clay structure

by Linda Bloomfield

Breaking clay down to its basic structure is great way to understand not only how it was formed, but why you are able to form it the way you do.

Defining the Terms

Elastic Material: A material able to resume its normal shape spontaneously after contraction, dilation, or distortion.

Hydroxyl: A chemical functional group containing one oxygen atom connected by a covalent bond to one hydrogen atom (OH^-).

Ion: An atom or molecule that has lost or gained one or more electrons.

Micron: Micrometer (µm), a unit of length equalling one millionth of a meter.

Octahedral: Solid shape with six corners and eight triangular faces.

Plastic Material: A material that is malleable, can be molded easily, and can permanently hold its shape.

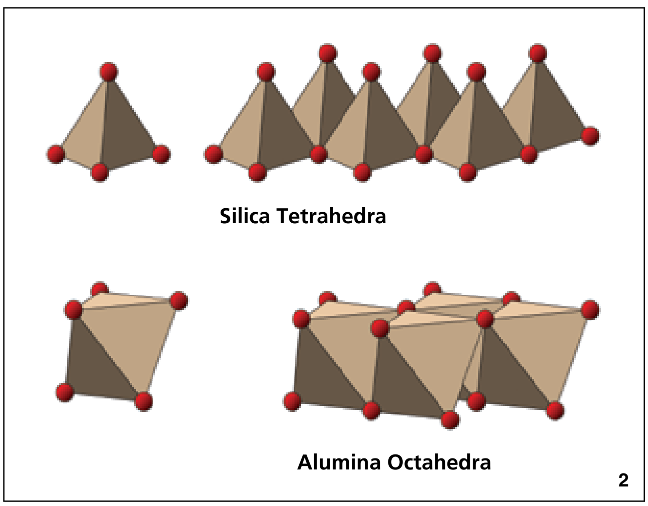
Tetrahedral: Triangle-based pyramid with four corners and four triangular faces.

Structure, Properties, Consituents

Clay is composed of flat, almost hexagonal plates with water in between (1). The plates can slide over each other but also stick together, so that the clay is plastic when wet. This means it can be formed easily but also holds its shape. This is not the same as an elastic material, which returns to its original shape when the force deforming it is removed. The particle size of clay is very small, particularly in sedimentary clays, which have been abraded during transport by rivers or glaciers. The smaller the particles, the more plastic the clay will be. Clays have much smaller particles than sand or silt, and are only a few thousandths of a millimeter wide (0.002 mm =2 µm). Clay crystals are roughly hexagonal in shape, similar to the related sheet minerals, such as mica, from which they are derived (see 1). Each tiny clay crystal consists of thousands of stacked atomic layers.


1

At the molecular level, clay is composed of alternating layers of silica, alumina, and water. The silica molecule has a tetrahedral shape, a triangle-based pyramid, with a silicon atom in the center and four oxygen atoms, one at each corner. Alumina molecules have an octahedral shape, two square-based pyramids joined together with an aluminium atom in the center and six oxygen atoms at the corners (2). In kaolinite, four of the oxygen atoms are joined to a hydrogen atom. This means the alumina is hydrated or combined with water. Alternating silica and hydrated alumina layers make up the structure of kaolinite; $Al_2O_3{\cdot}2SiO_2{\cdot}2H_2O$. The top of the alumina layer is composed of hydroxyl ions, OH^-, so although the kaolinite molecules are bonded together strongly within the sheet, they are only weakly bonded to the sheets above and below. This enables them to slide easily over each other. However, because of the strong bonds within the sheet, the kaolinite particles are relatively large and the plasticity of pure kaolinite is low. Kaolinite is the main constituent of china clay, ball clays, and fireclays.



2

1 Close up of kaolinite in Jurassic sandstone, UK North Sea, clay type confirmed by X-ray diffraction. Width of image: 20 microns across (50 images side by side would measure 1mm). *Photo: Evelyne Delbos. Courtesy of The James Hutton Institute.* **2** Silica tetrahedra and alumina octahedra. The red atoms at the corners are oxygen. The silicon atoms are in the centers of the tetrahedra and the aluminium atoms are at the centers of the octahedra. In clay, these build up in alternating layers in a sheet structure. *Diagram by Henry Bloomfield.* **3** The structures of the three main types of clay; kaolin, illite, and bentonite. The darker rectangular layers represent sheets of alumina octahedra and the layers with triangular ends represent sheets of silica tetrahedra. Kaolin has repeating alumina and silica layers bonded together with weak hydroxyl OH^- bonds. Illite has three layers bonded strongly with potassium (K^+) ions, while bentonite is similar but the layers are less strongly bonded and can swell by taking in water between each layer. *Diagram by Henry Bloomfield.* **4** Constituent materials of blended clay bodies and their properties and disadvantages. **5** Typical compositions of different clay bodies; earthenware, stoneware, porcelain and bone china.

