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ON THE CLASSIFICATION AND NOMENCLATURE OF CLAY MINERALS

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Abstract. A detailed classification of clay minerals with layer and layer-ribbon structures has been presented. The structure of layers has been taken as the division basis of minerals which have the crystalline structure composed of homotypic layers, and the kind of combination of layers — as the criterion for classification of mixed-layer clay minerals composed of heterotypic layers. Some simplification and unification of nomenclature of layer silicates have been proposed.

INTRODUCTION

The present work is an attempt at arranging the systematics of clay minerals on the basis of crystallochemical and structural criteria, in accordance with the current viewpoints concerning this group of minerals.

The classifications published up-to-now have become partly outdated as our knowledge of clay minerals has advanced, or they have a very general character (*e.g.* C.I.P.E.A. classification).

The classification presented in this work is based on the classification proposed by Frank-Kamienetsky (1960) and on the general classification of the layer silicates recommended by C.I.P.E.A. (Brindley 1966).

Clay minerals differ in the structure of layers, their composition and kind of stacking. Owing to this the proposed classification has been divided into two parts. The first of them (Table 1) pertains to clay minerals and related layer-silicates composed of layers of one type (homotypic-layer structures): the structure of a layer is here the criterion of the classification. The second part comprises the mixed-layer clay minerals, the structure of which involves different layers (heterotypic-layer structures). These minerals differ in the kind of the interstratified layers and in the manner of their stacking stratification (regular or random). Dif-

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ferent mutual orientation of the superimposed adjacent layers leads to the occurrence of several variants of the structure of the same mineral differing by the symmetry of the unit cell (polymorphic or polytypic modifications).

MINERALS WITH HOMOTYPIC LAYERS

Crystalline clay minerals are divided into two categories differing in the structure type (Table 1): clay minerals with layer structure and with layer-ribbon structure (sepiolite-palygorskite group).

The layer clay minerals have been divided as usually according to the number of tetrahedral and octahedral sheets forming a layer (2 : 1, 2 : 1 : 1 and 1 : 1). They are further divided into 7 mineralogical groups in agreement with the recognized classification of C.I.P.E.A. Each of these groups is characterized by the magnitude of electric charge of the layer and by the type of bonding between the layers (Frank-Kamienetsky 1960). These factors and the kind of interlayer cations decide namely whether the structure is stable or labile (swelling) in the normal conditions. The characteristic feature of minerals assigned to the given groups is their basal spacing d_{001} .

The minerals assigned to particular groups are then divided according to filling of octahedral layer (dioctahedral and trioctahedral). In the case of some layer minerals (chlorites, micas) it was also necessary to take into account an intermediate (di-trioctahedral) filling of layers. This may be due either to incomplete filling with cations of the octahedral brucite type layer owing to substitution of a fraction of divalent cations of this layer by trivalent ones (micas), or to occurrence in the structure of two types of octahedral layers both of gibbsite and brucite type (Al-Mg-chlorites). To the di-tri-octahedral group those minerals have been assigned in the structure of which about 5/6 on the average (83%) of octahedral layer sites is occupied by cations.

Some authors (Mering, Pedro 1969) divide additionally clay minerals according to whether the layer charge is due to isomorphic substitutions in tetrahedral or in octahedral layers. In some minerals, however, the charge of the layer may be due to both factors and hence it is difficult to divide consequently clay minerals on the basis of this criterion.

Isomorphic substitutions of the cations occurring commonly in the layer silicates gives rise to large variability of their chemical composition. In the past the modifications of minerals differing little in chemical composition were given sometimes different names and at present there exists necessity of simplifying the excessively developed mineralogical nomenclature. A separate name of a mineral is justified only in the case when the content of the characteristic element in the structure (Ni, Cr, Co, Fe and others) is so high as to essentially change the properties of a given mineral, or when this content exceeds 1/2 of octahedral layer cations (willemsite, nimite). At lower contents one should apply the name corresponding to the type of layers in the structure of minerals adding an adjective which indicates the presence of a given element (nickel vermiculite, chromium chlorite, etc.).

Table 1

		Layer-ribbon structures
Three-sheet and one-sheet layer 2 : 1 : 1	Two-sheet layer 1 : 1	
1,1-3,3	~ 0	
Hydrogen and electrostatic bond	Hydrogen bond (Stable structure)	Electrostatic bond stable structure
≈ 14	≈ 7	$b_0 \sim 18$ $b_0 \sim 27$
Chlorite	Kaolinite — Serpentine	Sepiolite — Palygorskite
Dioctahedral chlorite sub-group Dioctahedral chlorite (Donbassite)	Kaolinite sub-group Kaolinite Dickite Nacrite Halloysite Hydrohalloysite	Palygorskite sub-group Palygorskite
Trioctahedral chlorite sub-group Sheridanite Clinochlore Penninite Ripidolite Brunsvigite Diabantite Thuringite Chamosite Kochubeite Kämmererite Nimite	Serpentine — Cronstedite sub-group Mg-serpentine: { Chrisotile Lizardite Antigorite Mg-Al-serpentine: Amesite Ni-serpentine: { Garnierite? Nepouite? Noumeaite? Co-serpentine: ? Fe-serpentine: { Greenalite Cronstedite Berthierine Mn-serpentine: Grovesite Zn-Al-serpentine: Zinalsite	Sepiolite sub-group Sepiolite Loughlinite
Di-tri-octahedral chlorite sub-group Al-Mg-Chlorite (Sudoite) Cookeite Manandonite		

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Classification of clay minerals with homotypic layers

