

## The Clay Minerals Society Glossary for Clay Science Project

The Clay Minerals Society (CMS) Nomenclature Committee was asked by CMS Council to produce a glossary of clay science in 2003. The Committee developed several constraints on the development of the glossary: (1) it was decided to produce a glossary of *clay* terms, based on clay science. Terms may have other meanings in other disciplines, but the Committee did not want to include how other disciplines may use the terms (unless it is integral to the definition, e.g., as was the case of “particle size” for “clay”). The definitions provided below are terms *as used in clay science* and thus, this glossary is not a compendium, as is the case for the *AGI Glossary*. However, the definitions do not and should not stray from the basic science definitions as one would have in chemistry and physics. The point here was to include examples and perhaps direct the discussion toward clay science; the definition itself would conform to definitions in the other sciences. Unlike the *AGI Glossary*, where current usage is given even if that usage deviates from the original definition, the *CMS Glossary* provides the original definition and explains how the word may be currently and, perhaps incorrectly, used.

(2) Provisional or tentative definitions were avoided. The glossary may be used in ways that we may be unaware, such as by the legal profession, and the Committee only listed terms that are well defined. Definitions in contention that could not be reconciled in committee were not included. Multiple definitions are provided, if warranted, and discussion is provided on how the terms may have changed in meaning over (recent) time. (3) Established definitions by the International Mineralogical Association (IMA), CMS, and Association Internationale pour l'Etude des Argiles (AIPEA) Nomenclature Committees, or any other international body were not open for discussion. The Committee decided that further explanation may be warranted to show the utility of a term in clay science, but the definition is given unchanged from that provided by the international body. (4) In general, computer-program names and similar names are not part of the *Glossary*, both because such names tend to be ephemeral and because the Society does not advocate the use of a specific program.

The initial effort was not to include mineral and related (i.e., discredited, synonyms, etc.) names, although group names were included. There are other web sites that have compiled mineral name lists.

We appreciate the past efforts of C. Bowser, R. Brown, S. Grand, W. Huff, D. Laird, and D. Moore. The following committees developed the Glossary:  
2006/2007 CMS Nomenclature Committee: Stephen Guggenheim (Chair), D. Bain (*ex officio* member), E. Daniels, D.R. Peacor, H. Murray, H. Stanjek  
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## The Clay Minerals Society Glossary of Clay Science

**1:1 layer** see *layer*

**1A** see *Ramsdell-style notation*

**1T** see *Ramsdell-style notation*

**1Tc** see *Ramsdell-style notation*

**1M** see *Ramsdell-style notation*

**2:1 layer** see *layer*

**2:1:1 layer** previously used to describe chlorite where a 2:1 layer plus an interlayer describes the sheet and layer configuration. This nomenclature is no longer in use, see Guggenheim *et al.* (2006) and references therein. Use 2:1 layer. *Cf.*, tetrahedral sheet, octahedral sheet, layer, interlayer material

**2:2 layer** previously used to describe chlorite where a 2:1 layer plus an interlayer was summed to two tetrahedral sheets and two octahedral sheets. This nomenclature is no longer in use, see Guggenheim *et al.* (2006) and references therein. Use 2:1 layer. *Cf.*, tetrahedral sheet, octahedral sheet, layer, interlayer material

**2H<sub>1</sub>** see *Ramsdell-style notation*

**2H<sub>2</sub>** see *Ramsdell-style notation*

**2M<sub>1</sub>** see *Ramsdell-style notation*

**2M<sub>2</sub>** see *Ramsdell-style notation*

**2O** see *Ramsdell-style notation*

**2Or** see *Ramsdell-style notation*

**2T** see *Ramsdell-style notation*

**3R** see *Ramsdell-style notation*

**3T** see *Ramsdell-style notation*

**6H** see *Ramsdell-style notation*

**6R** see *Ramsdell-style notation*

**Ia** or **Ib** see *Ramsdell-style notation for chlorite*

**IIa** or **IIb** see *Ramsdell-style notation for chlorite*

**absolute humidity** see humidity

**accessory mineral** a mineral present in a rock which is not essential for the classification of that rock. Characterizing accessory minerals are often used as modifiers to the rock name, for example, as in nepheline basalt.

**acicular** a crystal habit of needle-like shape

**activated clay** originally defined as a clay that has been treated with acid to improve bleaching or adsorption properties. Clays treated in other ways, such as thermal or  $\text{Na}_2\text{CO}_3$  treatments, may also be considered activated, provided that there is an improvement in a specific performance characteristic (e.g., bleaching, adsorption, viscosification, sealing, binding). It is common to describe the activation process when describing activated clays, e.g., “thermal-activated clay”, “ $\text{Na}_2\text{CO}_3$ -activated clay”. *Cf.*, beneficiation

**activity number** In geotechnical engineering, the activity number (A) of a soil is the ratio of the plasticity index to the mass percentage of the clay fraction. See also Atterberg limits, consistency number, liquid limit, plastic limit, plasticity index, shrinkage limit.

**adobe** durable, sun-dried, hardened bricks made from mixtures of water, clay, silt, sand and straw, or other fibrous organic materials

**adsorbate** any substance which, in molecular, atomic, or ionic form, will penetrate into and be retained by another (liquid, solid, gel, etc.) material. *Cf.*, Solid-state diffusion, adsorbent

**adsorbed water**  $\text{H}_2\text{O}$  molecules attracted to and adhered to by atomic forces at internal or external surfaces of a phyllosilicate or other material in thicknesses of one or more molecules. The term “water” (rather than “ $\text{H}_2\text{O}$ ”) is not precisely used here because “water” is a (liquid) phase.

**adsorption** the process of attraction and adherence of atoms, ions, or molecules from a (gas, liquid, etc.) solution to a surface.

**adsorption, anion** the adsorption of anions on basal OH surfaces of a phase where structural hydroxyl groups are replaced by other anions, or on particle edges where unsatisfied positive bonds occur; exchange of edge hydroxyls also may occur (modified from O’Bannon, 1984).

**adsorption, cation** the adsorption of cations on basal surfaces where negative charges occur, possibly as a result of isomorphous replacement within the structure, and/or adsorption on mineral surfaces where unsatisfied charges may occur often where there are incomplete

coordination units. Surface adsorption is common on the basal oxygen atom plane of the 2:1 layer of phyllosilicates. Edge adsorption predominates in kaolin-type phyllosilicates having 1:1 layers (modified from O'Bannon, 1984).

**aerosol** see suspension

**ageing** a process where the commercial properties of wetted clay are improved by letting the clay sit undisturbed for a period to allow the water to become more homogeneously distributed

**agglomeration** see flocculation

**aggregation** see flocculation

**aging** see ageing

**allophane** sometimes referred to as “disordered allophane”, a poorly crystalline aluminosilicate phase related to imogolite in composition, with  $\text{SiO}_2 / \text{Al}_2\text{O}_3$  approximately between 1 to 2. Allophane is common in soils derived from volcanic ash, but may be present in soils derived from basic igneous rocks in tropical climates or in podzol soils derived from more acidic rocks. Allophane may precipitate in hot springs rich in silicic acid and aluminum. Allophane is comprised of spheres 3 - 5 nm in diameter. Allophane is white or colorless when moist, but earthy when dried. *Cf.*, imogolite

**alloy** see suspension

**aluminol group** a surficial AlOH group (see *silanol group*), which is able to incorporate or dissociate protons. See *silanol group*

**aluminosilicate** “In general, silicates which contain tetrahedrally coordinated aluminum are called aluminosilicates in contrast to silicates containing octahedrally coordinated aluminum for which the term aluminum silicates is used...” (Liebau, 1985, p. 13). Although this is the classic definition of aluminosilicate, many texts use the term inconsistently. For example, kyanite and andalusite, traditionally considered part of the “aluminosilicate group” with sillimanite, do not have tetrahedrally coordinated Al, although they are closely related (structurally and geologically) to each other and sillimanite. Clearly, taking the first part of definition by Liebau (1985) as the basis of the definition, the second part should not be limited to aluminum in octahedral coordination only. Phyllosilicates are generally considered aluminosilicates, because most phyllosilicates do have Al substitution for Si, but not all do (and those minerals without tetrahedral Al present, but with Al in other polyhedral coordinations are more properly referred to as “aluminum silicates”).

**aluminum silicate** see aluminosilicate

**amorphous** a term describing a non-crystalline phase where the constituent components (i.e., atoms, ions, molecules) are without long-range order, i.e., not related by translation periodicity. There are many variations of such order or lack of order, for example, glasses commonly occur

where atoms are arranged as coordination groups of tetrahedra (e.g., four oxygen ions in coordination about a silicon ion). Such tetrahedra share vertices to define local structure similar to that of crystalline phases; however, such groups of atoms are not related by long-range translation periodicity. This type of short-range order is much different than a simple random positioning of atoms. Amorphous character can be described by the nature of the analysis, e.g., such that the material may produce an X-ray diffraction pattern without discrete maxima, hence, “X-ray amorphous”. *Cf.*, non-crystalline, crystalline

**anchizone** a zone of transition from late diagenesis to low-grade metamorphism. The anchizone is defined by Kübler indices between 0.42 and 0.25 in mudrock lithologies. *Cf.*, diagenesis, Kübler index

**anhedral** see crystal

**anionic clay** a group of minerals containing layers where there is a positive layer charge and linkage of the layers by way of an anionic (negative) interlayer. The “clay” aspect refers to a naturally occurring fine-grained material that under appropriate water content will exhibit plasticity and will harden when dried or fired. *Cf.*, anionic swelling clay

**anionic swelling clay** The “clay” aspect refers to a naturally occurring fine-grained material that under appropriate water content will exhibit plasticity and will harden when dried or fired. The “anionic” aspect refers to the 2:1 layer that has a net negative residual charge, which must be offset by a positive (cationic) interlayer charge. There are two general types of swelling anionic clays: smectite and vermiculite. *Cf.*, anionic clay, clay, smectite, vermiculite, plasticity

**anisotropy** a description of material that has properties (optical, hardness, conductivity, etc.) that differ depending on the direction of measurement. These properties, when related to crystals, are dependent on composition, atomic structure, and structural defects. Nondirectional properties, such as density, also exist. When related to composite materials, such properties may be determined by layering, the properties of the constituent materials, etc. *Cf.*, isotropy

**Ångström, Å** a non-SI unit of measurement equal to  $10^{-10}$  meters, e.g.,  $1 \text{ Å} = 0.1 \text{ nm}$ .

**anneal** to heat and then cool slowly to reduce internal stress, which commonly involves new grain crystallization toward an equilibrium phase assemblage and texture. Usually relates to glasses and metals.

**antiferroelectric** a property of materials where there is an antiparallel alignment of electric moments that cancel out over the entire crystal. The “ferro” aspect of the word is a misnomer because iron is not a usual constituent; the word derives from analogy to antiferromagnetism. *Cf.*, antiferromagnetism

**antiferromagnetism** a property of material where magnetic moments have antiparallel spins so that there is complete canceling and hence no magnetic attraction or repulsion effects. Antiferromagnetism coupling effects are removed by heating to the Néel temperature, and the

material reverts to paramagnetism.

**argillaceous** an adjective that describes a rock or sediment that contains clay

**Árkai index** The powder X-ray diffraction pattern of fine-grained chlorite was used to obtain information about apparent chlorite “crystallinity” by M. Frey (Frey, 1987) and others, and by Arkai (1991) to correlate the reactions involving smectite-muscovite and smectite-chlorite with the Kübler index (and other metamorphic grade-indicating characteristics). Because diffraction patterns are affected by the presence of a diversity of defects, mean crystallite sizes, and other features, it is unclear if “crystallinity” is actually being measured and thus, the index should not be characterized as a “crystallinity” index. *Cf.*, crystalline, crystallinity index, Hinckley index, Kübler index

**asbestiform** minerals with the same shape characteristics as asbestos. *Cf.*, asbestos

**asbestos** a general commercial term for two fibrous silicate-mineral groups: chrysotile, the fibrous serpentine mineral, and fibrous amphiboles (amosite, crocidolite, anthophyllite, tremolite, and actinolite) and these two groups are considered by U.S. regulatory agencies. Asbestos minerals are incombustible, make excellent thermal and electrical insulators, resist chemical attack, and have high tensile strength. In addition to being fibrous, other characteristics include flexibility and the ability of fibers to be separated (often capable of being woven). The aspect ratio (i.e., length-to-width ratio) is often defined as at least 100:1. Actinolite and tremolite have no commercial value. Amosite (“brown asbestos”) is a variety of grunerite whereas crocidolite (“blue asbestos”) is a variety of riebeckite. Asbestos minerals have been implicated as pathogenic when inhaled, although the minerals are not equally pathogenic with chrysotile, which is considerably less dangerous than the amphiboles.

**asymmetric unit** the smallest part of a unit cell from which the entire unit cell can be generated by applying all symmetry operators present

**attapulgitite** refers to the mineral, palygorskite, and should not be used in the mineralogic or geologic literature. See Guggenheim *et al.* (2006) and references therein.

**Atterberg Limits** a designated series of tests in geotechnical engineering used for identifying, describing, and classifying fine-grained soils. These tests, which originally included six “limits of consistency” ( the upper limit of viscous flow, the liquid limit, the sticky limit, the cohesion limit, the plastic limit and the shrinkage limit) are now typically limited to the “liquid limit”, the “plastic limit” and, sometimes, the “shrinkage limit”. Atterberg limits are determined on a mass per mass basis by specific test methods, as standardized by ASTM Standard D4318 - 05, and expressed in percent. See Mitchell (1993). See also activity, consistency number, liquid limit, plastic limit, plasticity index, shrinkage limit.

**authigenic** refers to rock constituents or minerals that have formed in place and were not transported. Such materials have formed either at the same time as the rock in which they are found or after the formation of the rock. The term is also applied to minerals that are clearly the

result of new crystal growth on older crystals of the same kind, *e.g.*, K-rich feldspar overgrowths may be referred to as authigenic overgrowths.

**ball clay** a fine-particle size, plastic, sedimentary kaolinitic clay layer with minor to abundant organic matter, important in the manufacture of ceramics. Typically found in association with lignite layers. *Cf.*, underclay, seat rock

**basal reflection** a diffraction X-ray peak from a layer material originating from those atomic planes which comprise the layers (i.e., parallel to cleavage). For most layer silicates, basal reflections are of the Miller index type:  $00l$ , where  $l$  is an integer. The  $d$  values of the basal reflections may be used to obtain  $c \sin(\beta)$ , which is the repeat distance perpendicular to the plane of the layers. The  $c \sin(\beta)$  value is usually an indicator of the structure unit and thus, the type of phyllosilicate, assuming that no semi-random interstratifications occur in the phase (which can cause a displacement of the basal reflection positions). For example, mica minerals have a value of about 10 Å and chlorite minerals have a value of about 14 Å.

**beidellite-type montmorillonite** As described by Schultz (1969) based on chemical and thermal analysis, beidellite-type montmorillonite is a type of montmorillonite characterized by a large net negative layer charge of -0.85 to -1.20 per  $O_{20}(OH)_4$ , with tetrahedral substitutions causing more than 50% of the total layer charge. Current (chemical) nomenclature for montmorillonite is that it is an Al-rich, dioctahedral smectite with an ideal structural formula of  $(Al_{3.15}Mg_{0.85})Si_8O_{20}(OH)_4X_{0.85}.nH_2O$  with layer charge from primarily octahedral substitutions of Mg, whereas beidellite has a net layer charge that occurs from tetrahedral substitutions of Al, with an ideal structural formula of  $Al_{4.0}(Si_{7.15}Al_{0.85})O_{20}(OH)_4X_{0.85}.nH_2O$ . The term "beidellite-type montmorillonite" is obsolete and should not be used.

