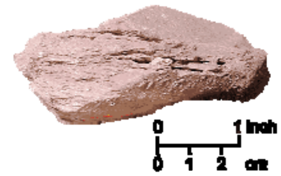
CLAYS AND CLAY BODIES

The Nature of Clay



Clay is a product of the decomposition of granite rock. 75% of the earth's crust is made of ALUMINA and SILICA, two of the major constituents of clay. Granite decomposes into FELDSPAR, the most common mineral, which is composed of ALUMINA, SILICA, and FLUX (of an alkaline nature e.g. sodium, potassium, lithium, calcium). The flux is somewhat soluble, and over long periods of weathering is carried off by moisture. The remaining alumina and silica are refractory (resistant to heat) and chemically inert. After long exposure to moisture, the alumina and silica become hydrated (water chemically added) to produce clay. This takes long periods of geologic time and cannot be synthesized. Clay is 14% chemical water. Unfired clay also contains physical water, which evaporates during drying. Stages of green (unfired) clay from most to least water: slip, plastic clay, leather-hard clay, bone-dry greenware. Especially in humid climates, even bone-dry greenware contains some physical water.

Factors that contribute to the plasticity of clay:

- plate-like particle shape of particles
- size of the particles
- chemical/electrical attraction between particles
- presence of carbonaceous (organic) matter

theoretical formula for clay:
$Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$

PLASTICITY is the ability of clay to respond to pressure with a continuous and permanent change of shape in any direction without breaking apart, and hold that shape when released. Daniel Rhodes says that clay is unique in its degree of plasticity. Factors that contribute to the plasticity of clay are the **PLATE-LIKE PARTICLE SHAPE** of clay (provides large surface area), the **SIZE OF THE PARTICLES** (small particles are more plastic than large ones), **CHEMICAL/ELECTRICAL ATTRACTION** between particles (adding an electrolyte, a.k.a. deflocculant such as soda ash or sodium silicate, will reduce the attraction between particles and reduce plasticity and clumping.. .good in casting slip, difficult to work in plastic-forming methods. (See THIXOTROPIC CLAY in Glen Nelson's CERAMICS: A POTTER'S HANDBOOK), and **PRESENCE OF CARBONACEOUS (ORGANIC) MATTER** (small amounts are helpful; too much produces a sticky clay that is hard to work and has high shrinkage).

Clay that lacks plasticity (a **SHORT** CLAY) will not bend well and tends to break instead of forming when bent. A classic test is to roll a coil of clay the thickness of a pencil and see if you can wrap it around your finger w/o breaking. Short clays lack plasticity, but will shrink less than more plastic clays. A clay can be too plastic (A **FAT** CLAY), and will feel sticky/slick. A fat clay generally slumps easily when thrown, and tends to have cracking problems in drying.

Types of Clay

PRIMARY CLAY, or RESIDUAL CLAY is clay is formed at the site of the parent rock. It is less common than SECONDARY (TRANSPORTED OR SEDIMENTARY) clay, but generally whiter, free from impurities. Because this clay is broken down by ground water, etc. and not transported, particle size is mixed (no opportunity for sorting or grinding) and the clay is usually not very plastic, and are refractory. Most KAOLINS are primary clays.
SECONDARY CLAY has been transported from multiple sources by water (alluvial), or wind (aeolian), which sort particle sizes, or by glacier
(glacial), which may grind but has uneven particle sizes. Many secondary clays contain organic (carbonaceous) and other impurities (iron, quartz, mica, etc.). Some of the more plastic kaolins are secondary clays. Other secondary clays: BALL CLAY, STONEWARE CLAY, FIRECLAY, EARTHENWARE CLAY, SLIP CLAYS, VOLCANIC CLAYS.

Categories and Brands of Clays (items in bold are usually in stock here)

Kaolin

is named from the Chinese "kao" (high) and "ling" (hill), where it was discovered. Synonymous with CHINA CLAY. Pure, white-burning, refractory (vitrifies at cone 34), generally non-plastic primary clay with larger particle size, although sedimentary kaolins like Grolleg, Tile 6 and Georgia Kaolin, and some Florida kaolins are more plastic and finer in particle size (with resulting higher shrinkage) than non-plastic kaolins.

