Analysis of Talc by X-ray Diffraction and Polarized Light Microscopy

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U.S. DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
Public Health Service
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ABSTRACT

There has been considerable controversy during the past few years over the composition of talc as used in cosmetic talc products. At one time most of these products were reported to contain chrysotile. Although these data were shown to be erroneous it seemed desirable to examine a large number of raw material talcs from various mines to determine precisely what minerals are present. One hundred talc samples have been analyzed by polarized light microscopy, dispersion staining, x-ray diffraction and, when necessary, by transmission electron microscopy and electron microprobe. The analytical methods were refined in scope, sensitivity and accuracy as a part of the project.

The samples ranged from 1 to 99% talc with an average of 63%. Twenty-three other minerals were identified including the serpentines: antigorite, lizardite and chrysotile, the amphiboles: anthophyllite, tremolite and actinolite; the carbonates: calcite, dolomite, ankerite and magnesite; the talc-like mineral chlorite as well as quartz, mica, feldspars, magnetite, coal, graphite, hydroxyapatite, clays, hydrous iron oxides and rutile. Chrysotile was found in only one sample which, however, contained only 1-2% talc. More than one-third of the samples contained tremolite or actinolite often in major amounts and usually partly fibrous. This report was submitted in fulfillment of Contract No. CDC-210-75-0063 by Walter C. McCrone Associates, Inc. under the sponsorship of the National Institute for Occupational Safety and Health.

CONTENTS

INTRODUCTION

Using the techniques of x-ray diffraction and polarized light microscopy we have analyzed 100 samples of talc powder supplied by NIOSH. When necessary electron microscopy and electron microprobe analysis have been used to supplement the data developed by the other techniques. The purpose of the work was to furnish NIOSH with the analytical results which are tabulated in the attached Data Summary, (Appendix A.) While so doing we have tried to refine the microscopical and x-ray methods used as they apply to the analysis of talc.

METHODS OF ANALYSIS

Each sample was analyzed by x-ray diffraction and microscopy. The x-ray work was done using a Philips x-ray generator and diffractometer. Each sample was first scanned continuously to record a diffraction pattern representing the whole sample. The minerals identified were listed and any questionable peak assignments were noted, for confirmation or resolution by polarized light microscopy including dispersion staining. Quantities of each component were estimated whenever possible, both by polarized light microscopy and from the continuous scan.

X-ray step scanning was done, preferably after microscopy, for amphibole and serpentine minerals and for quartz, in order to determine any quantities of these present in the talc. Results of these three types of analysis were reconciled with each other and then combined and presented in individual reports for each sample.

X-RAY DIFFRACTION

Sample preparation

To insure the best x-ray powder diffraction results the contract specifies that samples in which the average particle size exceeds 10 μm must be ground finer before undertaking x-ray diffraction analysis. Judgment of whether size reduction was necessary was made by determining the particle size distribution microscopically. The sample was used as received if the average particle diameter was below 10 μm. If the average particle was larger than 10 μm, or if the sample was not homogeneous because it contained lumps or huge particles, a 2-gram portion was milled in isopropanol for about 10 minutes in a McCrone Micronizing Mill and dried by slow evaporation to a free flowing powder.

Initially this powder was packed into aluminum cups which rotate in a motor-driven sample holder of our design in the Philips diffractometer. Satisfactory line scans were obtained with this sample mounting technique but step scanning results were not at all reproducible. After experimenting with various methods of mounting the sample, including the use of stationary as well as rotating sample holders, we concluded that the most reproducible results were achieved when the powder was pressed into a pellet and rotated in the sample holder.

We therefore prepared the samples by pressing them in a mold with a die, using a hydraulic press. The half-inch diameter briquettes or pellets thus produced had smooth surfaces which gave very much better reproducibility in step scanning. The aluminum cup was replaced by a flat aluminum disc to which the pellet was attached with a film of (high vacuum) grease. By resting it lightly on the grease the pellet can be leveled either in a leveling press or in the sample holder of the diffractometer, pushing with a flat such as a microscope slide. All crystalline materials used in the sample holder assembly on the surface exposed to the x-ray beam were found to contribute peaks to the line scan. Brass, aluminum and Teflon all caused a certain amount of difficulty in this way. Finally we eliminated all interference except an amorphous band near 16° 2θ by using KEL-F, a stiff fluorocarbon polymer, for all parts of the surface exposed to the x-ray beam. This sample holder is illustrated in the sketch below.

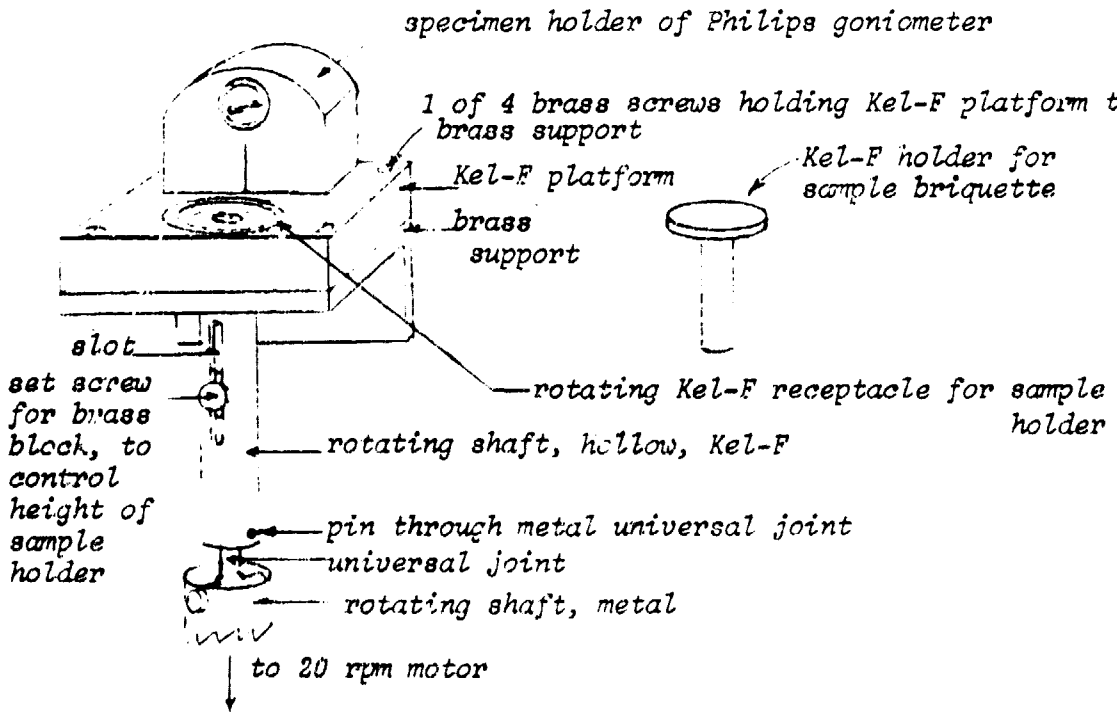

Figure 1. Rotating sample holder for x-ray diffractometer

The chief difficulty encountered with pressed pellets was that they were hard to make with parallel surfaces which, in turn, made them hard to level perfectly in the sample holder. For this reason we have sometimes had to correct the angles in the tables in Sample Data Reports listing step scanning data - we did this only when we were certain from other data of the true identity of the peak in question. The problem of making good pellets has been largely solved by fabricating a new, very well hardened steel mold and die.

Briquetting is thought to have the disadvantage of increasing the preferred orientations of platy minerals such as talc, chlorite and mica. Although a few of the samples were run both as pressed pellets and packed powder it is not possible to determine from the data at hand whether enhancement occurred as a result of briquetting because too many other variables are involved.

Briquetting has the advantage that pellets can be used over and over again, as is necessary for the calibration standards of which the appropriate ones should be rerun every day that step scanning is done. The calibration standards were prepared by weighing out requisite amounts of the standard and of Vermont talc which had been micronized for 60 minutes, mixing in isopropanol either in a Waring Blender or in the micronizing mill, drying and briquetting. Sample and standard pellets are conveniently kept in small glassine envelopes.

Line scanning

All x-ray work was done using nickel filtered copper radiation. A fine-focus Philips tube powered at 42 kV and 25 ma was used for about 80% of the work. The last 20% was done using a standard focus Philips tube at 40 kV and 18 ma. (The step scanning calibration curves were redetermined every time the generator or sample form was changed in any way.)

Line scanning for each sample was done from 4° to 70° 2θ. After considerable experimentation we concluded that because the samples usually are mixtures of several minerals it is best to scan at the most sensitive possible diffractometer settings to bring out small peaks which are due to minor constituents of the sample. This means that the strongest peaks are usually off-scale on the chart. We therefore measure these peak maxima by line scanning at lower sensitivity or by step scanning and the resulting peak intensity data on the line scanning chart.

X-ray line scans recorded in this way provide a good starting point for identifying the components in a talc sample. Beginning at 4° 2θ the peaks encountered and their assignments are as follows in Table 1.

Table 1. X-ray diffraction peak assignments

°2θ CuKα	d, Å	Intensity I/I_1	Peak assigned to	Alternatives	Comments or criteria for choice
6.3	14.0	80	chlorite	vermiculite	chlorites have strong peaks at 12.44°-12.55° and 25.13°; vermiculite has much weaker peaks at 12.39° and 24.99°.
8.75	10.1	100	biotite mica	muscovite, phlogopite,	biotite has a strong peak at 26.42°, muscovite at 26.83°, phlogopites from 26.49° to 26.60°
8.88	9.95	95	muscovite mica	biotite, phlogopite	
9.45	9.35	100	talc	-	-
9.59- -9.69	9.21- -9.12	50	grunerite (amosite)	cummingtonite	neither amphibole found in any talc sample analyzed
9.66- -9.79	9.15- -9.03	20- -80	cummingtonite (montasite)	grunerite	
10.52	8.40	100	riebeckite (crocidolite)	tremolite-actinolite	crocidolite not found in any talc sample; distinguish by microscopy-crocidolite is the only asbestos with negative elongation
10.55	8.38	100	tremolite-actinolite	riebeckite (crocidolite)	
10.61	8.33	100	grunerite (amosite)	cummingtonite (montasite) anthophyllite	anthophyllite has a fairly strong peak at 27.59°; amosite and montasite not found in any talc sample analyzed
10.61- -10.70	8.33- -8.26	70- -55	anthophyllite	grunerite (amosite), cummingtonite (montasite)	
12.01	7.36	100	chrysotile	lizardite	best distinguished by polarized light microscopy with dispersion staining
12.05	7.34	100	lizardite	chrysotile, antigorite	
12.20	7.25	100	antigorite	lizardite	

continued

°2θ CuKα	d, Å	Intensity I/I_1	Peak assigned to	Alternatives	Comments or criteria for choice
12.44- -12.55	7.11- -7.05	100	chlorite	antigorite, chrysotile, lizardite	chlorites have a strong peak near 6.3°
13.04	6.44	60	orthoclase	-	-
17.38	5.10	50	forsterite	-	-
17.48	5.07	16	tremolite	forsterite	look for strong tremolite peak at 10.55°
17.83	4.97	30	muscovite	-	-
18.62	4.76	20	tremolite	chlorite	look for strong tremolite peak at 10.55°
18.78	4.72	80	chlorite	-	-
18.99	4.67	66	talc	anthophyllite	talc peak of intensity 8 enhanced by orientation; look for anthophyllite peaks at 10.70° and 27.59°
18.99	4.67	20	anthophyllite	talc	
19.32	4.59	30	antigorite	lizardite, talc	distinguish serpentines from talc and from each other by microscopy; look for biotite peak at 10.1°
19.32	4.59	50	lizardite	antigorite, talc	
19.32	4.59	20	biotite	talc, lizardite, antigorite	
19.32	4.59	45	talc	lizardite, antigorite	

continued

°2θ CuKα	d, Å	Intensity I/I_1	Peak assigned to	Alternatives	Comments or criteria for choice
19.45	4.56	25	talc	chrysotile	look for chrysotile peak at 12.01°
19.49	4.55	40	chrysotile	talc	chrysotile peak is broad and poorly defined
19.58	4.53	12	talc	-	talc peak seldom observed
19.67	4.51	20	tremolite	anthophyllite	look for anthophyllite peak at 27.59°
19.75	4.49	35	anthophyllite	tremolite	
20.49	4.33	6	talc	-	seldom observed
20.83	4.26	35	quartz	-	-
20.93	4.24	30	antigorite	quartz	look for major peaks or use microscopy
21.03	4.22	45	microcline	tremolite	look for strong microcline peak at 27.50°, tremolite at 10.55° and use microscopy
21.13	4.20	35	tremolite	microcline	
21.55	4.12	6	talc	-	seldom observed
22.04	4.03	?	dolomite	orthoclase	assignable to orthoclase unless a major amount of dolomite present
22.09	4.02	90	orthoclase	dolomite	
22.90	3.88	30	lizardite	orthoclase, forsterite	look for major lizardite peaks at 12.05° and 36.03°; look for strong orthoclase peak at 28.04°, or use microscopy
22.90	3.88	30	orthoclase	forsterite, lizardite	
22.90	3.88	70	forsterite	orthoclase, lizardite	
22.96	3.87	16	tremolite	orthoclase, etc; calcite	look for major tremolite peak at 10.55°

continued

°2θ	d, Å	Intensity I/I_1	Peak assigned to	Alternatives	Comments or criteria for choice
23.02	3.86	12	calcite	tremolite	look for calcite peak at 29.40° and use microscopy
23.39	3.80	80	orthoclase	-	-
23.84	3.73	18	muscovite	-	-
24.10	3.69	5	dolomite	-	observed only when much dolomite present
24.36	3.65	60	chrysotile	lizardite	use polarized light microscopy with dispersion staining
24.50	3.63	60	lizardite	chrysotile, antigorite	
24.62	3.62	60	antigorite	lizardite	
25.13	3.54	80	chlorite	serpentines	look for chlorite peak at 6.3°
25.90	3.43	1	talc	-	nearly always present
26.38	3.376	40	tremolite	biotite	look for tremolite peak at 10.55°
26.42	3.37	100	biotite	tremolite	look for biotite peak at 8.75°
26.64	3.343	100	quartz	micas	look for quartz peak at 20.83°
26.66	3.34	25	muscovite	quartz	look for muscovite peak at 26.83°
26.83	3.32	100	muscovite	-	-
27.08	3.29	50	microcline	-	-

continued

°2θ CuKα	d, Å	Intensity I/I_1	Peak assigned to	Alternatives	Comments or criteria for choice
27.26	3.268	75	tremolite	grunerite (amosite)	use microscopy; grunerite has higher refractive indices
27.33	3.26	80	grunerite (amosite)	tremolite	
27 50	3.24	100	microcline	anthophyllite	look for anthophyllite peak at 10.70° and microcline peak at 27.08°; use microscopy
27.59	3.23	50	anthophyllite	microcline	
27.94	3.19	30	muscovite	orthoclase	look for muscovite peaks: 8.88° and 26.83°
28.03	3.18	100	orthoclase	muscovite	
28.58	3.12	55	riebeckite (crocidolite)	talc tremolite	use microscopy; crocidolite has negative elongation
28.58	3.12	100	talc	tremolite actinolite, riebeckite	enhanced by orientation; look for talc peak at 9.45°
28.59	3.121	100	tremolite	talc	look for tremolite-actinolite peak at 10.55° and talc peak at 9.45°
28.68	3.11	100	actinolite	talc	
29.17	3.06	100	anthophyllite	calcite, grunerite	look for anthophyllite peaks at 10.70° and 27.59°
29.17	3.06	90	grunerite (amosite)	anthophyllite	use microscopy-grunerite has oblique extinction
29.40	3.035	100	calcite	anthophyllite	look for calcite peak at 23.02°; use microscopy

continued

°2 θ CuKα	d, Å	Intensity I/I_1	Peak assigned to	Alternatives	Comments or criteria for choice
29.90	2.987	35	muscovite	—	—
30.40	2.938	40	tremolite	—	—
30.96	2.886	100	dolomite	—	—
31.26	2.859	25	muscovite	—	—
31.47	2.84	50	chlorite	—	—
31.88	2.805	45	tremolite	—	—
32.48	2.754	70	grunerite (amosite)	magnesite	look for amosite peak at 10.61°
32.63	2.742	100	magnesite	grunerite	confirm magnesite by microscopy
32.78	2.726	40	riebeckite (crocidolite)	magnesite	look for crocidolite peak at 10.52° or use microscopy
33.09	2.705	90	tremolite	—	—
33.53	2.670	10	dolomite	biotite	seen if much dolomite present; use microscopy
33.66	2.66	80	biotite	—	—
34.42	2.603	80	chlorite	—	—
34.58	2.592	30	tremolite	chlorite	look for tremolite peak at 10.55°
34.94	2.566	55	muscovite	chlorite	look for muscovite peaks at 8.88° and 26.83°
35.15	2.558	70	chlorite	muscorite	look for chlorite peak at 6.3°
35.46	2.529	40	tremolite	antigorite, biotite	look for tremolite peak at 10.55°
35.59	2.52	90	antigorite	biotite	look for antigorite peak at 12.20°
35.60	2.52	40	biotite	antigorite	look for biotite peak at 8.75°
35.71	2.512	70	forsterite	—	—
35.84	2.503	18	magnesite	calcite	look for magnesite peak at 32.63°

continued

°2θ CuKα	d, Å	Intensity I/I_1	Peak assigned to	Alternatives	Comments or criteria for choice
35.96	2.495	14	calcite	magnesite, lizardite	look for calcite peak at 29.40°
36.03	2.49	100	lizardite	calcite	look for lizardite peak at 12.05°
36.25	2.476	65	talc	—	—
36.52	2.458	80	chlorite	forsterite, quartz	look for chlorite peak at 26.64°, forsterite peaks at 17.38° and 22.90°
36.52	2.458	100	forsterite	chlorite, quartz	
36.52	2.458	12	quartz	chlorite, forsterite	
36.65	2.45	40	chrysotile	biotite	look for chrysotile peak at 12.01°
36.65	2.45	80	biotite	chrysotile	look for biotite peak at 8.75°
37.36	2.405	10	dolomite	—	—
37.70	2.384	25	muscovite	tremolite	look for muscovite peaks at 8.88° and 26.83°
37.76	2.380	30	tremolite	muscovite	look for tremolite peak at 10.55°
38.48	2.337	16	talc	tremolite	peak enhanced by orientation; look for talc peak at 9.45°
38.52	2.335	30	tremolite	talc	—
38.76	2.321	40	tremolite	—	—
39.31	2.285	18	calcite	quartz	look for calcite peak at 29.40°; use microscopy
39.45	2.282	12	quartz	calcite	look for quartz peak at 26.64°
40.28	2.237	6	quartz	—	—
41.14	2.192	30	dolomite	—	—
41.38	2.18	80	biotite	—	—
41.72	2.163	35	tremolite	antigorite	look for tremolite peak at 10.55°

continued

°2θ CuKα	d, Å	Intensity I/I_1	Peak assigned to	Alternatives	Comments or criteria for choice
41.78	2.16	40	antigorite	microcline	look for antigorite peak at 12.20°
41.78	2.161	30	microcline	antigorite	look for microcline peaks at 27.08° and 27.50°;use microscopy
41.99	2.15	60	lizardite	—	—
42.25	2.13	45	talc	—	—
42.44	2.128	9	quartz	—	seen only when much quartz present
42.99	2.102	45	magnesite	—	—
43.14	2.095	18	calcite	—	—
43.25	2.09	10	chrysotile	calcite	not seen in line scan of standard
44.95	2.015	15	dolomite	tremolite	look for dolomite peak at 30.96°
44.95	2.015	45	tremolite	dolomite	look for tremolite peak at 10.55°
45.30	2.000	60	chlorite	biotite	look for chlorite peak at 6.3°
45.30	2.000	80	biotite	chlorite	look for biotite peak at 8.75
45.47	1.993	80	muscovite	—	—
45.79	1.980	6	quartz	—	seen when much quartz present
46.81	1.939	12	magnesite	—	—
48.04	1.892	50	tremolite	—	—
48.50	1.875	17	calcite	talc	look for calcite peak at 29.40° or use microscopy
48.64	1.870	40	talc	calcite	look for talc peak at 9.45°
50.08	1.817	17	quartz	—	—
50.55	1.804	20	dolomite	—	—
51.17	1.786 1.781	30	dolomite	—	—
51.62	1.769	4	magnesite	—	—
53.88	1.700	35	magnesite	—	—

continued

°2θ CuKα	d, Å	Intensity I/I_1	Peak assigned to	Alternatives	Comments or criteria for choice
55.03	1.672	7	quartz	—	—
55.70	1.649	40	tremolite	—	—
57.40	1.604	8	calcite	—	—
58.89	1.567	8	dolomite	—	—
59.09	1.562	40	antigorite	—	doublet with peak at 60.20°
59.60	1.550	70	chlorite	—	—
59.80	1.545	10	dolomite	—	—
59.98	1.541	15	quartz	biotite	look for quartz peaks at 26.64° and 20.83°
60.02	1.54	80	biotite	quartz	look for biotite peak at 8.75°
60.20	1.536	40	antigorite	—	doublet with peak at 59.09°
60.24	1.535	60	chrysotile	antigorite	chrysotile has single peak, antigorite has doublet (59.09° and 60.20°)
60.41	1.531	70	lizardite	talc	doublet with peak at 61.80°
60.50	1.529	55	talc	—	—
60.58	1.527	40	talc	—	—
61.80	1.500	60	lizardite	anthophyllite	doublet with peak at 60.41°
61.80	1.500	25	anthophyllite	lizardite	look for anthophyllite peaks at 10.70° and 27.59°
62.35	1.488	6	magnesite	—	—
65.38	1.426	4	magnesite	—	—
67.09	1.394	20	talc	—	—
67.36	1.389	15	dolomite	—	—
67.74	1.382	7	quartz	—	—
68.14	1.375	11	quartz	—	—

continued

°2θ CuKα	d, Å	Intensity I/I_1	Peak assigned to	Alternatives	Comments or criteria for choice
68.30	1.372	9	quartz	—	—
68.36	1.371	4	magnesite	quartz	look for magnesite peak at 32.63°, or use microscopy
69.00	1.36	60	biotite	—	—
69.34	1.354	8	magnesite	—	—

