

TRICLINIC TALC AND ASSOCIATED AMPHIBOLES FROM GOUVERNEUR MINING DISTRICT, NEW YORK¹

MALCOLM ROSS, *U. S. Geological Survey, Washington, D. C. 20242*
WILLIAM L. SMITH, *Battelle Memorial Institute, Columbus, Ohio 43203*

AND

WILLIAM H. ASHTON, *Johnson and Johnson,*
New Brunswick, New Jersey 08903.

ABSTRACT

New chemical, optical, and X-ray data are given for talc, tremolite, and a manganoan amphibole (tirodite) from the Gouverneur mining district, New York. All talc examined is found to be triclinic, $a=5.25$, $b=9.13$, $c=9.44$ Å, $\alpha=90^\circ46'$, $\beta=98^\circ55'$, $\gamma=90^\circ0'$, space group C1 or C $\bar{1}$, structure type 1-layer triclinic (1Tc). Chemical analysis gives the composition of talc from the Arnold pit as $Mg_{3.04}Si_{3.96}O_{10}F_{0.10}(OH)_{1.90}$. On the basis of fluorine analyses of 22 talcs from worldwide localities it is observed that talc derived from metamorphosed sedimentary rocks contains appreciable fluorine, from 0.11 to 0.48 weight percent, whereas talc derived from ultramafic rocks contains less fluorine.

Two of the three tremolite specimens examined have prominent lamellae, oriented parallel to (10 $\bar{1}$), of a second amphibole having the following unit-cell parameters: monoclinic, $a=9.50$, $b=18.04$, $c=5.28$ Å, $\beta=102^\circ25'$, space group $P2_1$ or $P2_1/m$. Chemical and X-ray evidence indicates that this amphibole is tirodite having the approximate composition $Ca_{0.2}Mn_{0.9}Mg_{5.9}Si_8O_{22}(OH,F)_2$. The tirodite probably exsolved from the host tremolite at temperatures below 500°C.

New unit-cell data are given from three tremolites. X-ray powder data are given for talc and tremolite.

INTRODUCTION

The purpose of this paper is to present new chemical, X-ray, and optical data for talc and the associated amphiboles tremolite and tirodite found in certain schists from the Gouverneur mining district, New York. This study is part of a broader investigation which the authors are conducting on the physical and chemical properties of talc and the associated minerals lying in the system $CaO-MgO-SiO_2-H_2O-CO_2$. The metamorphosed sedimentary rocks of the New York Grenville Lowlands are ideal for such a study for many of the mineral compositions lie mostly within this system. The present paper will present data only for the talc-tremolite schists of the Gouverneur area. Although the chemical and physical properties of talc and tremolite were thought to be well known, our study and the recent studies of Bown (1966) and Rayner and Brown (1966) show that much is yet to be done in order to fully characterize these phases.

¹ Studies of silicate minerals (10). Publication authorized by the Director, U. S. Geological Survey.

THE GOUVERNEUR MINING DISTRICT

The Gouverneur, or Balmat-Edwards, mining district is in the Grenville Lowlands of the northwest Adirondacks, St. Lawrence County, New York. Most of the bedrock of the Gouverneur area consists of meta-sedimentary and metasomatic rocks referred to as the Precambrian Grenville Series. The talc containing schists are found in a northeast trending belt which was described by Engel (1962) as more than six miles long, dipping approximately 45° to the northwest probably extending down dip some 2,500 feet, and attaining a maximum thickness of greater than 400 feet. The talc bodies occur as sheets and lenses in a highly folded and sheared marble of the Grenville Series.

Metamorphic reactions between quartzite and dolomite produced various magnesium- and calcium-bearing silicates, especially diopside, tremolite, anthophyllite, and talc. Some of the talc and anthophyllite and probably all the serpentine formed by later alteration of tremolite. Some of the schists are calcitic, probably as a by-product in the alteration of tremolite to a more magnesium rich phase.

The amounts of the various minerals differ throughout the area; however, the predominant mineral is usually tremolite. In addition to the pyroxene, amphibole, talc, and serpentine constituents of the ores, there are also varying amounts of quartz, carbonates, gypsum, chlorite, and accessory minerals. Texturally the talcs range from massive to platy, and they vary in color from buff and gray to white.

OCCURRENCE

The Arnold pit of the International Talc Company, near Fowler, was visited in 1961 and again in October, 1966. Many of the samples described in this study were obtained from this pit.

The exposed rock at the Arnold pit, near the old Arnold shaft, consisted of a glaciated surface which was being cleared of soil, and into which excavations were being made. The width of the exposure was estimated to be from about 280 to over 300 feet in the area sampled. The sequence of rock types from the footwall dolomite to the hanging wall dolomite was observed to be as follows, as traversed across the floor of the mine in a westerly to northwesterly direction:

- (1) footwall dolomite
- (2) "limy talc" rock, about 30 feet (G-16)
- (3) "coarsely crystalline talc" lens, about 5 feet (G-17)
- (4) massive "talc ore," about 115 feet (G-18)
- (5) a sequence of an irregular interbedding of coarsely crystalline

tremolite (variety hexagonite) and massive talc ore, about 130 to 150 feet (G-19, 20, 21, 22)

(6) hanging wall dolomite.

The occurrence of a lens of coarsely crystalline talc near the footwall was atypical of the exposed rock. The complex interbedding of coarsely crystalline talc and the hexagonite-bearing rock was pronounced toward the hanging wall. The exposures of this type of talc ranged from a few inches to a few feet in width. The specimens of the coarsely crystalline talc which were collected for mineralogical study were found to be dominantly talc with a small amount of clear unaltered tremolite. The relatively coarse grained talc, known as "scale" at the mines, is associated with but distinctly different from the fine-grained commercial talc.