Plastic kaolin (higher shrinkage):
EPK - Edgar Plastic Kaolin. Florida kaolin. Yellowish tinge (in oxidation) when fired due to 0.7% iron and titanium traces. Dry shrinkage 7.5%, cone 04 shrinkage 10% cone 10 reduction 17% shrinkage. Limited plasticity, in spite of its name. Not as white as Tile 6.
GROLLEG - Satiny, like kaolin and ball clay. Imported from England & more expensive than domestic kaolins. 0.6% iron. Can be used as a slip w/the addition of a little flux. White-firing. Dry shrinkage 5%, cone 04 shrinkage 7%, cone 10 reduction 17% shrinkage.
PIONEER - Georgia kaolin. Slightly less plastic than Tile 6 with slightly more iron.
TILE 6 - Also known as Six Tile Clay, a Georgia kaolin. Fires slightly creamy (in oxidation) due to iron and titanium impurities. Cheaper substitute for Grolleg. A good kaolin for porcelain formulation. 16-18% shrinkage.
Less plastic kaolins - all have less shrinkage than plastic kaolins:
ENGLISH CHINA CLAY, KINGSLEY
AVERY - creamy, primary Carolina kaolin. Blushes orange as a wash in salt and wood firing. 15% shrinkage. Limited supply: USE FOR WASHES/SLIP FOR SALT AND WOOD ONLY.
GEORGIA KAOLIN. Dry shrinkage 6%, cone 04 shrinkage 9%, cone 10 reduction 15% shrinkage. 0.4% iron.
KAOPAQUE 20. a delaminated aluminum silicate from Georgia Kaolin.
CALCINED KAOLIN - trade name **GLOMAX**, has been heated to red heat (CALCINED) to remove chemically-combined water: "preshrunk" for reduced shrinkage in bisque slips.

Type of clay	**Brand names**	*= no longer available
Kaolins:	*plastic kaolins:* **EPK** **Grolleg** Pioneer **Tile #6**	*non-plastic kaolins:* Avery* China Clay **Georgia Kaolin** **Glomax** (calcined kaolin) Kaopaque 20
Ball Clays	C&C KT1 SPG	OM4 Tennessee XX Sagger
Fire Clays	**AP Green** Cedar Hts. Bonding Pine Lake	Carbondale Red Hawthrone Bond PBX Valentine* **XX Sagger**
Stoneware clays	Cedar Hts. **GoldArt** Jordan*	Foundry Hill Crème Lizella Ocmulgee*
Earthenware clays	Calvert Cedar Hts. **RedArt** Newman Red	**Lizella** Ocmulgee* Ranger Red
Slip Clays	Albany Slip* Alberta Slip	Barnard* Blackbird

Ball clay

was named for the practice of rolling the very plastic clay into balls during mining. A secondary (transported) clay with carbonaceous additions that color it grey, brown, or tan in the raw state, and fires to a light tone. More iron than kaolins, less than fire clays. Less refractory than kaolins due to more iron and smaller particle size. This small particle size gives highest shrinkage (up to 20%) and plasticity of all clays. Too plastic to be used alone. Increases green (dry) strength. Sometimes used as a glaze ingredient to add strength to the raw glaze coat. Matures in the cone 10-12 range. Maximum amount of ball clay for a "white" body is usually not more than 15% (the exception is some lowfire whiteware bodies).

TENNESSEE BALL, SPG BALL - lightest-burning ball clays. 14-16% shrinkage.
KENTUCKY OM4 (Old Mine 4) 16-18% shrinkage. 1% iron - more iron than Tennessee & SPG.
KT1 C&C BALL - similar to OM4 but lighter in color.