**beneficiation** a) a process or processes to concentrate an ore mineral. The British equivalent is "mineral dressing". b) the process of improving the performance characteristics of an industrial clay by processing and/or the addition of chemical additives, *eg.*, bentonite.

**bentonite** a) Mineralogical/Petrological term: A soft, plastic, light-colored rock composed primarily of clay minerals of the smectite group, particularly the clay mineral montmorillonite, which typically forms from chemical alteration of glassy volcanic ash or tuff under marine or hydrothermal conditions. Bentonite may contain accessory crystal grains that were originally phenocrysts in the parent rock as well as secondary authigenic mineral phases such as K-rich feldspar. Diagenetic or low-grade metamorphic alteration can modify the smectite to a variety of interstratified illite-smectite minerals, resulting in materials known as K-bentonites. b) Industrial term: A highly colloidal and plastic clay material, primarily composed of the clay mineral montmorillonite, that is commonly used in drilling mud, as a foundry sand binder, in cat litter, animal feed, cements, ceramics and various other industrial activities and products. Sodium bentonite swells significantly when exposed to water (to ~12X) whereas calcium bentonite has minimal swelling capability (to ~3X). *Cf.*, tonstein

**BET** see Brunauer-Emmett-Teller (BET) for specific surface area analysis

**bilateral** see mirror plane

**birefringence** an optical property whereby a crystal has more than one index of refraction. An optically clear calcite rhombohedron shows a doubling of images as a result of birefringence, i.e., double refraction.

**biscuit** see bisque

**bisque** a) unglazed ceramic that has undergone firing; b) the dried, but not yet fired, enamel coating. The bisque firing temperature is that initially used to stabilize the ceramic prior to glazing. Syn., biscuit

**bleaching clay** used in decolorizing oil products, typically fuller's earth or bentonite, by adsorption. For example, bleaching earth is used to remove the green color of chlorophyll in some cooking oils. Syn., bleaching earth

**bleaching earth** see bleaching clay

**bottom ash** the fused, amorphous, siliceous residue from burning coal in industrial burners. Crushed and sized bottom ash is used as an aggregate substitute in concrete and as a non-crystalline substitute for quartz sand in sand blasting. Cf., fly ash

**Bragg's law** Bragg's law describes the condition for an X-ray reflection (i.e., constructive interference) for crystalline materials and is given as  $n\lambda = 2d\sin\theta$ , where  $n$  is the path difference between reflecting planes, which must be an integer for constructive interference,  $\lambda$  is the wavelength,  $d$  is the interplanar spacing, and  $\theta$  is the glancing angle of incidence (reflection angle). In an X-ray diffraction experiment, the  $\lambda$  is known and is dependent on the X-ray source in use,  $\theta$  is the measured quantity, and  $d$  is the parameter that is characteristic of the material under study. Thus, both  $n$  and  $d$  are unknowns. In practice, the order of the reflection  $n$  is fixed for the value of  $d$  for a specific plane  $hkl$  (and thus is included in the value) and, the use of  $d_{hkl}$  symbolizes this inter-relationship. Thus, the modified version of the Bragg equation is used in practice, which is given as:  $\lambda = 2d_{hkl}\sin\theta$ .

**brittle** a descriptive term for tenacity where a mineral breaks easily with a lack of flexibility or elasticity

**brittle mica** a group name for platy phyllosilicates of 2:1 layer and a layer charge of  $\sim -2.0$  per formula unit. Rieder et al. (1998) defines the brittle micas as having greater than 50% of the interlayer cations as divalent. Brittle micas do not have swelling capacity. Common divalent cations in the interlayer include Ca and Ba. The subgroups of the brittle micas are based on dioctahedral or trioctahedral character, and species within the subgroups are based on chemical composition. Cf., mica, true mica, interlayer-deficient mica, group names

**Bravais lattice** one of 14 different types of space lattices (three dimensional arrays). The Bravais lattices are characterized by identipoints showing translational periodicity, and this

periodicity can be used to define a (unit) cell. There are five basic lattice types [*P*, *A* (or *B* or *C*), *F*, *I*, and *R*]. When distributed over the crystal systems, the five basic types produce 14 space lattices. *Cf.*, identipoint, lattice, array

**brucite sheet** inappropriate usage for trioctahedral sheet. See *trioctahedral sheet, interlayer material*

**Brunauer-Emmett-Teller (BET) for specific surface area analysis** surface area determination by sorption analysis of non-polar gases, typically  $N_2$ , on a solid, as calculated from the linear form of the BET equation (see Brunauer et al., 1938) for multi-layer gas adsorption on the surface of a sample of known weight. The technique requires removal of sorbed gases from the sample prior to BET analysis. Objections involving the use of BET analysis for clays containing  $H_2O$  include 1) platy surfaces of the phyllosilicate particles protect underlying adjacent surfaces from gas adsorption, and 2) interlayer regions may become inaccessible to  $N_2$  owing to pretreatments that remove interlayer  $H_2O$ , which collapses any swelling clays present, and thus results may be affected by preparation techniques. It is commonly considered to measure external surface area and, as such, should not be used for total specific surface area or as an indicator of the amount of chemically accessible internal surface area.

**calcine** to heat a substance to a temperature where it dissociates, for example the heating of calcite ( $CaCO_3$ ) to form  $CaO$  and  $CO_2$ . If clay is calcined, hydroxyl groups are removed from structural constituents and plasticity is destroyed.

**Calgon®** a commercial product consisting of sodium phosphate sometimes used as a dispersing agent for clays in aqueous suspensions. In this application, sodium phosphate buffers the solution and phosphate ions preferentially adsorb to clay edges. Both processes aid in dispersion of the clay. Calgon® is a registered trademark of The Calgon Corporation.

**Carborundum®** a commercial product composed of silicon carbide that is used as an abrasive in cutting, grinding and polishing applications. Carborundum® is a registered trademark of The Carborundum Corporation.

**cation exchange** a process whereby a cation bound to a site on a surface is replaced by a cation from a solution. In both phyllosilicates and zeolites, the cation may be located on either external surfaces or internal surfaces; thus, the full process may involve cations from the interior that diffuse toward the surface, and are in turn replaced by cations from the solution which diffuse inward. The term differs from solid-state diffusion primarily by time scale, where cation exchange occurs relatively quickly and solid-state diffusion requires a much longer period.

**cation-exchange capacity (or CEC)** the surface charge of a phyllosilicate that relates to a net negative imbalance of charges originating from the silicate layers of the mineral. The magnitude or capacity for exchange (see cation exchange) is related to the size of the net negative charge that occurs within the (commonly, 2:1) layer. Cation exchange occurs where a solution containing the exchangeable cations forms a concentration gradient with the exchangeable cation of the mineral. The charge on the mineral is operationally related to the magnitude of the number

of exchanged cations. The net negative charge is considered “permanent charge”, and this originates from either (or both) tetrahedral or octahedral solid solutions, changes in oxidation state of constituent cations in the layer, substitutions involving anions [e.g., O<sup>2-</sup> for (OH)<sup>-</sup>], and other possible factors.

**Celsius (centigrade)** A temperature scale based on a degree, °C, where the freezing point of pure water at one standard atmosphere is arbitrarily set at 0 and the boiling point at 100 °C. One Celsius degree equals one Kelvin. 0 °C equals 273.15 K. *Cf.*, Fahrenheit, Kelvin

**center of symmetry** symmetry involving a repetition of identical features about a point at the center of the object. Thus, any point in the object will have a corresponding point (to produce an inversion) repeated an equal distance from the object’s center along a line established by the original point and the center point of the object. Also known as an “inversion center”. *Cf.*, symmetry, mirror plane, rotation symmetry, rotoinversion

**Chambers-type montmorillonite** A now-obsolete term first used by Schultz (1969) to define montmorillonite samples on the basis of chemical and thermal analysis with a total net layer charge of -0.85 to -1.20 per unit cell [O<sub>20</sub>(OH)<sub>4</sub>], with a layer-charge contribution from tetrahedral substitutions of between -0.15 to -0.50, although exceptions were noted. See Tatatila-type montmorillonite. Terms used in this obsolete classification are: Wyoming-type, Otay-type, Chambers-type, Tatatila-type, beidellite-type (ideal and non-ideal), and non-ideal montmorillonite. Current nomenclature for montmorillonite is that it is an Al-rich, dioctahedral smectite with an ideal structural formula of (Al<sub>3.15</sub>Mg<sub>0.85</sub>)Si<sub>8</sub>O<sub>20</sub>(OH)<sub>4</sub>X<sub>0.85</sub>.nH<sub>2</sub>O with layer charge from primarily octahedral substitutions of Mg.

**China clay** Porcelain was first made in China using kaolin, feldspar, and quartz. Traders brought porcelain back to Europe and when porcelain was made in Meissen, Germany and in England, the primary kaolin used in the formulation was called "China Clay". The term is still used today largely in Europe and is synonymous with kaolin.

**chlorite** a group name for platy phyllosilicates of 2:1 layer with a variable layer charge. The interlayer material consists of a hydroxide octahedral sheet, which results in *d*(001) value of approximately ~ 14.0-14.4 Å. The group is further divided into subgroups that are either trioctahedral or dioctahedral, and these subgroups are further divided into mineral species based on chemical composition. See further explanation under “group names”.

**cis-vacant** a dioctahedral phyllosilicate where the vacancy is ordered and occurs in the octahedral site where the OH,F anions reside on adjacent corners of the octahedron (i.e., *cis* orientation). Alternatively, the description of the *cis* site is off the mirror plane (based on the idealized layer symmetry, not necessarily the structure in its entirety) of the layer. *Cf.*, *trans*-vacant

**clay** a naturally occurring material composed primarily of fine-grained minerals, which is generally plastic at appropriate water contents and will harden when dried or fired. Although clay usually contains phyllosilicates, it may contain other materials that impart plasticity and

harden when dried or fired. Associated phases in clay may include materials that do not impart plasticity and organic matter. Different disciplines have uniquely defined the size of clay particles, and it is for this reason that “fine grained” is used in the definition rather than a precise value. However, because of these size variations from discipline to discipline, it is important that the particle size be specified in the context of the application. (*Quot* Guggenheim and Martin, 1995). For definitions relating to non-clay-science applications, see Jackson (1997).

**clay mineral** refers to phyllosilicate minerals and to minerals which impart plasticity to clay and which harden upon drying or firing. This definition expands the previous definition of Brindley and Pedro (1972) by relating clay minerals to the properties of clays. Clay minerals may be of any crystallite size so that the term “clay mineral” is consistent with the definition of “mineral”, which is unrelated to crystallite size. (*Quot* Guggenheim and Martin, 1995). However, the unique properties of clays are partly related to their small particle size and high surface area (Guggenheim and Martin, 1996). *Cf.*, clay, phyllosilicate, mineral

**clay nanocomposite** a nanocomposite (i.e., fine-particulate material that is heterogeneous at the nanoscale level, at less than  $10^{-7}$  meters) where one or more of the constituent fine-particulate materials are clay minerals. Other parts of the composite may be, for example, polymers, which act as the dispersant. Some clay composites are fabricated with the polymer both around the clay particle and in the interlayer between the 2:1 or 1:1 layers. *Cf.*, nanocomposite

**clay-organic complex** see organoclay

**clay-polymer nanocomposite** see clay nanocomposite

**clay solution** or **sol** see suspension

**clay suspension** see suspension

**cleavage** The tendency of a crystal to break along certain (and generally smooth) planes of weakness. Planes of weakness in a crystal usually reflect either the presence of a plane of weaker or fewer bonds in a structure, and thus cleavage is a diagnostic property. These planes can be described as Miller indices, and are thus rational. *Cf.*, parting

**closure** see rotation symmetry

**coagulation** See flocculation

**coalescence** The process of coarsening of particles from a thermodynamically unstable dispersion. The total surface area is reduced.

**co-ion** an ion with a charge of the same sign as the charge of the solid interface. *Cf.*, counter ion

**colloid** An entity, either a solid or a liquid, dispersed in a medium. The entity must have one of its dimensions between 1 nm and 1  $\mu$ m. A colloid dispersed in a liquid is also termed a "sol".

The term may be used also for the system as a whole. (after Lyklema 1991)

**colloidal solution** see suspension

**colloidal suspension** see suspension

**commensurate** the relationship where a superstructure (or superlattice) is equal to an integral number of subcells (or sublattices). For example, some crystals of antigorite exist where the substructure *a*-cell dimension is 5.4 Å, and the superstructure of 32.4 Å, occurs from a wave-like curvature of the 1:1 along the [100] direction. Because the superstructure is  $6 \times 5.4 \text{ \AA} = 32.4 \text{ \AA}$ , the superstructure is commensurate with the substructure. In other crystals of antigorite, the superstructure may be related to the substructure by a non-integer number of subcells, and this is referred to as a non-commensurate relationship.

**compact** see cryptocrystalline

**converse piezoelectric**, see piezoelectric

**counter ion** an ion with a charge opposite in sign to the charge of the solid interface to which it is attracted. *Cf.*, co-ion

**cryptocrystalline** a rock-texture term for which the individual mineral grains in an aggregate are too small to be distinguished in an ordinary light microscope. If grains can be distinguished in a light microscope, the texture is “microcrystalline”. The rock is said to have a “compact” texture if grains cannot be distinguished by the naked eye. Carbonate petrographers use a discrete crystal dimension for individual carbonate grains for a rock to be classified as having “cryptocrystalline” texture, although the dimension does not appear to be in universal agreement.

**crystal** an element or chemical compound that is crystalline and shows planar faces that express this crystallinity. If the solid lacks faces, it is referred to as “anhedral” and if it is completely bounded by faces, then it is referred to as “euhedral”, and it is “subhedral” if bounded by poorly defined faces. The term “single crystal” is often used in a colloquial sense for crystalline grains which are anhedral.