Structural category		Layer structures					
Structural type		Three-sheet layer 2:1					
Charge of layer		~ 0	≈ 0,5—1,2	≈ 1,2—1,8	≤ 2	~ 2	~ 4
Principal type of bonding between layers		Van der Waals attraction (stable structure)	(unstable structure)		Electrostatic bond (stable structure)		
d_{001} [Å]		≈ 10	> 10	≈ 14,4	≈ 10		
Group		Talc — Pyrophyllite	Montmorillonite — Saponite	Vermiculite	Mica		Brittle mica
P o p u l a t i o n o f t h e o c t a h e d r a l s h e e t	Di octahedral (according to the gibbsite pattern)	Pyrophyllite sub-group Pyrophyllite	Di octahedral montmorillonite sub-group Montmorillonite Beidellite Nontronite Volkonskoite	Di octahedral vermiculite sub-group Di octahedral vermiculite	Di octahedral hydromica sub-group Glauconite Celadonite Illite (hydromuscovite) Brammallite	Di octahedral mica sub-group Muscovite Paragonite Leucophyllite Phengite	Di octahedral brittle mica sub-group Margarite
	Tri octahedral (according to the brucite pattern)	Talc sub-group Talc Minnesotaite Willemsite Kerolite	Tri octahedral montmorillonite sub-group Saponite Stevensite Pimelite Sauconite Hectorite	Tri octahedral vermiculite sub-group Tri octahedral vermiculite	Tri octahedral hydromica sub-group Hydrophlogopite Hydrobiotite Ledikite	Tri octahedral mica sub-group Phlogopite Annite Eastonite Biotite Hendricksite Manganophyllite Polyolithionite Lepidolite Zinnwaldite Teaniolite	Tri octahedral brittle mica sub-group Clintonite Ephesite
	Intermediate or di-trioctahedral					Siderophyllite Lepidomelane	

Table 1

Classification of clay minerals with homotypic layers

Layer structures							Layer-ribbon structures	
Three-sheet layer 2:1					Three-sheet and one-sheet layer 2:1:1	Two-sheet layer 1:1		
$\approx 0,5-1,2$	$\approx 1,2-1,8$	≤ 2	~ 2	~ 4	1,1-3,3	~ 0		
(unstable structure)		Electrostatic bond (stable structure)			Hydrogen and electrostatic bond	Hydrogen bond (Stable structure)		Electrostatic bond stable structure
> 10	$\approx 14,4$	≈ 10			≈ 14	≈ 7		$b_0 \sim 18$ $b_0 \sim 27$
Montmorillonite — Saponite	Vermiculite	Mica		Brittle mica	Chlorite	Kaolinite — Serpentine		Sepiolite — Palygorskite
Di octahedral montmorillonite sub-group Montmorillonite Beidellite Nontronite Volkonskoite	Di octahedral vermiculite sub-group Di octahedral vermiculite	Di octahedral hydromica sub-group Glauconite Celadonite Illite (hydromuscovite) Brammallite	Di octahedral mica sub-group Muscovite Paragonite Leucophyllite Phengite	Di octahedral brittle mica sub-group Margarite	Di octahedral chlorite sub-group Di octahedral chlorite (Donbassite)	Kaolinite sub-group Kaolinite Dickite Nacrite Halloysite Hydrohalloysite		Palygorskite sub-group Palygorskite
Tri octahedral montmorillonite sub-group Saponite Stevensite Pimelite Sauconite Hectorite	Tri octahedral vermiculite sub-group Tri octahedral vermiculite	Tri octahedral hydromica sub-group Hydrophlogopite Hydrobiotite Ledikite	Tri octahedral mica sub-group Phlogopite Annite Eastonite Biotite Hendricksite Manganophyllite Polyolithionite Lepidolite Zinnwaldite Teaniolite	Tri octahedral brittle mica sub-group Clintonite Ephesite	Tri octahedral chlorite sub-group Sheridanite Clinochlore Penninite Ripidolite Brunsvigite Diabantite Thuringite Chamosite Kochubeite Kämmererite Nimite	Serpentine — Cronstedite sub-group Mg-serpentines: { Chrisotile Lizardite Antigorite Mg-Al-serpentine: Amesite Ni-serpentines: { Garnierite? Nepouite? Noumeaite? Co-serpentine: ? Fe-serpentines: { Greenalite Cronstedtite Berthierine Mn-serpentine: Grovesite Zn-Al-serpentine: Zinnsite		Sepiolite sub-group Sepiolite Loughlinitite
			Siderophyllite Lepidomelane		Di-tri-octahedral chlorite sub-group Al-Mg-Chlorite (Sudoite) Cookeite Manandonite			

In the proposed classification an account has been taken of some minerals confirmed by recent studies. In the talc sub-group, its new modifications (Waal 1970) have been placed, in the structure of which Mg^{2+} ions are replaced by Ni^{2+} (willemsite) and by Fe^{2+} (minnesotaite).

In the mineralogical literature several mentions can be found on talc-like mineral or hydrotalc. It is described as a fine-grained mineral with a structure built of talc type layers containing molecular water and not exhibiting the swelling properties. Ostrowicki (1965) described the nickel modification of the talc-like mineral.

In the weathering zone of ultrabasic rocks there occur magnesium silicates called kerolites (the name was introduced by Breithaupt in 1923). Their nature has not been understood in detail. According to Diakonov (1963) substances described as kerolites constitute a mixture of serpentine and a talc-like mineral the formula of which is according to Vitkovskaya and Berkhin (1968), $Mg_6 [Si_{7.9}Al_{0.10}O_{20}] (OH)_4 (Na_{0.2}K_{0.06}) \cdot 5.4 H_2O$. Diakonov (1963) suggests therefore to apply the name kerolite to this talc-like mineral. It appears that talc-like mineral, hydrotalc and kerolite are in fact the same substance. Since the name kerolite is earlier than hydrotalc this former name has been accepted in the present classification. The nature of kerolite requires, however, further elucidation. This mineral in certain points (chemical composition, DTA) resembles trioctahedral magnesium montmorillonites. Since, however, it does not exhibit the swelling properties it seems more justified to include it in the talc-pyrophyllite group. Similarly like in the case of other magnesium silicates the iron and nickel modifications of kerolites are known.

