The IU Southeast Ceramics Studio

Clay and Glaze Materials Resource Handbook

compiled and edited by

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This manual has been edited and compiled exclusively for the ceramics students at Indiana University Southeast. The information contained within this manual has been sourced from multiple locations and I have edited, deleted, and added my own information during the process of compiling this resource. The primary sources are:

- Digitalfire's Reference Database : http://digitalfire.com/4sight/education/index.html
- The Ceramic Spectrum by Robin Hopper : http://www.amazon.com/Ceramic-Spectrum-Simplified-Approach-Development/dp/0873418212
- Clay and Glazes for the Potter by Daniel Rhodes : http://www.amazon.com/Clay-Glazes-Potter-Daniel-Rhodes/dp/0873418638
- Linda Arbuckle's Handouts and Resources : http://lindaarbuckle.com/arbuckle_handouts.html
- Wikipedia : http://www.wikipedia.org/

This handbook is intended to be a live document and therefore will change and be updated as new information becomes available and as more components are added. This version was completed in January, 2012.

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What is a glaze?

Glaze is a layer or coating of a vitreous substance which has been fired to fuse to a ceramic object to color, decorate, strengthen or waterproof it.

Why do we use it?

Glaze is functionally important for earthenware vessels, which would otherwise be unsuitable for holding liquids due to porosity. Glaze is also used on functional and decorative stoneware and porcelain. In addition to the functional aspect of glazes, aesthetic concerns include a variety of surface finishes, including degrees of gloss and matte, variegation and finished color. Glazes may also enhance an underlying design or texture which may be either the "natural" texture of the clay or an inscribed, carved or painted design.

What is it made out of?

Ceramic glazes generally contain silica to form glass, in combination with a mixture of metal oxides such as sodium, potassium and calcium which act as a flux and allow the glaze to melt at a particular temperature, alumina (usually from added clay) to stiffen the glaze and prevent it from running off the piece, colorants such as iron oxide, copper carbonate or cobalt carbonate, and sometimes opacifiers such as tin oxide or zirconium oxide.

All ceramic glazes are composed of three components:

- **GLASS FORMERS**
- **VISCOSITY AGENTS**
- **FLUXES**

In addition to the above three, most glazes will have varying amounts of two other components:

- **COLORANTS**
- **OPACIFIERS**

GLASS FORMERS

Silica is the major glass-former. By itself it will not melt in our kilns (it is a refractory material), but when combined with fluxes, it will melt to form glass in the glaze. Since it has a low coefficient of expansion, it is used to adjust crazing. It also makes the glaze harder and more durable.

Silica is added to glazes in the form of FLINT (a.k.a. quartz) as a pure source of silica AND/OR through the addition of other ingredients that contain silica: FELDSPAR, FRIT, TALC, CLAY, NEPHELINE SYENITE, CORNWALL STONE, PYROPHYLLITE, AND WOLLASTONITE. For example, EPK is 45% silica.

VISCOSITY AGENTS

Alumina is the major viscosity agent. Without the addition of alumina, the glaze would melt in the kiln and flow right off of your work! When we add a viscosity agent (alumina) to a glaze, the glaze is then converted from “glass” to something that will bind to the vertical surface of a ceramic form.

It is added to glazes in the form of ALUMINA HYDRATE as a pure source or alumina, or more commonly by the addition of materials that contain alumina: FELDSPAR, CLAY, FRIT, NEPHELINE SYENITE, CORNWALL STONE, PYROPHYLLITE. BORON is unique in that it is both a flux and viscosity agent.

FLUXES

Silica (the glassformer) and alumina (the viscosity agent) are both refractory and therefore will not melt in our ceramic kilns. To to get those materials to melt, we add varying amounts of fluxes. The primary fluxes we use are POTASSIUM, SODIUM, CALCIUM, MAGNESIUM, LITHIUM, STRONTIUM, and sometimes BARIUM. We add these fluxes by using a material that contains one or more of the fluxing agents. For example, Custer Feldspar has 10% potassium, 3% sodium, and .3% calcium, so with that material alone, we would add three different fluxes to a glaze or clay recipe.

FLUXES:

(table adapted from Linda Arbuckle, some rare fluxes have been omitted)

Flux	Active Temp	Characteristics	Sources (*soluble)
SODIUM (Na_2O) alkaline flux	low-high	▪ similar to potassium but a bit more active ▪ produces soft glaze surfaces that are easily abraded or attacked by acids ▪ high coefficient of expansion (crazes) ▪ brilliant color: Cu = turquoise, Mn = purple, Co = ultra-marine blue, Cr = yellow green, chartreuse w/ small amounts of Cr ▪ slightly more active than K or Li	SODA ASH * SALT * SODIUM BICARBONATE * FELDSPAR (Kona F-4) FRIT (may be part soluble) NEPHELINE SYENITE CORNWALL STONE CRYOLITE
POTASSIUM (K_2O) alkaline flux	low-high	▪ similar to sodium, generally, but a bit less active	PEARL ASH * FELDSPAR (Custer) FRIT (may be part soluble) NEPHELINE SYENITE CORNWALL STONE
LITHIUM (Li_2O) alkaline flu	low-high	▪ similar to KNaO, but has a low coefficient of expansion	LITHIUM CARBONATE (may deflocculate glazes) Li FELDSPARS (Spodumene, Lepidolite, Petalite) FRIT MACALOID
LEAD (PbO) metallic flux	low-med	volatilizes @ cone 6 ▪ blisters in reduction ▪ med. coeff. of expansion ▪ soft glaze, may be leached w/acids ▪ poisonous raw, may be leach toxic amts. in the fired state ▪ warm color response: + Fe = amber, warm brown.+ Cd & Se = red.+ Mn = plum. + Cr = orange. + Cu = grass green transparent	WHITE LEAD RED LEAD LITHARGE GALENA LEAD CHROMATE FRIT (eg. Ferro 3300 or O'Hommel Pb series
ZINC (ZnO) metallic flux	med-high	▪ low coeff. of expansion (in small amts. decreases crazing) ▪ high Zn opacifies and matts ▪ excess may cause crawling ▪ promotes crystals w/Ti & low Al ▪ nice Co blues, muddy Fe browns, + Cr =brown. + Cu = bluish green ▪ In cone 10 reduction, Zn is completely volatilized.	ZINC OXIDE CALCINED ZINC OXIDE FRIT
CALCIUM (CaO) alkaline earth flu	high	▪ produces hard glaze ▪ helps thermal shock resistance ▪ favors celadon greens in reduction ▪ NOT good for Cu red ▪ excess will matt or cloud ▪ forms eutectics often in small amounts ▪ + Cu = toward green in low temp. oxidation	WHITING DOLOMITE BONE ASH WOLLASTONITE FLUROSPAR FELDSPAR FRIT GERSTLEY BORATE CEMENT
Flux	Active Temp	Characteristics	Sources (*soluble)

BARIUM (BaO) alkaline earth flux	high	▪ not very active flux ▪ good matting agent ▪ Ba + B form eutectic & will not mat ▪ hardens glaze ▪ toxic raw, may leach in high Ba matt glazes. See article by Janet DeBoos in Janet DeBoos Ceramics Technical #3 (1997). Not recommended for food ware. Substitute .75 $SrCO_3$ instead. ▪ good for Cu reds in reduction ▪ Cu + high Ba = matt blue even in reduction. + Fe = blues in reduction. + Cr = warmer opaque green. + Co =purple-blue	BARIUM CARBONATE FRIT
MAGNESIUM (MgO) alkaline earth flux	high	▪ not very active flux ▪ good for crystal glazes ▪ high Mg = buttery matt & opaque ▪ hardens glaze ▪ colors toward pastels ▪ Mg + Co = purple	MAGNESIUM CARBONATE DOLOMITE TALC FRIT
STRONTIUM (SrO) alkaline earth flux	high	▪ similar to Ca in glaze effect, but slightly more active while less fluid. ▪use .75 $SrCO_3$ to replace 1 BaO (test!) Slow to melt: soak	STRONTIUM CARBONATE (slightly soluble)
BORON (B_2O_3) viscosity agent that also functions as a flux	low-high	▪ classified as a viscosity agent but also acts as a flux ▪ produces high gloss ▪ boils at high temps. ▪ wide firing range ▪ small amounts decrease crazing, large amounts may cause crazing ▪ inhibits crystal growth & devitrification ▪ thickens melted glaze, excess may cause crawling ▪ may have a solvent effect and leach slip color ▪ color may be opalescent, mottled w/ high boron	BORAX * BORIC ACID * GERSTLEY BORATE FRIT

We also use commercial made fluxes called Frits. There are thousands of Frits available, but here is a list of some of the ones you are likely to see in a ceramic studio:

FRIT	Substitute	Melting Temp	Comments
Ferro 3110	P-IVo5 Pemco	1400 F	Highly alkaline. Somewhat soluble: not recommended as a body flux. As a main flux causes crazing
Ferro 3124	P-311 Pemco Hommel 90	1600 F	Borosilicate, high calcium, good for tableware
Ferro 3134	P-54 Pemco Hommel 14	1450 F	High sodium, calcium, and boron. No alumina
Ferro 3195		1500 F	Alkaline-boron. Not as alkaline as 3110, w/more Ca, B, Al, but still tends toward alkaline color response
Ferro 3289	Fusion Frit 65 GF129	1500 F	Barium-some sodium
Ferro 3819	P-25 Pemco Hommel 25	1400 F	Alka-boron. Low Calcium

COLORANTS:

(table adapted from Linda Arbuckle, some rare colorants have been omitted)

Material	Notes	Properties	Sources
Iron (Fe) In slip: 1/2 - 8% are usual amounts. In glazes up to 15			
	Found as a source of colors in red clays. Begins to flux at low-fire temperatures. High amounts can increase fluxing in a base glaze, and reduction can increase the activity of iron in a glaze. May be used to modify other colorants, e.g. to modulate cobalt blues or copper colors. Black oxide mix: 4% Fe+ 4% Co + 4% Mn or Cu (note: hi Co may spit in firing and give blue halos on kiln shelves, copper in reduction may give black areas a pink edge quality)	+ Pb (lead) = amber + alkaline flux (Na, K, Li) = cooler tones + Zn (zinc) = duller Fe colors + Ca (calcium) = bleached Fe colors In oxidation firing: buff, ochre, rust, browns, and blacks. In glazes 1-3% tans, 4-6% red browns in most, but olive - yellow in high alkali glaze. 6-10% deep browns (tin may help). Presence of barium (toxic) or strontium may produce iron ambers similar to lead colors. In reduction firing: small amounts of iron (.5 - 3%) in a glaze yield celadon greens, bluegreens, olive, and grey-green colors. 1-6% with calcium phosphate (bone ash) = iron blues. Saturated iron (6% or more) in reduction or oxidation glazes with Mg and P , Fe may re-oxidize and form crystals during slow cooling and give "tomato" red, rust, persimmon reds. High Fe also makes brown, and black, e.g. temmoku, glazes	**red iron oxide** ($Fe2O3$ has finer particles than black iron) **black iron oxide** (FeO) **crocus martis** (purple-ish raw and in low-fire sigs) **rutile** (Fe & Ti + impurities), **ilmenite** (Fe & Ti in powdered or granular form) **ochre** (yellow ochre) **sienna** (raw or burnt, Fe + Mn) **umber** (raw or burnt, Fe + more Mn than sienna) **iron chromate** (Fe + Cr = taupe colors) **Barnard/Blackbird** slip clay, **Alberta Slip**, Albany slip (no longer mined, see Ceramics Mo. article Oct. '88 for potential substitutes) **Iron sulfate** (soluble for
Copper (Cu) In slip: 2-8%. In glaze: rarely used above 5%. Excess may give metallic pewter			
	Fluxes at low-fire emperatures and highly soluble in glazes. May vaporize above cone 8 and fume adjacent ware. In raku post-firing reduction copper produces metallic copper penny flashes. 2% Cu softens chrome greens in oxidation. "Tizzy" slip for cone 10 reduction is about 8% Cu	+ alkaline flux = alkaline turquoise (cf. Egyptian paste turquoise and Islamic wares) + Ba (barium) in high amounts (30% +) = barium blue matts (robin's egg) . High Ba is TOXIC: not for food wares. + Sr (strontium) colors similar to Ba, w/o toxicity. + Zn (zinc) = intensified Cu colors. Oxidation: turquoise to greens + Pb (lead) = transparent grass green (possibly w/slight lustrous surface) cf. T'ang Dynasty ware. Copper increases the solubility of Pb and may change a "safe"	**copper carbonate** ($CuCO3$ greenish) **black copper oxide** (CuO) **red copper oxide** (note: red CuO does not mix well in water and stays beaded up on the surface). **copper sulfate** ($CuSO4$ pale turquoise crystals, soluble, avoid skin contact

