NICKEL MINERALS FROM BARBERTON, SOUTH AFRICA: II. NIMITE, A NICKEL-RICH CHLORITE

S. A. DE WAAL, *National Institute for Metallurgy, Milner Park, Johannesburg, South Africa.*

ABSTRACT

A nickel-rich chlorite, nimite, comes from a small tabular body of nickeliferous rock about two miles west of the Scotia Talc Mine, in the Barberton Mountain Land. The nickeliferous rock comprises a mixture of nickel-rich chlorite, nickel-rich talc, ferroan trevorite, reevesite, violarite, and millerite.

The nimite is yellowish green, has a $2V_\alpha = 15° \pm 2°$, $\beta = 1.647 \pm 0.001$, and $\alpha = 1.637$, and has a measured specific gravity of 3.19. It has a monoclinic cell with $a = 5.320 \pm 0.002$ Å, $b = 9.214 \pm 0.003$ Å, $c = 14.302 \pm 0.003$ Å, and $\beta = 97.10° \pm 0.02°$. The eight strongest lines, in decreasing order of intensity, have *d*-spacings of 7.10, 3.55, 14.2, 4.74, 2.841, 2.582, 2.003, and 2.540 Å. The mineral was indexed, a space group $C2/m$ being assumed, and has the IIb type of layer structure of chlorite.

With heat treatment the nimite shows a marked decrease in the basal spacing, an enhancement of the intensities of the 001, 003, and 005 reflections, and a weakening of the intensities of the 002 and 004 reflections. A major loss of the water of crystallization occurs at 710°C, whereas an exothermic peak at 921°C in the DTA curve is ascribed to the recrystallization of nimite to a substance that proved to be mainly spinel.

The chemical analysis on a pure sample of nimite gives the cell formula

$H_{15.42}(Ni_{5.23}Mg_{3.33}Fe^{3+}_{0.72}Fe^{2+}_{0.51}Co_{0.07}Ca_{0.09}Mn_{0.01}Al_{1.97})(Si_{6.02}Al_{1.98})O_{36}$

The major infrared absorption bands of the nimite occur at the frequencies 445, 465, 676, 962 and 1010 cm^{-1}.

INTRODUCTION

As part of a study of the distribution of nickel in serpentinites and related rocks, the author collected and reinvestigated a sample of trevorite and associated silicate minerals from a well-known occurrence, approximately two miles west of the Scotia Talc Mine, in the Bon Accord area, Barberton, South Africa. In addition to violarite and millerite, ferroan trevorite, nickel-rich talc, nickel-rich chlorite, and reevesite, were encountered. The ferroan trevorite has been dealt with in detail (De Waal, 1969).

This paper deals with the nickel-rich chlorite. The name *nimite* is provisionally[1] proposed for this mineral and is derived from the abbreviated form for the National Institute for Metallurgy (N.I.M.). This name is pronounced nim′-ite.[1]

[1] A preliminary description received limited distribution as *Nat. Inst. Met. Res. Rep.* **344** (1968), was abstracted in *Chem. Abstr.* **70,** 127 (1969); consequently the name will be acted upon later by the International Mineralogical Association.

Field Relations and Petrography of the Nickel Ore

The nickel ore investigated was first reported by Trevor (1920). According to the South African Geological Survey (1959), the ore constitutes a tabular body with a thickness of 2 feet and a length of about 20 feet and is probably a contact deposit along the junction of the Moodies quartzite and the ultramafic rocks of the Jamestown Igneous Suite. It is also stated that the major minerals are nepouite and trevorite.

In hand-specimen the nickel ore has a greenish-grey (5G 6/1) (colour according to Rock-Color Chart, 1963) appearance on a fresh surface. The colour, however, tends to be somewhat mottled owing to the patchy distribution of the ferroan trevorite in the green silicates. This latter phenomenon strongly simulates brecciation.

In thin section, the rock consists of clusters of minute opaque grains embedded in the nickel-rich talc. The nimite forms irregular veins in the talc and opaque ore.

In polished section, the grain size of the ferroan trevorite varies considerably—from about 0.5 mm to less than 10μm in diameter. Polished sections further revealed the presence of violarite and millerite. The violarite is intergranular in the ferroan trevorite whereas the other sulphide appears as minute inclusions in the ferroan trevorite. The amount of sulphide varies markedly from one hand-specimen to another.

