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Dear Greg,

I have enclosed xerographic copies of all the organized work I could find that was not directly involved with compliance actions. Of course, the color photos don't give you a great deal of information in black and white. The captions underneath them will in some cases give some interesting insight. Probably the most interesting features are demonstrated by the high resolution electron micrographs. These show typical industrial talcs and anthophyllite. Anthophyllite shows major regularity and fairly constant double chain structure typical of amphiboles. The fibers seen in the industrial talc show a great disorder. The only major regularity is the 9 angstrom repeat from partial 1-tuple unit to the next. It is probably here in this feature that the discrepancies found in other analyses are born. It is only by a combined optical/electron optical approach can the nature of the intermediate fibers be determined. Even at that, they defy definite description.

In general, the Vanderbilt products that we have examined contain the minerals stated in the MSDS's. The controversy emerges when mineralogical definitions are or are not applied to the particles resulting after the material has been crushed to the final material. Asbestos as a mineralogical term applies to fibers of a mineral which grew naturally that way. As a legal term it has come to mean any particle which is three time longer than it is wide. This rule applies equally to chrysotile and dimension lumber. The minerals present in industrial talcs especially tremolite and anthophyllite as they currently are found are not mineralogically fibrous for the most part. They are not "asbestos" mineralogically speaking. These minerals are members of a group of similar minerals called the amphibole family. Amphiboles as well as other minerals tend not to occur in the same habit (crystal growth pattern) all of the time. That is, sometimes a mineral will be a fiber, sometimes it will be acicular, sometimes tabular sometimes massive; depending on where and under what conditions the mineral crystallized. It is in every case still essentially the same mineral. Sometimes, different names have been given to the various habits. (e.g. riebeckite = massive and crocidolite = fibrous varieties of the same mineral). For some minerals the same name applies regardless the habit. Specifically, this is the case for three of the minerals covered under the OSHA asbestos standard: tremolite, actinolite and anthophyllite.

Materials tend to break along the directions of least resistance to parting. In the amphiboles, there is a direction along which there is very little resistance to parting compared with other directions in the crystal. This direction happens to be parallel to the direction of growth in the asbestos varieties of the same mineral. When crushed, easy parting leads to particles of mineral which are elongated. In phase contrast microscopy, for particles less than about 1 micrometer in diameter, a differentiation whether or not an individual particle is mineralogically asbestos is not possible in general. The morphology for most larger particles is usually sufficiently distinct that a determination can be made. These particles are much more blunt, lacking the "bundle of sticks" effect, lacking splintered ends etc. In large ensembles of particles from asbestos vs non-asbestos forms it is possible to derive differences in the average aspect ratio or in the direction of repose in zero degree selected area diffraction patterns. It is not wise to consistently apply these tests on individual fibers.

The above discussion applies to the tremolite and anthophyllite that is present in the products. Please do not get lost in the technical nature of that discussion. It tends to obscure some really startling observations. When one looks at the industrial talcs in the microscope, he sees large numbers of particles that are much longer than 20 to 1 even to nearly 100 to 1 in aspect ratio. The first reaction is to say these are the asbestos fibers of tremolite and anthophyllite indicated by the known presence of those minerals in the products. Unfortunately, this is a false assumption. They are for the most part fibers of industrial talc. They have been dubbed intermediates by us, as talcboles by Malcom Ross and fibrous biopyriboles by David Veblen. What they are not is anthophyllite or tremolite.

Polarized light microscopy has shown these fibers to have indices of refraction in the range for talc (dispersion staining). They have been shown to have an average maximum angle of extinction of approximately 11 degrees compared with 0 degrees for anthophyllite and 17-22 degrees for tremolite. More surprising still are some fibers that on one end have dispersion colors for anthophyllite and on the other end colors consistent with talc. Light microscopy tends to eliminate these fibers as one of the minerals covered by the OSHA standard. Compare this with what we find for electron microscopy.

