DETECTION AND QUANTIFICATION OF ASBESTOS AND OTHER TRACE MINERALS IN POWDERED INDUSTRIAL-MINERAL SAMPLES

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Abstract

In 1983, a final ruling of the U.S. Occupational Health and Safety Administration (OSHA) specified that chemicals containing >0.1% of a carcinogenic substance or >1% of a substance hazardous to health must be labelled. Amphiboles of the fibrous or asbestos-type must be quantified at levels of 0.1% whereas the status of non-fibrous types is not finally determined at this time. Tremolite and actinolite can possibly be measured to 0.1% by XRD, but anthophyllite cannot be so measured. Recently the International Agency for Cancer Research (IARC) has designated quartz as a suspected carcinogen, and its quantity must be measured to the 0.1% level. Thus, it has become increasingly important to be able to detect and quantify minerals in bulk samples down to low or "trace" levels. It has been found that minerals needing to be quantified can often be concentrated by microcentrifuge and counted by means of polarized-light microscopy. For example, amphiboles in talc samples can be separated by using a heavy liquid (thallium formate-malonate) of density 2.810. Talc floats, and amphiboles sink. After centrifuging, the denser particles are removed from the bottom with a Pasteur pipette and placed in a clean centrifuge tube. Distilled water is added to the tube containing the denser minerals and the tube centrifuged again. After several washings with distilled water, the sample is removed along with a drop of water to a clean glass slide. A drop of 1.584 refractive index liquid and a cover glass are placed over the dried sample. The slide is scanned for particles greater than 5 μm in length and having an aspect ratio greater than 1:3. These are checked for refractive index, sign of elongation and extinction angle to differentiate them from talc particles on edge and other minerals. Amphiboles have all indices greater than 1.584, and talc has all indices equal to or lower than this value. Alternately the heavies at the bottom of the centrifuge tube can be filtered through a nucleopore filter. After the filter has been washed with distilled water and dried, a 1.584 refractive index liquid renders the filter transparent in two of the four extinction positions so that a count of amphibole particles can be made directly on the filter. The refractive index-density method which is so useful for talc powders should be equally useful for other nonsoluble industrial minerals.

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Introduction

By the late 60's and early 70's the health community became firmly convinced of the danger of asbestos to workers involved in mining and manufacturing, and the United States government agencies moved to regulate this substance in the workplace. The airborne fiber limit was first set at 5 fibers/cm^3 in 1972, then at 2 fibers/cm^3 in 1976, and finally to 0.2 fibers/cm^3 in 1986 (1). In addition, bulk minerals and chemicals were subject to a "Hazard Communication" regulation, which specified that a substance must be labeled if it contains >1% of a chemical hazardous to health or >0.1% of a carcinogenic substance (2).

Asbestos, tremolite, actinolite and anthophyllite are regulated at 0.1% according to the 1986 OSHA regulation. This has proven to be a problem in industrial minerals, such as talc, because this limit is below present detection levels by X-ray diffraction. It may be possible with very time-consuming step-scans to detect tremolite to this level, but this is not possible with anthophyllite. In addition, tremolite, actinolite and anthophyllite occur in fibrous and non-fibrous forms, and X-ray diffraction does not distinguish between these forms. At the time of this writing there is a court stay on the part of the Final Rule of 1986 covering non-fibrous tremolite, actinolite and anthophyllite (3).

In addition in 1987, the International Agency for Research on Cancer (IARC) determined silica (quartz, tridymite and cristobalite) to be a suspected human carcinogen (4). This automatically triggered the provisions of the 1983 Hazard Communication, and all industrial minerals containing >0.1% of free silica must be labeled as containing a carcinogenic substance.

From this brief outline, the increasing importance of detection and measurement of minerals at trace levels is apparent. The writer considers these to be "trace minerals" as they are analogous to "trace elements." Under present government regulations, several hundred or less particles are counted in a million particles. A method to do this has been developed and is presented here. It consists of standard techniques of optical and X-ray analysis in combination with heavy liquid separations.

Whereas an individual mineral species has variable density because of chemical substitutions, it is often possible to find a density which will effectively separate minerals of interest. Fig. 1 shows that talc has a distinctly different density from the amphibole minerals of concern. The major part of our effort has been devoted to experimentation with talc containing amphibole. This paper will discuss experimentation with talc and amphibole mixtures although the method is applicable to other powdered industrial minerals.

