

TABLE 1

Instrumental Methods — Capabilities

Instruments	Method			
	Morphology	Optics	Diffraction	Chemical Analysis*
LM: light microscope	$\geq 1 \mu\text{m}$	$\geq 1 \mu\text{m}$	NO	NO
DS: dispersion staining	$\geq 5 \mu\text{m}$	$\geq 1 \mu\text{m}$	NO	NO
XRD: x-ray diffraction	NO	NO	YES	YES
SEM: scanning electron microscope	$\geq 0.005 \mu\text{m}$	NO	NO	YES
TEM: transmission electron microscope	$\geq 0.001 \mu\text{m}$	NO	YES	NO**
EMA: electron microprobe	$\geq 5 \mu\text{m}$	NO	NO	YES
EMMA: electron microscope-microprobe analyzer	$\geq 0.005 \mu\text{m}$	NO	YES	YES
IMA: ion microprobe	$\geq 5 \mu\text{m}$	NO	NO	YES

*diffraction methods indirectly analyze chemically by identifying the crystalline phase present; chemical analysis by electron optical instruments may utilize energy or wavelength dispersive x-ray analyzers

**may be fitted with energy or wavelength dispersive x-ray analyzers

Identification of Asbestos Fibers by Microscopical Dispersion Staining*

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Abstract

The Cherkasov focal screening dispersion staining procedure has been successfully applied to the identification of asbestos. The various types of asbestos can be differentiated by noting the refractive index of the Cargille liquid giving matching wavelengths in the region near 550 nm. It is not necessary to use polarized light although the much more definitive data obtained with polarized light may eventually permit identification of the mine from which each asbestos came.

Although too few samples of amosite and crocidolite have been studied, it appears that these two types can be differentiated by dispersion staining. In Cargille liquid $n_D^{25^\circ\text{C}} 1.680$ the central stop without polars will show colors in the blue magenta region ($\lambda_0 = 550 - 650$ nm) for amosite and in the golden yellow region ($\lambda_0 = 400 - 500$ nm) for crocidolite. Furthermore, with polarized light crocidolite will show lower birefringence than amosite; in terms of λ_0 difference in a given liquid amosite will show 160–190 nm and crocidolite 120–140 nm. Finally, the higher value of λ_0 is observed for the vibration direction parallel to the length for crocidolite (three samples) but perpendicular to the length for amosite (two samples).

* Presented at INTER/MICRO-69, London, England.

Through publications¹⁻³ and current research, the pneumoconiotic (lung hardening) and frequently cancer-producing hazards of asbestos are finally fully acknowledged. Hence, there is need of a method of determining qualitatively and quantitatively environmental pollution by respirable asbestos dust (1-7 μm).

Asbestos is a fibrous form of silicate rock. There are six types: chrysotile, amosite, crocidolite, actinolite, tremolite and anthophyllite; only the first three are of commercial importance. All are amphiboles (minerals with chains of silica tetrahedra as their basic structure) except chrysotile which is a serpentine (mineral made up of layers of silica tetrahedra).

The property of asbestos that best lends itself to identification is refractive index. The fibers are so fine that electron microscopy would be necessary if morphology were to be used. There are no dependable differences in absorption color (except possibly for crocidolite) nor specific gravity (other than chrysotile) (Table I). If we wish to use chemical composition for identification of single asbestos fibers, we require highly sophisticated instruments and techniques—the electron microscope or an electron (or ion) microprobe. X-ray diffraction requires considerable sample and is not sensitive to small percentages in any sample (*i.e.*, < 5-10%). Very small asbestos fibers can, however, be identified simply and quickly using dispersion staining.

Experimental

The McCrone dispersion staining objective, based on the focal screening method of Cherkasov⁴, was used in this study of asbestos (Figure 2).

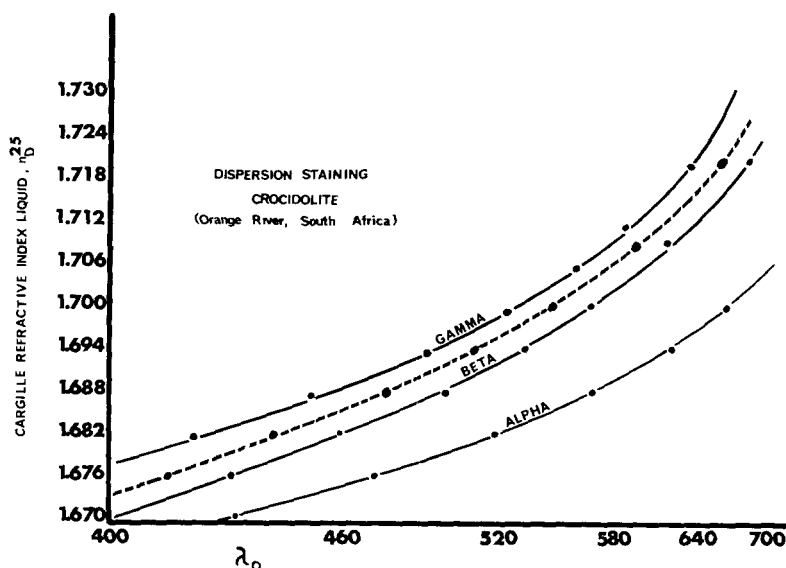


Figure 1. Dispersion staining data for a typical sample of crocidolite.