Step scanning

Samples were analyzed for tremolite, anthophyllite, chrysotile and quartz by step scanning. Because the samples are mixtures, sometimes very complex, it is better to step scan the strongest peak of each mineral that is reasonably interference-free than to use too weak a peak, e.g., the 1.54A line of quartz, even though it is better resolved from interfering substances. The regions chosen on this basis for step scanning are as follows:

		Line	Region
actinolite - tremolite		(2θ = 10.55°, 8.38A):	10.30° - 10.70° 2θ
anthophyllite		(2θ = 10.70°, 8.26A):	10.60° - 10.90° 2θ
	or	(2θ = 27.59°, 3.23A):	27.50° - 27.80 2θ
chrysotile		(2θ = 12.01°, 7.36A):	11.90° - 12.40 2θ
quartz		(2θ = 26.65°, 3.343A):	26.55° - 26.75° 2θ

Counting times of 100 seconds and steps of 0.01° 2θ were found best. Some peaks were scanned using shorter counts, especially when microscopy had indicated the absence of the mineral being sought. In no case, however, was the shorter count ever less than 30 seconds and usually we used 50 seconds.

Interference with the 10.55° 2θ tremolite-actinolite peak was essentially nil but the tail of this peak overlaps the anthophyllite peak at 10.70°, making a weak anthophyllite peak difficult to distinguish. As an alternative the anthophyllite peak at 27.59° can be used except when an interfering mineral such as microcline is present, as in Sample 076.

Chrysotile was detected in only one sample, No. 048, by light microscopy with no detection by step scanning. The chrysotile peak at 12.01°, the lizardite peak at 12.05° and the antigorite peak at 12.20° may not always be distinguishable from one another. Since other serpentine peaks in the line scan do not always stand out we have relied more upon microscopy to confirm which polymorphs are present, than upon the criteria for x-ray peak assignments given by Mumpton*, although the latter are useful when the serpentine concentration is great enough.

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* Mumpton, Frederick A. Characterization of Chrysotile Asbestos and Other Members of the Serpentine Group of Minerals, Siemens Review XLI (1974), Seventh Special Issue, X-ray and Electron Microscopy News.

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.

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* 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 /m in diameter, <200 μm in length and have a length to width ratio of at least 3:1.

Cargille high dispersion liquid $n_D^{25} = 1.550$:

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.*

Cargille high dispersion liquid $n_D^{25} = 1.585$

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.

Cargille high dispersion liquid $n_D^{25} = 1.605$:

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

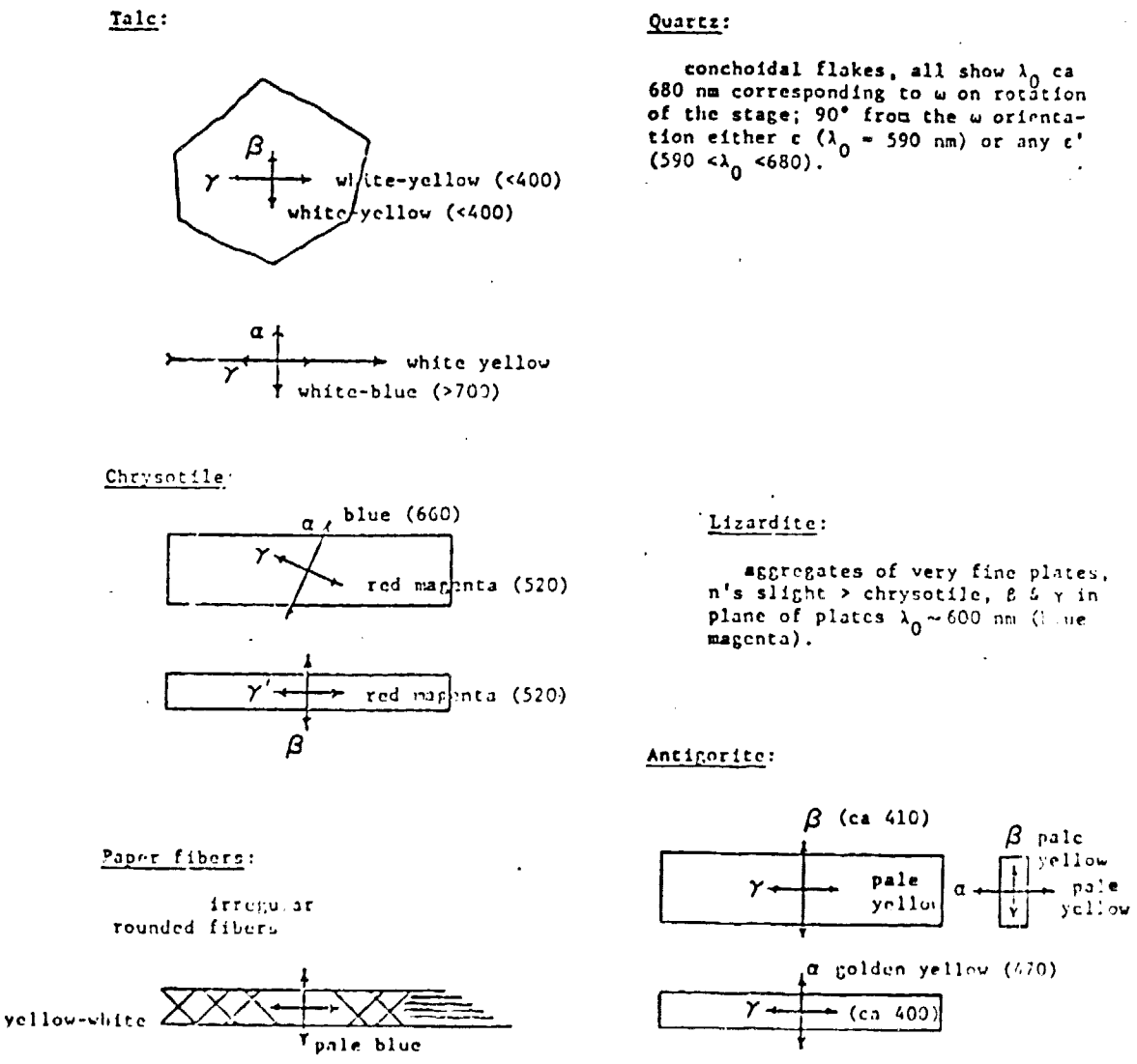


Figure 2. Central stop dispersion staining colors in Cargille liquid $n_D^{25} = 1.550$ (HD series).

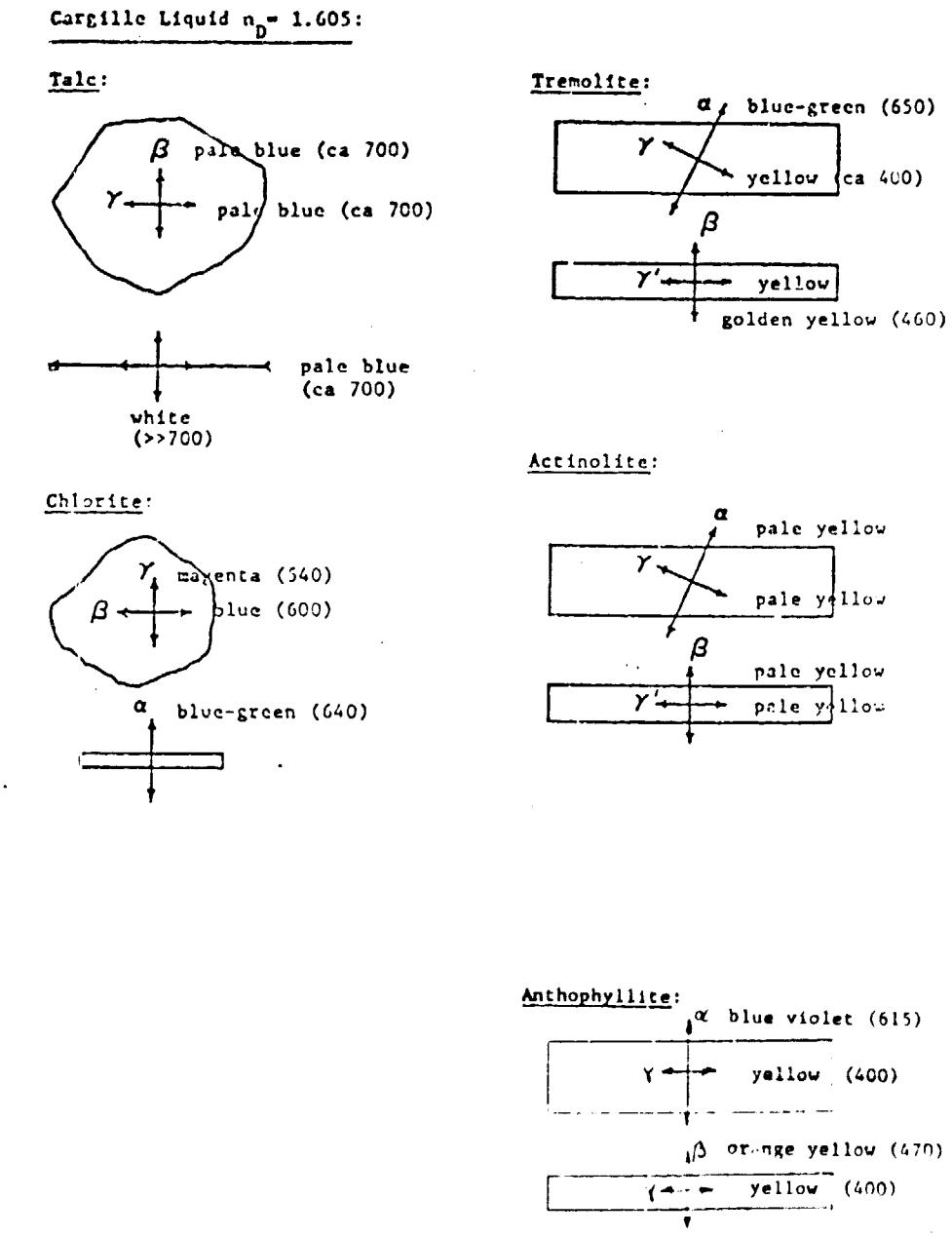


Figure 3. Central stop dispersion staining colors in Cargille liquid n_D^{25}= 1.605 (HD series).

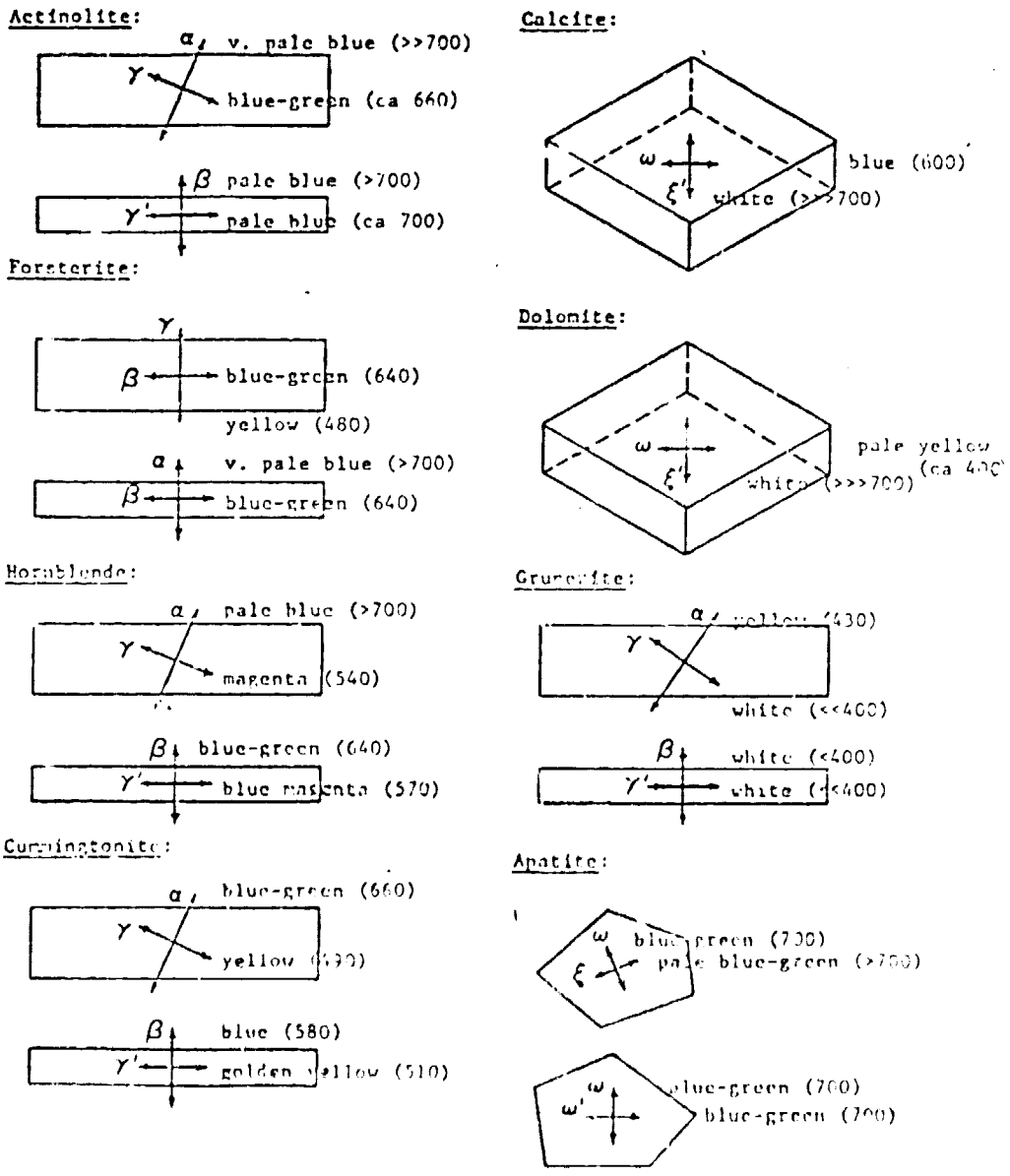


Figure 4. Central stop dispersion staining colors in Cargille liquid $n_D^{25} = 1.660$ (RF series).

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.

Cargille Liquid n_D = 1.700:

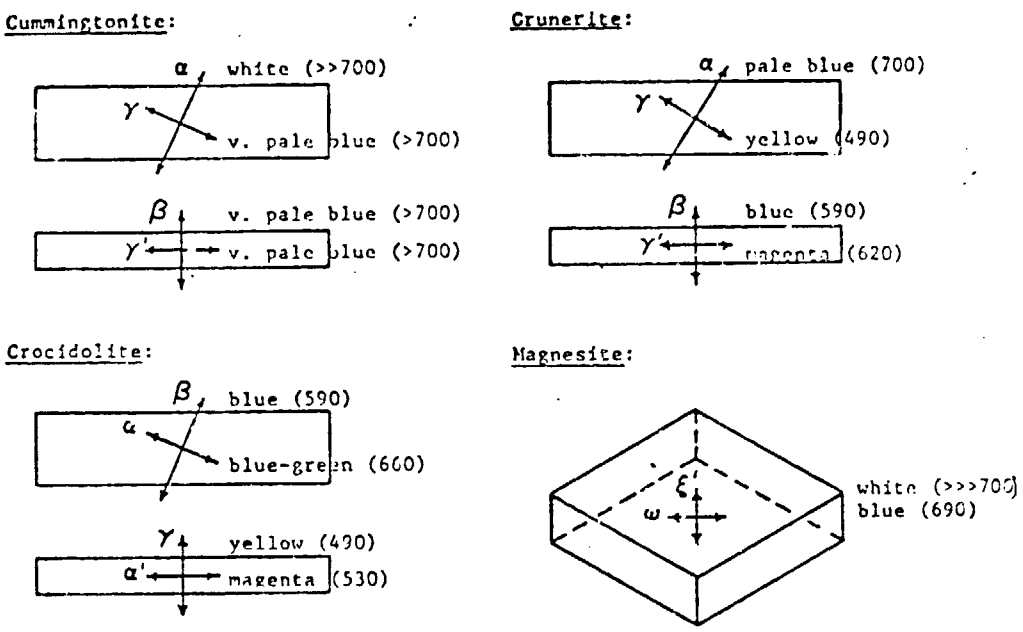


Figure 5. Central stop dispersion staining colors in Cargille liquid n_D^{25} = 1.700 (M series).

Appropriate samples of these minerals appear on the analytical dispersion staining chart, Appendix C, which also includes antigorite, calcite, dolomite, forsterite, grunerite (amosite), magnesite and riebeckite (crocidolite).

CALIBRATION CURVES

The first five mineral standards listed were used to prepare the briquettes for step scanning calibration as described on page 3 of this report. Using these briquettes calibration data were determined for quartz, chrysotile, tremolite and anthophyllite mixed with Vermont talc. The calibration curves follow as Figures 6 through 15. In each figure at least two curves are plotted, one based on integrated intensity and one on maximum peak height. In most regions both curves have slopes similar enough so that either could be used analytically. When this was not the case the integrated intensity curve was used. Curves were redetermined completely for the last 20 samples which, because of generator breakdown had to be run using the standard focus tube at lower power. Curves were checked at least after every tenth sample, as specified in the contract, but it was found better to check calibration every day that step scanning was done, i.e., after every one to three sample. Three methods of determining the integrated intensity were compared: totalling the heights of uniform steps under the peak, finding the area under the plotted peak by planimetry or squre-counting (Figure 9) and cutting out and weighing the plotted peak (Figure 11). Since we found that all three methods gave equivalent results we made the greatest use of the first because it required less curve plotting.