**crystal class** see point group

**crystal system** Crystal systems are defined based on the symmetry of a crystal. There are six crystal systems, given in decreasing symmetry: cubic (or isometric), hexagonal, tetragonal, orthorhombic, monoclinic, and triclinic. Minimum symmetry requirements are: four 3-fold or -3 axes (cubic), one 3- or 6-fold axes (hexagonal), one 4-fold axis (tetragonal), three mutually perpendicular directions with 2-fold and/or mirror plane symmetries (orthorhombic), one 2-fold axis and/or mirror plane (monoclinic), and center of symmetry or identity operation only (triclinic). Consequently, because of the symmetry present, the relative lengths of the crystallographic axes and the values of interaxial angles may be constrained: cubic,  $a_1 = a_2 = a_3$ ,  $\alpha = \beta = \gamma = 90^\circ$ ; hexagonal,  $a_1 = a_2 = a_3 \neq c$ ,  $\alpha, \beta = 90^\circ, \gamma = 120^\circ$ ; tetragonal,  $a_1 = a_2$

$\neq c$ ,  $\alpha = \beta = \gamma = 90^\circ$ ; orthorhombic,  $a \neq b \neq c$ ,  $\alpha = \beta = \gamma = 90^\circ$ ; monoclinic,  $a \neq b \neq c$ ,  $\alpha = \gamma = 90^\circ$ ,  $\beta > 90^\circ$ ; triclinic,  $a \neq b \neq c$ ,  $\alpha \neq \beta \neq \gamma$ . The term “isometric” is sometimes used as a morphological term where the measured crystal is equant. *Cf.*, crystallographic axes

**crystalline** a solid consisting of atoms, ions, or molecules packed together in a periodic arrangement. The material must have sufficient atomic ordering such that a (X-ray, electron, neutron, etc.) diffraction pattern containing well-defined maxima can be indexed using Miller indices (Nickel, 1995). *Cf.*, non-crystalline

**crystallinity index** an attempt to describe the state of crystallinity of a solid as a value of some characteristic, usually relating to diffraction. The term is a misnomer because it suggests that the complex idea of crystallinity may be represented by a single value. The use of the term “crystallinity index” should be avoided, although it may be placed within quotation marks when referring in a limited way to previously referenced work (Guggenheim *et al.*, 2002). Some indices are useful to describe e.g., crystallite size or grade of diagenesis. Indices were derived by Hinckley (1963) to distinguish between different samples of kaolinite, by Kübler (1964) to describe certain origins of samples of illite, and by Árkai (1991) to describe different origins of chlorite. It is recommended to refer to the author describing the procedures necessary to define the value, regardless of what the index may actually be describing, such as the Hinckley index. See Guggenheim *et al.* (2002) and references therein. *Cf.*, Árkai index, Kübler index, Hinckley index

**crystallographic axes** a set of reference axes used in crystallography. These axes are usually three in number, although in some cases, they may be four. The axes are generally mutually perpendicular, coincide with symmetry axes or the normals to symmetry planes, and in cases where the crystal lacks symmetry, parallel to lines of intersection of two faces with greatest areas. These axes are designated as  $a$ ,  $b$ ,  $c$ , and angles between axes are designated  $\alpha$ ,  $\beta$ , and  $\gamma$  where  $\alpha$  is located between axes  $b$  and  $c$ ,  $\beta$  is located between axes  $a$  and  $c$ , etc. according to the right-hand rule. See also: crystal system.

**crystal structure** the atomic arrangement for a crystalline material

**cubic** see crystal system

**Curie temperature** see ferromagnetism, ferroelectric

**Debye length** see diffuse double layer

**deflocculate** to disperse clumps of small particles adhering together in a suspension to form a colloid or near-colloid suspension. The resulting suspension is more fluid than the original.

**deflocculant** a substance that disperses particles to form a colloidal or near-colloidal suspension when added to a slurry that contains clumps of particles that have aggregated to form larger non-fused particles. Common deflocculants for simple (non-exchanged) clay systems include sodium carbonate or sodium phosphates, such as sodium pyrophosphate. These deflocculants produce a

buffered, high pH solution and are especially useful when size-separating clay particles. Cf. flocculation.

**dehydration** the removal of H<sub>2</sub>O from a phase. The H<sub>2</sub>O may be present as an integral part of the atomic structure or as “free” (adsorbed) water. Dehydration commonly is achieved by heating or by evaporation.

**dehydroxylate** any phase obtained by elimination of the hydroxyl from phyllosilicates prior to recrystallization. (*Quot Guggenheim et al., 2006*)

**dehydroxylation** the removal of (OH)<sup>-</sup> groups from the atomic structure of a phase. Decomposition/recrystallization usually results, but there are some materials that form dehydroxylate structures prior to recrystallization. Cf., dehydroxylate

**delamination** In clay science, delamination commonly refers to the separation of a phyllosilicate into small groups of layers or individual layers such that the separation is sufficiently great that the layers do not interact. See 1:1 layers, 2:1 layers.

**devitrification** crystallization from a glass

**diagenesis** the chemical, physical, and biological reactions incurred by sediment during burial, after initial accumulation. Diagenesis reactions may involve addition and removal of material, transformation by dissolution and recrystallization or replacement (authigenesis), or both, and phase changes (See *Ostwald ripening*). Weathering, incurred by sediments at the Earth's surface under ambient conditions, is not part of the diagenesis process and represents the lower temperature limit of diagenesis. Hydrothermal, geothermal, and contact metamorphism are not considered part of the diagenesis process. The lowest grade of metamorphism limits the diagenesis process at high temperature and high pressure. In clay-rich rocks, the boundary between diagenesis and very low-grade metamorphism (anchizone is the transitional zone) has a Kübler index of 0.42 - 0.25 degrees two theta. Reduction of smectite interlayers in illite-smectite interstratifications to <10% is typical of the diagenetic zone-anchizone transformation (Merriman and Peacor, 1999). Weaver and Brockstra (1984) proposed a boundary between diagenesis and metamorphism as that point at which disordered illite (1*Md*) has been converted to ordered (1*M*, 3*T* or 2*M*<sub>1</sub>). “Retrograde” diagenesis was described by Nieto et al. (2005) as “fluid-mediated retrograde processes occurring under diagenetic conditions”. See *anchizone, epizone, interstratification, Ostwald ripening, smectite-illite* Cf., Kübler index

**diamagnetism** describes a property of material where there is repulsion by a magnet. Cf., magnetic susceptibility, magnetism

**diatomaceous earth** a soft, naturally occurring, sedimentary rock, of marine or freshwater origin, composed of biogenic silica derived from tests (shells) of single-celled alga (diatoms). Diatomaceous earth has a high melting point (1715 °C) and is used in filters, mild abrasives, thermal insulators, and absorbants. *Syn.*, diatomite

**diatomite** see diatomaceous earth

**dielectric** see insulator

**diffuse double layer** All surface charges are balanced by oppositely charged counter ions. Some of these counter ions are bound, usually transiently (see cation exchange), in the so-called Stern or Helmholtz layer, some of them may diffuse away from the surface and form a diffuse layer. Both the charged surface and the diffuse ions form the electric double layer, which in total is uncharged. The thickness of the diffuse layer is solely a function of the ionic strength of the solution. The distance  $1/\kappa$ , where the thickness has decreased to roughly  $1/e$  is called the Debye (screening) length. The thickness decreases with increasing ionic strength because of the screening effect of ions. *Cf.*, Stern layer

**diffuse layer** see *diffuse double layer, Stern layer*

**diffusion** the process of mass transfer of matter from areas of high activity to low activity, or of energy where heat is transferred from higher temperatures to regions of lower temperature, over time. Diffusion is generally driven by thermal vibration of the mass.

**diffusion, volume** the temperature dependent process of mass transfer of matter in solids from areas of high concentration to low concentration. Volume diffusion commonly occurs along interstitial channels or grain boundaries, or by vacancy exchange with an atom, ion, or molecule. See diffusion.

**dilatancy** a property of a non-Newtonian fluid where the fluid shows a reduction in viscosity over time if not agitated (e.g., stirred) and an increase in viscosity when agitated. *Cf.*, Newtonian fluid, quick clay, thixotropy

**dioctahedral chlorite** a species of the chlorite mineral group with dioctahedral sheets only (e.g., donbassite) *Cf.*, trioctahedral chlorite, di, trioctahedral chlorite, dioctahedral sheet

**dioctahedral sheet** In the ideal case, the smallest structural unit in a phyllosilicate contains three octahedra. If two such sites are occupied with cations and one site is vacant, then the octahedral sheet is considered “dioctahedral”. If all three sites are occupied, the sheet is considered “trioctahedral”. (*Quot Guggenheim et al., 2006; see also references therein*). A dioctahedral sheet generally contains predominantly trivalent cations. *Cf.*, trioctahedral sheet

**disilicic** not a valid term, previously used as a classification of the micas where the number of silicon atoms per formula unit is two per four tetrahedral sites, see Rieder et al. (1998). *Cf.*, mica, true mica, brittle mica, interlayer-deficient mica, group names

**dispersed phase** see suspension

**di, trioctahedral chlorite** a species of the chlorite mineral group with a dioctahedral 2:1 layer and a trioctahedral interlayer (e.g., cookeite, sudoite). *Cf.*, trioctahedral chlorite, dioctahedral

chlorite, dioctahedral sheet, trioctahedral sheet

***d* value** As defined in the Bragg equation for diffraction,  $n\lambda = 2d \sin\theta$ , where  $n$  is an integer,  $\lambda$  is the wavelength,  $\theta$  is the glancing angle of incidence, and  $d$  is the (perpendicular) spacing between the diffracting planes. Because  $d$  is defined as a spacing, the term  $d$  spacing is redundant. See Bragg equation

***d* spacing** see *d* value

**earthenware** nonvitreous, opaque ceramic whiteware, which may or may not be glazed. Water adsorption is variously defined as greater than 3% or greater than 5%.

**earthy** having a dull luster, similar to soil, usually involving an aggregate of fine-grained material

**efflorescence** In geology, the weathering process where salt laden ground water is brought to the surface of a geologic material by evaporation, allowing the dissolved salts (e.g., halite, gypsum, calcite, natron) to crystallize forming a white/grey, often fluffy powder. Efflorescence is common in arid climates where rocks or soils of marine origin are exposed at or near the surface.

**elastic** a descriptive term for tenacity where an applied force deforms a crystal, but the crystal resumes its original shape after the applied force is released. *Cf.*, flexible, brittle

**emulsion** see suspension

**enantiomorph** or **enantiomorphic pair** see mirror plane

**end member** a mineral with a formula that is stoichiometric with respect to the asymmetric unit of the cell, and therefore reflects a lack of solid solution. See solid solution for an example, also see asymmetric unit

**epizone** the beginning of low-grade metamorphism. The epizone is defined by Kübler indices less than 0.25 in mudrock lithologies. *Cf.*, Kübler index

**equipoint** or **equivalent point** symmetry equivalent points, which commonly refers to positions of symmetrically equivalent atoms in a crystal structure

**equivalent point** see equipoint

**equivalent spherical diameter** Clay particles are often size-separated using Stokes' law, although Stokes' law applies strictly to spherical particles only. Clay particles with platy shapes settle at slower rates than spheres of equal density in a fluid, however. If Stokes' law is used in the size-separation analysis, it is appropriate to describe the platy clay particle as settling at velocity equal to that of a sphere of "equivalent" diameter (equivalent spherical diameter or esd

or e.s.d.). See Stokes' Law

**esd** or **e.s.d.** see equivalent spherical diameter

**euohedral** see crystal

**eutectic** the lowest (minimum temperature) point of a liquid field in a phase diagram. Cf., phase diagram

**exfoliation** a) a process of physical weathering where large granitic plutons break into onion-like sheets along joints that lie parallel to the exposed surface. b) In clay science, a large interlayer expansion of phyllosilicates, such that interatomic forces of one layer are apparently not influenced by another.

**expandable clay** see swelling clay

**extra-framework** see zeolite

**extrusion** the process of pushing a plastic material through a die to change its shape. Commonly used in the clay industry to manufacture bricks.

**Fahrenheit** A temperature scale where the freezing point of pure water at one standard atmosphere is set to 32 ° and the boiling point is set to 212 °. Cf., Celsius, Kelvin

**failure** loss of cohesiveness

**felsic** a geologic term describing magmas, igneous rocks and silicate minerals that have a relatively high concentration of lighter elements such as oxygen, sodium, aluminum, silicon and potassium. Felsic magmas typically are highly viscous when compared to mafic magmas. Felsic rocks are typically light colored when compared to mafic rocks Cf., mafic

**ferrimagnetism** a property of material where there is an antiparallel alignment of magnetic moments but these alignments are unbalanced either because one direction has stronger moments or a larger number of moments. Inverse spinel structures ("ferrites") are often ferrimagnetic, where magnetic moments of ferric iron cations in the tetrahedral sites and one-half the cations in the octahedral sites (also ferric iron) are opposed and cancel, whereas the remaining occupied octahedral sites can have either balanced (e.g., Mg, Cd, Zn, zero unpaired electrons) or unbalanced (e.g., Mn, Fe<sup>2+</sup>, Co, Ni, Cu) magnetic moments, approximately proportional to the number of unpaired electrons.

**ferrites**, see ferrimagnetic

**ferroelectric** describes a property of materials whereby an electric dipole moment remains even after a strong electric field is removed. The electric dipole moment (polarity) results from electronic polarization of individual atoms or ions, and/or a reorientation of polarizable

molecules in the crystal. Dipole moments in ionic crystals can also form from initial cation positional disorder within a site from unit cell to unit cell; domains (and a dipole) develop when an applied electric field causes a favored positioning of cations within the site cavities. Examples of ferroelectric materials include KDP (potassium dihydrogen phosphate), colemanite, and barium titanate. Dipoles are randomized at the “Curie temperature”.

**ferromagnetism** describes a property of material where permanent magnetism develops when a magnetic field is applied. Ferromagnetism results by a parallel alignment of magnetic moments which remains after the material is removed from the applied magnetic field. The phenomenon occurs with iron, and hence the name, but other elements (in general, elements between atomic numbers of 23 and 29) and alloys (e.g., MnBi) also show the effect. Upon heating, the effect is diminished, and when heated to the “Curie temperature”, the magnetic effects are fully removed.

**fibrous** a crystal habit describing thin, flexible filaments

**fire clay** a kaolinitic-rich clay with excellent refractory properties, and the fired product is commonly used as fire bricks. The refractory clays are classed as low, medium, high, and super duty with the latter heat resistant from 1430 to 1804 °C. Fire clays are low in alkali, alkali earth, and transition metals. Typically found in association with coal layers. *Cf.*, underclay, seat rock

**firing** heat treatment of clay materials that cause partial melting and fusion to create ceramics

**flexible** a descriptive term for tenacity where a mineral may bend without breaking, but does not return to its original shape after the force is released. *Cf.*, elastic

**flint clay** a fine-particle size, non-plastic, dense, brittle kaolinitic clay layer or deposit, that breaks with a conchoidal fracture. Typically found in association with coal layers. *Cf.* underclay, seat rock

**flocculation** In the original, flocculation refers to the destabilization of a suspension by the clumping of small particles to larger ones, but without fusion, owing to small amounts of polymers (e.g., see Lyklema, 1991). Common usage is no longer restricted to polymers, and may involve changes of the electrolyte. However, the mechanisms of destabilization differ where polymers vs electrolytes are considered: polymers are adsorbed and form bridges between particles, whereas electrolyte changes involve ionic strength variations that reduce repulsive forces between particles. Both processes produce clumping of small particles in a suspension to produce larger particles. The total surface area does not essentially change. *Syn.*, aggregation

**flux** 1. In metallurgy, a material which chemically cleans a metal surface to prepare it for welding, brazing or soldering. 2. In ceramics, a material which lowers the melting point of ceramic materials to facilitate glass formation. 3. In physics, the rate of transfer of heat, mass, magnetism, etc. that passes a unit area per unit time. *Cf.*, fusion

**fluxing** melting of a substance

**fly ash** fine particulate, airborne, typically amorphous, siliceous residue from burning coal in industrial burners. The chemistry of the coal and the type/chemistry of the fly ash collection system determines the composition of the fly ash. Pozzolanic (cementitious) fly ash is commonly used as an additive in cement. Non-pozzolanic fly ash is often used as a filler in wood and plastic products, in asphaltic concrete, in roofing tiles, and in other composite manufactured materials. Fly ash commonly contains a variety of heavy metals that were present in trace concentration in the unburned coal. *Cf.*, bottom ash

**foam** see suspension

**fog** see suspension

**form** a) in mineralogy, a crystal shape that is an expression of the ordered pattern of the atomic structure. The crystal form is commonly a regular geometric shape. b) in crystallography, a form consists of a group of symmetry-related crystal faces.

