

## 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.

*Constraints and goals of the Glossary.* 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.

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*Suggested reference format.* A sample of appropriate acknowledgment of source is:

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CMS Nomenclature Committee  
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## The Clay Minerals Society Glossary of Clay Science, 2017 version

**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

**absorption** In clay science, absorption occurs where the sorbate enters internal layers, voids, or pore spaces within the sorbent (usually, clay material). Other scientific fields, often do not specify a mechanism.

**absorption edge** (X-ray) The -“edge” concept (as in an “absorption edge”) is often used wherever there is a sharp drop (or increase) in a characteristic of a graph. For example, graphs of X-ray absorption vs energy (or wavelength) show a sharp decrease in absorption for foils of specific metals at distinct X-ray wavelengths, and these wavelengths mark the metal’s absorption edges. Metal foils have been used to reduce or remove extraneous X-ray wavelengths in (early) X-ray experiments; more modern experiments use a monochromator crystal. Because these absorption edges are characteristic for the metal, they may be used to identify the local atomic structure of the metal in a phase in spectroscopic studies, such as XANES (X-ray Absorption Near-Edge Structure) or EXAFS (Extended X-ray Absorption Fine Structure).

**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 composed of radiating masses of slender needle-like crystalline phases

**acid clay** see acid activated clay

**acid activated clay** a clay (most often a Ca-bentonite) treated with concentrated acid in aqueous suspensions at elevated temperatures and subsequently washed, dried and pulverized. The resultant modification enhances surface acidity, increases specific surface area, and forms porosity, all of which improves edible oil bleaching or adsorption properties. Surface acidity for a clay was noted by K. Kobayashi in 1899 in Japan, and he termed the clay as “acid clay”. Hence, “acid clay” and “activated clay” are separately described in Japan. More recent adaptations of acid activation applied to other fuller’s earth clays (e.g., sepiolite or palygorskite or mixture of palygorskite-montmorillonite) have either improved upon or eliminated processing steps associated with “classical” acid activation to produce different bleaching clay products for refining numerous edible oils. It is common to describe the activation process when describing activated clays, e.g., “thermal-activated clay”, “Na<sub>2</sub>CO<sub>3</sub>-activated clay”. See also bleaching clay, fuller’s earth; *Cf.*, beneficiation

**activated clay** see acid activated clay

**activation energy** The minimum energy two molecules, atoms, or ions must have to initiate (by colliding) a reaction is called the activation energy,  $E_a$ , and has units of kilojoules per mole.

**active principle** a pharmaceutical term denoting the active ingredient(s) in a drug. For a drug containing clay, the active principle may be loaded in clay lumen (e.g., halloysite, zeolite) or adsorbed to clay surfaces, including interlayer surfaces (e.g., as found in smectite). The clay portion, as an inactive carrier or coating, is referred to as the excipient or vehicle. The excipient is often used to improve the physical appearance, taste, smell, or smoothness of a pill or to promote disintegration (time release) of capsules or pills. *Syn.*, active ingredient, bulk active, *Cf.*, aesthetic medicine, antibacterial clay, excipient, geotherapy, healing clay, lumen, medicinal clay, pelotherapy

**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.

**activity** In thermodynamics, activity refers to an ‘effective’ concentration, which takes nonideal behavior into account. Thus, ion-to-ion interactions, such as charge shielding, may affect the activity by attractive or repulsive intermolecular forces. The activity of a dissolved species is calculated as  $a_i = \gamma_i m_i$  where  $\gamma_i$  is the activity coefficient and  $m_i$  is the molality. Activity is the term used to describe concentrations in solutions, whereas fugacity describes the activity of a gas.

**activity, clay** Skempton (1953) defines clay activity, or the colloidal activity of clay, as the ratio of the plasticity index to the percentage of the clay-size fraction. According to Skempton, three types of activity can be determined: inactive (activity  $< 0.75$ ), normal (activity 0.75 to 1.25) and active (activity  $> 1.25$ ). See low-activity clay, high-activity clay

**adatom** an atom attached to a substrate. *Syn.*, adsorbed atom

**admicelle** a micelle structure adsorbed to a surface. See micelle.

**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**  $H_2O$  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 “ $H_2O$ ”) 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).

**adsorption edge, surface characterization** For graphs in which the concentration of adsorbate per unit adsorbent is on the  $y$  axis and pH is on the  $x$  axis (adsorption vs pH plot), an adsorption edge (sharp increase in adsorption at a specific pH) for an oxide or phyllosilicate surface occurs when the plotted curve shows an "S-shape". An adsorption edge is commonly encountered for many cations adsorbed from a fluid onto the surface of a mineral or other solid substance (e.g., biological matter, glass). *Cf.*, adsorption envelope

**adsorption envelope** For graphs in which the concentration of adsorbate per unit adsorbent is on the  $y$  axis and pH is on the  $x$  axis (adsorption vs pH plot), an adsorption envelope occurs if adsorbed concentration decreases with pH, which is commonly encountered for many anions adsorbed from a fluid on an oxide or phyllosilicate surface. *Cf.*, adsorption edge

**adsorption isotherm** a plot of the amount of a substance adsorbed per unit surface area (or in less rigorous terminology as per unit mass) of a solid or liquid as a function of the equilibrium concentration of the adsorbate, at a specific temperature and pressure.

**aerosol** see suspension

**aesthetic medicine** Aesthetic medicine is a discipline involving all medical methods, including the application of materials such as some clays, to skin for cosmetic purposes (e.g., to tighten skin, add/change color, stimulate circulation, or reduce a scar ). Such procedures are generally non-invasive or minimally invasive. Procedures that are non-invasive or minimally invasive are typical. *Cf.*, active principle, antibacterial clay, geotherapy, healing clay, medicinal clay, pelotherapy

**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. *syn.*, aging, maturation

**agglomeration** see flocculation

**aggregation** see flocculation

**aging** see ageing

**air classification** a process of separating, fractionating, or manipulating fine particulate materials (or lighter particles) by gravitation in a vertically directed, usually upwards, moving air stream. This method is typically used for particles with sizes greater than 1 $\mu$ m. The smaller or lighter particles rise to the top (overflow) above the coarser heavier fractions (underflow) because their terminal velocities are lower than the initial velocity of the rising fluid. The terminal velocities of various particle sizes in any media is calculated by Stokes' law. See also Stokes' law; *Syn.*, elutriation

**airfloat kaolin** a process where kaolin is dried, transported on a column of rapidly moving air through a pulverization mill, and passed through a cyclonic air-classifier where coarse, sand-size particles are removed as gangue or returned to the mill for further size reduction. The term is used in the kaolin industry and refers to the less costly, dry-processed and air-classified powder products where bulk chemistry is of concern, but where purity, handling, and appearance may be less important. *Cf.*, air classification

**alkylammonium layer charge method** a method to determine the layer charge of phyllosilicates with 2:1 layers, primarily those phyllosilicates with interlayer-cation exchange capability, interstratified complexes, and micas. The layer charge is determined based on changes in basal spacing [ $d(001)$  value] as derived from various alkyl-chain lengths (C6-C18) of alkylammonium cations, following exchange in solutions with a series of  $n$ -alkylammonium hydrochloride salts (Lagaly and Weiss, 1969; Lagaly and Weiss, 1975). Alkylammonium-exchanged, low-charge smectites produce smaller basal-spacing values than higher-charge smectites or vermiculites. Greater expansion is produced by  $n$ -alkylammonium salts with longer alkyl chain lengths. Layer charge is estimated from the monolayer to bilayer transition alkyl-chain length. See Lagaly (1994) for further description, problems, and history. *Cf.*, alkylammonium organoclay bilayer, alkylammonium organoclay monolayer, alkylammonium organoclay paraffin complex, alkylammonium organoclay pseudotrilyer, organoclay

**alkylammonium organoclay bilayer** an interlamellar arrangement of two monolayers of alkylammonium cations [each monolayer has a C-C-C plane of the alkyl chain parallel to the (001) plane of the silicate 2:1 layers] between 2:1 layers of a phyllosilicate. The positively-charged end groups (e.g.,  $\text{NH}_3^+$ ) of the alkylammonium cations are attached to the interlayer silicate surfaces to produce a characteristic 17.6-Å spacing. See Lagaly and Weiss (1975); Lagaly (1994). *Cf.*, alkylammonium layer charge method, alkylammonium organoclay monolayer, organoclay

**alkylammonium organoclay monolayer** an interlamellar arrangement of one layer of alkylammonium cations with the C-C-C plane of the alkyl chains ( $n < 8$ ) parallel to the (001) plane of the 2:1 layer to produce a characteristic 13.6-Å spacing of a phyllosilicate. The positively-charged end groups (e.g.,  $\text{NH}_3^+$ ) of the alkylammonium cations are attached to alternate siloxane surfaces in the interlayer. See Lagaly and Weiss (1975); Lagaly (1994). *Cf.*, alkylammonium layer charge method, organoclay

**alkylammonium organoclay paraffin complex** an interlamellar arrangement of alkylammonium cations with the positively-charged (polar) end groups (e.g.,  $\text{NH}_3^+$ ) of the alkylammonium cations attached to the interlayer silicate surfaces of a 2:1 phyllosilicate. The alkyl chains are tilted from a perpendicular orientation with respect to the (001) surfaces, and this orientation produces basal spacings of  $>22\text{\AA}$ . The angles between the alkyl chain axes and silicate 2:1 layers increase with layer charge and range from  $50$  to  $60^\circ$  in vermiculites and to  $90^\circ$  in micas. See Lagaly and Weiss (1969; 1975); Lagaly (1994). *Cf.*, alkylammonium layer charge method, alkylammonium organoclay bilayer, alkylammonium organoclay monolayer, alkylammonium organoclay pseudotrilinear, organoclay

**alkylammonium organoclay pseudotrilinear** An interlamellar arrangement of alkylammonium cations with the positively-charged (polar) end groups (e.g.,  $\text{NH}_3^+$ ) of the alkylammonium cations attached to the interlayer silicate surfaces of a 2:1 phyllosilicate. Kinks in the alkyl chains shift the (non-polar) alkyl group tails between other alkylammonium alkyl chains to form a pseudotrilinear with a characteristic spacing of  $\sim 22\text{\AA}$  as determined from the thickness of three alkyl chains (Lagaly and Weiss, 1975; Lagaly, 1994). *Cf.*, alkylammonium layer charge method, alkylammonium organoclay bilayer, alkylammonium organoclay monolayer, organoclay

**alkylammonium salt** see quaternary alkylammonium salt

**alligator hide texture** see alligator skin texture

**alligator skin texture** An “alligator hide/skin” texture relates to a macro-texture observed on exposed and weathered clay surfaces. The texture evolves from polygonal shrinkage cracks that develops from bentonites with low dilatancy. See also popcorn texture.

**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

**alteromorph** An alteromorph is an alteration product of a crystal that preserves the external anhedron form of the precursor mineral. The alteromorph may have a different chemical composition and/or crystal structure than the precursor crystal. The alteromorph can result from replacement in the solid state or by fluid interactions. *cf.*, centripetal replacement, pseudomorph

**alumina** Alumina refers to  $\text{Al}_2\text{O}_3$  chemical composition only and the term does not imply a structure. The term commonly is used to describe a mineraloid or a glass, as in an alumina-rich glass. Thus, alumina does not specifically refer to corundum or other alumina-rich phase (e.g.,



boehmite, diaspora). *Cf.*, mineraloid

**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

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

**anhedral** see crystal

**anion** see ion

**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, double metal hydroxides

**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, double metal hydroxides, 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

**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.

**anode** see electrode

**antibacterial clays** Antibacterial clays are clays that kill bacteria by various means, including *but not limited to* the chemical transfer of toxins, elimination of nutrients, or physical disruption of metabolic functions. *Cf.*, active principle, aesthetic medicine, geotherapy, healing clay, medicinal clay, pelotherapy, zeta potential

**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

**argillan** see cutan

**argillite** see lutite

**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

**Arrhenius Equation** a formula describing the temperature dependence of a rate constant (k) for a chemical reaction:  $k = Ae^{-E_a/RT}$  where  $E_a$  is the activation energy, R is the ideal gas constant and T is the temperature (Kelvin). A is the pre-exponential factor.

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

**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. *Cf.*, aspect ratio, asbestiform, asbestosis

**asbestosis** Asbestosis is a disease that results in fibrosis of the lung from the inhalation of asbestiform particles, such as fibrous serpentine (chrysotile) and fibrous amphibole (crocidolite, amosite, anthophyllite, tremolite, actinolite), which can lead to mesothelioma (cancer). The amphiboles have a much greater residence time in the lung than the serpentines, which dissolve more readily at the pH of lung tissue (Hume and Rimstidt, 1992; Werner et al., 1995). See asbestos, asbestiform, *cf.*, asbestiform, asbestos, aspect ratio,

**aspect ratio** The aspect ratio is the ratio of the smallest dimension to the longest dimension. For fibers, the aspect ratio is the ratio between the width to the length. NIOSH defines asbestos, for example, with a length:width ratio (also commonly referred to as “aspect ratio”) of predominantly >3:1 fibers. For platy materials, such as clay minerals or polymer/clay nanocomposites, the properties of the composite are strongly impacted by the morphology of the particle. For montmorillonite the aspect ratio (height to diameter of plate) is generally 1:150. In industry, this ratio is commonly expressed simply as an aspect ratio of 150. The aspect ratio of platy and acicular morphologies is one measure of the anisotropy of nanoparticles.

**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** 1) refers to the mineral, palygorskite, and should not be used in the mineralogic or geologic literature. See Guggenheim *et al.* (2006) and references therein. 2) Attapulgitite is a common, globally used industrial term synonymous with palygorskite; especially, where mined and processed in the Florida-Georgia region of the United States or other commercial deposits around the world (e.g., China, Spain, Senegal, India, Australia, Greece, Turkey and Ukraine).

**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.

**b-fabric** The fabric of a soil or sediment ground mass where the fine material is described from the birefringence (“b-fabric”) based on the interference colors in thin section under crossed polarizers (after Bullock *et al.*, 1985). Syn. clay birefringent fabric; see listing. Types of b-fabric relating to clay or other fine material include:

*cross striated b-fabric* Similar in description to reticulate striated b-fabric but with birefringent streaks showing non-perpendicular angular relationships in the ground mass.

*granostriated b-fabric* A b-fabric consisting of clay particles oriented parallel to skeletal grain surfaces.

*monostriated b-fabric* A fabric with birefringent streaks that are not associated with natural surfaces and occur isolated in the ground mass.

*mosaic-speckled b-fabric* A speckled b-fabric where a mosaic-like pattern occurs of coalescing birefringent regions or speckles.

*parallel striated b-fabric* A fabric with birefringent streaks that are not associated with natural surfaces and occur in parallel or sub- parallel sets in the ground mass.