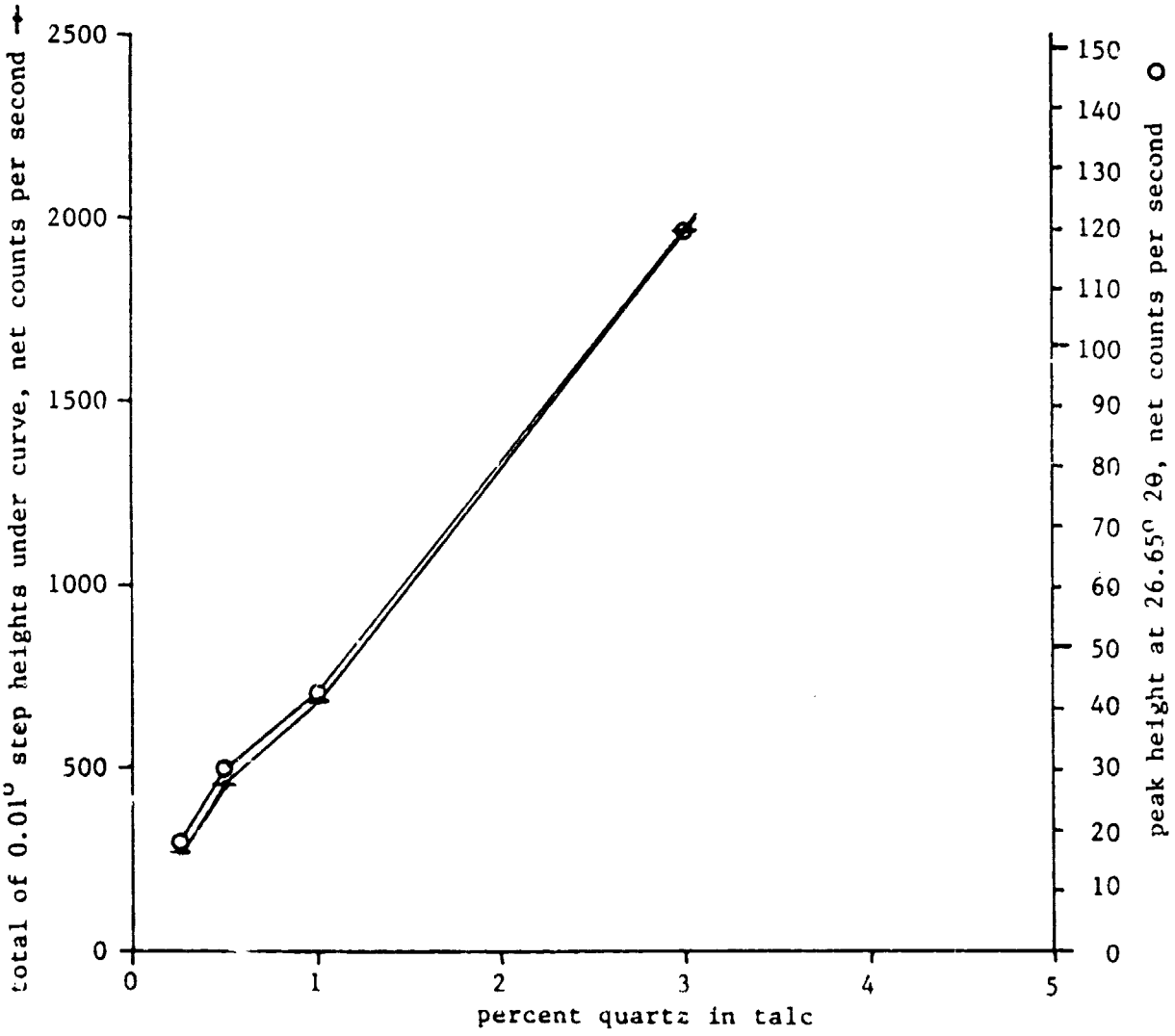


Figure 6. Calibration curves, 0.25 - 3% quartz in talc, 3.343 Å peak, nickel-filtered copper radiation at 42 kv and 25 ma.

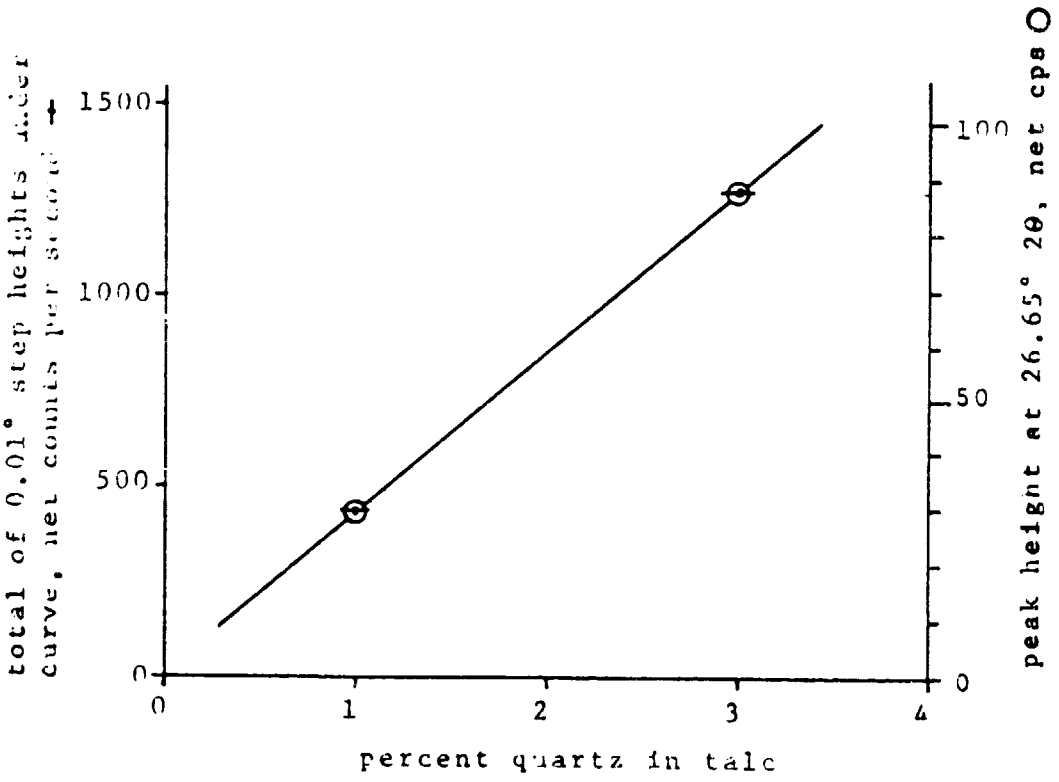


Figure 7. Calibration curves (coincident), 1-3% quartz in talc, 3.343 Å peak, nickel-filtered copper radiation at 40 kv and 18 ma.

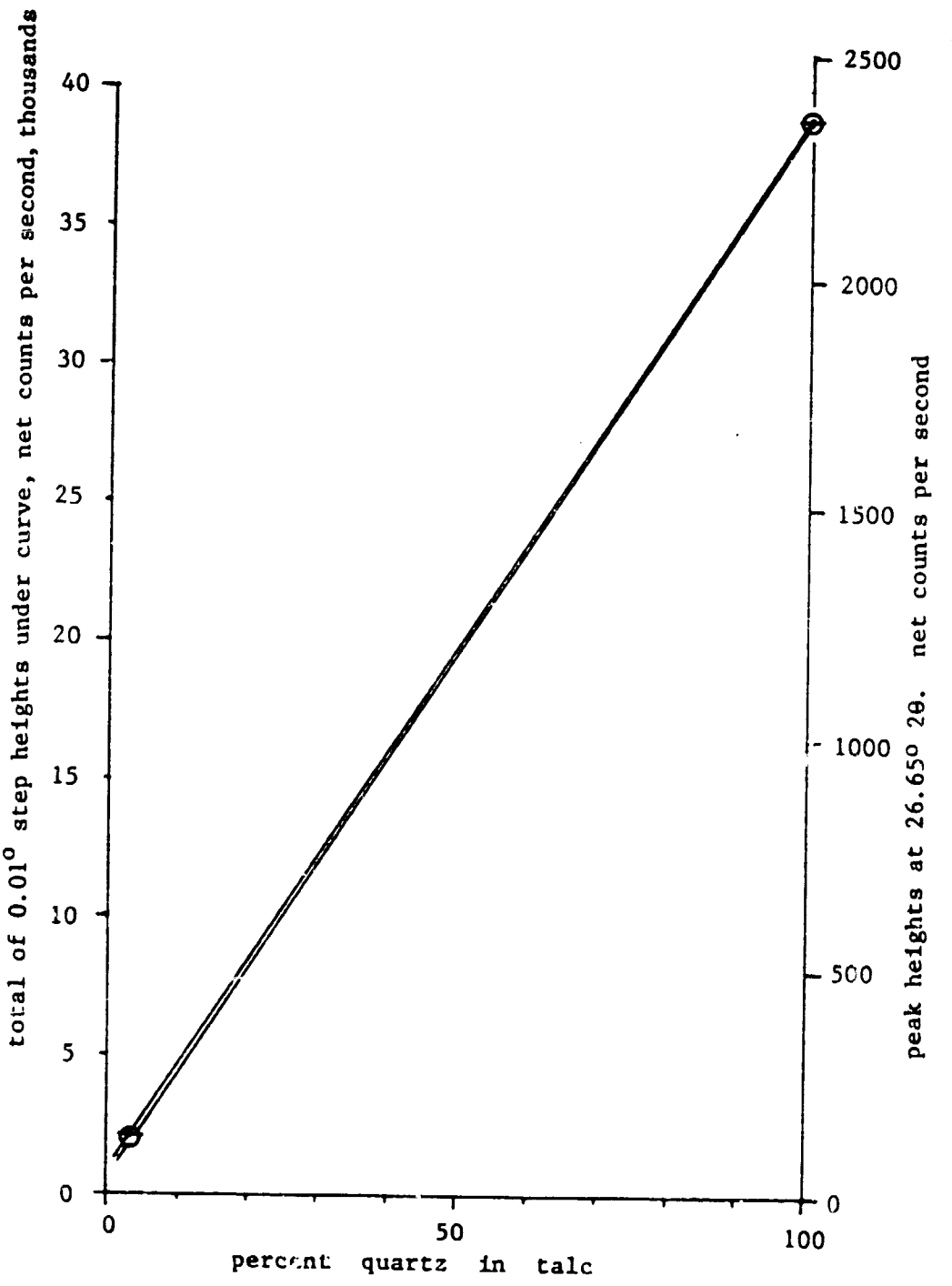


Figure 8. Calibration curves, 3 - 100% quartz in talc, 3.343 Å peak, nickel-filtered copper radiation at 42 kv and 25 ma.

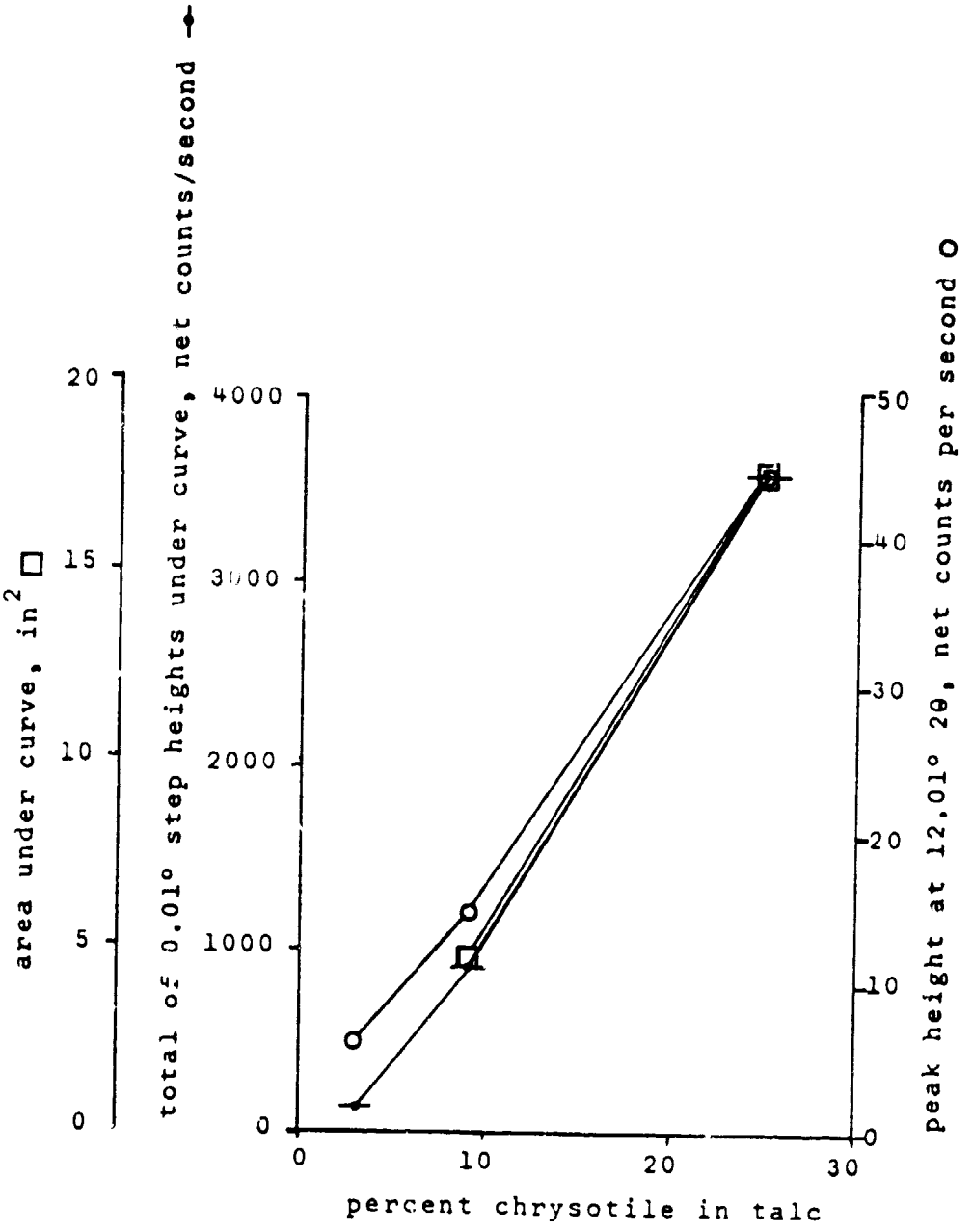


Figure 9. Calibration curves, 3 - 25% chrysotile in talc, 7.36 Å peak, nickel-filtered copper radiation at 42 kv and 25 ma.

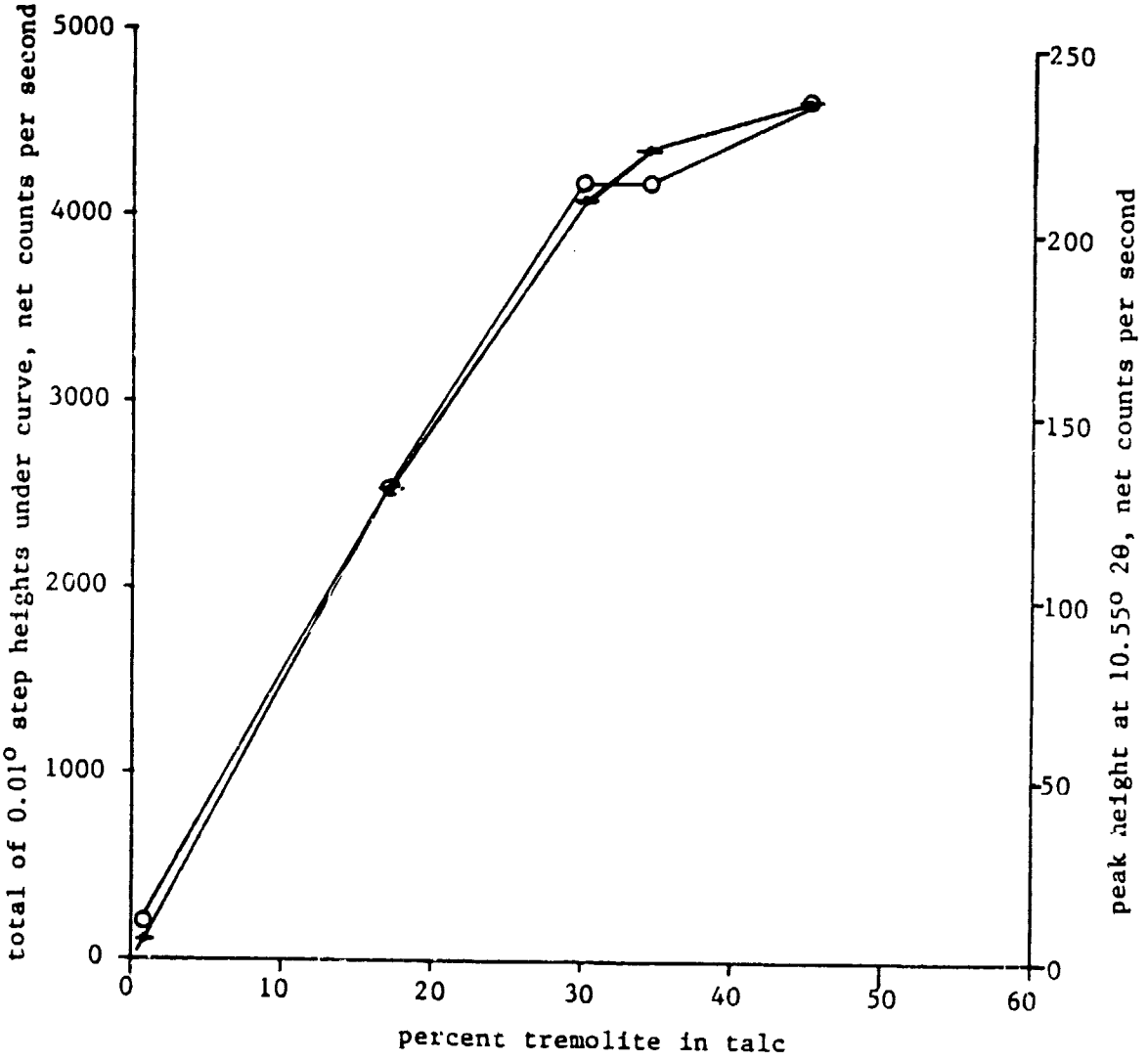


Figure 10. Calibration curves, 1 - 45% tremolite in talc, 8.38 Å peak, nickel-filtered copper radiation at 42 kv and 25 ma.

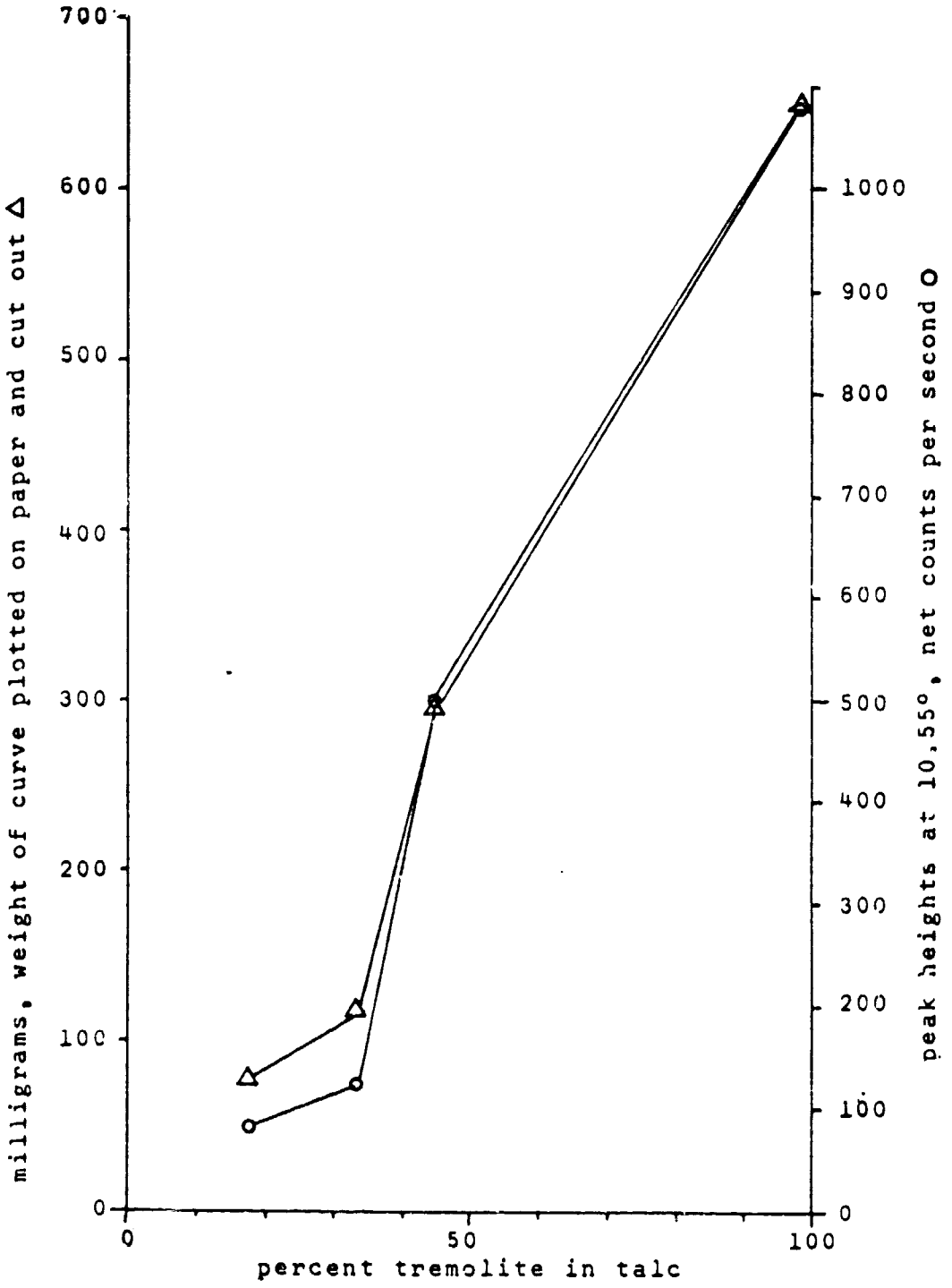


Figure 11. Calibration curves, tremolite (17- 98%) in talc, 8.38 Å peak, nickel-filtered copper radiation at 40 kv and 18 ma.