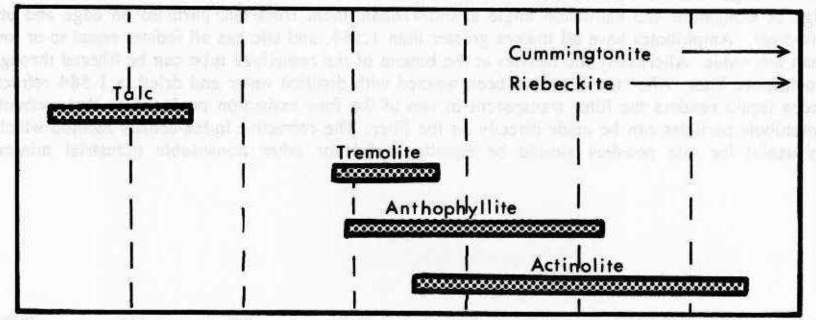

Figure 1 - Chart showing range of density for talc and amphibole minerals (10).

Description of Analytical Methods for Talc-Amphibole

Detection of amphiboles in powdered talcs is very difficult. Attempts were made to measure tremolite to 0.1% by using X-ray step diffraction scans with long counting times on each step. Since very low counts are obtained and since the intensity of the X-ray diffraction peak is dependent upon slight changes of chemistry due to substitutions of elements in the mineral structure and to the fibrous or nonfibrous condition of the mineral (5), this method was found to be unsatisfactory. For anthophyllite, the major peaks have such low X-ray intensities that the method was not attempted. The only viable method of analysis has been an optical particle count such as that proposed in 1973 by the Food and Drug Administration (6). Although the original method proposed analyzing an entire 1 mg sample, most users of the method scan 100 fields of view (f.o.v.). The procedure is stated below:

> "Weigh out 1 milligram of a representative portion of talc on each of two microscope slides. Mix the talc with a needle on one slide with a drop of 1.574 refractive index liquid, and then the other with 1.590 liquid, and place on each a square or rectangular cover glass sufficiently large so that the liquid will not run out from the edge (ca. 18 mm square) and will provide a uniform particle distribution. Fibers counted by this method should meet the following criteria: (i) Length to width ratio of 3 or greater (ii) length of 5 μm or greater (iii) width of 5 μm or less. Count and record the number of asbestos fibers found in each 1 milligram as determined from a scan of both slides with a polarizing microscope at a magnification of approximately 400X. In the 1.574 refractive index liquid, chrysotile fibers with indices less than 1.574 in both extinction positions may be present; in the 1.590 refractive index liquid, the other five amphibole types of asbestos fibers with indices exceeding 1.590 in both extinction positions may be present. Check the extinction and sign of elongation for tentative identification. For specific identification of asbestos fibers, make additional mounts in appropiate refractive index liquids, and refer to the optical crystallographic data in the table. A count of not more than 1000 amphibole types of asbestos and not more than 100 chrysotile asbestos fibers per milligram-slide constitutes the maximum limit for the presence of these asbestos fibers in talc. These limits assure a purity of talc at least 99.9 percent free of amphibole types of asbestos fibers and at least 99.99 percent free of chrysotile asbestos fibers."

A major difficulty with this method is that very many talc flakes are on edge or at such an great angle that the edge of the flake is seen. These particles then show an aspect ratio greater than 3:1 and must be tested for refractive index by checking the Becke line often in both extinction positions. The procedure is very time-consuming for 100 f.o.v. Using a standard petrographic cover glass there are generally about 10000 f.o.v. per immersion mount (1 mg of sample). Thus to be sure that less than 0.1% amphibole was present the count needed to be 5 particles or less (5 plus two standard deviations = 9.47) in 100 f.o.v.

Several investigators have pointed out the utility of using density along with other optical properties for identification of unknown minerals using the polarizing microscope (7, 8, 9, 10) Their approach is to observe the sink or float characteristics of particles in immersion liquids under the microscope. The approach used in this study was to separate the particles of interest using heavy liquids and a microcentrifuge.