Fireclays

are secondary clays with large particle size (thus low shrinkage), good resistance to heat, more iron than ball clays, firing buff to brown. Used to add "TOOTH" to a body, and raise the maturing temperature.
PINE LAKE - high silica, fairly light in color: 1.5% iron, slightly plastic. Dry shrinkage 6.5%, cone 04 shrinkage 8%, cone 10 reduction 10%.
A.P. GREEN FIRE CLAY - a 28 mesh clay from Missouri with 1.3% iron. Specks in the body. Light orange-brown in color @ cone 9. Dry shrinkage 6%, cone 04 shrinkage 9%, cone 10 reduction 16% shrinkage.
XX SAGGER - between a ball clay and fire clay, sometimes classified as a stoneware clay, or ball clay in Conrad, or in Rhodes as a sagger clay. Plastic, refractory. Used to make saggers. Creamy white to tan: 0.7% iron. Matures around cone 10. 14.2% shrinkage at high fire temperatures. Higher silica than ball clays, often used for salt bodies.
Carbondale Red – high iron fireclay. A very high iron refractory clay well suited for many ceramic applications requiring bright red color. It fires to a toasty red up to about cone 3 and then turns dark red to brown (partly due to soluble salts on the surface that darken the color). This material has a plasticity similar to a typical pottery clay body. Carbondale red provides formulators with an economical source of iron oxide. Some have suggested this as a substitute for Newman Red, however it is much more vitreous and higher in iron.
PBX Valentine - no longer available. A high-iron fireclay red in the raw state. Val Cushing suggests a substitution of 85% Hawthorn Bonding clay plus 15% Lizella red clay in place of PBX Valentine.
Hawthorne Bond - Missouri fire clay. Good plasticity, light color.

Stoneware clays

are secondary clays. Some can be used as dug w/o additions. Bigger particles than ball clay, less shrinkage than ball, less plastic than ball. Light to dark grey reduced, warm in color when reoxidized, tan to brown in oxidation. Mature around cone 10.

CEDAR HEIGHTS GOLDART - Airfloated 22 mesh stoneware clay. Warm in color: light or golden buff. May bloat at cone 10 at large percentages from sulphur content. 1.2% iron. Matures around cone 8-9, max. temp cone 12. 15-16% shrinkage at high fire temperatures. Goldart is air-floated. Coarser grinds of the same clay are available as Bonding Clay or Fire Clay.
JORDAN - NO LONGER AVAILABLE. 2.8% iron. Moderate shrinkage. Replace w/KY STONE or GOLDART.
SPINKS **FOUNDRY HILL CREME** - although mfg. say it can be used alone @ cone 10, this clay is highly plastic and shrinks excessively and feels sticky when used alone. Cream to buff in oxidation (low iron). Can be used w/10% feldspar at cone 5-6 for a throwing body. Additions for tooth recommended. The mine closed in 1989, but a new source is now available.

Earthenware clays

usually matures in the cone 08-01 range, and are generally not fired above cone 4. High iron color gives a red fired color, and causes melting and bloating at temperatures high enough to cause vitrification. The higher the firing temperature, the darker the color. Brittle if over-fired. Varies in plasticity from sticky to short. Raw clay may be red, ochre, grey, brown, or greenish and fires orange to red. Most of the usable raw clay found in nature is earthenware. Used in stoneware bodies up to 10% for color.

CALVERT - red clay lighter than RedArt: 4.8% iron.
CEDAR HEIGHTS REDART - cone 4 maximum (brittle, warps @ cone 4), recommended temperature for straight Redart is cone 06-3. Rich red color: 7.3% iron. Limited plasticity. Shrinkage at cone 04 9%, at cone 1 14%. Melts at cone 9.
OCMULGEE - Georgia clay. No longer mined. See Lizella.
LIZELLA - Mined by the Burns Brick Company of Georgia. High iron, but higher-firing than most red clays. Vitrifies mid-range (cone 4-8). Finer grained than Ochmulgee. Used alone, it is brittle and stressed in high-fire reduction. May be listed as a stoneware clay. More refractory than Redart.
RANGER RED - Texas earthenware clay, olive green raw, fires to a deep orange. Similar to RedArt, with perhaps a bit less shrinkage.

NEUMAN RED - fires dark red. Listed variously as an earthenware clay and a fire clay. Mined by Muddox in California. Axner carries it. It has about 0.5 absorbency at cone 10 reduction & a little more at cone 10 oxidation. While a nice clay, it tends to vary greatly, and can have chunky inclusions that cause problems for some applications. Some industrial companies use Neuman Red for brick clay and are not bothered by this. For use with a finer-grained earthenware and majolica-glazing applications, I recommend you screen the clay before using to remove extraneous inclusions.