Standard analysis of these materials by electron microscopy shows that the same fibers we called non-anthophyllite by light microscopy should be called anthophyllite. Semi-quantitative chemistry and selected area diffraction based on layer-line measurement or rough indexing matches anthophyllite. The fibers seen do show splintering, do show elongated aspect ratio. By electron microscopy alone, it should be concluded that the fibers are indeed anthophyllite. There is an error of logic here.

It is usually assumed that all there is present are the minerals stated in the MSDS or by private x-ray diffraction. The fault can be corrected when the analyst realizes that in this particular mineral, the deposit was anthophyllite at one time. Nature has begun transforming this deposit to the mineral talc. The particular mechanics of this are beyond the scope of this letter. Suffice it to say that it is being done in such a way as to leave the more major structure of the anthophyllite fibers intact while transforming them to talc. This residual structure has given rise to electron diffraction patterns that mimic amphibole patterns. Very careful measurement and calibration of these patterns reveal subtle strains in the structure leading to a mineral with similar features to talc and to anthophyllite and yet the numbers fall in between. Energy dispersive analysis by X-rays (EDX) shows a similar result. Both talc and anthophyllite have a magnesium silicate structure. Anthophyllite has 7 magnesium or magnesium replacing atoms for every 8 silicon or silicon replacing atoms. For talc the ratio is 6 Mg to 8 Si when appropriately normalized. This is a very small difference to try to quantify. Most laboratories don't try. We looked at an ensemble of known anthophyllite fibers and an ensemble of known talc particles. From the data thus obtained, we were able to show that the fibers found in the Vanderbilt talcs we looked at were mostly in the range between talc and anthophyllite. As a side note, there was insufficient calcium found in any of the very fibrous particles to allow the tentative identification of tremolite such as has been offered by some groups. We found an average of approximately 0.2 atomic units per 8 silicon atoms. This is lower than the 1.34 atoms required by the definitions accepted by the American Mineralogical Society.

In order to elucidate the structure, we then began to look at fibers of the material with High resolution electron microscopy. I have included with this letter some copies of representative photographs. The truth of the intermediate nature for these fibers is immediately apparent. The photos of the standard anthophyllite fibers show a mostly regular pattern of "double-chain" repeats. (The small spots are believed to be silicon atom positions in these photos). The double chain consists of one bright line with one lesser line. Please study these photos in comparison to those provided for the industrial talc fibers. Note that there is a great irregularity to these patterns. There are some areas where an amphibole pattern is observed. There are areas where a broader expanse of single chains occur and other places where there are n-tuple chains. There is no long range order here. Note however, that the long chains are all about 9 angstroms apart regardless whether they are part of a double chain, single or a multiple construct.

I have described these other fibers because they are the fibers with the closest morphological similarity to asbestos. They do have splintering and bundle of sticks and frayed ends as characteristics. These are characteristics which we often ascribe to truly asbestiform minerals. All the samples we have examined have been crushed prior to our receiving them. Therefore, we cannot say whether they grew in nature as asbestos fibers. They do look like asbestos and if morphology is the major role in toxicity or carcinogenicity these should be considered more important that the non-fibrous cleavage fragments of tremolite or anthophyllite. My purpose is not to discuss epidemiology but rather give a short explanation of some of the conclusions we have come to from years of studying the mineralogy and microscopical properties of Vanderbilt fibers. I conclude by stating simply that all the products we have investigated have shown elongated cleavage fragments of tremolite and anthophyllite having aspect ratios in excess of 3:1. We have found, in addition, a class of fiber present in the products which is intermediate in nature between talc and anthophyllite. In investigating these we have seen on occasion a fiber that would be called anthophyllite. Notwithstanding this, the bulk of truly fibrous particles fall into this intermediate class.

There is much more that could be said about what we have found but this letter should cover the major points. Should you have any questions or wish to discuss it further, I am at your service.

Sincerely,

11-26-84

Daniel T. Crane
Supervisory Physical Scientist
Microscopy Branch

cc Amanda Edens (OSHA)