**formality** the number of gram formula weights (= molecular weights) of the solute in one liter of solution. Useful where experiments use measured volumes and where temperature effects are not being studied. *Cf.*, molarity, normality, molality, mole fraction

**freeze drying** a dehydration process where material is dried via sublimation of contained water. The material is frozen in a vessel, subjected to gas-pressure reduction often followed by slight heating, and dried by removal of sublimated water vapor. In clay mineralogy, samples of clay are dispersed in water as a suspension prior to freeze drying. The residual clay often shows the aggregate structure and fabric of the dispersed phase.

**friable** the characteristic of a solid material that allows its particle size to be easily reduced

**fuller's earth** a clay or other earthy material of fine particle size that is highly absorbent and/or is a natural bleaching earth. The term is derived from the historical use of certain clays to "full" or remove oils and other contaminants from raw woolen cloth.

**fundamental particle** a sequence of 2:1 dioctahedral or trioctahedral layers which are coherently related by rotations of multiples of  $60^\circ$ . Such particles, as observed in sample separates, are assumed to be identical to the individual growth units in unseparated samples. Some data have shown that coherent scattering domains undergo separation during sample disaggregation, and that particles that result are not fundamental, but many investigators assume that there is a one-to-one relation between fundamental particles in separates and coherent scattering domains in unseparated soil or rock samples. *Cf.*, MacEwan crystallite, interparticle diffraction, coherent scattering domain

**fusion** the unification of two or more particles such that the substances between the two particles is of the same material as the particles. Fusion often refers to the melting together of two substances. In clay science, aggregates may form without fusion with bridges forming between particles by  $H_2O$  or by polymers, such that they behave as an apparently larger particle. *Cf.*,

flocculation

**gallery** see pillared clay

**gangue** In mining, the non-economic host rock in which valuable minerals (usually metalliferous ore minerals) are found. When the gangue is discarded, this material is referred to as “tailings”.

**gel** see suspension

**glass** a solid with a degree of order intermediate to the highly ordered arrangement of atoms, molecules, or ions in a “crystalline” solid and the highly disordered arrangement as found in a “gas”. Most glasses are in a metastable state and can be described as a supercooled liquid, which lack a melting point. Rapid cooling from a molten state (e.g., magma, lava) may result in a glass and this commonly depends on the volatile content of the melt. Not all glasses are formed from a melt. Although most opal forms from silica-saturated fluid under near-surface conditions, a rare “non-crystalline opal” (e.g., opal-AN) forms by transport of silica via steam to cold surfaces.

**glaze** a glassy coating produced on a ceramic by firing or the slurry used to make the coating

**glide plane** symmetry involving reflection across a plane coupled with a translation of  $a/2$ ,  $b/2$  or  $c/2$  parallel to an axis ( $a$ -glide,  $b$ -glide, or  $c$ -glide, respectively) or between two axes ( $n$ -glide with translations of  $a/2 + b/2$ ,  $b/2 + c/2$ , or  $a/2 + c/2$ ;  $d$ -glide or diamond glide with translations of  $a/4 + b/4$ ,  $b/4 + c/4$ , or  $a/4 + c/4$ ) or between three axes for tetragonal or isometric crystals with a translation component of  $a/4 + b/4 + c/4$ .

**green sand strength** see green strength

**green strength** a) In clayware manufacture, the ability of an unfired, molded clay body to resist mechanical deformation. b) In metal casting, a measure of the ability of a bentonite-bound sand mold to resist deformation (also called “green sand strength”).

**greenware** an unfired, molded clay body

**group names** Phyllosilicates are classified on the basis of characteristics involving planar structures, non-planar structures and regular interstratifications (e.g., Guggenheim et al., 2006). For planar structures and regular interstratifications, the layer type (e.g., 1:1, 2:1) is further divided by interlayer material present that is required to offset the net negative charge on the layer, and each division is given a group name. In addition, each group has a generally characteristic spacing [based on the  $d(001)$ ] perpendicular to the stacking direction, i.e.,  $c\sin\beta$ . The group names ( $x \sim$  layer charge per formula unit) for the planar structures (interstratifications are not given here) are: serpentine-kaolin ( $x \sim 0$ ,  $c\sin\beta \sim 7.1-7.3 \text{ \AA}$ ), talc-pyrophyllite ( $x \sim 0$ ,  $c\sin\beta \sim 9.1-9.4 \text{ \AA}$ ), smectite ( $x \sim -0.2$  to  $-0.6$ ,  $c\sin\beta \sim 14.4-15.6 \text{ \AA}$ ), vermiculite ( $x \sim -0.6$  to  $-0.9$ ,  $c\sin\beta \sim 14.4-15.6 \text{ \AA}$ ), true mica ( $x \sim -1.0$ ,  $c\sin\beta \sim 9.6-10.1 \text{ \AA}$ ), brittle mica ( $x \sim -2.0$ ,  $c\sin\beta \sim 9.6-10.1 \text{ \AA}$ ), interlayer-deficient mica ( $x \sim -0.6$  to  $-0.85$ ,  $c\sin\beta \sim 9.6-10.1 \text{ \AA}$ ), and chlorite ( $x \sim$

variable,  $c\sin\beta \sim 14.0\text{-}14.4 \text{ \AA}$ ). Groups are further divided into subgroups (e.g., serpentine, kaolin, talc, pyrophyllite, trioctahedral smectite, dioctahedral smectite, etc.) by mineral species based on the octahedral character (i.e., dioctahedral, trioctahedral) and subgroups are divided based on chemical composition to mineral species. Bailey (1980) designated the trioctahedral smectite subgroup as saponite and the dioctahedral smectite subgroup as montmorillonite.

**habit** overall morphology of a crystal resulting from crystal habit, often influenced by environmental conditions of formation, chemical composition, internal structure, and possibly other parameters. Examples of habits include acicular, lamellar, and equant.

**habit** Habit refers to the general shape of mineral particles, as in the “platy” habit of clay particles, inclusive of shapes that reflect the internal arrangement of atoms as well as crystal growth features.

**hardness** In mineralogy, hardness is the resistance to scratching. Mohs’ scale of hardness is generally used to obtain relative hardness information by comparing (i.e., by a scratch test) an unknown to one of ten minerals defined in the Mohs’ hardness scale. Hardness tests are performed on a smooth surface of the unknown. Hardness is not an isotropic property and thus, may depend on the direction in which the surface is scratched, although the differences in most minerals are small. *Cf.*, Mohs hardness, Vickers hardness

**Helmholtz plane** see *Stern layer*

**hexagonal** see crystal system

**Hinckley index** Hinckley (1963) attempted to define the “crystallinity” of kaolinite by describing changes in the powder X-ray diffraction pattern for various samples of kaolinite. The procedure, however, does not quantify the diversity of defects present and, if the procedure is used, it should not be characterized as a “crystallinity” index. See also, Plancon and Zacharie (1990); Guggenheim *et al.* (2002). *Cf.*, crystalline, crystallinity index, Kübler index, Arkai index

**H<sub>2</sub>O<sup>-</sup>** see water, adsorbed

**H<sub>2</sub>O<sup>+</sup>** see water, structural

**hormite** a mining term, now obsolete and not used in the geologic literature, that refers to the palygorskite-sepiolite group (Brindley and Pedro, 1970; Bailey *et al.*, 1971a).

**humidity** amount of water vapor contained in the atmosphere. “Relative humidity” is the ratio, usually expressed as a percent, of the amount of water vapor in the atmosphere to the maximum water vapor in the atmosphere possible at a specific temperature. “Absolute humidity” is the mass of water vapor per unit of dry air. When unspecified, reference is usually being made to relative humidity.

**hydromica** an obsolete term, superseded by interlayer-deficient mica

**hydrophilic** surfaces or molecules with strong attraction for H<sub>2</sub>O. *Cf.*, hydrophobic

**hydrophobic** hydrophobic materials, either surfaces or molecules, have little or no affinity for H<sub>2</sub>O. *Cf.*, hydrophilic

**identipoint** an identical point (a point whose environment is exactly the same as the environment around each other point) placed on an array. A set of identipoints within an atomic structure shows the scheme of repetition, or translational periodicity, of an array. *Cf.*, array, structure, Bravais lattice

**iep** see point of zero charge

**imogolite** a poorly crystalline aluminosilicate phase sometimes found in soils, including andisols and spodosols, and pumice deposits. An idealized stoichiometry of imogolite is  $\text{Al}_2\text{SiO}_3(\text{OH})_4$  or  $\text{Al}_2\text{O}_3 \cdot \text{SiO}_2 \cdot 2\text{H}_2\text{O}$ , although both the SiO<sub>2</sub> and H<sub>2</sub>O content may vary, possibly because of natural impurities, structure variations, or pretreatments. Particles are nanotubes about 2nm in diameter and to several micrometers in length, typically forming bundles 10 to 30 nm across. Tube curvature involves larger AlOH groups, which occur as a gibbsite-like sheet on the outer surface, and smaller, isolated SiOH groups, which are believed to be located on the inner surface of the cylinder and associated with the vacancy of the gibbsite-like sheet. The morphology makes imogolite potentially useful in industry for contaminant sorption, gas storage, as an oxidation catalyst, and as an electron emitter. *Cf.*, allophane

**improper rotation axis** see rotoinversion axis

**indurate** hardening of a rock or sediments by the effects of temperature, pressure, cementation, etc.

**inner sphere complexes** Inner sphere complexes are ions, which adsorb in the inner Helmholtz plane. There is spectroscopic evidence that these ions come so close to the surface that, e.g., water molecules from a hydration shell have to be removed from the contact plane. Since adsorption of ions on an increasingly charged surface requires energy from bonding, one speaks of specific adsorption.

**insulator, electrical** materials that are poor conductors of electricity. *Syn.*, dielectric

**interlayer** A general term that implies either the region between the two adjacent layers or the relation between the two adjacent layers (*quot* Guggenheim *et al.*, 2009). “Interlayer distance” is more precise to describe the distance between the adjacent layers (tetrahedral sheet to tetrahedral sheet, as shown in Fig. 1), and is measured by taking the average of the *z* coordinate of the basal oxygen plane. The “interlayer displacement” describes the displacement portion or lateral shift from tetrahedral sheet to tetrahedral sheet across the interlayer space. *Cf.*, layer, layer displacement

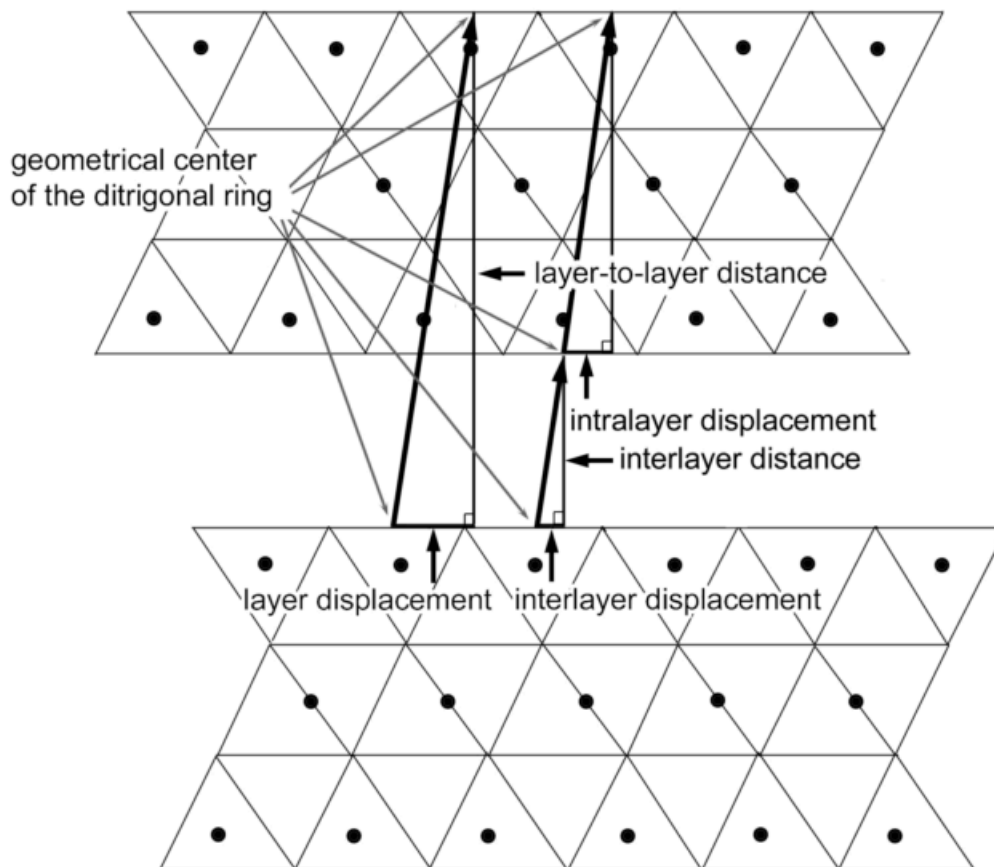


Figure 1. Illustration of terms used to describe interlayer, layers, and intralayer topologies. From Guggenheim *et al.* (2009).

**interlayer-deficient mica** abbreviated from interlayer-cation-deficient mica (Rieder *et al.*, 1998). A group name for platy phyllosilicates of 2:1 layer and a layer charge of between -0.6 to -0.85 per formula unit. Interlayer-deficient micas do not have swelling capacity. The subgroups of the brittle micas are based on dioctahedral or trioctahedral character (wonesite is the only known member of the trioctahedral subgroup), and species within the subgroups are based on chemical composition. The value of -0.6 is a general limit, as wonesite appears to be an exception with a layer charge of -0.5, although it has no swelling capacity. The value of -0.85 has been fixed from examples of dioctahedral species only. Previous to Rieder *et al.* (1998), the term “hydromica” was used to express a perceived excess in H<sub>2</sub>O above the O<sub>10</sub>(OH)<sub>2</sub> formula unit, but these phases are either interstratifications (e.g., hydrobiotite = interstratification of biotite and vermiculite) or micas that exhibit a deficiency in interlayer cation occupancy. Thus, the term “hydromica” was abandoned in favor of interlayer-deficient mica. The term for species “hydrobiotite” was confusing, and the use of the prefix “hydro” is now avoided. *Cf.*, mica, true mica, brittle mica, group names

**interlayer displacement** see interlayer

**interlayer distance** see interlayer

**interlayer material** For phyllosilicates, interlayer material separates the 1:1 or 2:1 layers and generally may consist of cations, hydrated cations, organic material, hydroxide octahedra, and/or hydroxide octahedral sheets (see fig. 1). The interlayer material offsets the net negative charge of the layer. In certain cases (e.g., talc, pyrophyllite, where the net layer charge is zero), there is no interlayer material, and an interlayer separating the layers is empty. After Guggenheim *et al.* (2006). *Cf.*, layer

**interlayer shift** see interlayer

**interparticle diffraction** a concept introduced by Nadeau *et al.* (1984) which theorizes that individual clay mineral particles of oriented samples used in X-ray diffraction studies are stacked in aggregated composite particles which coherently scatter radiation so as to give rise to 00l diffraction patterns similar to those of uncleaved McEwan crystallites. The composite particles are theorized to be produced during sample preparation following disaggregation of original rock or soil samples.