*porostriated b-fabric* A striated b-fabric that consists of clay particles oriented parallel to the surface of pores.

*reticulate striated b-fabric* A ground mass with two sets of birefringent streaks intersecting at right angles. The streaks are not apparently associated with natural surfaces.

*speckled b-fabric* A ground mass (or pedoplasma or s-matrix) of predominantly clay where

zones of birefringence show small (several microns), equidimensional, or slightly prolate regions or “speckles”.

*stipple-speckled b-fabric* A speckled b-fabric that consists of isolated regions or speckles.

*strial b-fabric* A ground mass composed mostly of clay characterized by preferred parallel birefringence orientation as an entity. This general orientation is commonly inherited from sedimentary processes and can occur in one or two preferred directions, “unistrial” and “bistrial”, respectively.

*striated b-fabric* A ground mass of predominantly clay with elongated birefringent zones or streaks showing nearly simultaneous extinction, commonly several hundred microns in size.

**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

**balneotherapy** the treatment of diseases, injuries, and other physical ailments by medicinal procedures in mineral springs, medical peloids or mud baths, inside the facilities of Health Resort Medicine Centers (Gutenbrunner et al., 2010). Balneotherapy is broadly interpreted to include hot or cold spring water baths, drinking of medical mineral waters rich in gases, salts, silica, sulfur, etc. Crenobalneotherapy is the term used in both France and southern Europe countries. *Balnea* is Latin for ‘hot baths’.

**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.

**batch reactor** a reaction vessel without inflow or outflow. Batch reactors are commonly used for sorption experiments and, less commonly, for mineral growth and dissolution experiments. *Cf.*, continuously stirred tank reactor, chemostat, plug flow reactor

**bauxite** the rock term for an aluminum ore consisting of primarily hydrous aluminum oxides [gibbsite,  $\text{Al}(\text{OH})_3$ ; boehmite,  $\text{AlO}(\text{OH})$ ; and diasporite  $\text{AlO}(\text{OH})$ ], often mixed with iron oxyhydroxides (goethite,  $\text{FeO}(\text{OH})$ , and hematite,  $\text{Fe}_2\text{O}_3$ ), kaolinite, and small amounts of anatase ( $\text{TiO}_2$ ). Most bauxite deposits result from weathering of a variety of Al-rich source rocks that are low in comparatively stable silicates. Bauxite deposits are related to paleo-tropical or subtropical climate rather than lithology, especially where long periods of tectonic stability permitted “deep and thorough” weathering of the precursor rock. *Cf.*, bauxitic clay

**bauxitic clay** clay material containing minerals rich in their bulk aluminum content (e.g.,

gibbsite, boehmite, diaspore). This material is used for making refractories or as an ore for aluminum metal. Also see bauxite

**BCF theory (Burton, Cabrera, Frank)** BCF theory describes crystal growth as nucleation and further crystallization by way of layer-by-layer attachment at edge, step, or kink sites on the surface of the growing crystal, as a function of the saturation state of the parent solution. Nucleation can occur at surfaces, dislocations, or impurities. The kinetics are influenced by temperature, impurity concentration, etc.

**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  $(Al_{3.15}Mg_{0.85})Si_8O_{20}(OH)_4X_{0.85} \cdot nH_2O$  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  $Al_{4.0}(Si_{7.15}Al_{0.85})O_{20}(OH)_4X_{0.85} \cdot nH_2O$ . 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

**bentonite, white** a generic industrial classification for a white- or nearly white-colored bentonite clay (primarily smectite, illite, and/or interstratifications), generally low in iron-bearing and organic phases, and often containing some kaolin and/or minor silicate accessory minerals (quartz, feldspar, opal, etc.). White bentonite is a common base material for many value-added industrial and consumer applications and products.

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

**bilateral** see mirror plane

**bilayer** see alkylammonium organoclay bilayer

**binuclear complex** A binuclear complex refers an entity of atoms (i.e., a complex or more appropriately, a molecular entity or coordination entity) with two central ions (by extension, a mononuclear complex has one central ion, a trinuclear complex has three, and polynuclear complexes have more than three). The central ion is a metal ion and an electron acceptor, with ligands as electron donors. If surface sites are involved, binuclear refers to a ligand (L) binding to two metal (M) surface sites; if a ligand is bound to only one site, the adsorption complex is termed mononuclear. See figure below.

### Modes of ligand coordination to oxide surfaces

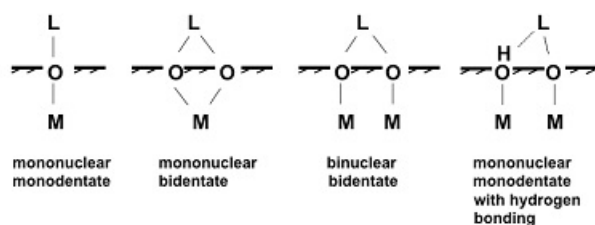


Figure 1. Illustration of mononuclear and binuclear (inner-sphere) complexes of adsorbed metal ions on a surface. See binuclear complex. From Maurice (2009), with permission.

**bioaccumulation** a process whereby an element or compound is incorporated into or concentrated on the surface of an organism, possibly transformed into another compound, and retained. The concentration of the element(s) or compound(s) in the biota may be greater than its concentration in the media from which it was derived. The process is of particular concern for toxins, pesticides, etc.

**biofilm** a microbial community generally supported by a surface and held together by extracellular attachment features such as exopolysaccharides (EPS) in a distinct 3-dimensional shape or architecture. Biofilm matrix may also include abiotic components, such as clay or other mineral particles, corrosion products, etc. that may act as support and/or as sources of nutrients.

**biological weathering** a biological process that produces either a chemical or physical breakdown of minerals or rocks. See weathering, physical weathering, chemical weathering

**biologically induced mineralization** a biomineralization process where solution conditions and/or surfaces for heterogeneous nucleation are altered by the cell to promote mineralization. However, the cell does not directly control the type of mineral formed or habit. Traditional definitions of minerals preclude a biological-process origin of minerals, but such definitions are being challenged, see the definition of “mineral” for a more classic approach. Cf., biomineralization, biologically controlled mineralization, mineral,

**biologically controlled mineralization** a biomineralization process where the cellular activities of an organism directly control mineral nucleation and growth, the location of nucleation, and mineral morphology. The process may be extracellular, intercellular, or intracellular. Traditional definitions of minerals preclude a biological-process origin of minerals, but such definitions are being challenged, see the definition of “mineral” for a more classic approach. *Cf.*, mineral, biologically induced mineralization, biomineralization

**biomineralization** the process whereby living organisms catalyze or otherwise mediate mineral formation. Traditional definitions of minerals preclude a biological-process origin of minerals, but such definitions are being challenged, see the definition of “mineral” for a more classic approach. *Cf.*, biologically controlled mineralization, biologically induced mineralization, biomineralization, mineral

**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

**blunger** See blunging

**blunging** a processing term used in industry to describe the high-energy mixing or disaggregation of clay (or a similar substance) into water to form a uniform slurry (i.e., suspension or slip) for use in ceramics or paper making. A blunger usually consists of a round or octagonal tank with a mixer-impeller attrition blade. Post-blunging slurry processing may be performed to separate and concentrate the clay mineral phase or remove grit and heavy minerals, via wet sieve, hydrocyclone, flotation, gravity separation, chemical modification and/or magnetic separation. See suspension, grit

**Born repulsion forces** Born repulsion forces are described as a strong, short-range repulsion term for bond energy between two charged ions. Born repulsion forces arise when neighboring ions approach sufficiently close so that the electron clouds involving the inner electron orbitals begin to overlap, thereby forcing higher energy states owing to the Pauli exclusion principle. The



term increases exponentially as orbital interpenetration increases with the decrease in interionic distance.

**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:  $\lambda = 2d_{hkl}\sin\theta$ .

**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

**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

**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<sub>2</sub>O, 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.

**c/f-related distribution** Stoops and Jongerius (1975) differentiated five characteristic types (e.g., fabrics) of soil and palustrine deposits based on coarse (c) and fine (f) or clay particles: monic, gefuric, cithonic, enaulic, and porphyric. The c/f related distribution is therefore the relationship between ground mass (matrix) and a general framework of coarser components (e.g. grains, aggregates). The different descriptions of the classifications, however, are not mutually exclusive:

*cithonic c/f-related distribution* A distribution where fine-grained material forms a wrap over the coarser skeletal components. Any orientation of the clay particles in the wrap or cover are not considered important in the definition.

*enaulic c/f-related distribution* A distribution where there is a framework of grain-supported skeletal components with partial infillings of fine grained materials and pore spaces.

*gefuric c/f-related distribution* The distribution involves fine-grained material connecting coarser components, where coarse material is not in direct contact with other coarse components.

*monic c/f-related distribution* This distribution consists of predominantly one size group, including all ground mass, amorphous material or skeletal components.

*porphyric c/f-related distribution* The distribution of generally coarse components within a ground mass of fine-grained material.

**calcan** see cutan

**calcine** to heat a substance to a temperature where it dissociates, for example the heating of calcite (CaCO<sub>3</sub>) to form CaO and CO<sub>2</sub>. 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.

**catalysis** see catalyst

**catalyst** A catalyst is a substance that influences the rate of a chemical reaction without being consumed by the reaction. Catalysis is the process by which a catalyst influences a reaction, and

this process often involves adsorption or the formation of intermediate compounds. When catalysis occurs, the overall Gibbs free energy of the reaction does not change.

**cataplasm** see poultice

**cathode** see electrode

**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** see ion

**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

**centripetal replacement** Alteration that occurs from a grain boundary inward or from internal fractures within a grain toward the center of the grain. Centripetal replacement is often recognized by texture, especially if alteration is incomplete. *Cf.*, alteromorph, peripheral replacement, pseudomorph

**cetyltrimethylammonium organoclay** see hexadecyltrimethylammonium organoclay

**cithonic c/f-related distribution** see c/f-related distribution

**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  $[O_{20}(OH)_4]$ , 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  $(Al_{3.15}Mg_{0.85})Si_8O_{20}(OH)_4X_{0.85} \cdot nH_2O$  with layer charge from primarily octahedral substitutions of Mg.

**chamotte** a ceramic raw material with a high silica and alumina composition typically produced by firing selected "fire clays" to high temperatures before grinding and screening to specific particle sizes. Chamotte is usually porous with a low bulk density. *Cf.*, fire clay

**chemical weathering** the process whereby chemical reactions alter or break down minerals or rocks under the influence of meteoric water at or near the Earth's surface. Specific chemical weathering reactions include, but are not limited to, dissolution (congruent or incongruent), oxidation, hydrolysis, cation exchange, complexation, hydration, carbonation, and sulfation. Chemical weathering may be biologically influenced. See weathering, physical weathering

**chemical potential** a thermodynamic term for the change of the Gibbs free energy of a system with respect to the change in the number of moles of a specific constituent. Chemical potential is equivalent to partial molar enthalpy, partial molar free energy, partial molar internal energy, and partial molar Helmholtz function. The chemical potential may be described as a force of energy change caused by a change of composition.

**chemical equilibrium** the state in which the rates of forward and reverse reactions are equal; thus, at equilibrium, the change in free energy  $\Delta G = 0$

**chemical kinetics** the study of reaction rates and mechanisms

**chemical thermodynamics** see thermodynamics

**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  $\sim 14.0$ - $14.4 \text{ \AA}$ . 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”.

**cicatrizers** substances that close a wound by scar formation; substances that heal (e.g., by healing clays). *Syn.*, cicatrize

**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 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 slickenside** In geology, slickenside is a field term for striated and polished surfaces on a fault plane, which can often indicate the direction of fault movement. A clay slickenside is where the groundmass constituents, mostly clay, have been rearranged so that the platy particulates parallel the surface. In clay science, the term “slickenside” is used also for the natural crack surfaces that are polished, but produced by swelling and shrinkage in smectite-rich soils. In soil science, clay slickensides are a diagnostic feature of Vertisols, which are clayey high shrink/swell soils. The shrink/swell action “inverts” or mixes the upper parts of the soil because organic-rich surface material falls into cracks during dry periods.

**clay groundmass** a general petrographic term for a fine-grained (clay size) material between coarser particles and pedofeatures in sediments or soils. The term groundmass in soils is analogous to matrix in sediments and sedimentary rocks. *Syn.* soil plasma, pedoplasma.

**clay birefringent fabric** Clay birefringent fabric is a petrographic feature showing the development of oriented, “bright” clay fabrics in the groundmass. These high birefringence regions under crossed polarizers are composites of many parallel clay particles that act together to produce a cohesive pattern. In sediments and soils, clay birefringent fabrics are commonly associated with bioturbation and wetting-desiccation cycles, respectively. See fabric.

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

**clay suspension** see suspension

**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** 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-organic complex** see organoclay

**clay-polymer nanocomposite** see clay nanocomposite

**clayshale** An indurated, fine-grained sedimentary rock composed of >66% clay-sized constituents with lamination (stratification of <10 mm thickness), after Potter et al. (2005). See clay, claystone, mud, mudrock, mudshale, mudstone, silt, siltstone.

**claystone** A fine-grained sedimentary rock having >66% clay-size constituents and little or no sand, with stratification (i.e., bedding) of >10 mm thickness. Bedding within the claystone may be massive (after Potter et al., 2005). See clay, clayshale, mud, mudrock, mudshale, mudstone, silt, siltstone.

**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

**clumping clay** A commercial-grade clumping clay is a clay where coherent clumps, capable of easy removal from a liter box, form from exposure to cat urine. Commercial clumping clays have added hydrophilic polymers to improve coherency and strength of the resultant clumps. The addition of these polymers is to address the problem of very concentrated urine in some cats, especially male cats, where the salt concentrations are very high. Manufacturers in the U.S. commonly use Na-rich montmorillonite from Wyoming and South Dakota as clumping clays.

**coagulation** See flocculation

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

**co-precipitation** an occurrence of a solid phase precipitate along with other components from solution. The mineral sorbent may partially or completely dissolve or the solution may become oversaturated with respect to a phase so that components may re-precipitate along with other components from solution.

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

**coating** In soil science, a coating is a layer of material, such as clay, organic material, mineral, non-crystalline material, etc., that partially or completely covers soil components (e.g., grains, voids). The term excludes b-fabrics. *Syn.*, cutan; *Cf.*, hypo-coating

**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  $\mu\text{m}$ . 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). See gelling clay.

**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  $\text{\AA}$ , and the superstructure of 32.4  $\text{\AA}$ , 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

**complex** A complex is a dissolved or surface species that forms by association of a cation and either an anion or a neutral molecule, the latter anion or molecule is often referred to as a ligand. The complex may have an overall charge that is positive, negative, or neutral.