A similar coarsely crystalline talc was noted in May, 1961, on the fourth level of the Wight mine of the International Talc Company, which is located about 3,000 feet to the southwest of the Arnold pit, in the same formation. The material from this part of the mine is richer in tremolite; the translucent to pure white talc and clear colorless tremolite being the major phases. Minor fibrous anthophyllite, partly altered to talc, is also present as a minor constituent. The sheetlike body of tremolite-coarsely

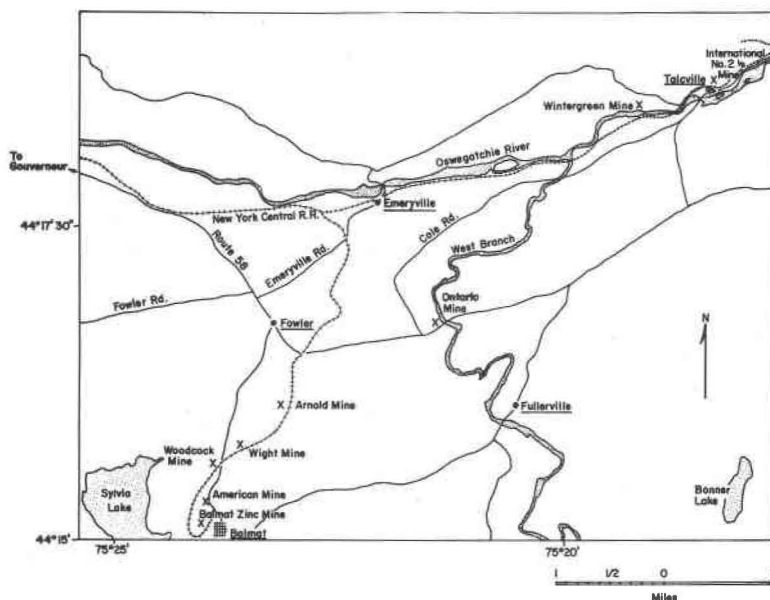


FIG. 1. Index map of the Gouverneur talc mining areas, St. Lawrence County, New York. Modified, in part, from Engel, 1962, Plate I.

crystalline talc rock was about 12 feet thick where examined and was reported to extend more or less continuously along the strike of the ore. The body extends from the surface or near the surface down through the sixth level of the mine.

Additional samples of well crystallized talc obtained previously from the Arnold pit (G-1), and the "Talc" mine (CS-1), Gouverneur, N.Y., and also a sample of nearly pure quartz-tremolite rock from an area 3/4 of a mile southwest of the Wight mine (G-24) were also studied. The location of the various mines is given in the index map (Figure 1).

The apparent mineral associations of the more carefully studied samples are as follows:

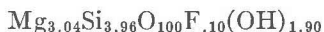
- (1) G-1, talc-minor clear tremolite and anthophyllite
- (2) G-16, clear tremolite-serpentine-talc-minor carbonate and tirodite
- (3) G-17, talc-minor clear tremolite
- (4) G-19, 21, lavender tremolite (hexagonite)-minor quartz, carbonate, tirodite, and tourmaline
- (5) G-24, tremolite-quartz-minor tirodite

Small amounts of carbonate appear as a cementing agent in samples G-16 and G-21. On the basis of a rapid reaction to dilute HCl the cementing carbonate is probably calcite.

TALC

Chemical composition.—The coarsely crystalline talcs (G-1, G-17) taken from the Arnold pit in 1961 and 1966 are nearly pure, only a few small crystals of tremolite appear on careful optical examination of the picked material. Three spectrographic analyses (Table 1) show less than 0.2 percent calcium thus the amount of included tremolite is negligible. Wet chemical analysis (Table 2) confirms the presence of fluorine in the talc structure. Total loss ($H_2O + F$) on ignition for samples G-1 and G-17 are given in Table 3.

The chemical formula of this talc as given by the analysis G-1 is:



The analysis shows a few tenths of a percent excess H_2O and this is considered due to analytical error. The small amounts of Fe, Mn, Al, Ca, etc., shown to be present are assumed to be mainly due to the small amount of tremolite.

Partial chemical analysis for H_2O and fluorine were also made of talc (G-17) and tremolite (G-21) sampled from the Arnold pit in 1966 (Tables 1 and 3). Fluorine analyses¹ for a number of other talc specimens obtained

¹ The samples were fused in 3.5 grs. of sodium carbonate, cooled and leached out in weak sulfuric acid. Samples were then transferred to stills and 100–125 ml. of 1:2 H_2SO_4

TABLE 1. SPECTROGRAPHIC ANALYSES OF TALC AND TREMOLITE FROM THE GOUVERNEUR TALC DISTRICT, NEW YORK

	Talc (G-1) ^a	Talc (G-1) ^b	Talc (G-17) ^c	Tremolite (G-21) ^d	Tremolite (G-24) ^e
Si	>10%	20-40	20-40	20-40	20-40
Mg	>10	20-40	20-40	15-30	10-20
Fe	0.03	0.1	0.1	0.2	0.1
Mn	0.03	0.01	<0.005	0.3	1-2
Al	0.03	0.1	0.05	0.2	0.3-1.0
Ti	0.001	0.01	0.005	0.02	0.03
Ni	— ^g	<0.005	<0.005	<0.005	—
Cu	—	<0.005	<0.005	<0.005	—
Li	0.001	0.005	0.005	0.02	—
Na	0.01	0.05	0.05	0.5	0.1-0.3
K	0.001	0.01	0.02	0.1	0.1-0.3
Ca	0.03	0.2	0.1	5-15	5-15
Sr	—	<0.005	—	—	—
Ba	—	<0.005	—	—	—
F	1.0	—	—	0.30 ^g	0.31 ^g

^a Arnold pit, Analyst: C. L. Waring, U. S. Geological Survey.

^b Arnold pit, Analyst: Bernard Snyder, Battelle Memorial Institute.

^c Arnold pit, Analyst: Bernard Snyder.

^d Arnold pit, lavender tremolite, Analyst: Bernard Snyder.

^e — not looked for.

^f Colorless tremolite, 3/4 mile SW of Wight mine, Balmat, N. Y., Analyst: Bernard Snyder.