Illite and Bentonite

Several other types of clay exist, which have slightly different structures. Illite (like mica) has three repeating layers: silica, alumina, then an inverted layer of silica, with potassium ions bonding together each group of three layers (3). At the top and bottom of each group is a layer of oxygen atoms, into which fit the potassium ions, K^+. The layers in illite are therefore bonded together more strongly than in kaolinite, which only has weak hydroxyl bonds between its layers. The potassium ions are attracted by an overall charge deficiency caused by substitution of some of the silicon atoms for aluminium and some of the aluminium atoms for magnesium or iron. Illite clays often contain a large amount of iron oxide, and are used by potters as red earthenware. The iron oxide acts as a flux and reduces the firing temperature of the clay. Illite is thought to be an intermediate stage in the conversion of muscovite mica to kaolinite or montmorillonite.

Montmorillonite (bentonite), like illite, has three repeating layers, but with water in between (see 3). The formula for bentonite is $Al_2O_3{\cdot}4SiO_2{\cdot}2H_2O$, which has twice as much silica as kaolinite, as there are two layers of silica for every layer of alumina. Because the three-layer sheets are only weakly bonded together, with oxygen atoms at the top and bottom, additional water can easily get in between. Some of the silicon atoms in bentonite are replaced by aluminium, and these in turn can be exchanged for magnesium and iron, which create an overall negative charge. Positively charged sodium or calcium ions are therefore attracted to balance the charge. Sodium bentonite can absorb a large amount of water, which causes it to expand greatly when added to water. This makes it very useful for suspending glaze ingredients in water. It is also used in small amounts to increase plasticity in clay bodies (see 4). However, as some of the aluminium atoms are substituted by iron or magnesium, bentonite usually has more impurities than kaolinite. Bentonite is more plastic and has greater dry strength but higher shrinkage than kaolinite. The clay particles are much thinner than those of kaolinite, less than a tenth of the thickness, like thin flakes rather than plates. Calcium bentonite swells less than sodium bentonite, but it has the useful property of attracting organic molecules and is used as an adsorbent in cat litter.

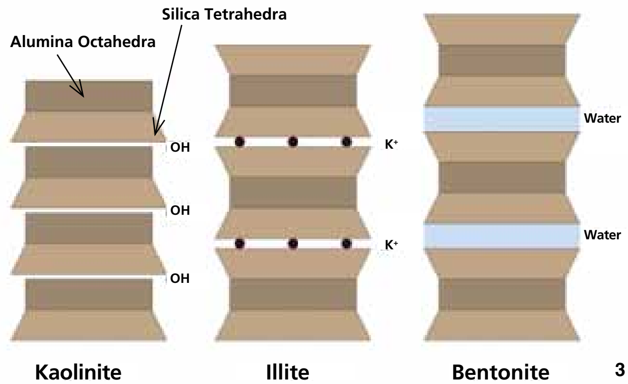
Many sedimentary clays contain a mixture of kaolinite, illite and montmorillonite, with layers repeating randomly. For example, RedArt clay (from Cedar Heights Clay Company, Ohio, USA) has the following composition: illite 40, kaolinite 10, mixed layered clays 15, quartz 30, red iron oxide 7. The structure and type of clay can be determined using X-ray diffraction, which measures the symmetry and spacing between the atomic layers. Kaolinite has the smallest spacing and bentonite has the largest.

Material	Useful Properties	Disadvantages
ball clay, bentonite	plasticity, dry strength	high shrinkage
fireclay	refractory	
kaolin/china clay	white, refractory	
stoneware clay	refractory	
red clay/illite	red or brown color	low firing, porous
feldspar, bone ash, whiting	flux, melter	warping
talc, cordierite, petalite	flux for flameproof bodies	
silica, quartz, flint	hardness, vitrified	dunting
grog, molochite	open texture	
iron oxide, magnetite	buff or brown color, speckle	flux in reduction
manganese dioxide	black color	toxic fumes

4

Clay	Typical Composition	Firing Temperature
Red Earthenware	Red Clay	1742–2102°F (950–1150°C)
White Earthenware	Feldspar 15 Ball Clay 25 Kaolin 25 Silica 35	1742–2102°F (950–1150°C)
Stoneware	Feldspar 15 Ball Clay 40 Kaolin 40 Silica 5	2192–2372°F (1200–1300°C)
Porcelain	Feldspar 27 Kaolin 55 Silica 17 Bentonite 5	2282–2552°F (1250–1400°C)
Bone China	Bone Ash 50 Feldspar 25 Kaolin 25	2192–2732°F (1200–1500°C)

5



3

the author *Linda Bloomfield studied engineering at Warwick University, with a year at MIT during her PhD studies. She started her pottery career while living in California, and became familiar with US potters' materials. She now lives in London, where she makes porcelain tableware and writes pottery books.*