**concretion** see glaebule

**concretion** see glaebule

**conditional stability constant** although not a true equilibrium constant, a conditional stability constant describes the equilibria of complex formation at ambient solution conditions. For example, a conditional stability constant may be used when pH is fixed at a specific value; the conditional stability constant would then vary with pH. Thus, the complex will be either strong

or weak depending on solution conditions, in this case with pH and possible protonation of the ligand. In other cases, temperature or ionic strength may alter metal to ligand strength, which changes the conditional stability constant. Conditional stability constants are commonly used to describe surface complexation reactions. *Syn.*, apparent stability constant; See also ligand

**congruent dissolution** dissolution where the same ratio of atoms present in the parent phase is released to the solution. This type of dissolution may be referred to as “stoichiometric” dissolution. *Cf.*, congruent melting, incongruent dissolution, incongruent melting

**congruent melting** Upon heating to form a liquid, the liquid (melt) has the same composition as the solid. *Cf.*, congruent dissolution, incongruent dissolution, incongruent melting

**constrained polymer region** For polymer nanocomposites, the volume around nanoparticles where the degree of freedom of movement of the polymer has been lowered. This region involves the interaction between the polymer and nanoparticle and is distinguished by having properties that are different from the bulk polymer properties. The volume of this region is dependent upon the strength of the interaction of the polymer and nanoparticle and the flexibility of the polymer. The concept, for example, explains why a gas diffusion coefficient of a polymer nanocomposite may differ from the bulk polymer. Gas diffusion may also be affected by the arrangement of clay particles that leads to a “tortuous path” and a reduction of diffusion through the nanocomposite.

**continuously stirred tank reactor (CSTR)** a reaction vessel with inlet and outlet flow and whose contents are stirred. CSTRs are commonly operated at steady state, but they may also function transiently. *Cf.*, batch reactor, chemostat, plug flow reactor

**converse piezoelectric**, see piezoelectric

**cosmetics** The United States [Federal Food, Drug, and Cosmetic Act](#) (FD&C Act) of 13 March 2013 defines cosmetics by their intended use, as "articles intended to be rubbed, poured, sprinkled, or sprayed on, introduced into, or otherwise applied to the human body...for cleansing, beautifying, promoting attractiveness, or altering the appearance" [FD&C Act, sec. 201(i)]. The act specifically excludes soap as a cosmetic. Clays and clay minerals used in cosmetics include bentonite, illite, kaolin, iron oxides, etc., often characterized by color or locality, and each purported to function or behave differently.

**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

**covalent bond** a chemical bond that involves sharing of one or more electrons, generally an electron pair. Covalent bonds require the appropriate geometric arrangement of coordinating atoms so that orbitals can overlap. Diamond, which involves carbon atoms, exhibits the ideal characteristics of covalent bonds. However, many elemental pairs involve covalent character and other bonding character (i.e., covalent plus ionic character as in the Si-O bond).



**critical radius** In crystal growth and heterogeneous geochemical kinetics theory, the “critical radius” refers to the smallest size that atoms or ions must come together to produce a stable nucleus for crystal growth or to allow bubbles to form.

**cross striated b-fabric** see b-fabric

**granostriated b-fabric** see b-fabric

**crossed polarizers** “Polars” or “polarizers” are devices that permit passage of light with vibrations in only one direction. In an optical “polarizing microscope”, two polarizers (the lower device is often referred to as the “polarizer” and the upper device is the “analyzer”) are oriented such that light vibrations are at 90 degrees from each other (and the two polarizers are said to be “crossed”). If nothing is present in the optical path between the two devices to change the light vibrations, all light is prevented from passing and the image is black. Material placed in the optical path changes the behavior of the light rays, with the behavior dependent on the crystallography of the material (e.g., crystal structure, crystallinity), the chemical composition, the thickness of the material, and refractive indices. If the analyzer is removed from the optical path, then the devices are not considered “crossed”. *Syn.*, crossed nicols, crossed polars

**crossed nicols** (archaic) The original polarizing prisms of petrographic microscopes were the early 19<sup>th</sup> century design of William Nicol, and each was referred to as a Nicol prism (Bloss, 1961). When both Nicol prisms were introduced into the optic path in mutually perpendicular orientations, the examination was said to be using “crossed Nicols”. The phrase “crossed nicols” is still used for this geometry of polarized light, regardless of whether the polarizing optics use Nicol prisms or another polarization device. See petrographic microscope, crossed polarizers

**crossed polars** see petrographic microscope, crossed polarizers, crossed nicols

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

**crystal class** see point group

**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 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,  $a_1 = a_2 = a_3 \neq c$ ,  $\alpha, \beta = 90^\circ, \gamma = 120^\circ$ ,  $\beta = 90^\circ$ ; 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

**crystal growth, driving force** In thermodynamics, the driving force ( $F_d$ ) associated with crystal growth is:  $F_d = \Delta\mu/k_B T = \sigma$ , where  $\Delta\mu$  is the change in chemical potential,  $\sigma$  is the supersaturation state,  $k_B$  is the Boltzmann constant, and  $T$  is absolute temperature.

**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.

**CSTR** see continuously stirred tank reactor

**cubic** see crystal system

**Curie temperature** see ferromagnetism, ferroelectric

**cutan** A pedofeature involving material (commonly oriented clay coatings, but also gels, amorphous, etc. coatings) that covers the surfaces of voids, grains, and aggregates, and are common in paleosols. Cutans may be derived and differentiated as diffusion cutans, illuviation cutans, and stress cutans. Other cutans may describe compositional variations. Cutans may be identified in a paleosol or soil under the optical microscope. See pedofeature.

*argillan* an (oriented) clay coating over grains, voids, or aggregates. Compositional characteristics may be used as prefix modifiers, as “ferri-argillan” (iron oxide stained) or “organo-argillan” (stained by organic matter). See cutan, pedofeature, ferran, mangan. *Syn.*, clay skin.

*calcan* a cutan composed of calcite.

*ferran* a cutan of iron oxide and hydroxide

*mangan* a cutan of manganese oxide and hydroxide

*organan* a cutan composed of organic matter

*silan* a cutan formed of opal or chalcedony

*sesquan* a cutan composed of Al-Fe oxides

*soluan* a cutan of soluble salts (e.g. gypsum)

***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

**Debye length** see diffuse double layer

**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.

**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.

**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** Delamination is a term used to describe a layer-separation process between the planar faces of adjacent layers of a particle. Delamination describes a process whereby intercalation occurs with the introduction of guest material and the stacking of layers remains. This term differs from exfoliation. Exfoliation implies that the orientation between the layers of the host structure is lost, and that interlayer cohesive forces are overcome. Where delamination or exfoliation cannot be distinguished, use “intercalation” or “delamination/exfoliation” to describe the process. See intercalation, exfoliation, 1:1 layers, 2:1 layers. (From AIPEA Nomenclature Committee, 2011, unpublished)

**devitrification** crystallization from a glass

**deposits, eluvial** In geology, sedimentary deposits (or eluvium) derived by weathering, either with or without significant movement by the effects of gravity. In soil science, a soil horizon developed by the removal of soil material in suspension or solution (leaching) from a layer of a soil.

**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 (*1Md*) has been converted to ordered (*1M*, *3T* or *2M1*). “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 algae (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, 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.

**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.

**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

**dislocation** see line defect

**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

**domain microfabric** see microfabric, clay

**double metal hydroxides** a group name for naturally occurring and synthetic compounds with the general formula of  $M^{2+}_{(1-x)}M^{3+}_x(OH)_2A^{-x}$  where  $M^{2+}$  is a divalent metal with Mg being the most common in nature (others include Ni, Cu, Ca Fe),  $M^{3+}$  is a trivalent metal normally Al or Fe (also Cr),  $A^-$  is a monovalent anion, and x is commonly near 0.3. The most common anion in nature is  $CO_3^{2-}$  [ $SO_4^{2-}$ ,  $Cl^-$ ,  $(OH)^-$  also occur]. For divalent anions, the formula is altered to (x/2). The positively charged portion of the structure is brucite-like, with the anion portion analogous to the interlayer in the phyllosilicates. The interlayer materials are readily exchangeable and may include  $H_2O$  and occasional cations. *Syn.*, layer double hydroxides, LDH, double layer hydroxides, hydrotalcite-like group, HT, anionic clay, and various similar versions

**double metal hydroxide organoclays** see double metal hydroxides

**double layer hydroxides** see double metal hydroxides

**drilling mud** fluids (e.g., water, oils, organics) plus dissolved additives and appropriately sized, suspended solids (e.g., Na-rich bentonite, palygorskite, organoclay, barite, sand) needed to produce bulk physicochemical and rheological properties appropriate for deep bore holes and for the removal of “cuttings” generated during the drilling process. For example, one such physiochemical requirement for drilling mud is a high specific gravity to prevent blowout if high-pressure strata is encountered during drilling at depth.

**driving force, crystal growth** see crystal growth, driving force

**drug** The United States [Federal Food, Drug, and Cosmetic Act](#) (FD&C Act) of 13 March 2013 defines drugs, in part, by their intended use, as "articles intended for use in the diagnosis, cure, mitigation, treatment, or prevention of disease" and "articles (other than food) intended to affect the structure or any function of the body of man or other animals" [FD&C Act, sec. 201(g)(1)]. Clays and clay minerals are used in pharmaceuticals to enhance bioavailability, either as an excipient or an active principle, or as a way to control the release of the drug (Rodrigues et al, 2013).

**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

**edge dislocation** see line defect

**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

**electric dipole** For atoms or molecules, an electric dipole occurs where there is a separation of positive and negative charge over a short distance. For example, an electric dipole occurs for H<sub>2</sub>O where (the bent) molecule forms a small negative charge near the oxygen atom whereas an equal, but positive charge forms on the opposite side of the molecule associated with the hydrogen atoms.

**electrical potential ( $\psi$ )** the potential energy per unit of charge; the difference in electrical potential between two points is the voltage (V).

**electrode** An electrode is a charged wire or plate. An anode is a positively charged electrode and a cathode is a negatively charged electrode. Charged particles are attracted to the electrode of opposite charge.

**electronegativity** Electronegativity (electron affinity) is the ability for an atom to attract electrons. The original definition was specific to atoms, but it is often applied to functional groups, although reference to the dipole moment, polarity, and/or Lewis acid/base character may be more appropriate to describe the attraction of electrons within a particular molecule or bonding environment.

**electron tunneling** Electron tunneling is a quantum mechanical property that occurs because electrons behave as waves of energy and are thus capable of passing through an energy barrier that would not be possible in classical mechanics. In scanning tunneling microscopy (STM), the tip and sample wave functions overlap so that when a bias voltage is applied, there is some finite probability of finding the electron on the other side of the energy barrier. Depending upon the direction of the bias voltage in STM, an electron may jump the gap or 'tunnel' across the barrier from tip to sample or from sample to tip.

**elephantiasis, nonfilarial** see podoconiosis

**elutriation** see air classification

**eluvium** see deposits, eluvial

**embryo** In crystal nucleation theory, an incipient and metastable particle with a size smaller than a critical radius. See critical radius

**emulsion** see suspension

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

**enauclic c/f-related distribution** see c/f-related distribution

**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

**endothermic** see enthalpy

**enthalpy** Enthalpy,  $H$ , is a thermodynamic state function equal to internal energy plus the product of pressure times volume or  $H = E + PV$ , i.e., the heat content of the system. For example, the change in enthalpy,  $\Delta H$ , is the heat involved, either released (exothermic) or absorbed (endothermic), in a system for a constant pressure process (e.g., a reaction at a fixed pressure). Exothermic reactions have a negative enthalpy change, whereas endothermic reactions have a positive enthalpy change. See state function, entropy

**entropy** a thermodynamic state function, which is classically defined as a change,  $\Delta S$ , in a system involving reversible heat ( $q_{\text{rev}}$ ) in a process and absolute temperature ( $T$ ), such that  $\Delta S_{\text{sys}} = q_{\text{rev}}/T$ . A reversible heat process implies an equilibrium process, and thus the change in entropy allows the determination of the favored direction of a process or reaction. If the total entropy change is positive from the initial state to the final state, the process spontaneously occurs. Where an increase in entropy,  $\Delta S$ , is positive, this indicates a greater degree of motion or randomness of atoms, molecules, or ions in a system. See enthalpy, Gibbs energy, state function

**enzyme** a (bio)molecule that serves as a catalyst for a chemical reaction.

**epitaxy** an oriented crystalline overgrowth forming on a monocrystalline substrate. This overgrowth occurs when the lattice dimensions within the common plane of the overgrowth and the substrate are similar. For moderate differences, dimensional variations of the two phases may still result in a continuous contact. However, for larger differences in the lattices of the two phases, small particles may form of the overgrowth phase if only limited accommodation occurs.



**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 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

**equivalent point** see equipoint

**erosion** movement and removal of natural materials by the action of erosive agents, such as water, ice, and wind. See weathering

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

**essential element (medical/biological)** a term broadly defined as a major element (e.g., H, O, C, N, Na, K, Ca, Mg, P, S, Cl) that plays physiologically important functions in human health. Essential elements can be derived through diet or through percutaneous migration from peloids. *Cf.*, essential trace element; see peloid

**essential trace element (medical/biological)** a term for trace elements (e.g., Li, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, W, Mo, Si, Se, F, I, As, Br, Sn) required for human health and specific to the function of certain proteins and enzymes. An essential trace element may be derived through percutaneous migration or through diet. *Cf.*, trace element

**euohedral** see crystal

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

**excipient** The inactive ingredient in a pharmaceutical product. The excipient, often clay, may be the vehicle for the active principle or may be added to improve the physical appearance, taste, smell, or smoothness of a drug or to promote disintegration (time release) of capsules or pills. *Cf.*, active principle

**exfoliation** a) In clay science, exfoliation involves a degree of separation of the layers of a host structure where units, either individual layers or stacking of several layers, are isotropically dispersed (freely oriented and independent) in a solvent or polymer matrix (Bergaya et al., 2011). This may be achieved by intercalation, by mechanical means, or by other methods. Where

delamination or exfoliation cannot be distinguished, use “intercalation” or “delamination/exfoliation” to describe the process. See intercalation, delamination, 1:1 layer, 2:1 layer. (From AIPEA Nomenclature Committee, 2011, unpublished) b) a process of physical weathering where large granitic plutons break into onion-like sheets along joints that lie parallel to the exposed surface.

**exothermic** see **enthalpy**

**expandable clay** see swelling clay

**extensive property** a thermodynamic property that depends upon the amount (e.g., number of moles) of a substance, for example, internal energy,  $E$ . *Cf.*, intensive property

**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.

**$F$  center defect** see point defect

**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

**Faraday constant** the magnitude of electric charge per mole of electrons; has the value of  $F = 96,485$  coulombs/mole

**fat clay** a qualitative industrial term used to distinguish clays possessing high plasticity (i.e., “fat”) or only slight plasticity (i.e., “lean”). The term originates from a soil classification system (Unified Soil Classification System used in both engineering and geology).