Slip clays

contain iron and impurities that melt completely at cone 9-10. Used in glazes.
ALBANY SLIP CLAY - NO LONGER AVAILABLE.Substitutions (see Ceramics Mo. Oct.'88): Dolomite 9, Soda Ash 1, Redart 90 OR Dolomite 8.5, Pearl Ash 4, Soda Ash 1, unwashed Wood Ash 10.5, OM 4 50, Flint 20, Red Iron 6.
ALBERTA SLIP - a direct substitute for Albany slip formulated by the Archie Bray Foundation in Helena, MT.
BLACKBIRD/BARNARD - similar to Albany slip but lighter in color. Barnard no longer available.

Volcanic clays

are formed from the weathering of volcanic glass or ash. Particles average to small, with the smallest particles of clay being found in this category.
BENTONITE ($Al_2O_3.4SiO_2.H_2O$) is the most common volcanic clay and is approx. five times more plastic than ball clay. Used in small amounts (2-3%) in clay bodies to add plasticity, or in glazes to prevent settling and hardening of ingredients in the bucket, and strengthen the dry glaze coat. 3.6% iron. ALWAYS MIX BENTONITE WITH OTHER DRY INGREDIENTS BEFORE ADDING TO WATER. IT BLOATS IN WATER, FORMING CLUMPS THAT ARE VERY DIFFICULT TO MIX. **MACALOID** is a synthetic bentonite that does not bloat in water and may be directly mixed into liquids.

Non-clay body additions

Will decrease the plasticity of the body and make it more open, aiding drying and decreasing shrinkage:

Fluxes

lower the maturing temperature and promote vitrification (reduces absorbency). The main body flux for stoneware is feldspar, which is inexpensive and has a long firing range. Earthenware bodies often use talc, nepheline syenite, frits, wollastonite, lithium compounds, or feldspar combined with other fluxes.
CUSTER FELDSPAR - contains alumina, silica, and predominantly potassium, a potash feldspar. If a recipe simply calls for generic feldspar, Custer is generally used. Melts in the high-fire range. *Other feldspars classified as potash spars include*: Orthoclase, Buckingham, Clinchfield, Keystone, Yankee, Kingman, Maine, Plastic Vitrox, Madoc H, Kona A-3, Oxford, K-200, and Elbrook. In a clay body recipe, Custer can be used interchangeably with any of these.
G-200 Feldspar - potassium feldspar.
KONA F-4 - contains alumina, silica, and primarily sodium, a soda feldspar. Behaves similarly to Custer, but melts a bit lower. *Other soda spars*: Albite, #54 Glaze Spar, Kona C-6, Lu-Spar, Minpro #4, Eureka, Bainbridge, #56 Glaze Spar, Clinchfield #303. These can be used interchangeably with Kona F-4 in clay recipes.
SPODUMENE is a lithium-fluxed feldspar (alumina, silica, and lithium). Lithium has a low coefficient of expansion, and substitution of 5-10% spodumene for other feldspar will reduce fired shrinkage a small amount and promote good thermal shock resistance in ovenware. More expensive than KNaO (sodium and/or potassium) spars. Lepidolite, Lithospar, and Petalite are other lithium spars.
PYROPHYLLITE contains alumina and silica, and has properties similar to talc. Substitution of pyrophollite for part of the feldspar and/or silica in a body will improve thermal shock resistance.
WOLLASTONITE is a calcium silicate that improves thermal shock resistance and may be substituted for some of the flint and whiting (Calcium carbonate).
PLASTIC VITROX (P.V.Clay) is a complex mineral ($1RO^{\cdot}1.69Al_2O_3^{\cdot}14.64SiO_2$) mined in CA. Source of Al, Si, K. Resembles a potassium feldspar and Cornwall stone in composition.