Secondary alteration of the ore is manifested by the formation of opal and moderate greenish-yellow (10Y7/4) reevesite in druses. These minerals have been mildly stained by iron oxide, and small amounts of goethite are present.

Experimental Methods

Microscopy was the basis of the present study.

All colours allotted macroscopically are in accordance with the Rock-Color Chart (1963) issued by the Geological Society of America. The symbols (in parentheses) correspond to those in the Rock Color Chart.

The optical axial angle was determined by using the Mallard constant, which in turn was calculated from axial angle measurements on natural barite and chemically pure ammonium sulphate.

The chlorite was purified for chemical analysis by use of its specific gravity and the characteristic magnetic property of the ferroan trevorite, which forms the major impurity in the mineral. The final purified product was estimated as being more than 98 percent pure. Minor quantities of ferroan trevorite and nickelian talc were still present when the mineral was investigated under a binocular microscope.

Determinations of specific gravity were conducted on a Berman balance with purified powdered nimite. The value thus obtained was checked in a Clerici cell, as described by Jahns (1939). The latter experiment was carried out in a temperature-controlled room at 21°C. For thorough mixing of the liquids in the cell, air was passed through it from the bottom with a hypodermic syringe. The refractive indices of the liquids were determined on an Abbé refractometer.

The specific gravity of the nimite was also calculated from its cell volume, its chemical composition, and Avogadro's number (6.0228×10^{-23}).

The indices of refraction of the nimite were determined by an immersion method. A sodium lamp was used as a light source, and the indices of refraction of the matching liquids were measured with a Leitz-Jelley refractometer.

The X-ray diffraction work was done on a Philips diffractometer equipped with a vertical goniometer. The adjustment of the goniometer was checked with standard samples of quartz and silicon at 10.45, 14.24, 25.11, and 44.01 degrees θ. The maximum deviation, although both positive and negative, never exceeded 0.02 degrees θ. The estimated standard deviation of measurements obtained on the same standards amounted to 0.01 degrees θ. If, however, the broad nature of the chlorite lines, when compared with silicon and quartz lines, was considered, any correction for the maladjustment of the goniometer would be relatively insignificant. The relative line intensities were calculated from integrated peak areas by use of a Disc Integrator, model 221. To avoid preferred orientation, a dilution method, with cork powder and the sideloading technique (Swanson *et al.*, 1967) was employed.

For the refinement of the cell constants, the computer program CELFIT (Bracher, B. H. 1967) *U. King. At. Energy Auth. Res. Group Rep.* 26pp.) was used. CELFIT comprises the refinement of cell dimensions by a method of least squares until the shifts in these parameters fall below limits specified by the user.

Differential thermal analysis was conducted at a heating rate of 12.2°C per minute in a normal air atmosphere.

The heat treatment of the nimite was done in an electric oven in which the maximum temperature deviations did not exceed 4°C. The heated samples were then investigated with a Debye-Scherrer X-ray camera (diameter = 114.6 mm). Cobalt Kα radiation was used, and an exposure time of sixteen hours was allowed.

The infrared-absorption spectrum of the nimite was obtained on a Beckman spectrophotometer, model IR12.

Results

The optical and physical properties of the nimite are presented in Table 1. In the same table are listed the data given by Partridge (1944) for a 'green silicate' that accompanies the trevorite. There is a degree of correspondence between the two sets of data, but it is the author's contention that the 'green silicate' actually consisted of a mixture of two minerals, namely, the nimite and a nickel-rich talc (to be described in a later paper). The two values given for the calculated specific gravity were obtained by (1) ignoring adsorbed water, and (2) considering adsorbed water.

In Table 2 the chemical analysis and unit-cell formula of the nimite are compared with those of brunsvigite, an iron chlorite.

The X-ray powder data of the nimite are presented in Table 3. The mineral is indexed according to the space group $C2/m$ and, by analogy with the work done by Brown and Bailey (1962), has the IIb type of chlorite structure.