In the subgroup of dioctahedral montmorillonites the chromium montmorillonite, volkonskoite, has been induced, the presence of which has been confirmed by more recent publications (Ross 1960). Among dioctahedral montmorillonites one distinguishes usually beidellite. Distinction of this mineral is questioned (*vide* Ross 1960). It exhibits, however, many different properties which justify its acceptance as a separate mineral, defined after Weir and Greene-Kelly (1962) as a montmorillonite with octahedral layer of gibbsite type in the structure of which more than 50% of layer charge comes from substitution of Si by Al in tetrahedral layer. It can be distinguished from normal montmorillonite by the Greene-Kelly method.

In the trioctahedral montmorillonite subgroup two magnesium silicates have been distinguished: saponite and stevensite. The structural differences between them are sufficiently large to recognize them as separate minerals. The structure of stevensite represents a certain kind of link between the crystalline structure of saponite and talc.

The name of nickel montmorillonite has aroused discussion. Spangenberg (1938), investigating layer silicates from Szklary (Lower Silesia) has found that pimelite occurring there is such the montmorillonite. On the contrary Ostrowicki (1965) has shown that pimelite from Szklary is not a montmorillonite but a talc-like mineral containing nickel. The name pimelite has been, however, accepted as a name of nickel montmorillonite. Pure nickel montmorillonite has been synthesized already. The present classification takes it hence into account. The classification comprises

also zinc montmorillonite, sauconite (Ross 1946). Copper montmorillonite, miedmontite, has been shown on the other hand to be a mixture of chrisocola and dioctahedral mica (Chukhrov *et al.* 1968).

Certain difficulties arise in establishing classification scheme of micas owing to great differences in their chemical composition and structure.

In the present classification (Tab. 1) only more frequently occurring micas have been included and supplemented by those which constitute the end members of more important isomorphous series.

More common than typical micas constituents of clayey rocks are so called hydromicas. By hydromicas one understands here minerals of the mica structure which show a deficiency of K^+ . The electric charge is compensated by H_3O^+ introduced in the interlayer spaces, or by incorporation into a layer of additional protons in accordance with viewpoint of Jørgensen and Rosenquist (1963), and also partially by oxidation of Fe^{2+} . The charge of a layer in the crystalline structure of hydromicas is usually smaller than that in the structure of micas, they do not exhibit, however, the swelling properties.

There is no sharp boundary between micas and hydromicas. Gradual transition between them is observed. Hydromicas are hard to distinguish from micas by X-ray method only. For their distinction detailed studies and exact data on chemical composition are required. Thus while determining mineral composition of clays they are considered often as the whole — no distinction is made between them. For this reason it seems appropriate to include them into the mica group as a subgroup of dioctahedral and trioctahedral hydromicas.

To describe hydromicas close to muscovite two names are used: illite and hydromuscovite. Some authors consider them as synonyms, others believe that illite and hydromuscovite are different minerals. After Grim and co-workers (1937) illite is a name of fine grained authigenic micas occurring in clays which show a deficit of potassium and excess of water as compared with normal mica but do not exhibit swelling properties. The term hydromuscovite on the other hand could be reserved for hydromica formed by degradation of muscovite. More detailed investigations allow namely frequently to distinguish the hydrated mica type minerals, which were formed authigenically (illite) from those formed by degradation of muscovite (hydromuscovite). These latter show usually higher content of Al in tetrahedral layer and can be assigned to $2M_1$ polytypic modification. Similarly names hydrobiotite and hydrophlogopite pertain to the products of partial degradation of biotite and phlogopite, the crystalline structure of which retains a 10 Å basal spacing and do not show the swelling properties.

To the mica group one numbers usually glauconite (Smulikowski 1954) and celadonite. In the crystal lattice of glauconite however usually the occurrence of interlayering with the swelling montmorillonite layers is observed (Burst 1958, Hower 1961) and the sharp boundary between glauconite of the mica type structure and montmorillonite does not exist. These former occur, however, more frequently in nature. Celadonite, a mineral of the terrigenous origin, is both structurally and chemically very similar to glauconite. Taking into account the fact that the

majority of glauconites and celadonites are closer structurally to illite, they have been assigned to the subgroup of dioctahedral hydromicas.

In the subgroup of trioctahedral brittle micas there have been included (Table 1) anandite, brittle mica containing Ba in interlayer positions and Fe^{2+} and Mg^{2+} in octahedral layer (Pattiaratchi *et al.* 1967).

Xantophyllite, seyberite and their modifications known under separate names turned out to be identical with clintonite (Forman *et al.* 1967).

The group of chlorites, according to the present knowledge comprises not only trioctahedral minerals but also dioctahedral and di-tri-octahedral minerals. Müller (1963) named a dioctahedral chlorite *sudoite*. Earlier, in 1940 Lazarenko has discovered a mineral *donbassite* of the properties intermediate between kaolinite and chlorite. As it has been proved later *donbassite* is in reality a dioctahedral chlorite. It has been suggested on this basis to name a dioctahedral chlorite a *donbassite* (Lazarenko 1969).

