ANALYSIS OF TALC BY X-RAY DIFFRACTION AND POLARIZED LIGHT MICROSCOPY

Lucy B. McCrone
Walter C. McCrone Associates, Inc.
Chicago, Illinois 60616

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ERRATA

page	
vi	line 5, should read: ....expired....
2	Figure 1 caption, add: ... , actual size.
3	paragraph 5, last line, insert: ...and enter the resulting....
14	tabulation, line 2, change: ...$10.60^{\circ} = 10.90^{\circ}$.. to ...$10.60^{\circ} - 10.90^{\circ}$...
17	paragraph 2, line 3, should read: .. $\leqslant 5\ \mu m$...
23	paragraph 2, line 13, add s: ..three samples...
	line 16, should read: ...square-counting...
34	2. line 2, insert a colon after ...sample:..

The quartz peak at 26.65° is three times the intensity of the next strongest, at 20.83°, and is preferred except when muscovite mica is present. The 26.65° quartz peak is usually distinguishable by step scanning from the muscovite peak at 26.85° and the biotite mica peak at 26.42°, but not from the 25% intensity muscovite peak at 26.66°. When much muscovite is present, as in Sample 125, the 20.83° peak is preferable.

Minimum levels of detection by step scanning found for standards in talc using the peaks discussed above are: tremolite - 0.5%, anthophyllite - 2.5%, chrysotile - 3% and quartz - 0.2%. Our tremolite standard is predominantly nonfibrous; others have reported that fibrous tremolite gives about 1/4 to 1/3 the response at 8.38Å obtained from nonfibrous tremolite in talc*. Most of the samples in which we found tremolite contain a preponderance of the nonfibrous habit.

POLARIZED LIGHT MICROSCOPY

We have applied two kinds of microscopical analysis in identifying components of talc samples. First, petrographic observations in plane polarized light (mainly morphology and refractive indices) and between crossed polars (morphology, birefringence, type of extinction, extinction angle and sometimes interference figures). Second, the use of dispersion staining to identify minerals. Appendix C, the analytical dispersion staining chart, is specifically designed for talc samples.

Most of the above observations are made at 200X magnification using the 10X dispersion staining objective with a 20X ocular. High power objectives are sometimes used to examine the smallest particles and fibers or for interference figures. Our usual procedure is as follows.

Procedure

1. Analyze the x-ray line scan to identify the major components and define any questions to be answered by microscopy.

2. Mount representative samples, about 0.1 mg each, of the unmilled material in the Cargille refractive index liquids specified below. Observe central stop dispersion staining colors in each liquid and relate them to the curves in Appendix 3. Check birefringence and extinction between crossed polars, and refractive indices relative to the mounting medium. Look for fibers by dispersion staining and between crossed polars and check whether particles are really fibers or plates on edge by making them tumble in the liquid to exhibit all views - tapping on the coverslip with a needle will make the particles tumble into a succession of random orientations. Table 2 gives the refractive indices of most minerals of interest in talc samples.

* J. Schelz, private communication.

Table 2. Refractive indices of minerals sought in talc samples

Mineral	Refractive Indices, $n_D^{25°C}$		
	α or ω	β	γ or ε
chrysotile	1.544	1.552	1.555
quartz	1.544		1.553
lizardite	1.545	-	1.558
antigorite	1.545	1.557	1.560
talc	1.546	1.588	1.589
chlorite	1.566	1.567	1.596
tremolite	1.599	1.610	1.621
anthophyllite	1.603	1.617	1.628
actinolite	1.633	1.641	1.647
forsterite	1.643	1.663	1.682
calcite	1.653		1.486
grunerite (amosite)	1.669	1.681	1.697
dolomite	1.677		1.500
magnesite	1.694		1.509
riebeckite (crocidolite)	1.698	1.703	1.708

Minerals, especially silicates but also the isomorphous series of carbonates (calcite, dolomite, magnesite etc.) vary in refractive index. Table 2 and Appendix C show average indices for the minerals which might be found in talc. Generally, the dispersion staining curves for these minerals move parallel to themselves as the composition changes. The birefringence values ($\gamma-\beta$, $\beta-\alpha$ and $\epsilon-\omega$) will generally remain nearly constant for a given mineral although the indices themselves may vary considerably.

Both morphology and optics are noted in order to identify the asbestiform minerals. To be asbestiform requires that they be fibers, (as defined by NIOSH) measuring $\leq 5 \mu m$ in diameter, $<200 \mu m$ in length and have a length to width ratio of at least 3:1.