In Table 4, the X-ray data for the nimite after heat treatment are

TABLE 1. OPTICAL AND PHYSICAL PROPERTIES OF NIMITE COMPARED WITH THE 'GREEN SILICATE'

Mineral	Nimite	Green silicate[c]
Colour	Yellowish green (10GY5/4) Faintly pleochroic in thin section; X = yellow green and Z = apple green	Dark green to apple green
Moh's hardness	3	2–2½
Cleavage	{001} pronounced	
Optical axial angle	$2V_\alpha = 15° \pm 2°$	$2V_\alpha = 14° \pm 2°$
Specific gravity	Berman balance: 3.123±0.002 Clerici cell: 3.19 Calculated 3.201[a] 3.210[b]	Pycnometer: 3.037±0.002
Refractive index	$\beta = 1.647 \pm 0.002$ $\alpha = 1.637$ ($\gamma \simeq \beta$)	$\beta = \gamma = 1.650 \pm 0.002$ $\alpha = 1.605 \pm 0.003$
Unit cell parameters	$a = 5.320 \pm 0.001$ Å $b = 9.214 \pm 0.003$ Å $c = 14.302 \pm 0.003$ Å $\alpha = 90.00°$ $\beta = 97.10 \pm 0.02°$ $\gamma = 90.00°$ Cell volume = 695.74 Å^3	

[a] Adsorbed water ignored.
[b] Adsorbed water considered.
[c] After Partridge (1944).

compiled. The changes that occurred after treatment at 600°C show a marked analogy to the change found by Martin (1955), in thuringite, when this mineral was heated to 550°C.

The main features are a pronounced decrease in the basal spacing, the enhancement of the intensities of the 001, 003 and 005 reflections, and the weakening of the intensities of the 002 and 004 reflections. A total collapse of the nimite structure appears between 700°C and 800°C. The DTA and TGA curves (Figure 1) indicate that this change in structure is seemingly related to the major loss of the water of crystallization at approximately 710°C. The exothermic reaction (Fig. 1) at 921°C most probably is due to recrystallization of the nimite to a substance that by X-ray diffraction analysis proved to be mainly spinel (Table 4).

TABLE 2. CHEMICAL ANALYSIS OF NIMITE AND OF BRUNSVIGITE

	Nimite[a]		Brunsvigite[b]	
SiO_2	27.27		27.11	
TiO_2	n.d.		0.35	
Al_2O_3	15.21		17.42	
Fe_2O_3	4.35		2.91	
Cr_2O_3	less than 0.01[c]		—	
FeO	2.78		30.98	
NiO	29.49		—	
MnO	0.06		—	
MgO	10.13		9.75	
CaO	0.38		0.21	
CoO	0.38		—	
H_2O^+	10.48		11.07	
H_2O^-	0.27		0.51	
	100.80		100.31	
Number of ions per 36(O, OH)				
Si	6.016	8.00	5.864	8.00
Al	1.984		2.136	
Al	1.970		2.307	
Ti	—		0.057	
Fe^{3+}	0.722		0.473	
Fe^{2+}	0.513	11.94	5.605	11.63
Ni	5.232		—	
Mn	0.011		—	
Mg	3.331		3.143	
Ca	0.090		0.048	
Co	0.067		—	
(OH)	15.42		15.98	

[a] Analyst: Analytical Chemistry Division, National Institute for Metallurgy. n.d. = not determined.

[b] After Deer, Howie, and Zussman (1962).

[c] Spectrographic analysis.

A complete infrared pattern of the nimite is given in Figure 2. The general distribution and intensities of the absorption bands are typical of the chlorite group of minerals as given by Hayashi and Oinuma (1965, 1967). In Table 5, the absorption bands of the nimite are compared with those of an aluminian chlorite, a magnesian chlorite, and an iron chlorite.

A study of this table reveals the close correspondence between the nimite and the iron chlorite in the region from 400 to 900 cm^{-1}. In the region from 900 to 1020 cm^{-1}, the position of the absorption band differs

