Clay:
From weathering product to art medium

What is a Ceramic ?

In the visual arts, clays are used primarily in the fashioning of ceramic items

A ceramic can be loosely defined as a hard, brittle, nonmetallic material made from clay and other Earth materials and hardened by firing (vitrification) at high temperatures; it contains minute silicate crystals suspended in a glassy cement.

Note that unlike a glass, a ceramic has a crystalline structure This is due to the relatively long cooling period allowed for most ceramics.

Rapid cooling (quenching) would result in the formation of glass, but would also cause the ceramic to crack or perhaps even explode.

What is Clay ?

The term “clay” is used in a number of ways. It can refer to:

1. A member of a large group of fine-grained platy minerals related to micas.

2. It can refer to a mixture of minerals with clay-size particles, i.e. <1/256 mm)--These are generally dominated by clay minerals.

Or

3. It can refer to a mass of minerals (primarily clay minerals) that behave plastically when wet.

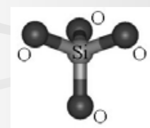
In this lecture, we will consider clay as a mass of minerals dominated by clay minerals.

Structure of Clay Minerals

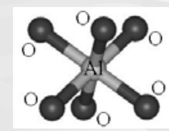
Clay minerals are hydrous (water) aluminum phyllosilicates (sheet silicates)

Clay minerals are made of three basic building blocks:

Sheets of linked silica tetrahedra

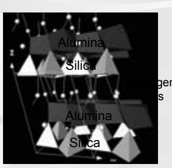


Sheets of linked alumina octohedra

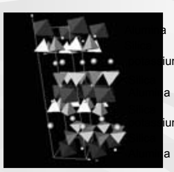


Plus assorted positive ions that bond these sheets together, mostly hydrogen (protons), potassium, iron, and magnesium.

The Structure of two common clay minerals



Kaolinite



Illite

In both cases, silica sheets and alumina sheets are covalently bonded (oxygen atoms share electrons). The result is a composite aluminosilicate sheet.

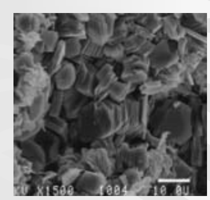
These composite sheets are ionically bonded together by positive hydrogen or metallic ions.

Properties of Clay: Ability to Be Shaped

Clay mineral crystals have a platy habit and also have perfect basal cleavage.

Under weak stress, the plates slide past one another, allowing the mass of clay to deform readily (especially when lubricated by water).

This mobility accounts for the ease with which clay can be molded and formed.



Scanning electron microscope image of a mass of kaolinite (a clay mineral).

Clay mineral form and habit

At high magnification (showing individual clay grains), the thin, platy shape of clay mineral grains is clearly evident .

Clay grains are both thin and broad (like hexagonal plates) and are commonly found stacked on top of one another.

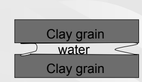
Scanning electron microscope image of a mass of kaolinite (clay mineral) crystals.

Properties of Clay: Cohesion

When slightly wet, clay is typically highly cohesive (i.e. it sticks together very well)

This relates to the high surface area of the broad, flat surfaces of the mineral grains.

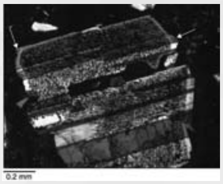
Small amounts of water cling to the clay particles and each other, producing a high degree of intergranular cohesion.



This is similar to what happens when you take two pieces of glass, put some water in between them and then push them together (one on top of another). If you have ever tried this you will note that it is relatively difficult to pull the plates apart or to push them in opposite directions.

Where clays are made

As we learned previously, clay minerals are produced by the weathering and chemical alteration of other minerals, particularly feldspars.



Feldspar weathering to clay (dark flecks within crystal)

There are many different kinds of clay minerals, but on a practical level, we can loosely categorize clays into two main types:

Primary clays (also called china clays or kaolin)

- found close to their original site of formation (i.e. site of weathering or alteration) due to little or no post-formation transport.

- consist mostly of the clay mineral kaolinite

Secondary clays (also called sedimentary clays)

- transported from original site of formation (i.e. site of weathering) found far away from their original site of weathering

- can contain kaolinite, but also generally also contain other clay minerals as well as quartz, iron oxides, and organic matter (more heterogeneous).

Which clays are used for ceramics ?

Rarely do potters use a clay from a single source as a working clay.

Most ceramic clays are blends of materials from different sources.

Experience has taught us that the best results are obtained when several different clays are blended together. Such a blended clay is called a ***clay body***.

By blending, potters can vary the texture and colour of their clays.

A material called ***grog*** (crushed quartz or pre-baked clay) is also added to some clay bodies.

Why Add Grog ?

Grog is commonly either sand or fired clay which has been crushed and sized (typically much coarser than the main potting material).

Grog particles are larger and more rigid than clay particles and lack water content which allows them (in sufficiently high concentrations) to effectively stiffen the soft clay matrix.

Grog reduces the shrinkage effects associated with firing due to its inability to contain or retain water.

Therefore, its presence reduces the overall shrinkage of the clay during the drying (dehydration) process; more grog = less overall shrinkage, less grog = more shrinkage. Less shrinkage means that less clay is required to produce a finished piece of a given volume.