Selection of Heavy Liquid and Density

Many heavy liquids are available to the mineralogist. Whereas there is some risk associated with such substances (11, 12, 13, 14), with proper care they can be handled safely. An advantage of the method used here is that only small quantities of the liquid are used. An important consideration in selecting the heavy liquid used in this investigation was the desire to be able to remove the liquid from the particles by washing with distilled water. Clerici solution (thallium formate-malonate) and Klein's solution (cadmium borotungstate) diluted with water were selected. Both proved satisfactory but Clerici solution is less expensive.

To determine mineral densities, talc and amphiboles were obtained from all the major talc producing regions of the United States and tested. The lowest density at which talc floated was determined by slowly increasing the density of Clerici solution by adding, drop-by-drop, more dense liquid to a less dense liquid which contained talc. At the point at which the talc floated, the index of refraction of the liquid was determined using an Abbe Refractometer. The density was determined using a density-refractive index chart (15) (Fig.2). A similar procedure was followed for amphiboles except that the proper density for the amphibole to sink was determined. These tests indicated that the best density for a heavy liquid to separate talc from amphibole was 2.810.

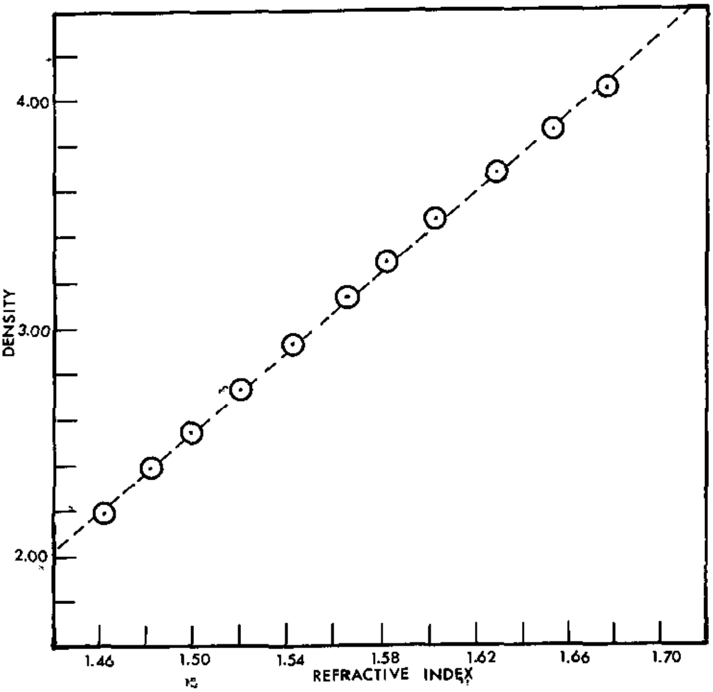

Figure 2 - Density-refractive index graph for Clerici solution at 23° C (15).

To avoid having to continuously use the refractometer to adjust the density, commercially produced density standards adjusted to 2.800, 2.810 and 2.820 were purchased. The liquid could then be conveniently adjusted to 2.810. The adjustment is easier if "stock solutions" are made up, one with slightly higher density and one with slightly lower density. Using such solutions eliminates the rapid change of density that occurs with the addition of a single drop of distilled water or very heavy liquid. It is important that the solution is well mixed after each addition of more or less dense liquid. If not well mixed, density stratification occurs.

Selection of Centrifuge

Once the proper density heavy liquid has been selected, the mineral particles are separated by means of a centrifuge. Several points need to be considered when selecting a centrifuge. These are: (1) In order to separate very small particles in liquids which differ from them only slightly in density, it is important for the particles to move through a short column of liquid or the centrifuge time will be impractically long. A microcentrifuge with 1.5 ml tubes was, therefore, selected. (2) The centrifuge must have a variable speed setting on the spin. The reason for this requirement is that microcentrifuges are designed to handle low-density liquids (<1.2 g/ml). Heavy liquids at high spin speeds exert forces which are great enough to break the centrifuge tubes and tube holders which causes major damage. When using a variable speed centrifuge it is important not to run the machine at top speed while using heavy liquids. The maximum safe speed can be determined using the following approximation (16):