TABLE 3. X-RAY POWDER DATA FOR NIMITE

I^a	*hkl*	*d* (meas)	*d* (calc)	I^a	*hkl*	*d* (meas)	*d* (calc)
25	001	14.2	14.2	1	$20\bar{6}$	1.8827	1.8812
100	002	7.10	7.10	<1	205	1.8253	1.8239
16	003	4.74	4.73	1	206	1.6620	1.6625
1	020	4.60	4.61	2	$20\bar{8}$	1.5661	1.5647
45	004	3.55	3.55	2	060	1.5349	1.5359
7	005	2.841	2.838	1	062	1.5012	1.5007
1	200	2.644	2.639	1B	0.0.10	1.4188	1.4192
3	$20\bar{2}$	2.582	2.580	1B	064	1.4101	1.4093
2	201	2.540	2.539	1	208	1.3948	1.3948
2	$20\bar{3}$	2.438	2.436	1B	400	1.3190	1.3200
2	202	2.379	2.380	<1	401	1.3001	1.2995
2	$20\bar{4}$	2.258	2.255	1	$40\bar{4}$	1.2901	1.2904
<1	$20\bar{5}$	2.062	2.064	1B	$40\bar{6}$	1.2179	1.2184
1	007	2.028	2.027	1B	0.0.12	1.1821	1.1826
3	204	2.003	2.003				

[a] Integrated peak areas.

noticeably from that of the iron chlorite because the relevant band of the nimite has actually split up in two poorly resolved peaks, one at 962 cm^{-1} and the other at 1010 cm^{-1}. Since the iron chlorite under discussion has a composition close to that of nimite (Table 6), the major differences between the infrared patterns of these two minerals can be ascribed mainly to the influence of the nickel.

Specific-Gravity Determination. The determinations of specific gravity by the two methods mentioned show considerable deviation from the calculated value (Table 1). The Berman balance obviously gives a value that, despite a small standard deviation, is much too low and not acceptable. Trapped air both in the cleavage cracks in the mineral grains themselves and as minute bubbles between the grains of the powder is most probably the cause of this unacceptably low value.

The value derived from the refractive index of the Clerici liquid is much nearer to the calculated value, though also somewhat low. In this instance, only trapped air in cleavage cracks would contribute to the low value.

It is obvious from the above discussion that the determination of the specific gravities of micaceous minerals is a far more complicated matter than is usually realized. Trapped air seems to be the greatest single contributor to poor results, and special care must be taken to avoid its consequences.

TABLE 4. X-RAY DATA FOR NIMITE AFTER HEAT TREATMENT

	500°C[ab]		600°C[a]		700°C[a]		800°C[a]		980°C[c]	
hkl[d]	*I*	*d*	*I*	*d*	*I*	*d*	*I*	*d*	*I*	*d*
001	25	14.20	100	13.90	100	13.90	80	12.89	20	4.65
002	100	7.10	30	6.95	15	6.96	—	—	10	2.63
003	10	4.73	20	5.02	—	—	—	—	60	2.47
020	12	4.57	10	3.52	20	4.54	10B	4.50	10	2.35
004	40	3.54	20	3.45	15	3.47	—	—	100	2.04
	—	—	15	3.10	30	3.11	10	3.11	20	1.53
005	10	2.84	30	2.76	15	2.77	—	—	80	1.43
200	10	2.64	25	2.66	20	2.63	10B	2.60	30	1.23
	25	2.57	20	2.56	15	2.56	—	—	20	1.17
	15	2.53	5	2.53	20B	2.50	10B	2.51	20	1.02
	20	2.434	40	2.44	25	2.41	—	—	20B	0.91
	20	2.376	20	2.37	10	2.36	—	—	50B	0.83
	20	2.253	30	2.24	25	2.23	15VB	2.20		
	5	2.064	20	2.17	10	2.17	—	—		
	30	2.000	15	2.04	10	2.06				
	15	1.879	20B	1.99	5	1.98	—	—		
	5	1.821	20B	1.86	5	1.85				
	5B	1.725	1	1.73	5	1.72	—	—		
	7	1.661	10	1.69	5	1.69	—	—		
	12	1.565	1	1.64	—	—	—	—		
	25	1.534	30B	1.54	50	1.52	15VB	1.51		
	5	1.499	10B	1.50	5	1.48	—	—		
	< 5	1.462	—	—	—	—	—	—	—	
	5	1.410	1	1.41	—	—	—	—		
	+18 lines to 0.908		+18 lines to 0.915		+8 lines to 0.993					

[a] Temperature range ±4°C at maximum heating time 1 hour.
[b] Corrections for film shrinkage taken into account.
[c] DTA residue.
[d] hkl after data in Table 3.

