as does Sanford (1982). In both cases, they discuss associated minerals that can form in different zones of the altering serpentinite, and note that at higher temperatures amphiboles can form in the blackwall.

Chrysotile deposits also occur in some of the partially altered peridotite bodies in Vermont, and the proximity of these deposits to the talc deposits have been used in litigation to argue that the talc deposits must also contain chrysotile. From a mining perspective it would be nice if proximity to an economically important ore body was all it took to extend the ore body! However, in these areas the two different ore deposits occur under different geological conditions. O'Hanley (1987 and 1988) notes chrysotile formation is rare in serpentinite rocks. He points out that for smaller serpentinite bodies, like those that form the mineable talc ore, a complete alteration of peridotite has occurred, while for larger serpentinite bodies, like those of the chrysotile mine, not all of the peridotite altered to serpentinite. This is important because the mechanical properties of these two rock types differ, with the latter

breaking in such a way as fractures can occur and allow for chrysotile formation. Chidester et al. (1951) also point out that the talc deposits in this region form from totally serpentinitized ultramafic rocks, while the chrysotile deposits occur in partially serpentinitized ones.

In the spring of 2010 MEG was approached by attorneys representing companies that had obtained talc from a talc mine near Johnson, Vermont (i.e., an ultramafic hosted talc). There were allegations that talc products from this mine contained asbestos. Unlike at Gouverneur we at first had no samples from this deposit; thus, our initial work to determine if the deposit contained asbestos involved a review of the published literature on the deposit and gaining an understanding of its geological formation. As noted above McCarthy et al. (2006) would classify this type of deposit as Type 1, and they did not list any potential asbestos minerals occurring in this type of deposit. Van Gosen et al. (2004) reached a similar conclusion on the talc ore procured from these types of deposits. Chidester (1962) analyzed talc ore samples from this deposit and Chidester et al. (1964) analyzed talc products; the conclusion reached was this was some of the purest talc known. McCrone (1977) and Boundy et al. (1979) used a combination of PLM, TEM, and powder XRD and found no asbestos in any Vermont talc, including talc from the Johnson mine.

During the course of our work on issues surrounding the former mine we were very interested in obtaining samples from the deposit to characterize them ourselves. Obtaining such samples may also help to shed light on how non-asbestos minerals at the mine may have been misidentified as asbestos. Figure 13 shows powder XRD patterns of two products from the Johnson mine. Note the lack of the peaks for amphiboles, which have not been reported in products from this mine or any other in Vermont (Boundy et al., 1979; McCrone, 1977). As expected these samples are nearly monomineralic talc with small amounts of chlorite. Because of similar structures, the 001 peak for serpentine groups minerals occurs near the 002 peak for chlorite; however, in these samples no serpentine group minerals were detected by powder XRD.

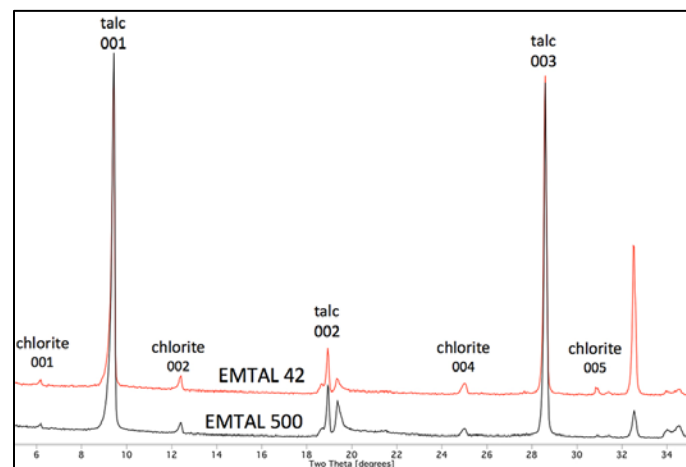


Figure 13. Powder XRD patterns of two products produced from the former talc mine near Johnson, Vermont.