SERPENTINES

	Chrysotile
Composition	$3\text{Mg}0.2\text{Si}0_2 \cdot 2\text{H}_2\text{O}$
Spec. Grav.	2.36 2.5
Cryst. Syst.	Monoclinic
Extinction	$\gamma \wedge L^* = 0^\circ$
Sign (elong.)	+

TABLE I
ASBESTOS

AMPHIBOLES

Actinolite	Tremolite	Anthophyllite	Amosite	Crocidolite
$2\text{Ca}0.4\text{Mg}0.8\text{SiO}_2 \cdot \text{H}_2\text{O}$	$2\text{Ca}0.5\text{Mg}0.8\text{SiO}_2 \cdot \text{H}_2\text{O}$	$7\text{Mg}0.8\text{SiO}_2 \cdot \text{H}_2\text{O}$	$5.5\text{Fe}0.1.5\text{Mg}0.8\text{SiO}_2 \cdot \text{H}_2\text{O}$	$\text{Na}_2\text{O} \cdot \text{Fe}_2\text{O}_3 \cdot 3\text{Fe}0.8\text{SiO}_2 \cdot \text{H}_2\text{O}$
3.03-3.5	2.9-3.2	2.85-3.4+	2.6-3.0	3.0-3.45
Monoclinic	Monoclinic	Orthorhombic	Monoclinic	Monoclinic
$\gamma \wedge L = 10-15^\circ$	$\gamma \wedge L = 10-21^\circ$	$\gamma \wedge L = 0^\circ$	$\gamma \wedge L = 14-21^\circ$	$\alpha \wedge L = 3-15$
+	+	+	+	—

*L=long direction of fibers

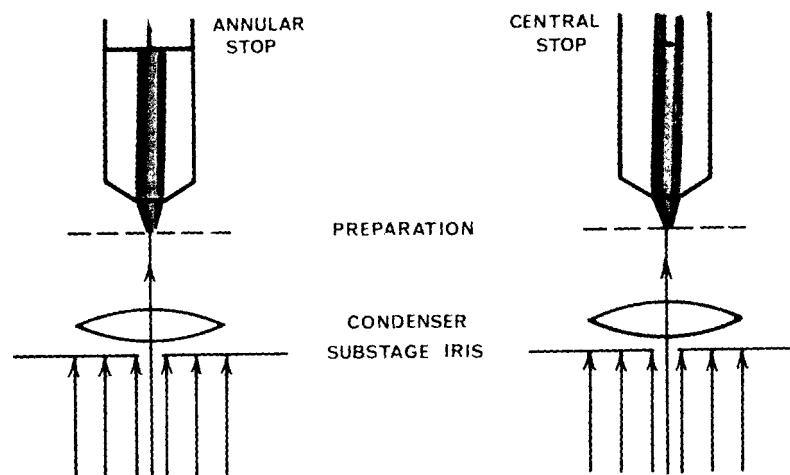
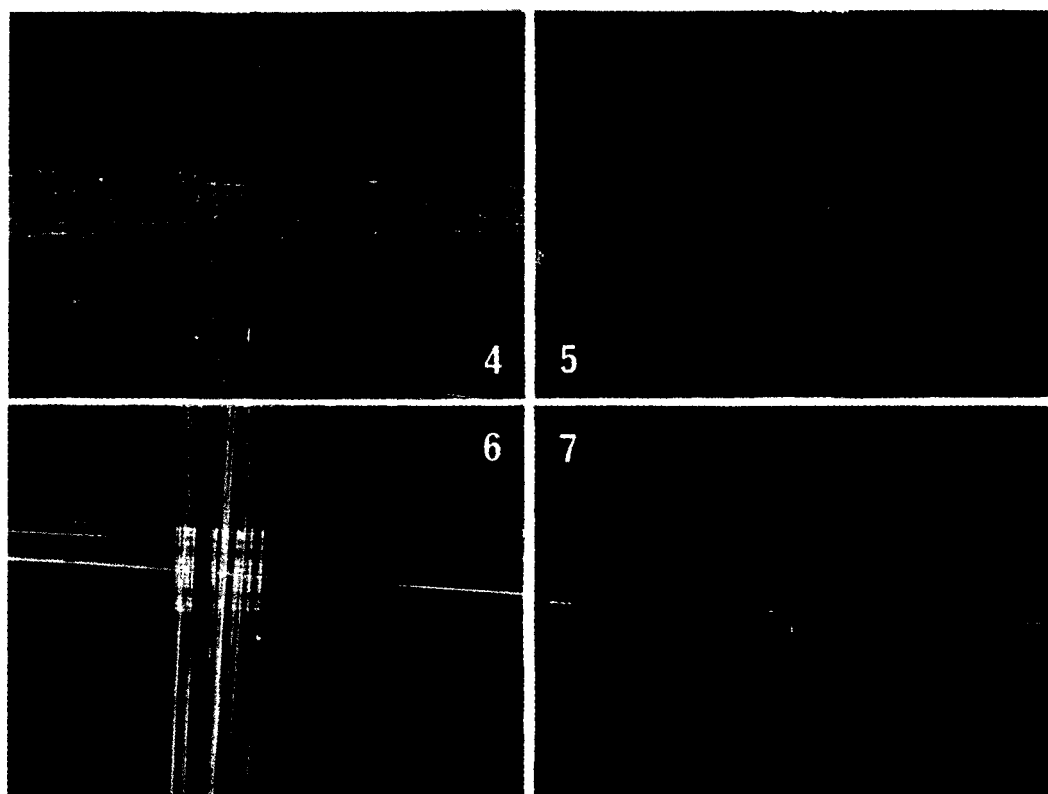