^g By wet chemical analysis.

from worldwide localities were made to obtain more knowledge on the range of fluorine content in this mineral. These fluorine analyses are given in Table 4.

Physical properties.—Talc specimens collected from the Arnold pit show two distinct habits; one variety is fine grained somewhat fibrous in nature (G-16) and is associated with white tremolite. The second variety is coarsely crystalline (G-1, 17), often occurring in nearly mono-minerallic zones. Only the coarse variety was studied by X-ray techniques.

The coarsely crystalline talc forms platy crystals up to 1 cm in width. The crystals are pure white, translucent, with a slight adamantine luster. Some crystals grow as nearly perfect pseudotrigonal pyramids lying on (001). Often the pyramids are truncated by a small (001) face.

added (volume kept below 150 ml.). Fluoride was separated from interfering substances according to the method of Willard and Winter (steam distillation at 165°C). The distillate was collected in 500 ml. volumetric flasks. Fluoride content of the distillate was then determined by a thorium nitrate colorimetric titration.

TABLE 2. CHEMICAL ANALYSES OF TALC (G-1) FROM ARNOLD PIT, FOWLER, N. Y.

	G-1 ^a	Ratios ^b	Ideal ^c
SiO ₂	62.68	3.958	63.37
MgO	32.33	3.042	31.88
F	0.48	0.096	—
H ₂ O (—)	0.33	—	—
H ₂ O (+)	4.79	1.009	4.75
			100.00
Total	100.61		
O = F/2	—0.20		
	100.41		

^a Arnold pit, collected in 1961, Analysts: Joan Lathouse and R. D. Foltz, Battelle Memorial Institute.

^b Ratios calculated on basis of Mg + Si = 7.000.

^c Mg₃Si₄O₁₀(OH)₂.

Ten talc crystals from sample G-1 were examined with the Buerger precession camera. All crystals gave identical unit-cell parameters; the best measurements are given in Table 5. This talc is triclinic; the space group is $C\bar{1}$ or $C1$, and the structure type is one-layer triclinic (1Tc). In contrast to photographs of the common micas, the $0kl$ and $hk0$ precession precession photographs show a strong triclinic intensity distribution. There is little apparent monoclinic pseudosymmetry in any of the X-ray photographs. X-ray powder data for this material are given in Table 6.

Two talc crystals from sample G-17, one crystal from a sample from the "Talc" mine, Gouverneur, N. Y. (CS-1) and one crystal from a Balsam, North Carolina, sample (CS-2) were also studied by precession

TABLE 3. FLUORINE AND H₂O ANALYSES FOR TALC AND TREMOLITE^a

Total loss (H ₂ O + F) in weight percent	Talc (G-1)		Talc (G-17)		Tremolite (G-21)	
	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.
to 110°	0.33	0.0	0.12	0.0	0.05	0.0
110°–550°	0.57	4.99	0.19	4.96	0.11	2.37
550°–1000°	4.70		4.33		1.45	
F	0.48	0.48	0.42	0.42	0.30	0.30
H ₂ O (+)	4.79	4.51	4.10	4.54	1.26	2.07

^a Analyst: Joan Lathouse, Battelle Memorial Institute.

TABLE 4. FLUORINE ANALYSES OF TALC FROM VARIOUS LOCATIONS AND ORIGINS

Sample	Location and Origin	% F
G-1	Gouverneur talc district, New York	0.48
G-17	Gouverneur talc district, New York	.42
WA-3	Gouverneur talc district, New York, metamorphosed magnesian carbonate sediments.	.45
42771 E	Val Chisone, Italy	.44
23	Val Chisone, Italy metamorphosed magnesian carbonate sediments.	.31
25	Murphy, North Carolina, metasomatic replacement of magnesian carbonate sediments.	.36
30	Inyo County, California, replacement of quartzite along dolomite contact.	.34
26	Brumado, Bahia, Brazil, magnesia metasomatism of siliceous carbonate sediments.	.29
11	Casa Nova, Bahia, Brazil, lenses of replaced siliceous magnesian carbonate sediments.	.27
S 423	Windsor County, Vermont, schistose talc-carbonate rock, not of ultrabasic origin, but associated with ultrabasic body.	.26
7	Allamoore, Texas, metamorphism of interbedded limestone and magnesia rich tuff.	.20
8	Madoc, Ontario, Canada, metamorphosed magnesian carbonate sediments.	.18
31	Dillon, Montana, replacement of dolomite in fracture zones.	.18
29	Flinders Range, South Australia, metasomatism of silicified magnesian carbonate sediments.	.17
32	Esmeralda County, Nevada, metamorphosed quartzite lens in dolomite.	.17
28	Tong yang, South Korea, metamorphosed magnesian carbonate sediments.	.16
14	Dausa, Rajasthan, India, metamorphosed magnesian carbonate sediments.	.11
33	Tamaulipas, Mexico, hydrothermally altered basic dike, enclosed in serpentinized schist.	.04
WA-1b	Lamoille County, Vermont, automorphic alteration of ultrabasic rock, associated with serpentine.	.04
3	Zambales, Philippines, altered ultrabasic rock, associated with serpentine.	.01
27	Transvaal, South Africa, altered ultrabasic rock, associated with serpentine.	.007
13	Providence County, Rhode Island, associated with serpentine pods in greenstone.	.004

Note: Sediments refers to metamorphic rocks of sedimentary origin.