$$RPM_{max} = \text{rated rpm}^{*} \sqrt{1.2/D}$$

*information supplied with centrifuge and dependent
upon tube type and capacity

D is density of heavy liquid

For the present work:

$$RPM_{max} = 13{,}250^{**} \sqrt{1.2/2.810}$$

$$= 8{,}659$$

** 1.5 ml polypropylene tube

Sample Preparation

60 to 100 mg of talc are weighed into a disposable centrifuge tube. About 1.2 ml of heavy liquid adjusted to 2.810 is added, and the sample with liquid is mixed by shaking. The tube is then placed in a bell jar which is evacuated with a vacuum pump for three minutes. This removes air bubbles adhering to the particles. The charged tubes are placed in a centrifuge and spun for 8 minutes at a speed of 7000 rpm.

The amphiboles should sink leaving the talc floating, so that the particles that have sunk are of interest. The liquid and particles lying at the bottom are removed with a micropipette and transferred to a syringe. The syringe is attached to a filter holder, and the liquid with heavies is filtered using a Nuclepore filter (pore size 1.0 μm) which is held in a plastic filter holder. About 40-50 ml of distilled water is washed through the filter to remove the heavy liquid. The filter (plus residue) is then carefully transferred to a clean glass slide with a tweezers and permitted to dry.

The amphiboles can be examined without removing them from the filter because the Nucleopore filter has an index of refraction of 1.584 in two of the four extinction positions. This is the proper index of refraction to distinguish between talc and amhiboles. Talc has indices less than or equal to 1.584, whereas amphiboles have indices greater than this value. A drop of 1.584 refractive index liquid renders the Nuclepore filter transparent when scanned in the matching extinction position. The fields are scanned for particles having an aspect ratio $>3:1$. These can then be checked for sign of elongation and relative index of refraction in the usual way. The determination of extinction position is slightly different when looking at particles on an anisotropic filter. Since the filter is anisotropic it will change colors on rotation. The extinction positon of a particle is the angle at which it matches the color of the filter. Occasionally a particle will appear dark or the same color at all rotations. This simply indicates that the extinction position of the particle and the filter are the same.

Two comments should be made. First, it is easier to do an optical count if the carbonate minerals are removed from the talc by acid treatment before analysis. Calcite will float in 2.810 liquid but magnesite and dolomite will sink. Second, the heavy liquids that are left in the centrifuge tubes can be reused by filtering them through a filter with 0.4 μm pores using a syringe and plastic filter holder as used before. Also heavy liquids if left standing for a period of time crystallize and get cloudy. The crystals can be removed in the same way as the heavy minerals.

Analytical Results

To determine the level of amphibole contamination of a sample the efficiency of the spin-down for the amphibole particles and the number of talc particles in our sample must be known. Before examining results from *actual processed talc samples, these two factors are considered.*

Efficiency of Spin-down

In order to determine the percentage of total amphibole that would be brought down during a single centrifuge run, talc-dolomite samples were analyzed. Dolomite has a density of 2.86 which is comparable to that of the amphiboles (see Fig. 1). Mixtures of talc plus dolomite at various percentage concentrations could be spun down, tranferred to a filter as previously described and the filter plus sample weighed. After putting the filter (plus sample) back in the holder and washing with acid followed by distilled water, the sample plus filter is reweighed. The weight difference indicates the amount of dolomite brought down. Fig. 3 shows the results of these analyses. The bottom line on the graph shows the values obtained when a micropipette *removing 0.15 ml was used and the top when 0.6 ml* was removed. The top line shows more scatter in the data, so most of the results reported in this paper are obtained with a 0.15 ml sample and using an efficiency factor of 14%.

The efficiency results of 14% and 33% show that the proposed method could be improved by finding a better method of removing the sample from the centrifuge tube. Several investigators have used liquid nitrogen to freeze the tube contents partly (17) or completely (18). These methods were not tested: however, it was found to be advantageous in some cases to put the heavies from two tubes *onto a single filter to get a higher fiber count.*