Figure 14 shows four PLM images from a talc ore sample obtained from the mine. Note there are both platy and elongate particles. Thus if one were to rely simply on a 3:1 counting criteria, many of these particles would be termed as fibers. Take for example the particle in the center of the field of view, note in both Figures 14a and 14b it is tilted at 45° angle. However in Figure 14c it is brought parallel to the lower polarizer and nearly disappears because in this orientation the liquid and grain's refractive indices are near-equal, whereas in Figure 14d the particle has been rotated 90° and clearly stands out as in this orientation its refractive index value differs significantly from the liquid. Thus this elongate talc particle would have been counted as a fiber if seen in air with a PCM, and in turn could have been presupposed to be asbestos.

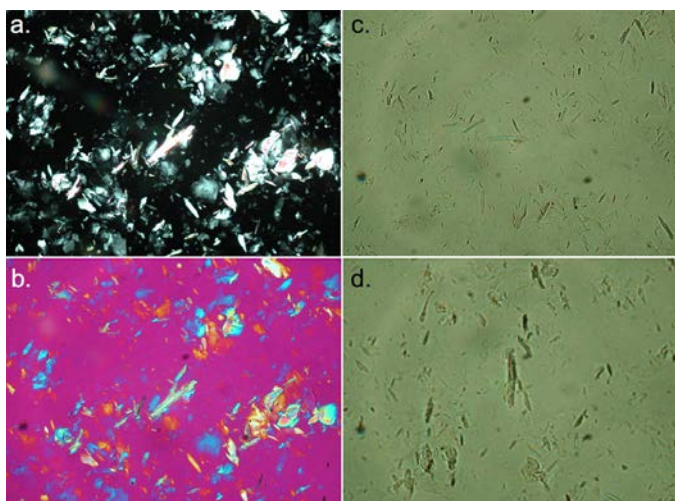


Figure 14. Four PLM images of talc obtained from a talc ore sample from the former talc mine near Johnson, Vermont in a near-index matching fluid for talc: (a.) cross-polarized light, (b.) cross-polarized light with full-wave plate inserted, and (c. & d.) plane polarized light. Note image (c.) has been rotated approximately 45° clockwise and (d.) 45° counterclockwise from (a. & b.). (Field of view about 500 microns.)

Moving from the PLM to the higher magnification of a TEM, Figure 15 shows an image of a platy talc particle – the most common morphology of talc (Figure 15a) as well as its associated EDS spectra (Figure 15b), and its electron diffraction pattern (Figure 15c). The diffraction pattern is a [001] zone axis producing a pseudo-hexagonal diffraction pattern. Figure 16 shows a less common morphology for talc – in this case an elongate particle which would most certainly meet the counting criteria to be considered a fiber. Regardless, note how both particles have similar EDS spectra as well as similar, well-formed, pseudo-hexagonal diffraction patterns.

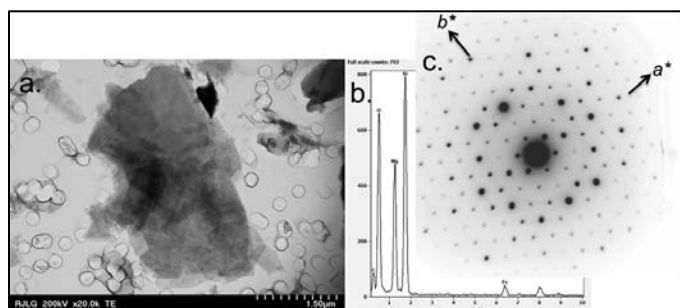


Figure 15. A TEM image (a.), associated EDS spectra (b.), and electron diffraction pattern (c.) of a platy talc from the former talc mine near Johnson, Vermont.

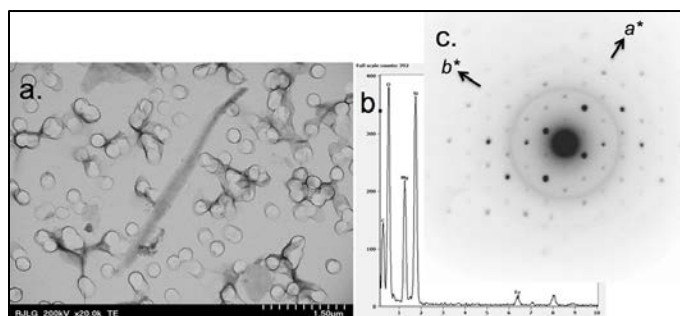


Figure 16. A TEM image (a.), associated EDS spectra (b.), and (c.) electron diffraction pattern of a talc fiber from the former talc mine near Johnson, Vermont.