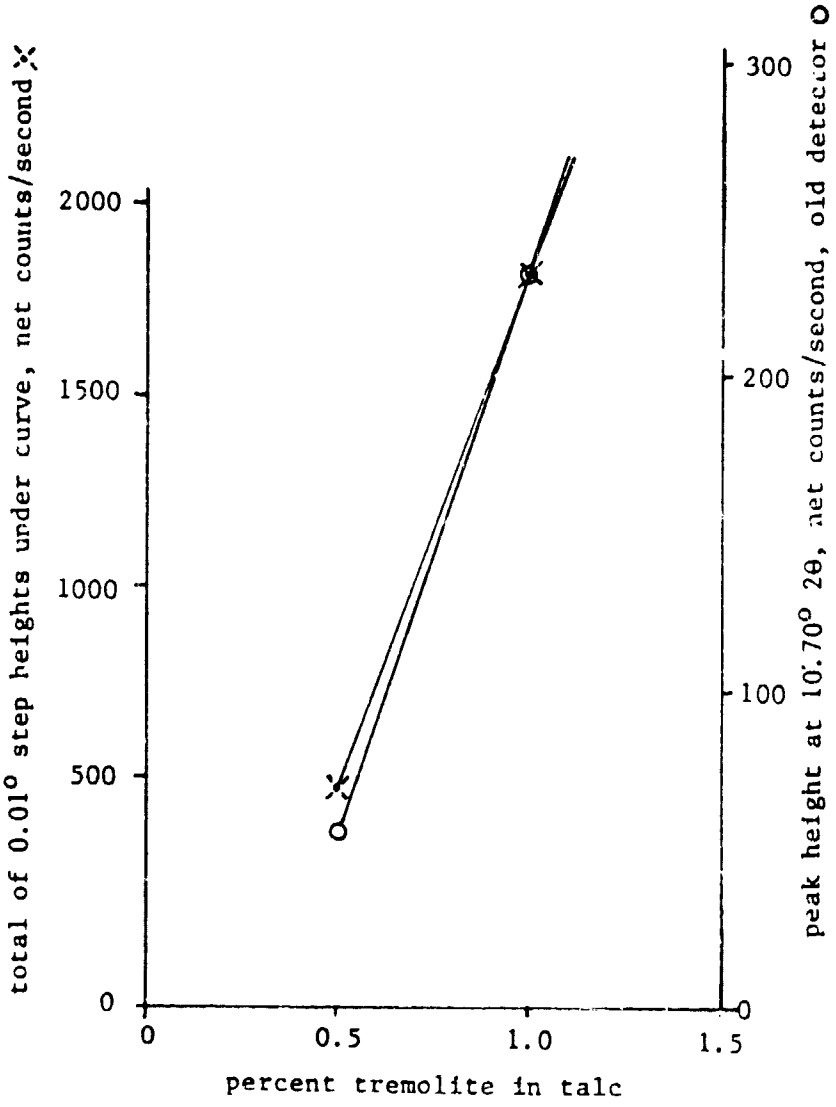


Figure 12. Calibration curves, 0.5 - 1.0% tremolite in talc, 8.38 Å peak, nickel-filtered copper radiation at 42 kv and 25 ma, old detector.

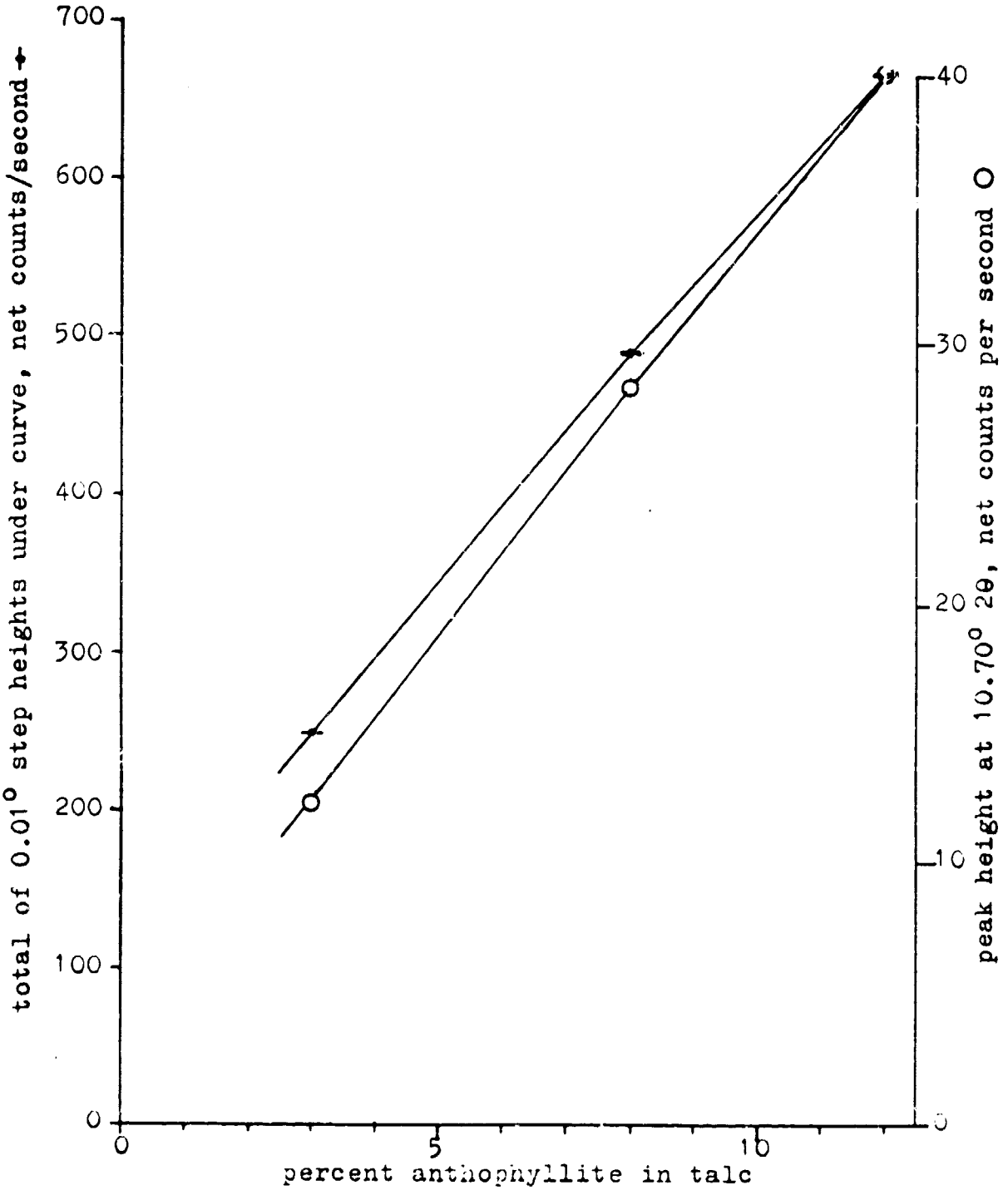


Figure 13. Calibration curves, 3 - 12% anthophyllite in talc, 8.26 Å peak, nickel-filtered copper radiation at 42 kv and 25 ma.

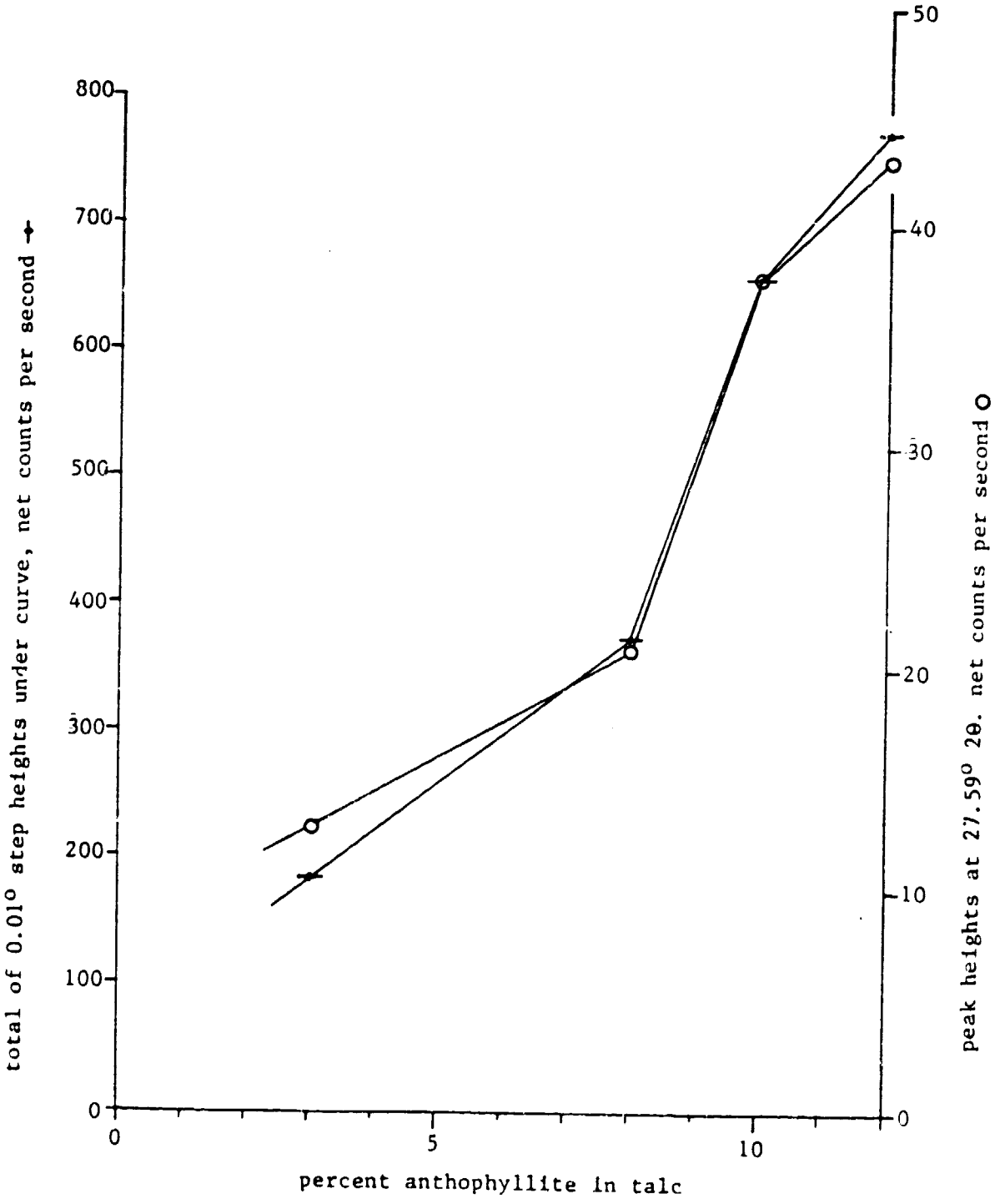


Figure 14. Calibration curves, 3 - 12% anthophyllite in talc, 3.23 Å peak, nickel-filtered copper radiation at 42 kv and 25 ma.

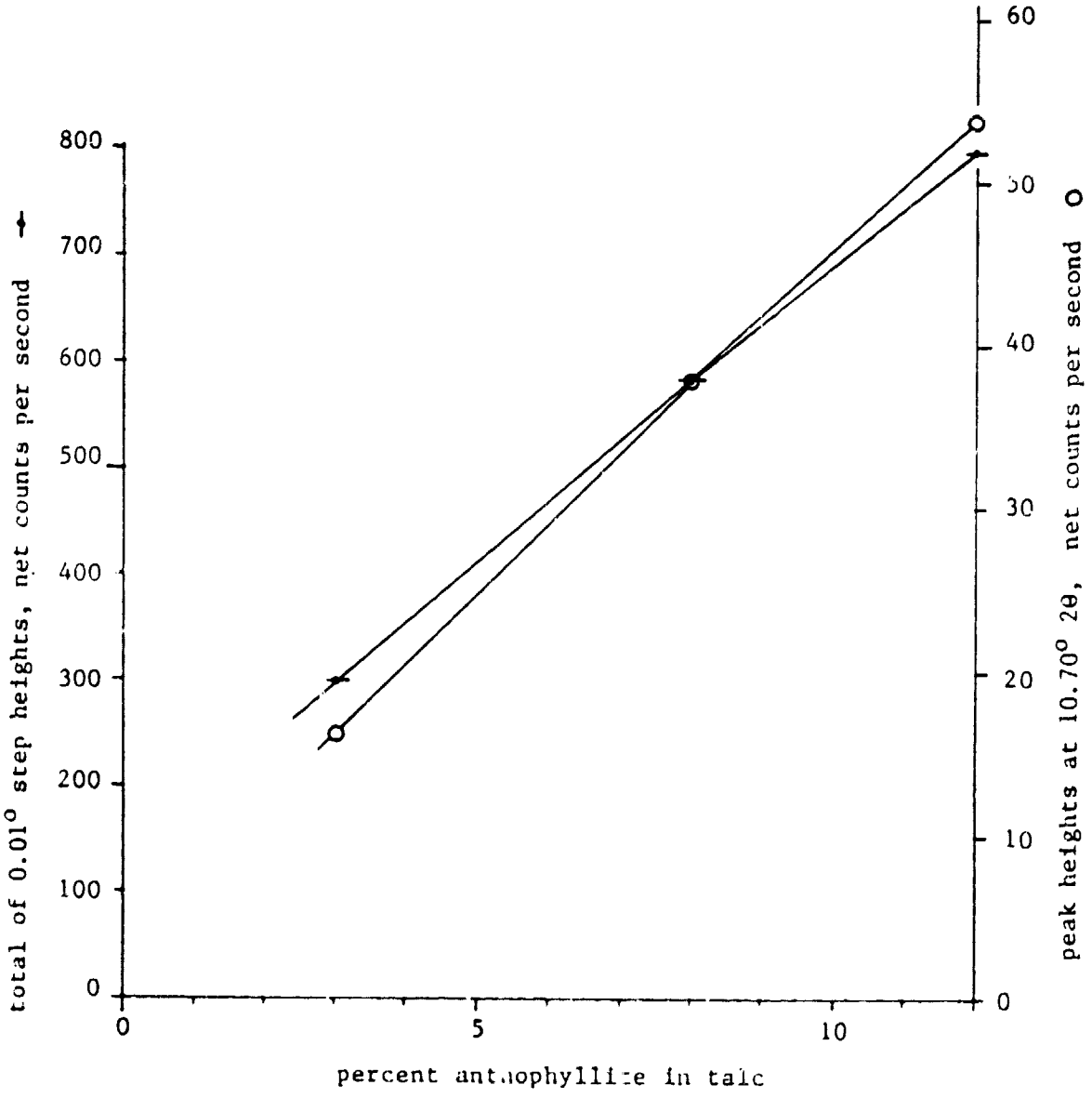


Figure 15. Calibration curves, 3 - 12% anthophyllite in talc, 8.26 Å peak, nickel-filtered copper radiation at 40 kv and 18 ma.

SAMPLE COMMENTARY

The purpose of this section is to put down some random observations concerning certain samples or the set of samples as a whole.

1. No amosite (grunerite) or crocidolite (riebeckite) asbestos was detected in any sample.

2. Chrysotile was found only in one sample, No. 048. This is not really a talc sample about 70% of it consists of the olivine, forsterite, and only one or two percent of talc. The amount of chrysotile was estimated at 4-5% by microscopy and a similar amount of antigorite was also detected by x-ray diffraction.

3. Two other samples, 062 and 063, contained modest amounts of forsterite (5%) but no chrysotile or antigorite, though a little lizardite was noted in Sample 062. One percent or less of magnetite, Fe_3O_4, was common to the three forsterite-containing samples.

4. Tridymite was found in one sample only, No. 090, at a level of 30%. This sample contained 22% quartz and 25% clay but only 5-10% talc.

5. Small amounts of magnetite, Fe_3O_4, were found in many samples but one sample, No. 077, contained 15%. No other sample contained nearly this much.

6. Anthophyllite was not detected unless at least 8% of tremolite-actinolite was also present. It was found in all samples containing 13% or more tremolite.

7. Tremolite and/or actinolite were found in large quantities, up to nearly 60%, in many samples. Emphasis on the Gouverneur talcs partly explains why so many were found.

8. Quartz was present in all but nine of the 100 samples. The maximum quartz contents of 21% and 22% occurred in two samples, 055 and 090, which appear to be related only by their low talc content otherwise.

9. There were ten very pure talc samples: 009, 057, 067, 068, 069, 071, 072, 109 and 111. The purest of them is 057. Impurities, which differed in each sample, were chlorite, dolomite, quartz, magnesite and mica.

10. Seven samples contained more than 50% of chlorite: 053, 076, 098, 099, 102, 118 and 125. Rutile, TiO_2, was identified in two of these samples.

11. Eight samples had high magnesite contents, from 30 to 50 percent, and fourteen samples were high in dolomite, 10 - 20%. High calcite content was uncommon; one sample, No. 105, contained up to 15% and four others were in the 8 to 10 percent range. One sample, 073, contained 90% of dolomite.

APPENDIX A

Data Summary

Appendix A is a five page table which summarizes the analytical results for each of the 100 samples. Four methods of quantitation were used and are coded as follows:

method	code
x-ray diffraction step scanning	S
x-ray diffraction line scanning	L
polarized light microscopy	M
difference	D

The method usually used in finding the quantity of a given mineral is noted after the % sign in the column heading for that mineral. When a method different from that noted in the heading was used the letter code for that method follows the percentage listed in the table for the particular sample.

In the case of tremolite-actinolite "% fibers" means the percentage of the total tremolite and/or actinolite that is fibrous, as contrasted with massive particles. This was, of course, always determined by polarized light microscopy with the use of dispersion staining.

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	<0.6			<0.5M		~20			0.2	~41	33 (25% fibers)			
007	4.15		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	hydroxyapatite
035	28.9				3-4		~1			40-50	<1 (biotite)	<0.25	45-55		<1 coal <1 magnetic		
036	3.21				~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	6.2		0?		10-15		~5		10-15		~5 (biotite)	1.7	50-60	6.5 (1-2% 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)			

CONTINUED

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 (5% 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	7.73		9	~5 L	~10		2-3 M	6 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			

CONTINUED

No.	E	Size, μm	% antigorite	% anthophyllite	% calcite	% chlorite	% chrysotile	% dolomite	% feldspar	% lizardite	% magnesite	% mica	% quartz	% talc	% 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		8.61			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				

CONTINUED

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	
086	–						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			

CONTINUED

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	2.50				3-4		<1			40-50		0.1 M	45-55		<1 coal	
111	8.8				1-2					~1			97-98			
112	3.93				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

% Fibers = % of total tremolite

APPENDIX B

Appendix B consists of 13 x-ray line scans of known minerals, as listed below.