<u>Cargille high dispersion liquid $n_D^{25} = 1.550$:</u>

A representative sample mounted in this liquid will show characteristic λ_0 colors for any of the following: talc, quartz, chrysotile, lizardite, antigorite and many fibers (paper, silk, viscose rayon and human hair, etc.). The crystallographic data in Appendix C and morphological observations should ensure identification of most of these substances or allow the conclusion that any other substance showing colors in this liquid is not one of those listed (Figure 2). Characterization of this extraneous substance will often be possible by referring to the Particle Atlas.*

<u>Cargille high dispersion liquid $n_D^{25} = 1.585$</u>

This liquid is useful for distinguishing talc from chlorite. Edge views of chlorite are magenta for the index perpendicular to the plate. Talc is magenta for the index parallel to the plate.

TALC ON EDGE → MAGENTA - CHLORITE

MAGENTA - TALC

<u>Cargille high dispersion liquid $n_D^{25} = 1.605$:</u>

Chrysotile and all other substances giving dispersion staining colors in liquid 1.550 will be white or pale blue in 1.605 (Figure 3). Talc is the only substance in this group that shows a λ_0 close to the visible (ca 700 nm). All talc plates show both n's (β & γ) close to 1.605 in the red hence the central stop shows a pale blue in all directions lying in the talc plate and white corresponding to the α direction. Other minerals showing colors in $n_D = 1.605$ include tremolite, chlorite and actinolite (Figure 4).

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* McCrone, W.C. and J.G. Delly. 1973. The Particle Atlas, Edition Two. Ann Arbor Science Publishers, Ann Arbor, Michigan

Anthophyllite often shows colors similar to tremolite but exhibits parallel extinction on all views. Tremolite shows parallel extinction for one view but oblique extinction of 10° to 21° for the $\alpha - \gamma$ view.

Cargille Liquid n_D = (RF series)

Non-talc minerals showing dispersion staining colors in n_D = 1.660 include actinolite, forsterite, hornblende, calcite, cummingtonite and dolomite (Figure 5).

Cargille Liquid n_D = 1.700 (M series)

Minerals to look for in n_D = 1.700 include cummingtonite, grunerite, crocidolite and magnesite.

STANDARDS

LIST OF MINERALS

The following mineral standards were used for microscopy and quantitative x-ray diffraction:

Vermont talc (kindly supplied by Windsor Minerals)
anthophyllite, Haddam, Connecticut
chrysotile, Victory Mine, Globe, Gila County, Arizona
tremolite, Fowler, New York
α-quartz, synthetic single crystal

In addition, the minerals listed below were used for microscopy and qualitative x-ray diffraction:

lizardite, Kennack Cove, Cornwall, England
chlorite, Calaveras County, California
prochlorite, Chester, Vermont
anthophyllite, Guffey, Colorado
anthophyllite, Cashiers, North Carolina
actinolite, Lake Wenatchee, Washington
tremolite, fibrous, Dahl Creek, Alaska

X-ray line scans of all of the above are attached as Appendix B.

SAMPLE No.	Particle size, µm	% L+M antigorite	% S anthophyllite	% M calcite	% L chlorite	% S chrysotile	% L dolomite	% L feldspar	% L+M lizardite	% L magnesite	% L mica	% S quartz	% D talc	% S tremolite-actinolite	% other: M opaque particles	% other M	
001	2.97		12	<1			<1 M		10-15			2.5	40-55 L	30 (3% fibers) L			
002	1.64		8	<1					10-15			0.75	30-45 L	45 (<1% fibers) L			
003	1.87		13	<1			<1 M		10-12			1.5	38-50 L	35 (2% fibers) L			
004	5.48		11-23	<1			<1 M		10-12			1.3	19-32	45 (~5% fibers)			
005	5.11		8	<1					~15			0.7	~20	57 (1% fibers)			
006	6.0		5	<0.5			<0.5 M		~20			0.2	~41	33 (25% fibers)			
007	4.95		15	<0.2			<0.2 M		~20			1.1	~5	59 (10% fibers)			
009	11.3				<1 S		~1 M			<1 M			98-99				
034	6.37				10-20		2-4					<0.25	75-87	<0.1 M		<0.5 hydoxyapatite	
035	28.9				3-4		~1			40-50	<1 (biotite)	<0.25	45-55		<1 coal <1 magnetic		
036	321				~5		10-20			10-15		<0.25	60-70				
037	16.2				1-2		<0.1 M			40-50		<0.25	48-59				
038	22.4				2-3		1-2			20-25	<1 (biotite)	0.5	69-76		<1 coal <1 magnetic		
039	4.5			<1	2-5		~2			~40		<0.25	50-55				
040	6.15				3-5		1-2			35-40			53-61				
041	6.0		0?		10-15		~5		10-15		~5 (biotite)	1.7	50-60	6.5 (~2% fibers)	~1 magnetite		
042	1.47		10	<1			1		10-15			2.6	31-36 L	40 (1-2% fibers)			
043	7.12		4.5	<0.5			<0.5 M		10-15			<0.25	43-48	37 (<0.1% fibers)			
044	5.62	~5	5.5				<0.5 M		~10			<0.25	30-35	49 (<0.1% fibers)			
045	6.15		8				<0.5 M		10-15			0.7	33-38	43 (1-2% fibers)			