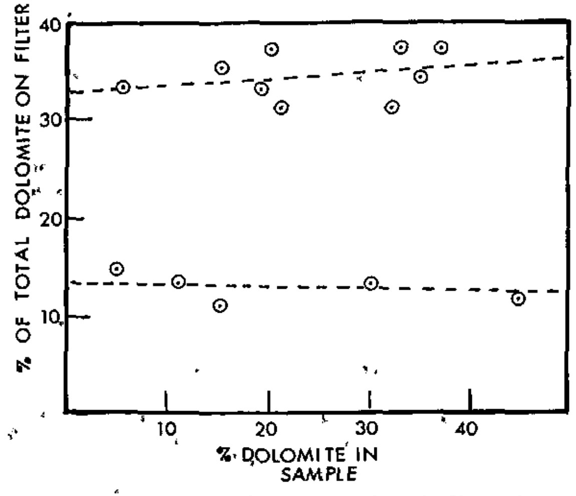

Figure 3- Graph showing the percentage of dolomite caught on the filter under two different experimental conditions. See text for further explanation.

Number of Amphibole Particles in One Milligram

The 1973 Food and Drug Administration's proposed method is based on the assumption that a one milligram sample of talc contains one million particles.

$$1000 \text{ equals } 0.1\%$$

$$1000/.001 = 1 \times 10^6 \text{ particles}$$

A quick calculation using weight and volume shows that one million particles per milligram is probably a conservative estimate. In OSHA's regulations for airborne dusts where limits are in Mppcf (million particles per cubic foot) and in Mg/M^3 (milligrams per cubic meter), the two values when equated show that a one milligram sample is considered to contain from 5 million to 200 million particles depending upon the substance. While one may think of dusts as having very small particles, respirable dust is, for the most part, greater than 5 μm (19). It is different from processed talc, however, in lacking the large particles >10 μm which represent a disproportionally large percentage by weight of processed talcs. Since one million particles per 1 mg sample is considered conservative, percentages of fibrous particles will calculate on the high side rather than the low side, so this value is used.

$$\text{ppmg} = \text{fibrous particles per mg} = \frac{(\text{number of fibers counted})/(\text{number of f.o.v.}) \times 5740 \text{ f.o.v.}^*}{0.14 \times (\text{number of mg of sample})}$$

*number of fields of view needed to cover entire filter

Percent fiber then can be determined:

$$\% \text{ fiber} = (\text{ppmg}/1 \times 10^6) \times 100\%$$

The results in this paper are generally given in ppmg (particles per milligram).

Counts of total talc particles per milligram can be made on the actual sample. This is done by preparing a standard one milligram sample on a glass slide. One drop of distilled water or methanol is added to the powder (not on top but along side), and the liquid and powder mixed with a small spatula. The mixture is smeared evenly over the glass slide and permitted to dry. The slide is left uncovered so that the talc particles stand out in high relief relative to air. Counts are usually done of particles in a part of the field of view using a grid eyepiece to define the area.

Results of counts as just described have shown that processed talcs generally contain 0.9-20 x 10^6 particles/mg in the optical size range. The only exceptions are some baby/body powders with very large particles. These are often very difficult to count because the flakes are very thin and tend to lie on top of or overlap other flakes making it necessary to exercise some judgement as to whether one is observing separate particles or a step on the surface of a single particle. Obviously some particles would be covered completely by others and not seen at all. Values on these talcs are 0.4-0.8 x 10^6 particles/mg.

Analytical Results Obtained with Mixtures

A number of problems were encountered in testing the proposed method. Foremost is the question of whether pure starting material would adequately represent the minerals in actual processed talc samples. In addition is the problem of how to mix samples so that the very small percentage of particles representing the contaminant are randomly distributed in the sample. To avoid these problems, an actual processed talc known to contain amphibole was chosen and a talc without such minerals. The percent amphibole was determined in the former by performing standard 1 mg -100 f.o.v. counts using traditional methods on eight separate preparations. This yielded a value 2.19 ± 0.97%. Mixtures were then prepared by first weighing pure talc powder in the centrifuge tube and then adding a small amount of 2.2% talc. The procedures described in the section "Sample Preparation" then were followed. 20 fields of view were counted. The results are indicated in Table 1. Except for samples *e* and *h*, all are within 2 standard deviations of the actual value. It should be noted that actual unknowns are generally spun-down and analyzed in triplicate, so that any discrepancies can be detected. Discrepancies can be caused by preparation problems such as the gaskets not being tight on the filter holders so that part of the sample escapes. Fortunately this is generally obvious before reaching the counting stage. In this test, the samples were not run in triplicate because of the difficulty of mixing a sample to put into three centrifuge tubes. If differences had been found during such an experiment it would have been more likely due to mixing problems than to counting procedures.