Figure B-1	X-ray line scan of Vermont talc, full scale = 2000 counts/second
Figure B-2	X-ray line scan of Vermont talc, full scale = 500 counts/second
Figure B-3	X-ray line scan of anthophyllite, Cashiers, NC
Figure B-4	X-ray line scan of anthophyllite, Guffey, CO
Figure B-5	X-ray line scan of anthophyllite, Haddam, CT
Figure B-6	X-ray line scan of chrysotile, Victory Mine, Globe, Gila County, AZ
Figure B-7	X-ray line scan of lizardite, Kennack Cove, Cornwall, England
Figure B-8	X-ray line scan of α-quartz, synthetic
Figure B-9	X-ray line scan of fibrous tremolite, Dahl Creek, AK
Figure B-10	X-ray line scan of tremolite, Fowler, NY
Figure B-11	X-ray line scan of actinolite, Lake Wenatchee, WA
Figure B-12	X-ray line scan of chlorite, Calaveras County, CA
Figure B-13	X-ray line scan of prochlorite, Chester, VT

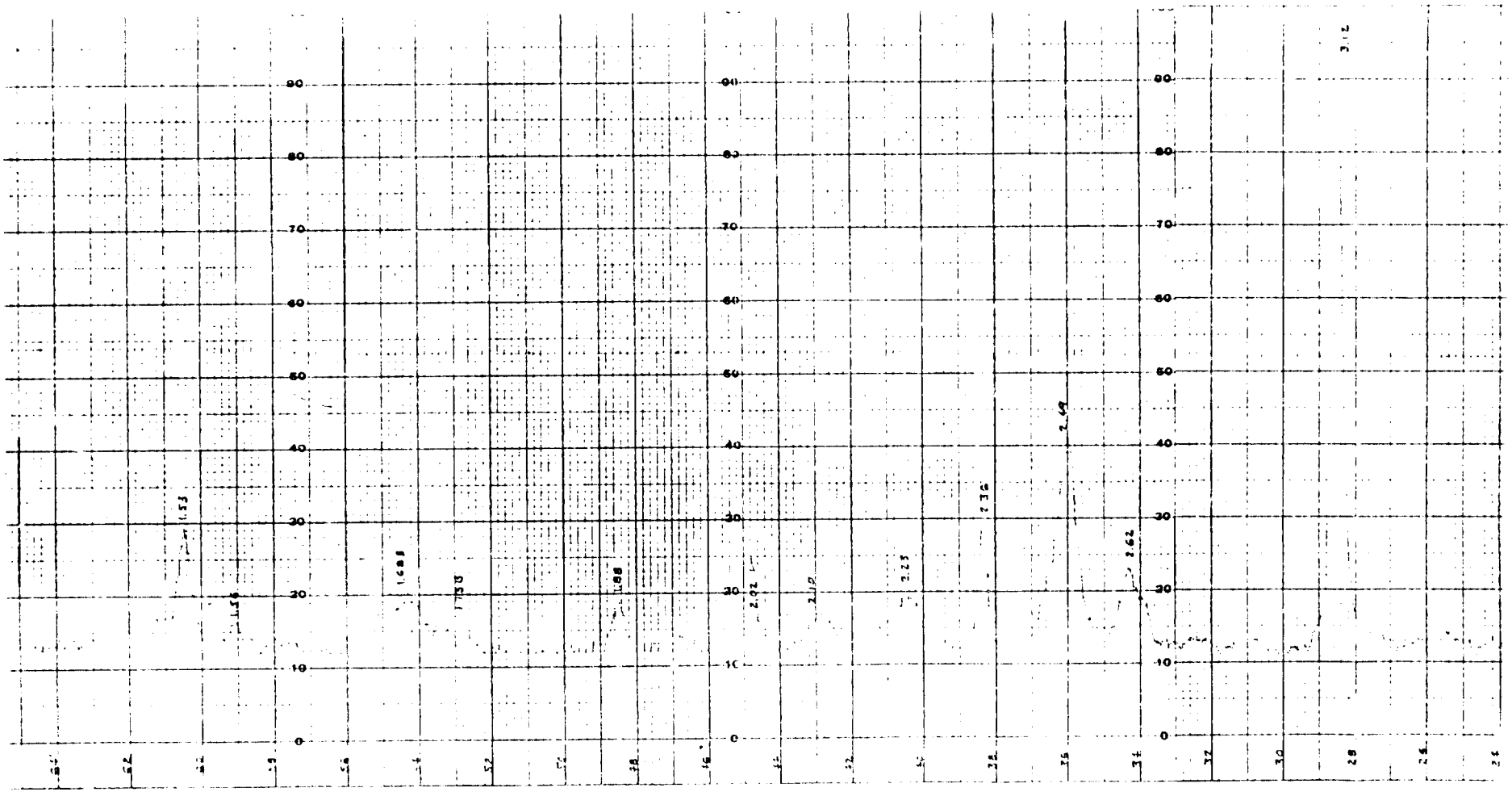
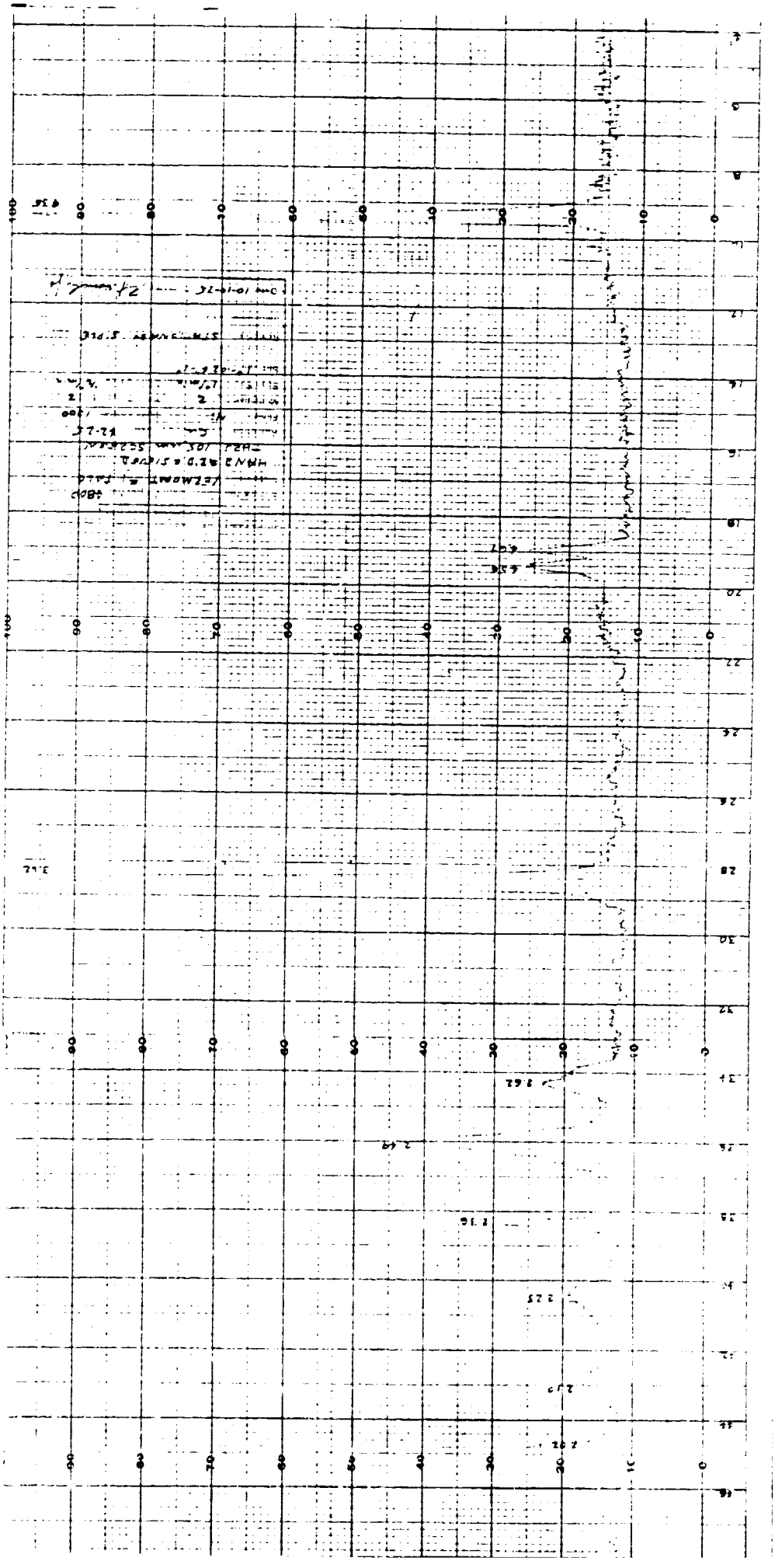


Figure B-1. X-ray line scan of Vermont talc, full scale = 2000 counts/second



/second

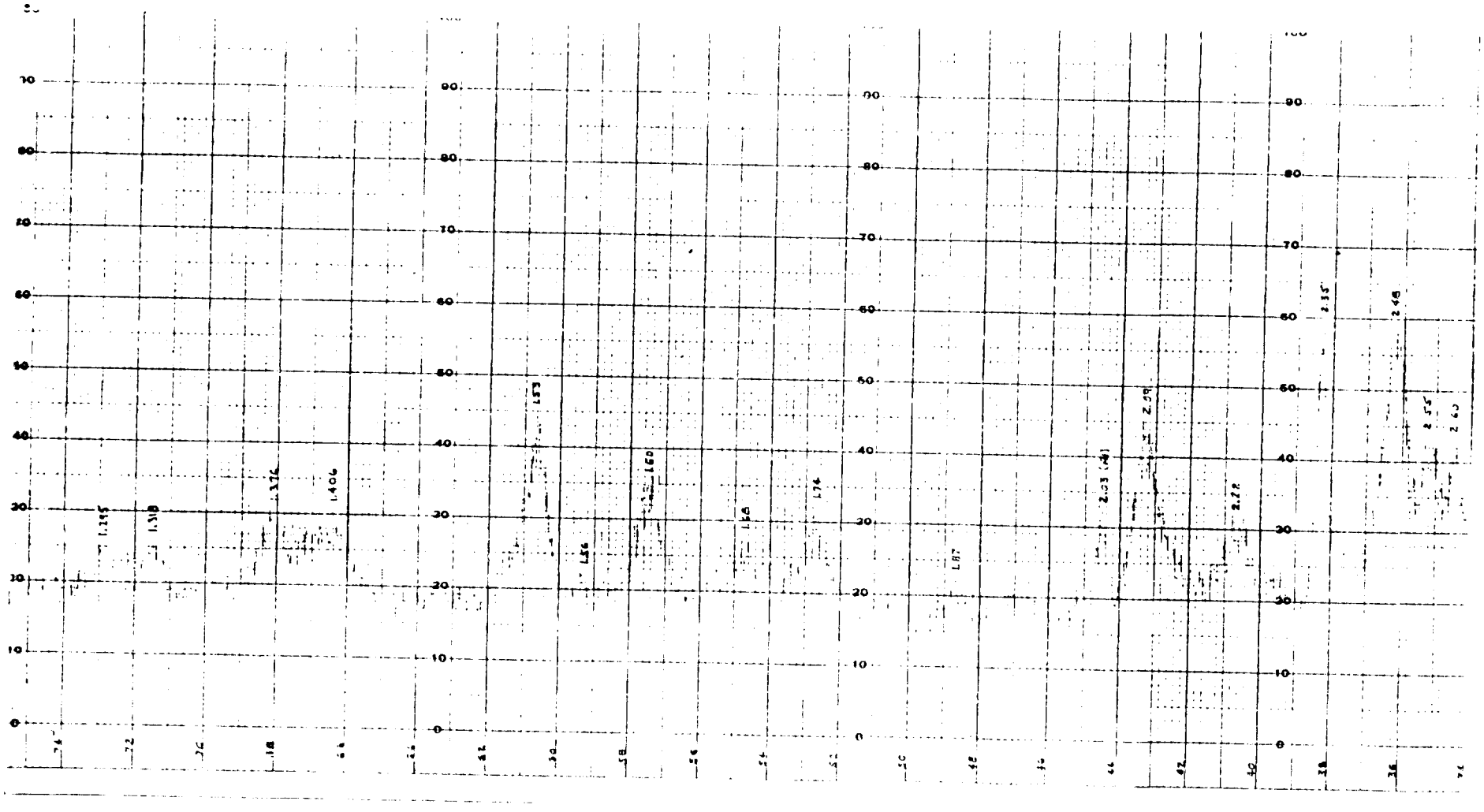
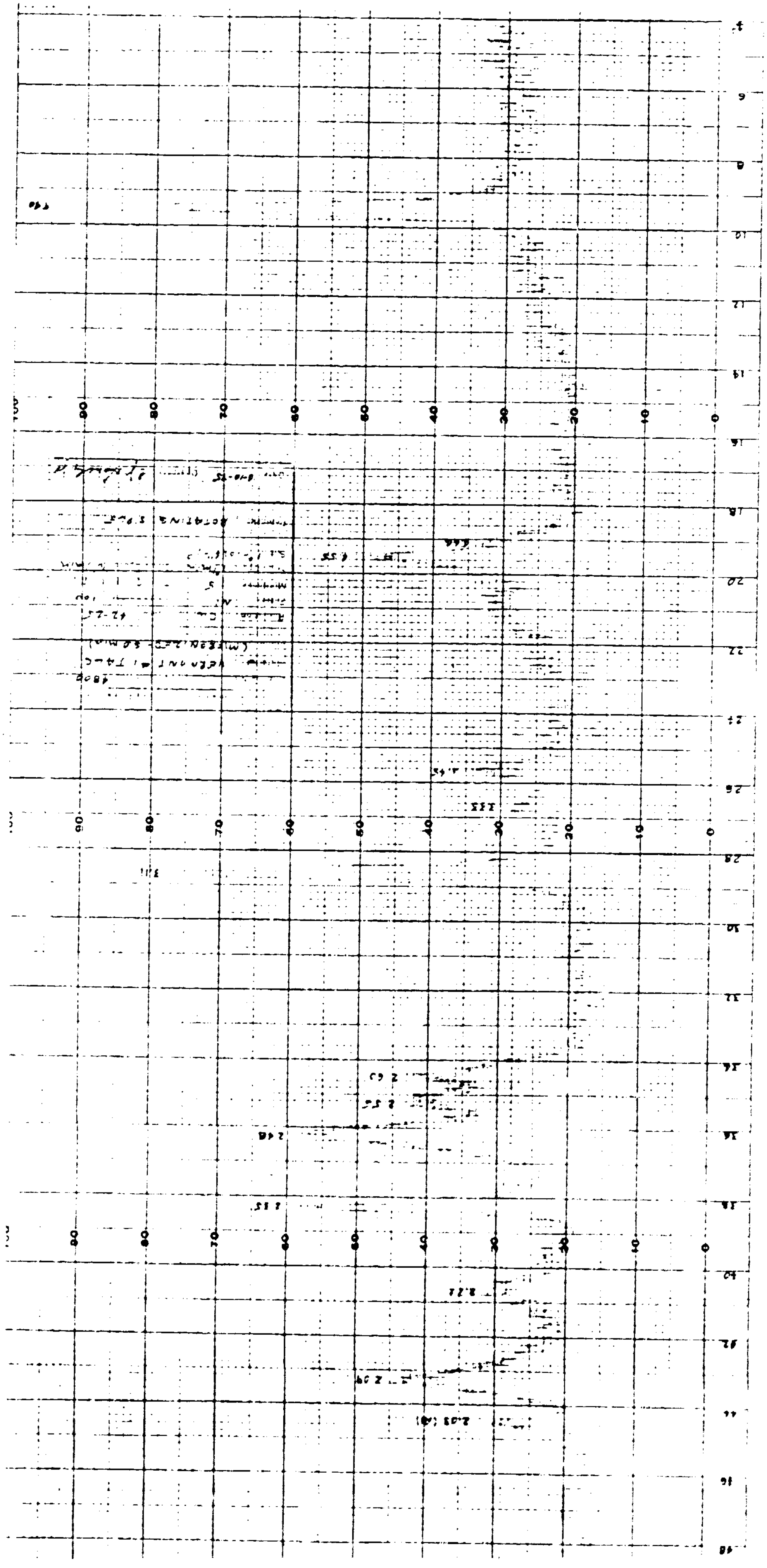