**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

**ferran** see cutan

**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. See refractory material. *Cf.*, underclay, seat rock

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

**fissile** the property of breaking or cleaving into flake-shaped, nearly planar paper-thin fragments. Fissility reflects fabric and texture such as the parallel alignment of clay minerals and phyllosilicates and fine-grain size laminations. See lamination.

**fissility** see fissile

**flame retardancy** Flame retardancy is the property of an additive that lowers the flammability of a material. Flame retardancy is measured by several standard testing methods, with the most common test being the UL94 test. However, more information is obtained by utilizing a cone calorimeter. Clay/polymer nanocomposites lower the flammability of the polymer significantly in both types of flammability tests. Clay layer-by-layer composites have been shown to greatly lower the flammability of textiles. The flammability of materials for construction and clothing is

of particular interest for the interiors of airplanes, commercial and residential construction, home furnishings, children sleepware, and clothing for industrial workers. *Cf.*, layer-by-layer composites

**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

**floccule** A cluster of loosely bound particles in a suspension that combine to produce a larger particle. In clay mineralogy, a floccule, or “floc”, is comprised of very fine-grained clay minerals in association with fine silt and organic debris, held together by electrostatic forces or organic sheaths (after Potter et al., 2005). See flocculation.

**flow quick-clay landslide** see quick-clay landslide

**flux** a) In metallurgy, a material which chemically cleans a metal surface to prepare it for welding, brazing or soldering. b) In ceramics, a material which lowers the melting point of ceramic materials to facilitate glass formation. c) 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

**fluxional bond** a dynamic bond where atoms exchange between symmetry-related sites. In cases where the configurations are non-equivalent, the result is an isomer or tautomer, whereas a fluxional molecule involves chemically equivalent configurations.

**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

**free-swell test** A free-swell test is a process- or quality-control test to measure the compatibility of a clay with various solvents by placing a specified amount of clay in the fluid of interest, allowing it to remain undisturbed, and by determining the amount of swelling after a specified time. A graduated cylinder is often used to judge the amount of swelling after one or two hours, and 1 gram of clay is typically used, although each manufacturer/supplier follows their own protocols. The test is relative to a clay with no swelling behavior, as there are no standard-swelling behaviors. The test is especially useful to determine the optimum organoclay for paint or grease formulations.

**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.

**Frenkel defect** see point defect

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

**fugacity** see activity

**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°. 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<sub>2</sub>O 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”.

**gastrolith** a small mineral concretion in the stomach. Some gastroliths may form if excess (ingested) clay cannot be eliminated by the digestive system. Some species, such as birds, reptiles, or dinosaurs, swallow small stones (gastroliths) that are believed to aid in digestion. These gastroliths are generally not concretions and are rounded and polished owing to the abrasive action within the stomach.

**gefuric c/f-related distribution** see c/f-related distribution

**gel strength** A measure of the ability of a colloidal system (i.e., a gel or sol) to withstand a load (shear force) without loss of the high slurry viscosity and/or the mechanical elasticity, often measured with a rheometer and expressed in units of mass per area. The gel strength is a function of the inter-particle forces present in the solid-liquid system. *Cf.*, colloid, suspension, gel, sol

**gel** see suspension

**gelling clay** an industrial term for clay minerals (especially palygorskite, sepiolite, Na- or Na-exchanged montmorillonite, hectorite, and organoclay) having a high slurry viscosity at low percent solids when mixed with fluid. Such clay minerals form a colloid where the dispersed phase and the dispersion medium produce a semisolid material, similar to jelly. Industrial applications include thickening/suspension agents, adhesives, sealants, putties and glazing compounds. Gelling viscosity is typically measured on Fann or Brookfield viscometers. For aqueous applications and some fibrous clay minerals such as palygorskite, the gelling behavior and viscosity is enhanced by adding magnesium oxide or by extruding the slurry to align the needle-shaped crystallites. For montmorillonite, gelling behavior can be enhanced by soda ash treatments to increase the exchangeable Na-cation content and the swelling capacity of the clay mineral. For solvent-based applications, various smectites can be surface modified by

quaternary-amine compounds to form organoclays that display superb gelling characteristics.  
See colloid

**geophagy** the deliberate ingestion of (specifically) soil/clay; a form of pica. *Cf.*, pica

**geotherapy** commercialized therapies using geologic materials, such as peloids, or processes, e.g., hot springs or mud baths. *Cf.*, peloid, pelotherapy

**Gibbs free energy** See Gibbs energy

**Gibbs energy** a thermodynamic state property useful to determine the spontaneity of a reaction within a system (without regard to the surroundings as is the case with entropy changes) and the direction of the reaction. The change in Gibbs energy,  $\Delta G$ , is equal to  $\Delta H - T\Delta S$ , where  $\Delta H$  is the change in enthalpy (cal/mole),  $T$  is the absolute temperature (K), and  $\Delta S$  is the change in entropy (cal deg<sup>-1</sup> mole<sup>-1</sup>). A substance reacts if the change in Gibbs energy is negative going from the initial state to the final state. Gibbs energy is often referred to as Gibbs free energy. See enthalpy, entropy, state function

**glaebole** a pedofeature forming segregated lumps of material with diverse composition (similar to cutans) as part of a soil groundmass. The non-planar shapes and more distinct outlines differentiate glaeboles from cutans. Three common glaeboles include mottles, nodules, and concretions.

*nodule* a glaebole that is irregular to nearly spherical, with a massive internal structure.

*concretion* a nodule-shaped glaebole showing an internal structure of concentric layers.

*mottle* poorly differentiated glaeboles occurring as diffuse patches in the groundmass.

**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

**grit** a qualitative term in the clay-mining industry that refers to small, hard accessory minerals occurring in the bulk clay deposit, such as quartz, feldspar, rutile, ilmenite, and apatite, which imparts an undesirable “abrasive” character to the bulk clay.

**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 ( $x$  ~ layer charge per formula unit) for the planar structures (interstratifications are not given here) are: serpentine-kaolin ( $x \sim 0$ ,  $c\sin\beta \sim 7.1$ - $7.3$  Å), talc-pyrophyllite ( $x \sim 0$ ,  $c\sin\beta \sim 9.1$ - $9.4$  Å), smectite ( $x \sim -0.2$  to  $-0.6$ ,  $c\sin\beta \sim 14.4$ - $15.6$  Å), vermiculite ( $x \sim -0.6$  to  $-0.9$ ,  $c\sin\beta \sim 14.4$ - $15.6$  Å), true mica ( $x \sim -1.0$ ,  $c\sin\beta \sim 9.6$ - $10.1$  Å), brittle mica ( $x \sim -2.0$ ,  $c\sin\beta \sim 9.6$ - $10.1$  Å), interlayer-deficient mica ( $x \sim -0.6$  to  $-0.85$ ,  $c\sin\beta \sim 9.6$ - $10.1$  Å), and chlorite ( $x$  ~ variable,  $c\sin\beta \sim 14.0$ - $14.4$  Å). 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.

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

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

**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. Examples of habits include acicular, lamellar, and equant.

**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

**half life** the time,  $t_{1/2}$ , required for the number of radioactive atoms in a system to decay and thus decrease to half of the original number.



**healing clay** clay used therapeutically, for example, to alleviate pain, absorb toxins, reduce swelling, or protect skin. Common healing clays are montmorillonite (in bentonite), palygorskite/sepiolite, and kaolin. *Cf.*, active principle, aesthetic medicine, antibacterial clay, geotherapy, medicinal clay, pelotherapy

**heat capacity** a measure of the heat energy required to raise the temperature of a substance by 1 °C. For example, the specific heat energy or capacity is the amount of heat needed to raise 1 gram of a substance by 1 °C. The heat capacity is, therefore, equal to the mass of the substance times the specific heat. Thus, the molar heat capacity is the heat capacity per mole.

**heat of fusion** the energy (often heat) required to transform a given quantity of a solid to a melt without changing temperature. *Cf.*, heat of sublimation, heat of vaporization

**heat of sublimation** the energy (often heat) required to directly transform a given quantity of a solid to a gas without changing temperature (or going through the liquid state). The heat of sublimation is the sum of the heat of fusion and heat of vaporization at the given temperature. *Cf.*, heat of vaporization, heat of fusion

**heat of vaporization** the energy (often heat) required to transform a given quantity of a liquid into a gas or vapor without changing temperature. *Cf.*, heat of sublimation, heat of fusion

**Helmholtz plane** see *Stern layer*

**hemostatic wound dressing** Hemostatic wound dressings are used to control bleeding when tissue damage occurs. One active ingredient applied either directly or with gauze bandages to a wound is clay (commonly, kaolins, zeolites, and smectites), which is used to absorb fluid and to promote blood clotting.

**heterogeneous nucleation** precipitation from solution of one solid phase on another.

**heterogeneous reaction** a reaction that involves more than one physical state (i.e., solid, liquid, gas). *Cf.*, homogeneous reaction

**hexadecyltrimethylammonium organoclay** expandable 2:1 clays (e.g. smectite, vermiculite) treated with solutions of the quaternary alkylammonium salt, hexadecyltrimethylammonium (HDTMA) bromide (also called cetyltrimethylammonium bromide), form organophilic-type organoclay. HDTMA organoclay can effectively remove organic contaminants, such as toluene, from water; see Boyd et al. (1988). *Cf.*, adsorptive organoclays, organoclay, organophilic-type organoclay

**hexagonal** see crystal system

**high-activity clays** In geotechnical engineering, high-activity clays have activities that range

from about >1 to 7+, with smectitic clays (i.e., smectite or mixed-layer clays with a smectite-like component) being the most common having activities near 3 (where Ca-saturated, or in high salinity environments) to 7+ (where Na-dominated and at low salinity). See activity, clay; low-activity clays; quick clays

**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

**homogeneous reaction** a reaction that involves only one physical state (i.e., solid, liquid, gas). *Cf.*, heterogeneous reaction

**homogeneous nucleation** direct precipitation of a solid phase within a solution and not on the surface of another phase.

**honeycomb microfabric** see microfabric, clay

**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).

**HT** see double metal hydroxides

**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.

**hydrogen bond** The hydrogen (H) atom in solids is often asymmetrically located between an electronegative donor atom (D) and an electronegative acceptor (A) atom, such that the D-H distance is smaller than the H-A distance. The H atom can penetrate the electron cloud of the donor atom. The D-H--A configuration may be linear or bent, and there may be multiple A atoms. The overall bond is considered essentially ionic in character, with an overall bond strength (for D-H--A configurations) considerably weaker than a (sigma) covalent bond but considerably stronger than van der Waals interactions. The H atom may serve to balance overall charge, for example as an O-H in oxygen-based structures, in which case the H does not link a donor to an acceptor atom.

**hydrolysis** a) occurs when a molecule reacts with water to break a chemical bond, and thereby often incorporating H<sub>2</sub>O into the substance. b) Hydrolysis at a surface involves the breakdown of the H<sub>2</sub>O molecule into hydroxides and protons to form protonated/deprotonated surface sites.

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

**hydrophilic** surfaces or molecules with strong attraction for H<sub>2</sub>O. Hydrophilic solutes are polarizable and tend to dissolve more readily in water than in oil. *Cf.*, hydrophobic

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

**hydrotalcite-like group** see double metal hydroxides

**hypo-coating** In micromorphology of soils, hypo-coating is a pedofeature that consists of a layer of material that is related and immediately adjacent to the surface of, for example, voids, grains, or aggregates. *Syn.*, neo-cutan; *Cf.*, coating, cutan, quasi-coating

**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 Al<sub>2</sub>SiO<sub>3</sub>(OH)<sub>4</sub> or Al<sub>2</sub>O<sub>3</sub> · SiO<sub>2</sub> · 2H<sub>2</sub>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

**impurity defect** see point defect

**incongruent dissolution** dissolution where the release of constituents from the dissolving phase into the solution does not reflect the stoichiometry of the original phase. *Cf.*, congruent melting, congruent dissolution, incongruent melting

**incongruent melting** a reaction where the solid phase reacts to form a mixture of liquid plus crystals, with neither having the composition of the original solid. *Cf.*, congruent melting, incongruent dissolution

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

etc.

**inheritance** a) the phenomenon by which minerals are formed in another environment in space or time from that where they are now found. b) The term is also used when some element of a pre-existing mineral structure is inherited by another mineral via the phenomenon of transformation. See also neof ormation, transformation

**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

**intensive property** a thermodynamic property that is independent of the amount of a substance, such as the property of heat capacity. *Cf.*, extensive property

**ion** Atoms or molecules become ions by the gain or loss of electrons, which have a negative charge. A positively charged ion, or cation, involves a loss of one or more electron(s). A negatively charged ion, or anion, involves a gain of one or more electron(s).

**intercalation** Intercalation is a general term to describe the movement of atoms, ions or molecules into a layered host structure, often a swelling clay mineral. This process can be reversible or non-reversible. The host-structure layers are essentially unchanged with the inserted material going between the layers. The layers must remain semi-contiguous via stacking. Intercalation commonly involves cation exchange or solvation reactions. Intercalation may involve, for example, H<sub>2</sub>O molecules or surfactants of single planes (monolayers) to paraffin-type layers between the layers of the host phase. The resulting structure is an “intercalated structure”. See delamination, exfoliation. (From AIPEA Nomenclature Committee, 2011, unpublished)

**interference colors** In optical crystallography, an interference color results with crossed polarizers where light enters an appropriately crystalline medium and refracts (separates into two ray fronts); thus, each wave front travels at slightly different velocities with a change in both speed and direction. Upon leaving the medium, the wave fronts interfere (recombine) and produces a component of light where there is a difference, or retardation, between the two wave fronts. This difference results in a change in wavelength in the final wave front, which produces a change in color, called an interference color.

**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. 2), 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

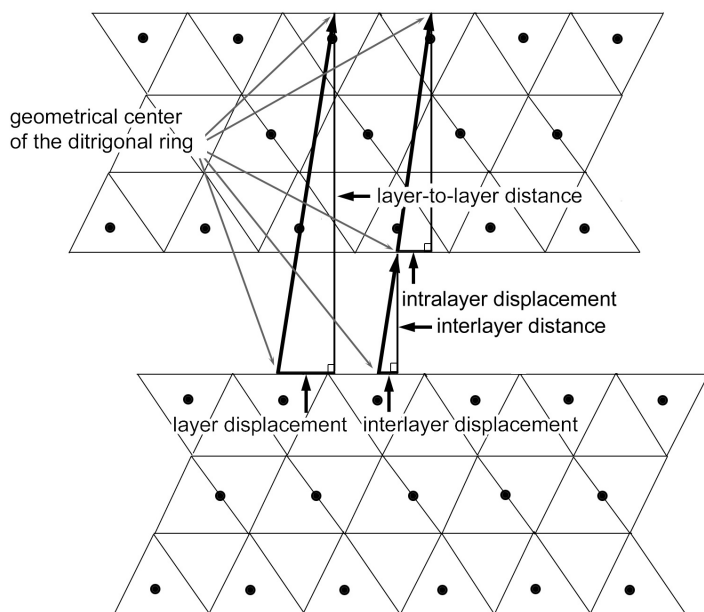


Figure 2. Illustration of terms used to describe interlayer, layers, and intralayer topologies. From Guggenheim *et al.* (2009).