TABLE 5. UNIT-CELL DATA FOR TALC

	Arnold pit, G-1		A <i>P</i> ^b	B	C	D	E
	<i>C</i> ^a	<i>P</i> ^b					
<i>a</i> (Å)	5.27 ₆	5.27 ₅	5.29	5.26	5.27	5.27	5.28 ₇
<i>b</i> (Å)	9.13 ₇	5.27 ₅	5.30	9.10	9.13	9.13	9.15 ₈
<i>c</i> (Å)	9.44 ₈	9.45 ₀	9.47	18.81	18.88	18.94	18.95
α	90°46'	84°53'	86°6'				
β	98°55'	98°59'	98°54'	100°0'	100°15'	100°40'	99°30'
γ	90°0'	120°0'	120°0'				
System	triclinic	triclinic	triclinic	monoclinic	monoclinic	monoclinic	monoclinic
Diffraction symbol	$\bar{1}C*$	$\bar{1}P*$	$\bar{1}P*$	<i>C</i> */ <i>c</i>	<i>C</i> */ <i>c</i>	—	—
Structure type	1Tc	1Tc	1Tc	2M ₁	2M ₁	2M ₁	2M ₁

^a *C*-setting (preferred setting).^b *P*-setting (conventional setting).

A Rayner and Brown (1966), Harford County, Md.

B Gruner (1934), Harford County, Md.

C Hendricks (1938), Harford County, Md.

D Zvyagin and Pinsker (1949).

E Stemple and Brindley (1960), Manchuria.

techniques. All give the same unit-cell data as that given in Table 5.

Ross, Takeda, and Wones (1966) have shown that many mica samples are composed of more than one polytype. Thus a number of crystals from a given layer silicate sample should be examined before assuming the specimen is homogeneous. Talc G-1 from the Arnold pit appears to be so. Our present study coupled with that of Rayner and Brown (1966) suggests that most talc is triclinic. Previous reports of the monoclinic form may be in error.

Unit-cell data for talcs studied previously are compared to that of the Arnold pit talc in Table 5. X-ray data for sample G-1 is given both in the *C*-centered setting and in a conventional primitive cell setting so that it may be compared to the results of Rayner and Brown. The transformation matrix from the *C*-centered unit-cell to the conventional primitive cell is: $100 | -1/2 -1/2 0 | 001$. The *C*-centered setting is preferred for it facilitates comparison with other layer silicate structures. Rayner and Brown examined the same specimen as that studied by Hendricks in 1938 and probably is also identical to that examined by Gruner in 1934. Thus, the only evidence for a two-layer monoclinic talc is the work of Stemple and Brindley (1960) and Zvyagin and Pinsker (1949).

The optical properties of the Arnold pit talc (G-1) are: biaxial positive, optic angle variable ranging from 0° to 10°, $\alpha = 1.545 \pm 0.002$, $\beta = \gamma = 1.584 \pm 0.002$. The value of the optic angle is highly dependent on the

TABLE 6. OBSERVED^a AND CALCULATED^b X-RAY POWDER DATA FOR TALC (G-1)
FROM THE ARNOLD PIT, GOUVERNEUR, N. Y., MINING DISTRICT

C-setting <i>hkl</i>	P-setting <i>hkl</i>	<i>d</i> (calc.) Å	<i>d</i> (obs.) Å	<i>I</i> ^c
001	001	9.333	9.34	vs
002	002	4.667	4.68	w
020	010	4.568	4.56	s
$\bar{1}10$	100	4.531		
110	$\bar{1}10$	4.523		
$\bar{1}\bar{1}1$	$\bar{1}\bar{1}1$	4.316		
$\bar{1}11$	$\bar{1}01$	4.298		
021	011	4.125	4.14	vw
021	0 $\bar{1}1$	4.082		
1 $\bar{1}1$	101	3.885	3.85	vw
111	1 $\bar{1}1$	3.862		
$\bar{1}\bar{1}2$	$\bar{1}12$	3.504	3.43	w
$\bar{1}12$	$\bar{1}02$	3.481		
022	012	3.287		
022	0 $\bar{1}2$	3.243		
003	003	3.111	3.115	s
1 $\bar{1}2$	102	3.061		
112	1 $\bar{1}2$	3.040		
$\bar{1}\bar{1}3$	$\bar{1}13$	2.751		
$\bar{1}13$	$\bar{1}03$	2.733		
$\bar{1}30$	110	2.632		
130	$\bar{1}20$	2.627	2.632	wm
201	211	2.617		
200	210	2.606	2.598	m
$\bar{1}31$	$\bar{1}21$	2.590		
023	013	2.588		
$\bar{1}31$	$\bar{1}\bar{1}1$	2.578		
023	0 $\bar{1}3$	2.555		
1 $\bar{3}1$	111	2.490	2.48	s-d
131	1 $\bar{2}1$	2.472		
202	212	2.442		
1 $\bar{1}3$	103	2.424		
201	2 $\bar{1}1$	2.415		
113	1 $\bar{1}3$	2.409		
$\bar{1}\bar{3}2$	$\bar{1}22$	2.382		
$\bar{1}32$	$\bar{1}\bar{1}2$	2.361		
004	004	2.333	2.336	vw

^a CuK α radiation, Ni filter ($\lambda=1.5418$ Å). Camera diameter: 114.59 mm. Lower limit 2θ measurable: approximately 8° (11.0 Å).

^b Calculated from the following unit-cell parameters: $a=5.275$, $b=9.137$, $c=9.448$ Å, $\alpha=90^\circ46'$, $\beta=98^\circ55'$, $\gamma=90^\circ0'$, space group CT. All calculated spacings are given to $d=2.284$ Å.

^c vs (very strong), s (strong), ms (medium strong), m (medium), wm (weak medium), w (weak), vw (very weak), d (diffuse).

TABLE 6. (*Continued*)

<i>C</i> -setting <i>hkl</i>	<i>P</i> -setting <i>hkl</i>	<i>d</i> (calc.) Å	<i>d</i> (obs.) Å	<i>I</i> ^a
040	020	2.284	2.284	vw
			2.219	m-d
			2.103	m-d
			1.994	wm
			1.871	m
			1.731	w
			1.688	vw-d
			1.558	w
			1.527	ms
			1.515	w
			1.320	w
			1.296	w
			1.271	vw

amount of twinning in the crystal; highly twinned crystals have low optic angles.