Figure 2. The arrangement for focal screening; the annular stop permits passage of the matching wavelength and the central stop white light minus the matching wavelength.



Figures 4-7. Central stop colors for chrysotile (Figure 4), anthophyllite (5), amosite (6) and crocidolite (7) each with the appropriate Cargille refractive index liquid, 1.560 (Figure 4), 1.610 (Figure 5), 1.670 (Figure 6), 1.700 (Figure 7). The vibration direction of the polar is east-west in each figure.

Dispersion Staining Colors

Colors observed

Annular
stop

dark-blue

blue-violet

blue

blue-green

green

yellow-green

yellow

orange

orange-red

brownish-red

Illumination are often used for these methods are empirical. A mixture of colors observed is often used. With the Cherkasov method and hence essentially pure

was determined as a function of each of 26 asbestos samples. Table II was found to be most effective for better resolution and contrast; fibers. The procedure involved: only in those Cargille refractive indices colors to it.

Both polarized and unpolarized

vibration direction of the polar (other asbestos fibers).

β and γ (crocidolite) or α and β random orientations under these $\beta \leq n \leq \gamma$ positions and all $\geq \alpha$ positions. The two extreme positions are designated α (highest asbestos fibers other than crocidolite) and λ_0 for crocidolite.

often observed with asbestos Figure 1 shows the data for one sample way.

Asbestos fibers show nominally a range of wavelengths observed during due to polarization by reflection