In Figure 17 both dark- and bright-field TEM images (Figure 17a and 17b, respectively) of two talc particles of differing morphology –

one platy and the other appearing fibrous - are shown along with their associated EDS spectra and diffraction patterns. While the EDS spectra are similar for these two particles, the diffraction patterns differ; the platy talc shows well-defined spots, while the fibrous one shows one-dimensional streaking which is also seen in chrysotile (Millette, 2006).

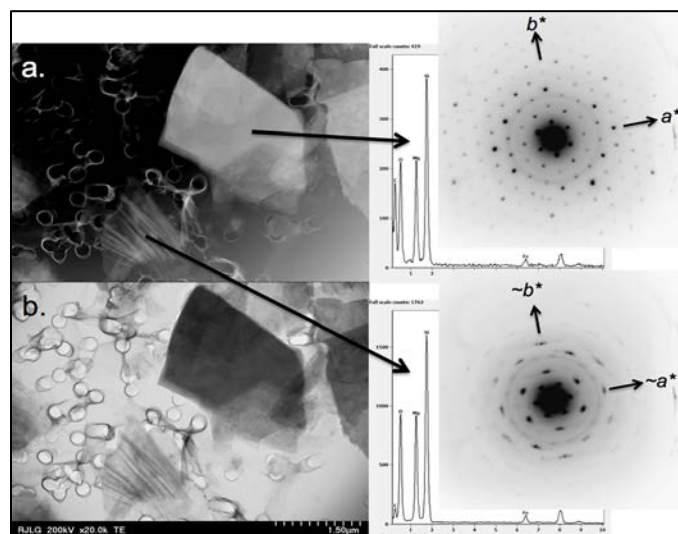


Figure 17. Dark-field (a.) and bright-field (b.) images of talc particles showing two different morphologies. Note arrows point to their associated EDS spectra and electron diffraction patterns.

Figure 18 shows one other feature we observed in these talc particles, which others have also been observed – so-called “talc-scrolls.” The upper left image and its associated EDS spectra and diffraction patterns look similar to the other platy talcs shown herein; however, notice the electron diffraction pattern obtained from the scrolled area again shows a one-dimensional streaking, and a similar EDS spectra to the non-scrolled area. Lastly notice that in the higher magnification image on the lower left that there even appears a “hollow-tube,” again another earmark of a chrysotile fiber. Thus it would seem possible for an analyst to confuse a scrolled talc particle with chrysotile unless they had corresponding compositional data that would help to differentiate the two.

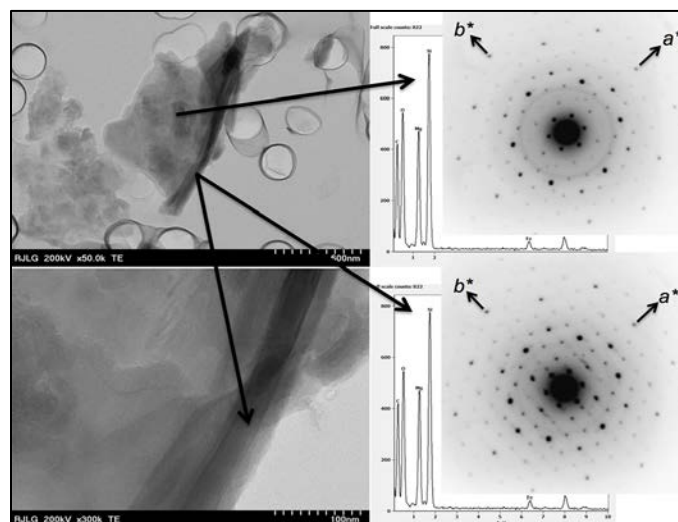


Figure 18. TEM images at differing magnifications of a talc particle showing scrolling on its right side, with associated EDS spectra and electron diffraction patterns.