NEPHELINE SYENITE (Neph Sy) is composed of alumina, silica, and KNaO (sodium and/or potassium). The KnaO is higher in ratio than in a feldspar, resulting in a slightly lower melting point than feldspar. 10% neph sy is the equivalent of 15% spar in fluxing power at cone 10.
TALC is a major low-fire body flux. It contains magnesium and silica, and has a long firing range. In low temperature bodies, it increases thermal expansion, resulting in glaze compression during cooling and reduced crazing.
FRIT is a man-made mixture of soluble and/or toxic materials that is melted into a glass, cooled, and ground. Frits render soluble fluxes (e.g. soda ash, pearl ash, borax) or toxic fluxes (lead) insoluble by combining them w/silica (NOTE: this does not necessarily reduce solubility in the fired glaze). Frits may be slightly soluble and deflocculate clay bodies, making them difficult to work in plastic clay bodies. More expensive than natural materials, reduced firing range compared to feldspars. Low-fire melting range. Manufacturers: FERRO, PEMCO, O'HOMMEL. Frits are made in a variety of recipes, and each manufacturer has a numbering system for their formulas. Chemical analysis of each frit is available from suppliers. Frit is usually a last resource as a body flux, due to cost and potential soluble salts problems.
SILICA is already present in clays and feldspars. Additional silica is added to improve glaze fit, add hardness to the body (combines with fluxes and helps vitrify the body). By itself, it is refractory. A non-plastic body addition, it will help open the body. Also called **FLINT** or **QUARTZ.**

Miscellaneous Additions

GROG is bisqued, fired clay, used to open the body, reducing plasticity and shrinkage, and aiding drying. Grog is available in a variety of sizes from very fine to coarse, and is usually tan to brown. The coarse sizes can be used to add texture to clay bodies. MOLLOCHITE is white, porcelain grog. You can make colored grog by making colored clay, bisque-firing it, and grinding or pounding it to the desired size.
NYLON FIBER can be added to give extra tensile strength for building and improve dry strength of greenware. Chopped nylon fiber is available from ceramic suppliers, or you can cut up 100% nylon rope into short segments and separate the fibers. It only takes a small amount to be effective. Clay with fiber should NEVER by put through a pug mill because the fiber will clog the screen.

PAPER PULP is used as an additive to sculpture clays. It decreases plasticity but increases green strength, decreases finished weight. Paper must be beaten to fine fibers before being added. Paper pulp will decompose, losing its fibrous properties in the clay and smelling sour. A bit of bleach added to the clay will help delay this. People using small amounts of paperclay for mending, etc. freeze it in small amounts to be thawed out and used as needed. Rosette Gault has written a book on paperclay. Clay with pulp should NEVER by put through a pug mill because the fiber will clog the screen.
KYANITE contains alumina and silica and improves mechanical strength of the fired product and promotes good thermal shock resistance.
BENTONITE is a clay-like substance added up to 3% to improve plasticity. Excess may result in sticky clay. Bentonite bloats in water, and should be mixed with another dry ingredient before adding liquid. **MACALOID** is a synthetic Bentonite that does not bloat.
COLORANTS may be added to light-colored bodies. Iron is the source of color in most clays. There are fewer problems adding red clays for color than pure iron oxide. Mason stains, especially those listed as body stains, may be added in amount of 15-20% for colored clays. Some stains may be fugitive at high temperatures and/or in reduction. Oxides may also be added. Some are toxic, such as manganese, and care should be used handling them. Large amounts of oxides with low melting points (copper, iron, cobalt) may increase fluxing in clay and bloating in cone 10 reduction. Adding granular oxides, such as granular rutile, manganese or ilmenite, will produce dark specks in the body and possibly in glazes.

Clay bodies

are formulations of clays, fluxes, silica, and other ingredients to yield specific properties: color, texture, maturing temperature, absorption, shrinkage, plasticity, drying and firing properties. Functional bodies are better if strong and more vitrified. Sculpture clays should be open for even drying of thick walls, and have limited shrinkage. Combustible fillers (straw, sawdust, vermiculite, etc.) may be added to control shrinkage, aid drying, and reduce

fired weight, and nylon fiber added for tensile strength in forming and added green strength. Throwing bodies should be reasonably plastic. Handbuilding bodies should control shrinkage and be open to aid even drying. Plasticity needs depend on the method used for forming. Slip-casting bodies do not need plasticity, but should have low shrinkage.
In iron-colored clay bodies, it is better to use an iron-bearing clay than to add iron oxide, which may cause brittleness or weak spots if not sufficiently mixed in. Red iron oxide is a powerful colorant and may cause staining of hands, tools, and clothing. Black iron is coarser and may produce specking. Whiting as a body flux will bleach iron colors. Please note that manganese is TOXIC, and not a good addition as a body colorant unless you plan to work wearing gloves. Some oxides used as colorants are also fluxes, and in high amounts will lower maturing temperature (e.g. all forms of iron, copper, manganese, cobalt).