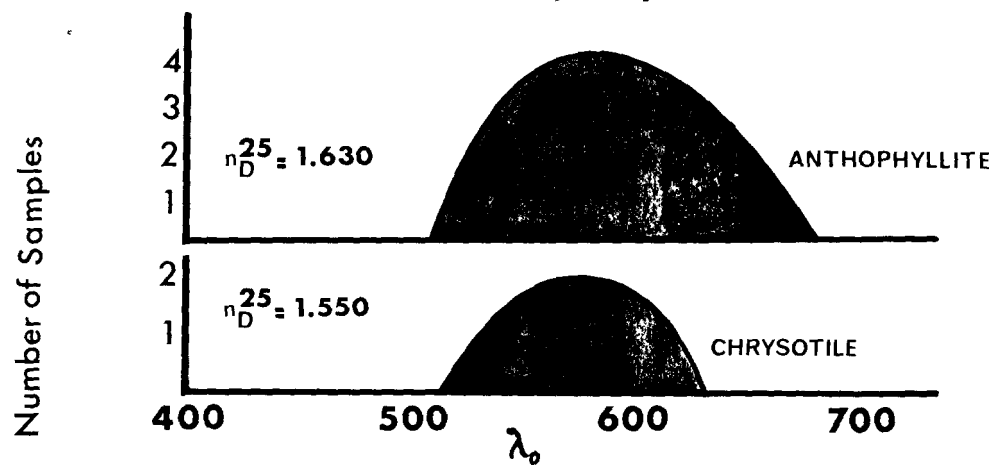
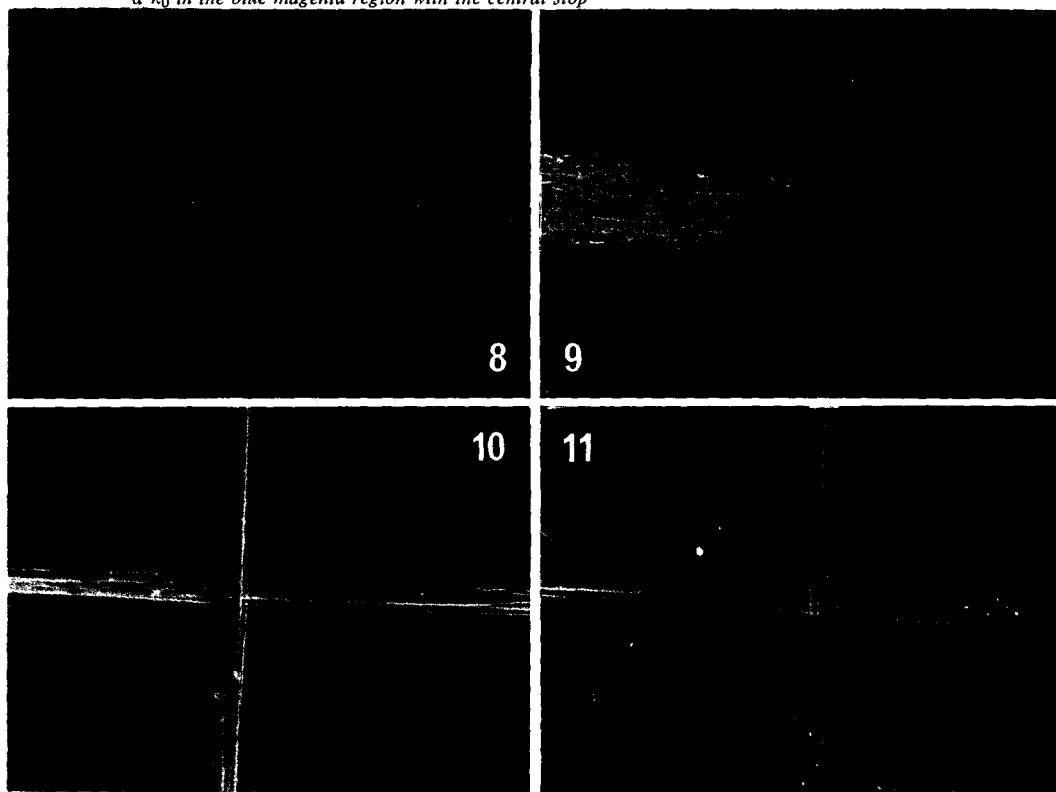


Figure 3 The range of matching wavelengths shown by anthophyllite and chrysotile with unpolarized light. The Cargille liquid was chosen so that most samples of each asbestos show a λ_0 in the blue magenta region with the central stop.



Figures 8-11 Central stop colors for chrysotile (Figure 8), anthophyllite (9), amosite (10) and crocidolite (11) in the same Cargille liquids as Figures 4-7 respectively. Unpolarized light was used for this series.

from the microscope mirror, there is a slight change in color when the stage is rotated. All our data were taken with the fibers normal to the mirror reflection vibration direction.

Figures 4-7 show the dispersion staining colors of representative samples of chrysotile, anthophyllite, amosite and crocidolite respectively. Each is shown in the various orientations (relative to the polarizer vibration direction) necessary for determination of α , β and γ . Careful study of these figures may indicate the simplified procedure used to orient the fibers at precise 90 degree angles to each other.

To determine if the simpler application of dispersion staining without a polarizer is adequate for identifying asbestos, the fields of view of Figures 4-7 were also taken with no polar (Figures 8-11). The λ_0 curves obtained without polar were plotted in a single graph (Figure 12). The bunching of the curves of each different type of asbestos indicates that for identification purposes a liquid can be chosen that will impart a characteristic color to one species of asbestos only. A polarizing microscope is not, therefore, required. However, we can anticipate that with additional samples of crocidolite and amosite there might be some overlap. For this reason, the distinction between the signs of elongation (Figures 6 and 7) and the crocidolite blue absorption color are mentioned as special aids for differentiation. In this case a polarizer is useful.