Ceramic disc with coarse-grained grog

Types of Clay Bodies

Clay bodies can be loosely categorized into three basic types:

Earthenware
Stoneware
Porcelain

Earthenware

-Typically made from secondary clays

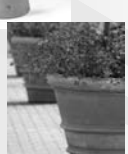
-Well suited for the manufacture of thick-walled vessels such as mugs, plates, and flower pots

-Cheapest to make (secondary clays more common than primary clays)

-Not fired to vitrification temperatures (relatively low T; 900-1100 deg. C)

-Colour can range from white to terra cotta (if iron oxide present)

-Texture ranges from fine to rough, depending on grog content



Stoneware

-Made mostly from primary clays bodies

-Suited for the manufacture of vessels that are stronger (thinner walled) than earthenware

-Also used to make non-porous products such as floor tiles and drainage pipes

-Typically not fired to vitrification tempertures (intermediate T; 1200-1300 deg. C)

-Often coarse in texture (contains grog)

-Colour: usually brown due to presence of iron oxide.

-Textured often with fine speckles

Stoneware mug

Porcelain

-Made from primary clays

-Suited for manufacture of very thin objects that are very strong (e.g. dinnerware)

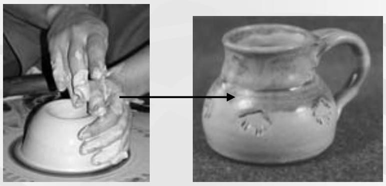
-Smooth texture (no grog)

-Homogeneous composition and lack of grog requires vitrification (High T; 1200-1500 deg. C)

-Porcelain was produced as early as 10th century in Asia (hence the term “China” for high-quality porcelain)

-Bone is sometimes added to the clay for more translucent appearance (hence “bone china”)

From Clay Body To Ceramic



Air Drying

A ceramic piece is air-dried to a "greenware" state before it is fired.

Wet clay contains a large amount of water (25 % minimum). When clay dries, water evaporates from it.

As this happens, clay particles are drawn closer together, resulting in shrinkage.

If drying (and therefore shrinkage) is uneven, stresses are produced in the clay, forming cracks or warped areas. This is why it is important to ensure that the piece is of fairly uniform thickness and that the clay is thoroughly mixed (if more than one type is being used).

Kiln Drying

Complete drying doesn't take place until the piece is placed in the kiln.

This happens when the boiling point of water has been reached.

Water molecules between the clay particles are then evaporated away.

Evaporation of the water content of the clay must be allowed to occur slowly, or the formation of steam within the body of the clay may cause it to burst.

The Big Transformation

After all the free water is driven off (above 500 deg. C), the major transformations of the clay take place.

At this point, the clay is irreversibly changed as hydrogen and oxygen of the clay minerals are driven off as water.

The remaining solid material of the clay produces the minerals mullite and quartz.

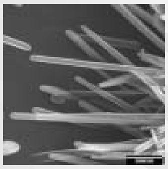
$3\ Al_2Si_2O_5(OH)_4$	→	$Al_6Si_2O_3$	+	$4\ SiO_2$	+	$6\ H_2O$
Kaolinite (s)		mullite(s)		quartz (s)		water(g)

Mullite is a mineral which occurs only rarely in nature

Th effect of changing crystal structure

The strength of fired clay is increased by the formation of a meshwork of needle-like mullite crystals.

Mullite is an aluminum silicate mineral characterized by elongate crystals. These lace the structure together, giving it cohesion and strength.



Vitrification

Finally, the mineral components of the ceramic fuse together.

Glass fills in spaces between the interlocking mullite crystals, binding them together.

When cooled, the ceramic, now made of fused mineral components, is hard and durable.

Some shrinkage can occur at this point. Thus, heating conditions must be carefully controlled.

Fused mullite crystals

Differences in Firing Temperatures

Clays vitrify at various temperatures depending upon the clay minerals present, as well as the amount of impurities (e.g. iron oxides) present in the clay body.

Primary clays (as used in porcelain) vitrify at very high temperatures (1250 – 1400 ^{O}C). This is because the clay body (almost pure kaolinite) has a very high melting point.

Secondary clays (as used in earthenware) vitrify at lower temperatures (700- 1200 ^{O}C). Iron oxides in such clays can contribute to lowering the average melting point of the clay body.

Porosity also differs between items made of primary and secondary clays – primary clays produce items with lower porosity than those made of secondary clays.

Glazing

After the ceramic has completed its firing process, it is glazed.

The ceramic pieces are glazed to both beautify the item and to give the item a waterproof finish.

Glaze is basically a form of glass, consisting basically of

- Glass-forming minerals (e.g. silica, feldspar)
- Stiffeners (such as clay)
- Fluxes which lower the melting point of the other glaze components (calcite and dolomite are common fluxes).

When fired, these ingredients melt (over 2000 ^{O}C). A glass results from cooling of this molten stuff

Glaze Colour and Opacity

Just as impurities can alter the colour of natural minerals, small amounts of certain substances can be added to glaze to produce different colours.

Common glaze additives and resulting colours are:

Copper oxide: greens and blues
Cobalt oxide: blues and violet
Iron oxide: yellow, orange and red
Manganese dioxide: deep purple

Additives are also used to increase the opacity of glazes. Common ones are titanium oxide and tin oxide.

Finished Product

Now that the ceramic piece has been completed, it can now be sold to feed the artist's starving family.

END OF LECTURE