Figure B-2. X-ray line scan of Vermont talc, full scale 500 counts/second



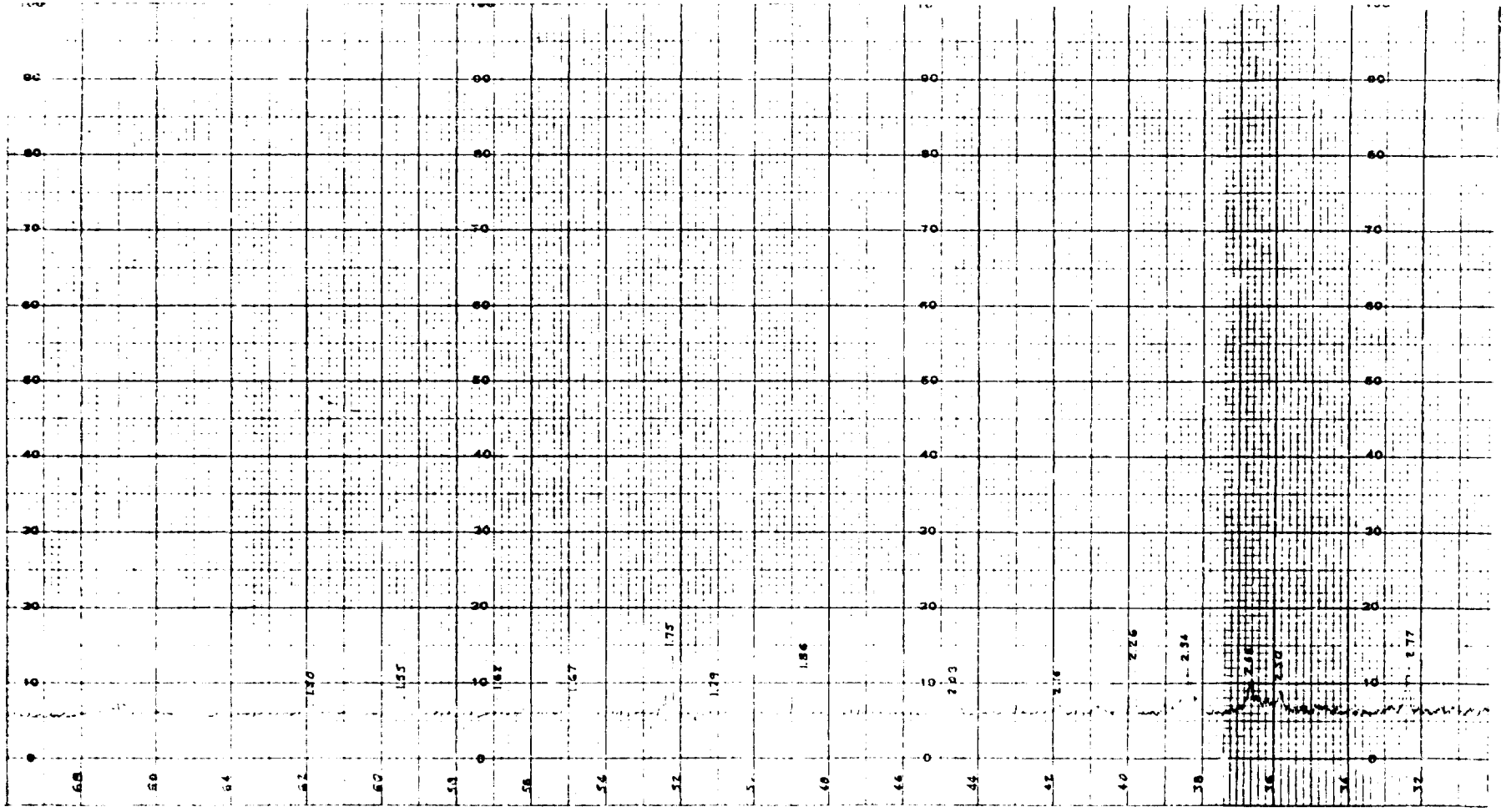
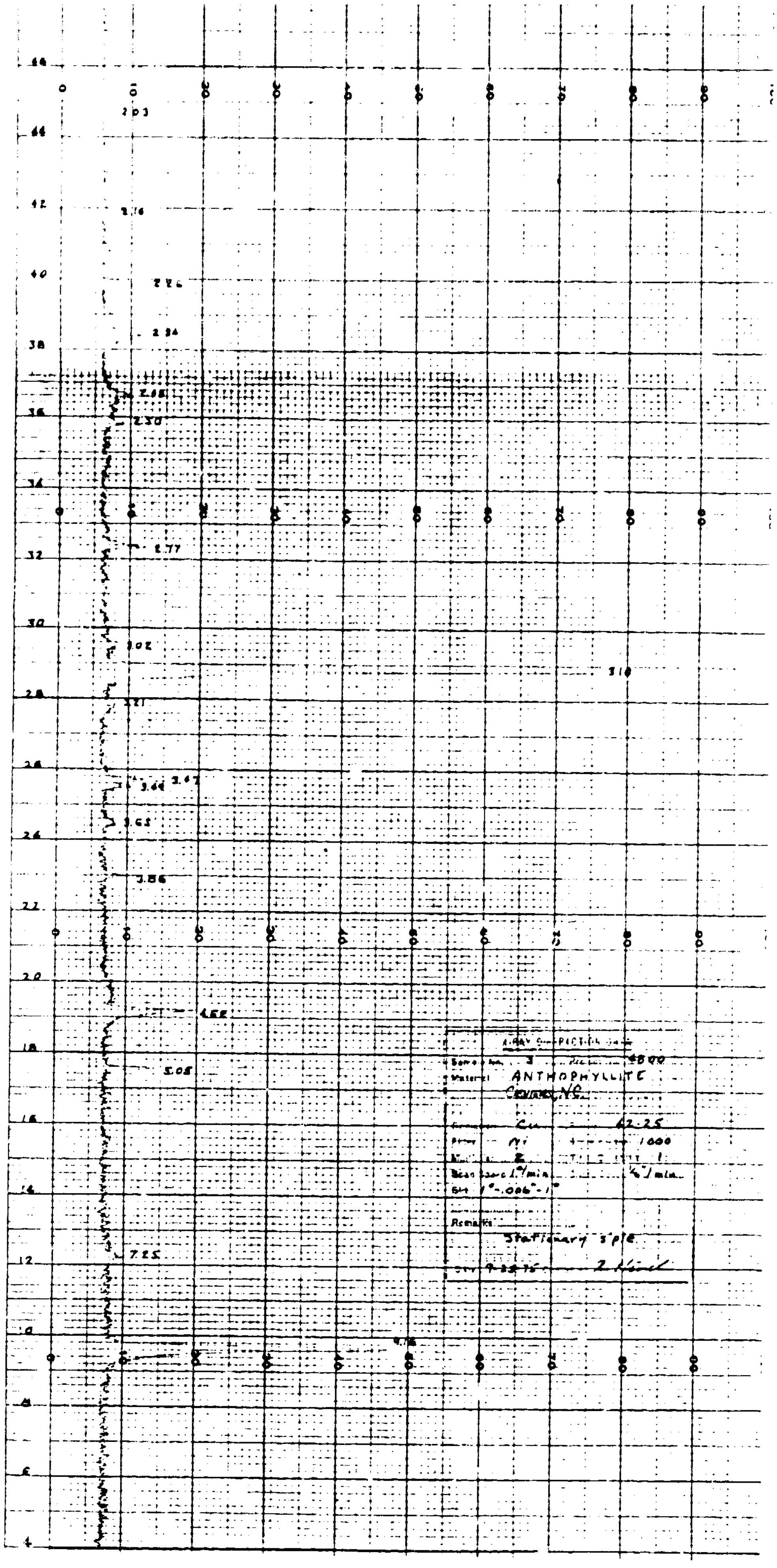


Figure B-3. X-ray line scan of anthophyllite, Cashiers, NC



ANTHOPHYLLITE
Cu
42.25
Ni
1000
Slit 1°-.006"-1°
Remarks
Stationary s'ple
2.03
2.34
2.77
3.86
5.06
7.25

Figure B-4. X-ray line scan of carbonaceous core, Gulfcoast, CO

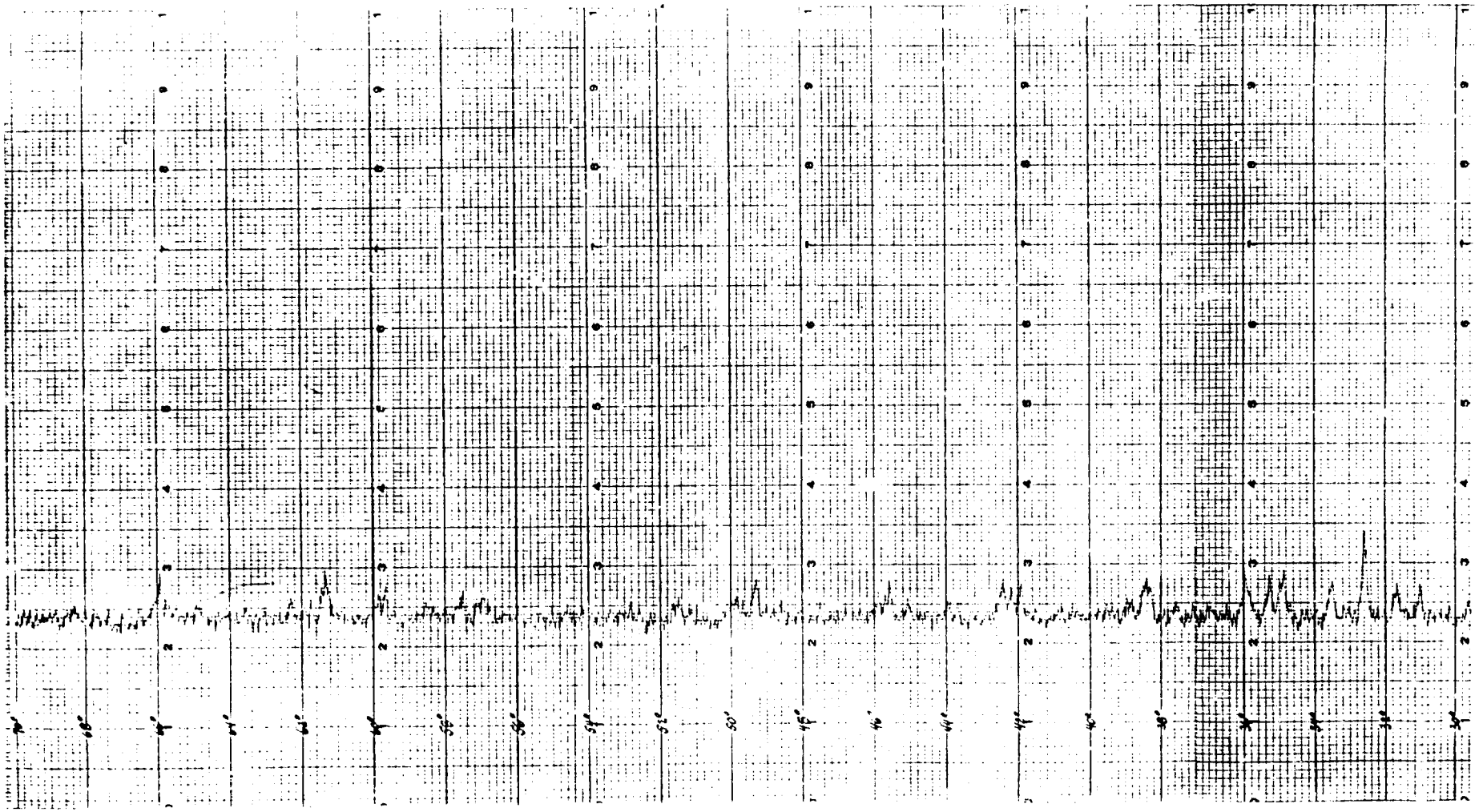
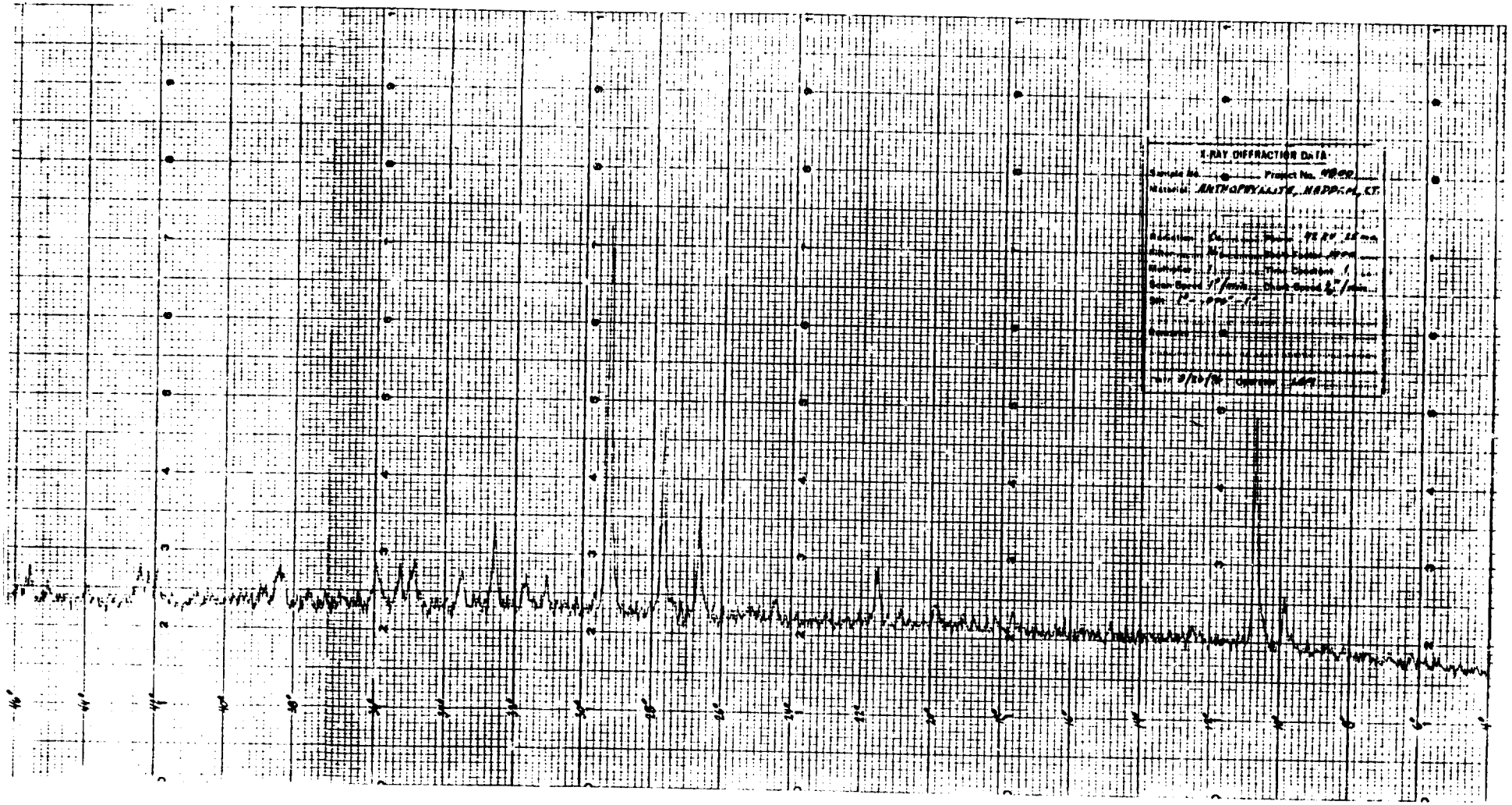


Figure B-5. X-ray line scan of anthophyllite, Haddam, CT



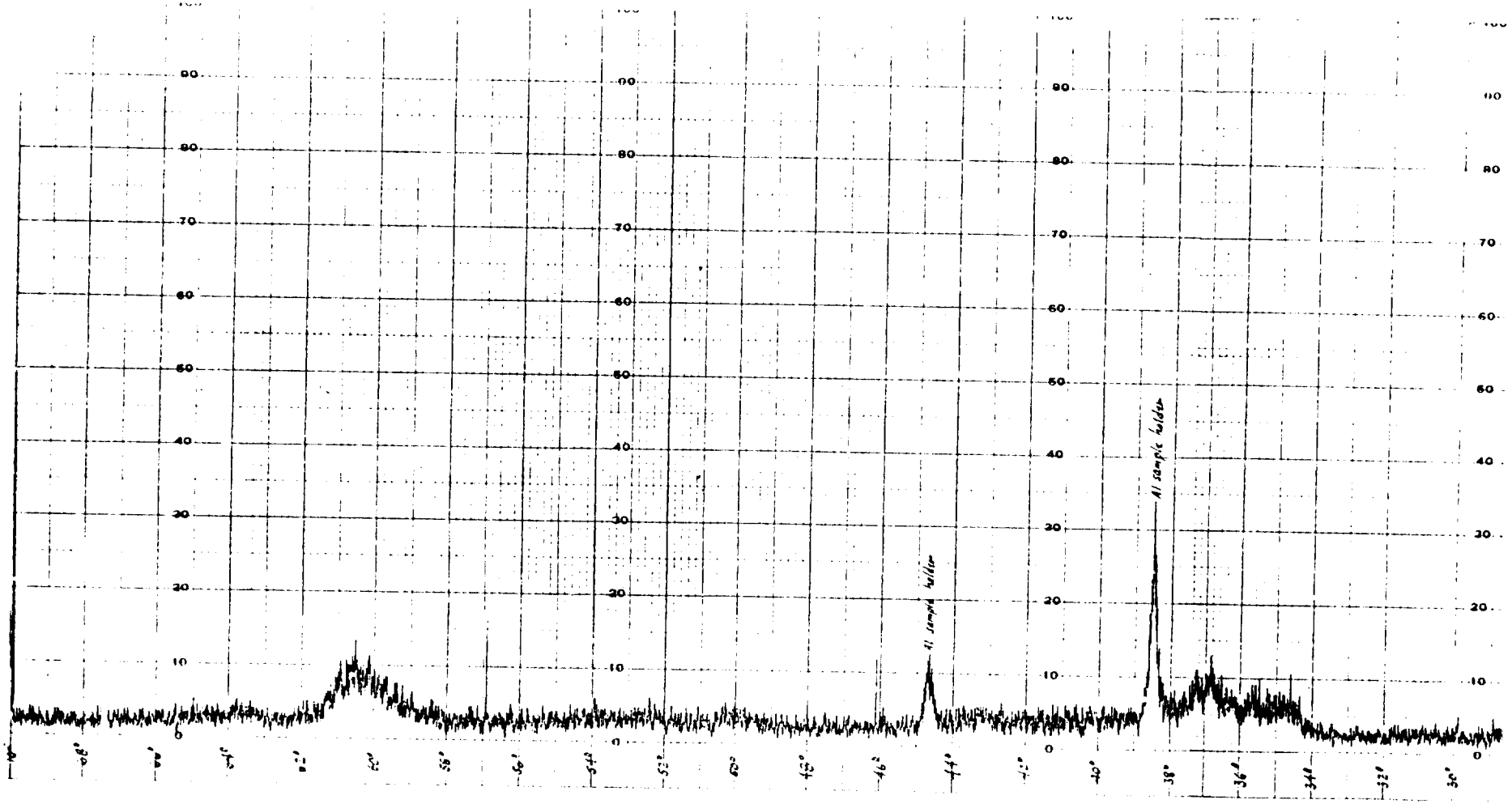
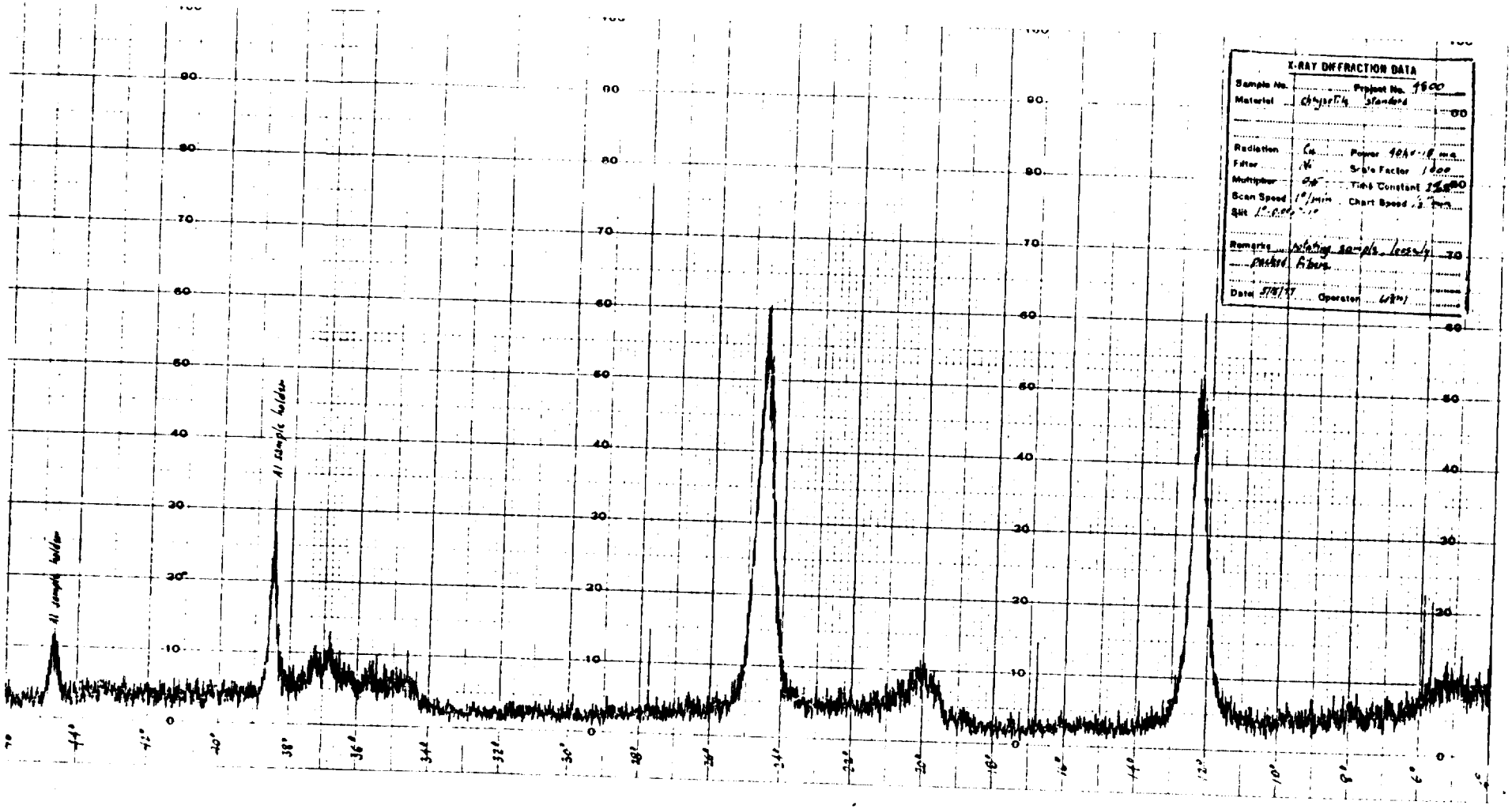