EARTHENWARE fires from about cone 08-02 (1751°F-2048°), and can be white, buff, orange, red, or brick. Usually not as vitrified as high-fired clays. Tends to warp and melt before it vitrifies. Less shrinkage than more vitrified clays, often used for sculpture. General absorption range 5-10 %. Addition of 0.5% barium carbonate will react with the soluble salts in earthenware bodies, esp. terra cottas, and prevent scumming on dried and bisqued wares by forming insoluble compounds of barium and soluble salts.

STONEWARE can be from medium range (cone 4-6, 2170-2230°) to high temperature (cone 10, 2350°), white to dark in color, medium to coarse in texture. General absorption range for stoneware is 1-5%.

PORCELAIN is a high-temperature body (cone 10-11), very dense and fine-grained, vitrified, translucent when thin, white to pale blue-grey in reduction, white to creamy in oxidation. General absorption range 0-2%. If a texture is desired, molochite, a porcelain grog, is usually used to maintain white color. Very white porcelains are often short (low in plasticity.)

SALT OR WOOD Jack Troy in *Salt-Glazed Ceramics* recommends alumina to silica ratios of 1:4 to 1:12.5 as best for salt. Magnesia (found in the talc sometimes used as a body flux) over 3% causes dulling, but is good at 1.5% and under. Presence of alumina and magnesia may promote ochre colors and orange flashing. Iron content in high fire clays is accentuated. A brown reduction stoneware will often be dark brown in vapor glazing. High iron can cause poor thermal shock resistance in high-fire reduction salted pots. Calcium in clay bodies in amounts above 3%, esp. w/iron, produce green to green-yellow salt glazes.

CASTING BODIES are formulated for low shrinkage and low water content. They are used in liquid form in plaster molds, which draw water from the slip and build up a layer of clay on the inside of the mold. Once this layer is the desired thickness, the mold is inverted and the liquid slip remaining drained out, leaving the layer of clay on the mold to continue to dry. Casting bodies are deflocculated with soda ash, sodium silicate, Darvan, or a combination of those.

Clay-body troubleshooting:

CLAY BODY PROBLEM:	CORRECTION:
sticky clay w/excessive shrinkage (fat clay)	Add coarser clays (non-plastic kaolins, fireclay), or nonplastic ingredients. Decrease ball clay, remove bentonite.
clay with poor plasticity (short clay)	Add ball, use more plastic kaolin. Decrease non-plastic additions, add 1-2% bentonite
warping in drying	Add coarser clays (fire clay, non-plastic kaolins), grog, non-plastics. Decrease fine-grained clays (ball clay, bentonite).
fired clay brittle	Fire lower, less iron if reduced, less flux. Add refractory clays (kaolins, fireclays).
warping in firing	Decrease flux. Add refractory clays (fire clay, kaolin), or grog. Fire lower.
punky, soft clay	Add flux. Fire higher.

See Daniel Rhodes' ***Clay and Glazes for the Potter*** for suggested percentage ranges for clay body formulation. There is more latitude in formulating clays than glazes. Begin with a base clay body, depending on characteristics desired. White bodies begin with kaolin, stoneware w/stoneware clay, terra cotta w/a red clay. Add clays to increase/decrease plasticity and shrinkage, silica for glaze fit and hardness, and other additions to control shrinkage or add other desirable properties.

Sources for more information on clay, clay bodies:

Conrad, John, ***Advanced Ceramic Manual.*** Please note error on p.22 and p. 223 of Conrad in Empirical chart:
REDART is NOT a stoneware clay: at cone 9 it's melted down; it is an EARTHENWARE clay.
Hamer, Frank, The Potters Dictionary of Materials and Techniques, see clay, cristobalite, etc.
Martin, Andrew, *The Essential Guide to Mold Making & Slip Casting*, Lark Books
McKee, Charles, Ceramics Handbook; a Guide to Glaze Calculation, Materials, and Processes.
Rhodes, Daniel, Clay and Glazes for the Potter, Stoneware and Porcelain.
Studio Potter magazine, v.6 no. 2 features porcelain, v.11 no. 2 features earthenware, v.10 no. 1 features clay