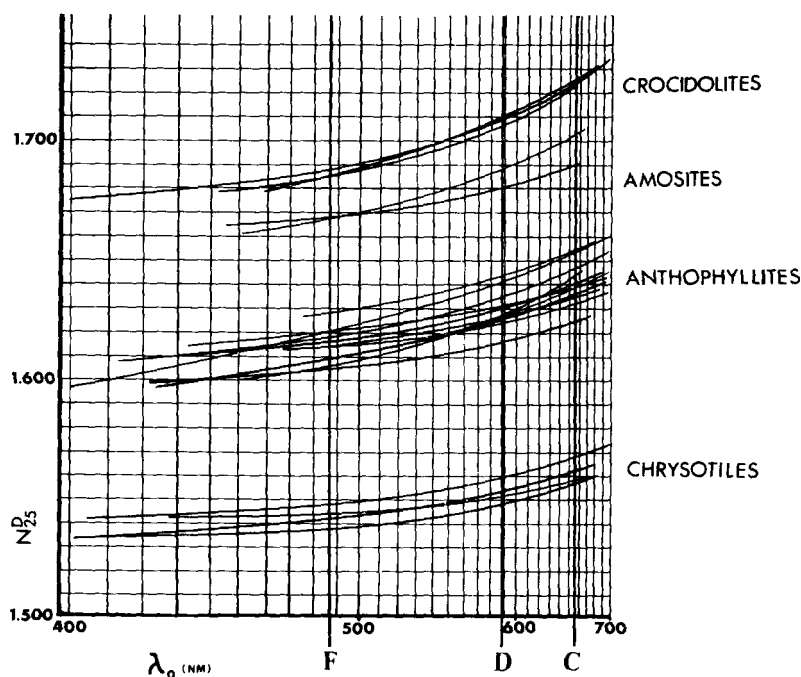


Figure 12. Matching wavelengths shown by different samples of four types of asbestos when mounted in the Cargille refractive index liquids shown and observed with unpolarized light.

The characteristic color will vary somewhat for different samples of the same type of asbestos. So, the problem arose of determining the ranges of colors for each asbestos in the chosen liquid (the liquid in which most samples of any asbestos type give a color of wavelength 580–620 nanometers). To determine this range of colors for any type of asbestos, the matching wavelengths observed in the chosen liquid are plotted against the number of different samples showing that λ_o . The area under the resulting curve (colored in Figure 3 as per Table II) shows all the colors shown by our samples of anthophyllite and chrysotile. Too few samples of amosite or crocidolite have been studied to justify their inclusion in Figure 3.

Conclusion

The limited results obtained indicate that asbestos can be identified by dispersion staining. More work on many more samples will establish the full range of λ_o values for each asbestos. Relating λ_o data to asbestos source may then also pinpoint the mine source of unknown asbestos samples.

Acknowledgement

The authors are grateful to Dr. Bertram G. Woodland, Curator of Igneous and Metamorphic Petrology of the Field Museum of Natural History in Chicago for the samples of asbestos from various sources.

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- ⁴ Brown, K. M., and McCrone, W. C., (1963). *Dispersion Staining*, Parts I and II, *Microscope*, **13** 311 and **14** 39.

APPENDIX (Continued)

Lincoln Co., Nevada E1101	γ	1.609	1.611	1.616	1.623	1.630
	*	1.602	1.605	1.609	1.615	1.621
	β	1.596	1.599	1.602	1.609	1.615
	α	1.589	1.592	1.595	1.600	1.606
Rio Grande de Sul, Brazil E14494	γ	1.610	1.615	1.620	1.630	1.641
	*	1.605	1.610	1.615	1.624	1.635
	β	1.603	1.607	1.611	1.620	1.628
	α	1.596	1.600	1.604	1.611	1.618
California E14464	γ	1.619	1.624	1.630	1.642	1.656
	*	1.614	1.619	1.624	1.635	1.646
	β	1.612	1.616	1.622	1.632	1.642
	α	1.601	1.605	1.610	1.618	1.627
Pine Mt., Georgia	γ	1.607	1.613	1.619	1.632	1.647
	*	1.602	1.608	1.614	1.625	1.638
	β	1.597	1.602	1.607	1.617	1.628
	α	1.589	1.593	1.597	1.606	1.614
Encampment, Wyoming	γ	1.619	1.620	1.626	1.630	1.638
	*	1.613	1.616	1.619	1.625	1.630
	β	1.609	1.612	1.615	1.621	1.626
	α	1.598	1.600	1.603	1.607	1.611
Bedford, Virginia E12790	γ	1.614	1.619	1.622	1.634	1.644
	*	1.609	1.613	1.618	1.628	1.638
	β	1.606	1.610	1.615	1.624	1.633
	α	1.599	1.603	1.607	1.614	1.622

Crocidolites

Orange River, South Africa	γ	1.688	1.694	1.700	1.712	1.726
	*	1.684	1.690	1.696	1.707	1.721
	β	1.680	1.686	1.692	1.702	1.713
	α	1.674	1.678	1.682	1.690	1.698
Westerburg, South Africa	γ	1.686	1.692	1.697	1.708	1.718
	*	1.682	1.687	1.692	1.701	1.710
	β	1.679	1.683	1.688	1.697	1.706
	α	1.674	1.678	1.683	1.691	1.699
South Africa	γ	1.691	1.696	1.701	1.712	1.723
	*	1.685	1.690	1.695	1.705	1.714
	β	1.680	1.685	1.690	1.700	1.710
	α	1.674	1.679	1.683	1.692	1.700