TABLE 5. INFRARED-ABSORPTION BANDS OF NIMITE, AN Al-CHLORITE, A Mg-CHLORITE, AND AN Fe-CHLORITE

Nimite	Al-chlorite[a]	Mg-chlorite[a]	Fe-chlorite[a]
(a) In the region 400 to 900 cm^{-1}			
445m	—	420m	445m
465m	475m	462m	478m
—	—	—	495
—	528	—	—
545	555	548	540
634	—	—	620
676m	692m	663m	658m
—	—	725	—
750	—	756	744
810	825	818	812
—	—	830	—
—	—	—	855
(b) In the region 900 to 1020 cm^{-1}			
962m	1004m	988m	973m
1010m	—	—	—

m = major absorption bands.
[a] After Hayashi and Oinuma (1965, 1967).

Nomenclature of the Nickel-Rich Chlorites. The nomenclature of the hydrous silicates of nickel is in a state of confusion, and, since this paper deals with chlorite, the author considers it relevant to comment on the nomenclature of the nickel-rich chlorites. However, before this can be done, it is necessary to define the author's concept of the chlorite, septechlorite, and serpentine groups of minerals.

In general, the author adhered to the definitions of these three groups as outlined by Deer, Howie, and Zussman (1962). It is known that all these minerals have the basic formula

$$Y_{3-x}Al_xSi_{2-x}Al_xO_5(OH)_4$$

where Y = Mg, Fe, Ni, Co, etc., and Cr and Fe^{3+} may substitute for Al.

Chlorite, in the sense used in this paper, has the above basic formula, is a 14 Å layered phyllosilicate, and has a Y-number larger than 0.5,

TABLE 6. UNIT-CELL FORMULAE OF NIMITE AND AN FE-CHLORITE BASED ON 18 OXYGEN ATOMS

	Nimite	Fe-chlorite
Mg	1.666	0.789
Mn	0.006	0.588
Ni	2.616	—
Fe^{+2}	0.257	2.823
Fe^{+3}	0.361	0.123
Al	0.985	1.453
Al }	0.992	1.130
Si }	3.008	2.870

After Hayashi and Oinuma (1967).

where Y is the number of (Al, Fe^{3+}, Cr) ions per four available tetrahedral positions. The 14 Å character is a major parameter. A mineral with Y below 0.5, but with a 14 Å structure, will be grouped with chlorite. Such conditions, however, seem to be very rare.

Septechlorite, as put by Brown (1961), has 'the serpentine type of structure but containing sufficient aluminium to place them (the septechlorites) in the chlorite range of composition.' It follows that the septechlorite (or aluminium serpentine, after Brown) is a 7 Å layered phyllosilicate with the stated basic formula and Y larger than 0.5.

Serpentine, in consequence, is a 7 Å layered phyllosilicate that has the relevant basic formula, but with Y below 0.5.

Following the given definitions of chlorite, septechlorite, and serpentine, the various names for hydrous nickel silicates that appeared in the literature can be discussed.

Nepouite has been described by Glasser (1906), who introduced the name, by Montoya and Baur (1963) from New Caledonia, and by Slansky (1955) from Kremze in southern Bohemia. Chemical data (Table 7) published by those authors conform to the basic formula of the serpentine group. The X-ray and dehydration information listed by Montoya and Baur, and Slansky confirm the relation with the serpentine group of minerals.

From the given data it is contended that nepouite is essentially a nickel serpentine. This contention would be in line with the suggestions of Dana (1958) and Winchell (1951). Dana groups the nepouite with serpentine, and Winchell proposed a continuous series between antigorite and nepouite. The author accordingly suggests that nepouite should be retained as a general term for the nickel serpentines, because of the close association between the serpentines and nepouite in the literature.

TABLE 7. CHEMICAL DATA ON NEPOUITE

	Glasser (1906)[b]		Slansky (1955)	Montoya and Baur (1963)[b]	
Si	8.067	8.006	$(Ni, Mg)_6Si_4O_{10}(OH)_8$	7.364	
Al	—	—		0.636	8.00
Al	0.281	0.304		0.417	
Fe^{3+}	—	—		0.213	
Cr	—	—		0.017	
Fe^{2+}	0.390	0.233		—	11.13
Mg	1.333	4.017		4.384	
Ni	9.691	7.346		6.098	
Ca	0.132	0.142		Trace	
	11.83	13.04			
H	15.797	15.587		17.73	
	Y=0[a]	Y=0		Y=0.3	
	R^{3+}=?[a]	R^{3+}=?		R^{3+}=2	
	R^{2+}=14[a]	R^{2+}=14		R^{2+}=14	

[a] Y, R^{3+}, and R^{2+} after Phillips (1964). R^{3+} according to Phillips is insignificant where Y lies between 0.0 and 0.5.