**interstratification** a clay material where two or more kinds of layers are interleaved in a coherently diffracting structural domain with a degree of ordering which may vary from random to completely ordered. Layers may be 1:1 layers or 2:1 layers and interlayers may be of swelling or non-swelling nature. X-ray diffraction and transmission electron diffraction (TEM) are two common techniques used to determine layer proportions and regularity of interleaving. Energy dispersive techniques are commonly used to obtain chemical information. Regular interstratifications may be designated as mineral species, provided that they conform to specific criteria as specified by the International Mineralogical Association. Non-regular interstratifications are commonly characterized according to the information available, e.g., mica-smectite irregular interstratification, and do not warrant species status.

**intralayer displacement** see layer displacement

**ion exchange** see cation exchange

**isoelectric point** (iep) see point of zero charge

**isometric** see crystal system

**isomorphic** see isomorphous

**isomorphous** Isomorphous literally means “having the same form”. The idea was first described by F. Beudant around 1800 (see Zoltai and Stout, 1984, p. 5-6) to describe crystals having the same form but having compositions between  $\text{FeSO}_4$  and  $\text{ZnSO}_4$ . Thus, the term

subsequently became commonly used to describe a series of crystals having continuously varying composition even where crystal faces are lacking. Such homogeneous chemical mixtures display a continuous range of properties, e.g., from the Fe to Zn end members. Such a series of solids is referred to as an “isomorphous substitution” series (archaic) or “solid solution” series. See “solid solution” for additional discussion. Isomorphic (syn)

**isotropy** a description of material with physical properties that are the same regardless of direction of measurement. *Cf.*, anisotropy

**kandite** discredited term, use kaolin-serpentine group (Bailey, 1980)

**kaolin** a) Petrologic term: rock composed primarily of kaolinite, nacrite, dickite, or halloysite (i.e., minerals of the kaolin group). In most cases, the identification of the specific species is unknown. The rock is commonly white, earthy, and soft. b) Mineralogic term: a sub-group name (within the group “serpentine-kaolin”) for those phyllosilicates that are dioctahedral, with 1:1 layers, and with a net layer charge of approximately 0.0. Species of this sub-group include kaolinite, nacrite, dickite and halloysite. Previously, the group name was “serpentine-kaolinite”, and the subgroup name was “kaolinite”, but this scheme created confusion because it was unclear if “kaolinite” was referring to the more general sub-group or the species “kaolinite”. The AIPEA Nomenclature Committee (Guggenheim et al., 1997) formalized the change in the belief that the use of “kaolin” as a rock name or as a mineral group or sub-group name is recognizable by context. *Cf.*, dioctahedral, 1:1 layers

**kaolinite-serpentine group** superceded by kaolin-serpentine group

**kaolinite subgroup** superceded by kaolin subgroup

**K-bentonite** See *bentonite*

**Keggin ion** An aluminum-rich Keggin-type structure is commonly used as a pillaring agent in clays. This complex has a composition of  $\text{Al}_{13}\text{O}_4(\text{OH})_{24}(\text{H}_2\text{O})_{12}^{7+}$ , and is often referred to as Al<sub>13</sub>. Other compositions with the Keggin structure are possible, but they have not been as extensively studied in pillared clays. Keggin structures are of commercial interest because they are catalysts. See pillared clay.

**Kelvin** A temperature unit where one K equals 1/273.16 of the thermodynamic temperature of the triple point of pure water, which is the temperature at which ice, water and water vapor can coexist in thermodynamic equilibrium (definition from the 13th Conference of the Générale des Poids et Mesures). 0 K, termed “absolute zero”, is the temperature at which atoms do not thermally vibrate. *Cf.*, Celsius, Fahrenheit

**Kübler index** Kübler (1964, 1967) attempted to define a “crystallinity” index for illite (“IC”) by examining the powder X-ray diffraction of intergrown illite and muscovite, originally to identify the anchizone (diagenesis) and the anchizone-epizone (metamorphic) boundaries. Measured values are expressed as small changes in the *d* value based on the width for the 10-Å peak at half height above the background for Cu radiation. If the procedure is used, it should not be

characterized as a “crystallinity” index, as it is unclear if “crystallinity” is actually being measured because such patterns also reflect the presence of smectite and other K-rich micas, different mean crystallite sizes, lattice strain, layer stacking order, instrument parameters and other features. *Cf.*, crystalline, crystallinity index, Hinckley index, Arkai index

**lattice** a collection of equivalent points (i.e., identipoints) which are distributed periodically in space, and this term, in three dimensional space, commonly refers to Bravais lattices. From Guggenheim *et al.* (2006) and references therein. The term “layer lattice” is incorrect because it implies a structure rather than a lattice. *Cf.*, array, Bravais lattice, identipoint, structure

**layer** For phyllosilicates, a layer (see Fig. 1) contains one or more tetrahedral sheets and an octahedral sheet. There are two types of layers, depending on the ratios of the component sheets: a “1:1 layer” has one tetrahedral sheet and one octahedral sheet, whereas a “2:1 layer” has an octahedral sheet between two opposing tetrahedral sheets. *Quot* Guggenheim *et al.* (2006); also see references therein. *Cf.*, plane, sheet, tetrahedral sheet, octahedral sheet

**layer charge** In phyllosilicates, the “layer charge” or “net layer charge” is the total negative charge deviation from an ideal, unsubstituted dioctahedral or trioctahedral composition. For example, for an  $R^{3+}$ -rich dioctahedral 2:1 layer, the layer composition is ideally:  $R_2Si_4O_{10}(OH)_2$ . In muscovite mica where  $R = Al$  and there is an Al substituted Si site, the layer composition is:  $Al_2(Si_3Al)O_{10}(OH)_2$  and because an  $Al^{3+}$  substitutes for an  $Si^{4+}$ , there is an unsatisfied residual charge on the layer that results, a layer charge of -1. In muscovite, this residual charge is compensated by an interlayer cation,  $K^+$ , so that the structure is charge neutral. Because of the anion framework of  $O_{10}(OH)_2$ , layer charges are always negative, and may be reported in the literature as either a positive or a negative value. A negative layer charge results from either a solid solution where a cation of lesser positive charge substitutes for a cation of greater charge or by a vacancy (no charge) substitution for a cation. Anion substitutions [e.g., O for (OH)] are also possible but uncommon. The location and size of the substitution has a profound effect on the physical properties of clays. The layer charge is used in the classification scheme for phyllosilicates.

**layer displacement** the sum of the intralayer displacement plus the interlayer displacement, which defines the total relative displacement between adjacent layers, as shown in Figure 1. For 2:1 layers, the layer displacement is measured from the geometric center of the ditrigonal ring. The “intralayer displacement” is the shift that originates from the octahedral slant within one layer and is measured from the geometric center of the ditrigonal ring from the lower to the upper tetrahedral sheet of that layer (Figure 1). Layer displacement should be used instead of “interlayer shift”. *Cf.*, interlayer, layer

**liquid limit** one of the Atterberg Limits tests. The water content of a fine-grained soil/water mixture that defines the boundary between the liquid and plastic states for that soil, as defined by the test method described in ASTM Standard D4318 - 05. See Mitchell (1993). See also activity, Atterberg Limits, consistency number, plastic limit, plasticity index, shrinkage limit.

**liquidus** a term describing the lower limit where only a liquid phase exists in a phase diagram.

*Cf.* Phase diagram, solidus

**LOI** see loss on ignition

**loss on ignition (LOI)** weight loss after heating, and (usually) subsequent cooling, to determine the presence of volatiles in a solid. *Cf.*, water, structural; water, adsorbed

**luster** appearance of a mineral surface in reflected light

**mafic** a geological term describing magmas, igneous rocks and silicate minerals that have a relatively high concentration of magnesium and iron and a low silica concentration. Mafic magmas typically have low viscosity, when compared to felsic magmas. Mafic rocks are typically darkly colored when compared to felsic rocks. *Cf.*, felsic

**magnetic susceptibility** the ratio of the magnetization,  $M$ , relative to the macroscopic magnetic field intensity,  $B$ . “Diamagnetic” substances have negative values, “paramagnetic” substances have positive susceptibilities. *Cf.*, diamagnetism, paramagnetism

**magnetism** describes a property of material where there is attraction by a magnet. *Cf.*, diamagnetism, paramagnetism

**mica** a general term for platy phyllosilicates of 2:1 layer and a layer charge of  $\sim -1.0$  per formula unit (true mica group) or  $\sim -2.0$  per formula unit (brittle mica group) or between  $-0.6$  to  $-0.85$  per formula unit (interlayer-cation-deficient mica group, abbreviated to interlayer-deficient micas). Micas do not show swelling capability. Octahedral character, either trioctahedral or dioctahedral, further divides the mica groups into subgroups, whereas chemical composition separates the species within the subgroups. *Cf.*, true mica, brittle mica, interlayer-deficient mica, group names

**micaceous** A mineral habit where individual grains are platy in shape, as often caused by a single plane of cleavage. *Cf.*, habit

**microcrystalline** see cryptocrystalline

**micron ( $\mu\text{m}$ )** an old name for micrometer

**micrometer ( $\mu\text{m}$ )** an International System (SI) unit of measure equal to  $10^{-6}$  meters.

**mineral** An element or chemical compound that is normally crystalline and that has been formed as a result of geological processes (*quot* Nickel, 1995). A mineral forms by a naturally occurring process (e.g., “geological” process); phases formed by the interaction of individuals (even if outdoors under conditions not fully controlled by the individual) are not minerals. Nickel (1995) discussed exceptions to the requirements, such as the equivalence of extraterrestrial and “geological” processes, metamict (non-crystalline) minerals, mercury (a liquid mineral), and others (*quot* Guggenheim et al., 2006). Some naturally occurring processes, but without a geological component, such as compounds that form biologically (e.g., oxalate crystals in certain

plants, marine animal shells), are not minerals. Synthesized materials are not minerals, but may be referred to as “synthetic minerals” (e.g., “synthetic diamond”, “synthetic halite”) because the use of “synthetic” negates the naturally occurring/geological aspects specifically. See *crystalline*

**mirror plane** or symmetry plane, used to describe a repetition of features whereby identical points occur an equal but opposite distance along any line perpendicular from this imaginary plane. Consequently, an object is “bilateral” in that it shows a matching of features (also referred to as “reflection”) but a change in “handedness”, e.g., most people, standing with arms by their sides and feet side-by-side, have a mirror (bilateral or reflection) relationship between the left side and the right side. *Cf.*, symmetry, center of symmetry, rotation symmetry

**Mississippi bentonite** an obsolete term, see Southern bentonite

**mist** see suspension

**mixed layer** see interstratification

**Mohs hardness** Mohs’ scale of hardness is composed of a series of common minerals with increasing hardness: (1) talc, (2) gypsum, (3) calcite, (4) fluorite, (5) apatite, (6) orthoclase, (7) quartz, (8) topaz, (9) corundum, and (10) diamond. Hardness is determined by a scratch test, as minerals of greater or equal hardness can scratch those of equal or lesser hardness. *Cf.*, hardness, Vickers hardness

**molality** the number of moles of solute per kilogram of solvent. Because weights of a solute/solvent are generally fixed at all temperatures, this scale is useful for experiments where physical properties (e.g., boiling point, freezing point) are examined over a temperature range. *Cf.*, molarity, formality, normality, mole fraction

**molarity** the number of moles of the solute in one liter of solution. Useful where experiments use measured volumes and where temperature effects are not being studied. *Cf.*, formality, normality, molality, mole fraction

**molecular sieve** see zeolite, pillared clay

**mole fraction** number of moles of one component divided by the total number of moles of all components *Cf.*, molarity, formality, normality, molality

**monoclinic** see crystal system

**montmorillonite-saponite group** old group name superceded by smectite, *Cf.*, smectite

**muck** indicates a soil composite that is largely organic in nature, lacks recognizable plant structures and is very darkly colored. It differs from peat in being darker, lacking plant structures and having increased mineral content. It differs from ball clay in having significantly higher organic content and in being much darker.

**mudstone** A general term for a rock which is similar to shale but used to describe a clay-rich rock without laminations. The fraction of clay and/or silt components are not well defined. The silt component may be of major proportions.

**nanocomposite** Nanocomposites are fine-particulate materials that are heterogeneous at the nanoscale level (i.e., less than  $10^{-7}$  meters). Such materials have structures and properties that are composite-particle-size dependent. The composite-particle size is sufficiently large that it is not considered a chemical (atom) cluster or complex.

**nanotube** a natural or man-made, nanometer-scale tubular structure. See nanocomposite, imogolite.

**nanometer (nm)** an international system (SI) unit of measurement equal to  $10^{-9}$  meters.

**Néel temperature** see antiferromagnetism

**neof ormation** the formation of a new mineral from diagenesis, metamorphism, or other geologic process.

**Newtonian fluid** a fluid where the viscosity, equal to the ratio of shear stress to shear rate, is constant. A Newtonian fluid is approached in suspensions of water and clay where the clay is fully deflocculated. *Cf.*, dilatancy, quick clay, thixotropy

**non-crystalline** a solid where the constituent components are randomly packed. Many variations can occur between the two extremes of crystalline vs. non-crystalline. For example, a non-crystalline material, such as many glasses, consists of atoms arranged as groups of tetrahedra or octahedra. However, although such groups have almost the same mutual arrangements, they are displaced without periodicity with respect to each other (i.e., limited order or short-range order). (*Quot* Guggenheim *et al.*, 2006) *Cf.*, crystalline

**normality** the number of gram equivalent weights of the solute in one liter of solution. Useful where experiments use measured volumes and temperature effects are not being studied. *Cf.*, molarity, formality, molality, mole fraction

**octahedral layer** inappropriate usage for an octahedral sheet, see *octahedral sheet*

**octahedral sheet** For phyllosilicates, an octahedral sheet contains edge-sharing octahedra that are connected in a continuous two-dimensional arrangement. These octahedra generally contain small (e.g., Al,  $\text{Fe}^{3+}$ ) or medium size (e.g., Mg,  $\text{Fe}^{2+}$ , Li) cations with coordination anions (e.g., O, OH, Cl, S). In some phyllosilicates (e.g., modulated phyllosilicates), the octahedral sheet may be only partially continuous, for example, forming one-dimensional strips of octahedra or islands of octahedra. There are two types of octahedral sheets, dioctahedral and trioctahedral. After Guggenheim *et al.* (2006) and references therein. *Cf.*, dioctahedral sheet, trioctahedral sheet, plane, layer

**organoclay** a phyllosilicate, typically smectite, vermiculite, or kaolin, but others are possible, with sorbed organic molecules, such that the properties of the phyllosilicate are altered. Commonly, the sorption occurs between the 2:1 or 1:1 layers. The mechanism for sorption may vary depending on the organic molecule and concentration. Syn., organo-clay, clay-organic complex; *Cf.*, phyllosilicate

**orthorhombic** see crystal system

**osmosis** A physical process by which a solvent (typically, water) diffuses through a semi-permeable membrane (a porous material which is permeable to the solvent, but not the solute), owing to differences in solvent activity of two solutions which are separated by the membrane.