The nomenclature of trioctahedral chlorites is characterized by great arbitrariness. In the present paper the division and nomenclature of chlorites proposed by Foster (1962) has been accepted. This classification is based on crystallochemical criteria. Classification of chromium chlorites has been proposed by Lapham (1958). He defines *kämmererite* as a chlorite containing Cr^{3+} exclusively in the octahedral layer and *kochubeite* as a chlorite in which Cr^{3+} is localized also in tetrahedral layer. For chlorites containing less than 2% Cr_2O_3 he proposes a name corresponding to the content of the main components with addition of the adjective „chrom“. Nickel chlorite has been named *nimite* (Waal 1970).

The di-trioctahedral chlorites, known for long time, are *cookeite* $LiAl_2(OH)_6Al_2[Si_3AlO_{10}](OH)_2$ and *manandonite* (lithium, borium and aluminum containing chlorite). Recently some occurrences of Al-Mg-chlorite has been reported. They were described by Sudo (1959) and named according to suggestion of Eggleston and Bailey (1967) *sudoite*. This name has been accepted also in the present classification.

The layer silicates with double sheet layers (1:1) are placed in the kaolinite-serpentine group which is divided into kaolinite and serpentine subgroups. The kaolinite subgroup contains *halloysite* $Al_4[Si_4O_{10}](OH)_3$ and its hydrated form — *hydrohalloysite* $Al_4[Si_4O_{10}](OH)_8 \cdot 4H_2O$. The nomenclature of these two minerals is not uniform. Names such as *halloysite* or *metahalloysite* for the anhydrous mineral and respectively *en-delite* or *halloysite* for the hydrated one are in use. The differences between these two minerals are best reflected in names of *hydrohalloysite* and *halloysite* which are encountered more and more often in new publications. The name *metahalloysite* resembles rather that of *metakaolinite* which is the product of dehydroxylation of kaolinite. In some classifications of clay minerals *halloysite* is excluded into a separate group together with *chrisotile*, bearing in mind a tubular form of these minerals. Owing, however, to the structural resemblance of *halloysite* to kaolinite this is not justified. In the modern mineralogical systematics morphology cannot be a decisive criterion of the classification. In *halloysite* and *hydrohalloysite* crystalline structure the isomorphous sub-

stitutions of Al^{3+} by Cr^{3+} , Fe^{3+} (ferrihalloysite, Kunze and Bradley 1964) and also by Cu^{2+} (Chukhrov *et al.* 1969) are possible. In the past anauxite was included in the kaolinite subgroup; it turned out however to be the mixture of kaolinite and opal (Allen *et al.* 1969).

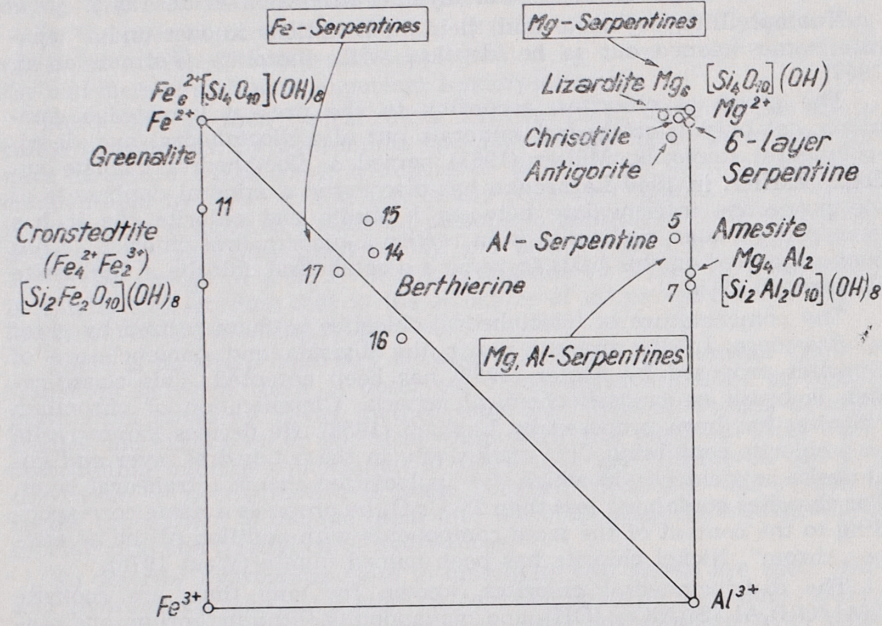


Fig. 1. Classification of trioctahedral layer silicates of 1:1 type according to chemical composition of the octahedral layer. The points correspond to minerals, the formulae of which have been given in Table 2

The serpentine subgroup contains magnesium serpentines (chrysotile, lizardite, and antigorite) as well as berthierine, greenalite, cronstedtite and amesite determined in the past as septechlorites. Berthierine, greenalite and cronstedtite can be defined as ferrous — ferric serpentines, and amesite together with other serpentines containing aluminum as magnesium-aluminum serpentines (Tab. 2).