Recall chlorite occurred in these samples as evidenced by the powder XRD (Figure 13). And even though it was not observed in powder XRD, it would come as no surprise to find small amounts of

antigorite in these samples based on how they formed. However, it might be difficult to distinguish between these two minerals and talc with diffraction data alone. This problem arises for two reasons: 1) all three of these mineral are sheet silicates, thus they will preferentially come to rest on a TEM grid to produce [001] zone axis patterns and 2) the [001] zone axis diffraction for these three minerals are very similar. To strengthen this last point Figure 19 gives the cell parameters for talc, antigorite, and chlorite as well as a calculated [001] zone axis diffraction pattern for each. Because of the similarity in the a and b repeats, and the fact all three have the same diffraction constraints, their diffraction patterns are nearly identical. Thus to differentiate between these three minerals in the TEM, EDS spectra would be required.

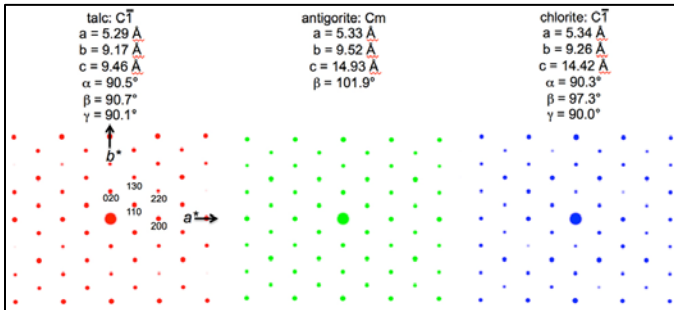


Figure 19. Cell parameters and calculated [001] zone axis electron diffraction patterns for talc, antigorite, and chlorite. In the talc pattern the directions of a^* and b^* are indicated and a few spots indexed; this labeling is the same for antigorite and chlorite.

Figure 19a shows a TEM image of a platy antigorite and talc particle. In the image the yellow arrows point the Mg peak in the EDS spectra for each. Note the Mg peak is higher than the Si peak for antigorite while the reverse is true for talc. Recall antigorite has a Mg/Si ratio of 3/2 while talc is 3/4 which explains the difference in the peak heights between the two. Lastly Figure 20b shows a TEM image of chlorite and its associate EDS spectra. The main criterion to distinguish chlorite from talc is the presences of an Al peak for chlorite in the EDS spectra.

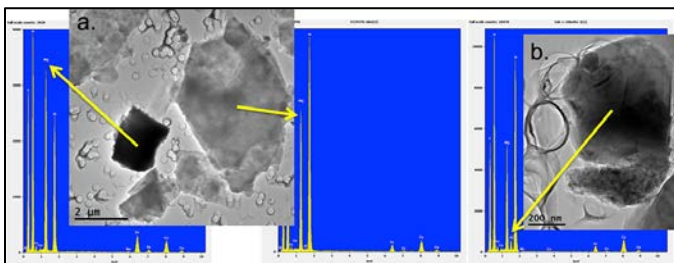


Figure 20. TEM images and EDS spectra for: (a.) platy antigorite and talc and (b.) chlorite. Note in (a.) the arrows point to the Mg peak, while in (b.) to the Al peak.

FINAL THOUGHTS

With recent increases in civil litigation the talc industry faces some challenges. One of the main challenges deals with publications (for example Rohl et al., 1976) and industry documents from the 1970s and 1980. During this period of time (i.e., before 1992) there was often no clear distinction made between a countable fiber and asbestos (Gunter, 2010). Thus, a 3:1 amphibole particle, even a cleavage fragment, would be considered amphibole asbestos. Also, talc particles themselves were counted as fibers in PCM, and often deemed to be asbestos fibers, especially in industry documents.

As a more detailed example of a publication in this time period, Cralley et al. (1968) defines a fiber as "A fiber is defined as a particulate having at least a 1:3 ratio of diameter to length." Also in this paper they state they never actually identified the minerals in the talc products: "Although the specific fibrous materials were not identified, they were predominantly fibrous talc, as shown by x-ray diffraction,

with the probable presence in minor amounts of other fibrous minerals such as tremolite, anthophyllite, chrysotile, and pyrophyllite." Yet this paper is often used in litigation as evidence that asbestos occurs in talc.

In conclusion even today there are still on-going discussions of how best to determine if talc contains asbestos (for example see Millette (2015) and references therein). There are also industry and regulatory groups working on methods to be used to certify talcs are asbestos free.

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DISCLOSURE

M.E. Gunter is currently working with past and current producers of talc, and has served as an expert witness for their defense; however, no funds or input from any source was directly used for the preparation of this manuscript.

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