AMPHIBOLES

Chemical properties.—Two varieties of tremolite occur in the Arnold pit specimens; one lavender to pink in color (G-19, 21), the other pure white (G-16, 17). The lavender form occurs in large prismatic crystals several millimeters long. The varietal name "hexagonite" is often used to describe this tremolite; the type material reported as coming from Edwards, St. Lawrence County, N. Y. (Dana, 1892, p. 389, 393). The white variety of tremolite is associated with the "limy talc" (G-16) and to a small extent, with the coarsely crystalline talcs (G-1, 17). The lavender tremolite occurs in nearly mono-mineralic zones between the massive talc ore and hanging wall dolomite.

An exceptionally well-crystallized colorless tremolite rock collected 3/4 of a mile southwest of the Wight mine was also examined (G-24). Spectrographic analyses of the lavender and colorless varieties (G-21, G-24) are given in Table 1. Quantitative analyses for H₂O and fluorine for the G-21 tremolite are given in Table 3. The analyzed samples G-21 and G-24 contain a small amount of tirodite and quartz.

Engel (1962, p. 309) gives complete mineral analyses for two tremolites collected from the old Arnold mine. These analyses are recalculated in our Table 7. The various analyses (Table 1, 7) show that the Gouverneur tremolites have a nearly end-member composition with some Mn²⁺, K, and Na replacing calcium, F replacing (OH), and Al replacing Si.

There are four different occupied cation sites in the tremolite crystal

TABLE 7. TREMOLITE CHEMICAL ANALYSES FROM ENGEL (1962, p. 309)

Weight percent			Atomic ratios ^a			
	9 ^a	15 ^b		9 ^b	15	
SiO ₂	57.83	57.76	Si	7.915	7.897	8.001
Al ₂ O ₃	0.57	0.64	Al	0.092	0.104	
Fe ₂ O ₃	0.20	0.00	Fe ³⁺	0.021		
MgO	24.25	24.73	Mg	4.945	5.038	
FeO	0.11	0.14	Fe ²⁺	0.012	0.016	5.066
TiO ₂	0.03	0.05	Ti	0.003	0.005	
MnO	2.81	0.06	Mn ²⁺	0.325	0.007	
CaO	11.42	13.27	Ca	1.675	1.944	
K ₂ O	0.14	0.09	K	0.025	0.016	2.033
Na ₂ O	0.17	0.28	Na	0.044	0.073	
H ₂ O ⁻	0.06	0.13				
H ₂ O ⁺	2.09	2.38	OH	1.907	2.170	(1.882)
F	0.41	0.26	F	0.178	0.113	0.118
Cl	0.01	0.02	Cl	0.002	0.005	
CO ₂	0.00	—				
	100.10	99.81				
O=F+Cl	0.17	0.11				
	99.93	99.70				

^a Arnold No. 3 mine, 11th level, Fowler, N. Y.^b Arnold mine, 14th level, Fowler, N. Y.^c Number of ions on the basis of: number of oxygen atoms=22.00 and (OH)=2.00-F-Cl.

structure, designated M₁, M₂, M₃, and M₄. The smaller metal atoms such as Mg and Fe enter the M₁, M₂, and M₃ sites whereas the larger cations such as Ca and Na enter the large M₄ site. With our present knowledge of amphibole structure we do not expect any alkalis or alkaline earths to enter the M₁, M₂, or M₃ sites. Ideally the M₄ site should take up 2.00 calcium atoms per formula unit. The small cations, however may enter the M₄ sites in appreciable quantities replacing some of the calcium or sodium.

Physical properties.—X-ray studies of the lavender and white tremolite were made using both single crystal and X-ray powder techniques. The lavender tremolite specimens (G-19, 21) are essentially mono-mineralic. The crystals appear optically perfect with no evidence of twinning, exsolution or alteration. Single crystal photographs show tremolite G-21 to be monoclinic, space group *C2/m*, *Cm*, or *C2* with $a = 9.81_6 \text{ \AA}$, $b = 18.04$,

TABLE 8. UNIT-CELL DATA FOR TREMOLITES FROM THE
GOUVERNEUR, NEW YORK TALC DISTRICT

	G-21 ^a		G-24 ^a		G-16 ^d
	Single crystal	Powder ^b	Single crystal	Powder ^b	Single crystal
<i>a</i> (Å)	9.81 ₆	9.818 (5)	9.79 ₆	9.812 (2)	9.81 ₈
<i>b</i> (Å)	18.04	18.047 (8)	18.04	18.077 (3)	18.04
<i>c</i> (Å)	5.27 ₆	5.275 (3)	5.28 ₁	5.273 (2)	5.281
β	104°30'	104°39' (3')	104°25'	104°43' (2')	104°35'
<i>V</i> (Å ³)	904.4	904.2 (6)	903.9	904.5 (3)	904.2
System	monoclinic		monoclinic		monoclinic
Diffraction symbol	<i>C</i> */*		<i>C</i> */*		<i>C</i> */*

^a Lavender tremolite, Arnold pit, St. Lawrence County, N. Y.^b Obtained from least-squares refinement of powder data given in Table 9. Errors in thousandths of an Ångstrom and minutes given in parentheses.^c White tremolite, 3/4 mile SW Wight mine, N. Y.^d White tremolite, Arnold pit, St. Lawrence County, N. Y.

$c=5.27_6$, and $\beta=104^\circ30'$. The $h0l$ precession photographs exposed to unfiltered molybdenum radiation for 100 hours show extremely weak spots representing a second phase. X-ray data for this tremolite are summarized in Table 8. X-ray powder data for tremolite G-24 and G-21 are given in Table 9. Spectrographic analysis was given in Table 1.

In addition to lavender tremolite described above two white tremolites (G-16, G-24) were examined by X-ray single crystal techniques. Both tremolites show, under crossed nicols, thin lamellae oriented parallel to the $(10\bar{1})$ plane. In sample G-24 the lamellae are so distinct they can be seen in the hand specimen with a low power binocular microscope.