		lead glaze to one that leaches Pb. Lead blisters in reduction and is ONLY fired in oxidation. Reduction: copper reds: plum, oxblood, peach bloom, flambe, etc.	
Manganese (Mn) In slip 2-10%. Over 15% fluxes high-fire slips enough to vitrify. In glaze 2-4% will dissolve in glazes. Over 4% in glaze can produce crystalline Mn on the glaze surface at high temperatures. Over 20% = bronze metallic surface			
	Begins to melt at 1112EF. Brown to plummy brown to purple brown. May produce greens at high temperatures and in reduction. Pinks. Mason's very refractory 6020 pink stain is MnAl pink. Often used to modify cobalt colors. May blister if used in large amounts w/ sulfur present. May cause pinholing in glaze surface. All forms: skin contact is not a signficant hazard but highly TOXIC if inhaled, moderately toxic if ingested	+ high alkaline fluxes (K, Na, Li) and low alumina 1-3% MnO2 = violet. .25-.5 CoO will intensify this color. + alumina in a frit = pink stain (e.g. Mason 6020 pink body stain) + Pb (lead) = purple + tin = "interesting coffee color" according to Hamer.	**manganese oxide** (MnO) **manganese dioxide** (MnO2) **manganese carbonate** (MnCO3)
Chrome (Cr) In slip .50 - 2%. Excess (> 6%?) black breaking to green. In glazes .25 - 2%			
	Powerful, refractory colorant. Remains undissolved and give opaque, dense color in glazes. Usual color is opaque John Deere tractor green. Colorant in popular "Mean Green" or "Reeve Green" highfire glaze. Cr is colorant in the highly toxic (Pb+Cr) orange sculpture glaze Otto's texture. Fumes very toxic. Possible allergic reactions. Fumes toxic.	+ Zn (zinc) = brown + Pb (lead) at low temp. (010 - 04) = red, orange (Otto's texture is a famous green to orange scaley sculpture glaze), w/high Na + Pb = yellow. + alkaline flux & small amounts of Cr (chrome) = chartreuse + at least 5% Sn (tin) and small amounts. of Cr (0.5%) = chrometin pink, even up to high fire temps. Above cone 6 Cr may fume adjacent tin-glazed pieces and pink them. Cr-Sn pink used to make many pink stains. Beware using these in Zn bases. Cr + Co combinations are used in many blue-green, teal, etc. stains. Beware using these w/Zn bases.	**chrome oxide** (Cr2 O3 green raw).Chrome oxide has slight skin contact, inhalation, and ingestion toxicity. **iron chromate** (FeCrO4 browngreys) potassium bichromate or dichromate (bright orange crystals raw, soluble in water, highly TOXIC if absorbed, inhaled, or swallowed, olive drab) **lead chromate** (TOXIC)
Rutile (Ti + Fe) In slip 2-6%. In glaze 4-25			
	Refractory mineral that is mostly Ti plus uyp to 15% iron and sometimes traces of Cr (chrome) and/or V vanadium). Used to produce modified iron colors, such as tan or yellow in oxidation to blues in reduction. Produces broken or mottled colors in glazes, crystallization (matt and opaque). Pearly in a	In reduction glazes may produce blues and pearly colors in the pink-purple-blue range As a wash on top of glazes (refractory – mix w/flux) produces buff-golden crystalline effect, esp. in high-fire. On top of majolica glaze at lowfire temperatures, rusty orange.	**granular rutile** (produces specking) powdered form, light or dark (less or more Fe) forms. Tan, grey-brown to dark brown raw.

	salt-glaze slip. Used w/cobalt for greens or steel greys, or w/chrome for yellower greens. Used for matt oranges in high fire. Darkens a glaze more than Ti. If using as wash, add flux, e.g. over temmoku to produce a golden crystalline surface, test 50% TiO2 + 50% Gerstley Borate	May give Cr-Sn pinking or halos if the particular batch of rutile has slight Cr impurities. Varies	
Cobalt (Co): In slip .25 - 2%. In glazes .25 - 1%			
	Strong colorant. Melts at low-fire temperatures. Expensive. Stable in all kiln atmospheres to usually give a blue color. May be overbearing and need softening w/iron, nickel, manganese, etc.. High cobalt over-glaze colors (e.g. in majolica blue or black) or surfaces may spit during firing, leaving a halo on the kiln shelf	+ Mg (magnesium) = purple to lavenders + Pb (lead) = warm blues + alkaline fluxes (Na, K, Li) = brilliant blue toward ultramarine + Zn (zinc) = intensified blue + Ti (titanium) = green Mixed with colorants: + rutile or titanium = green + Cr (chrome) = teal + pink stain = purpl	**cobalt carbonate** (CoCO3 lavender raw) **cobalt oxide** (CoO black raw) May spot unless sieved well. **cobalt sulfate** (CoSO4 lavender crystals raw) SOLUBLE. Hazardous.
Nickel (Ni) In slip 1-6%. In glazes 1-4%			
	Refractory colorant. Above 2% may matt a glaze surface. Colors are uncertain and hard to repeat. Used to modify Co toward bluegreys. Small amounts of nickel in glazes (below 1%) usually produce greys. With zinc and other ingredients in certain ratios, purples or yellows may be produced. Mason nickel yellow-green green is refractory.	½ -4% + Zn in reduction = yellow, purple, or blue 2% + high Ba = brown in glaze 1% + high alkaline glaze @ cone 1-3 = blue + high calcium = tan-purpl	**nickel oxide** (NiO green raw, Ni2O3 black raw) **nickel carbonate** (NiCO3)

OPACIFIERS:

(table adapted from Linda Arbuckle)

A base glaze is generally thought of as an un-colored coating. Depending on the materials and amounts, it may be transparent. Many satin glazes are a bit frosty, and matts are often translucent or opaque. Adding certain materials to a transparent gloss glaze will make it opaque. Tin and zirconium oxide make white, opaques that can then be further colored if desired. Titanium (and ilmenite and rutile, which are high in Ti) makes a more ivory colored opaque, and will cause crystalline formation in susceptible glazes.

Material	Notes	Color Properties	Sources
Tin (Sn) up to 10% in glaze			
	Increases surface tension, and high Sn glazes may tend to crawl where thick	Usually white, very opaque. +5% Sn + small amounts of CrO or Cr fuming = pink	**tin oxide** (SnO) chrome-tin pink stains
Zirconium (ZrO) 5-12% in glaze			
	Produces harder glaze than Sn or Ti. Less strong than tin (general rule: 1 Sn = 1.5 Zr opacifier). Produces a more translucent white than tin, and a slightly shinier surface.	White, opaque	All below are brand names for zirconium opacifiers: **Zircopax**: all temps., 5-10% = white **Ultrox**: all temps., stronger than **Zircopax**. 6% = white **Superpax**: stronger than Zircopax **Opax**: best at lower temps
Titanium (Ti)			
	Often produces crystaline matts, broken or mottled color. Usually an antique white, yellowish-buff color. Refractory. If using as wash, add flux, e.g. over temmoku to roduce a pale golden crystalline surface, test 50% TiO_2 + 50% Gerstley Borate.	+ Co = green crystalline W/Cu reds = toward purples. 2% added to glaze can give microcrystalline formations & interesting colors. 1 TiO_2 + 1 Gerstley borate (by vol) used as a "patina" over fired terra sigillata is ivory to light yellow	**titanium dioxide** (TiO_2)

Elements from the Periodic Table common in ceramics:

Aluminum	**Al**		Hydrogen	**H**		Sodium	**Na**
Barium	**Ba**		Iron	**Fe**		Strontium	**Sr**
Boron	**B**		Lead	**Pb**		Sulfur	**S**
Cadmium	**Cd**		Lithium	**Li**		Tin	**Sn**
Calcium	**Ca**		Magnesium	**Mg**		Titanium	**Ti**
Carbon	**C**		Manganese	**Mn**		Vanadium	**Va**
Chlorine	**Cl**		Nickel	**Ni**		Zinc	**Zn**
Chromium	**Cr**		Oxygen	**O**		Zirconium	**Zr**
Cobalt	**Co**		Phosphorus	**P**			
Copper	**Cu**		Potassium	**K**			
Fluorine	**F**		Silicon	**Si**			

Glossary of Terms common to clay and glaze calculation:

C.O.E. (Coefficient of Thermal Expansion) = A measure of the reversible volume or length change of a ceramic material with temperature. The more it expands during heating the more it contracts while cooling down. Glazes that do not have a similar thermal expansion to the clay body cause problems like crazing, shivering, and weakened ware. At 2000F fused silica (non crystalline) has an expansion of almost zero (compared to room temperature) whereas quartz mineral has the highest expansion 1.5%. Fused alumina is 0.9% and stabilized zircon 0.8%.

Colorant = A material that transforms a glossy or white glaze into a colored glaze. Colorants can be raw metal oxides (e.g. iron oxide, chrome oxide) or smelted (e.g. stains). Potters and smaller companies often use raw colorants whereas industry employs stains. Unlike stains which are prefired, the color of a raw powder colorant likely bears no resemblance to the color it will produce in a glaze. In ceramics, color is a matter of chemistry. The color produced depends on the chemistry of the host glaze and of the mix of colorants added. The same metal oxide can participate in many color systems. Some colorants produce the same color across a wide range of host glazes (cobalt), others are very sensitive to the presence or absence of specific helper or hostile oxides (chrome-tin). Colors are the most vibrant in transparent glazes where there is depth. In opaque glazes colorants tend to produce pastel shades. Some colors are potent, 1% can produce a strong color. Others are weak and 10% make be needed.

http://digitalfire.com/4sight/glossary/glossary_crazing.html

Deflocculate/Deflocculation = The process of making a clay slurry that would otherwise be very thick and gooey into a thin pourable slurry. Deflocculants (or electrolytes) are liquids or powders added in small amounts and they work their magic by imparting electrical charges to clay particles making them repel each other. It is the opposite of flocculation.

To deflocculate a slurry properly it is very important to be able to measure its specific gravity and viscosity accurately. Yet it is very common for slip casters to be tied to a recipes and have little understanding of how to control their slip. Many will work for years with substandard slip without knowing it, others will throw away all scrap rather than reprocessing it simply because they do not understand slip rheology.

It is common for potters to mix slips using clays intended for modeling or sculpture. Far better casting mixes can be made using mixes of materials that emphasize permeability instead of plasticity. Once you have used a slip properly formulated and deflocculated for casting you will never go back to using an inadequate slip.

Sometimes glazes are deflocculated to reduce their water content, this is most likely where glaze is being applied to once-fire ware.

Common deflocculants are sodium silicate, Darvan, Calgon.

Flocculant/Flocculation = The opposite of deflocculation. The process of making a ceramic glaze or clay slurry that would otherwise be thin and liquid into a gel. This is typically done to improve suspension properties or allow application of slips and glazes without problems of running and dripping. However flocculated slips have a high water content and thus a higher shrinkage. Common flocculants are calcium chloride, vinegar, epsom salts.
Glazes can change their viscosity with storage, when they thicken they are said to 'flocculate'. In these cases slightly soluble materials in the mix (e.g. nepheline syenite) can act to change the viscosity of the slurry.

Glaze Compression = Every solid has a thermal expansion, that is, an amount by which is expands and contracts on heating. If the thermal expansion of a glaze does not match the body it is on, then the glaze either cracks (when it is under contraction) or chips off when under compression.

The compression occurs while the piece is cooling in the kiln. When the glaze solidifies it acquires its solid characteristics. This might happen at 1500F, for example. As the piece continues to cool in the kiln it contracts. If the body is contracting more than the glaze then the glaze is being put under compression. Some compression is actually desirable and strengthens the glaze-body combination. However too much compression puts the piece under internal stresses seeking an opportunity to relieve themselves. When the difference is severe the piece will not survive cooling in the kiln without fracturing. When individual shards of such pieces are dropped onto a cement floor, for example, they will literally explode into hundreds of tiny pieces. In less severe mismatches, glazes will flake off areas where they wrap around contours (e.g. the lips of mugs), this is known as shivering. This can be serious if it occurs while a piece is being used and someone ingests a micro-flake of glaze (having razor sharp edges). More info at http://digitalfire.com/4sight/glossary/glossary_glaze_compression.html

L.O.I. (Loss on Ignition) = Simplistically, LOI is the amount of weight a material loses on firing. LOI is usually crystal-bound water or carbon material that burns away.

However LOI can also be other things (e.g. sulfur, chlorine, oxygen). It is also more complex for many materials since they go through a number of changes during temperature rise and these changes may involve weight loss or even weight gain (e.g. for non-oxide materials that capture oxygen from the atmosphere or other materials). Some of these changes may occur at a temperature higher than that at which they are being used. In addition, some materials that might otherwise break down quickly and form gases of decomposition may linger when they are in a glaze or frit that is being fired quickly (e.g. fluorine).

A fired glass has no organics or carbonates; so it always has zero LOI. This means that LOI is never shown for a glaze formula and you will never need to worry about it for any batch-to-formula or analysis calculations.

However, many raw materials that go into the kiln do lose weight during firing; so they are not sourcing as many oxide molecules as a calculation might suggest. If a raw material loses weight on firing, it must be accounted for in calculations. You can think of LOI as being like the shells which we throw away from a bag of nuts. We compensate for anything lost during firing by increasing the formula weight. For example, 100 grams of kaolin going into a kiln produce only 88 grams of oxides for glass making. By increasing the formula weight of the kaolin by the correct amount, a full calculated oxide yield will result.

Opacifier/Opacification = A glaze additive that transforms an otherwise transparent glaze into an opaque one. Common opacifiers are tin oxide and zircon compounds. Opacifiers typically work by simply not dissolving into the melt, the white suspended particles reflect the light. However another mechanism of opacity is crystallization, this can occur when a crystallizing ingredient is super saturated into the mix (e.g. TiO_2) or when slow cooling a glaze to encourage crystallization of less saturated oxides that crystallize easily (e.g. boron blue). More info at http://digitalfire.com/4sight/glossary/glossary_opacifier_opacification.html

Oxidation = A firing where the atmosphere inside the kiln has sufficient supplies of oxygen to satisfy chemical reactions in the glaze and clay. Electric kilns are synonymous with oxidation firing, however they often have stagnant air flow and thus may fire to a more neutral atmosphere than intended or realized. Direct-connected kiln vents improve this situation. Oxidation glazes are brighter colored than reduction ones and iron is not a flux in oxidation kilns. Generally potters and hobbyists who use reduction fire at higher temperatures.

Porosity (Absorption) = In ceramic testing this term generally refers to the pore space within a fired clay body, as such it is also referred to as absorption. It is measured by weighing a specimen, boiling it in water, weighing it again, and calculating the increase in weight. As ceramic clay bodies vitrify in a kiln they densify and shrink (thus reducing pore space). The % porosity of a body is thus an indicator of its degree of vitrification. Porosity also implies strength (in comparison to specimens fired at different temperatures that have greater or lesser porosities). Porcelains normally can be fired to a point of zero-porosity but doing so brings them close enough to melting that ware tends to warp in the kiln. Stonewares and earthenwares reach a minimum porosity that can be well above zero (as much as 3%), firing beyond that bloats or melts the body. If porosities are measured over a range of temperatures for a body it is possible to create a graph to get a visual representation of the body's maturing range. The porosities plotted against temperature produce a line that decreases to a minimum, levels out then drops quickly rises.