Table 1. Mixtures of talc contain 2.2% tremolite with pure talc.

No.	actual	measured (σ)	
a	0.06 %	0.04 %	(0.01)
b	0.06	0.04	(0.01)
c	0.07	0.05	(0.01)
d	0.15	0.18	(0.04)
e	0.15	0.07	(0.02)
f	0.24	0.20	(0.04)
g	0.37	0.30	(0.05)
h	0.47	0.34	(0.06)
i	0.73	0.70	(0.10)
j	0.74	0.94	(0.16)
k	1.03	0.86	(0.09)

Actual Commercial Talc Samples

A sample of commercial talc known to contain very small quantities of amphibole was tested with the traditional 1 mg-100 f.o.v. technique and the centrifuge technique. Ten 100 f.o.v. counts on separately prepared mounts were counted. The results indicated 259 ppmg (range for 95% confidence is 0-573 ppmg). The results obtained using the centrifuge are shown on Table 2.

The standard deviation for particle counts can be calculated using Poisson's distribution $\sigma = (N)^{0.5}$ (20). The standard deviations listed under the centrifuge method in the Table are calculated in this way. Poisson's distribution is the best that can be achieved if the variation is due to random particle distribution on the slide and there is no other systematic sources of error.

Fig. 4 shows the appearance of a typical amphibole in the talc from which the results shown in Table 2 were obtained. It is made up of fibrils. Note that the photographs in this paper generally show very large particles. This is due simply to the fact that they are easier to photograph and are selectively chosen for this reason.

Another talc known to contain amphibole is shown in Fig. 5. It displays the reason for evaluating talc optically rather than using X-ray diffraction. The volume of the amphibole particles in this talc is much greater than the volume of amphibole in the talc of Fig. 4, and XRD would yield a much larger value even if it contained the same number of amphibole particles as the previous example.

The particles shown in Figures 6-9 are from talcs which, although periodically analyzed by SEM, were not believed to contain amphiboles. Amphibole particle counts are extremely low and generally there is no indication of particles being made up of fibrils. The figures show typical particle shapes for each talc type shown. No amphibole particles were found in the talc shown in Figures 8 and 9 during a count of 20 random fields of view; however, particles were noted during a quick scan

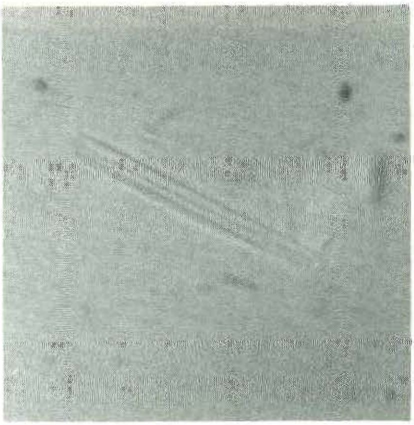

Figure 4 - Amphibole particle (65 μm in length) in talc which measured 259 ppmg (±317).

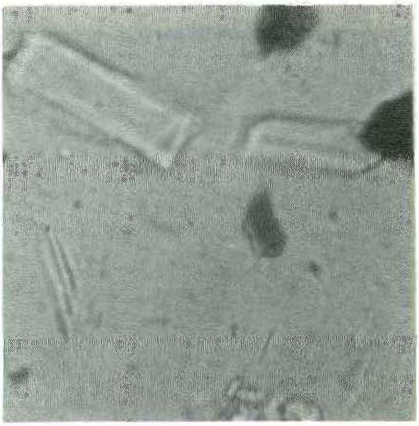

Figure 5 - Tremolite particles (69 μm in length) in talc. This sample measured 833 ppmg (±336).