Figure B-6. X-ray line scan of chrysotile, Victory Mine, Globe, Gila County, AZ



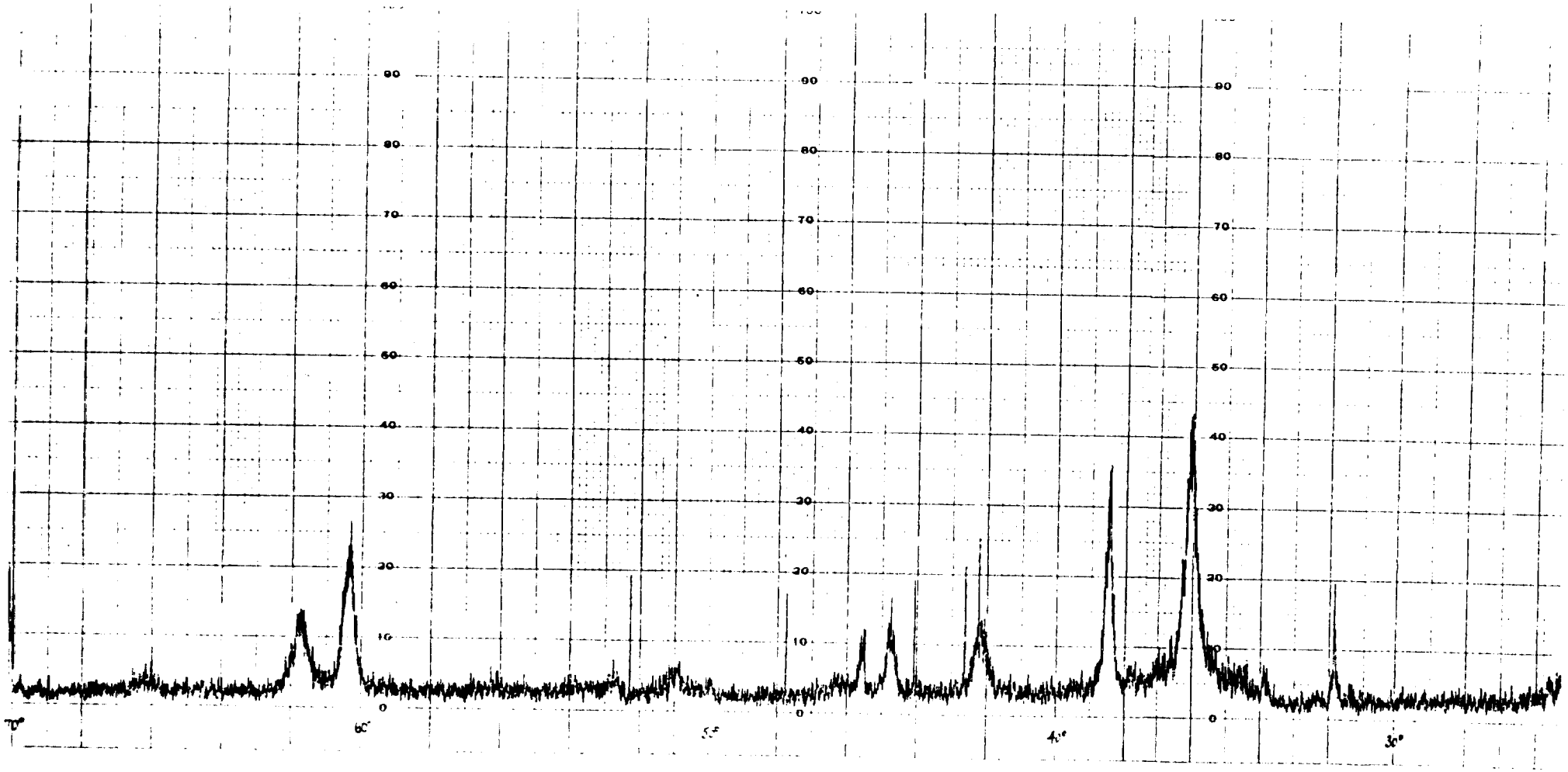
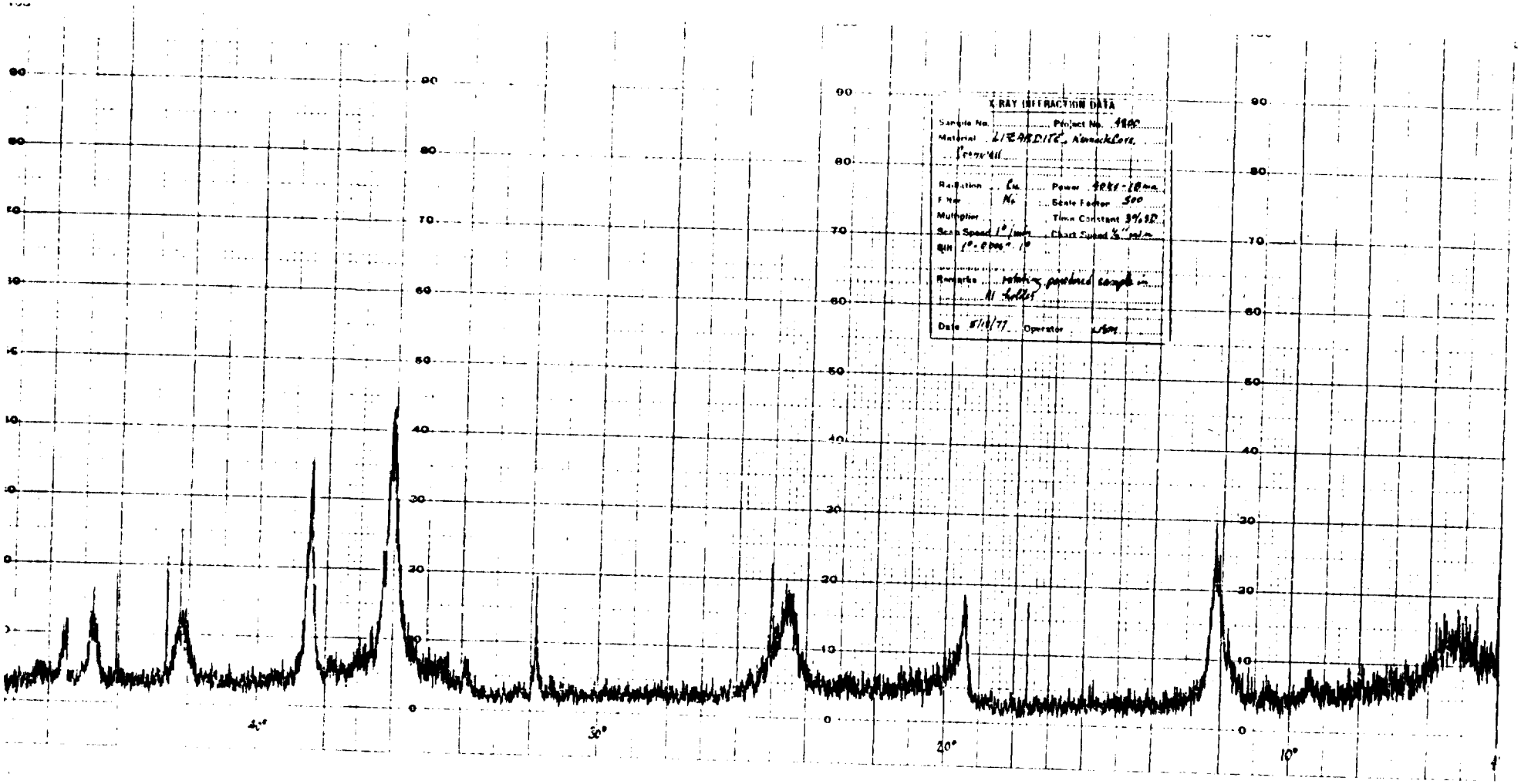


Figure B-7. X-ray line scan of lizardite, Kennack Cove, Cornwall, England



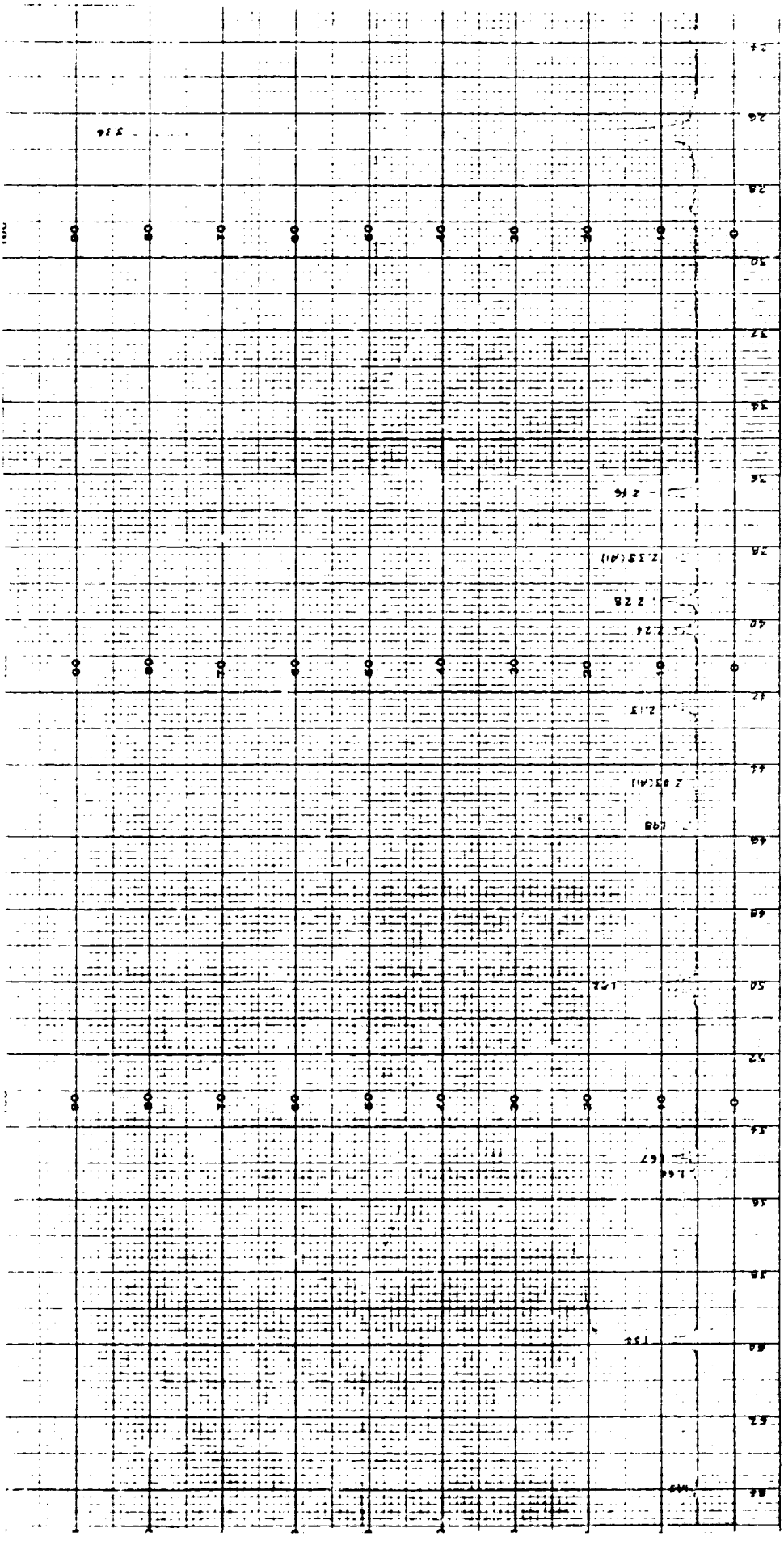
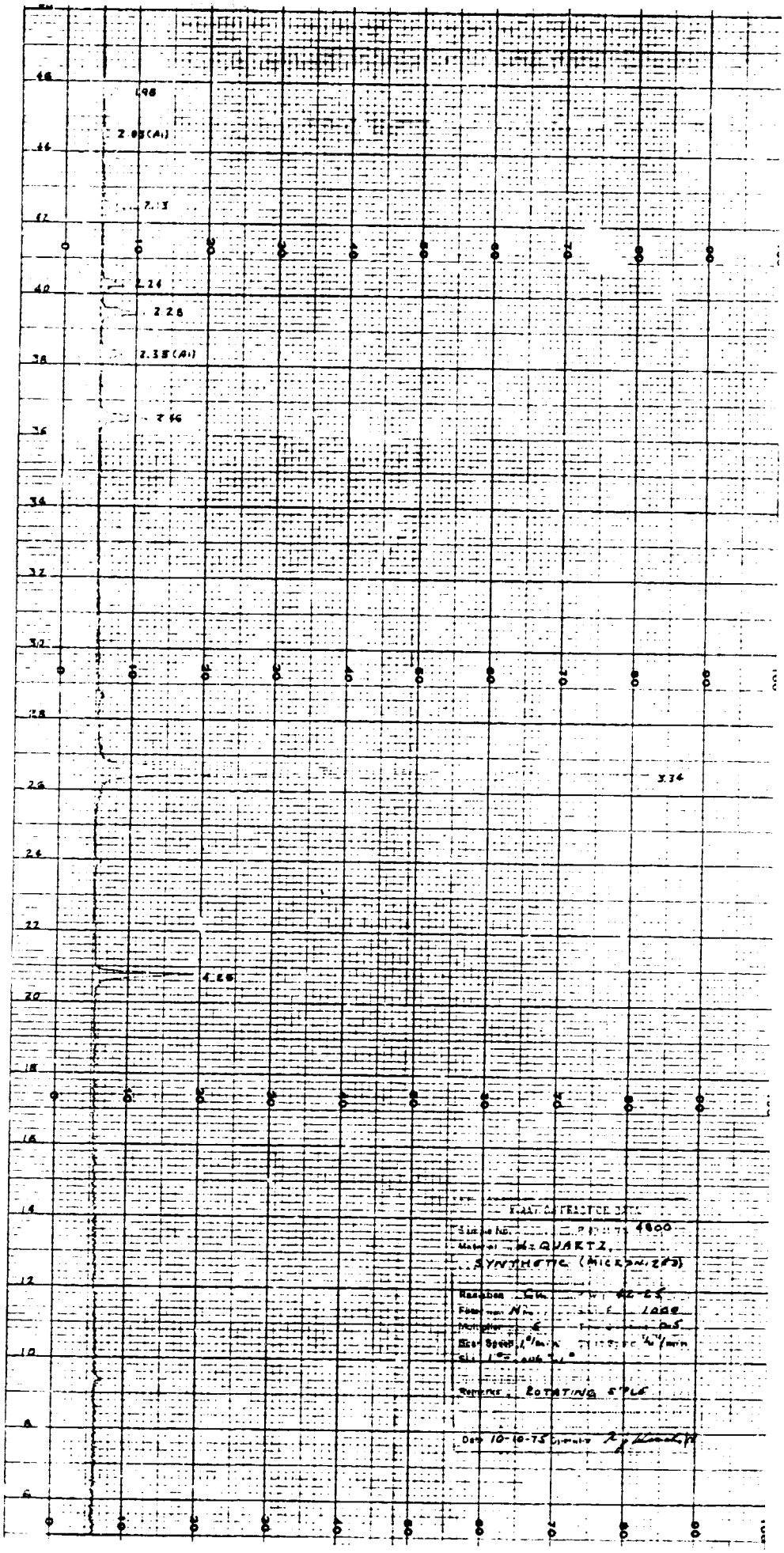