P.C.E. = Pyrometric Cone Equivalent: Pyrometric Cone Equivalent is measured by making a cone of the material and firing it until it bends to 3 oclock.

The cones are the size of small orton kiln-sitter cones and they are set into special refractory rings that hold them at the correct angle to bend inwards. A ring can hold many cones so many tests can be done in one firing. The ring is fired in a small kiln capable of cone 25-30 (clays that normally mature at cone 10, for example, might not melt until cone 20 or higher). When placing the ring into the kiln the placement of the cones is noted (to identify them) and the temperature at which each bends is recorded.

Reduction = Firing a kiln for part of its cycle with an atmosphere having no free oxygen. In traditional ceramics reduction firing requires a specially designed fuel fired kiln that restricts the flow of incoming air so there is enough to burn the fuel and no more (in some cases it is restricted so that is actually less than enough to introduce carbon into the atmosphere). Reduction is generally done to produce the visual effects associated with reducing metallic glaze and clay body components to their metallic state and for variegated effects in glazes. These effects include some colors and effects impossible or difficult to achieve in oxidation (e.g. copper reds, earthtone colors, dolomite mattes, iron speckling in clay bodies). Many people fire their gas kilns up in oxidation but at two places in the ramp (e.g. cone 06, 10) they reduce the kiln for a period (for body and glaze reductions). Others begin reduction firing at (e.g. at cone 06) and continue it to the end and then oxidize for a short period to clear the kiln.

Si:Al Ratio = This number is part of the calculation of the chemistry of a glaze recipe. It singles out the silica and alumina oxide molecules and gives their relationship. For example, if there is 5.0 SiO_2 and 0.5 Al_2O_3, then the ratio is 5.0:0.5 or 10:1, or just 10. This ratio is significant in stoneware glazes, for example, because high silica tends to produce glossy glazes when alumina is low and high alumina creates matte glazes when silica is low. It thus follows that the higher the Si:Al ratio the glossier a glaze will be.

However we must recognize that this ratio is not a general or fool-proof measure of gloss. Validity of the Si:Al ratio assumes a transparent glaze that is melting well and relatively free of other mechanisms that create matteness (e.g. high magnesia or calcia in low fire). Also remember that very low alumina glazes are fluid and encourage crystal formation during cooling; if these crystals are small they can completely cover the surface turning it matte.

Sintering = Sintered clay has been fired high enough so that it no longer will slake or break down when exposed to water. Bisque fired ware is sintered. However the term sintering refers more to the particle bonding mechanism where particles are not glued together by the melting of a flux. Rather adjacent particles bond by the migration of species across the connection and by the deposition and buildup of material that has become gaseous in the kiln atmosphere. Refractories are often sintered to considerable strength. Sintered alumina bodies are very porous yet they can have a 'ring' like that of a fine porcelain.

Soaking = The practice of holding the kiln at final firing temperature for a period of time. This is usually done to mature the clay and give the glaze opportunity to flow and heal imperfections. The advent of electronic kiln controllers has made it possible for anyone to soak. Soaking is especially advantageous for glazes with a stiff melt (i.e. low temperature zirconia whites) and for porcelains that require translucency, density, and glassy surfaces.

Thermal Shock = Stresses imposed on a ceramic by the volume changes associated with sudden shifts in temperature. Ceramic materials with good thermal shock resistance are able to withstand sudden temperature changes without cracking. Cracking usually occurs when one part of an item is a different temperature than another part and therefore expanding or contracting at a different rate. Fired ceramic does not withstand thermal shock nearly as well as other materials like steel, plastic, wood, etc. Ceramic is hard and resistant to abrasion but it is brittle and propagates cracks much more readily.

Vitrification = 'Vitrification' is a process. As clay is fired hotter and hotter, it reaches a point where, if cooled, it will produce ware of sufficient density and strength as to be useful for the intended purpose. The intended purpose may well require some porosity to gain another more important advantage (i.e. stability in the kiln, resistance to blistering). However 'vitreous' ware is usually functional, water proof, sanitary, hard, and strong. Such products must be fired closer to the melting range of the clay. Ware that has fired dense and strong is also said to be 'mature'. To vitrify some clays requires that they be fired high enough to cause deformation, ware thus needs to be supported in setters or the cross section redesigned to be more stable. Porcelains and very vitreous. Stoneware are generally semi vitreous.

Glazing and Firing Defects:

Black Coring = Black coring usually occurs during a reduction firing and is a result of fast firing and/or lack of oxygen in the kiln between 700 and 900C (usually in the bisque firing). If body carbon fails to oxidize to CO2 it steals oxygen from Fe2O3 (reducing it to FeO, a powerful flux.) This FeO will then flux the body, sealing it and preventing the escape of remaining carbon in the body. This produces the characteristic 'black core' you see on ware cross section. The more iron in a body, the greater the risk of this problem if firing is not right. Once iron is reduced to it is very difficult to reoxidize it back to Fe2O3. Note that electric kilns can also produce this problem, depending on the carbon and iron content of the clay, density of the pack, available airflow, and speed of the firing.

Bloating = Bubbling that occurs in clay bodies if they are over fired. Aggravating conditions include the presence of mineral particles that generate gases during the over firing stage, the presence of excessive carbon not burned away by bisquit or oxidation firing, laminations in the clay matrix, the presence of an early melting glaze that seals the surface preventing gas escape. Many bodies do not tolerate overfiring well (e.g. manganese speckled bodies, heavy iron stonewares). Many kilns do not have reliable shut-offs or the temperature measurement devices on computer controlled kilns have deteriorated or are not accurate and users are unwittingly firing them too high. It is best to confirm firing temperature using properly set cones to avoid bloating with touchy bodies.

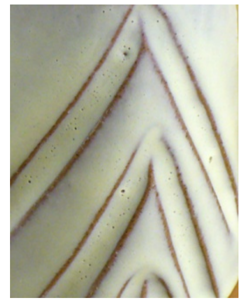
Crawling = A condition where fired glaze separates into clumps or islands leaving bare clay patches showing in-between. More prevalent in once fired ware. There are many causes for crawling (typically glazes shrink too much during drying and don't have a good bond with the bisque).
Some times glazes are made to crawl intentionally. One technique to make this happen is to add 15-20% magnesium carbonate (testing required to determine amount) to a low fire transparent glaze.
http://digitalfire.com/4sight/glossary/glossary_crawling.html

Crazing = Small hairline cracks in glazed surfaces that usually appear after firing but can appear years later. It is caused by a mismatch in the thermal expansions of glaze and body. A glaze of higher expansion shrinks more than the clay to which it is attached and therefore crazes.

There are many treat-the-symptoms approaches to crazing but the bottom line is: If there is a thermal mismatch it will reveal itself sooner or later no matter how you adjust firing or glaze thickness to hide the problem. If crazing is visible, it is an indication of a significant problem. This is because long before crazing becomes visible, serious strength problems result where glaze and clay are not expansion-compatible. In addition, crazing also call into question the functional safety of ware (e.g. bacterial hazards). More info at http://digitalfire.com/4sight/glossary/glossary_deflocculate_deflocculation_deflocculant.html

Dunting = Cracking that occurs in ceramic ware that is cooled too quickly. Dunting can exhibit itself as simple hairline cracks or ware can fracture into pieces. Ware of uneven cross section, ware with glaze that fits poorly, or large pieces (i.e. large flat plates) are often subject to dunting. Ware with high amounts of cristobalite or quartz undergoes sudden volume changes when heated or cooled through the inversion temperatures of quartz.

Pinholing = A glaze defect where tiny holes are present in the fired glaze surface. These holes normally go down to the body surface below. Pinholing is a plague in industry, the tiniest hole in the glaze surface of a tile or utilitarian item can make it a reject. Industry goes to great pains to get materials of very fine particle size for their bodies and glazes to reduce the occurrence of glaze defects. Glazes which melt and flow well often still have pinholes if gas producing particles are present in the body (these expel gases up through the glaze melt thereby disturbing its surface). Blisters, dimples and pinholes often occur together.



Shivering (peeling) = A defect in glazed ware where the glaze is compressed by a body having a higher thermal expansion. While it is normal, even necessary for glazes to be under some compression to avoid crazing and improve ware strength, over compression will actually cause the glaze to peel off the ware on edges to relieve the stress. Shivering is the opposite of crazing.

Clay and Glaze Materials

Albany Slip

-- high iron, low melting natural clay slip, no longer mined – use Alberta Slip for a substitute --
Silica/Alumina ratio: 6.7:1
Equivalent Molecular Weight: 697.298

Albany was a low plastic silty clay that was mined in Albany, New York for many decades. It melts to a glossy chocolate brown glaze at cone 8-10. It was a very popular glaze ingredient for dark colors and tenmoku and iron crystal effects. In the early 20th century it was used extensively on heavy utilitiarian stoneware across North America and even on electrical insulators. Glazes could be formulated very easily using this material as a starting point since it was already balanced and had good slurry properties. Potters especially adopted this material and it appears in thousands of recipes used across North America.

There are a number of substitutes for Albany and anyone with ceramic chemistry calculation software can easily speculate on a mix of materials that matches the chemistry on paper. However keep in mind that judging the similarity to Albany is a complex issue of mineralogy, physical properties and chemistry and it depends on the reliability of the information at hand on what Albany actually was.

http://digitalfire.com/4sight/material/alberta_slip_32.html

Molecular Formula of Albany Slip:

K_2O 0.23992757	Al_2O_3 1.00000000	SiO_2 6.67360788
Na_2O 0.08963332	Fe_2O_3 0.22664856	TiO_2 0.06956391
CaO 0.71691565	LOI 3.65142589	
MgO 0.46250189		

Percentage Analysis

57.48 % SiO_2
14.62 % Al_2O_3
3.24 % K_2O
0.80 % Na_2O
2.67 % MgO
5.77 % CaO
5.19 % Fe_2O_3
0.80 % TiO_2
9.43 % L.O.I.
____
100.00 % TOTAL

NOTES:

Alberta Slip

-- substitute for Albany Slip –
Silica/Alumina ratio: 7.6:1
Equivalent Molecular Weight: 699.193

This material was formulated as a physical and chemical substitute for the late and very popular Albany Slip from New York state. Like Albany it is a low melting iron stained clay. Alberta Slip is more consistent than Albany was since it is made from a blend of raw materials.

Alberta slip has a slightly lower iron content than Albany had so some glazes may not fire as dark (this can be counteracted by adding additional iron oxide). Alberta slip melts as well and works in most glazes that call for Albany. Alberta slip is more plastic (less silty) so recipes containing larger proportions may shrink and crack during drying.

Complete information on how it was formulated can be found in the book Magic of Fire available from Digitalfire Corp. and at the web site http://digitalfire.com.

Plainsman Clays has made this material for many years and it is established in the market place across North America. You can use it at 100% to create a chocolate brown glossy glaze at cone 10 (but there is a problem with doing this as we shall see in a moment). Many Albany glazes are based on the addition of an active flux that increases melt fluidity so much that greenish and yellowish crystals grow on cooling to completely change the character of the surface. Many black glazes are also based on Alberta Slip, since it already contains lots of iron you only need to add a little more and some extra cobalt or manganese.

The plasticity of Alberta Slip is helpful where smaller amounts are used since it can assume the burden of suspending the glaze.

Arroyo Slip may also be used as a substitute for Albany Slip

Molecular Formula of Alberta Slip:

K20 0.23810000	Al2O3 1.00000000	SiO2 7.55330003
Na2O 0.22610000	Fe2O3 0.22060001	TiO2 0.04060000
CaO 0.78790000		
MgO 0.57850000		
BaO 0.00770000		

Percentage Analysis

64.88 % SiO2
14.58 % Al2O3
3.21 % K2O
2.00 % Na2O
3.34 % MgO
6.32 % CaO
0.17 % BaO
5.04 % Fe2O3
0.46 % TiO2

100.00 % TOTAL

NOTES:

Alumina Hydrate

-- source of alumina, used primarily in kiln wash, rarely used in glazes --
Equivalent Molecular Weight: 137.970

Hydrated alumina contains significant water in its crystal structure. There are differing water contents depended on the type of alumina hydrate, but the main refined article of commerce in the market is known as alpha aluminum trihydroxide (with an LOI of 34%). If you are unsure about the alumina hydrate you have in stock you can do a simple LOI test.

Hydrated aluminas are fine granular white powders that have good flow properties. As with any form of alumina, this material has a very high melting temperature. It can be useful in glazes as a source of aluminum oxide, however the powder must be very fine. The hydrated version of alumina stays in suspension better in glaze slurries and has better adhesive qualities. Also using hydrated alumina in glazes and glass can promote the fining operation of coalescing and removing finely dispersed gas bubbles. Small additions of fine alumina hydrate added to a glaze can also enhance the color of Cr-Al pinks. Larger additions of fine material can impart matteness if the glaze is able to take it into solution (sourcing alumina from kaolin and frits may be more practical).

http://digitalfire.com/4sight/material/alumina_hydrate_42.html

Molecular Formula of Alumina Hydrate:
Al_2O_3 1 LOI 2

Percentage Analysis

73.88 % Al_2O_3
26.12 % L.O.I.

100.00 % TOTAL

NOTES:

Barium Carbonate

-- flux, used primarily in satin matte glazes, and in earthenware bodies to prevent scumming --
Equivalent Molecular Weight: 197.000

While $BaCO_2$ has a high melting temperature, it will break down much readily in a glaze melt (liberating the BaO for glass building). It decomposes even more readily during glaze melting in a reduction atmospheres. The dissolution process happen most quickly if $BaCO_3$ is present in small amounts (e.g. 5% or less). Even if present in larger amounts, the glaze matrix can solidify with both types, one participating in the glass microstructure and the other acting as a refractory filler, opacifier and matting agent (especially in low temperature glazes). Effects produced when baria is acting as a filler are sometimes mistaken for those of a true baria crystal matte. Such will likely leach toxic BaO (other oxides will opacify or produce a low fire matte i.e. CaO, MgO, Alumina, Zircon).