The differences between these serpentines are shown in the diagram (Fig. 1). This drawing is composed of two triangular diagrams on which the points showing filling of the octahedral layer of serpentines by various cations according to their formulae listed in Table 2 are drawn. According to current viewpoints namely the octahedral layer exerts a decisive influence on the structure of the whole layer and on the dimensions of the unit cell. In the case when the octahedral layer contains four cations, one of which occurs in small quantity, this latter cation is regarded together with the main cation of the same valency (e.g. Mg^{2+} together with Fe^{2+} in berthierine). The formulae of chrysotile, lizardite and antigorite were taken after Page (1968) and they represent

Table 2

Trioctahedral layer silicates of 1:1 type (Serpentines)

Minerals	Formula	Unit cell			Author
		Symmetry, space group	Number of layers n	Parameters	
Chrysotile	1. $(\text{Mg}_{5.72}\text{Fe}_{0.05}^{3+}\text{Fe}_{0.05}^{2+})_{0.05}\text{Si}_{3.90}\text{Al}_{0.05}\text{O}_{9.52}(\text{OH})_{8.48}$ (Page 1968)	monoclinic	2	Clinochrysotile $a_0 = 5.34$ $b_0 = 9.25$ $c_0 = 14.65$ $\beta = 93.16^\circ$	Whittaker 1956
Lizardite	2. $(\text{Mg}_{5.49}\text{Fe}_{0.03}^{2+}\text{Fe}_{0.29}^{3+})_{0.03}\text{Si}_{3.88}\text{Al}_{0.15}\text{O}_{9.72}(\text{OH})_{8.28}$ (Page 1968)	orthogonal	2	orthochrysotile $a_0 = 5.34$ $b_0 = 9.2$ $c_0 = 14.63$	
6-layer serpentine	3. $(\text{Mg}_{5.74}\text{Mn}_{0.01}\text{Fe}_{0.01}^{2+}\text{Fe}_{0.12}^{3+})_{0.01}\text{Si}_{3.91}\text{Al}_{0.01}\text{Fe}_{0.08}\text{O}_{9.80}(\text{OH})_{8.20}$ (Erindley, Knorring 1954)	orthogonal	2	parachrysotile $a_0 = 5.3$ $b_0 = 9.24$ $c_0 = 14.17$	
Antigorite	4. $(\text{Mg}_{5.44}\text{Fe}_{0.29}^{2+}\text{Fe}_{0.01}^{3+})_{0.01}\text{Si}_{4.01}\text{O}_{10.32}(\text{OH})_{7.68}$ (Page 1968)	orthogonal	1	$a_0 = 5.31$ $b_0 = 9.20$ $c_0 = 7.31$	Rucklidge Zussman 1965
3-layer serpentine		orthogonal	6	$a_0 = 5.322$ $b_0 = 9.219$ $c_0 = 43.59$ $a_0 = 5.311$ $b_0 = 9.202$ $c_0 = 43.70$	Zussman Brindley 1957 Kistanović Pavlović 1967
Al — serpentine	5. $(\text{Mg}_{1.14}\text{Al}_{1.44}\text{Fe}_{0.14}\text{Ca}_{0.02}\text{K}_{0.12})_{0.12}\text{Si}_{2.99}\text{Al}_{1.08}\text{O}_{10}(\text{OH})_8$	monoclinic	1	$a_0 = 8 \times 5.32 = 41.5$ $b_0 = 9.22$ $c_0 = 6 \times 7.28 = 43.68$ $\beta = 93.30^\circ$	Aumento 1967
Amesite	6. $(\text{Mg}_{4.12}\text{Al})_{0.12}\text{Si}_{4.12}\text{O}_{10}(\text{OH})_8$	monoclinic	3	$a_0 = 43.3$ $b_0 = 9.23$ $c_0 = 7.27$ $\beta = 91.6^\circ$	Kunze 1956
Garnierite	7. $(\text{Mg}_{3.00}\text{Fe}_{0.82}^{2+}\text{Al}_{1.12})_{0.82}\text{Si}_{2.02}\text{Al}_{1.98}\text{O}_{10}(\text{OH})_8$ (Brindley, Oughton, Youell 1951)	rhombic (pseudohexagonal)	9	$a_0 = 5.346$ $b_0 = 9.205$ $c_0 = 21.93$	Coats 1968
	8. $(\text{Ni}, \text{Mg})_{0.12}\text{Si}_{4.12}\text{O}_{10}(\text{OH})_8$ (theoret.)	hexagonal $P\bar{3}_1$ lub $P\bar{3}_2$	6	$a_0 = 5.295$ $c_0 = 63.99$	Jahanbaggio Zoltai 1968
		hexagonal $R\bar{3}$ or $R\bar{3}$	1	$a_0 = 5.31$ $b_0 = 42.1$	Steadman Nuttall 1962
		orthogonal	1	$a_0 = 5.33$ $b_0 = 9.25$ $c_0 = 7.30$ (synthetic)	Feitknecht Berger 1942

Trioctahedral layer silicates of 1:1 type (Serpentines)