Amosites

Lydenburg Dist., Transvaal	γ	1.676	1.682	1.687	1.699	1.712
	*	1.665	1.670	1.676	1.687	1.698
	β	1.658	1.663	1.668	1.678	1.689
	α	1.652	1.657	1.662	1.672	1.682
Penge, Transvaal	γ	1.672	1.677	1.682	1.692	1.701
	*	1.665	1.669	1.674	1.682	1.691
	β	1.660	1.664	1.668	1.676	1.684
	α	1.653	1.657	1.661	1.669	1.676

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APPENDIX

Dispersion Staining Data, $n_D^{25^\circ\text{C}}$ of Cargille refractive index liquid

Chrysotiles

Sample	Orientation	Matching wavelength, λ_0 , nm				
		450	486(F)	520	590(D)	656(C)
Thetford Mines, Quebec	γ	1.539	1.542	1.546	1.553	1.559
	*	1.535	1.539	1.543	1.550	1.556
	β	1.533	1.539	1.543	1.547	1.556
	α	1.528	1.531	1.534	1.541	1.546
Eden, Vermont E19048**	γ	1.549	1.553	1.558	1.566	1.574
	*	1.543	1.547	1.551	1.559	1.566
	β	1.543	1.547	1.551	1.559	1.566
	α	1.534	1.539	1.543	1.550	1.557
Thetford Mines, Quebec E20436	γ	1.545	1.549	1.552	1.559	1.565
	*	1.540	1.546	1.547	1.553	1.558
	β	1.538	1.541	1.544	1.550	1.554
	α	1.536	1.539	1.542	1.548	1.552
Thetford Mines, Quebec E12185	γ	1.543	1.547	1.550	1.556	1.563
	*	1.540	1.543	1.546	1.552	1.558
	β	1.536	1.540	1.543	1.549	1.555
	α	1.531	1.534	1.537	1.543	1.548
King's Mine, Quebec	γ	1.543	1.547	1.551	1.559	1.566
	*	1.539	1.543	1.547	1.554	1.561
	β	1.535	1.539	1.543	1.550	1.557
	α	1.529	1.532	1.535	1.542	1.547
Barquisimeto, Venezuela	γ	1.536	1.541	1.546	1.556	1.566
	*	1.530	1.537	1.541	1.550	1.559
	β	1.530	1.534	1.539	1.547	1.555
	α	1.524	1.528	1.532	1.540	1.548

* no polars were used.

** sample identification number of the Field Museum of Natural History, Chicago, Illinois, U.S.A.

Anthophyllites

Minas Gerais, Brazil E16696	γ	1.604	1.613	1.620	1.633	1.645
	*	1.602	1.608	1.614	1.628	1.638
	β	1.599	1.606	1.612	1.625	1.636
	α	1.582	1.588	1.594	1.606	1.616
Maryland E3713	γ	1.617	1.623	1.630	1.642	1.658
	*	1.613	1.618	1.624	1.636	1.649
	β	1.609	1.614	1.619	1.630	1.642
	α	1.599	1.604	1.609	1.620	1.630
New Mexico E3709	γ	1.620	1.625	1.629	1.638	1.648
	*	1.616	1.621	1.625	1.634	1.642
	β	1.609	1.612	1.616	1.620	1.628
	α	1.601	1.604	1.607	1.613	1.618
Macon Co., N. Carolina E3700	γ	1.614	1.618	1.623	1.632	1.641
	*	1.610	1.614	1.619	1.627	1.635
	β	1.606	1.610	1.614	1.622	1.629
	α	1.594	1.597	1.604	1.607	1.613

Detection and Identification of Asbestos
by Microscopical Dispersion Staining

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There is a great need for a dependable, sensitive and rapid method for the detection and identification of asbestos. Microscopical dispersion staining satisfies all of these requirements. It is dependable because it is based on the measurement of three refractive indices as well as the dispersion of those indices. Refractive indices are among the most valuable identifying characteristics for small particles. It is sensitive because the refractive indices are "read" as bright dispersion staining colors against a black background. These colors can be observed on particles well below one micrometer in diameter. It is rapid because any particle in the microscopical preparation showing the optical properties of asbestos signals its presence by a unique color combination with polarized light. One particle of asbestos in a field of view containing many thousands of other particles will be immediately apparent on scanning the eye across the field of view.

Besides optical crystallographic methods like dispersion staining only DTA and diffraction have this ability to tag a particular crystalline phase in a mixture. X-ray diffraction, however, is several orders of magnitude less sensitive than dispersion staining and requires much more time. There are, however, compounds whose dispersion staining colors are, at least at first glance, confused with chrysotile colors. Here, fortunately, particle morphology is able to differentiate between these interfering substances. Quartz is one example, lizardite another. The latter, however, is a tabular talc-like mineral and quartz shows conchoidal fracture into usually thin flakes. Both are easily differentiated from fibrous asbestos by morphology.