Figure B-8. X-ray line scan of α-quartz, synthetic



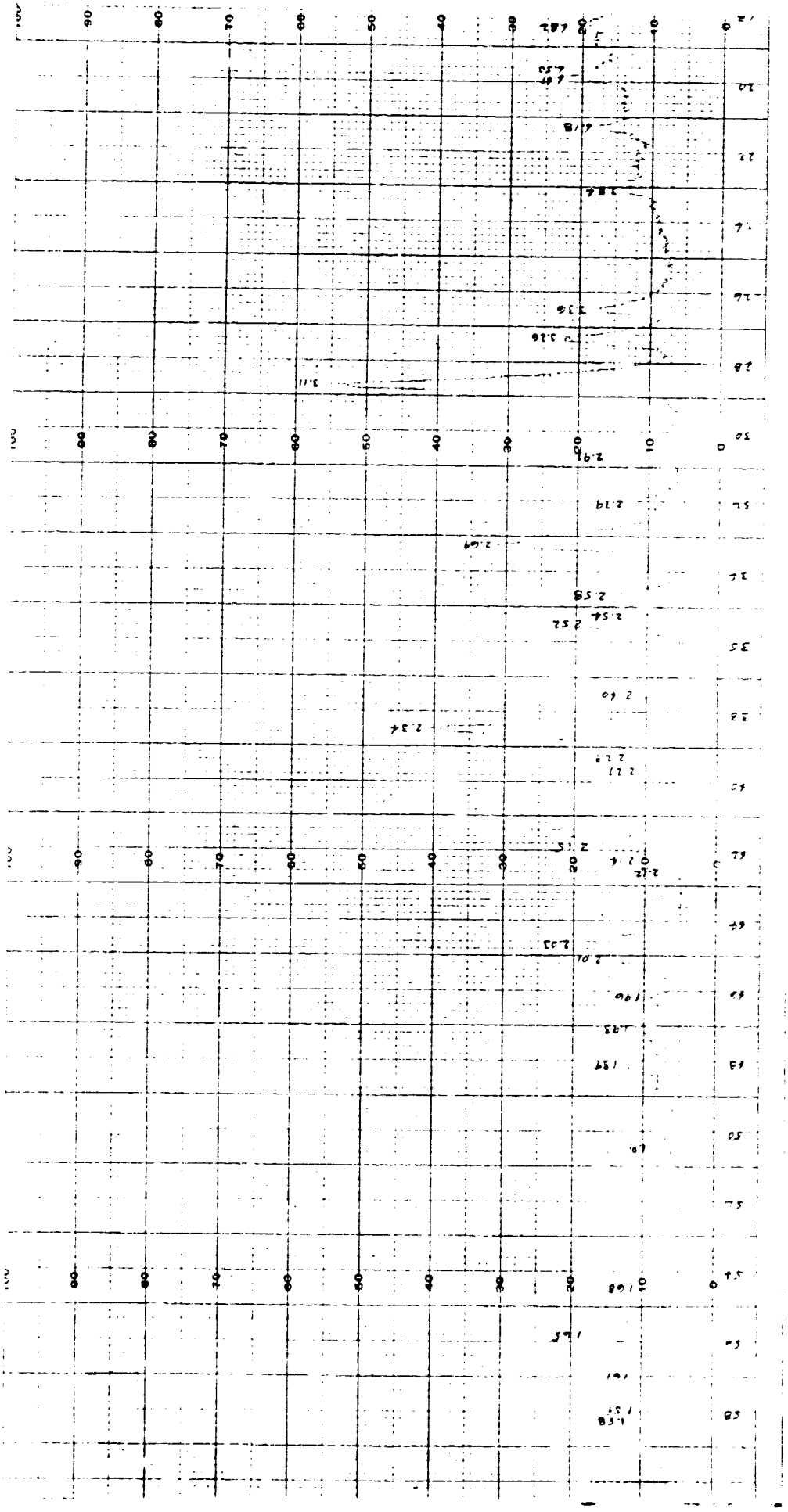


Figure B-9. X-ray line scan of fibrous tremolite, Dahl Creek, AK

Dahl Creek, AK

Figure B-10. X-ray line scan of tremolite, Fowler, NY

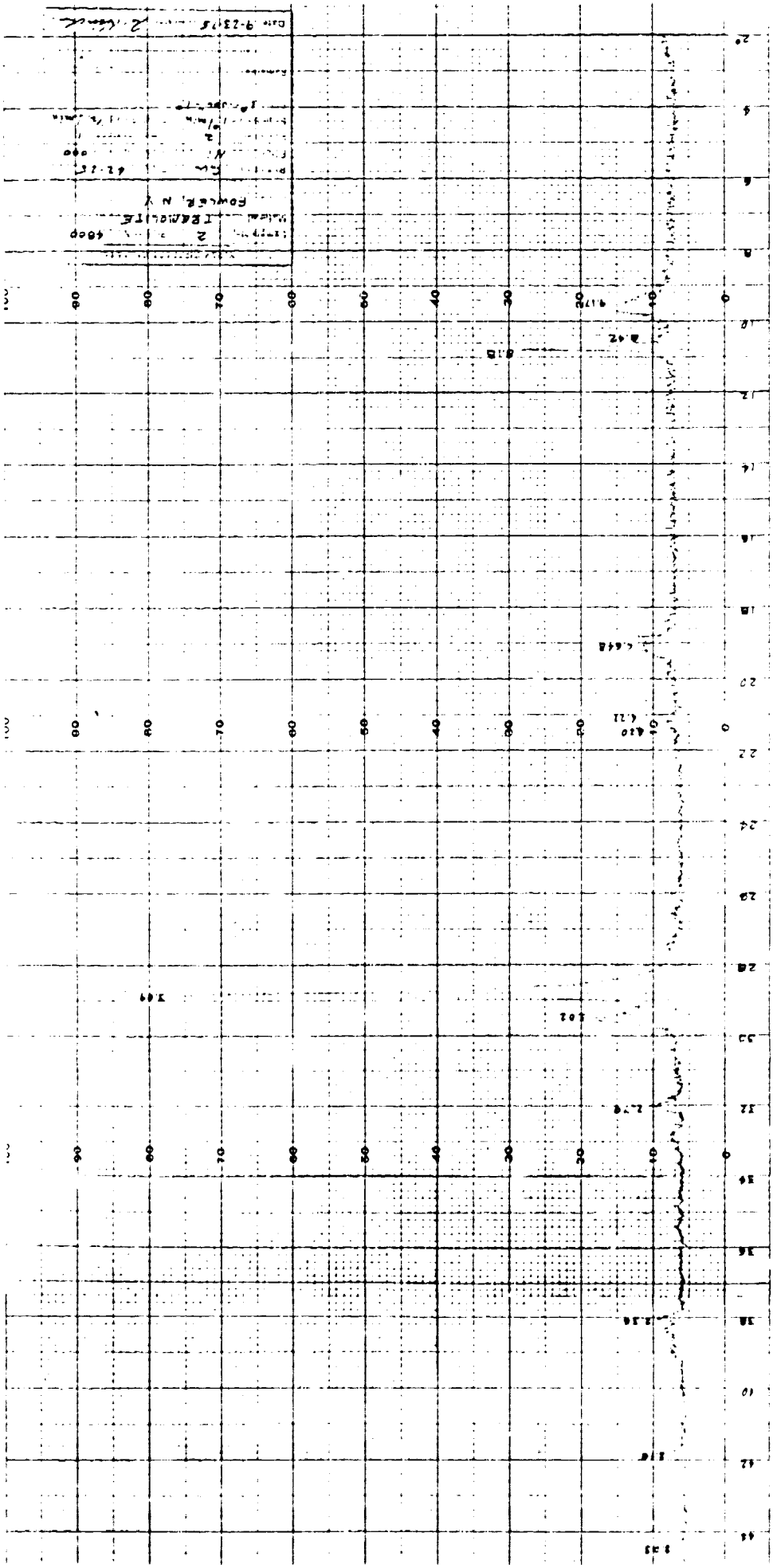
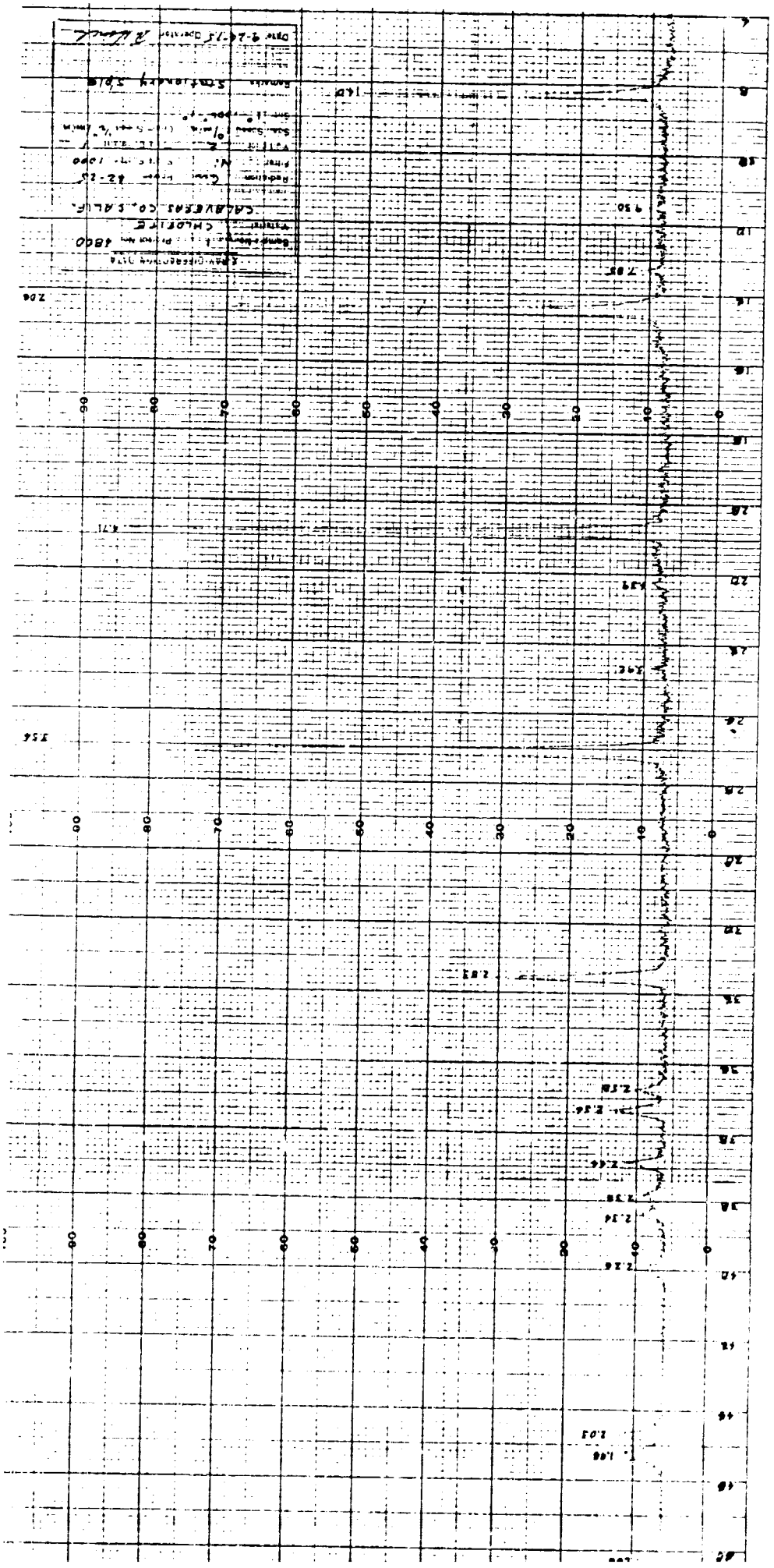


Figure B-11. Xerox flow scan of aquifer, Lake Wenatchee, WA

Figure B-12. X-ray line scan of chlorite, Calaveras County, CA



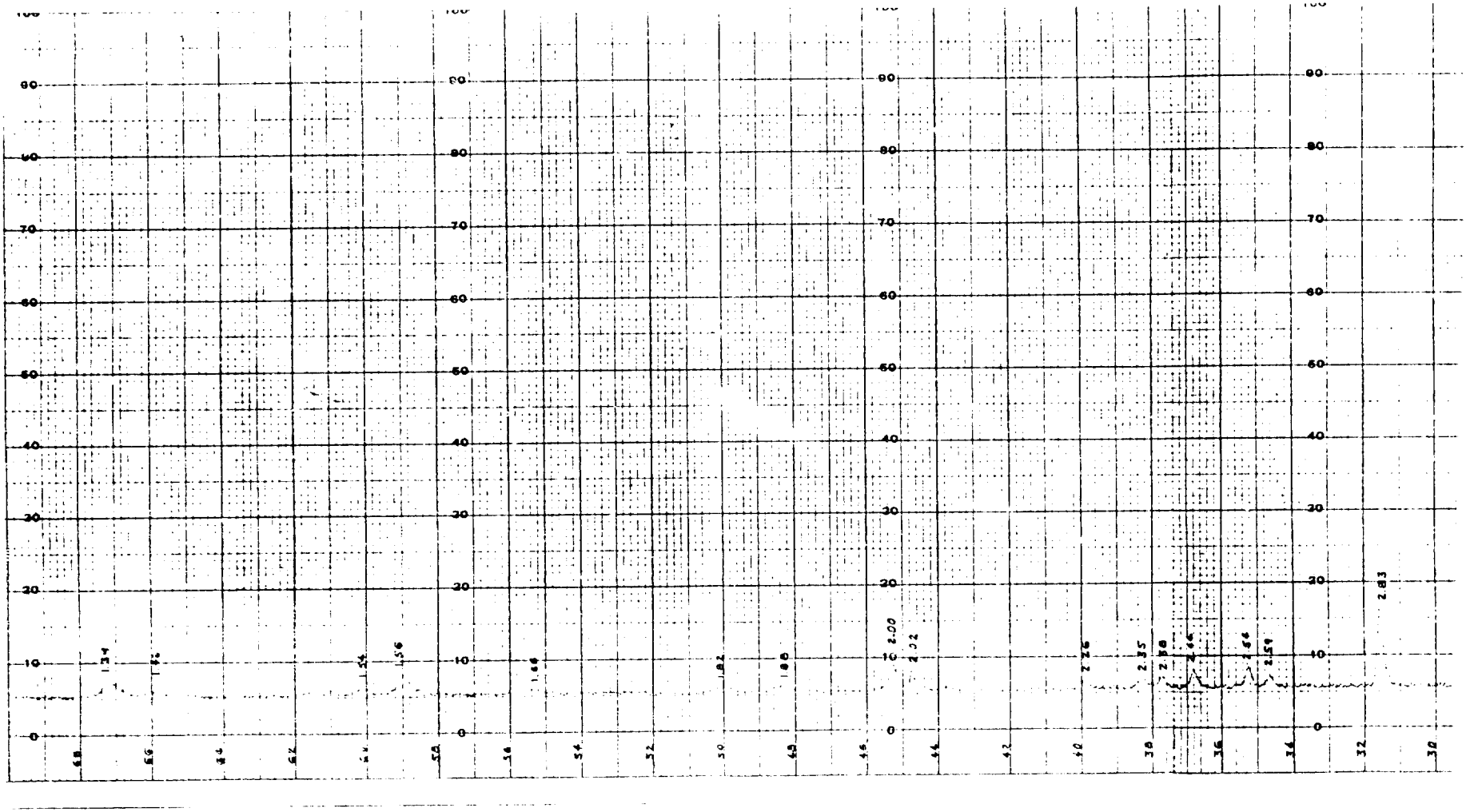
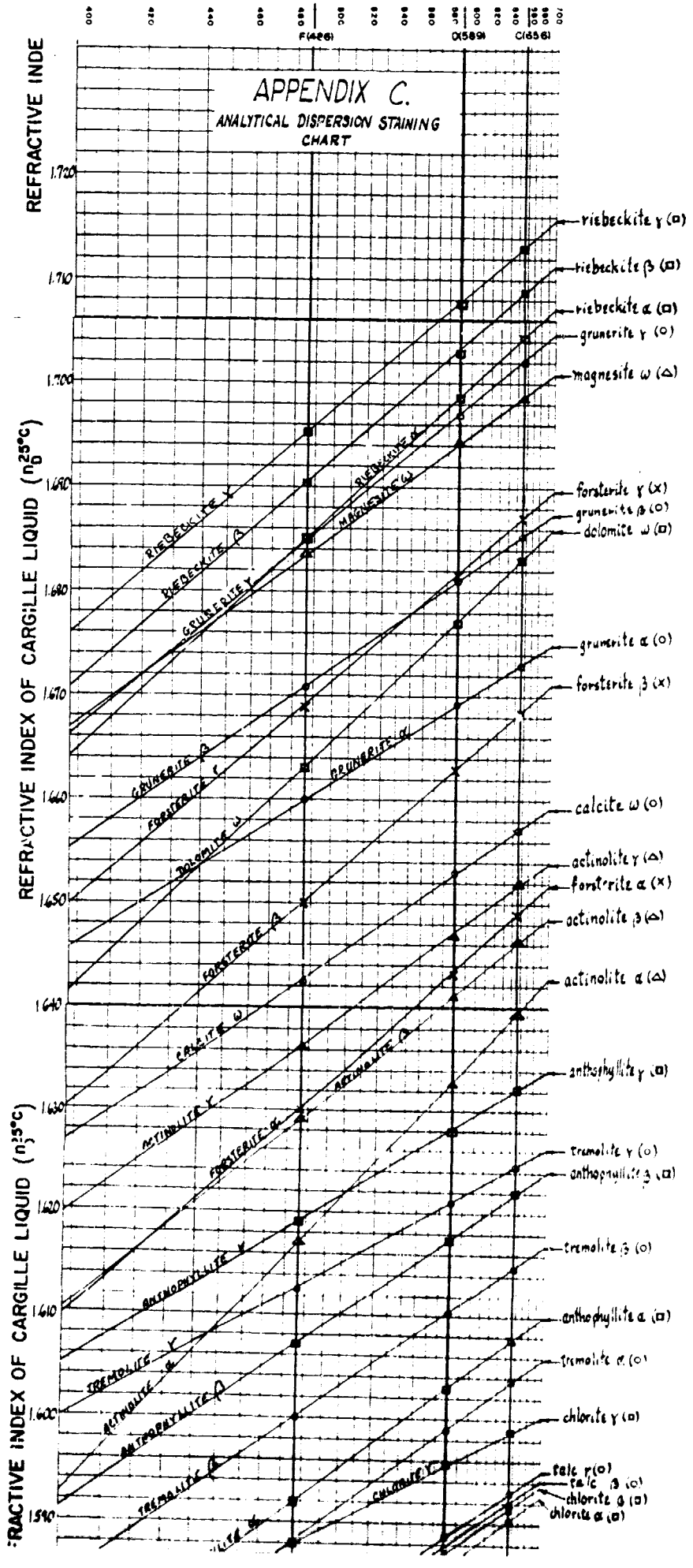
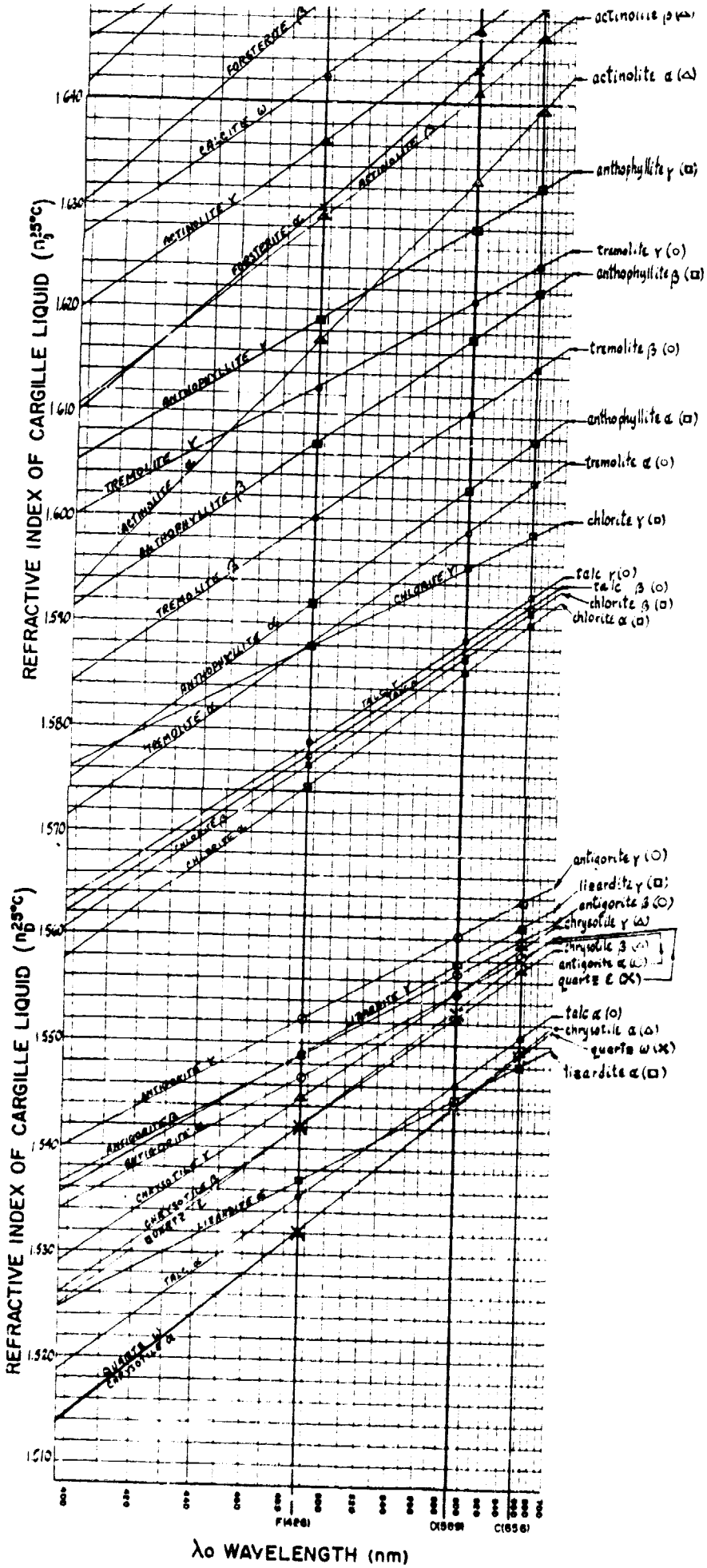


Figure B-13. X-ray line scan of prochlorite, Chester, VT


APPENDIX C.
ANALYTICAL DISPERSION STAINING CHART
F(486)
D(589)
C(656)
REFRACTIVE INDE
REFRACTIVE INDEX OF CARGILLE LIQUID ($n_D^{25°C}$)
REFRACTIVE INDEX OF CARGILLE LIQUID ($n_F^{25°C}$)
1.720
1.710
1.700
1.690
1.680
1.670
1.660
1.650
1.640
1.630
1.620
1.610
1.600
1.590
riebeckite γ (□)
riebeckite β (□)
riebeckite α (□)
grunerite γ (○)
magnesite ω (△)
forsterite γ (×)
grunerite β (○)
dolomite ω (□)
grunerite α (○)
forsterite β (×)
calcite ω (○)
actinolite γ (△)
forsterite α (×)
actinolite β (△)
actinolite α (△)
anthophyllite γ (□)
tremolite γ (○)
anthophyllite β (□)
tremolite β (○)
anthophyllite α (□)
tremolite α (○)
chlorite γ (□)
talc γ (○)
talc β (○)
chlorite β (□)
chlorite α (□)
RIEBECKITE γ
RIEBECKITE β
RIEBECKITE α
GRUNERITE γ
MAGNESITE ω
GRUNERITE β
FORSTERITE γ
DOLOMITE ω
GRUNERITE α
FORSTERITE β
CALCITE ω
ACTINOLITE γ
FORSTERITE α
ACTINOLITE β
ACTINOLITE α
ANTHOPHYLLITE γ
TREMOLITE γ
ANTHOPHYLLITE β
TREMOLITE β
ACTINOLITE α
ANTHOPHYLLITE α
TREMOLITE α
CHLORITE γ
TALC γ
TALC β
CHLORITE β
CHLORITE α


REFRACTIVE INDEX OF CARGILLE LIQUID ($n_D^{25°C}$)
λo WAVELENGTH (nm)
1.640
1.630
1.620
1.610
1.600
1.590
1.580
1.570
1.560
1.550
1.540
1.530
1.520
1.510
F(486)
D(589)
C(656)
actinolite β (□)
actinolite α (△)
anthophyllite γ (□)
tremolite γ (○)
anthophyllite β (□)
tremolite β (○)
anthophyllite α (□)
tremolite α (○)
chlorite γ (□)
talc γ (○)
talc β (○)
chlorite β (□)
chlorite α (□)
antigorite γ (○)
lizardite γ (□)
antigorite β (○)
chrysotile γ (△)
chrysotile β (△)
antigorite α (□)
quartz ε (×)
talc α (○)
chrysotile α (△)
quartz ω (×)
lizardite α (□)
FORSTERITE β
CALCITE ω
ACTINOLITE γ
ACTINOLITE β
FORSTERITE α
ACTINOLITE γ
ANTHOPHYLLITE γ
TREMOLITE γ
ACTINOLITE α
ANTHOPHYLLITE β
TREMOLITE β
CHLORITE γ
ANTHOPHYLLITE α
TREMOLITE α
TALC γ
TALC β
CHLORITE β
CHLORITE α
ANTIGORITE γ
ANTIGORITE β
ANTIGORITE α
CHRYSOTILE γ
CHRYSOTILE β
FORSTERITE γ
LIZARDITE α
TALC α
QUARTZ ω
CALCITE ε