Minerals	Formula	Unit cell			Author	
		Symetry, space group	Number of layers n	Parameters		
Mg - Al serpentines	1. $(Mg_{5.72}Fe_{0.05}^{2+}Fe_{0.03}^{3+})_2(Fe_{0.05}^{2+}Fe_{0.03}^{3+})_2(Si_{3.90}Al_{0.08}O_9)_{12}(OH)_8$ (Page 1968)	monoclinic	2	Clinochrisotile $a_0 = 5.34$ $b_0 = 9.25$ $c_0 = 14.65$ $\beta = 93^\circ 16'$	Whittaker 1956	
	2. $(Mg_{5.49}Fe_{0.03}^{2+}Fe_{0.29}^{3+})_2(Si_{3.88}Al_{0.15}O_9)_{12}(OH)_8$ (Page 1968)	ortogonal	2	ortochrisotile $a_0 = 5.34$ $b_0 = 9.2$ $c_0 = 14.63$	Rucklidge Zussman 1965	
	3. $(Mg_{5.74}Mn_{0.01}Fe_{0.01}^{2+}Fe_{0.12}^{3+})_2(Si_{3.91}Al_{0.01}Fe_{0.08}O_9)_{12}(OH)_8$ (Brindley, Knorring 1954)	ortogonal	2	parachrisotile $a_0 = 5.3$ $b_0 = 9.24$ $c_0 = 14.17$		
	4. $(Mg_{5.44}Fe_{0.30}^{2+}Fe_{0.29}^{3+})_2(Si_{4.01}O_{10.32})(OH)_7$ (Page 1968)	ortogonal	1	$a_0 = 5.31$ $b_0 = 9.20$ $c_0 = 7.31$		
	Mg-Al - serpentines	5. $(Mg_{4.14}Al_{1.44}Fe_{0.14}Ca_{0.02}K_{0.12})(Si_{2.92}Al_{1.08}O_{10})(OH)_8$	ortogonal	6	$a_0 = 5.322$ $b_0 = 9.219$ $c_0 = 43.39$ $a_0 = 5.311$ $b_0 = 9.202$ $c_0 = 43.70$	Zussman Brindley 1957 Krstanović Pavlović 1967
		6. $(Mg_{4.41})_2(Si_2Al_2O_{10})(OH)_8$	monoclinic	6	$a_0 = 8 \times 5.32 = 41.5$ $b_0 = 9.22$ $c_0 = 6 \times 7.28 = 43.66$ $\beta = 93.30^\circ$	Aumento 1967
		7. $(Mg_{5.00}Fe_{0.82}^{2+}Al_{1.12})(Si_{2.02}Al_{1.98}O_{10})(OH)_8$ (Brindley, Oughton, Youell 1951)	monoclinic	1	$a_0 = 43.3$ $b_0 = 9.23$ $c_0 = 7.27$ $\beta = 91.6^\circ$	Kunze 1956
		8. $(Ni, Mg)_3(Si_4O_{10})(OH)_8$ (theoret.)	rhombic (pseudo-hexagonal)	3	$a_0 = 5.346$ $b_0 = 9.205$ $c_0 = 21.93$	Coats 1968
		9. $Co_6(Si_4O_{10})(OH)_8$ (theoret.)	hexagonal P_3 lub P_3^2	9	$a_0 = 5.295$ $c_0 = 63.99$	Jahanbagloo Zoltai 1968
		10. $Fe_6(Si_4O_{10})(OH)_8$ (theoret.)	hexagonal R or $R\bar{3}$	6	$a_0 = 5.31$ $b_0 = 42.1$	Steadman Nuttall 1962
	Ni - serpentines	11. $(Fe_{4.5}^{2+}Fe_{1.0}^{3+})_2(Si_4O_{10})(OH)_8$	ortogonal	1	$a_0 = 5.33$ $b_0 = 9.25$ $c_0 = 7.30$ (synthetic)	Feitknecht Berger 1942
		12. $(Fe_{4.2}^{2+}Fe_{0.8}^{3+})_2(Si_2Fe_2^+O_{10})(OH)_8$	monoclinic	2	$a_0 = 5.33$ $b_0 = 9.23$ $c_0 = 14.96$	Huggins 1961
		13. $(Fe^{2+})_6(Si_2Fe_2^+O_8)(OH)_{10}$	ortogonal	1	$a_0 = 5.37$ $b_0 = 9.30$ $c_0 = 7.37$ (synthetic)	Feitknecht Berger 1942
14. $(Fe^{2+}_{3.6}Mg_{0.4}Al_{1.2}O_{10})(OH)_8$ (Brindley, Youell 1953)		ortogonal	1	$a_0 = 5.54$ $b_0 = 9.59$ $c_0 = 7.19$ (synthetic)	Steadman Youell 1958	
15. $(Fe^{2+}_{3.6}Mg_{0.4}Al_{1.2}O_{10})(OH)_8$ (Deudon 1955)		monoclinic Cm	1	$a_0 = 5.49$ $b_0 = 9.52$ $d_{001} = 7.08$	Brindley 1951	
Fe - serpentines	16. $(Al_{1.18}Fe_{2.60}^{2+}Fe_{0.24}^{3+}Mg_{0.32}^{2+}Si_{3.18}Al_{0.82}O_{10.30})(OH)_{7.70}$ (Locality-Wellingbrough; Youell 1958)	hexagonal P $31m$ P 6_3 cm, P 6_3 P $31c$ P 3_1 R 3	1 2 3 6	$a_0 = 5.49$ $c_0 \approx 7.085$	Steadman Nuttall 1963	
	17. $(Al_{1.70}Fe_{3.66}^{2+}Fe_{0.02}^{3+}Mg_{0.40}^{2+}Si_{2.66}Al_{1.84}O_{10.04})(OH)_{7.90}$ (Locality-Corby, Main, Ironstone; Youell 1958)	monoclinic Cc	1	$a_0 = 5.49$ $b_0 = 9.51$ $c_0 = 7.32$ $\beta = 104^\circ 31'$	Brindley 1961	
	18. $(Mn, Mg, Fe, Al)_6(Si_4O_{10})(OH)_8$	ortogonal	1	$a_0 = 5.49$ $b_0 = 9.51$ $c_0 = 14.29$ $\beta = 82^\circ 38'$		
	19. $(Zn_{0.5}Al)_6(Si_4O_{10})(OH)_8$	monoclinic	1	$a_0 = 5.39$ $b_0 = 9.33$ $c_0 \sin \beta = 21.12$		
Zn - Al Mn - ser- pentine	20. $(Mn, Mg, Fe, Al)_6(Si_4O_{10})(OH)_8$	monoclinic	2	$a_0 = 5.39$ $b_0 = 9.33$ $c_0 \sin \beta = 7.04$ $\beta = 104.5^\circ$	Bannister et al 1955	
	21. $(Zn_{0.5}Al)_6(Si_4O_{10})(OH)_8$	1M, 1T, 2H	1,2	$a_0 = 5.11$ $b_0 = 9.19$ - 9.23 $c_0 \approx 7.3$ $\beta = 104^\circ$	Chukhrov et al. 1971	

their mean chemical composition. The chemical composition of these minerals was studied also by Whittaker and Wicks (1970).