**interlayer shift** 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. 2). 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 displacement** see interlayer

**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

**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 001 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

**intrinsic stability constant** a stability constant,  $K$ , for a complex is determined from the activity of the complex in solution divided by the activity of the reactants in a system at equilibrium. The larger the value of  $K$ , the greater is the stability of the complex. For multiple complexes that may result in a reaction, several constants may be determined, thus  $K_{\text{overall}}$  is the product of multiple constants:  $K_1 \times K_2 \times K_3 \dots$ . ‘Intrinsic’ is used because the stability constant is an essential physical chemical parameter that relates concentrations of the components of a reaction at equilibrium.

**intumescence** an irreversible expansion of a solid upon heating. Vermiculite commonly shows expansion upon rapid heating (intumescence) owing to the loss of interlayer H<sub>2</sub>O at relatively low temperatures and the separation of the layers. Slow heating of vermiculite may produce worm-like threads, and it is this characteristic that gives the vermiculite group its name: *vermiculari*, to breed worms, in Latin.

**ion exchange** see cation exchange

**ion-dipole interaction** a fluxional bond formed between an ion and a polar molecule. The classic example is where water molecules hydrate a sodium cation. However, the interaction is not restricted to H<sub>2</sub>O, as many polar organic molecules will form ion-dipole interactions. See

fluxional bond.

**ionic potential** the ratio ( $I_p$ ) of charge ( $z$ ) on an ion to the radius ( $r$ ) of the ion,  $I_p = z/r$ .

**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

**K-bentonite** See *bentonite*

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

**kaolin, soft** see kaolin, hard

**kaolin, hard** a white to gray clayey-textured rock predominantly composed of kaolin group minerals (primarily kaolinite). Hard kaolin is fine grained, difficult to break, and commonly with sharp, protruding (jagged) edges. Hard kaolin requires more complex mine extraction and mineral processing techniques than “soft kaolin” (kaolin-rich rock that is smooth to the touch, weak, and friable).

**kaolin** a) Petrologic term: rock composed primarily of kaolinite, nacrite, dickite, or halloysite (i.e., minerals of the kaolin group). In most case, 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 subgroup** superceded by kaolin subgroup

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

**Kaopectate®** a commercial product (made by Chattem, Inc.) involving a formulation of kaolin and pectin that was used as an anti-diarrheal. Since 2003, the formulation was changed to bismuth subsalicylate, but some formulations containing attapulgite as the active principle are sold in Canada.

**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 Al13. 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

**kinetics** see chemical kinetics

**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

**laminae** see lamination

**laminar microfabric** see microfabric, clay

**lamination** sequences of thin bedding (or “laminae”) occurring because of variations in the sediment supply in sedimentary rocks. Potter et al. (2005) suggests that laminae are <1 cm.

**Laponite®** Laponite is a synthetic clay mineral with a hectorite-like composition,  $\text{Na}_{0.7}\text{Si}_8\text{Mg}_{5.5}\text{Li}_{0.3}\text{O}_{20}(\text{OH})_4$ , and structure. Laponite is manufactured by BYK Additives & Instruments to modify the rheology of aqueous fluids. Laponite-S482 is a common excipient in



pharmaceuticals.

**lattice misfit** A lattice misfit is where there are (one or more) dimensional mismatches between a substrate crystal and an overgrowth crystal that has formed by heterogeneous nucleation. A lattice misfit parameter,  $d$ , may be calculated from  $d = D_a/a$ , where  $a$  is the lattice parameter of the (stress-free) substrate crystal, and  $D_a$  is the difference in lattice parameters between the underlying substrate and the overgrowth precipitate. *Cf.*, epitaxy, lattice

**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-by-layer composite** composites produced on nearly any substrate, including textiles, where the composite is fabricated by successive dipping/rinsing/drying of the substrate in two different solutions, one solution containing a clay, usually montmorillonite, and the second solution containing a complimentary polymer (e.g., any polycationic polymer). These composites are typically transparent, and generally 40 to 50 bilayers thick. Layer-by-layer composites lower flammability substantially and improve gas barrier properties. See flame retardancy

**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

**layer double hydroxides** see double metal hydroxides

**LDH** see double metal hydroxides

**lean clay** see fat clay

**Lennard-Jones potential** a description of the interactive forces occurring between a pair of neutral atoms or molecules. The potential is comprised of force-field terms: at long-separation distances, van der Waals attraction predominates, whereas at short-separation distances, strong repulsion predominates as a result of the Pauli exclusion principle. The Lennard-Jones potential is accurate for noble gas interactions and a relatively good model for most neutral atoms and molecules. The Lennard-Jones potential is computationally simple and thus commonly used in modeling programs.

**LHC** see liquid holding capacity

**ligand** see complex

**line defect** A line defect involves a series of structural imperfections that produces a linear feature and, commonly, offsets or “dislocations”, within an atomic structure. An “edge dislocation” forms where a plane of atoms or ions that would normally extend throughout the crystal terminates along a line within the crystal. Distortions are at a maximum along the line of termination. A “screw dislocation” is a localized screw axis involving atoms or ions (or blocks of atoms or ions) to form a spiral, much like a spiral staircase, with a step at the outer surface of the crystal. Because the screw dislocation is a local feature, the screw axis is not related to the space group (overall symmetry) of the structure, and the crystal regains its overall atomic periodicity at distances further from the central line of the dislocation. The step at the surface of the crystal is believed to enhance crystal growth because atoms or ions can better adhere and bond to sites associated with greater surface area at the step. *Cf.*, point defect, screw axis

**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.

**liquid holding capacity** the maximum capacity that a fine-grained, porous, granular material can absorb a liquid into the pore structure of the individual grains and still remain free-flowing. The point where the liquid impregnated granules adhere to the sides of a container (i.e. become “wetted”) represents a rough measure of internal liquid holding capacity of the material (i.e., the point beyond where granules begin adhering together and lose free-flowing properties).

**liquidity index** (water content – plastic limit) ÷ index of plasticity, or:  $(w - w_p) \div (w_l - w_p)$ . See also Atterberg Limits, plastic limit.

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

**lithomarge** a sectile and compact kaolin clay when wetted, often white to red/pink in color and mottled. When dry, lithomarges are friable.

**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

**low volatile matter (LVM)** an industrial term referring to superheated but not fully calcined clays. *Cf.*, superheating

**low-activity clay** In geotechnical engineering, low-activity clays have activities of  $< 1$ , and include illite, chlorite, and kaolinite. Fe and Al oxide minerals and clay-sized primary minerals are also considered low activity. See activity, clay; high-activity clays; quick clays

**lumen** a) Industrial/clay: A lumen is the bore of a tube. Thus, halloysite is a tubular mineral with an approximately 30 nanometer diameter lumen that runs the length of the tube. b) Medical: A cavity of passage in a tubular organ; e.g., the lumen of the intestine. Also, commonly applied to those clay minerals where medications are loaded into the tube bore, and the clay particle is coated with an excipient to control the timing of delivery.

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

**lutite** Lutite is an older field term for an argillaceous, fine-grained rock that is equivalent to claystone and mudstone. In clay mineralogy, the term “lutite” is commonly applied to authigenic clays. An equivalent term is “argillite”.

**LVM** see low volatile matter

**macronutrient** a general term for major dietary nutrients required in relatively large quantities per day. For example for human consumption, macronutrients include Ca, K, Na, Mg that may be potentially provided by ingestion of clays, whereas clays in soils provide these nutrients for plants. *Cf.*, micronutrient

**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

**mangan** see cutan

**matrix** see clay groundmass

**matrix microfabric** see microfabric, clay

**matured muds** see peloid

**medicinal clays** a general term for a clay used as an active principle or excipient ingredient in medication. *Cf.*, active principle, aesthetic medicine, antibacterial clay, geotherapy, healing clay, pelotherapy

**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

**micelle** an aggregate of surfactant molecules (each molecule consisting of a non-polar hydrophobic tail and polar hydrophilic head) dispersed as a liquid colloid. In aqueous solutions, a micelle forms with the tails oriented inward and the heads facing outward to solution.

**Michaelis-Menten kinetics equation** The Michaelis-Menten kinetics equation describes the kinetics of many enzyme-catalyzed reactions and involves an enzyme binding to a substrate to form a complex. This complex produces a product and additional enzymes, which produces more complexes with a consequential increase in the reaction rate. The equation has been successful in describing the rates of many biochemical reactions (e.g., protein-protein reactions) other than in complexes involving enzyme binding substrates.

**microcomposite, organoclay** an organoclay with at least one dimension in the micrometer range dispersed in a polymer. *Cf.*, organoclay, organoclay nanocomposite

**microcrystalline** see cryptocrystalline

**microfabric, clay** Clay microfabric is the description of the spatial distribution of clay particles in either clay-rich rock or sediment, commonly observed directly by electron microscopy of aggregates, domains, or layer stacking effects within the material. Microfabric variations may affect physical properties, conditions of formation, and evolution of the material. See Bennett et al. (1977) and Potter et al. (2005) and see microstructure. Types of clay microfabric are (after Grabowska-Olszewska et al., 1984):

*domain microfabric* A domain microfabric is composed of unoriented, coarse domains of kaolinite crystals with parallel axial orientation. Domain boundaries involve face-to-edge and edge-to-edge particles. Pore shapes are complex, with equidimensional interdomain pores (2-8  $\mu\text{m}$  in diameter) and smaller fissure-like intradomain pores (<0.5  $\mu\text{m}$ ). This microfabric is characteristic of eluvial kaolinitic clays; domains often form from weathered feldspar crystals.

*honeycomb microfabric* Honeycomb microfabric consisting of unoriented, high porosity (60-90%), nearly equidimensional cells or domains commonly 2 - 12  $\mu\text{m}$  in size in sedimentary clay-rich soils. Cell walls are comprised of microaggregates of face-to-face and face-to-edge clay particles of montmorillonite-illite mineralogy. Silt/sand grains are rare and are distributed throughout the soil. Most cell contacts are of flocculation type (clumping of small particles), which promotes the high porosity. The fabric is syngenetic (i.e., formed during sedimentation) and forms in recent marine and lacustrine sediments.

*laminar microfabric* A sedimentary clay soil with a laminar-flow appearance from well developed bedding/sorting of its structural components, mostly microaggregates with face-to-face, and occasional face-to-edge, boundaries. Pores between aggregates are fissure- and wedge-shaped parallel to the lamination. This microfabric is common of clay-rich deposits (>50%) of varying mineral composition and forms in syngenetic and/or post-depositional environments.

*matrix microfabric* A microfabric characterized by a continuous unoriented clay matrix with a non-uniform distribution of silt/sand grains. The clay (illitic and mixed-layer particles) forms microaggregates with face-to-face, face-to-edge, and edge-to-edge boundaries. Pore sizes range from 8 to 2  $\mu\text{m}$  for poorly compacted and compacted sediment/soil respectively. Formation can be syngenetic and/or post-depositional.

*pseudoglobular microfabric* Pseudoglobular microfabric is formed by the weathering of iron-rich igneous or metamorphic rocks with neof ormation of iron phyllosilicates (e.g., nontronite). This microfabric contains spheroidal microaggregates ranging in diameter of 5 - 20  $\mu\text{m}$ , sometimes composed of sheet-like particles with face-to-edge contacts or with face-to-face and face-to-edge interactions. Porosity is made of equidimensional interglobular (10 - 15  $\mu\text{m}$ ) and equidimensional or elongate intraglobular voids.

*skeletal microfabric* Skeletal microfabric is comprised of a generally uniform, porous structure of unoriented silt/sand grains (to 60%) and clay (10 - 30%), the latter forming a discontinuous matrix and commonly accumulating along the larger-grain boundaries to tenuously bond the grains together. This microfabric is more compact than the honeycomb microfabric with porosities ranging from 40 - 60%. The skeletal microfabric occurs more commonly in recent clay deposits of varying mineral composition (but often illitic). Formation can be syngenetic and/or post-depositional.

*sponge microfabric* Sponge microfabric consists of coarse aggregates (> 80  $\mu\text{m}$  in diameter)

of sheet-like microaggregates with mostly face-to-edge and face-to-face contacts, forming a continuous fine-cellular network resembling sponge. The clay material is not orientated and pores are irregular in shape and  $< 3 \mu\text{m}$  in size. For example, this microfabric has been reported in smectite clays of hydrothermal origin. See microfabric, microstructure

*turbulent microfabric* A microfabric with a turbulent-flow appearance derived from clay microaggregates that are well oriented along deformed laminations of clay-coated silt/sand grains within a matrix of deformed bedded clay. Clay microaggregates are bounded by face-to-face clay particles, and locally, by face-to-edge contacts at very small angles. The clay content is  $> 20\%$ . The pores are primarily fissure-like and elongated along the lamination. This microfabric is commonly formed during the diagenesis (compaction) of clay sediments with precursors of honeycomb and matrix microfabrics.

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

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

**micronutrient** a general term for dietary essential nutrients required in relatively small amounts (less than 50 milligrams per day). For example, micronutrients include vitamins (organic compounds) and trace elements (e.g., Fe, Cu, Zn, I, Se, Mn, Mo, Cr, F, Co) for human consumption that may be potentially provided by ingestion of clays, whereas clays in soils provide these nutrients for plants. *Cf.*, macronutrient

**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. Likewise, “biomineral” is acceptable for similar reasons as synthetic mineral. See crystalline, *Cf.*, biologically controlled mineralization, biologically induced mineralization, biomineralization

**mineraloid** a natural solid with insufficient long-range atomic ordering to be classified as a mineral. For example, limonite ( $\text{FeO} \cdot \text{OH} \cdot n\text{H}_2\text{O}$ ) is often considered an amorphous “mineral” or mineraloid.