Barium carbonate produces gases as it decomposes and these can sometimes cause many pinholes or blisters in glazes. There are many barium frits available and incorporating one of them to source the BaO instead is a classic application of ceramic chemistry calculations. The resultant glaze will be more fusible and will have better clarity and fewer defects.

In art ceramics barium carbonate is popular for the production of classic barium crystal mattes, BaO readily forms crystalline phases during cooling. These are dependent on adequate kiln temperatures, cooling cycle and the chemistry of the host glaze (a slightly reducing atmosphere is also beneficial). Barium can act to initiate crystal development in other chemistries, for example metallic glazes can benefit by the addition of some barium carbonate.

Barium carbonate is commonly added to clay bodies in small amounts (0.2-0.8%) to halt fired surface scumming or efflorescence It is slightly soluble in water and provides Ba^{++} ions to link with SO_4^{--} ions in the water to form $BaSO_4$ (barium sulfate). This new sulfate molecular form is much less soluble (2-3 mg/L), so it stays internal (rather than migrating to the surface during drying). However companies try minimize the use of barium (or even high clays with high soluble salts) because the barium sulphate generates sulphuric acid during firing and it corrodes kiln refractories. To get the best dissolution it is best to add the barium to the water first and mix as long as possible, then either add the water to the other dry ingredients (for plastic bodies) or add the other ingredients to the water (for slips).

http://digitalfire.com/4sight/material/barium_carbonate_86.html

Molecular Formula of Barium Carbonate:
BaO 1

Percentage Analysis
100.00 % BaO

Potential Health Hazards:
HIGHLY Toxic-avoid ingestion. Glazes containing barium may not be safe for ware intended for use with food - test them for barium release.
NOTES:

Barnard Clay (Blackbird Clay)

-- high iron clay slip --
Silica/Alumina ratio: 9.3:1
Equivalent Molecular Weight: 937.531

Barnard clay has long been used by potters as a source of iron in dark firing glazes. It offers price advantages over using iron oxide and being a clay aids in suspending the materials in the slurry. Barnard has proven valuable for iron slip glazes requiring high clay content. For example, a mixture of 90% Barnard and 20% calcium carbonate will produce a nearly black glaze around cone 9.

Published chemistries appear to be highly variable. We have seen iron amounts as low as 14% and as high as 34% (the other oxides are likewise variable).

Barnard clay is a silty material with very low plasticity; so low that it is difficult to form test specimens from it in the plastic state. The material is extremely messy to work with and stains containers and everything it touches. There is some variation in the color (and thus of thevfired results of glazes and slips employing it).

This is one of the most stained clay materials available. Fired bars are very dark brown at cone 02 proceeding to black at cone 4. At cone 6 it is beginning to melt.

To duplicate this material the base clay needs to have low plasticity and be high in iron and silica and low in alumina and flux. Since iron oxide and silica need to be added flux containing clays could possibly be diluted enough to work. If you would like more information please email us and we can give you trial recipes in return for your reports on their testing.

http://digitalfire.com/4sight/material/barnard_slip_90.html

Molecular Formula of Barnard Clay:

K_2O 0.2036	Al_2O_3 1.0000	SiO_2 9.3245
Na_2O 0.0178	Fe_2O_3 0.8602	TiO_2 0.0788
CaO 0.0450		MnO_2 0.3668
MgO 0.1745		LOI 3.8949

Percentage Analysis

59.74 % SiO_2
10.87 % Al_2O_3
2.05 % K_2O
0.12 % Na_2O
0.75 % MgO
0.27 % CaO
14.65 % Fe_2O_3
3.40 % MnO
0.67 % TiO_2
7.48 % L.O.I.

100.00 % TOTAL

NOTES:

Bentonite

-- glaze suspender --
Silica/Alumina ratio: 5.1:1
Equivalent Molecular Weight: 522.100

Bentonite is a clay mineral with incredibly small particle sizes. This, in combination with the active chemistry on the surface of the particles (that makes them hold onto water), makes it the most plastic and impermeable common clay material used in ceramics. Its contribution to working properties in glazes and clay bodies is balanced by the undesirable properties that are also imparted. Thus anyone who uses this material should have their eyes open to its advantages and disadvantages.

There is a huge variation in the chemistries of bentonites, it is impossible to specify an average (bentonite is not employed in ceramics for its chemistry). Any generic chemical analysis is thus only an attempt to represent the amounts you might find in a common variety. Because of the high iron content, bentonite is considered a dirty material and thus the tug-of-war between the valuable working properties it imparts and the need for whiteness or pure color that it impedes.

Fine particle size: Bentonite is colloidal (particles are so small the action of water molecules is enough to keep them in suspension). It is typically 10 times finer than ball clay. It can have a surface area of almost 1000 square meters per gram (50 times that of kaolin, 5000 times that of silica flour).

Plasticity: Because of their active electrolytic behavior and fine particle size, bentonites exhibit extremely high plasticity (and associated high shrinkage). In pottery and porcelain clay bodies additions of only 2% can produce marked improvements in workability and dry strength without much effect on fired color. The use of up to 5% is common, especially where high plasticity is needed it a white burning body. However the need for higher additions than this may indicate a lack of other clean or adequately clays in the recipe. Also, high amounts of bentonite will dramatically slow down the drying rate. In certain applications it is practical to use bentonite as the only plasticizer in a mix (in larger percentages). The plasticity-producing effects of bentonite depend on the shapes, sizes, surfaces and electrolytics of the particles it is interacting with, equal additions of bentonite to two different host bodies may have much different effects on the plasticities.

Drying performance: Bentonite makes bodies more plastic and dry harder but this comes at a cost, they shrink more during drying and thus potentially crack more.

Bentonite is far too plastic to prepare test specimens (e.g. for drying, strength and shrinkage evaluation). However, a mix of 20-30% virgin material with calcined material can be extruded and formed (test specimens will still shrink to a very small size).

Permeability: Most bentonites are impermeable to water. To demonstrate this fill a tall glass cylinder with bentonite to near the top and then carefully pour water on top. The water will penetrate down into the clay only a few millimeters and no matter how long you leave it it will not penetrate further. This occurs because the powder swells as the water penetrates and adjacent particles 'hang onto' the water between them. The water thus becomes a glue that holds the mass together and prevents more from entering or passing through. This phenomenon accounts for why glazes and bodies of high bentonite content dry slower. As an example, if you pour a slurry of silty clay onto a plaster surface the water is often pulled out in seconds. However a bentonite slurry may require days or weeks to pull the water out evenly.

Swelling: Most bentonites expand (as much as 15 times) when added to water. This characteristic is valuable in thickening liquids and slurries and is another contributing factor to maintaining suspensions. Bentonite is used in large quantities in the gas and oil drilling industries to suspend high specific gravity slurries which are used as a medium to float out the chunks of rock cut by the drill bit.

Suspension: Bentonite is used to keep particulates in suspension in all sorts of consumer and industrial products, and in glazes in ceramics. The mechanism is charge attraction, that is, opposite electrolytic charges develop on the surfaces and edges of dispersed particles and give rise to a stable 'house-of-cards" structure that can be disrupted by shear stress. However when the stress is removed, the structure re-establishes itself. The amazing thing is that large amounts of other types of particles can be tolerated within this structure, they are kept in suspension as well. Thus maximum suspending benefit can be achieved by blunging bentonite with the water before adding the other dry materials (to insure that every particle is whetted on all sides). However, this cannot be done without a powerful high-speed propeller mixer. Thus it is normal to blend dry ingredients including bentonite first and then add them to the water. However beware of too much bentonite in glazes, they will dry too slowly and will shrink too much during drying causing cracks that later turn into crawling during firing.

Thixotropy: This is a tendency of a suspension to gel after sitting for a time and then re-liquify when it is agitated. Clay bodies also exhibit this behavior, stiffening on aging but then re-softening when worked. Thixotropy is valuable in clay slurries for this reason, they gel when not being used and thus do not settle out. While typical industrial thixotropic agents employ various mechanisms bentonite works by charge attraction (see above).

Chemically inert, Inorganic, Non-irritating: Formulations that are not fired are not altered chemically by bentonite additions. Bentonite does not support organic growth. Thus it is suitable as a carrier for personal care products like hand cream and cosmetics.

Binder: Bentonite binds particles together in ceramic bodies to make them stronger in the green or dry state. Its minute particles fill voids between others to produce a more dense mass with more points of contact. Adding bentonite to glazes also imparts better dry strength and a harder and more durable surface. To fully appreciate how plastic, hard and strong bentonite can be, try mixing 25:75 with silica and preparing plastic test bars.

Firing: Standard grades typically vitrify (around Orton cone 6-10) from grey to deep red coloration. However soluble salts can be so high that they form a glaze on pure test specimens. Utility grades often contain granular iron material that causes specking in clay bodies, even materials rated at 325 mesh can contain significant speck-causing particles. For good reason, bentonite is considered a very dirty material. However commercial micro-fine grades (100% minus 325 mesh) are available (these are very expensive however). Barium carbonate can be added to bodies to precipitate the solubles bentonite brings. Thus the iron content is the only firing issue associated with visual character. Contrary to what many think, a white body can often tolerate a up to 5% bentonite without firing significantly darker.

White firing bentonites: There are a number of white firing and highly refined bentonites produced for the ceramic industry. However they tend to have much less plasticity and are many times more expensive. Consideration and testing are thus needed to determine if a white burning material twice as expensive (or more) of which you need to use twice to four times as much is worth it (in a worst case scenario that may be ten times more expensive!). Normal microfine bentonite raw bentonite even at 5% does not darken the color of the porcelain as much as you might think. Examining recipes often shows that the kaolin and ball clay are contributing more iron than the bentonite. Even white plasticizers often have up to 0.5% iron also. 5% bentonite increases the iron content of the body by .25% without considering the factors above. Considering them it might cut it to half that. Use only 2.5% bentonite and it is not really an issue.

Firing cracks, explosions: Bentonite slows down water penetration. Not only does a bentonite-containing clay body dry slower but it does not dry as completely. Although ware might look dry it likely is not, several percent tightly-bound water remains. If ware is not temperature-dried before being fired there is a risk that water will not be able to escape fast enough during firing and ware will crack, fracture under steam pressure.

http://digitalfire.com/4sight/material/bentonite_106.html

Molecular Formula of Bentonite:

K20 0.3848	Al2O3 1.0709	SiO2 5.4340
Na2O 0.2087	Fe2O3 0.1056	LOI 0.1756
CaO 0.0601		
MgO 0.3428		
Li2O 0.0036		

Percentage Analysis

62.52 % SiO2
20.91 % Al2O3
6.94 % K2O
2.48 % Na2O
2.65 % MgO
0.65 % CaO
0.02 % Li2O
3.23 % Fe2O3
0.61 % L.O.I.

100.01 % TOTAL

NOTES:

Black Iron Oxide

-- colorant, source of iron --
Equivalent Molecular Weight: 71.850

The black iron used in ceramics is generally this synthetic form (the natural equivalent mineral magnetite contains 5-15% impurities). Synthetic black iron is much more expensive than the natural finely ground material (-200 mesh) but if there are good reasons for its use and percentages in the product recipe are low enough the cost may be justified. In ceramics, black iron is used as a source of Fe (in preference to red iron) where its black raw color and its better distribution properties are needed. For example, Alberta Slip is a recipe of raw clays and minerals intended to duplicate Albany Slip. The recipe calls for a small amount of iron oxide because the clay blend does not fire to quite as dark of a color. Since the original Albany Slip powder was a dark grey, black iron (rather than red) is employed in the Alberta Slip recipe to match this color better and provide the needed iron to the fired product.

The chemistry shown here is not the actual, synthetic black iron is almost pure Fe_3O_4. This chemistry is intended to work with INSIGHT where it is normal to define only FeO and Fe_2O_3.

Synthetic black iron is fluffier and lighter than synthetic red iron oxide (a bag of black iron is much larger than a bag of red). It is a very fine powder, 100% will easily wash through a 325 mesh screen. Synthetic black iron does not agglomerate as badly as red iron, thus it disperses in glaze slurries better (thus avoiding fired speckle). You can determine which form you have by washing a sample through a 325 mesh screen, if there is residue it is natural magnetite.

The exceedingly fine particle size of iron oxides makes them very messy to work with, they stain the skin in a manner than only soap can remove even though they do not dissolve in water.

High purity, low heavy metal content grades of black iron are available. All forms should have 90% or more Fe_3O_4. Black iron is also used as a colorant for a wide range of non-ceramic products.

Most synthetic magnetites are made by some type of chemical precipitation (0.2-1 micron particle size). However a high temperature dry process can be used to convert synthetic hematite into synthetic magnetite (thus the greater cost). The resultant product of this process has a slightly larger particle size (2-10 micron). 100% pure material would contain 72.3% Fe.

http://digitalfire.com/4sight/material/iron_oxide_black_873.html

Molecular Formula of Black Iron Oxide:
FeO .5 Fe_2O_3 .5

Percentage Analysis

68.97 % Fe_2O_3
31.03 % FeO

100.00 % TOTAL

NOTES:

Bone Ash

-- flux, source of phosphorous, producing interesting red/browns in combination with iron – Equivalent Molecular Weight: 310.183

Bone ash is TriCalcium Phosphate in the form of Hydroxyapatite $Ca_5(OH)(PO_4)_3$. This reacts when making bone china to give Anorthite ($CaAl_2Si_2O_8$) and $Ca_3(PO_4)_2$.

$2*Ca_5(OH)(PO_4)_3 \rightarrow 3*Ca_3(PO_4)_2 + Ca(OH)_2$

Real bone ash is obtained by calcinating bone up to approximately 1100°C and then cooling and milling. This material is still manufactured today since some of its important properties are due to the unique cellular structure of bones that is preserved through calcination. Real bone ash has excellent non-wetting properties, it is chemically inert and free of organic matters and has very high heat transfer resistance.