In the structure of serpentines similarly like in that of other layer silicates Mg^{2+} may be replaced in different degree by Ni^{2+} . There are known chrysotile, lizardite and antigorite containing several percent of NiO (magnesium-nickel serpentines).

There are also known layer silicates with the crystalline structure of serpentines and with Ni^{2+} predominance in the octahedral layer (nickel serpentines). Zvyagin (1965) observed large structural differences among them. These silicates have been given names like garnierite, nepouite, noumeaite, their distinction is however disputable. Between Mg-serpentines and Ni-serpentines there occur a continuous series of solid solutions. In the crystalline structure of serpentine Mg^{2+} can be also replaced by Co^{2+} (Co-serpentines). The pure cobalt serpentine has been synthesized. The manganese serpentine is grovesite (Bannister *et al.* 1955). Recently zinc-aluminium serpentine, zinalsite was identified (Chukrov *et al.*, 1971).

The layer-ribbon serpentines, sepiolite and palygorskite (attapulgitite) differ, according to recent data (Dritz, Aleksandrova 1966) in filling of the octahedral ribbon sites by cations. From this point of view the structure of sepiolite corresponds to trioctahedral layer silicates and that of palygorskite to dioctahedral ones. Similarly like magnesium layer silicates sepiolite has nickel, ferric and aluminum modifications. For layer-ribbon silicates b_0 parameter of the unit cell may be taken as a characteristic feature.

MIXED LAYER MINERALS

The layer minerals with mixed heterotypic layers are usually built of layers of two kinds. The minerals built of three or more different layers are rare. The mixed-layer minerals are divided and named according to the kind of interstratified layers.

The division of mixed-layer clay minerals, composed of layers of two kinds is shown in the form of a diagram in Fig. 2. On the diagram there are marked combinations of two different layers found among the mixed layer clay minerals. They are divided further, according to the manner of arranging of layers, into structure with regular and random interstratification of layers.

Along the line limiting the diagram on the right-hand side there lie the layer structures composed of homotypic layers but of different interlayer cations, which fill selectively the interlayer spaces, or of different number of monomolecular layers of H_2O molecules between the layers. These two factors are the reason of occurrence of two or more values of distances between the interstratified layers. In the case of chlorites these structures consist of one type of three-sheet silicate layer and of different octahedral sheets between these layers. In the case of minerals in which the layers are not joined together by molecules of H_2O or (and) interlayer cations, the differences in the manner of stacking

of homotypic layers lead to the formation of polytypic or polymorphic modifications (kaolinite, serpentines).

Minerals with regular mixed-layer structure are given the mineralogical names like corrensite, allevardite (rectorite). Frank-Kamienetsky and co-workers (1963) have proposed the name tosudite for the regular mixed-layer clay mineral: dioctahedral chlorite-montmorillonite.

Recently the name tarasovite (in honour of the Ukrainian poet Taras Shevchenko) has been proposed for a mineral the structure of which is composed of mica layers of one type in which there occurs the pheno-

INTERSTRATIFYING LAYERS	KAOLINITE	SERPENTINE	MONTMORILLONITE		VERMICULITE		MICA		CHLORITE		PYROPHYLLITE	TALC
			DIOCT.	TRIOCT.	DIOCT.	TRIOCT.	DIOCT.	TRIOCT.	DIOCT.	TRIOCT.		
TALC				R D?						?		
PYROPHYLLITE			R D?		?					?		
CHLORITE	TRIOCT.	+		R D		R ² D		R D		R D		
	DIOCT.		R ³ D		?		?		R D			
MICA	TRIOCT.			R D		R D		R D		R D		
	DIOCT.			R ¹ D		+		R ⁴ D		R D		
VERMICULITE	TRIOCT.			R D		R D		R D		R D		
	DIOCT.			+		R D		R D		R D		
MONTMORILLONITE	TRIOCT.		?	R D		R D		R D		R D		
	DIOCT.			R D		R D		R D		R D		
SERPENTINE												
KAOLINITE												

Fig. 2. Classification of mixed-layer clay minerals

a — crystalline structures built of heterotypic layers, b — crystalline structures built of homotypic layers but with interlayer space filled in a different manner, c — polymorphic or polytypic modifications; R — regular mixed-layer structures, D — random mixed-layer structures, + — structures confirmed but little studied, ? — probable structures, 1 — allevardite, 2 — corrensite, 3 — tosudite, 4 — tarasovite

menon of segregation (non-miscibility) of interlayer cations. The interlayer sites are filled successively by: (Na⁺, H₂O), (K⁺, Na⁺), (Ca²⁺, H₂O) (Lazarenko, Korolev 1970).

CONCLUSION

Layer and layer-ribbon clay minerals are sufficiently well recognized to make uniform their nomenclature and to establish their consequent classification assuming as the basic criterion the structure of a layer (homotypic-layer structures) and type of interstratified layers (heterotypic layer structures).

The aim of the present paper has been to present some proposals in this matter taking into account the data published up to 1971 concerning clay minerals. The progress in mineralogy is the cause of fast outdated of every classifications of minerals, and the constant necessity of their rearranging and supplementing.

The classification of the clay minerals should be, in particular, supplemented by including allophane, imoglite and kindred minerals, which are at present too little understood to make it possible to propose their classification and standarization of their nomenclature.

More detailed elucidation is required also in the case of relation between crystalline structure of stilpnomelane and related minerals: ganophyllite and bannisterite and other layer silicates, in particular micas.