Dispersion staining is, therefore, a straightforward technique easily applied by any microscopist with some knowledge of optical crystallography. We have found it extremely useful for the rapid and routine examination of any particulate samples for any of the various kinds of asbestos¹. The necessary background information for applying the method is given in Figure 1 which plots the matching wavelength, λ_0 , as a function of refractive index of the Cargille refractive index liquids used in these determinations. Most of the asbestos minerals have distinctive indices without overlap. Figure 1 ^{suggests} ~~shows~~, however, that amosite and crocidolite ^{may} ~~do~~ overlap partially. There should be no confusion in this situation, however, since gamma for amosite overlaps only with alpha for crocidolite. The data in Figure 1 are plotted as the averages of a considerable number of values for individual mine samples previously published¹. It is interesting to look a little bit more closely at this variation in dispersion staining data ^{from} ~~for~~ mine to mine and Table I lists the matching wavelength, λ_0 , for gamma (parallel to the fiber length) and alpha (perpendicular to the fiber length) for a group of more than thirty asbestos samples from different parts of the world. There is some variation from sample to sample, indicating composition variations. However, all of the data ^{lie} in the same characteristic chrysotile region and show no overlap with any of the fibrous amphiboles.

Since dispersion staining is a relatively new technique requiring a certain amount of skill, not only in reading the matching wavelengths but also in adjusting the microscope for best dispersion staining colors, it seems well to summarize a few of the common difficulties.

1. The refractive indices given in dispersion staining tables are not dispersion data for that compound. To illustrate this we can cite the data for the ω index of quartz.

	<u>486 nm</u>	<u>589 nm</u>	<u>656 nm</u>
true refractive indices, ω	1.550	1.544	1.542
dispersion staining data	1.538	1.544	1.547

The value 1.538 for ω at 486 nm is n_D for the Cargille liquid that matches quartz ω at 486 nm. The actual refractive index of that liquid at 486 nm is 1.550, the same as quartz ω . This operation, which simplifies the analytical procedure, is used for all dispersion staining data. One can, of course, calculate the true refractive indices of any substance from the dispersion staining data. The necessary data to do this can be found in the table of dispersion of refractive index data for the Cargille liquids.

2. True refractive index data and dispersion staining data are identical at 589 nm, hence refractive index data at 589 nm for any substance becomes dispersion staining data for that substance. Chrysoberyl, for example, does not appear in the dispersion staining tables but Winchell² gives $n_D = 1.746$ (α), 1.748 (β) and 1.756 (γ). From these data one would mount a suspected chrysoberyl in Cargille liquid $n_D = 1.750$ and expect to see annular stop colors ranging from orange (α) to greenish-yellow (γ) or greenish-blue (α) to magenta-blue (γ) with the central stop. This greatly extends the usefulness of dispersion staining.

3. We are often asked if the dispersion staining objective can be supplied with a higher magnification. This gives us the opportunity to point out that higher magnification is not desirable. One is trying to "resolve" color of the particles not the particles themselves. Central stop dispersion staining is a darkfield procedure, hence a strong light source will show points of light for particles smaller than the resolving power limit of the microscope system, i.e., $1.22 \mu m$ for $\lambda = 589 nm$, NA = 0.25, 10X objective. These points of light will be colored for particles showing dispersion in that liquid. The lower limit of detection is a function of light intensity and contrast.

4. There are a number of points of technique which greatly improve the sensitivity of the dispersion staining procedure. These include:

- a. The particles must be well separated in the mounting liquid since nonstained particles close to or overlapping stained asbestos can mask their presence.
- b. The dispersion staining colors for chrysotile and the fibrous amphiboles are more brilliant if one uses the high dispersion Cargille set of refractive index liquids.
- c. In spite of the above injunction concerning high magnification, it is sometimes useful to use a 20-25X ocular with the 10X dispersion staining objective.
- d. The optics for the dispersion staining objective, the axis of stage rotation, the substage apertures and lenses must be well aligned on the same optical axis. It is a good idea to take special pains to align the optical system and to maintain that microscope for dispersion staining examination only.
- e. The problem of glare from other particles in the field of view is solved to a great extent by having a centered and nearly closed field diaphragm in the optical system. This concentrates attention on particles in the center of the field and eliminates well over 90% of the glare which makes it difficult to see very fine asbestos fibers.
- f. It is desirable to be able to change the orientation of any particles which appear at first sight to give the distinctive dispersion staining colors characteristic of chrysotile (or other fibrous amphiboles). Rolling the particle by ^{lightly tapping on} sliding the cover slip with a viscous liquid prep ~~is the ideal way of doing this and~~ helps greatly in differentiating quartz, paper fibers and mineral wool from chrysotile.
- g. The slides and cover slips used for dispersion staining preps should be unusually clean since any optical discontinuities on any surface of the prep cause glare and interfere with visibility of the dispersion staining colors.
- h. Finally, it is desirable to have standards of the substance you are looking for mounted in the same refractive index liquid. If one is looking for chrysotile, it is also useful to have standard preparations of quartz, paper fibers and talc in order to remind oneself quickly of the essential differences in appearance and color for these substances.