Bone ash has traditionally been added to porcelain to achieve a high degree of translucency (thus the name 'bone china'). The manufacture of bone china is difficult to master because the clays are non-plastic, ware is unstable in the kiln, and it is difficult to burn consistently to the body's narrow firing range.

Up to 1-2% bone ash can be used in enamels for opacification (more will usually cause pinholes). In glazes, as with enamels, too much or too high a temperature will cause blistering. In this use the phosphorus' influence toward a stiff melt generally checks the fluxing action of the calcia.

Bone ash or calcium phosphate are used to opacify opal glass (1-3%) because the P_2O_5 content forms colorless compounds with iron impurities.

http://digitalfire.com/4sight/material/bone_ash_123.html

Molecular Formula of Bone Ash:

CaO 3 P2O5 1

Percentage Analysis

54.30 % CaO
45.70 % P2O5

____

100.00 % TOTAL

Comments:
$Ca_3(PO_4)_2$

NOTES:

Borax (Borax Decahydrate)

-- flux, glassformer –
Equivalent Molecular Weight: 382.000

Borax Decahydrate is the refined form of natural sodium borate. Composed of boric oxide (B_2O_3), sodium oxide, and water, it is a mild, alkaline salt, white and crystalline, with excellent buffering and fluxing properties. Borax Decahydrate is an important multifunctional source of B_2O_3 (e.g. frits), particularly for processes in which the simultaneous presence of sodium is beneficial.

Borax is available in large crystal, powder, and granular form, the latter being the most practical for ceramic use. Although the 10 molecules of water in the theoretical formula vary somewhat, they are the source of the designation "10 Mol Borax". The water content can vary with storage (it tends to loose water with time). Where precision is required, it is necessary to measure the water content just before use.

It begins to melt in its own water of crystallization at 60.8C. It is soluble in water, acids, glycol and other solvents. Almost all American borax comes from deposits of the crystalline precipitate mineral tincal in the Mohave Desert of California (Asian borax is called Tincal).

The solubility of borax normally disqualifies it for use in clay bodies and glazes (since during drying it will come to the surface with the water and be concentrated there). Actually, this phenomena can be used to advantage to make self glazing products like Egyptian Paste and it can produce a hardened surface in non-fired products. In addition, the migration issue during drying can be tolerated in some circumstances, borax can be employed in a traditional ceramic slip or glaze blend as a low-cost super-flux to produce a glaze or slip for low temperatures.

Rio Tinto Borax has many technical, granular and powder grades of this material. It is also produced at the Bandirma Borax Plant in Turkey.

http://digitalfire.com/4sight/material/borax_decahydrate_2271.html

Molecular Formula of Borax:
Na_2O 1 B_2O_3 2

Percentage Analysis

30.86 % Na_2O
69.14 % B_2O_3

100.00 % TOTAL

Potential Health Hazards:
moderately toxic-avoid ingestion or contact with open cuts or wounds.

NOTES:

Boric Acid

-- flux, glassformer, source of boron –
Equivalent Molecular Weight: 124.000

Boric acid is a crystalline water soluble boron mineral. It is white in appearance and can be used as granules or as a powder. Both forms are stable under normal conditions, free-flowing, and easily handled by means of air or mechanical conveying. In solution, they are mildly acidic.

Boric Acids are used as the B2O3 source in the formulation frit. Fast fire frits for tiles find this material especially useful (compared to the deca and pentahydrate forms) because of their requirement for low sodium levels.

It is currently produced at Bandirma Boric Acid plant in Turkey and at Rio Tinto Borax. Depending on the particle size, the product is classified as "Granular" and "Powder".

http://digitalfire.com/4sight/material/boric_acid_129.html

Molecular Formula of Boric Acid:
B2O3 1

Percentage Analysis

100.00 % B2O3

100.00 % TOTAL

Comments:
Used only for making frits from dry materials.
Potential Health Hazards:
moderately toxic-avoid ingestion or contact with open cuts or wounds.

NOTES:

Burnt Umber

-- colorant –

Equivalent Molecular Weight: 295.949

Umber is a hydrated iron oxide that also contains significant manganese, calcia and silica. The calcined for (burnt) form has a higher proportion of iron. The material is used to darken the fired color of clay bodies.

Burnt umber can be any of a variety of natural and synthetic iron oxides. A variety of impurities are common (especially manganese).

http://digitalfire.com/4sight/material/burnt_umber_151.html

Molecular Formula of Burnt Umber:

CaO 0.18	Al_2O_3 0.18	SiO_2 0.89
MgO 0.11	Fe_2O_3 1.0	MnO_2 0.39
	LOI 0.89	

Percentage Analysis

18.06 % SiO_2
6.20 % Al_2O_3
1.50 % MgO
3.41 % CaO
53.96 % Fe_2O_3
11.46 % MnO
5.42 % L.O.I.

100.01 % TOTAL

NOTES:

Chrome Oxide

-- colorant –

Equivalent Molecular Weight: 151.990

Chrome oxide is a very refractory ceramic colorant (even a 50% mix with a high borax frit will not even begin to melt it in a crucible). Chrome oxide is the only stable oxide of the metal chromium. It is a bright to dark green crystalline powder insoluble in alkalis and acids. It is manufactured from the mineral Chromite mined in southern Africa, Asia, Turkey and Cuba. As with other powerful coloring agents, chrome must be milled fine enough to eliminate specking in glass or glaze.

Chromium is a 'fast' colorant, meaning can produce strong green colors under all furnace conditions, slow or fast, reducing or oxidizing. It is also a flat colorant (due to its refractory nature), it usually produces an army helmet opaque green. It is powerful, typically only 2% will produce a dark color. It cannot be used to make a metallic glaze.

Chrome oxide is usually employed in raw glazes whereas potassium dichromate is used in fritted glazes.

http://digitalfire.com/4sight/material/chrome_oxide_218.html

Molecular Formula of Chrome Oxide:

Cr2O3 1

Percentage Analysis

100.00 % Cr2O3

100.00 % TOTAL

Potential Health Hazards:
all chromium compounds should be viewed as potentially carcinogenic

NOTES:

CMC Gum

-- glaze suspender, thickener –

The term CMC is generic and refers to organic sodium carboxymethylcellulose. Gums are used in ceramics to harden unfired ceramic glazes (cement the particles together) for safer handling of the ware. Highly fritted glazes (lacking clay content) used in factory settings benefit greatly from the addition of gum. Gum additions are often unnecessary if the glaze has natural hardening properties (i.e. from 20% or more clay). Gum is an important addition to stain mixes that are applied over-glaze by stamping or painting.

Gum can act as a suspending agent by virtue of the fact that it thickens the slurry, however the side effects may make the use other additives more attractive (i.e. an adequate amount of the right clay in the batch, bentonite). In fact CMC containing slurries sometimes do settle out more quickly; adding epsom salts or calcium chloride will help.

An important side effect of gum additions is that they cause slower drying. While this is advantageous for brushing glazes, it can make it very difficult to achieve an adequate glaze thickness and prevent drip marks. Dipping glazes work best if they are both naturally thixotropic and quick drying. Both of these properties can be detrimentally affected by gum additions.

Many people make a CMC gel by mixing 30-40 grams of powder per liter of water. This gel can then be used as part of the water amount when mixing glazes. Incorporating propylene glycol also can work well for making paintable stain mixes (i.e. 1 part thin gel with 1 part glycol).

Veegum CER is a mix of CMC and Veegum T.

Powdered gum can be very difficult to disperse in water thus it is difficult to add it to an existing liquid batch. However if gum powder is mixed with other dry ingredients before adding them to the water it can be done (often 0.5-1.5%). A much more effective method is to boil water, add about 25-30 grams of powdered gum per litre and mix vigorously with a mechanical mixer. This mixture must be added during mixing to replace part of the water. It is difficult to set a standard proportion because the amount of gum needed is totally dependent on the glaze's ability to harden. A starting point for glazes that powder or smudge excessively might be 1 part gum solution to 3 parts water. Performance of the mix compared with the side effects can then be evaluated and the proportion adjusted.

Organic binders need to burn away in such a fashion that the particles of mineral and frit are drawn into contact with each other to encourage reaction and prevent crawling.

Depending on time, temperature, pH, gum can be attacked by microbes or molds. If this happens store in a cooler place, make smaller batches, adjust the pH to make a less friendly environment, or add an antiseptic (i.e. NaN_3). Many brush on glazes use CMC and can have a shelf life for this reason.

CMC gum trade name examples are Aqualon from Hercules, Gabrosa from Alzo Nobel.

NOTES:

Clay (Theoretical)

Silica/Alumina ratio:
Equivalent Molecular Weight: 258.000

Molecular Formula of Clay (Theoretical):

Al_2O_3 1.00000000 SiO_2 2.00000000
LOI 2.00000000

Percentage Analysis

46.54 % SiO_2
39.50 % Al_2O_3
13.96 % L.O.I.

100.00 % TOTAL

NOTES:

Cobalt Carbonate

-- colorant –
Equivalent Molecular Weight: 118.940

A pinkish tan powder. It is a strong colorant and almost always produces blue in glazes (unless in very high percentages where it is black). Cobalt carbonate is an extremely active melter (even more than cobalt oxide), in a mix of 50% Ferro frit 3134 it will boil at cone 6. The carbonate form of cobalt is very fine grained and disperses better in the glaze slurry and the glaze melt, it gives more more evenly distributed color than cobalt oxide. However, as with any carbonate, it produces gases as it decomposes and these can cause pinholes or blisters in glazes if they need to escape at the time when the glaze needs to solidify. Also the carbonate form contains less cobalt per gram, therefore colors are less intense than the oxide form.

Supplies of this material often differ in shade (lighter and darker).

Available grades of Cobalt Carbonate are not actually $CoCO_3$ but a mix of the carbonate and the hydroxide. Cobalt II carbonate theoretically would have the formula: $CoCO_3.3Co(OH)_2.H_2O$.

Manufacturer information sheets often quote the percentage of Co instead of CoO (thus a lower amount in the range of 45-47%. Trace elements like Ni, Fe, Mn, Cu, Zn, Pb and Mg are quoted but none are in large enough amounts to worry about in ceramics. Na can be 0.5%. Products are sold based on Co content, higher purity grades may have only 1 or 2% higher Co content. Particle size can be about 2.5 microns.

The carbonate is produced from a liquid reaction between cobalt II acetate and sodium carbonate to produce red violet crystals that are recovered by filtration. The material is insoluble in cold water but will decompose in hot water.

http://digitalfire.com/4sight/material/cobalt_carbonate_229.html

Molecular Formula of Cobalt Carbonate:
CoO 1

Percentage Analysis

100.00 % CoO

100.00 % TOTAL

NOTES:

Cobalt Oxide

-- colorant –
Equivalent Molecular Weight: 241.000

CoO is a metallic coloring oxide that produces blue in glazes at all temperatures (unless in very high percentages where it will be black). Black Cobalt Oxide is the principle source of CoO used in glazes, glass, and enamels. Cobalt is the most powerful ceramic colorant and it is stable in most systems. Like copper, it melts very, very actively in oxidation and if it is mixed into a fluid frit base in high enough a percentage, it will completely crystallize during cooling.

Cobalt is also useful as a body and slip stain (see the oxide CoO oxide for more information). However, it is very very expensive, this severely limits its practical use in many things.

Suppliers often stock a mixed oxide material of an analysis somewhere between CoO and Co2O3. However since Cobalt is used at 2-3% maximum in most glazes the 10% error in cobalt content will not make much difference.

Cobalt(II) oxide is a product of Co2O3 cobalt oxide decomposing at 900 °C. It occurs in ores with nickel, arsenic, sulfur, and manganese in deposits in Canada, Morocco, and southern Africa. During the roasting process toxic by-products of arsenic and sulfur are produced. The associated ores may contaminate the Co3O4 to some extent (i.e. with Na2CO3). CoO can also be made by heating the carbonate. Some people have tried roasting the ore themselves in a kiln, however as noted this can be hazardous, not to mention that if fired too high the ore can melt and eat through the container walls.

This material can be found in technical and ceramic grades. Cobalt will often produce glaze specking if it is not thoroughly sieved or ball milled to distribute the particles. Also, there is some inconsistency in commercial products, different batches or materials from different suppliers will vary in the amount of specking. Cobalt carbonate tends to disperse better in glazes to give even blue coloration because it is not as powerful and produces some glaze blistering problems. A high cobalt stain is also an alternative.

http://digitalfire.com/4sight/material/cobalt_oxide_230.html

Molecular Formula of Cobalt Oxide:
CoO 3

Percentage Analysis

100.00 % CoO

100.00 % TOTAL

NOTES:

Colemanite

-- flux --
Silica/Alumina ratio: 51.2:1
Equivalent Molecular Weight: 184.400

Colemanite has been a popular natural source of insoluble boron for many decades. It is similar to Ulexite in its oxide contribution to glazes (although the latter sources Na_2O also). Frits are used as boron sources in industry whereas potters and smaller companies have used colemanite.

Colemanite does not melt as low or as uniformly as Ulexite. Gerstley Borate contained significant amounts of colemanite. Pure colemanite, however, is much higher in B_2O_3 than Gerstley Borate.

Colemanite is available from Turkey, Chile and California. The chemistry of these varies quite a bit, and of course, none of the available materials have the theoretical chemistry shown here.

Very high percentages of colemanite in a glaze can result in wrinkling of the fired surface, likely due to to a phenomenon called 'decrepitation' that occurs when colemanite is heated. Be sure to screen out any materials coarser than 200 mesh, or ball mill the glaze. Gum or other binders also help.

http://digitalfire.com/4sight/material/colemanite_231.html

Molecular Formula of Colemanite:

Na_2O 0.0006	Al_2O_3 0.0019	SiO_2 0.0972
CaO 0.9705	B_2O_3 1.2875	LOI 1.8340
MgO 0.0290	Fe_2O_3 0.0002	

Percentage Analysis

3.17 % SiO_2
0.11 % Al_2O_3
0.02 % Na_2O
0.63 % MgO
29.56 % CaO
48.55 % B_2O_3
0.02 % Fe_2O_3
17.94 % L.O.I.