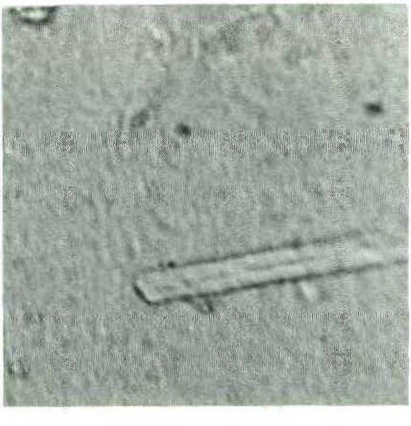

Figure 6 - Amphibole particle (length 63 μm) in talc which measured 88 ppmg (±24).

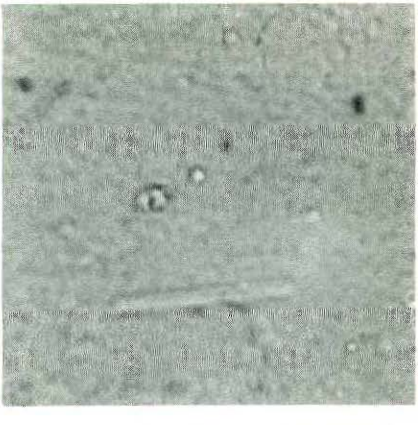

Figure 7 - Amphibole particle (40 μm in length) in talc which measures 25 ppmg (±28).

Figure 8 - This talc showed no amphibole particles during a standard 20 f.o.v. scan. This indicates <25 ppmg. Particles could be found by a quick scan or filter. This one is 22 μm in length.

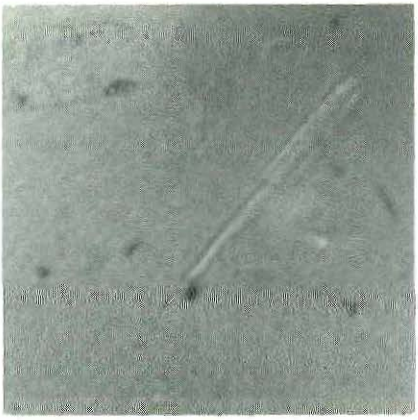

Figure 9 - Similar to the talc shown in Figure 8, no amphibole particles were detected during a routine scan. This indicates < 10 ppmg. The particle shown has a length of 66 μm.

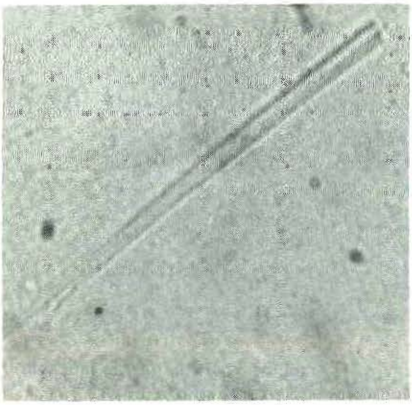

Figure 10 - Amphibole counted on a Nucleopore filter. The count is 102 ppmg (± 102). Length of particle is 133 μm.

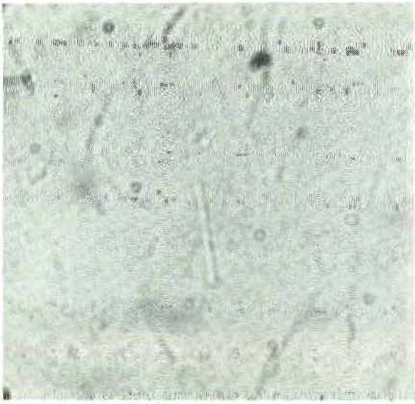

Figure 11 - Same talc as Figure 10. The amphibole is counted on a glass slide without a filter as described in the text. The count is 62 ppmg (± 87). The particle length is 34 μm.

of the slide. These shown in the photographs were found in this way. The lower limit indicated assumes that the smallest number which could be found in 20 f.o.v. is 1. On samples with such low counts one might scan more fields of view, but no purpose was served by doing this in the present case.

Table 2. Comparison of values obtained by traditional 1 mg-100 f.o.v. count with centrifuge method using various sample weights.

(a) Standard 1 mg-100 f.o.v. counts

Sample	fibers/mg
a	216
b	392
c	234
d	351
e	113
f	376
g	94
h	309
i	0
j	505
	---
average	259 ± 157

(b) Centrifuge method (20 f.o.v.)