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SAMPLE No.	Particle size, µm	% L+M antigorite	% S anthophyllite	% M calcite	% L chlorite	% S chrysotile	% L dolomite	% L feldspar	% L+M lizardite	% L magnesite	% L mica	% S quartz	% D talc	% S tremolite-actinolite	% other: M opaque particles	% other M	
046	8.2				1-2 M		2-3 M					0.5	94-97.5	0.1-0.5M			
047	7.6				1-2 M		4-5 M						93-95				
048	6.85	3-5			3-5	4-5 M					5-8 muscovite M	≤0.25	1-2 M	5-7 M	1 magnetite	70 forsterite L	
049	6.8		10	<0.5			<0.5 M		10-15			0.8	30-40	38 (3% fibers)			
050	5.24		15	<1			<0.5 M		~10			1.1	~14	59 (<1% fibers)			
051	14.5			~5	~15		~5 M				8-10 biotite M	3.6	~55	5 (<1% fibers)			
052	7.13		9	~5 L	~10		2-3 M	6-8 orthoclase M	~1	1-2 M	15 biotite M	2.4	35-50	8 (0.01% fibers)	~1 magnetite		
053	5.73		12 ?	0.5-1	5-8		3-5			5-10	1 muscovite M	2	55-84	4.5 (5% fibers)	0.2 magnetite		
054	17.5				~5				≤1 M	1 M		0.6	90		1 graphite	<1 hydroxyapatite	
055	17.0				~60						10 muscovite	21	~5 L			2-3 hydroxyapatite	
056	24.8	15 M	0? M	2	5-10		5-8				~5 biotite	9	25-45	8	1 magnetite		
057	6.14											0.5	~99				
058	3.22	1-2		~1			5-10					1.1	85-92				
059	5.8	<0.5 M					10-15					1.8	82-87		≤1 graphite		
060	15.2	~1-2					1-2 M			~1-2		2	92-95	<0.2 M			
061	11.0						~5		≤1 M		0.5-1 biotite M	3.4	88-92				
062	5.7			~2 L			5-10		~1			4.3	77-88		<1 magnetite	5 forsterite L	
063	6.9			1-2 L			5-10					8.5	70-75		~1 graphite <1 magnetite	5 forsterite	
064	5.81						5-10				~1 ?	2.6	84-91				
065	4.94						10-20					3.0	76-87				

SMPL No.	Particle Size, µm	% L+M antigorite	% S anthophyllite	% M calcite	% L chlorite	% S chrysotile	% L dolomite	% L feldspar	% L+M lizardite	% L magnesite	% L mica	% S quartz	% D talc	% S tremolite-actinolite	% other: M opaque particles	% other: M	
066	5.85			<1 L	2-5		1-2			30-50			43-67L				
067	3.73				2-3							0.5	96-98				
068	6.91				1-2		<0.2 M					0.2	97-98		<0.5 graphite		
069	4.88				~1		<1 M					1.5	97		<0.5 graphite		
070	8.64			1			5 M		<1			1.5	90-92				
071	2.61						2-3 M					0.5	96-98				
072	5.51						2-3 M					0.7	95-97			<0.5 hematite	
073	4.3						~90 M						~10 M				
074	3.94				5-8		3-5		2-3		1-2 biotite	1.6	72-80	5 (~5% fibers)	1-2 magnetite		
075	9.3	1-2		1-2	5-8		5-10		1-2			0.4	70-82	4 (10% fibers)	~1 magnetite		
076	9.95			1-2	~50		~1 M	2-4 microcline M			2-4 biotite	1.7	27-35	5 (2% fibers)	2-5 magnetite		
077	16.8			<1 ? L	10-20 M		8 M		1-3		1-2	2.3	42-58	6	15 magnetite		
078	4.45			~5	5-8		5-10		~1			12	54-70			2 clay	
079	15.6						5-10					2.4	85-95				
080	5.3			~5	1-2		15		~1			2.2	67-76				
081	6.41			2-3 L	1-2		15-20		<1			2.5	65-80				
082	-						12					2.5	70-85				
083	-						12			~5		4	78-83				
084	-						10-12					3.7	75-86				
085	14.6						10					3.1	75-87				