100.00 % TOTAL

Comments:
Use Gerstley borate as a close substitute.

NOTES:

Copper Carbonate

-- colorant –
Equivalent Molecular Weight: 221.110

This form of copper carbonate is the article of commerce, this is what you are getting when you buy copper carbonate. It is a mixture of theoretical copper carbonate and copper hydroxide. The chemical structure sees two Cu atoms bonding to an OH each and sharing a CO3. Thus there are no variations in the carbonate/hydroxide mix since this refers to the structure of the molecule.

As with other metallic coloring carbonates, copper carbonate is bulkier than the oxide form, thus it tends to disperse better to give more even results. It is also more reactive chemically that the oxide form and thus melts better. As such, it is ideal for use in brush work where minimal speck is required. However it produces gases as it decomposes and these can cause pinholes or blisters in glazes. Also the carbonate form contains less copper per gram, therefore colors are less intense than the oxide form.

The hydroxyl component is an important aid in dispersing the powder throughout the glaze slurry and thus avoid specks in the fired glaze.

Supplies of green copper carbonate basic often vary in color and density (darker and heavier, lighter and fluffier) reflecting variations in raw materials and manufacturing procedures. Despite variations in the physical appearance of the material, the amount of contained copper metal remains essentially constant.

http://digitalfire.com/4sight/material/copper_carbonate_basic_236.html

Molecular Formula of Copper Carbonate:
CuO 2

Percentage Analysis

100.00 % CuO

100.00 % TOTAL

Comments:
CuCO3•Cu(OH)2 - Natural Malachite

NOTES:

Copper Oxide (also Black Copper Oxide)

-- colorant –
Equivalent Molecular Weight: 79.540

One of the oldest colorants used by potters. It is a popular source of copper in glazes and glass. It is a very strong flux, in a mix of 50% Ferro borax frit 3134 it will dissolve a firebrick crucible at cone 6! It is the most stable form of oxidized copper (Cuprous oxide oxidizes to cupric oxide in normal firings).

The oxide form of copper can give a speckled color in glazes whereas the carbonate form will give a more uniform effect.

Copper normally produces green colors in amounts to 5% where it moves toward black. In reduction firing, it turns to Cu_2O and gives vibrant red hues. It the glaze is fluid copper will tend to crystallize heavily. See CuO and Cu_2O in the oxides database for more information.

Above 1025C copper becomes increasingly volatile and its crystalline structure breaks down. At 1325C CuO melts. This can affect the color of other glazes pieces in the kiln. Glazes containing copper can change significantly because of loss of copper. Some potters alternate between reduction and oxidation, and even put a dish filled with copper carbonate in the center of the kiln to minimize this phenomenon.

http://digitalfire.com/4sight/material/copper_oxide_black_237.html

Molecular Formula of Copper Oxide:
CuO 1

Percentage Analysis

100.00 % CuO

100.00 % TOTAL

NOTES:

Copper Sulfate

-- colorant, used in lowfire fuming applications (pitfire, raku, etc), may be found at certain hardware stores, as well as in Miracle Grow and many fertilizers **--**
Equivalent Molecular Weight: 159.600

Copper sulfate is a blue crystalline powder or granulate. It slowly effluoresces in air. It can be easily dehydrated to its gray anhydrous form by heating, then changed by to crystals by adding water. It is soluble in water, methanol, slightly soluble in alcohol and glycerol.

It is made by exposing copper or copper oxide to a dilute sulfuric acid and then evaporating and the crude sulfate to purify by recystallization. Many grades are available and huge amounts are manufactured so that less pure grades and inexpensive.

Copper sulfate is used in agricultural chemicals, feeds, germicides; in the textile and leather industries, in pigments, electric batteries, as a reagent in analytical chemistry, in medicine, as a wood preservative, for engraving and lithography; in the mining and petroleum industries; for use in synthetic rubber; steel manufacture; and in asphalts. The anhydrous salt is used as a dehydrating agent.

Copper sulfate is employed in ceramics for metallic coloration and is sometimes sprayed as a solution or used as a creamy paste on biscuit for pit firing.

http://digitalfire.com/4sight/material/copper_sulfate_239.html

Molecular Formula of Copper Sulfate:
CuO 1

Percentage Analysis

100.00 % CuO

100.00 % TOTAL

Potential Health Hazards:
poisonous and soluble-avoid contact with skin or inhalation of mists

NOTES:

Cornwall Stone

-- flux, glassformer –
Silica/Alumina ratio: 8.3:1
Equivalent Molecular Weight: 685.600

Also know as: WG Stone, Pegmatite. Graven. Gowen. Manx stone. Meldon stone. Growan. Petunste. Amakusa.

Cornwall stone is a low iron feldspar material used primarily as a flux in clay bodies and glazes. It melts 1150-1300C. It has a more diversified selection of fluxes than other feldspars but also has one of the highest silica contents. By itself it does not melt as well as feldspars (melt flow begins around cone 11 oxidation). It is popular in engobes for its adhesive power during and after firing and in glazes for its low shrinkage and minimal contribution to defects. The blue powdered material is higher in fluorine, the white is calcined and more refractory.

Its diversity of oxides make it similar in composition to common stone, thus its name. It is common to see synthetic substitutes for this material since it is easy to blend other feldspars to approximate the analysis of Cornish stone. These substitutes have the advantage of having no fluorine.

The parent ore materials are much more complex than other feldspars, and tend to be a mix of varying types of igneous rock in different stages of decomposition. Earlier stages of the ore materials are bluer (from fluorine) and contain more fluxes than newer rocks where some of the alkalis and fluorine have been leached and washed away creating a softer material. Cornish stones tend to be classified into major types according to the amount of flux present. Although Cornish stone is quite variable in composition, its low iron makes it an attractive material.

http://digitalfire.com/4sight/material/cornwall_stone_240.html

Molecular Formula of Cornwall Stone:

K_2O 0.2796	Al_2O_3 1.0138	SiO_2 8.4000
Na_2O 0.4464	Fe_2O_3 0.0055	TiO_2 0.0021
CaO 0.2540	P_2O_5 0.0242	LOI 0.2346
MgO 0.0152		
Li_2O 0.0048		

Percentage Analysis

73.59 % SiO_2
15.07 % Al_2O_3
3.84 % K_2O
4.04 % Na_2O
0.09 % MgO
2.08 % CaO
0.02 % Li_2O
0.50 % P_2O_5
0.13 % Fe_2O_3
0.02 % TiO_2
0.62 % L.O.I.

____
100.00 % TOTAL

Comments:
Available from WG Cornwall Stone, Hamill and Gillespie, Inc

NOTES:

Cryolite

-- flux –
Equivalent Molecular Weight: 410.000

A fluoride of aluminum and sodium associated with granite. It is a valuable source of insoluble sodium used in enameling and sometimes in frits and glazes. This material is a very active melter.

Because cryolite lacks oxygen it is useful in creating artificial reduction glazes for electric firing.

Since this material is looking for oxygen to satisfy vacancies resulting from the gassing away of fluorine, it will take it from the kiln atmosphere or from neighboring molecules. The net effect of this take up is that cryolite has a lower than expected LOI.

The reaction is likely 2 Na_3AlF_6 producing 3 Na_2O, 1 Al_2O_3 and 12 F. 2 Na_3AlF_6 has a weight of 419.8, 3 Na_2O. Al_2O_3 has a weight of 287.8 and 12 F is 228. In a theoretical reaction 419.8 grams goes in and 515.8 comes out (assuming F stays in the elemental state and oxygen is absorbed from elsewhere as needed). However various factors can play to effect a partial gassing of fluorine and an incomplete supply of oxygen to fill all vacancies. The complexity of the situation can be demonstrated by mixing it half-and-half with kaolin, weighing, firing to cone 6 and weighing again. In one such test we did the cryolite lost 13.9% of its weight. Considering that the kaolin component loses 13% there still should have been a net gain. The mixture was an incredibly active melter (it needs to be fired in a deep crucible), this suggests that F was gassing.

http://digitalfire.com/4sight/material/cryolite_250.html

Molecular Formula of Kryolite:

Na_2O 3 Al_2O_3 1 F 12

Percentage Analysis

19.76 % Al_2O_3
36.04 % Na_2O
44.19 % F

99.99 % TOTAL

Comments:
It is little known that this material is also used as a pesticide on, among other things, Kiwi Fruit. Known to release Fluoride in Humans

Potential Health Hazards:
Possibly Toxic - avoid breathing dust. Properly ventilate kilns - releases Fluorine when fired.

NOTES:

Cullet (Glass)

-- very rarely used, flux, glassformer --
Silica/Alumina ratio: 60.3:1
Equivalent Molecular Weight: 242.400

A wide variety of cullets are available normally made from soda lime glass of the type used for windows and containers. Cullet melts very well and can be treated as a high sodium frit (glazes with significant cullet will thus usually tend to craze).

http://digitalfire.com/4sight/material/glass_cullet_810.html

Molecular Formula of Cullet:

K_2O 0.0257	Al_2O_3 0.0475	SiO_2 2.8652
Na_2O 0.5082	B_2O_3 0.1047	
CaO 0.3459		
MgO 0.1202		

Percentage Analysis

71.00 % SiO_2
2.00 % Al_2O_3
1.00 % K_2O
13.00 % Na_2O
2.00 % MgO
8.00 % CaO
3.00 % B_2O_3
____
100.00 % TOTAL

Comments:
An estimated analysis of your average glass.

NOTES:

Custer Feldspar

-- flux, most common potassium feldspar –
Silica/Alumina ratio: 6.8:1
Equivalent Molecular Weight: 620.683

This is one of the main feldspars used in the ceramic industry in North America, especially in the west. It is used in industries such as abrasives, sanitary ware, floor and wall tile, dinnerware, pottery, and electrical porcelain throughout the United States, Mexico and Canada. This ceramic grade high potash feldspar is available in crude, 200, 325 mesh and chip form.

http://digitalfire.com/4sight/material/custer_feldspar_253.html

Molecular Formula of Custer Feldspar:

K20 0.6642	Al2O3 1.0432	SiO2 7.1326
Na2O 0.3027	Fe2O3 0.0056	LOI 0.1044
CaO 0.0331		

Percentage Analysis

69.02 % SiO2
17.13 % Al2O3
10.08 % K2O
3.02 % Na2O
0.30 % CaO
0.14 % Fe2O3
0.30 % L.O.I.
____
99.99 % TOTAL

NOTES:

Darvan

-- polymer deflocculent –

Darvan is a deflocculant and used to disperse ceramic suspensions to minimize their water content. It is a liquid alternative to the long popular sodium silicate. About twice as much is required typically (0.4-0.5%) however Darvan does offer a number of advantages. Typically soda ash is not needed as a complement and Darvan does not attack plaster molds. In addition slurries are much less sensitive to over deflocculation and are more stable. It is thus easier to reprocess scrap. However a number of engineers still prefer using a sodium silicate:soda ash mix to control thixotropic properties better, especially if little scrap is being added.

There are a number of different varieties of Darvan:

Darvan 811 and Darvan 812 are low molecular weight short chain polymers for use in vitreous and semivitreous bodies and glazes. In comparison to the conventional soda ash-sodium silicate system, these polyelectrolytes produce slips with longer casting range, higher solids content, improved viscosity stability, fewer "soda" or "hard spots", and significantly increased mold life. Slips also tend to reclaim better without the need for constant adjustments with more deflocculant.

Darvan No. 7 is a high molecular weight, long chain polymer that has been used successfully as a general purpose dispersing agent for both ceramic bodies and glazes. Like 811 and 812, this poly-electrolyte shows the advantages mentioned above. Slips prepared with Darvan No. 7 show little tendency to thicken on standing (thus this version is considered better for glazes).

Darvan 811-D is a dry granular product with great potential for low moisture castables and in other refractory products, where a dispersing agent in the powdered form is preferred.

Darvan 821-A and C are ammonium types for electronic and specialty ceramic products. They have a low ash contents and work well when prolonged ball milling or shear mixing are necessary.

The active agent in Darvan is polyacrylic acid. Its molecules are negatively charged along their length. They attach to clay particles and cause them to repel each other.

There are two cautions with this material:
-It has a shelf life of two years, thus you should only buy material that has a manufactured date on the label.
-Some types cannot go below 40 degrees F without detrimental effects on their performance. Darvan definitely cannot be frozen. Companies who buy is in drum lots should roll the drum around to mix it up in case low temperatures have encourage any components to settle out.
In either of these cases, it will simply not disperse your slurry as expected.

http://digitalfire.com/4sight/material/darvan_260.html

NOTES:

Dolomite

-- high temperature flux, can be used in glazes melting over 1170C to produce a silky matte surface. This occurs because high percentages of dolomite help to form diopside crystals ($CaMg(SiO_3)_2$) on cooling, and it is these that produce the popular butter-matte effect. This effect is most pronounced in reduction. –

** **in the IUS studio, the dolomite bags are labeled Stonelite** **

Silica/Alumina ratio: 8.1:1
Equivalent Molecular Weight: 176.479

Dolomite as a ceramic material is a uniform calcium magnesium carbonate. In ceramic glazes it is used as a source of magnesia and calcia. Other than talc, dolomite is the principle source of MgO in high temperature raw glazes. 'Dolomite matte' stoneware glazes, for example, are highly prized for their pleasant 'silky' surface texture. Dolomite by itself is refractory, but when combined with the typical oxides in a glaze (especially boron) it readily enters the melt.

Commercial dolomites are not able to achieve the theoretical 54:46 calcium carbonate:magnesium carbonate ratio, they tend to have less magnesia. It is simple to do an LOI test by firing a specimen of powder in a thin bisqued bowl to confirm the consistency of dolomite shipments. The chemistry shown here is theoretical and many commercial materials approach this with much less than 1% of two or three other oxides (e.g. Al_2O_3, SiO_2).