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Leszek STOCH

O KLASYFIKACJI I NAZEWNICTWIE MINERALÓW ILASTYCH

Streszczenie

W pracy przedstawiono szczegółową klasyfikację minerałów ilastych opartą na kryteriach krystallochemicznych i strukturalnych, uwzględniającą aktualne dane dotyczące tych minerałów. Za kryterium podziału minerałów o strukturze krystalicznej złożonej z pakietów homotypowych przyjęto budowę pakietów (tab. 1), a dla minerałów o mieszanej strukturze warstwowej złożonej z pakietów heterotypowych ich rodzaj i kombinację (fig. 2).

Nazewnictwo mineralogiczne krzemianów warstwowych jest nadmiernie rozbudowane. Wykazują one dużą zmienność składu chemicznego wynikającą z izomorficznego zastępowania się kationów w strukturze. Odmianom o różnym składzie nadawano dawniej często odrębne nazwy. Obecnie istnieje potrzeba uproszczenia tego nazewnictwa. Odrębna nazwa jest uzasadniona wówczas, gdy zawartość charakterystycznego pierwiastka w strukturze (Ni, Cr, Co, Fe i inne) jest na tyle duża, że w sposób istotny zmienia własności danego minerału lub gdy stanowi on więcej niż połowę kationów warstwy oktaedrycznej (np. willemseit, nimit).

Przy mniejszej zawartości należy stosować nazwę odpowiadającą typowi pakietów w strukturze minerału z dodatkiem przymiotnika wskazującego na obecność danego pierwiastka (np. wermikulit niklowy, chloryt chromowy itp.).

Proponuje się uporządkowanie nazewnictwa serpentynów (tab. 1 i 2). Różnice pomiędzy serpentynami magnezowymi, magnezowo-glinowymi i żelazowo-żelazowymi ilustruje figura 1. Składa się ona z dwu diagramów trójkątnych na które naniesiono punkty przedstawiające obsadzenie warstwy oktaedrycznej serpentynów przez różne kationy, zgodnie z wzorami zestawionymi w tabeli 2.

OBJASNIENIA FIGUR

- Fig. 1. Podział krzemianów warstwowych trioktaedrycznych, typu 1:1 według składu chemicznego warstwy oktaedrycznej
 Punkty odpowiadają minerałom, których wzory zestawione zostały w tabeli 2
- Fig. 2. Podział minerałów ilastych o mieszanej strukturze pakietowej
 a — struktury krystaliczne zbudowane z pakietów heterotypowych, b — struktury krystaliczne zbudowane z pakietów homotypowych, lecz o przestrzeni międzypakietowej wypełnionej w różny sposób, c — modyfikacje polimorficzne lub politypowe; R — struktury mieszane o przewarstwiach regularnych, D — o przewarstwiach bezładnych, + — struktury stwierdzone, mało poznane, ? — struktury prawdopodobne; 1 — allewardyt (rectoryt), 2 — corrensyt, 3 — tosudyt, 4 — tarasowit

Лешек СТОХ

О КЛАССИФИКАЦИИ И НОМЕНКЛАТУРЕ ГЛИНИСТЫХ МИНЕРАЛОВ

Резюме

В работе представлена детальная классификация глинистых минералов, основанная на кристаллохимических и структурных критериях, с учетом новейших характеристик этих минералов. В качестве классификационного критерия минералов с кристаллической структурой, сложенной гомотипными пакетами, принято строение пакетов (табл. 1), а минералов со смешанной структурой, сложенной гетеротипными пакетами — тип и модификации пакетов (фиг. 2).

Минералогическая номенклатура слоистых силикатов чрезмерно усложнена. Они характеризуются большими колебаниями химического состава, обусловленными изоморфными замещениями катионов в структуре минералов. Отдельным разновидностям минералов присваивались часто разные названия. В настоящее время назрел вопрос о упорядочении их номенклатуры. Самостоятельное название может быть обосновано в таком случае, когда содержание характерного элемента в структуре (Ni, Cr, Co, Fe и др.) настолько велико, что оно существенным образом меняет свойства этого минерала, или же когда оно превышает половину количества катионов октаэдрического слоя (например, виллемseit, нимит). При меньшем содержании следует применять название, соответствующее типу пакетов в структуре минерала с добавлением прилага-

тельного, указывающего на присутствие данного элемента (например, никелевый вермикулит, хромовый хлорит и т.п.).

Предлагается упорядочить номенклатуру серпентинов (табл. 1 и 2). Различия между магниевыми, магний-алюминиевыми серпентинами и серпентинами, содержащими закисное и окисное железо, показывает фигура 1. Она состоит из двух треугольных диаграмм, на которых точками показано построение октаэдрического слоя серпентинов разными катионами, согласно формулам в таблице 2.

ОБЪЯСНЕНИЯ К ФИГУРАМ

- Фиг. 1. Классификация слоистых триоктаэдрических силикатов типа 1:1 на основании химического состава октаэдрического слоя
Точки соответствуют минералам, формулы которых приведены в таблице 2
- Фиг. 2. Классификация глинистых минералов со смешанно-спойстой пакетной структурой
a — кристаллические структуры, сложенные гетеротипными пакетами, *b* — кристаллические структуры, сложенные гомотипными пакетами, но с разным выполнением межпакетного пространства, *c* — полиморфные или политипные модификации. *R* — смешанные структуры с регулярной слоистостью, *D* — смешанные структуры с беспорядочной слоистостью, + — достоверные, слабо изученные структуры, ? — вероятные структуры, 1 — аллевардит (ректрит), 2 — корренсит, 3 — тосудит, 4 — тарасовит