[b] Calculated by present author on a basis of 36 (O, OH).

Röttisite has been described by Breithaupt (1859), and a relationship between it, *conarite*, *revdinskite* (or *rewdanskite*), and nickel chlorite has been suggested by Spangenberg (1938). Röttisite and revdinskite investigated by Faust (1966) proved to be mainly pimelite—the nickel montmorillonite—so that both these terms seem to fall away.

Conarite (connarite or comarite) has a chemical formula of

$$H_4Ni_2Si_3O_{10}$$

which is altogether different from the chlorite and serpentine groups of minerals, and Faust (1966) reports that the X-ray pattern of this mineral is 'unlike that of any of the known hydrous nickel silicates,' so that this mineral most probably is a new species.

The name *schuchardtite* was introduced by Schrauf (1882). Two years later, Starkl (1884) gave dehydration data on the same material and also a few excellent chemical analyses (Table 8). Schuchardtite has also been described by Spangenberg (1938), and he suggested a relationship of this mineral with röttisite, comarite, revdinskite, and nepouite. X-ray work by Schuller (1956) indicates that schuchardtite is a 14 Å chlorite. If the schuchardtite is classified according to the system suggested by Phillips (1964) the name nickeloan pennine will apply, which means that the name schuchardtite needs revision.

The name *garnierite* has been widely used in literature for hydrous

TABLE 8. CHEMICAL INFORMATION ON SCHUCHARDTITE

	Schrauf (1882)[a]	Starkl (1884)[a]	Spangenberg (1938)
Si	6.580 } 8.00	6.593 } 8.00	Al_2O_3 0.63–5.30
Al	1.420 }	1.407 }	NiO 9.07–21.15
Al	2.130	2.006	MgO 31.21–17.03
Fe^{3+}	0.588	0.572	Fe_2O_3 1.76–2.46
Fe	0.531 } 11.85	0.589 } 11.39	
Ni	0.808	0.905	
Mg	7.509	7.005	
Ca	0.288	0.312	
H	14.990	16.05	
Y[b]	0.7	0.7	
R^{3+}[b]	1	1	
R^{2+}[b]	10	10	

[a] Calculated by the present author on a basis of 36 (O, OH).
[b] After Phillips (1964).

nickel silicates, and Pecora *et al.* (1949) suggested that it should be applied only as a general field term for these minerals. The present author fully agrees with this suggestion.

In conclusion the author wishes to discuss the actual *classification of nimite*. The recent proposal of Phillips (1964) for the classification of chlorite is favoured by the author, since it considers structure as well as chemical composition. In view of the relevant published data, it is felt, however, that the name nepouite is misused by Phillips. The present author therefore proposes that the names nepouite, schuchardtite, and nimite, as in Table 9, should be added to Phillips's list.

TABLE 9. CLASSIFICATION OF THE NIMITE, SCHUCHARDTITE, AND NEPOUITE BY MEANS OF THE CHLORITE NUMBERS[a]

	Y	R^{3+}	R^{2+}	Structure
Nepouite	0–0.5	1, 2, 3, 4	14	7 Å
Schuchardtite	0.5–0.9	1	14	14 Å
Nimite	0.9–1.2	1	14	14 Å

[a] It will be noted that the R^{2+} number of schuchardtite is here proposed to be 14, instead of 10, as for the schuchardtite originally described. As already stated, schuchardtite, according to the system of Phillips, would be classified as a nickeloan pennine.

ACKNOWLEDGMENTS

The author wishes to thank Dr W. R. Liebenberg, Deputy Director, of the National Institute for Metallurgy, and Dr S. A. Hiemstra, Head of the Mineralogy Division, for constructive criticism during the investigation, and various staff members and colleagues for assistance at all times.

REFERENCES

BREITHAUPT, J. F. A. (1859) Neue Mineralien; 2. Röttisite; 3. Konarit. *Berg-Huettenmaenn. Ztg.* **18,** 1, 1–2.

BROWN, G. (1961) *The X-ray Identification and Crystal Structures of Clay Minerals.* Jarrold and Sons Ltd. London.