**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

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

**molecular sieve** see zeolite, pillared clay

**molecularity** the number of reacting molecules, atoms, or ions in a single-step chemical reaction. For example, a unimolecular reaction may involve radioactive decay of a single atom, or one molecule producing other molecules. A bimolecular reaction involves the collision and reaction between two molecules, atoms or ions to form other products. *Cf.*, Transition State Theory

**monic c/f-related distribution** see c/f-related distribution

**monoclinic** see crystal system

**monolayer** see alkylammonium organoclay monolayer

**mononuclear complex** see binuclear complex

**monostriated b-fabric** see b-fabric

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

**mosaic-speckled b-fabric** see b-fabric

**mottle** see glaebole

**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.

**mud** soft, plastic, sticky or slippery matter, generally containing water and clay minerals derived from fine-grained soil/regolith/sediment materials. Mud is commonly composed of clay-size particles, but often contains mixtures of sand- and silt-size particles as well as microorganisms. Potter et al. (2005) considers mud a sedimentological field term for unconsolidated fine-grained sediments of any composition and consisting of 50% or more of particles smaller than 0.0063 mm (i.e., clay and silt size fractions). *Cf.*, see geotherapy, matured mud, pelotherapy, poultice, Udden-Wentworth scale

**mudrock** An indurated, sedimentary clay-bearing rock with 33-65% clay-size constituents and stratification of >10 mm thickness (bedding). An individual mudrock bed may be internally massive (after Potter et al., 2005). See clayshale, claystone, mud, mudstone, mudshale, silt, siltstone.

**mudshale** An indurated, sedimentary clay-bearing rock with 33-65% clay-size constituents and lamination (stratification of <10 mm thickness), after Potter et al. (2005). See clay, clayshale, claystone, mud, mudstone, mudrock, silt, siltstone.

**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. See clay, clayshale, claystone, mud, mudrock, mudshale, silt, siltstone.

**mud therapy** therapeutic use of healing mud (hydrated clay) in an empirical way and without medical supervision for palliative or cosmetic purposes. Traditionally, mud therapy was practiced in the natural environment where the mud occurs, but this is no longer the case. Also, see aesthetic medicine, antibacterial clay, geotherapy, healing clay, pelotherapy, peloid

**mull** In soil science, mull is a type of humus of the A horizon, without distinct layering, and composed of organic matter intimately mixed with the fine-grained mineral fraction. *Syn.*, mull humus

**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.

**nanocomposite, organoclay** an organoclay with at least one dimension in the nanometer range dispersed in a polymer (e.g. nylon-6 clay-nanocomposites; see Gilman et al., 1997). The less hydrophilic surface of organoclays facilitates dispersion in a polymer. Dispersing ~5% organoclay in a polymer can make the polymer more flame retardant and improve the physical properties. See Gilman et al., 1997; Picken et al., 2008; Ruiz-Hitzky and Van Meerbeek, 2006. *Cf.*, organoclay, organoclay microcomposite

**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.

**natural peloid** see peloid

**Néel temperature** see antiferromagnetism

**neo-cutan** see hypo-coating

**neof ormation** The phenomenon by which secondary minerals are formed by crystal growth entirely from solutes without any incorporation of pre-existing structural components from other preexisting (parent) minerals. See inheritance, transformation

**Nernst Equation** a model to determine the equilibrium reduction potential of a half-cell in an electrochemical cell, such that  $E_{\text{red}} = E_{\text{red}}^{\circ} - (RT/zF) \ln(a_{\text{red}}/a_{\text{Ox}})$ , where  $E_{\text{red}}$  = half-cell reduction potential,  $E_{\text{red}}^{\circ}$  = standard half-cell reduction potential,  $R$  = ideal gas constant,  $T$  = absolute temperature,  $z$  = number of electrons transferred in the half-cell,  $F$  = Faraday constant,  $a_{\text{red}}$  = activity of the reduced species, and  $a_{\text{Ox}}$  = activity of the oxidized species. An alternative form of the equation can be used for the total cell potential where  $E_{\text{cell}} = E_{\text{cell}}^{\circ} - (RT/zF) \ln Q$ , where  $E_{\text{cell}}$  is the cell potential or electromotive force,  $E_{\text{cell}}^{\circ}$  is the standard cell potential,  $Q$  is the reaction quotient, and the other parameters are given above. The Nernst equation is most useful for dilute solutions because concentrations are approximately equal to activities. The equation only applies where there is no current flow at the electrode and also because concentration is approximately equal to activity. Otherwise, corrections must be applied.

**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

**nodule** see glaebole

**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, Fe<sup>3+</sup>) or medium size (e.g., Mg, Fe<sup>2+</sup>, 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

**organan** see cutan

**organoclay, grafted compound-type** see organoclay

**organoclay, organophilic** Using organic contaminant adsorption isotherms and sorptive behavior, organophilic-type organoclays (which produce simple, linear isotherms) are defined as having large exchanged organic-cation alkyl groups. These groups seem to act as a solvent phase (e.g. partitioning phase, i.e., solubilized), but are located in the interlayer, to adsorb organic contaminants (Jaynes and Boyd, 1991b). a) Synthetic systems. These clays are prepared from smectite or vermiculite by using large quaternary (> C-10) organic cations, such as hexadecyltrimethylammonium (C-16) or dioctadecyltrimethylammonium (C-18). These higher charge clay minerals (e.g., vermiculite, illite, high-charge smectite) adsorb greater numbers of large organic cations and yield organoclays that are more effective in absorbing organic contaminants compared to the unmodified clay. See also Boyd and Jaynes (1994). b) Natural systems. Soil organic matter and organic compounds adsorbed to (internal or external) clay-mineral surfaces can act as a solvent phase for organic contaminants dissolved in water. Organic compounds (e.g., benzene, toluene, xylenes in gasoline) are more soluble in soil organic matter or the organic phase derived from organic compounds adsorbed to mineral particles than in water. Nonionic organic compounds may be partitioned (i.e. solubilized) into soil organic matter; see Chiou *et al.* (1979). *Cf.*, organoclay, adsorptive; organoclay

**organoclay, adsorptive** Based on organic contaminant adsorption isotherms and sorptive behavior, the adsorptive-type organoclays (generally producing nonlinear and Langmuir-type isotherms) have exchanged organic cations that act as interlayer props to hold the interlayer open. This arrangement facilitates additional organic contaminant adsorption onto the siloxane surfaces, which are relatively hydrophobic except near exchangeable cation sites (Chen, 1976; Jaynes and Boyd, 1991a). These clays are prepared from smectite by replacing inorganic

exchangeable cations with small organic cations, such as tetramethylammonium or trimethylphenylammonium. Lower charge clay minerals (i.e., lower charge smectite) with adsorbed small organic cations yield organoclays that more effectively adsorb organic contaminants compared to the unmodified clay. See Boyd and Jaynes (1994). *Cf.*, organoclay, organophilic; organoclay.

**organoclay** a phyllosilicate, typically smectite, vermiculite, or kaolin, but also other minerals (e.g., double metal hydroxides) with sorbed organic molecules, such that the properties of the mineral 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. In alkylammonium organoclays, alkylammonium cations replace inorganic cations, and these organic cations are bonded to the layers via electrostatic (= Coulombic) forces. In organophilic alkylammonium organoclays where large organic cations completely fill the interlayer, van der Waals interactions between the alkyl groups augment the Coulombic forces, which increase both adsorption and organoclay stability. Adsorptive type organoclays have small organic cations that partially fill the interlayer, are stabilized by Coulombic forces, and act as pillared materials where there are accessible areas between the pillars for additional adsorption. These pillars increase surface areas relative to untreated clay or organophilic clays. In grafted compound-type organoclays with organic compounds such as silanes in the interlayer, bonding to the clay layer is covalent. Organoclays with adsorbed neutral polymers are attached to the clay layer by weak multiple dipole-induced dipole type bonds. In organoclays prepared from charged polymers, such as proteins, the polymers are bonded by both electrostatic and dipole-induced dipole bonds. Organoclays can be used as adsorbents, thickening and thixotropic agents, in nanocomposites, and in new materials with catalytic, optical, and electronic properties (Lagaly et al., Ogawa, and Dékány, 2006). *Syn.*, organo-clay, clay-organic complex; *Cf.*, organoclay, adsorptive; organoclay, alkylammonium; organoclay, organophilic alkylammonium phyllosilicate; pillared clay; phyllosilicate

**organo-peloid** see peloid

**organophilic** a characteristic property of a clay whereby the clay can sorb an organic solvent. These clays are usually surface modified, commonly by sorbing various quaternary ammonium compounds, which allow the clay to swell in organic liquids. See organoclay, *Cf.*, organophobic

**organophilic organoclay partition phase** see organophilic, organoclay

**organophobic** a characteristic property of a clay whereby the clay repels an organic liquid. Most naturally occurring clays are organophobic and are not wetted by nonpolar organic liquids. See organoclay, *Cf.*, organophilic

**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  $(Al_{3.15}Mg_{0.85})Si_8O_{20}(OH)_4X_{0.85} \cdot nH_2O$  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 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.

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

**overburden** In mining, overburden refers to the unusable material(s) that is above the ore of interest. Overburden may be removed or left in place (by tunneling below it).

**palliative** Palliative refers to the relief of pain (or more generally, other side effects of an illness), but without treatment of the underlying condition. Clay baths (*balnea*) are commonly used as a palliative treatment for chronic pain (e.g., arthritis).

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

**papule** A pedofeature formed by fragments of laminated clay coatings. See pedofeature.

**paraffin complex** see alkylammonium organoclay paraffin complex

**parallel striated b-fabric** see b-fabric

**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

**paramud** hydrated clays mixed with paraffin, heated to 40-45°C before topical application in a <5 cm thick layer for ~30 min. Paramud applications are usually covered by a non-permeable cover to conserve heat. The procedure is often claimed to result in moisturizing the skin and opening pores.

**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

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

**ped** individual, natural soil aggregates composed of primary particles that form a soil structure. Adjoining peds are separated by planes of weakness formed by voids or cutans.

**ped, primary** A ped that can not be divided into smaller peds is a primary ped. Several primary peds may be packed together to form compound peds (referred to as secondary and tertiary peds). *Cf.*, ped

**pedofeature** A pedofeature refers to a unit fabric in a soil that is easily differentiated from the adjacent fabrics by a difference in concentration of a component, such as variations of chemical (e.g., organic, ferric iron, manganese) components, grain-size fraction, or internal fabric. The b-fabrics are commonly not considered as pedofeatures. See b-fabric, cutan, papule

**pedoplasma** see soil plasma

**pedoplasiation** production and redistribution (either physical or chemical) of soil plasma during soil formation and development. See soil plasma

**peloid** a matured mud or muddy dispersion composed of a mixture of fine-grained material (commonly clay), mineral water (or sea water) and often organic compounds that result from biological metabolic activity, with healing and/or cosmetic properties. Peloids involve a maturation or ageing process, which may occur naturally, although commercially available peloids are often processed for weeks to several years in special ponds, typically containing mineral waters or brines of varying composition. Based on the composition of the fine-grained components, the terms inorganic peloid (phyllo-peloid, sulpho-peloid), organic peloid (organo-peloid), and mixed peloid have been proposed. Also, see mudtherapy, pelotherapy, peloid

maturation. *Cf.*, ageing. *Syn.*, matured mud

Various types of peloids have been described:

*natural peloid* a healing mud formed in the natural sedimentary environment and used at the source. *syn.*, healing mud

*phyllo-peloid* an inorganic peloid mostly composed of clay-sized phyllosilicates.

*sulfo-peloid* or *sulpho-peloid* an inorganic peloid mostly composed of sulfur or sulfide minerals.

*organo-peloid* a peloid composed primarily of organic-rich materials (e.g. peat).

**peloid maturation** a process that occurs with the intimate blending of fine-grained materials (commonly clays and/or organic material) with medicinal mineral water or sea water for variable periods of ageing. Biological activity during maturation may play a role in enhancing healing properties and in shortening ageing time. Cation exchange between minerals and water may also occur during maturation, affecting the fluid chemistry, and this may enhance the physical properties (e.g. plasticity) of the suspensions.

**pelotherapy** therapies involving the use of peloids (muds or poultices). *Cf.*, active principle, aesthetic medicine, antibacterial clay, geotherapy, healing clay, medicinal clay, peloid

**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

**percutaneous migration** As applied to clay science, percutaneous migration refers to the diffusion of elements from clay poultices (peloids) through the skin.

**peripheral replacement** Replacement of a reactant mineral by a product mineral beginning at the outermost margin of the reactant mineral's grain or fracture-bounded remnants. See centripetal replacement.

**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

**petrographic microscope** an optical (transmitted visible light) microscope with polarizing filters

or prisms along the optical path. The petrographic microscope is commonly used to examine thin sections and grain mounts. See thin section, crossed Nichols, plane light.

**pH** the negative logarithmic ( $\log_{10}$ ) measure of hydrogen ion ( $H^+$ ) 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 ( $H^+$ ) and hydroxide ( $OH^-$ ) 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.

**pharmacognosy** The branch of knowledge concerned with medicinal drugs derived from natural products. This knowledge base includes the study of physical, chemical and biological properties of natural substances, for example, clays and clay minerals, used medicinally.

**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.

**phase** a part of a system with distinct chemical and physical properties that is mechanically separable from other parts of the system

**phenyltrimethylammonium organoclay** see trimethylphenylammonium organoclay

**phyllo-peloid** see peloid

**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

**physical weathering** the breakdown of rocks to fragments through primarily non-chemical processes. Non-chemical processes may include, but are not limited to, ice and/or root wedging, thermal expansion, stress release (e.g., exfoliation), and physical consequences of crystal wedging, and volume change caused by hydration and/or dehydration. Physical weathering may be biologically influenced. See weathering, chemical weathering

**pica** a disorder involving the eating of material that does not have nutritional value. Pica is the more general term for the eating of odd things, such as clay, ice, hair, starch, etc. *Cf.*, geophagy

**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 (Al<sub>13</sub>, inorganic). Other types of layered materials can also be pillared. See Keggin ion. *Cf.*, zeolite

**PL or PPL** see plane light

**plane of vibration** see plane light

**plane polarized light** see plane light

**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

**plane light** Polarized light, or plane light, is light that vibrates within a single plane (“plane of vibration”) which is defined as the plane parallel to the ray’s path and its vibration direction. The polarized light results from the introduction of a single polarizing device into the optic path of a petrographic (polarized light) microscope, with the plane of vibration obtained from the privileged direction of the polarizer. See petrographic microscope. *Abbr.* PL, or PPL (plane polarized light).

**plasma, soil** see soil plasma

**plasma** see soil plasma

**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.

**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.

**plug flow reactor** a column or cylindrical reactor used to describe the reaction kinetics within a continuous, flowing system. *Cf.*, batch reactor, chemostat, continuously stirred tank reactor

**pneumatolitic** a petrologic term that refers to alteration or crystallization involving a gas phase, typically forming from cooling magma.