Sample	Sample size	fibers/mg		σ
P1	47 mg	253		146
P2	115	277		98
P3	59	296		64
PP1	308	275		108
PP2	60	341		108
	60	291	305	98
	60	283		100

Application to Other Problems

The results and photographs presented to this point were obtained with particles collected on a Nuclepore filter (1.0 μm pore size). There may be times, however, when one may wish to separate minerals by density but examine them with refractive index liquid other than 1.584. This can easily be done by modifying the procedure slightly in this way. After the sample has been spun, the material on the bottom of the tube is transferred to a second centrifuge tube by micropipette. If the heavies are of interest, distilled water is added to this second tube. If the float is of interest the distilled water is added to the original tube. Once the heavy liquid is mixed with distilled water the density is lower than the minerals, either float or heavies, so that the sample can be spun down in the centrifuge. The liquid is removed with a micropipette and fresh water added. After spining down in distilled water five or six times, the sample is transferred with a drop of water to a glass slide. After it is dry, any refractive index liquid may be used. Figures 10 and 11 show an example of the same sample prepared on a filter and on glass. The counts are essentially the same.

This procedure has been used for concentrating quartz from talc samples and for obtaining tremolite counts on acid insoluble residues of carbonate rocks. Work on these and other applications continues. The density-refractive index chart (Fig. 1) is presented for the convenience of those wishing to apply the method to other mineral associations.

Discussion

The method proposed in this paper permits one to find amphibole particles and to view their shape much more easily and rapidly than standard optical methods. It was found that talc contains <0.1% amphibole if less than 20 particles are observed in 20 fields of view. On the other hand, using the traditional 1 mg procedure, less than 5 particles in 100 fields of view would indicate <0.1%. It is much easier to find the amphibole particles by optical methods after concentrating them with heavy liquids because there is less interference by talc particles. In the 1 mg count many talc particles are seen on edge thereby needing to be tested for refractive index. Although the standard deviations are quite high, the proposed method permits one to routinely analyze industrial mineral samples where it was impractical to do so.

It is not known whether talc that passes the 0.1% Hazard Communication regulation will it pass the airborne asbestos regulation (2 Mg/M^3) (21). Unfortunately, one cannot conclude anything about whether or not a talc powder will pass the fiber regulation if it is below the talc dust limit because the mandated analytical procedure is phase contrast which bears little to no relationship to true fiber content where mixed mineral dusts are involved (22). An additional problem as indicated previously is that the coarser particles of a bulk powder will not become airborne so that a different portion of the sample will be present in the air as compared with the bulk powder. On the other hand, if we consider true fibers greater than 5μm in length it would appear that the 2Mg/M^3 would offer a good certainity that the airborne level would be less than 0.2 fibers/cm^3. The only way it could be higher would be if only 1/100 of each milligram of talc could become airborne and if all the fibers were in that 1/100 of the sample. Since this is very unlikely, it appears that the dust limit for talc is sufficiently stringent for fiber as well.

The Hazard Communication regulation generally assumes that percent is either by weight or volume. If percent by weight is used, samples containing stubby particles such as that shown in Fig. 5 would seem to be more dangerous then those samples containing an equal number of long narrow particles similar in shape to those in Fig. 4 because the weight percent would be higher. For this reason percent by count was chosen. One can, however, determine weight or volume percent by measuring amphibole particle dimensions during a count. This would no doubt be necessary in samples where grinding had to be done before analysis.

In the course of this investigation, samples of talc have been found to contain amphibole which were not previously known to contain this mineral. In many cases periodic SEM analyses had been done. The problem with SEM is that little is accomplished in going to sub-optical sizes unless there is also an increase in the ratio of amphibole to talc particles, and there is no indication that this occurs in bulk samples except possibly in the case of "true asbestos" where the particles have broken into fibrils (23, 24, 25). It is possible that the centrifuge techique will be useful for concentrating and separating amphibole from talc for SEM work. This will require the use of less viscous heavy liquids so that reasonable centrifuge times can be used for these very small particles.

It should not be construed from comments in this paper that all talcs contain amphibole particles. There certainly are amphibole-free talcs. There are others in which the amphiboles have not been previously recorded because of their low level. All U.S. cosmetic, pharmaceutial or high grade talcs that were analyzed during this study are in compliance with federal regulations, generally by a large margin.

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