**osmosis, reverse** The process of forcing a solvent (typically, water) through a semi-permeable membrane from a solution with lower water activity to a solution with higher water activity by applying a pressure opposite to and in excess of the osmotic pressure. Reverse osmosis is a process commonly used to purify (i.e., to physically separate and remove dissolved ions from) water.

**osmotic pressure** The differential pressure exerted by a solvent across a semi-permeable membrane owing to the difference in solvent activity between two solutions separated by the membrane.

**Ostwald ripening** a recrystallization process where the smallest crystals dissolve and the chemical constituents are added to the larger crystals of the same phase. This process of crystal growth and coarsening occurs in a solution. The driving mechanism is a shift to lower surface free energy (Ostwald, 1900 in Baronnet, 1982).

**Otay-type montmorillonite** Defined by Schultz (1969) for montmorillonite samples [current nomenclature for montmorillonite is that it is an Al-rich, dioctahedral smectite with an ideal structural formula of  $(Al_{3.15}Mg_{0.85})Si_8O_{20}(OH)_4X_{0.85}.nH_2O$  with layer charge from primarily octahedral substitutions of Mg] with a large net negative layer charge [-0.80 to -1.20 per unit cell,  $O_{20}(OH)_4$ ] obtained almost entirely (<0.15 charge from tetrahedral sheet) from cation substitutions in the octahedral sheet, although exceptions were noted. This classification scheme was based on chemical and thermal analysis. The term is obsolete and should not be used. Terms used in this obsolete classification are: Wyoming-type, Otay-type, Chambers-type, Tatatila-type, beidellite-type (ideal and non-ideal), and non-ideal montmorillonite.

**outer Helmholtz plane** see *Stern layer*

**outer sphere complexes** Ions adsorbing in the outer Helmholtz plane form outer sphere complexes. The larger distance to the surface relative to the shorter distances of inner sphere complexes may result from retaining  $H_2O$  molecules (via hydration) between the surface and the ion.

**palysepiole** an invalid term, use palygorskite-sepiolite group; see Guggenheim *et al.* (2006). See palygorskite-sepiolite group

**paramagnetism** a weak magnetic attraction that develops in the presence of a magnetic field when magnetic moments align in the material. Paramagnetism is found in substances with atoms, molecules and lattice defects possessing an odd number of electrons. Hence, transition metals with partly filled inner shells show paramagnetic behavior. Metals (e.g., Fe) may be paramagnetic. *Cf.*, magnetic susceptibility

**parting** a mechanical property where a mineral breaks along a planar or near-planar structural weakness. Parting usually results from plane-like defects, often twinning, or is produced by anisotropic stress. In contrast, cleavage is a property of the periodic crystal structure. *Cf.*, cleavage

**perlite** hydrated volcanic glass containing 2-5 wt. % H<sub>2</sub>O. Because of their high viscosity, rhyolitic melts form glasses upon cooling. Devitrification produces a “perlitic structure”, which is characterized by concentric cracks. Perlite has a pearly luster, and is glassy gray to black. When heated, H<sub>2</sub>O is released and glass shards dehydrate and expand to volumes to 20 times their original size. Associated zeolites are common. Perlite, after heating, is used as aggregate, fillers, in plaster products and in light-weight concrete, as coatings for steel beams as fire protection to reduce the possibility of melting or partial melting, etc.

**permanent charge** see point of zero charge

**pearly** having a luster similar to that of mother-of-pearl with an interplay of rainbow-like colors (iridescent)

**peptize** a) The formation of a stable dispersion of colloidal particles in water, usually by chemical additives; b) In bentonite clay-product manufacturing, the use of chemical additives to improve the performance characteristics of the clay for a particular end use. *Cf.*, peptized clay.

**peptized clay** a clay to which chemicals have been added to improve the performance characteristics of the clay for a specific end use. *Cf.*, peptize.

**pH** the negative logarithmic ( $\log_{10}$ ) measure of hydrogen ion (H<sup>+</sup>) activity which defines the acidity or alkalinity of a solution. In pure water, a value of 7 is neutral and represents an exact balance between the activities of hydrogen (H<sup>+</sup>) and hydroxide (OH<sup>-</sup>) ions. Values lower than 7 represent an increase in hydrogen ion activity and are acidic. Values higher than 7 represent a decrease in hydrogen ion activity and are alkaline.

**phase diagram** a graphical representation of the relationships involving possible phases that occur in a system, typically based on parameters such as temperature (*T*), pressure (*P*), composition (*X*), and typically at equilibrium conditions. However, other parameters may be used where convenient and non-equilibrium diagrams may be useful to show important phase

relationships.

**phyllosilicate** a family of minerals contain continuous two-dimensional tetrahedral sheets of composition  $T_2O_5$  (T = Si, Al, Be...) with tetrahedra linked by sharing three corners of each, and with a fourth corner pointing in any direction. The tetrahedral sheets are linked in the unit structure to octahedral sheets, or to groups of coordinated cations, or individual cations. Although continuous tetrahedral sheets often form six-fold rings, other ring configurations are considered part of the phyllosilicate family. See Guggenheim *et al.* (2006) and references therein. *Cf.*, clay mineral

**piezoelectric** a property of crystals where an electric moment forms in proportion to tension or compression, with a reversal in polarity depending on the direction of the stress. The phenomenon is dependent on certain non-polar crystal classes or symmetries of the material. A “converse piezoelectric” effect is known where the crystal changes shape if an electric current is applied along the polar axis. Quartz exhibits piezoelectric and converse piezoelectric effects.

**pillar** see pillared clay

**pillared clay** a clay mineral intercalated with small organic or inorganic complexes (or “pillars”), which do not completely fill the interlayer space. The size and shape of the resultant cavities (or “galleries”) are determined by the size, shape, and orientation of the pillars. Pillared clays are potentially useful to remove organic molecules based on shape-selective adsorption (“molecular sieves”). For clays, intercalations involve positively charged complexes (either organic or inorganic “cations”) to offset the negatively charged layers of the clay. Common types of complexes include those of the methylammonium group (organic) and the Keggin ion (Al13, inorganic). Other types of layered materials can also be pillared. See Keggin ion. *Cf.*, zeolite

**plane** in phyllosilicate mineralogy, a set of one or more types of atoms (e.g., a plane of Si and Al atoms, a plane of basal oxygen atoms) that form a two-dimensional flat or nearly flat surface. See Guggenheim *et al.* (2006) and references therein. *Cf.*, sheet, layer

**plasticity** When referring to clay, this is a property where moistened material, when deformed under the application of pressure, will retain the induced deformed shape when the applied pressure is removed.

**plastic limit** one of the Atterberg Limit tests. The water content of an homogenous, fine-grained soil/water mixture where the mixture begins to exhibit plastic behavior upon deformation, as defined by the test method described in ASTM Standard D4318 - 05. Syn. “lower plastic limit”. See Mitchell (1993). See also activity, Atterberg Limits, consistency number, liquid limit, plasticity index, shrinkage limit.

**plasticity index** the numerical difference between the liquid limit and the plastic limit; i.e., the difference between the water content of a fine-grained soil/water mixture at the boundary between its liquid and plastic states and the boundary between its plastic and brittle states, based

on tests outlined by Atterberg and standardized by ASTM Standard D4318 - 05. See Mitchell (1993). Syn. Plasticity number. See also activity, Atterberg limits, consistency number, liquid limit, plastic limit, shrinkage limit.

**point group** The ten basic operations (center of symmetry, mirror plane, proper and improper rotation axes) and their 22 allowable combinations (total = 32) are called “point groups” or “crystal classes”. A combination is allowable only if “closure” is produced. See “rotation symmetry” for the definition of “closure”.

**point of zero charge** (pzc or zeropoint of charge) the pH value of a solution where the negative variable charge equals the positive variable charge for a mineral. The variable charge results from unsatisfied bonds at grain boundaries and any compensating negative (OH<sup>-</sup>) or positive (H<sup>+</sup>) ions, and thus is a function of the solution surrounding the mineral grain. The variable charge of a phyllosilicate involves the edges of the particle, whereas the layer charge is the “permanent charge” and not of interest in determining the point of zero charge (“total charge” is the sum of the variable and permanent charges). Surface properties change with the presence and types of ions satisfying the residual charges at the crystal surfaces. For example, the type of ions attaching to the surface can affect flocculation/dispersion properties and therefore, sedimentation rates. Sposito (1998) defines the point of zero charge more succinctly as “the pH value of a solution, where the net surface charge of a particle is zero”. The point of zero charge should not be confused with the “point of zero net proton charge”, which refers to particles where only protons are charge determining. The point of zero charge is not necessarily identical to the isoelectric point (iep), in part because of how they are derived experimentally. The point of zero charge is usually determined from titrations at various ionic strengths, which yield intersecting curves at a single point (the “common intersection point”) which, in the absence of sorption of other charge-determining ions, is identical to the point of zero charge. The iep is determined by electrokinetic methods as the pH where the particle mobility is zero. Both points are only identical if specific adsorption of other ions is absent.

**point of zero net proton charge** see point of zero charge

**polymer-clay nanocomposite** see clay nanocomposite

**polymorphism** the ability of a given element or compound to crystallize in more than one form, with each form having a distinct crystal structure. *Cf.*, polytypism

**polytype** refers to a structure that develops from layer-stacking sequences via polytypism. See *polytypism*

**polytypism** an element or compound in two or more layer-like crystal structures that differs in layer-stacking sequences. Polytypism differs from polymorphism in permitting small differences in chemical composition between structures, not to exceed 0.25 atoms per formula unit of any constituent element. Layer structures that differ from one another by more than this amount are to be called *polytypoids* rather than *polytypes*. (*Quot* Bailey, 1977) *Cf.*, polymorphism

**polytypoid** see polytypism

**porcelain** a high-strength and low-absorption glazed or unglazed ceramic whiteware of high quality

**prismatic** a crystal shape where one dimension is considerably greater than the other two

**proper rotation axis** see rotation symmetry

**pyroelectric** a property of crystals where an electric dipole moment develops in response to a temperature change. The material cannot exhibit temperature gradients, and the property diminishes over time at temperature. Only polar crystal classes exhibit this property. An analogous magnetic property, “pyromagnetism”, can also exist.

**pyromagnetism**, see pyroelectric

**pzc** see point of zero charge

**quick clay** Natural, highly hydrated clay minerals and particles of clay size (<2 micrometers) that exhibit thixotropic properties. Quick clays are often formed in post-glacial conditions where flocculated clays deposited in saline or brackish waters have been exposed to infiltrated fresh water upon uplift and exposure of the deposit. The fresh water causes the clay to be in a deflocculated potential state and to contain large quantities of adsorbed water. When the deposit is disturbed, the clay-water mixture flows like a liquid. *Cf.*, thixotropy

**Ramsdell-style notation** a method commonly used to describe phyllosilicates, where a set of related polytypes is designated by a single name, usually a species name or a group name, followed by a structural symbol suffix that defines the layer stacking differences (after Guinier *et al.*, 1984). The symbolism is based on the number of layers (first part of the suffix), which is followed by an italicized capital letter that defines the crystal system: *C* (= cubic), *H* (= hexagonal), *T* (= trigonal with hexagonal Bravais lattice), *R* (= trigonal with rhombohedral Bravais lattice), *Q* (= quadratic or tetragonal), *O* (= orthorhombic, previously *Or*), *M* (= monoclinic), and *A* (= anorthic or triclinic, previously *Tc*). A subscript “d” indicates disorder and a subscript “1” or “2” indicates that another polytype exists with the same number of layers and symmetry. *Cf.* Ramsdell-style notation for chlorite

**Ramsdell-style notation for chlorite** a method commonly used for chlorite where a set of related polytypes is designated by a single name, usually a species name (e.g., clinocllore, chamosite) or the group name (in this case, chlorite), followed by a structural symbol suffix that defines the layer stacking differences. Unlike the Ramsdell-style notation for phyllosilicates, the chlorite notation was developed for one-layer polytypes; although multi-layer chlorite polytypes are known, they are rare. The first part of the symbolism (I or II) designates the orientation of the interlayer sheet, the italicized second part (*a* or *b*) describes how the interlayer sheet cations project on to the hexagonal ring of the adjacent 2:1 layer, and the third part (1 through 6) indicates how the next 2:1 layer resides relative to the interlayer sheet. Although there are 24

possible combinations of regular one-layer polytypes, only 12 of these are unique. A dash separates the second and third parts of the symbol, when the third part can be determined. Some polytypes do not have 2:1 layers that are symmetrically disposed about the interlayer, in which case the second part of the symbol may be given as *ab* or *ba*. Examples: clinochlore-IIb-4, chamosite-Ibb, pennantite-Ia. Cf. Ramsdell-style notation

**reciprocal lattice** The reciprocal lattice, first constructed by P. Ewald, involves a set of points, each of which represents a set of planes in space,  $1/d$  from the origin. The value of  $d$  is the spacing between a set of planes in a unit cell. This lattice is useful to better visualize a diffraction pattern and its geometric relationship to the unit cell of the crystal under study. The relationship is obtained from the modified Bragg equation ( $1/d_{hkl} = 2\sin \theta/\lambda$ ), which is the condition where a possible X-ray reflection can occur. Thus, the point located at  $1/d$  represents the cross-section of the pole of this set of planes,  $hkl$ , and corresponds to a possible X-ray reflection from the crystal. The unit cell as determined by the reciprocal lattice (referred to as the “reciprocal unit cell”), by construction, is defined in relation to the unit cell of the atomic structure (referred to as a the “direct cell” or “real cell”) of the crystal under study:  $a^*$  is perpendicular to the plane containing  $b$  and  $c$ ,  $b^*$  is perpendicular to the plane containing  $a$  and  $c$ , and  $c^*$  is perpendicular to the plane containing  $a$  and  $b$ , where the  $*$  (referred to as “star”, as in “ $a$  star”, “ $b$  star”, etc.) indicates a reciprocal lattice measurement. Cf., crystallographic axis, Bragg’s law

**recrystallization** a) *Sensu stricto*. solid-state transformation(s) of crystalline material to another crystalline material. In this process, larger, more defect-free grains result than the predecessor grains. Although the bulk composition does not change, the resultant assemblage may be of the same mineralogy or different (e.g., polymorphs) mineralogy. In rocks, this is a mechanism by which plastic deformation can ultimately produce, via recrystallization, an assemblage of strain-free grains. It is unclear if recrystallization is truly “solid state” because the process may involve the formation in inter-granular fluid films. A “secondary recrystallization” also can result where there is an increase in particle size of grains by subsuming neighbors. It is unlikely that clay minerals transform in this manner; low-temperature transformations involving clays usually require the presence of water. b) *Sensu lato*. Conversion of pre-existing chemical and mineralogical composition (either crystalline, poorly crystalline, or amorphous) either to new crystalline material of the same mineralogy or to a new phase assemblage, commonly involving limited amounts of aqueous fluids. For clays, the crystal-surface energy to crystal volume is reduced to drive recrystallization, even at low temperatures. See Ostwald ripening

**reflection** see mirror plane

**refractory clay** See *fire clay*

**Reichweite (or R, R0, R1, etc.)** literally means “the reach back”. The expression of both the probability of finding a B layer after an A layer in a two-component system of layers containing A and B layers, and the influence A has on the identity of the next layer, after Jadgozinski, 1949. When flipping a coin, R is equal to 0 because there is no influence at all of one flip on another. The probability of getting a head depends only on the proportion of heads and tails, in this case 0.5, and thus there is a null relation between the influence of A on B. For perfect order of 50% I

(illite) and 50% S (smectite) layers, ISISIS... the  $R = 1$ . A sequence of ISII... is  $R = 3$ , with one S layer surrounded by three I layers. Common usage is R0 for  $R = 0$ , R1 for  $R = 1$ , etc.