SAMPLE No.	Particle size, μm	%L+M antigorite	%S anthophyllite	%M calcite	%L chlorite	%S chrysotile	%L dolomite	%L feldspar	%L+M lizardite	%L magnesite	%L mica	%S quartz	%D talc	%S tremolite-actinolite	%other: M opaque particles	%other M	
C86	–						12					5	65-83				
087	8.7	<1					3-5		~3			1.6	85-93	25 (80% fibers)			
088	–			~5 L			~15					4	68-90				
089	9.6			~2	8-10		10-20			15-25		2.4	33-57			~5 ankerite	
090	1.34	~5		1-2	~1 M				~5			22	5-10 M			30 tridymite	25 clay
091	8.4			≪1	1-2			1-5 (plagioclase?)				2.7	88-93				
092	–			5	~1							2.1	77-90	7.5			
093	–			~1	1-3		1-2					1.3	89-95				
094	4.1			5			~5				1-3 biotite	2.3	67-90				
095	3.2			~5	~2		~5	1-3 (plagioclase?)			≤1 M	1.6	59-88				
096	4.13			5-8 L	~1		2-4	1-2 (plagioclase?)			1-2 biotite	1.2	69-90				
097	3.44			8-10 L	≤1		5-8					1.9	72-92				
098	6.05			3-4	92-93 D				0.2			0.8	~1 L			2 rutile	
099	4.33			~2	86-92 D		~5					1.4	2-4 L				
100	8.38			0.3	3-5								94-96	≤1			
101	–			<0.5	1-3			5 (albite?)			1 M	1.7	80-94				
102	–			0.6	90-95 D							1.0	5-10 L				
103	7.05			5-10 L			5-10					1.5	70-93	<0.1			
104	4.95			8			5-10		1-2			1.7	55-77	10			
105	4.66			10-15 L			4-5		1-2			1.2	52-81	10			

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Sample No.	Particle size, μm	% L+M antigorite	% S anthophyllite	% M calcite	% L chlorite	% S chrysotile	% L dolomite	% L feldspar	% L+M lizardite	% L magnesite	% L mica.	% S quartz	% D talc	% S tremolite-actinolite	% other: M opaque particles	% other: M	
106	6.07			8 L			5					1.8	82-93				
107	-			~ 2 L			15				~2 biotite	<0.1 M	78-86				
108	6.67				15		0.5-1					0.75	82-84				
109	4.7				1							1	93-98				
110	2.30				3-4		≤1			40-50		0.1 M	45-55		<1 coal		
111	8.8				1-2					~1			97-98				
112	3.33				6		15			30			45-75		<1 magnetite + coal		
113	3.52				~ 2		2			45			46-57		5 magnetite + coal		
114	6.85	1-2			5-8		1-2			15-20		0.9	66-87		<1 magnetite <1 coal		
115	4.17	1-2	11-18	0.2					1-3			3.8	29-71	44			
116	1.55				<1?		~ 5					0.6	90-94			5 glass	
117	11.2	2-3		1-2 L	2-3		10-15		1-2	10-15		5.5	55-76				
118	4.34	1-2		2-3	82-94 D						~1 muscovite	<0.25	2-3 L				
119	3.58	1-2	7	<1					1-2			3.4	72-73	13.5			
120	4.23	≤2	10.5						2-3			3.2	32-68	37			
121	4.8		11.5-16	<1					1-2			5.5	31-69	45			
122	8.85			5			1-2				1-2 biotite	<0.25	90-93	0.1 (5% fibers) M			
123	5.6			1 L			2				1-3 phlogopite	0.8	93-95	0.01 (50% fibers) M			
124	8.9											3.5	77-85		2-3 coal	10 $Fe_2O_3 \cdot xH_2O$	
125	9.15				80-88 D						5-10 muscovite	5	~1 L		2-3 flyash	1 rutile	