BROWN, B. E., AND S. W. BAILEY (1962) Chlorite polytypism: I. Regular and semi-random one-layer structures. *Amer. Mineral.* **47,** 819–850.

DE WAAL, S. A. (1969) Nickel minerals from Barberton, South Africa: I. Ferroan trevorite. *Amer. Mineral.* **54,** 1204–08.

DEER, W. A., R. A. HOWIE, AND J. ZUSSMAN (1962) *Rock-forming Minerals. vol. 3 Sheet Silicates.* William Clowes and Sons, Ltd. London. 131–163.

FAUST, G. T. (1966) The hydrous nickel-magnesium silicates-the garnierite group. *Amer. Mineral.* **51,** 279–298.

FORD, W. E. (1958) *A Textbook of Mineralogy.* 4th ed. John Wiley and Sons, Inc. New York.

GLASSER, M. E. (1906). Sur une espèce minèrale nouvelle, la nèpouite, silicate hydrate de nickel et de magnesie. *C. R. Acad. Sci. Paris.* **143,** 1173–1175.

HAYASHI, H., AND K. OINUMA (1965) Relationship between infrared absorption spectra in the region of 450 to 900 cm^{-1} and chemical composition of chlorite. *Amer. Mineral.* **50,** 476–483.

———, AND ——— (1967) Si-O absorption band near 1000 cm^{-1} and OH absorption bands of chlorite. *Amer. Mineral.* **52,** 1206–1210.

HEY, M. H. (1954) A new review of the chlorites. *Mineral Mag.* **30,** 277–292.

JAHNS, R. H. (1939) Clerici solution for specific gravity determination of small mineral grains. *Amer. Mineral.* **24,** 116–122.

MARTIN, R. T. (1955) Reference chlorite characterization for chlorite identification in soil clays. *Clay and Clay Minerals.* Proc. Third Nat. Conf., Houston **1954,** 117–145.

MONTOYA, J. W., AND G. S. BAUR (1963) Nickeliferous serpentines, chlorites, and related minerals found in two lateritic ores. *Amer. Mineral.* **48,** 1227–1238.

PATRIDGE, F. E. (1944) Trevorite and a suggested new nickel-bearing silicate from Bon Accord, Sheba Siding, Barberton District. *Trans. Geol. Soc. S. Africa.* **46,** 119–136.

PECORA, T., S. W. HOBBS, AND K. J. MURATA (1949) Variations in garnierite from the nickel deposit near Riddle, Oregon. *Econ. Geol.* **44,** 13–23.

PHILLIPS, W. R. (1964) A numerical system of classification for chlorites and septechlorites. *Mineral. Mag.* **33,** 1114–1124.

ROCK COLOR CHART COMMITTEE, New York. (1963) *Rock Color Chart.* The Geological Society of America. New York.

SCHRAUF, A. (1882) Beitrage zur kentniss des Associationskreisis der Magnesiasilicate. *Z. Kristallogr. Mineral.* **6,** 386–387.

SCHÜLLER, A. (1956) Die erzbildenden nickelsilikatischen Minerale von Kuhschnappel und ihre röntgenographische Diagnose. *Z. Angew. Geol.* **8/9,** 353–370.

SLANSKY, E. (1955) Nickel hydrosilicates from Kremze in Southern Bohemia. *Univ. Carolina, Geol., Praha.* **1,** 1–28.

VERMEULEN, P. H. (Ed). (1959) *The Mineral Resources of South Africa. 4th ed.* Government Printer. Pretoria.

SPANGENBERG, K. (1938) Die wasserhaltige Nickelsilicate. *Zentralbl. Mineral. Geol. Palaeontol. Abt. A*. **12**, 360–364.

STARKL, G. (1884) Ueber Schuchardtite. *Z. Kristallogr. Mineral.* **8**, 239–240.

SWANSON, H. E., H. F. MCMURDIE, M. C. MORRIS, AND E. H. EVANS (1967) Standard X-ray-diffraction powder patterns. *U.S. Nat. Bur. Std. Monograph* 25, *Sec. 5*. p. 2.

WINCHELL, A. N. (1951) *Elements of Optical Mineralogy. Part II*. 4th ed. John Wiley and Sons, Inc. New York.

Manuscript received, February 25, 1969; accepted for publication, October 20, 1969.