**relative humidity** see humidity

**rheology** the study of the deformation and flow of materials. For clay scientists, this may involve the study of the plasticity (i.e., creep, rupture) of clay, clay-water interactions, clay suspensions and interparticle forces, the electrical double layer, etc.

**rotational stacking disorder** Phyllosilicates commonly show rotations between adjacent layers involving  $n60^\circ$  (where  $n$  is an integer from 1 to 6), and with registry or partial registry between layers. Stacking disorder or partial disorder involves the lack of regularity in the  $n$  value. Equivalence to this type of stacking order/disorder may be achieved also by random or partially random translations along the pseudohexagonal  $a$  or  $b$  axes (commonly along  $a$ , and very rarely along  $b$ ) of the layer silicate. See *turbostratic stacking*

**rotation axis** see rotation symmetry

**rotation symmetry** symmetry involving a repetition of features about an axis. The axis type may be either a one-fold, two-fold, three-fold, four-fold, or six-fold axis, where the angle of repetition may be determined by  $360/n$ , where  $n$  is equal to the axis type (1, 2, 3, 4, or 6). A one-fold rotation axis is the identity operation. Another name for this type of axis is "proper rotation axis". Cf., symmetry, rotoinversion axis

**rotoinversion axis** A general type of symmetry axes that involves a rotation followed by an inversion operation, with a repeating set of rotation/inversion operations until "closure" (returning to the starting position in the rotation/inversion or repetition process) is reached. The one-fold rotoinversion axis ( $\bar{1}$ ) is equivalent to a center of symmetry, and the two-fold rotoinversion axis ( $\bar{2}$ ) corresponds to a mirror plane; only the latter are used, respectively. In addition, the  $\bar{3}$  implies that the object possesses a center of symmetry and a 3-fold axis and a  $\bar{6}$  is equivalent to a 3-fold and a mirror plane perpendicular to it. Thus, only the  $\bar{4}$  is a unique symmetry operation. Cf., symmetry

**safety glass** see tempered glass

**screw axis** symmetry involving a rotation about an axis followed by a translation parallel to the axis. The rotations correspond to a 2-, 3-, 4- or 6-fold axis and requires a translation following each rotation. The symbol for a screw axis is  $n_m$ , where  $n$  is the rotation component and  $m/n$  is the translation component. For example, in a  $4_1$  screw axis, the translation is  $1/4$  of a unit cell and the rotation corresponds to a 4-fold axis. Thus, symmetry consistent with a  $4_1$  screw axis is generated by a  $90^\circ$  rotation followed by a  $1/4$  cell translation, with the process continuing until closure. Cf., rotation symmetry, rotoinversion axis, symmetry, unit cell

**sepiolite-palygorskite group** a group name for phyllosilicates with characteristics that are dominantly fiber-like, but with some plate-like character. The atomic structure has continuous

planes of basal oxygen atoms (thus forming the plate-like character) with the apical oxygen atoms of the tetrahedra pointing alternatively in opposite directions away from the basal plane. The tetrahedral apices link to partial octahedral sheets, discontinuous along one direction but infinite in the other, to form a pattern of octahedral ribbons (thus forming the dominant fiber-like character). These minerals are classified as modulated phyllosilicates. The width of ribbons may vary, which leads to different numbers of octahedral cation sites per formula unit (5 for palygorskite, 8 for sepiolite).

**serpentine-kaolin** a group name for platy phyllosilicates of 1:1 layer and a layer charge of  $\sim 0$  per formula unit. Generally, the  $d(001)$  spacing is approximately 7.1-7.3 Å. The group is further divided into subgroups that are either trioctahedral (serpentine) or dioctahedral (kaolin), and these subgroups are further divided into mineral species based on chemical composition. The 1:1 layers are bonded by long hydrogen bonds ( $\sim 2.9$  Å) and possible coulombic interactions between the octahedral sheets of one layer and the tetrahedral sheet of the adjacent layer. See “group names”.

**seat earth** a British term for underclay *Cf.*, underclay

**seat rock** a rock or sedimentary layer underlying a coal bed with physical characteristics suggesting that it served as a soil which supported the vegetation that produced the coal. (Modified from Huddle and Patterson, 1961)

**septechlorite** an invalid term, use kaolin-serpentine group (Bailey, 1980)

**sheet** For phyllosilicates, a sheet refers to corner-sharing linkages of tetrahedral coordination polyhedra (i.e., tetrahedral sheet) or edge-sharing linkages of octahedral coordination polyhedra (i.e., octahedral sheet). For a tetrahedral sheet, three corners of a tetrahedron are shared with other tetrahedra and the fourth corner may point in any direction. See Guggenheim *et al.* (2006) and references therein. *Cf.*, tetrahedral sheet, octahedral sheet, layer

**SI** International System (of units); Système International d'Unités

**silanol group** a surficial SiOH group, which is able to incorporate or dissociate protons. A ferronol group (FeOH) is an additional surface group that behaves similarly to an aluminol or silanol group. See *aluminol group*

**sintering** bonding of powdered material by solid-state reactions at temperatures lower than melting.

**site energy** energy required to separate an ion an infinite distance from its equilibrium position in a crystal. In calculating an electrostatic site energy, the site energy is the sum of all the Coulombic and all the repulsive energies between the ion in the site and all neighbors in the unit cell.

**slake** The process of disaggregation of a dried clay, soil or fine-grained sedimentary rock rich in

clay to a fine-grained sediment, by exposure to air, moisture or water.

**smectite** a group name for platy phyllosilicates of 2:1 layer and a layer charge of  $\sim -0.2$  to  $-0.6$  per formula unit. Generally for natural samples, the  $d(001)$  spacing is approximately 14.4-15.6 Å, although other spacing may occur depending on H<sub>2</sub>O retention and interlayer occupancy. The group is further divided into subgroups that are either trioctahedral (according to Bailey, 1980, this subgroup name is “saponite”) or dioctahedral (subgroup name of “montmorillonite”, according to Bailey, 1980), and these subgroups are further divided into mineral species based on chemical composition. Guggenheim *et al.* (2006) did not give subgroup names. Smectite minerals have large specific surface areas (10 - 700 m<sup>2</sup>/g) and exhibit a high expansion (swelling) capability in the presence of H<sub>2</sub>O. Smectite and vermiculite minerals are often referred to as “swelling” or “expandable” clay minerals. Cation-exchange capacity or solvation of polar molecules is large. Smectite is commonly a primary constituent of bentonite (see bentonite for respective genesis information) and pelitic sediments (e.g., shales) and occurs in soils. Prior to *circa* 1975, the smectite group was called the montmorillonite-saponite group, but this nomenclature was abandoned because of the confusion between the use of the same name for both a group and species. Very early (Kerr and Hamilton, 1949), smectite was used as a term for fuller’s earth (initially), montmorillonite, and certain bentonitic clay deposits. See “group names”.

**smectite-to-illite transition** the conversion of smectite to illite involving a significant change in the chemical composition of the 2:1 layer from a smectite-like composition to an illite-like composition. The resulting net negative charge on the layer must become sufficiently large to preferentially fix potassium or other large cations and cause dehydration of the interlayer. The process of conversion may be one of apparent solid-state transformation or mostly in the solid state or apparent neof ormation via a solution. The degree of conversion may be useful to understand crystallization parameters during burial diagenesis or metamorphism (e.g., Hower *et al.* (1976) or hydrothermal activity (e.g., Inoue *et al.*, 1987). *Cf.*, illite/smectite

**smoke** see suspension

**sol or clay solution** see suspension

**solid emulsion** see suspension

**solid foam** see suspension

**solid solution** isostructural phases that show a compositional variation whereby one or more ions can substitute at a specific atomic site in a crystal structure. In fact, the ions can also be elements or ionic groups, and it is possible that more than one atomic site may be involved. A common type of “substitutional solid solution series” shows a miscibility between two end members, with permissible variations in composition between these two end members. For example, olivine (Mg,Fe)<sub>2</sub>SiO<sub>4</sub>, represents a chemical variation (i.e., solid solution) between two end members, forsterite Mg<sub>2</sub>SiO<sub>4</sub> and fayalite Fe<sub>2</sub>SiO<sub>4</sub>, where Mg and Fe can substitute for one another in two atom sites. The chemical formula may be written as Mg<sub>2-x</sub>Fe<sub>x</sub>SiO<sub>4</sub>, where x

represents the Fe content, and this value can vary between 0 and 2.0. Other types of solid solutions include “interstitial solid solution” where atoms may reside in interstices between the ideal locations of the atoms of a structure and “omission solid solution” where a site is incompletely filled. “Limited solid solutions” may occur where the compositional variation does not range entirely between the two end members. In addition, two or more substitutions (“coupled substitutional solid solution”) may occur over multiple sites so that the requirement of overall charge neutrality in a phase is satisfied, for example, where  $\text{Na}^+ + \text{Si}^{4+}$  substitute for  $\text{Ca}^{2+} + \text{Al}^{3+}$  in the plagioclase feldspar structures between end members albite,  $\text{NaAlSi}_3\text{O}_8$ , and anorthite,  $\text{CaAl}_2\text{Si}_2\text{O}_8$ .

**solid solution, coupled substitutional**, see solid solution

**solid solution, interstitial**, see solid solution

**solid solution, limited**, see solid solution

**solid solution, omission**, see solid solution

**solid solution, substitutional**, see solid solution

**solid-state diffusion** a process of mass transfer where atoms, ions or molecules move through a solid. *Cf.*, absorbent, adsorbate, cation exchange

**solidus** in a phase diagram, the solidus describes the upper limits where only solid phases exist. *Cf.*, liquidus, phase diagram

**soluble salts** Unprocessed clay samples commonly contain soluble salts, including chlorides, sulfates, and carbonates, which should be removed either prior to analysis or prior to drying or firing. Such salts can inhibit deflocculation, and they may interfere with the determination of particle size. In addition, they may prevent the preferred orientation of clay-mineral aggregates in preparation for some X-ray analysis procedures. During drying, soluble salts migrate to the clay body surface and can interfere with glazing; after firing, these salts can cause efflorescence.

**Southern Bentonite** Initially, an industrial or commercial term, designating calcium bentonite from Mississippi, USA. This material exhibits characteristics of low water adsorption, dilation, viscosification and high green-sand binding strength. Use of the term has broadened to include any bentonite having performance characteristics equal to that of high quality calcium bentonite from Mississippi. Whereas the term “Southern Bentonite”, and its synonyms, continue to have meaning in the industrial and commercial realm, they are scientifically obsolete and should not be used in that context. *syn*: Mississippi Bentonite

**space group** the symmetry used to describe a three-dimensional crystal structure, including both translation-free symmetry operators, translational symmetry (i.e., screw axes and glide planes), and Bravais lattices. There are 230 space groups. In mineralogy, Hermann-Mauguin symbols are used, whereas in chemistry and spectroscopy, Schoenflies symbolism is used to characterize

the different combinations of symmetry elements.

**spectroscopy** the study of the interaction of radiation with matter

**spray drying** in scientific research, a drying technique used primarily to minimize preferential orientation of clay in X-ray analysis methods. Spray drying involves high dispersion of a solid (i.e., clay), usually suspended in a water-organic binder, where the binder is subsequently evaporated. Although effective, the process usually involves large sample sizes (typically grams). In industrial applications, spray drying is used to economically produce commercial quantities of dried clay having a controlled aggregate particle size, from a liquid clay suspension, without the need for mechanical grinding.

**Stern layer** Helmholtz and later Stern divided the solution side of a diffuse double layer into an inner part (Stern or Helmholtz layer) and an outer part (Gouy or diffuse layer). In a more simple model, the ions with a finite size "d" adsorb on a surface and form a so-called outer Helmholtz plane. In the so-called triple layer model, the Helmholtz plane is subdivided into an inner Helmholtz plane (iHp, where specifically adsorbed ions such as protons or K on high-charged clay minerals reside) and an outer Helmholtz plane (oHp, where non-specifically adsorbed ions reside). Note that for all models the following equation holds:

$$\text{Sigma\_zero} + \text{Sigma\_iHp} + \text{Sigma\_oHp} + \text{Sigma\_diffuse} = \text{zero.}$$

where: Sigma\_zero denotes the charge density (in Coulomb per square meter) of the solid, Sigma\_iHp denotes the charge density of species adsorbed in the inner Helmholtz plane (usually specifically adsorbed ions), Sigma\_oHp denotes the charge density of species adsorbed in the outer Helmholtz plane (usually nonspecifically adsorbed species), and Sigma\_Diffuse is the charge density of the diffuse double layer formed in the solution. See *diffuse double layer*

**Stokes' law** a mathematical expression that describes how a spherical particle, nominally less than 20 micrometers, settles in a viscous fluid. This equation is used in clay science, although clay particles are generally flat plates and not spherical, and thus fall at slower velocities than spheres of equal density as calculated using Stokes' law. Cf., equivalent spherical diameter

**structure** the accepted atomic, ionic, and molecular arrangement of atoms of a material. (*Quot* Guggenheim *et al.*, 2006)

**subhedral** see crystal

**sublimation** the physical process where a solid phase transitions directly to a gas phase without going through a liquid phase.

**surface complexation** There are two kinds of surface complexes, one with no H<sub>2</sub>O molecules interposed between it and the mineral surface, termed an inner-sphere complex, and one in which at least one H<sub>2</sub>O molecule is interposed, and this is termed an outer-sphere complex (Sposito, 1989). Inner-sphere complexes are chemically bonded; outer-sphere complexes or those that exist in the diffuse layer are said to be physically adsorbed (Parks, 1990).

**surfactant** a wetting agent that lowers the surface tension of a liquid or lowers the interfacial tension between two liquids. Detergents are an important economic group of wetting agents that can affect clay surfaces.

**suspension** A two-phase system with a solid (“dispersed phase”) dispersed in a fluid (“continuous phase”). In colloid chemistry, a suspension differs from a colloidal suspension (or “sol”) by having particles  $>1\mu\text{m}$ . The term "suspension" is preferred over "clay solution" or "colloidal solution" to avoid confusion with true solutions, which do not have an interface. Thus, the presence of an interface between the solid and the liquid phase (in the thermodynamic sense) is important. The table below lists names for systems with dispersed phases.

Table of descriptive names for systems with dispersed phases (after Hiemenz and Rajagopalan, 1997)

Continuous phase	Dispersed phase	Descriptive names (* recommended)
gas	liquid	aerosol*, fog, mist
gas	solid	aerosol*, smoke
liquid	gas	foam
liquid	liquid	emulsion
liquid	solid	suspension*, sol, colloidal solution, gel
solid	gas	solid foam
solid	liquid	gel, solid emulsion
solid	solid	alloy

**swelling clay** a clay that can sorb large amounts of water and thereby expands in volume. Both vermiculite and smectite are swelling clays. Some clays that are referred to as “swelling clays” have been shown to be interstratifications of two varieties of phyllosilicate layers, one being expandable via adsorption of  $\text{H}_2\text{O}$  and one not, as in “swelling chlorite” which is interstratified chlorite and smectite. *Syn.*, expandable clay

**symmetry** is used to describe an object with a systematic repetition of features, and is particularly useful to describe crystal shapes or atom locations in an object

**symmetry plane** see mirror plane

**syntaxy** a geometrically fixed intergrowth between two phases. Originally defined as between two polymorphs only and extended to include an oriented intergrowth between any two phases.