**podoconiosis** derived from the Greek *podo* (foot) and *konia* (dust), and refers to a condition in which some nano-particles enter the bloodstream through skin causing a condition characterized by gross enlargement of areas of the body (mostly limbs) by blockage of the lymphatic system or by a non-parasite immune system response. This condition is similar to elephantiasis, which is caused by parasite blockage of the lymphatic system. *Syn.*, nonfilarial elephantiasis

**point defect** Point defects are structural imperfections that occur at a specific point within an atomic structure, and may produce a variation in the ideal chemical composition of the crystal. “Schottky defects” occur where a vacancy replaces a cation or an anion from their ideal sites in an atomic structure. In such cases, charge neutrality must be maintained, and thus for example, where a cation is replaced by a vacancy either higher valence cations must be substituted for lower valence cations or a corresponding anion must be replaced by a vacancy. “Frenkel defects” involves a misplacement of a cation (“cationic Frenkel defect”) from its site to an interstitial position where a site does not normally reside. Like the Schottky defect, the Frenkel defect must involve charge neutrality (for example, producing a “cationic Frenkel defect” and an “anionic Frenkel defect”). “Impurity defects” affect the chemical composition of the crystal and involve an atom or ion of a different type either in place of an atom or ion that belongs to the crystal or in an extraneous (interstitial) position. An “*F* center defect” in alkali halides involves a trapped electron in an otherwise vacant site that was formerly occupied by an anion. This defect is thought to cause a color change in the halide. *Cf.*, line defect

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

**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.

**polarized light** see plane light

**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

**polynuclear complex** see binuclear complex

**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

**popcorn texture** Popcorn texture is a term for a macro-texture observed on exposed and weathered clay surfaces commonly associated with deposits of sodium bentonite (usually on open-pit mine-faces, bed outcrops, or stockpiles). These high-swelling bentonites develop irregularly rounded lumps resembling mounds of popped corn caused by successive periods of swelling and shrinkage from the cyclical uptake and loss of water within the clay. See also alligator skin texture.

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

**porostriated b-fabric** see b-fabric

**porphyric c/f-related distribution** see c/f-related distribution

**poultice** a moist, often medicated, mass applied to a wound or a painful area to reduce pain or to help in healing. The medicated mass may produce soothing vapors to aid in healing. Poultices are commonly hydrated clays, often bentonite. Poultices are also used to dissolve stains from porous decorative stone by the long-term application of a solvent via the poultice. *Syn.*, cataplasm

**primary mineral** A primary mineral is a mineral of igneous, metamorphic or sedimentary origin now residing in weathering, sedimentary, diagenetic or hydrothermal environments where many alteration processes operate. A primary mineral is present in the parent rock; thus, in soils and other weathering or alteration environments, a primary mineral is one that remains from the parent rock whereas a secondary mineral is one that forms as the rock weathers. *Cf.*, secondary mineral

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

**proper rotation axis** see rotation symmetry

**pseudoglobular microfabric** see microfabric, clay

**pseudomorph** A pseudomorph is an alteration product of a crystal that preserves the external euhedral crystal form of the precursor mineral. The pseudomorph may have a different chemical composition and/or crystal structure than the precursor crystal. The pseudomorph can result from replacement of the original structural bonds by formation of new bonds that minimize the energy toward equilibrium in response to changes in the chemical (T, P, X) environment. *cf.*, alteromorph, centripetal replacement

**pseudotrilinear** see alkylammonium organoclay pseudotrilinear

**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

**quasi-coating** In micromorphology of soils, quasi-coating is a pedofeature that consists of a layer of material related to surfaces (i.e., voids, grains, aggregates) but not immediately adjacent to the surface. *Syn.*, quasi-cutane. *Cf.*, hypo-coating

**quasi-cutan** see quasi-coating

**quaternary alkylammonium salt** alkylammonium salts, such as hexadecyltrimethylammonium bromide, have four alkyl or methyl groups attached to nitrogen with a permanent positive charge. The similar n-hexadecylamine hydrochloride used in the alkylammonium layer charge method is only positively charged in neutral to acidic solutions. See alkylammonium layer charge method

**quaternary phosphonium salt** a quatery organic salt based on the phosphonium ( $\text{PH}_4^+$ ) ion. Tetramethyl phosphonium chloride is the phosphonium analog of tetramethyl ammonium chloride. *Cf.*, quatery alkylammonium salt

**quick clay** Landslide-prone, silty-clay to clayey-silt size sediments that become liquid upon failure (shear strength  $<0.5$  kPa). Pre-failure strength exceeds post-failure strength by 30 (minimum) to hundreds of times. Quick clay is not thixotropic; it cannot reform after failure. 'Quick clay' applies only to the undisturbed material.

Quick clays of Scandinavia, Eastern and Western Canada, and Alaska developed in fine-grained, glacial rock flour that accumulated in marine and brackish water during Pleistocene glacial retreat (Torrance, 2012). The salt induced a flocculated microstructure that gained strength as additional sediment accumulated. The water content approximates the high-salinity liquid limit of the sediment. Quick clays in the down-glacial-flow direction from the magnetite-rich, iron-ore deposits of Quebec and Labrador gained unusually high undisturbed strengths owing to iron-oxide cementation. Isostatic uplift elevated the deposits above sea level, and an oxidized weathered crust formed. In broad, level areas, downward percolation of rain displaced the salty pore waters. In areas adjacent to uplands, artesian pressures have displaced the salt upwards to the surface drainage system. The oxidized zone is thinner where salt removal was upward than where it was downward. During salt removal, the structure and water content remained nearly unchanged, whereas the liquid limit of the sediment decreased to its low salinity value, and the liquidity index increased from about 1.0 (high salinity) to 1.2 – 4+ (low salinity). At liquidity indices  $>2$ , the thoroughly disturbed material flows like motor oil.

Chemical, mineral and microstructural factors are critical to quick-clay development. The mineralogy must be dominated by "low activity minerals" (illite, chlorite, quartz, feldspars, amphiboles, iron oxides, and carbonates). Other requirements include: flocculated microstructure (salt-induced), leaching of salt (which decreases the liquid limit), and reducing conditions that inhibit the formation of swelling clays. Experiments to produce quick clay using 'pure' clay, such as illite, have been unsuccessful, but using dispersed material from what had once been 'quick clay' has succeeded. Whereas non-swelling phyllosilicates must be present, clay-sized primary minerals also appear to be necessary.

A mineralogical variant is a quick clay that developed contemporaneously in marine sediment in Japan that is dominated by low-activity ( $<1.1$ ), high-ferrous-iron, non-swelling clay, and volcanic ash (Torrance and Ohtsubo, 1995). However, where oxidizing conditions develop that allow conversion of the ferrous iron to ferric iron to decrease the layer charge sufficiently to produce a swelling smectite, the resultant liquid-limit increase renders the oxidized zone no longer 'quick'. *Cf.*, liquid limit, liquidity index, plasticity index, quick-clay landslide, shear strength, thixotropy, Udden-Wentworth scale.

**quick-clay landslide** A landslide in which quick clay plays an important role. They usually start with a small triggering landslide along a riverbank or terrace, but may also be triggered by human actions or earthquakes. “Flow quick-clay landslides” occur where a substantial depth (a few meters, or more) of quick clay underlies a relatively thin surface-weathered zone. Flow failures commonly occur stepwise and retrogressively over a substantial time period (minutes to more than an hour). The liquid debris carries the thin crust out of the landslide scar and along the river valley. Very little debris remains within the scar. Flows are the norm in Scandinavia and constitute about half of the quick-clay landslides in eastern North America. In “spread quick-clay landslides”, the non-quick overburden is thicker and the large chunks of crust are difficult to transport. Once failure is initiated, the failure plane advances rapidly into the quick-clay zone and, as the quick clay liquefies and starts to move, the overburden breaks into a series of slices that are oriented perpendicularly to the direction of movement. In most cases, a large proportion of the landslide debris remains within the landslide scar. Ridges of nearly intact slices alternate with zones of liquid and plastic debris to create a ribbed, horst and graben-like topography. Spread-type landslides are rapid (tens of seconds to minutes in length). *Cf.*, quick clay

**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., clinochlore, 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

**reaction order** The order of a reaction is empirically observed and determined by the sum of the powers of the concentrations of the rate equation. If the rate of a reaction,  $R$ , is proportional to the concentration of one species,  $R = k[A]$ , where  $k$  = constant and  $[A]$  = concentration of species A, then this is a first-order reaction. A second-order reaction may have a rate equation of

$R = k[A][B]$  for two reactants, A and B, and the powers of each sum to  $1 + 1 = 2$ . Sometimes, the rate determining step can be deduced from knowing the reaction order of a series of reactions.

**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 material** A refractory material retains its chemical and physical properties at high or very high temperatures (ASTM, v. 15.01 indicates high temperature at  $>1,000$  °F). The high-temperature materials are generally non-metallic and are commonly composed of, but not limited to, oxides of aluminum, calcium, magnesium, and silicon. Refractory materials are common in linings for furnaces, kilns, and incinerators, and are used in some crucibles. Fire clays are often used to manufacture refractory materials. See fire clay

**refractory clay** see fire clay, refractory material

**regolith** crustal material above unweathered bedrock, including unweathered rock where it is entirely surrounded by unconsolidated or weathered natural material. The term is not related to

the geologic age of the bedrock, the individual constituent materials of the regolith, or the formation or assembly of the ensemble of constituent materials.

**regular volatile matter (RVM)** an industrial term referring to dehydration of untreated, porous clay until it contains between ~5 - 20 wt % free moisture, with dehydration achieved by heating below or near the boiling point of water (< 105 °C) to preserve the integrity of the clay and to create empty pore spaces so that the material may resorb fluids.

**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

**relict soil** a soil formed on a preexisting landscape under a previous pedogenetic regime, and not subsequently buried by geologically younger materials. See also paleosol.

**remolded quick clay** “Remolded quick clay” refers to the material after the flocculated microstructure of the quick clay has been destroyed. By definition, remolded quick clay behaves as a liquid. The flow properties of remolded quick clay are required for analysis of the flow behavior of landslide debris as it leaves the landslide scar and flows. Most remolded quick clays behave in the ‘modern viscometric’ thixotropic manner of shear resistance increasing and decreasing, respectively, as the shear rate increases and decreases. The change is never more than a trivial portion of the quick clay strength prior to collapse. Remolded silt-rich, quick clay may exhibit extreme dilatancy at high shear rates, leading to shear blockage. *Cf.*, quick clay, quick clay landslide, dilatancy

**reticulate striated b-fabric** see b-fabric

**reticulate** a texture visible at hand-specimen or thin-section scale in which one generation of secondary minerals or soil plasma is arranged in a net or network geometry. See soil plasma

**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.

**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

**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 pseudo-hexagonal  $a$  or  $b$  axes (commonly along  $a$ , and very rarely along  $b$ ) of the layer silicate. See *turbostratic stacking*

**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

**rubification** a weathering process wherein minerals in a soil release iron which subsequently precipitates to form free iron oxides, such as hematite (red) and goethite (yellow brown), to produce reddening of a soil horizon.

**RVM** see regular volatile matter

**safety glass** see tempered glass

**saprolite** A residual, sedentary, *in situ* regolith developed by chemical weathering of rocks, most often primary crystalline (igneous and metamorphic) bedrock. Saprolite preserves parent-rock textures in the form of abundant, predominantly argillaceous, and commonly pseudomorphous weathering products of individual primary minerals. Preservation of parent-rock mineral textures and fabrics in saprolite is often associated with high microporosity and may be a consequence of isovolumetric weathering. Saprolites are typically some meters thick but can be hundreds of meters thick.

**saturation index** a measure of how far from equilibrium a solution is with respect to a given mineral. The saturation index,  $SI$ , is determined from  $SI = Q/K_{eq}$ , where  $Q$  is the reaction quotient and  $K_{eq}$  is the equilibrium constant, often given as  $\log_{10}(Q/K_{eq})$ . When  $SI = 0$ , then the system (water + mineral) is at equilibrium, if  $SI < 0$ , the mineral will dissolve, and if  $SI > 0$ , then the mineral will precipitate.

**Schottky defect** see point defect

**screw dislocation** see line defect



**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 ° rotation followed by a 1/4 cell translation, with the process continuing until closure. Cf., rotation symmetry, rotoinversion axis, symmetry, unit cell

**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)

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

**secondary mineral** a mineral formed by an alteration process; the chemical constituents of a secondary mineral may be derived from the decomposition of a primary mineral and/or derived from outside the system during the alteration process. Cf., primary mineral

**secondary crystal growth** crystal growth from nanoparticles to larger particles that occurs by an assembly of aggregates, sometimes known as “oriented attachment”.

**self-activating clay** an organoclay + organic solvent with an optimum gel strength that has not been augmented by additives, such as polar molecules (e.g., ethyl alcohol, acetone, propylene carbonate). See gel strength, organoclay

**self-dispersing clay** Self-dispersing organoclays are clays that have additives to develop viscosity at much lower shear and energy input than other, non self-dispersing organoclays. An example of additives to form an appropriate complex are EDTA(ethylenediaminetetraacetic acid) and dimethyldihydrongenated tallow quaternary ammonium. This molecule intercalates into the organoclay and props the interlayer open to allow exfoliation.

**sensitivity (St)** A geotechnical term that evaluates the degree of strength loss when natural silty-clay and clayey-silt size sediments are thoroughly disturbed by natural or human actions. Sensitivity (St) of sediments is the ratio of the undisturbed in-situ shear strength to the shear strength after thorough remolding. Generally, the higher the sensitivity, the greater the geotechnical challenge, for example, in leading to flow landslides or excessive consolidation.

**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”.

**sesquan** see cutan

**shale** Shale is a mudrock with a high proportion of clay and silt sized particles, that usually exhibits lamination and fissility. When blocky and non-fissile the mudrock is named mudstone. *Cf.*, mudstone.

**shear strength** In soil science, shear strength is a measure of the ability of a soil to resist failure along a surface when subjected to a critical combination of shearing and normal forces. The shear strength has cohesive (commonly related to clay content) and frictional components (related to the interaction of angular particles). Pore water pressures also play a role.

**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

**shrinkage** a ceramics industry term describing the reduction in size of a solid body relating to dehydration during initial drying and/or devolatilization during the final firing stage of making the ceramic body (e.g., bricks, whiteware, sanitary articles, porcelain, and stoneware).

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

**silan** see cutan

**silane coupling agent** a class of reagents characterized by a central silicon atom coordinated tetrahedrally to four R groups. Such compounds are commonly used to bond an inorganic substrate, such as clay minerals, to a polymer. In the most reactive form, two or three of the R groups are chlorine atoms and the remaining are organic groups. The chlorine atoms in these compounds are very reactive with water and hydrolyze readily to form condensation polymers with Si-O-Si backbones, or the chlorine atoms can react with hydroxyl groups on clay mineral surfaces with loss of HCl. A less reactive form has two or three of the R groups as methoxy or ethoxy groups with the remaining R group being another nonlabile organic group. These silanes

can be hydrolyzed to form similar polymers or reactions with hydroxyls on clay minerals, but generally require heat and vacuum to drive the condensation reaction. These agents allow the surface of hydroxyl containing compounds to be converted to hydrophobic or reactive surfaces depending on the character of the organic R group.