Dolomite is a carbonate (like whiting) in that it loses considerable weight during firing when it disassociates to form MgO, CaO and CO_2, this process being complete by about 900C. However, in many circumstances where a raw glaze employs both CaO and MgO, dolomite is an economic alternative to sourcing with a mix of calcium carbonate and talc. However care needs to be taken to obtain a consistent grade since dolomites tend to vary more in mineralogy and can contain iron contamination that can darken the fired glaze.

Synthetic substitutes to source MgO and CaO (e.g. frits) are worth considering, especially if glazes are not high temperature. Frits have no loss on ignition (therefore do not generate glaze bubbles) and melt far earlier than mineral sources of MgO and CaO. Using ceramic calculations it is quite easy to adjust a recipe to source MgO from a frit instead of raw materials.

http://digitalfire.com/4sight/material/dolomite_273.html

Molecular Formula of Dolomite:

CaO	1.0000	Al_2O_3	0.0018	SiO_2	0.0145
MgO	0.9127	Fe_2O_3	0.0011	LOI	4.5720

Percentage Analysis

0.49 % SiO_2
0.10 % Al_2O_3
20.85 % MgO
31.78 % CaO
0.10 % Fe_2O_3
46.67 % L.O.I.
____
99.99 % TOTAL

Comments:
approximate analysis - dolomites vary widely

NOTES:

EPK

-- Edgar Plastic Kaolin, one of the most common kaolins in American, source of silica and alumina --
P.C.E. 35
Silica/Alumina ratio: 2.1:1
Equivalent Molecular Weight: 270.407

Molecular Formula of EPK Kaolin:

K20	0.011382	Al2O3	1	SiO2	2.098103
CaO	0.012194	Fe2O3	0.008673	TiO2	0.012194
MgO	0.010841	P2O5	0.003524	LOI	2.071275

Percentage Analysis

46.62 % SiO2
37.71 % Al2O3
0.40 % K2O
0.16 % MgO
0.25 % CaO
0.18 % P2O5
0.51 % Fe2O3
0.36 % TiO2
13.80 % L.O.I.

99.99 % TOTAL

http://digitalfire.com/4sight/material/ep_kaolin_291.html

A secondary water washed kaolin mined in Florida. It is fairly plastic and very white firing compared with most other American kaolins. It has excellent casting properties. It is not plastic enough for throwing bodies, thus it should be augmented by a more plastic kaolin or by a plasticizer like bentonite or hectorite.

EPK is considered by many to be the best North American kaolin for use in suspending glazes as it tends to produce a smooth thixotropic slurry. 15-20% will normally make the glaze gel slightly, thus when a piece is immersed in the slurry and removed it drips very little and the wet glaze layer stays in place for the time it takes to dewater. Since EPK is very close to theoretical kaolin chemistry, it will subsitute for any other kaolin that can make the same claim (e.g. Pioneer).

This material is mined and processed in Edgar Florida. It is extracted hydraulically (a high pressure stream of water is used to wash the clay/sand mix from the bank into a small lake). The slurry is pumped from the bottom and transported to vibrating screens that separate out the sand and grade it into sizes. The clay that passes the screens is pumped into a pond and settled with the aid of a flocculant. The slurry is then dried and the flocculant neutralized. The main product at this mine is high quality white sand, the clay is a byproduct. The company is confident that there are reserves for the next hundred years or more and the quality will be constant throughout the life cycle of the deposit.

Epsom Salt

-- flocculant for glazes, suggested addition: .2 – 1 percent of the dry weight of the glaze --
Equivalent Molecular Weight: 246.492

Colorless transparent crystals. Some clay suppliers add hydrous magnesium sulfate (Epsom salts) to their clay mixes to improve plasticity and stabilize bodies against the thixotropic and spontaneous softening effects of certain soluble compounds in the mix (e.g. from soda feldspar, nepheline syenite). It is typical to use .2-.3%.

Magnesium sulfate is also used to 'set' (flocculate, thicken, gel) glazes to suspend them and make them adhere to non-porous surfaces without running off. It forms a mild sulfuric acid that changes the electrostatic charge on clay particles causing them to reorient at right angles to each other. Thus it is typically added to glazes that have adequate clay particles for it to interact with.

The most effective addition strategy is to make a saturated solution and add this in very small amounts to a slurry. If the crystals are added directly it takes time for them to dissolve and act and it is very easy to overdo it and thicken the slurry too much.

Usually only about 0.1% is needed, but up to 0.5% can be used with particularly troublesome glazes. When evaluating how much is needed in a glaze slurry, be careful to give the added material time to dissolve.

Epsom salts can be a helpful addition to glazes containing Gerstley Borate to help prevent particle agglomeration of a slurry that causes it to gel (try about 4 g per 100g of Gerstley Borate).

http://digitalfire.com/4sight/material/epsom_salts_292.html

Molecular Formula of Epsom Salt:

MgO 1	SO3 1
	LOI 7

Percentage Analysis

16.36 % MgO
32.48 % SO3
51.16 % L.O.I.

100.00 % TOTAL

Comments:
$MgSO_4 \cdot 7H_2O$ natural Epsom Salt

NOTES:

Frits

Frits are commercially manufactured fluxes and there are literally thousands of them, each with different characteristics and designed for different purposes. In the IUS studio, we primarily use Ferro Frits 3110, 3124, and 3134, although we usually have 10-20 other ones in stock. For a comprehensive list of most of them, check out this link on the Digital Fire Ceramic Materials Database: http://www.digitalfire.com/4sight/material/frits.html

The list below is what we have in stock as of 1/1/12:

Ferro Frit 3110

-- flux --
M.P./°F 1400°
Silica/Alumina ratio: 31.7:1
Equivalent Molecular Weight: 259.100

Soft sodium borosilicate frit for glazes. Often used in crystal glazes.

This frit can be very useful to reduce the feldspar content in glazes (since many high feldspar glazes have low clay content and therefore poor slurry suspension properties and dried hardness). The chemistry of this frit is similar to a feldspar (but with low alumina and CaO in addition to the alkali fluxes). That means if you can substitute this for at least part of the feldspar you can increase the kaolin (to supply the alumina) and thereby improve slurry properties. In addition you will be able to reduce the amount of troublesome calcium carbonate. Of course, you need to use ceramic chemistry to calculate how to do this, the INSIGHT software manual has chapters in the lessons section on how to do this.

It can be used with 3403 for bright and semi-matte wall tile glazes. Can be used as a body flux.

Cone Range: 08-8
New name is: KFG 4110
This frit has a very low melting point like 3124, 3185.
Formerly Frit 1078

http://digitalfire.com/4sight/material/ferro_frit_3110_349.html

Molecular Formula of Ferro Frit 3110:

K2O 0.0636	Al2O3 0.0947	SiO2 3.0034
Na2O 0.6435	B2O3 0.0967	
CaO 0.2928		

Percentage Analysis

69.63 % SiO2
3.73 % Al2O3
2.31 % K2O
15.40 % Na2O
6.34 % CaO
2.59 % B2O3
____
100.00 % TOTAL

Comments:
10.1 x 10-6 coefficient of thermal expansion (50-450° C)

NOTES:

Ferro Frit 3124

-- flux --
M.P./°F 1600.0
Silica/Alumina ratio: 9.5:1
Equivalent Molecular Weight: 277.434

This borosilicate frit is high in calcium which means it will affect browns and iron oxide colors. This frit has a chemistry similar to an alumina addition to Frit 3134.

It is intended for use in partially fritted glazes for wall tile and pottery, in lead bisilicate dinnerware glazes in the cone 3-5 range.

http://digitalfire.com/4sight/material/ferro_frit_3124_350.html

Molecular Formula of Ferro Frit 3124:

K2O 0.02050000	Al2O3 0.26940000	SiO2 2.55470000
Na2O 0.28190000	B2O3 0.54740000	
CaO 0.69760000		

Percentage Analysis

55.31 % SiO2
9.90 % Al2O3
0.70 % K2O
6.30 % Na2O
14.10 % CaO
13.70 % B2O3

100.01 % TOTAL

Comments:
7.9 x 10-6 coefficient of thermal expansion (50-450° C)
melting range 1600° F

NOTES:

Ferro Frit 3134

-- flux, leadless and zero alumina high calcia borosilicate frit –

This is a popular frit and has been used for many years as a general purpose melter across all tempreatures. Equivalents are made by many frit companies. The manufacturer says that it is "intended for use as a lime and borate source in partially fritted glazes, lead bisilicate glazes and low cost hobby glazes cone 06-10".

The reason this is billed as useful in partially fritted glazes is because of how dissimilar its chemistry is to a typical low fire glaze and the fact that it has a very high thermal expansion (the expansion is because of its lack of alumina coupled with high sodium content, even higher than a feldspar). Interestingly, if alumina is added the thermal expansion drops drastically because there is so much boron to counteract the sodium (this is what Frit 3124 is).

The very high CaO content makes this and similar frits very useful for developing chrome-tin pinks and maroons. CaO sourcing raw materials do not normally melt at low temperatures but a frit of this chemistry (high soda and boron) does.

Unlike raw material sources of the other oxides, this frit has no alumina. Because all glazes (except crystalline) require alumina, this frit must be mixed with a material that sources high alumina. Feldspars are not a normal option because they would supply even more high expansion soda and potash. The only logical answer is clay (normally kaolin). Since crystalline glazes require almost no alumina, this frit is an ideal material on which to build them.

Not many frits have higher boron than this one, so this is considered an excellent source where boron is required but a minimum amount of frit is needed. Since this frit has no alumina adding it to a recipe does not require reduction of clay content to reduce alumina. These reasons are likely why it is billed as useful from 06-10 (although boron is uncommon in high fire glazes).

The high expansion of this frit is quite useful since it can be used in a frit blend to create low-temperature glazes with adjustable thermal expansion. The high boron means it can tolerate a very high alumina content from other materials, especially clay. For example this glaze: 40 Frit 3124, 40 Frit 3134 and 20 Kaolin is expansion adjustable since the Frit 3134 can be increased at the expense of 3124 if the glaze is shivering and vice versa if it is crazing.

This frit is often used as part of the strategy to substitute for Gerstley Borate in glazes. It is valuable because it contains lots of sodium and calcium while at the same time sourcing the B2O3 without alumina. This often enables reducing the feldspar content in the glaze(in addition to eliminating the GB), and then replenishing the oxides contributed by both with this frit. Since this frit contains not alumina, it is possible to add kaolin to supply it, it acts to suspend the glaze in the absence of the Gerstley Borate.

http://digitalfire.com/4sight/material/ferro_frit_3134_351.html

NOTES:

Ferro Frit 3185

-- flux –

M.P./°F 1350.0

Equivalent Molecular Weight: 807.240

http://digitalfire.com/4sight/material/ferro_frit_3185_353.html

Molecular Formula of Ferro Frit 3185:

K20 1.0000 B2O3 4.430 SiO2 7.27

Percentage Analysis

52.08 % SiO2
11.23 % K2O
36.69 % B2O3

100.00 % TOTAL

Comments:

6.0 x 10-6 coefficient of thermal expansion (50-450° C)

NOTES:

Ferro Frit 3191

-- flux, source of alkali borate intended for use in abrasives indust –

http://digitalfire.com/4sight/material/ferro_frit_3191_354.html

Chemistry %

CaO	11.27
Na2O	12.46
B2O3	27.97
SiO2	48.30

COLE - Co-efficient of Linear Expansion	9.2
MLRG - Melting Range (C)	1300F

NOTES:

Ferro Frit 3193

Silica/Alumina ratio: 11.7:1
Equivalent Molecular Weight: 271.500

http://digitalfire.com/4sight/material/ferro_frit_3193_355.html

Molecular Formula of Ferro Frit 3193:

K_2O .074	Al_2O_3 .208	SiO_2 2.440
Na_2O .407	B_2O_3 .610	
CaO .519		

Percentage Analysis

53.99 % SiO_2
7.81 % Al_2O_3
2.57 % K_2O
9.29 % Na_2O
10.72 % CaO
15.61 % B_2O_3

99.99 % TOTAL

NOTES:

Ferro Frit 3195

-- flux –
Silica/Alumina ratio: 6.8:1
Equivalent Molecular Weight: 340.900

This frit is very high in boron and fluid.
Not good for use in underglaze colors.