Precession photographs of both specimens give unit-cell data close to that of the lavender tremolite (Table 8). Superimposed on the strong single-crystal patterns of the host tremolite phase is a weaker pattern of a second amphibole. This second phase is a clino-amphibole having space group symmetry $P2_1/m$ or $P2_1$ with $a=9.48$ Å, $b=18.03$, $c=5.29$, and $\beta=101^\circ55'$.

The unit-cell data for the $P2_1/m$ amphiboles (G-16 and G-24) are given in Table 10 where the data is compared to that obtained by Bown (1966) on a similar specimen. As pointed out by Bown, who first reported existence of this $P2_1/m$ amphibole, the two coexisting amphibole phases have a common b -axis with the b -dimensions almost identical. The

TABLE 9. OBSERVED^a AND CALCULATED^b X-RAY POWDER DATA FOR WHITE (G-24) AND LAVENDER (G-21) TREMOLITE FROM THE GOUVERNEUR, N. Y. MINING DISTRICT

<i>hkl</i>	Tremolite, G-24			Tremolite, G-21		
	<i>d</i> (calc.) Å ^a	<i>d</i> (obs) Å	<i>I</i>	<i>d</i> (calc.) Å ^d	<i>d</i> (obs) Å	<i>I</i>
020	9.039	9.054	15	9.024		
110	8.403	8.410	40	8.405		
001	5.100	5.092	20	5.103		
130	5.087			5.082	5.046	60
$\bar{1}11$	4.873	4.875	10	4.873	4.866	5
200	4.745	4.751	10	4.749	4.739	10
040	4.519	4.523	30	4.512	4.514	10
021	4.441			4.442		
220	4.201	4.209	15	4.203	4.197	50
201	4.020	4.028	5B	4.021		
111	3.980			3.984		
131	3.875	3.880	15	3.873	3.878	10
221	3.673			3.673		
041	3.382			3.380		
131	3.379			3.380	3.373	25
150	3.379			3.374		
240	3.273	3.272	65	3.271	3.274	85
310	3.116	3.120	100+	3.119	3.115	100+
201	3.103			3.107		
$\bar{3}11$	3.016			3.016	3.013	5
060	3.013			3.008		
241	3.004	3.004	5	3.002		
$\bar{1}51$	2.942	2.944	45	2.939		
					2.942	35
221	2.935			2.937		
330	2.801	2.802	25	2.802		
$\bar{3}31$	2.727			2.727	2.727	20
151	2.706	2.712	100+	2.705	2.709	60
$\bar{1}12$	2.608			2.609		
061	2.594	2.594	35	2.591	2.589	15
241	2.558	2.557	5	2.559		

^a CuK α radiation, Ni filter ($\lambda=1.5418$ Å). Pattern taken with North American Philips X-ray diffractometer internally standardized with sodium fluoride. Specimens contain a small amount of quartz and tiroidite.

^b All calculated interplanar spacings are given down to $d=2.530$ Å. Calculated spacings less than this are given only where indexable to an observed spacing.

^c Calculated from the following unit-cell parameters: $a=9.812$ Å, $b=18.077$, $c=5.273$, $\beta=104^\circ43'$, space group $C2/m$. Composition by electron microprobe analysis: $\text{Ca}_{1.5}\text{Mn}_{0.3}\text{Mg}_{5.2}\text{Si}_5\text{O}_{22}(\text{OH}, \text{F})_2$.

^d Calculated from the following unit-cell parameters: $a=9.818$ Å, $b=18.047$, $c=5.275$, $\beta=104^\circ39'$, space group $C2/m$.

TABLE 9. (Continued)

<i>hkl</i>	Tremolite, G-24			Tremolite, G-21		
	<i>d</i> (calc.) Å ^c	<i>d</i> (obs) Å	<i>I</i>	<i>d</i> (calc.) Å ^d	<i>d</i> (obs) Å	<i>I</i>
002	2.550			2.552		
260	2.543			2.541		
202	2.530	2.530	25	2.530	2.531	20
350	2.381	2.379	15	2.380	2.379	100+
351	2.335			2.334	2.336	45
420	2.295	2.295	20	2.296	2.295	20
312	2.272	2.267	20	2.272	2.268	20
242	2.208			2.207	2.210	5
171	2.182	2.182	5	2.180	2.177	10
132	2.164			2.166		
		2.164	55			
261	2.162			2.161	2.161	25
152	2.130	2.132	5	2.129		
202	2.040			2.043	2.043	5
		2.046	10			
280	2.040			2.038		
351	2.015	2.015	25	2.015	2.015	30
370	2.000	1.999	10	1.999	1.998	100+
190	1.965			1.962		
					1.961	15
422	1.962	1.961	10	1.962		
510	1.888	1.887	30	1.889	1.892	35
460	1.864	1.864	15	1.864	1.864	10
442	1.837			1.836	1.836	10
530	1.810			1.812	1.810	15
441	1.805	1.805	10	1.806		
172	1.726			1.725		
					1.720	15
223	1.716			1.716		
372	1.713	1.710	5	1.712		
282	1.685	1.685	15	1.684		
					1.685	10
133	1.683			1.683		
		1.675	10			
2, 10, 1	1.649			1.646		
		1.649	40		1.648	30
461	1.648			1.648		
1, 11, 0	1.619	1.617	15	1.617	1.618	30
403	1.586			1.586		
					1.585	20
600	1.582			1.583		
					1.561	5

(Table 9 continued on following page)

TABLE 9. (Continued)

<i>hkl</i>	Tremolite, G-24			Tremolite, G-21		
	<i>d</i> (calc.) Å ^c	<i>d</i> (obs) Å	<i>I</i>	<i>d</i> (calc.) Å ^d	<i>d</i> (obs) Å	<i>I</i>
571	1.555	1.555	10	1.555	1.554	20
402	1.551			1.553		
					1.530	10
1, 11, 1	1.524	1.525	10	1.522		
282	1.514			1.514	1.514	100+
263	1.512	1.511	10	1.511		
482	1.502	1.503	20	1.501		
2, 10, 2	1.471	1.470	10	1.469	1.468	5
0, 12, 1	1.445	1.445	10	1.443		
		1.433	35		1.435	75
591	1.398	1.398	10			
731	1.365	1.365	15			

a-axes of the tremolite and $P2_1/m$ amphibole lie in a common (010) plane and at an angle of $2^\circ 30'$ of one another. The study by Bown was made on a tremolite from the Wight mine, St. Lawrence County, N. Y. showing "extremely fine (001) lamellae." His material is probably very similar in composition to specimens G-16 and G-24. In the $I2/m$ setting of Bown