*Cf.*, epitaxy, topotaxy

**tailings** see gangue

**talc layer** inappropriate usage for a 2:1 layer, see *layer*

**talc-pyrophyllite** a group name for platy phyllosilicates of 2:1 layer and a layer charge of  $\sim 0$  per formula unit. Generally, the  $d(001)$  spacing is approximately 9.1-9.4 Å. The group is further divided into subgroups that are either trioctahedral (talc) or dioctahedral (pyrophyllite), and these subgroups are further divided into mineral species based on chemical composition. The layers are bonded by weak van der Waals interactions. See “group names”

**Tatatila-type montmorillonite** A term first used by Schultz (1969) to describe a montmorillonite with the same chemical characteristics of the Chambers-type montmorillonite (i.e., a total net layer charge of -0.85 to -1.20 per unit cell  $[\text{O}_{20}(\text{OH})_4]$  with a layer-charge contribution from tetrahedral substitutions of between -0.15 to -0.50), but with higher temperatures of dehydroxylation at 710-730 °C rather than at 660-690 °C. Use of this term is obsolete. See Chambers-type montmorillonite. Terms used in this obsolete classification are: Wyoming-type, Otay-type, Chambers-type, Tatatila-type, beidellite-type (ideal and non-ideal), and non-ideal montmorillonite. Current nomenclature for montmorillonite is that it is an Al-rich, dioctahedral smectite with an ideal structural formula of  $(\text{Al}_{3.15}\text{Mg}_{0.85})\text{Si}_8\text{O}_{20}(\text{OH})_4\text{X}_{0.85}\cdot n\text{H}_2\text{O}$  with layer charge from primarily octahedral substitutions of Mg.

**tempered glass** glass that has been heat treated in a specific way such that its thermal properties and mechanical strength are improved. This treatment often involves heating to near the glass softening point followed by controlled cooling, resulting in a glass that will break into granular fragments rather than sharp plates. Such glass is also known as “safety glass.”

**tenacity** resistance to breaking or deforming a crystal

**tensile strength** the maximum stress developed in a material by a pulling load at the point of rupture, given as a load per cross sectional (e.g., kg per  $\text{cm}^2$ )

**terra cotta** unglazed or glazed building blocks of either low- or high-fired clay, typically used as ornamental features on buildings

**terra rosa** a red glaze made from hematite

**tetrahedral layer** inappropriate usage for a tetrahedral sheet. See *tetrahedral sheet*

**tetrahedral sheet** A tetrahedral sheet contains continuous two-dimensional corner-sharing coordination tetrahedra involving three corners and the fourth corner pointing in any direction. The tetrahedral sheet generally has a composition of  $\text{T}_2\text{O}_5$  (T = Si, Al,  $\text{Fe}^{3+}$ , Be, B...). After Guggenheim *et al.* (2006); see also references therein. *Cf.*, octahedral sheet

**tetragonal** see crystal system

**tetrasilicic** an invalid term, previously used as a classification of the micas where the number of silicon atoms per formula unit is four per four tetrahedral sites, see Rieder et al. (1998). *Cf.*, mica, true mica, brittle mica, interlayer-deficient mica, group names

**thermal analysis** the recording of the change in temperature and/or mass of a material when heated.

**thermal conductivity** rate of heat flow through a material. Heat flow is given as a unit of cross sectional area, per unit of temperature and time along the direction of heat flow.

**thermal diffusion** see diffusion. *Cf.*, thermal conductivity

**thermal expansion** the change in volume of a material with increase in temperature. It is often expressed as the coefficient of thermal expansion, which is the degree of expansion divided by the change in temperature.

**thixotropy** A property of non-Newtonian, pseudoplastic fluids where the fluid shows a reduction in viscosity over time under constant shear stress and an increase in viscosity when the shear stress is reduced or removed. The thixotropic characteristics of aqueous sodium bentonite suspensions used in oil and gas exploration drilling fluids enable drill cuttings to be easily suspended and removed from the drill hole during drilling. Yogurt can be used to illustrate thixotropy; consider cold yogurt in a container before and after shaking. *Cf.*, dilatancy, Newtonian fluid, quick clay

**tonstein** A kaolinite-rich rock formed by alteration of glassy volcanic ash or tuff deposited in an organic-rich aqueous environment, such as those associated with coal-forming environments.

**topotaxy** a geometrically fixed intergrowth between a reactant and one or more of its products which resulted from a solid-state transformation. Different authors have suggested that the product phase(s) should maintain orientation a) of most atom positions or b) of symmetry axes of the reactant phase. c) The reaction involves conversion throughout a single crystal. *Cf.*, epitaxy, syntaxy

**total charge** see point of zero charge

**transparent** describes a material that allows radiant energy to pass through it without significant adsorption, scatter or reflection. *Cf.*, opaque, translucent

**trans-vacant** A *trans*-vacant phyllosilicate is dioctahedral with the vacancy ordered to the site where the OH,F anions are on opposite octahedral corners (i.e., *trans* orientation). *Trans* sites are located on the mirror plane of an ideal layer in a phyllosilicate. *Cf.*, *cis*-vacant

**triclinic** see crystal system

**tri,dioctahedral chlorite** a species of the chlorite mineral group that would have a trioctahedral 2:1 layer and a dioctahedral interlayer. There are no known chlorite structures of this type. Bailey (1988) described franklinfurnaceite, which has Ca between the 2:1 layer and the interlayer and thus is not a true chlorite, as tri,dioctahedral if the Ca is not considered. *Cf.*, dioctahedral chlorite, di, trioctahedral chlorite, trioctahedral chlorite, dioctahedral sheet, trioctahedral sheet

**trioctahedral chlorite** a species of the chlorite mineral group with trioctahedral sheets only. This is the common form of chlorite. *Cf.*, dioctahedral chlorite, di, trioctahedral chlorite, trioctahedral sheet

**triple layer model** see *Stern layer*

**trioctahedral sheet** In the ideal case, the smallest structural unit contains three octahedra. If two such sites are occupied with cations and one site is vacant, then the octahedral sheet is considered “dioctahedral”. If all three sites are occupied, the sheet is considered “trioctahedral”. (*Quot Guggenheim et al.*, 2006; see also references therein). A trioctahedral sheet generally contains predominantly divalent cations *Cf.*, dioctahedral sheet

**trisilicic** an invalid term, previously used as a classification of the micas where the number of silicon atoms per formula unit is three per four tetrahedral sites, see Rieder et al. (1998). *Cf.*, mica, true mica, brittle mica, interlayer-deficient mica, group names

**true mica** a group name for platy phyllosilicates of 2:1 layer and a layer charge of  $\sim -1.0$  per formula unit. True micas do not show swelling capacity. Rieder et al. (1998) defines the true micas as having greater than 50% of the interlayer cations as univalent cations. The true mica group is further divided into subgroups based on the octahedral sheet being either trioctahedral or dioctahedral. *Cf.*, mica, brittle mica, interlayer-deficient mica, group names

**turbostratic stacking** In phyllosilicates, turbostratic stacking involves highly disordered (non regular) stacking arrangements of layers where there is no registry from one layer to another, much like a stack of playing cards lying flat on each other but with no alignment of edges. Smectite minerals and halloysite commonly have turbostratic stacking. See rotational stacking disorder

**underclay** a fine-particle sedimentary seat rock composed mainly of clay minerals, that is generally non-bedded and contains traces of plant roots. Kaolinite-rich underclay deposits are economically important for ceramics manufacturing. (modified from Huddle and Patterson, 1961) *Cf.*, seat rock, ball clay, flint clay, fire clay

**unit structure** For phyllosilicates, the unit structure is the total assembly of the layer and any interlayer material. After Guggenheim *et al.* (2006) and references therein. *Cf.*, layer, interlayer material

**Vegard's law** describes a solid solution series where there is a linear relationship between the

lattice parameters and the chemical composition (as atomic percentage). The term “law” is a misnomer because a linear relationship often does not exist.

**vermiculite** a group name for platy phyllosilicates of 2:1 layer and a layer charge of ~ -0.6 to -0.9 per formula unit. Generally for natural samples, the  $d(001)$  value is approximately 14.4-15.6 Å, although other spacings may occur depending on H<sub>2</sub>O retention and interlayer occupancy. The group is further divided into subgroups that are either trioctahedral or dioctahedral and these subgroups are further divided into mineral species based on chemical composition. Both vermiculites and smectites have swelling capabilities. Distinguished from smectite in that Mg-exchanged vermiculite has  $d(001)$  of 14.5 Å after glycerol solvation, whereas smectite has  $d(001)$  of 17.7 Å. Vermiculite occurs in soils, and are most common in subtropical and temperate climates. See “group names”; *Cf.*, smectite

**Vickers hardness** the measured hardness of a surface as tested using a special diamond pyramid-shaped indenter under various loads. A Vickers number is reported based on surface area indented (in mm<sup>2</sup>) divided by pressure (in Newtons). *Cf.*, hardness, Mohs hardness

**viscosity** a measure of the resistance of a fluid to flow when the fluid is placed under stress

**vitreous** glassy luster *Cf.*, luster

**vitrification** The process of changing a solid, often crystalline material, into an amorphous glass-like material by heating the solid to its melting point followed by sufficiently rapid cooling and solidification so that short-distance atomic ordering resulting in recrystallization does not occur. As vitrification proceeds, the porosity decreases. Devitrification is the reverse process.

**water, adsorbed or (H<sub>2</sub>O<sup>-</sup>)** H<sub>2</sub>O molecules attracted to internal or external surfaces of a phyllosilicate, or other material, and adhered to these surfaces in thicknesses of one or more molecules. The term “water” (rather than “H<sub>2</sub>O”) is not precisely used here because “water” is a (liquid) phase. Elevated temperatures, typically 110 °C for 12 hours, can desorb the adhered H<sub>2</sub>O. However, for phyllosilicates, a temperature of 110 °C may not liberate all the adsorbed water molecules present, and temperatures of as high as 300 °C (in special cases, even higher) may be needed for some vermiculites and smectites. *syn.* absorbed water, *Cf.*, water, structural

**water, combined** see water, structural

**water, crystallization of** see water, structural

**water, hydration of** see water, structural

**water, hygroscopic** H<sub>2</sub>O adsorbed by soil that is equilibrated with the atmosphere to which it is exposed at a given temperature and relative humidity, usually 25 °C at 98 % relative humidity.

**water, interlayer** water (or more precisely, H<sub>2</sub>O molecules) adsorbed between the (1:1 or 2:1)

layers of a phyllosilicate. The use of “water” is a misnomer because the interlayer H<sub>2</sub>O is not equivalent to bulk water (i.e., a phase, a liquid), which involves randomly oriented H<sub>2</sub>O. Instead, the interlayer H<sub>2</sub>O is affected structurally by the adjacent 1:1 or 2:1 layers and by the cations present in the interlayer. *Cf.*, water, adsorbed

**water, lattice** see water, structural

**water, molecular** see water, structural

**water, structural** or (**H<sub>2</sub>O<sup>+</sup>**) water (more precisely, H<sub>2</sub>O or OH molecules) that is directly bound to cations at crystallographic sites in a crystal structure. This H<sub>2</sub>O or OH is capable of being driven off at elevated temperature, generally by heating to 1000 °C. For phyllosilicates, structurally bound “water” is in the form of hydroxyl (OH) groups coordinated to cations, and the high temperature is required to promote dehydroxylation. Fluorine and certain other anions may be driven off at these temperatures also. However, hydrates, such as gypsum (CaSO<sub>4</sub> · 2H<sub>2</sub>O), have structural water coordinated to cations as H<sub>2</sub>O (e.g., water of hydration) that is liberated by heating to relatively low values, 65 - 95 °C. *syn.* combined water, molecular water, structurally bound water, water of crystallization, water of hydration. “Lattice water” is also used, but is not recommended because a “lattice” refers to a collection of identipoints, see “lattice”. *Cf.*, water, adsorbed

**water, structurally bound** see water, structural

**water, zeolitic** water molecules adsorbed within the cavities/tunnels of the zeolite framework structure, commonly removed by heating at 350 to 400 °C for about 12 hours. “Zeolitic water” was a term used by early workers to describe interlayer water of phyllosilicates. However, the analogy is imperfect (and not in use anymore) because the number of interlayer water molecules affects the layer-to-layer spacing of a phyllosilicate, whereas the shape and size of zeolitic tunnels are not significantly affected by the number of H<sub>2</sub>O molecules present. *Cf.*, water, structural; water, adsorbed

**whiteware** any ceramic that fires to a white or ivory color, commonly used in wall tiles, tableware, etc.

**Western Bentonite** An industrial or commercial term, originally used to designate the high quality sodium bentonite from Wyoming, USA. This material exhibits characteristics of high water adsorption, dilation, viscosification and dry sand binding strength. Usage of the term has since broadened to include any bentonite having performance characteristics equal to that of high quality sodium bentonite from Wyoming. Whereas the term “Western Bentonite”, and its synonyms, continue to have meaning in the industrial and commercial realm, they are scientifically obsolete and should not be used in that context. *syn.* Wyoming Bentonite, Wyoming Sodium Bentonite, Wyoming-Type Bentonite

**Wyoming bentonite** an obsolete term, see Western bentonite

**Wyoming sodium bentonite** an obsolete term, see Western bentonite

**Wyoming-type bentonite** an obsolete term, see Western bentonite

**Wyoming-type montmorillonite** As described by Schultz (1969) based on chemical and thermal analysis, Wyoming-type montmorillonite is a type of montmorillonite characterized by a small net negative layer charge of about -0.35 to -0.85 per  $O_{20}(OH)_4$ , with tetrahedral substitutions causing from -0.15 to -0.50 of the total layer charge and specific thermal properties. Current nomenclature for montmorillonite is that it is an Al-rich, dioctahedral smectite with an ideal structural formula of  $(Al_{3.15}Mg_{0.85})Si_8O_{20}(OH)_4X_{0.85}.nH_2O$  with layer charge from primarily octahedral substitutions of Mg, whereas beidellite has a net layer charge that occurs from tetrahedral substitutions of Al, with an ideal structural formula of  $Al_{4.0}(Si_{7.15}Al_{0.85})O_{20}(OH)_4X_{0.85}.nH_2O$ . Although the structure of a mineral is important (not given here), thermal properties are not part of the definition. The Wyoming-type montmorillonite of Schultz (1969) is best described as an intermediate in the montmorillonite-beidellite series. The term "Wyoming-type montmorillonite" is obsolete and should not be used.

**zeolite** a family of hydrated aluminosilicate minerals with a three-dimensional Si,Al tetrahedral framework-type structure with molecular-size channels and cages. Rings of four, six and eight tetrahedra are common structural subunits of the framework. The "extra-framework" content includes cations and  $H_2O$ ; the cations are often exchangeable and the  $H_2O$  may be dehydrated or partially dehydrated. The tetrahedra are occupied by >50% Si, as required by the Lowenstein Al-avoidance rule; in some cases, Be is present. Zeolites are used commercially in ion-exchange, molecular-sieve, and hydration-dehydration applications.

**zero point of charge** see point of zero charge

**zpc** see point of zero charge

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