**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*

**silica** Silica refers to SiO<sub>2</sub> chemical composition only and the term does not connote structure. The term commonly is used to describe a mineraloid or a glass, as in a silica-rich glass. Thus, silica does not specifically refer to quartz or opal (but opal has a structure involving small, non-crystalline silica spheres). *Cf.*, mineraloid

**silt** A general term for any non-consolidated, clast-rich material that consists of >50% primary particles with diameters of 4-63 μm (American geologists), 2-63 μm (European geologists), or 2-50 μm (American soil scientists). See siltstone

**siltstone** A sedimentary rock with primarily silt-size components; siltstone rocks may show sedimentary structures, such as flow structures and cross-bedding. Siltstones are often, but not always, chemically cemented. See mud, mudstone, silt

**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.

**skeletal microfabric** see microfabric, clay

**slake** see slaking

**slaking** the breakdown of large soil or clay material aggregates (typically >2-5 mm) or fine-grained sedimentary rock rich in clay into small particles (<0.25 mm) when rapidly immersed in water. Slaking occurs when aggregates are not sufficiently strong to withstand internal stresses caused by rapid water uptake into the pore structure or fabric of the aggregate. Internal stresses result from differential swelling of clay particles, trapped and escaping air from pores, rapid release of heat during wetting, and the mechanical action of moving water. Slaking is influenced by the presence of smectitic clays (either smectite, especially Na-montmorillonite, or interstratified clay with a smectite component) that shrink when dry and swell when wet. Organic matter often reduces slaking by binding the particles or by slowing the rate of surface wetting.

**slip** See blunging

**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

**soil plasma** In soil science, plasma refers to fine-grained (too fine to resolve individual constituents by visible-light microscopy) crystalline or amorphous materials in soils, which includes saprolites. See saprolite, clay groundmass, *Syn.* pedoplasma

**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  $(\text{Mg,Fe})_2\text{SiO}_4$ , represents a chemical variation (i.e., solid solution) between two end members, forsterite  $\text{Mg}_2\text{SiO}_4$  and fayalite  $\text{Fe}_2\text{SiO}_4$ , where Mg and Fe can substitute for one another in two atom sites. The chemical formula may be written as  $\text{Mg}_{2-x}\text{Fe}_x\text{SiO}_4$ , 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, limited**, see solid solution

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

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

**solid solution, interstitial**, 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

**soluan** see cutan

**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.

**sorbent** a generic term for materials displaying a high degree of absorptive and/or adsorptive physicochemical properties, often useful in consumer or industrial applications.

**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.

**specific heat capacity** see heat capacity

**speckled b-fabric** see b-fabric

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

**sponge microfabric** see microfabric, clay

**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.

**spread quick-clay landslide** see quick-clay landslide

**stability constant** see intrinsic stability constant

**state function** In thermodynamics, a state function is one that is not dependent on the path (i.e., history) that the system has undergone and is only dependent on the state of the system as determined by temperature, pressure, volume, etc. at a particular moment.

**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  $\Sigma_{\text{Diffuse}}$  is the charge density of the diffuse double layer formed in the solution. See diffuse double layer

**stipple-speckled b-fabric** see b-fabric

**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

**strata** plural of stratum; see stratum.

**relict soil** A soil formed on a preexisting landscape but under a previous pedogenetic regime, and not subsequently buried by geologically younger materials. See also paleosol.

**stratum** a layer of sediment or sedimentary rock (pl. strata).

**strial b-fabric** see b-fabric

**striated b-fabric** see b-fabric

**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.

**sulfo-peloid** see peloid

**superheating** an industrial term for the high-temperature heating of porous clays to remove adsorbed water by volatilization, in addition to partial dehydroxylation (structural water) of the clay minerals present. For most clay minerals, the point where the rapid loss of structural water first occurs is often referred to as the onset of LVM characteristics. Termination of heating at this or a somewhat higher temperature commonly generates a material whose porous bulk fabric remains intact and which does not readily slake in water. Unlike calcination, which implies a complete dissociation reaction, superheating produces limited dehydroxylation without destroying plasticity (i.e., without destroying clay-like properties). Thus, LVM clays will still display a measurable weight loss on ignition. *Cf.*, low volatile matter (LVM); slake; calcine; loss on ignition; water, adsorbed; water, structural; water, zeolitic

**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.

**surface** a boundary, planar or near planar, between two phases. The term is often used to connote planar or near planar interfaces between a condensed phase (solid) and gases, liquids, or other solids, or between any two phases (e.g., liquid-liquid, gas-gas, liquid-gas). Surfaces generally have an interfacial energy term and a chemical compositional gradient existing from the surface, and a discrete molecular entity or multi-component substance may exist on or at the surface. In clay science, clay surfaces include “external surfaces” where there are broken bonds at particle edges and “internal surfaces” at the junction between the layer and the interlayer. The external surfaces include the broken-bond particle edges and the terminating basal surface. Internal surfaces, although a term commonly used in clay science, may not strictly adhere to the above definition because the material (or lack of material) in the interlayer is not necessarily a “phase”, but the atomic arrangement (or its behavior) in the interlayer is sufficiently distinct from the layer that the term is useful (e.g., the discrete molecular entity or multi-component substance addressed above). Internal surfaces are readily accessible to the environment outside the particle (often owing to the small particle size) and may have characteristics consistent with the permanent layer charge of the particle and interlayer cation size and charge. Environmental characteristics, such as water activity (e.g., pH, relative humidity), solute concentration, etc., may influence the behavior of the internal surface. External surfaces are also affected by environmental characteristics, but often the broken bonds affect the characteristics/structure of the electrolyte nearest the external surface. *Cf.*, interlayer, layer, phase

**surface-controlled growth dissolution** ‘surface controlled’ growth or dissolution requires the rate-determining step in the growth or dissolution reaction to occur at the mineral surface; this rate-determining step is in the form of an attachment to or a detachment from the surface of a metal or metal-ligand ‘activated complex.’

**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 >1µm. 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. See blunging.

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

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**swelling clay mineral** a clay mineral that can sorb large amounts of water and thereby expands in volume. Both vermiculite and smectite are swelling clay minerals. *Cf.*, swelling clay.

**swelling clay** a clay that can sorb large amounts of water and thereby expands in volume. The swelling clay minerals, smectite and vermiculite, if they occur as fine-grained material, are referred to as “swelling clays”. In industry, bentonites are commonly referred to as “swelling clay”. Some clays that are referred to as “swelling clays” have been shown to be dominated by clay minerals characterized by interstratifications of two varieties of phyllosilicate layers, one being expandable via adsorption of H<sub>2</sub>O and one not, as in “swelling chlorite” which is interstratified chlorite and smectite. *Syn.*, expandable clay; *Cf.*, swelling clay mineral

**symmetry plane** see mirror plane

**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

**syngenetic** material formed contemporaneously with rocks that are associated or enclose material

**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

**system** a region of space within the universe. Systems are considered in thermodynamic or other studies to determine how a change in the environment (e.g., temperature changes, pressure changes, etc.) will affect the system. Systems may be closed by encapsulating in noble metals, placing a liquid in a sealed beaker, etc. A “closed system” is affected only by receiving energy from or giving energy to the outside environment. An “open system” differs from a closed system by an exchange of matter, in addition to energy. An “isolated system” receives neither matter nor energy across the boundary.

**system, closed** see system

**system, isolated** see system

**system, open** see system

**tactoid** In the context of polymer/clay nanocomposites, a tactoid is any collection of “primary” (i.e., the smallest division of the phyllosilicate particle that retains the chemical character of the compound, either a 1:1 or 2:1 layer), colloidal-size clay particles, which are essentially acting as a unit.

**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 ~ 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  $[O_{20}(OH)_4]$  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  $(Al_{3.15}Mg_{0.85})Si_8O_{20}(OH)_4X_{0.85} \cdot nH_2O$  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 cm<sup>2</sup>)

**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

**tetragonal** see crystal system

**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  $T_2O_5$  (T = Si, Al,  $Fe^{3+}$ , Be, B...). After Guggenheim *et al.* (2006); see also references therein. *Cf.*, octahedral sheet

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

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

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

**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.

**thermodynamics** the study of energy (potential, kinetic and internal energy) and its conversion to heat (involving work, determining forces, energy transfer, etc.) to characterize systems. Chemical thermodynamics considers energy changes that occur from reactants to reaction products or with physical changes of state during a chemical reaction. Thermodynamics considers macroscopic qualities (temperature, pressure, volume, composition, etc.) and does not provide mechanistic (atomic theory, atomic structure, molecules, etc.) understanding.

**thin section** Material, such as a sliced piece of mineral material, rock material, or soil material, that is mounted on a glass microscope slide, and placed in the optical path of a polarizing (petrographic) microscope is referred to as a “thin section”. The standard thickness of the material mounted on the glass is 30  $\mu\text{m}$ . See petrographic microscope.

**thixotropy** a) In the classic sense, thixotropy refers to a material that exhibits reversible sol-gel-sol-... behavior. For example, ‘chemically modified’ bentonite drilling muds used by the petroleum industry are thixotropic. The property prevents the granular material (“cuttings”) produced during drilling from settling out when drilling is stopped (briefly, or for substantial periods), thus preventing the drill rod from seizing. b) The ‘modern viscometric’ meaning refers to the increase in shear resistance when the shear rate is increased, and the decrease when the shear rate is reduced. Most thoroughly dispersed clay materials above some relatively low concentration exhibit this phenomenon. *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

**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

**trace element** Mineralogical term: an element found in small quantities in a mineral and not considered essential because it is not required for the structure to exist. A trace element is not quantitatively defined, but is generally considered to be <1wt. %. b) Medical/biological term: an element that occurs in animals or plants in small quantities and is required for physiological health. *Cf.*, essential trace element

**transformation** The phenomenon by which primary minerals in general, and chain silicates and phyllosilicates in particular, alter usually by weathering to secondary minerals through the direct incorporation and reuse of some part of the structure of the parent mineral. Products of transformation reactions are often pseudomorphous or alteromorphous after the primary reactant (parent) mineral, and often exhibit regular crystallographic and orientation relations with the reactant mineral. See neof ormation, inheritance

**Transition State Theory (TST)** If an energetically unstable complex is present, TST states that a transitional state, or activated complex, occurs. This activated complex is a transitional state between the reactants and products, and is considered a hypothetical way to develop or explain the kinetics of, most commonly, a single-step (elementary) chemical reaction. The transitional state represents an energy barrier that must be overcome for mineral growth or dissolution. *Cf.*, molecularity

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

**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

**trimethylphenylammonium organoclay** Low-charge smectite (e.g., SWy-1, SWy-2) treated with trimethylphenylammonium chloride (= phenyltrimethylammonium chloride) or

trimethylammonium chloride yield organoclays that can effectively remove nonionic organic contaminants from water (Lee et al., 1990; Jaynes and Boyd 1990).

**trinuclear complex** see binuclear complex

**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

**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

**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 ~ -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

**TST** see Transition State Theory

**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

**turbulent microfabric** see microfabric, clay

**Udden-Wentworth scale** The Udden-Wentworth scale (often referred to as the Wentworth scale) is a size scale (diameter) for clasts and is used primarily in sedimentology and related disciplines. The Udden-Wentworth scale considers size only and does not imply composition. The “clay” term in the scale has the potential to be confusing because “clay” is defined in clay mineralogy as having specific properties unrelated to particle size alone. Thus, to avoid confusion, use of “clay size” instead of “clay” is recommended here to delineate size characteristics of particles only. Further divisions, such as “fine”, “medium”, “coarse”, etc. may

be used also. Pettijohn (1957) discusses the history of the use of size terms, alternative classification schemes, and modifications to the nomenclature. See clay

*Udden-Wentworth scale (after Pettijohn, 1957)*

Grade	Scale
boulders	>256 mm
cobbles	64 - 256 mm
pebbles	2 - 64 mm
sand	1/16 to 2 mm
silt	1/256 to 1/16 mm
clay	<1/256 mm

**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

**van der Waals forces** van der Waals forces are residual forces between atomic groups or molecules and are comprised of primarily dispersion and dipole-dipole forces. Dispersion forces, or London forces, involve the temporary formation of polarity where one side of an atom (or molecule) may have more electrons at a given moment than the opposing side. Thus, one side is slightly more negative than the other slightly more positive side (by having a deficiency in electrons). Neighboring atoms have similar polarity, and a weak bond is formed where opposite charges between atoms attract each other.

**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) 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. b) an industrial/commercial commodity obtained from heat-treated naturally-occurring material composed of hydrous phyllosilicates (e.g., vermiculite, hydrobiotite, biotite). This material is heated rapidly to high temperature to cause exfoliation by volume expansion to produce an expanded product of low bulk density. The product involves an intimate mosaic-like intergrowth of dehydrated or partially dehydrated layers and thus is a

heterogeneous mixture of phases. The product resembles vermiculite (*sensu stricto*) primarily based on its physical properties, such as density, some adsorptive properties, and chemical composition. 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

**vittrification** 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 vittrification proceeds, the porosity decreases. Devitrification is the reverse process.

**water, adsorbed** or (**H<sub>2</sub>O**) 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 ( $\text{H}_2\text{O}^+$ ) water (more precisely,  $\text{H}_2\text{O}$  or OH molecules) that is directly bound to cations at crystallographic sites in a crystal structure. This  $\text{H}_2\text{O}$  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 ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ), have structural water coordinated to cations as  $\text{H}_2\text{O}$  (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  $\text{H}_2\text{O}$  molecules present. *Cf.*, water, structural; water, adsorbed

**weathering** the physical (mechanical) and/or chemical breakdown of rock, sediment, and soil in place under the influence of the hydrosphere and/or atmosphere. Biota may influence or control physical or chemical weathering. See physical weathering, chemical weathering. *Cf.*, erosion

**Wentworth scale** see Udden-Wentworth scale

**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

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

**Wulff rule** The Wulff rule or Gibbs-Curie-Wulff Theorem states that when the surface free energy of a crystal is minimized at equilibrium conditions, the perpendicular distance from a given crystal face to the center of the crystal divided by the surface free energy of that face is a constant for all faces of the crystal.

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



**Wyoming 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  $(Al_{3.15}Mg_{0.85})Si_8O_{20}(OH)_4X_{0.85} \cdot nH_2O$  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  $Al_{4.0}(Si_{7.15}Al_{0.85})O_{20}(OH)_4X_{0.85} \cdot nH_2O$ . 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.

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

**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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