

A garnierite with a high nickel content from Western Australia

E. H. NICKEL

Division of Mineralogy, CSIRO, Wembley, W.A., Australia, 6014

P. J. BRIDGE

Government Chemical Laboratories, Perth, W.A., Australia, 6000

SUMMARY. The garnierite, which occurs in the oxide zone overlying a nickel sulphide deposit, consists of talc-like and serpentine-like components, with the former predominating. Chemical and electron-probe analyses give NiO contents ranging between 39.6 and 43.9 weight %.

THE weathering of nickel sulphide deposits in Western Australia has resulted in the formation of a variety of secondary nickel minerals (e.g. Nickel, 1973; Nickel *et al.*, 1974; Keele and Nickel, 1974). One such mineral, occurring in the surface gossan at the Scotia mine, can be termed, for want of a suitable alternative name, a talc-like garnierite. Samples of this material have come to hand from Mr. J. Just of Australian Selection (Pty.) Limited, from Mr. I. Williams of the Geological Survey of Western Australia, and from one of the authors (P.J.B.).

Occurrence. The Scotia mine (30°13' S., 121°16' E.) is about 65 km north of Kalgoorlie in the Eastern Goldfields region of Western Australia. The primary sulphide ore consists largely of pentlandite and pyrrhotine at an ultramafic-amphibolite contact in close proximity to granite (Hudson, 1972). The garnierite appears to occur in the oxidized zone overlying the sulphides, since it was found on waste heaps from the excavation of a ventilation shaft at the mine. Mine records indicate that a mineral answering to the description of the garnierite was noted at depths between 15 m and 23 m below the surface. In the sample from J. Just, hereafter referred to as CSIRO-5766, the garnierite occurs as a discontinuous surface coating on a limonitic fragment of serpentinite. The sample collected by I. Williams (MDC-4271) consists of a quartz-garnierite intergrowth in a silicified ferruginous gossan (L. C. Hodge, Government Chemical Laboratories, personal communication). In the sample collected by P. J. Bridge, hereafter referred to as MDC-4782H, the garnierite occurs as soft patches in a vein of nickeloan magnesite, which contains serpentinite fragments and is coated with small quartz crystals.

Nomenclature. The mineral name 'garnierite' has had a chequered career, which has been well summarized by Faust (1966) and by Brindley and Pham Thi Hang (1973),

among others. The conclusion reached by these authors is that garnierite should be used as a general or group name for hydrous nickel-magnesium silicates. Brindley and Pham Thi Hang subdivided garnierites into 7 Å (serpentine-like) and 10 Å (talc-like) categories, based on the position of the strong basal diffraction peak. This seems to be a useful way of characterizing the previously rather ill-defined minerals and mineral mixtures loosely grouped under the name 'garnierite'. This classification is a structural rather than a chemical one, since virtually complete solid solutions exist between nickel and magnesium end-members in both categories. Brindley and Pham Thi Hang also pointed to the existence of mixed-layer types comprising both types of silicate layers. Springer and Wicks (1972) have suggested that sepiolite-type minerals should also be included under the term 'garnierite' (see also p. 69).

The question of how pecoraite (Faust *et al.*, 1969), nepouite (Maksimovich, 1973), and willemseite (de Waal, 1970), the nickel analogues of chrysotile, lizardite, and talc respectively, fit into this scheme merits some consideration. Although Brindley and Pham Thi Hang did not consider the problem, it seems reasonable to restrict use of the terms 'pecoraite' and 'nepouite' to the pure 7 Å end-members, and of 'willemseite' to the pure 10 Å end-member, retaining the term 'garnierite' for less well-defined types.

Chemical composition. The garnierite from sample MDC-4271 was separated from the intergrown quartz by heavy-liquid separations and analysed by traditional wet-chemical methods at the Government Chemical Laboratories. The garnierites in samples MDC-4782H and CSIRO-5766 were analysed *in situ* by electron-probe microanalyser at the CSIRO laboratories. The results of the analyses, shown in Table I, indicate that the compositions of the three samples are quite similar (in sample MDC-4271 the alkalis and chlorine are present in roughly equal atomic proportions, which indicate that they are probably present as a chloride impurity and can, therefore, be disregarded as far as the composition of the garnierite is concerned).

The composition of MDC-4271 corresponds to the formula $(\text{Ni}, \text{Mg}, \text{etc.})_{3.36} (\text{Si}, \text{Al})_4 \text{O}_{10} (\text{OH})_{2.74} \cdot 1.09 \text{H}_2\text{O}$. The ratio of octahedral to tetrahedral cations is $O/T = 0.84$, which lies between the ideal O/T ratios of 1.5 for a serpentine-type mineral and 0.75 for a talc-type mineral. Using the formulation proposed by Brindley and Pham Thi Hang (1973), based on the mole ratios of octahedral and tetrahedral cations, the composition corresponds to 78 % talc-type and 22 % serpentine-type layers. Samples MDC-4782H and CSIRO-5766 have O/T ratios of 0.92 and 0.90 respectively, indicating a somewhat lower ratio of talc to serpentine components.

X-ray diffraction pattern. X-ray powder diffraction patterns of the garnierite are rather diffuse, and therefore the lines cannot be measured with a high degree of accuracy. The patterns of all three samples are virtually identical, the only difference being the weak 7.3 Å line in MDC-4782H. When compared with the powder patterns of clinochrysotile and talc (Table II), the garnierite patterns bear a general resemblance to that of talc, except for the 7 Å chrysotile line in MDC-4782N, and the broad band between 2.5 and 2.6 Å, which takes the place of a series of individual talc lines. The garnierite patterns are, in fact, very similar to the diffractometer tracings of 10 Å garnierites published by Brindley and Pham Thi Hang (1973). The

willemseite X-ray diffraction pattern (de Waal, 1970) is also similar although, like talc, the willemseite lines are apparently better defined than those of the garnierites described here.