TABLE 10. UNIT-CELL DATA FOR THE SECOND AMPHIBOLE PHASE
EXSOLVED FROM THE GOUVERNEUR TREMOLITES

	G-24 ^a	G-16 ^b	Bown (1966) ^c	Mg-cummingtonite ^d
<i>a</i> (Å)	9.50 ₂	9.47 ₆	9.51	9.467
<i>b</i> (Å)	18.04	18.03	17.95	17.937
<i>c</i> (Å)	5.28 ₄	5.28 ₅	5.27	5.292
β	102°25'	101°55'	102°0'	102°14'
<i>V</i> (Å ³)	884.6	883.5	880.0	878.1
System	monoclinic	monoclinic	monoclinic	monoclinic
Diffraction symbol	$P2_1/*$	$P2_1/*$	$P2_1/*$	$C*/*^2$

^a Data obtained from the same single crystal patterns as those of tremolite G-24 (Table 8).

^b Data obtained from the same single crystal patterns as those of tremolite G-16 (Table 8).

^c Cell edges transformed from the *I*-centered cell: $a=9.87$ Å, $b=17.95$, $c=5.27$, $\beta=109.5^\circ$, space group $I2/m$.

^d Unit-cell data of an iron free cummingtonite, $Mg_7Si_8O_{22}(OH)_2$, as extrapolated by Viswanathan and Ghose (1965).

the lamellae are oriented parallel to the (001) plane. Bown suggested that the lamellae are clino-anthophyllite.

Ross, Papike and Weiblen (1968) have made a more complete study of the composition and structural state of the amphiboles in sample G-24 and also have studied a sample of the manganoan amphibole tirodite (Segeler, 1961) from the International Talc mine No. 3 in the nearby Talcville, N. Y. area. X-ray precession photos and least-squares powder refinement of tirodite give the following unit-cell data: $a = 9.550 \pm 0.001$ Å, $b = 18.007 \pm 0.003$, $c = 5.298 \pm 0.001$, $\beta = 102^\circ 39' \pm 1'$, space group $P2_1/m$ or $P2_1$. The single crystal photos also show a weaker pattern of a second amphibole oriented parallel to the (101) plane of tirodite. The unit-cell data for this second phase is: $a = 9.78$ Å, $b = 17.99$, $c = 5.27$, $\beta = 104^\circ 25'$, space group $C2/m$. The (101) lamellae can be seen optically in the tirodite grains. Electron microprobe scans over the Talcville tirodite give the approximate composition as $\text{Ca}_{0.4}\text{Mn}_{1.2}\text{Mg}_{5.4}\text{Si}_8\text{O}_{22}(\text{OH}, \text{F})_2$. The lamellae are about one micron thick and have a much higher calcium and lower manganese content than the host tirodite phase.

Microprobe examination of sample G-24 shows that in addition to the crystals of calcium-rich tremolite there are a few grains of a manganese-rich amphibole. The lamellae in the tremolite are manganese-rich and similar in composition to tirodite. The lamellae in the Mn-rich amphibole are calcium-rich. The approximate compositions of the tremolite and Mn-rich host phases are $\text{Ca}_{1.5}\text{Mn}_{0.3}\text{Mg}_{5.2}\text{Si}_8\text{O}_{22}(\text{OH}, \text{F})_2$ and $\text{Ca}_{0.2}\text{Mn}_{0.9}\text{Mg}_{5.9}\text{Si}_8\text{O}_{22}(\text{OH}, \text{F})_2$ respectively. Chemical and X-ray evidence leaves no doubt that sample G-24 contains two amphiboles, tremolite and tirodite, with tremolite exsolving tirodite and tirodite exsolving tremolite. It is estimated that tirodite composes about 5 weight percent of the sample. The tirodite sample from Talcville is an analogue to sample G-24, the major phase is tirodite, the minor exsolved phase is tremolite.

In order to obtain more precise unit-cell data for the lavender and white tremolites (G-21 and G-24) the X-ray powder diffractometer data (Table 9) was subjected to least-squares refinement. The refined parameters are compared to the single crystal X-ray data in Table 8. The amount of tirodite in sample G-21 is probably less than one weight percent and in sample G-24, probably less than 5 weight percent. No lines of tirodite could be detected in either sample and thus should not have effected the refinement.

The optical properties of all three tremolites studied (G-16, G-21 and G-24) are nearly identical (biaxial negative, $\alpha = 1.604 \pm 0.002$, $\beta = 1.612 \pm 0.002$ and $\gamma = 1.628 \pm 0.002$), suggesting similar chemical compositions. The lavender variety does not show (101) lamellae although the X-ray

photographs show definitely that the second amphibole phase is present but composing probably less than one volume percent of the crystal. The lamellae are much more pronounced in G-16 and G-24 and the X-ray diffraction single crystal patterns of the lamellae are relatively strong with many reflections appearing in the $h0l$, $h1l$, and $h2l$ nets.

DISCUSSION

Talc.—Talc deposits may form by the metamorphism of carbonate rocks, by the replacement of silicified carbonate rocks, or by the alteration of ultramafic rocks. There are reported occurrences of talc formed from mafic and felsic igneous rocks, pegmatites, tuff, and low magnesian sediments; however, these involve complex and unique conditions that are atypical of the major occurrences. Talc bodies may also form by contact metamorphism in rare instances where the chemical conditions are correct.