The color plates show the general nature of the dispersion staining colors and the specific appearance of the various kinds of asbestos in their specific liquids. Figure 2 shows the arrangement of annular and central stops in the objective back focal plane. These may be a centered 2-3 mm opening in any opaque film or a 3-4 mm dot of India ink on an 18 mm cover slip, respectively; although a dispersion staining objective is available commercially. Note that the substage iris is closed to allow only an axial beam of light to strike the object. The color series obtained with each stop are shown in Figure 3. Chrysotile is shown in Figures 4-5 mounted in two different standard Cargille refractive index media. Polarized light is used with an E-W vibration direction for Figure 4 and N-S for Figure 5. Observed λ_0 values are given in Table II.

Table II. Matching Wavelengths for Chrysotile.

Refractive index, n_D , of Cargille liquid	Parallel to fiber length	Crosswise of fiber
1.550	500	570
1.560	610	640

Figures 6-8 show anthophyllite, all with E-W polar. Figures 6 and 7 show the fibers mounted in 1.610 and 1.620, respectively. Figure 8 shows two different anthophyllites (Maryland and North Carolina) mounted in 1.627. This figure, like the others, are double exposures with the stage rotated 90° between exposures. The two different sources result in small variations in λ_0 .

Amosite is shown in Figures 9-11 mounted in Cargille liquids 1.670, 1.680 and 1.690, respectively. Figure 12 shows crocidolite in Cargille liquid $n_D = 1.700$ and Figure 13 shows one particle of chrysotile in a talc sample mounted in Cargille liquid, $n_D = 1.550$.

CONCLUSION

The combination of particle morphology and optics uniquely identifies any of the fibrous asbestos compounds. The most rapid method for obtaining this information is through the use of dispersion staining. Properly carried out, the dispersion staining method is capable to sensitivity in the ppm range.

REFERENCES

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Table I

Matching Wavelength (λ_0) in H. D. 1.550 Liquid

	$\parallel$ lg	$\perp$ lg
Quebec; Lake Asbestos	510	610
Quebec; King, Asbestos Corp.	510	610
Quebec; Asbestos Corp.	500	610
Quebec; Bell Mines	510	600
Quebec; Johnsons	500	600
Quebec; Careys, Bradford	480	590
Quebec; Flintkote	500	610
Quebec; Normandie	570	610
Ontario; Reeves	480	590
Ontario; Munro	560	610
Vermont; Hyde Park, GAF	510	620
Vermont; Jeffery	500	580
New Foundland; Advocate	510	610
New Foundland;	590	620
Yukon; Clinton Creek	500	580
British Columbia; Cassiar	500	580
California; Pacific Asbestos Corp.	480	610
California; Coalings	590	630
Arizona;	600	620
Venezuela;	610	680
Rhodesian;	520 (460)*	620 (550)
Rhodesian; Shabina	480	580
Rhodesian; Havelock C and G	490	590
Rhodesian; Havelock HVL	490	590
Rhodesian; Havelock VRA	500	630
Cyprus;	600	660
Greece; Zandini	580	620
Yugoslavia;	520	590
Italian; Balengera	500 (400)	600 (510)*
Russian;	500	600
Australia; Woodsreef	610	680

Figure Captions

1. Asbestos dispersion staining curves.
2. Schematic arrangement for annular and central stop dispersion staining.
3. Color series for annular and central stop dispersion staining.
4. Chrysotile in Cargille liquid $n_D = 1.550$.
5. Chrysotile in Cargille liquid $n_D = 1.560$.
6. Anthophyllite in Cargille liquid $n_D = 1.610$.
7. Anthophyllite in Cargille liquid $n_D = 1.620$.
8. Two different anthophyllites in Cargille liquid $n_D = 1.627$.
9. Amosite in Cargille liquid $n_D = 1.670$.
10. Amosite in Cargille liquid $n_D = 1.680$.
11. Amosite in Cargille liquid $n_D = 1.690$.
12. Crocidolite in Cargille liquid $n_D = 1.700$.
13. One magenta chrysotile fiber in talc mounted in Cargille liquid $n_D = 1.555$.