Optical and physical properties. The garnierite is bright green in colour, with a Munsell colour coding $u/z/r = 42.5/6/4$, which is quite similar to colour values reported by Brindley and Pham Thi Hang for their high-nickel garnierites. In grain

TABLE I. *Analyses of garnierite*

MDC-4271*		MDC-4782H†		CSIRO-5766‡			
Atomic ratios‡		Atomic ratios‡		Atomic ratios‡			
SiO ₂	43.58	Si	3.972	42.1	3.93	44.5	3.99
Al ₂ O ₃	0.27	Al	0.028	0.6	0.07	0.2	0.01
Fe ₂ O ₃	0.46	Fe	0.031	0.1	0.01	1.0	0.07
Cr ₂ O ₃	0.20	Cr	0.015				
NiO	39.62	Ni	2.903	43.3	3.25	43.9	3.15
MgO	1.60	Mg	0.216	2.5	0.36	2.2	0.30
CoO	0.45	Co	0.032				
CuO	2.32	Cu	0.159	0.6	0.04	1.1	0.07
ZnO	0.14	Zn	0.009				
CaO	0.06	Ca	0.005				
Na ₂ O	0.57	Na	0.082				
K ₂ O	0.08	K	0.008				
Cl	0.72	Cl	0.111				
H ₂ O ⁺	8.10§	H ₂ O	2.462	10.8	3.36	7.1	2.21
H ₂ O ⁻	0.69§	—	—				
	98.86			[100.0]		[100.0]	
O ≡ Cl	0.16						
	98.70						

* Chemical analysis; analyst R. S. Pepper, Government Chemical Laboratories.

† Electron probe analyses, determined as elements and recalculated as oxides; analyst E. H. Nickel, CSIRO.

‡ Calculated on the basis of 4 (Si+Al) atoms.

§ These values are regarded as somewhat unreliable due to minor contamination by heavy liquids.

|| By difference.

mounts in oil-immersion liquids it is light green. Birefringence is low, and the refractive index is 1.60, which clearly distinguishes the mineral from willemseite, which has a high birefringence and refractive indices α 1.600 and β 1.652 (de Waal, 1970).

The D.T.A. curves of the garnierite show a strong endothermic peak at 140 °C and a weaker one at 950 °C, which are both at slightly higher temperatures than the deflections in the weight-loss curves for 10 Å garnierites given by Brindley and Pham Thi Hang (1973). These two endothermic peaks can be attributed to loss of hygroscopic water and to dehydroxylation, respectively. The mineral appears to be unaffected by glycolation.

TABLE II. Powder diffraction patterns of garnierite, clinochrysotile, and talc

Garnierite				Clinochrysotile*		Talc*	
MDC-4271		MDC-4782H		(PDF No. 21-543)		(PDF No. 19-770)	
<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>
10 Å	vs	10 Å	vs	—	—	9.35 Å	100
—	—	7.3	w	7.31 Å	100	—	—
—	—	—	—	—	—	4.59	45
4.6	mw	4.6	mw	4.57	50	4.56	25
—	—	—	—	—	—	4.53	12
—	—	—	—	3.65	70	—	—
3.2b	mw	3.2b	mw	—	—	3.12	40
—	—	—	—	—	—	2.635	18
—	—	—	—	—	—	2.610	14
2.5	broad	2.5	broad	—	—	2.597	20
to		to		—	—	—	—
2.6	band	2.6	band	—	—	2.589	14
—	—	—	—	—	—	2.496	20
—	—	—	—	—	—	2.479	30
—	—	—	—	—	—	2.464	14
—	—	—	—	2.270	30	—	—
—	—	—	—	2.205	30	—	—
—	—	—	—	2.092	30	—	—
—	—	—	—	1.827	30	—	—
—	—	—	—	1.744	30	—	—
1.53	s	1.53	s	1.535	50	1.529	55
—	—	—	—	—	—	1.524	12b
—	—	—	—	1.506	30	1.511	12
—	—	—	—	1.463	30	—	—
1.31	w	1.31	w	1.313	30	—	—

* Lines with intensities ≤ 10 not listed.

Conclusions. The mineral described in this paper conforms to high-nickel, mixed-layer garnierite, with the 10 Å component predominating, as described by Brindley and Pham Thi Hang (1973). The nickel content, however, is substantially higher than that of any 10 Å garnierites reported in the literature to date.

With respect to nomenclature, the authors agree with the usage of Brindley and Pham Thi Hang (1973) in applying the name garnierite to ill-defined mineral mixtures consisting of 7 Å and 10 Å components. The present work does not shed any light on the question of whether the definition should be broadened to include sepiolite-type minerals, as suggested by Springer and Wicks (1972).

Acknowledgement. The authors express their appreciation to Mr. N. L. Marsh who performed the differential thermal analyses.

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[*Manuscript received 17 April 1974*]

Note added in proof: Since the preparation of this paper, Prof. Brindley kindly drew our attention to a forthcoming paper, *The Nature and Nomenclature of Hydrous Nickel-containing Silicates*, by G. W. Brindley and Z. Maksimovic, to be published in vol. 10 of *Clay Minerals*.