Twenty-two specimens of essentially pure talc obtained from nineteen different deposits have been analyzed for fluorine content (Table 4). All of the talc samples were found to contain fluorine. Although too few samples have been studied to permit firm conclusions to be drawn, the following relationships may be inferred:

(a) Talc from deposits believed to be derived from the metamorphism of carbonate sedimentary rocks, formed by the replacement of silicified carbonate rocks, or occurring in talc-carbonate-amphibole schists, were found to contain 0.11 to 0.48 percent fluorine.

(b) Talc from the five deposits believed to be derived from the alteration of mafic or ultramafic rock, and which are intimately associated with serpentine, show fluorine content below 0.04 percent.

The present study coupled with that of Rayner and Brown (1966) definitely shows that the common variety of talc has a one-layer triclinic structure. Other polytypes, if they occur will probably be rare compared to the 1Tc form. To summarize, talcs from the following localities have been shown to have the one-layer triclinic structure:

- (1) Harford County, Maryland, U.S.N.M. 82519
- (2) Arnold pit, St. Lawrence County, New York
- (3) "Talc" mine, St. Lawrence County, New York
- (4) Balsam, North Carolina.

Tremolite.—Engel and Engel (1968) suggest that the temperature of metamorphism in the Gouverneur mining district in the is 500° to 600°C range. Some of the tremolites were enriched in manganese at the expense of calcium and sodium (e.g., Table 7, analysis 9b). The evidence given by Ross, Papike and Weiblen (1968) shows that the manganese-enriched

tremolite coexisted with a second amphibole tiroditite which was enriched in calcium. On cooling both phases unmixed to produce the (101) lamellae. Apparently at high temperatures the M_4 site can hold appreciable quantities of manganese. The appearance of exsolution lamellae in tremolite should be very useful in understanding the paragenesis of the Gouverneur schists and can also give information on the extent of solid-solution in tremolites.

Alteration of the tremolite-bearing schists.—Optical and X-ray examination of a number of tremolite rocks from the Gouverneur area show the following retrograde alteration sequences:

- (1) Sample CS-1, "Talc" mine
tremolite + talc $\rightarrow$ anthophyllite + talc
- (2) Sample G-2, International talc mine, N. Y.; G-5, Fullerville, N. Y.
tremolite $\rightarrow$ anthophyllite $\rightarrow$ talc
- (3) Sample G-6, Fowler, N. Y.
anthophyllite $\rightarrow$ talc
- (4) Sample G-18, Aronold pit
tremolite $\rightarrow$ serpentine
- (5) Sample G-26, Wight mine
tremolite $\rightarrow$ anthophyllite $\rightarrow$ talc?

Tremolites CS-1, G-5, and G-26 show prominent exsolution lamellae. Stemple and Brindley (1960) give evidence for the transformation tremolite $\rightarrow$ talc in a specimen from the Gouverneur area.

All of the very fine grained talc, anthophyllite, and serpentine noted in the Gouverneur schists appear to have grown by a latter alteration of tremolite or anthophyllite. The coarsely crystalline talc (*e.g.*, G-1, G-17) is associated with clear unaltered tremolite and appears to be a primary metamorphic assemblage; not a result of any retrograde alteration. The coarsely crystalline talc is not valuable commercially because of its poor milling quality. The fine-grained alteration products of the amphiboles (*e.g.*, G-16, G-18) forms the commercial ore. The superior milling quality of this ore is probably due to the fine-grained nature of the magnesium silicate alteration products.

ACKNOWLEDGEMENTS

We wish to thank Margaret H. Appleman for preparing the tremolite X-ray powder patterns and handling the computer computations, Paul W. Weiblen of the University of Minnesota for the electron probe analysis, and James J. Papike for advice on amphibole crystal chemistry.

REFERENCES

- Bown, M. G. (1966) A new amphibole polymorph in intergrowth with tremolite: Clino-anthophyllite: *Amer. Mineral.*, **51**, 259–260.

- DANA, E. S. (1892) *System of Mineralogy*. 6th ed.: John Wiley and Sons, Inc., New York.
- ENGEL, A. E. J. (1962) The Precambrian geology and talc deposits of the Balmat-Edwards District, northwest Adirondack Mountains, New York. *U. S. Geol. Surv. Open File Rep.*, 357p.
- ENGEL, A. E. J. AND CELESTE G. ENGEL (1958) Progressive metamorphism and granitization of the major paragneiss, northwest Adirondack Mountains, New York. *Geol. Soc. Amer. Bull.*, **69**, 1368-1414.
- GRUNER, J. W. (1934) The crystal structures of talc and pyrophyllite. *Z. Kristallogr.*, **88**, 412-419.
- HENDRICKS, S. B. (1938) On the crystal structure of talc and pyrophyllite. *Z. Kristallogr.*, **99**, 264-274.
- RAYNER, J. H. AND G. BROWN (1966) Triclinic form of talc. *Nature*, **212**, 1352-1353.
- ROSS, M., H. TAKEDA AND D. R. WONES (1966) Mica polytypes: Systematic description and identification. *Science*, **151**, 191-193.
- ROSS, M., J. J. PAPIKE AND PAUL W. WEIBLEN (1968) Exsolution in clinoamphiboles. *Science* (in press).
- SEGELER, C. G. (1961) First U. S. occurrence of manganoan cummingtonite, tirodite. *Amer. Mineral.* **46**, 637-641.
- STEMPLE, I. S. AND G. W. BRINDLEY (1960) A structural study of talc and talc-tremolite relations. *J. Amer. Ceram. Soc.* **43**, 34-42.
- VISWANATHAN, K. AND S. GHOSE (1965) The effect of Mg^{2+} - Fe^{2+} substitutions on the cell dimensions of cummingtonites. *Amer. Mineral.* **50**, 1106-1112.
- ZVYAGIN, B. B. AND Z. G. PINSKER (1949) Electronographic determination of the elementary cells of pyrophyllite and talc and structural relation of these minerals to montmorillonite. *Dokl. Acad. Sci. USSR* **68**, 505.

Manuscript received, July 18, 1967; accepted for publication, September 25, 1967.