It is a complete cone 06-02 leadless glaze with the addition of a little kaolin to suspend. Add more kaolin in the upper ranges.

http://digitalfire.com/4sight/material/ferro_frit_3195_356.html

Molecular Formula of Ferro Frit 3195:

Na_2O 0.3135	Al_2O_3 0.4044	SiO_2 2.7513
CaO 0.6865	B_2O_3 1.0991	

Percentage Analysis

48.50 % SiO_2
12.10 % Al_2O_3
5.70 % Na_2O
11.30 % CaO
22.40 % B_2O_3

100.00 % TOTAL

NOTES:

Ferro Frit 3304

-- flux, high lead zincless frit for clear glaze cone 04-08 --

Chemistry %

Na_2O	1.10
PbO	54.40
Al_2O_3	4.00
SiO_2	40.50

COLE - Co-efficient of Linear Expansion	6.6 x 10-6
MLRG - Melting Range (C)	1500F

Made from flint, soda, clay and lead.
http://digitalfire.com/4sight/material/ferro_frit_3304_389.html
Health Hazard! – contains lead –

Ferro Frit 3396

-- flux, lead alkali frit --

Chemistry %

Na_2O	9.40
PbO	33.50
B_2O_3	21.00
SiO_2	36.10

COLE - Co-efficient of Linear Expansion	8.30
MLRG - Melting Range (C)	1300F

http://digitalfire.com/4sight/material/ferro_frit_3396_395.html
Health Hazard! – contains lead –

Ferro Frit 3403

-- flux, lead alumina bisilicate frit --

Chemistry %

CaO	0.10
K_2O	1.40
Na_2O	0.30
PbO	67.80
Al_2O_3	2.30
SiO_2	28.10

COLE - Co-efficient of Linear Expansion	7.2
MLRG - Melting Range (C)	1350F

Cone Range: 08-02
This is basically a lead bisilicate frit with a few impurities.
Very low melting temperature.
Sub also: Glostex L71
Health Hazard! – contains lead --
http://digitalfire.com/4sight/material/ferro_frit_3403_396.html

Ferro Frit 3417

-- flux, leaded frit for all fritted glazes cone 06-01 --

Chemistry %

CaO	4.50
K2O	1.90
Na2O	1.50
PbO	30.50
Al2O3	3.00
B2O3	12.60
SiO2	43.60
ZrO2	2.40

COLE - Co-efficient of Linear Expansion 6.7

MLRG - Melting Range (C) 1400F

Health Hazard! – contains lead --
http://digitalfire.com/4sight/material/ferro_frit_3417_397.html

Ferro Frit 5301

-- flux –
M.P./°F 1500
Silica/Alumina ratio: 6.3:1
Equivalent Molecular Weight: 247.144

Formerly Frit 4101
Useful in high expansion crackle glazes at 06 or to deal with shivering.
A formula from Ron Roy shows no fluorine, the other oxides are all slightly less to retain 100% (except for Na2O which is slightly more).
CaO 2.6, K2O 6.0, Na2O 15.4, Al2O3 13.3, B2O3 13.7, SiO2 48.9

http://digitalfire.com/4sight/material/ferro_frit_5301_468.html

Molecular Formula of Ferro Frit 5301:

K20 .134	Al2O3 .274	SiO2 1.72
Na2O .765	B2O3 .418	F 1.115
CaO .101		

Percentage Analysis

41.80 % SiO2
11.30 % Al2O3
5.11 % K2O
19.19 % Na2O
2.29 % CaO
11.74 % B2O3
8.57 % F

100.00 % TOTAL

Comments:
11.6 x10-6 Coefficient of expansion

Frit P-25 (Pemco)

-- flux –
Silica/Alumina ratio: 6.9:1
Equivalent Molecular Weight: 318.900

Often used with 10% clay addition for low temperature crackle glazes. Frequently used as a component in partially fritted wall tile glazes.

http://digitalfire.com/4sight/material/pemco_frit_p-25_671.html

Molecular Formula of Frit P-25 (Pemco):

K2O 0.1837	Al2O3 0.3806	SiO2 2.6294
Na2O 0.7602	B2O3 0.7740	
CaO 0.0285		
ZnO 0.0276		

Percentage Analysis

49.55 % SiO2
12.17 % Al2O3
5.43 % K2O
14.78 % Na2O
0.50 % CaO
0.70 % ZnO
16.86 % B2O3
____
99.99 % TOTAL

Frit P-311

-- flux –
M.P./°C 1500
Silica/Alumina ratio: 9.2:1
Equivalent Molecular Weight: 275.056

http://digitalfire.com/4sight/material/pemco_frit_p-311_677.html

Molecular Formula of Frit P-311:

K2O 0.0203	Al2O3 0.2697	SiO2 2.4858
Na2O 0.2884	B2O3 0.5703	
CaO 0.6912		

Percentage Analysis
54.30 % SiO2
10.00 % Al2O3
0.70 % K2O
6.50 % Na2O
14.10 % CaO
14.40 % B2O3
____
100.00 % TOTAL

Comments:
7.0 x10-6 Coefficient of expansion ICP 669 °C melting range 1500-1630°F - interchangeable with Ferro Frit 3124

Frit P-54

-- flux --

Equivalent Molecular Weight: 189.700

Used in wall tile glazes, was replaced with P-926 which has a lower solubility.

http://digitalfire.com/4sight/material/pemco_frit_p-54_687.html

Molecular Formula of Frit P-54:

Na_2O 0.3199	B_2O_3 0.6349	SiO_2 1.4572
CaO 0.6801		

Percentage Analysis

46.17 % SiO_2
10.46 % Na_2O
20.12 % CaO
23.26 % B_2O_3

100.01 % TOTAL

Comments:

8.9 x10-6 Coefficient of expansion Pemco Frit - interchangeable with Ferro Frit 3134

Frit (Pemco) 626

-- flux, low fire high-barium leadless borosilicate --

Chemistry %

BaO	27.40
Na_2O	5.60
Al_2O_3	5.40
B_2O_3	12.40
SiO_2	49.20

COLE - Co-efficient of Linear Expansion 7.20

MLRG - Melting Range (C) 1460-1570F

Add 10% clay for cone 06-02 glaze.

http://digitalfire.com/4sight/material/pemco_frit_p-626_691.html

Fluorspar

-- flux, can produce unusual blues in combination with cobalt and copper –
Equivalent Molecular Weight: 78.000

CaF2 is used in frit preparation and as a low-fire enamel opacifier. It's value lies in the fact that it is an active flux and at the same time an opacifier.

At higher temperatures the fluorine becomes volatile and is released as a poisonous gas. This happens as O2 combines with CaF2 to produce CaO and F2 gas. Even if the gas can be tolerated, the material slowly decomposes to evolve the fluorine gas, and thus is troublesome for use in glazes because of the blistering problems.

If fluorspar is being used as a source of Ca at higher temperatures to create CaO oxide in a glass there has to be an oxidizing atmosphere in the kiln to supply the needed oxygen.

Fluorspars have varying amounts of iron contamination and can be very clean.

http://digitalfire.com/4sight/material/fluorspar_317.html

Molecular Formula of Fluorspar:
CaO   1   F   1

Percentage Analysis

74.70 % CaO
25.30 % F

100.00 % TOTAL

Potential Health Hazards:
releases fluorine when fired - adequately ventilate kiln

NOTES:

Foundry Hill Creme

-- ball clay –
P.C.E. 30
Silica/Alumina ratio: 5.5:1
Equivalent Molecular Weight: 495.027

An intermediate-grained ball clay blend offering excellent moisture retention and more plasticity. In plastic bodies, for example, the moisture retention means that items will dry slower and this can lead to a more even drying process.

http://digitalfire.com/4sight/material/foundry_hill_creme_319.html

Molecular Formula of Foundry Hill Creme:

K2O 0.03533496	Al2O3 1.00000000	SiO2 5.48733504
Na2O 0.04429470	Fe2O3 0.04978254	TiO2 0.03285237
CaO 0.04429470	P2O5 0.00298658	MnO2 0.00149329
MgO 0.06271816	SO3 0.00546917	
	LOI 2.26830680	

Percentage Analysis

66.58 % SiO2
20.59 % Al2O3
0.67 % K2O
0.55 % Na2O
0.51 % MgO
0.50 % CaO
0.09 % P2O5
1.61 % Fe2O3
0.03 % MnO
0.53 % TiO2
0.09 % SO3
8.26 % L.O.I.
____
100.01 % TOTAL

Comments:
H. C. Spinks Clay Co., Inc.
P.O. Box 820
Paris, TN 38242
901-642-5414
Potential Health Hazards:
free silica -wear a NIOSH approved dust mask when handling dry material

NOTES:

G-200 Feldspar

-- potassium fledspar –
Silica/Alumina ratio: 6.1:1
Equivalent Molecular Weight: 561.316

G-200 Feldspar is a high quality potassium / sodium / calcium aluminum silicate ground to 200 mesh for ceramic applications. Carefully beneficiated and controlled for quality, G-200 offers high potash content and low iron oxide per unit of alumina.

August 2009: The Feldspar Corporation has traditionally blended sodium feldspar from Spruce Pine, NC with potassium feldspar from Monticello, GA. This was done in an effort to match the chemistry from a depleted mine. However this material is being replaced by G-200HP. It is higher in potassium and alkali levels because the blending practice is being stopped by Imerys. They are recommending a 7:3 blend of sodium feldspar (Minspar 200) with the new G-200HP feldspar to match G200. Kona F4 Feldspar has the same chemistry as Minspar but its mine is closing.

http://digitalfire.com/4sight/material/g-200_feldspar_800.html

Molecular Formula of G-200 Feldspar:

K20 0.6428	Al2O3 1.0225	SiO2 6.2192
Na2O 0.2761	Fe2O3 0.0028	LOI 0.0501
CaO 0.0811		

Percentage Analysis

66.54 % SiO2
18.57 % Al2O3
10.79 % K2O
3.05 % Na2O
0.81 % CaO
0.08 % Fe2O3
0.16 % L.O.I.
______
100.00 % TOTAL

NOTES:

Georgia Kaolin

-- clay –
P.C.E. 34
Silica/Alumina ratio: 2.0:1
Equivalent Molecular Weight: 265.143

Molecular Formula of Georgia Kaolin:

K20	0.00397	Al2O3	1	SiO2	2.013236
Na2O	0.001588	Fe2O3	0.007411	TiO2	0.04738
CaO	0.011381	LOI	1.984914		
MgO	0.009263				

Percentage Analysis

45.62 % SiO2
38.46 % Al2O3
0.14 % K2O
0.04 % Na2O
0.14 % MgO
0.24 % CaO
0.45 % Fe2O3
1.43 % TiO2
13.49 % L.O.I.
____
100.01 % TOTAL

Comments:
Pioneer is the default Georgia Kaolin

NOTES:

Gerstley Borate

-- flux –
(no longer mined, use Gillespie Borate as a substitute)
Silica/Alumina ratio: 14.7:1
Equivalent Molecular Weight: 179.393

This was mined in southern California for many years. The mine was closed in 2000 and remaining stocks were to be depleted in 2-3 years. There was alarm across the ceramic community in North America about the demise of Gerstley Borate because it formed the basis of so many glazes. However now (June 2011), the supplier, Lagunaclay.com, says there is a large supply available. For the best information on substitutes visit gerstleyborate.com. There is a page on the site dedicated to understanding what Gerstley Borate was chemically, physically and mineralogically. There are a number of materials that have been developed as substitutes, these are outlined at the website also.

However the best approach is to finding an alternative is the use of ceramic chemistry on a glaze-by-glaze basis (to substitute other materials). In many cases, it is better to use frits to supply the CaO and B2O3, they are more consistent and reliable and do not flocculate or gel the glaze.

Prior to and during the decade of uncertainty about the future of this material, the supplier did not provide updated chemistry information. We rationalized it (as explained at http://gerstleyborate.com) as 24% CaO, 4% MgO, 0.5% K2O, 4% Na2O, 2% Al2O3, 25% B2O3, 14% SiO2, 0.5% Fe2O3 and 14% 26% LOI. In June 2011 we changed the chemistry provided here to the one provided by Laguna on their website (rounded to 1 decimal). This new chemistry has more B2O3 and less CaO (other oxide amounts are fairly similar).

http://digitalfire.com/4sight/material/gerstley_borate_806.html

Molecular Formula of Gerstley Borate:

Na2O 0.1585	Al2O3 0.0200	SiO2 0.2932
CaO 0.6807	B2O3 0.7472	LOI 2.9316
MgO 0.1609	Fe2O3 0.0035	

Percentage Analysis

9.82 % SiO2
1.14 % Al2O3
5.48 % Na2O
3.62 % MgO
21.28 % CaO
28.92 % B2O3
0.31 % Fe2O3
29.44 % L.O.I.

100.01 % TOTAL

Comments:
no longer available as of 13/1/2000
Available again in summer 2001
Use Gillespie Borate as a substitute

Gillespie Borate
-- Gerstley Borate Substitute --
http://digitalfire.com/4sight/material/gillespie_borate_2141.html

NOTES:

Goldart

-- clay –
P.C.E. 29
Silica/Alumina ratio: 3.5:1
Equivalent Molecular Weight: 373.466

Cedar Heights Goldart is a selectively mined, plastic stoneware clay which is airfloated to 200 mesh particle size. It offers excellent working properties and has a wide firing range. It is balanced enough to be used alone. It fires to a light or golden buff and has a maximum firing range of cone 10-12.

Goldart has been used for many years in the pottery and ceramic industries as a body ingredient. It appears in many clay body recipes found in textbooks and magazines.

Cedar Heights Bonding is a 50 mesh version of Goldart. Goldart can be used as a substitute for Jordan fireclay.

http://digitalfire.com/4sight/material/goldart_198.html

Molecular Formula of Goldart:

K_2O 0.0743	Al_2O_3 1.0000	SiO_2 3.5265
Na_2O 0.0097	Fe_2O_3 0.0332	TiO_2 0.0818
CaO 0.0146		SO_3 0.0056
MgO 0.0388		LOI 2.0788

Percentage Analysis

56.71 % SiO_2
27.30 % Al_2O_3
1.87 % K_2O
0.16 % Na_2O
0.42 % MgO
0.22 % CaO
1.42 % Fe_2O_3
1.75 % TiO_2
0.12 % SO_3
10.03 % L.O.I.

100.00 % TOTAL

	absorption	shrinkage
Cone 05	9.33%	21.90%
Cone 1	11.33%	15.42%
Cone 7	12.91%	4.17%
Cone 10	13.80%	0.91%

NOTES:

Grog

-- filler in clay bodies, not used in glazes –
Silica/Alumina ratio: 2.1:1
Equivalent Molecular Weight: 233.898

Grog is a generic term referring to granular material made by grinding brick or other fired ceramic (although it can also be made by crushing certain natural minerals or artificially by calcining mineral and grinding it). Grogs are added to bodies to improve drying performance, reduce drying shrinkage, improve fired abrasion resistance, reduce thermal expansion, reduce fired shrinkage, reduce density, impart visual character, etc. Refractory grogs are available as well as ones with low thermal expansion.

Grog is marketed in designations that refer to the size range of the particles. 20-40 mesh grog means that all material under 40 and over 20 has been graded out to provide a material whose particle size range is between these sizes. A -40 grog (minus 40 mesh) is one that has particles that range all the way from 40 mesh down to fine power sizes. Companies are not always successful in maintaining their materials within the range they specify. In addition, two materials from different companies with the same designation, 20-40 for example, can be quite different since one may have the majority of sizes at the coarse end of the range and the other at the finer end. Companies manufacturing grogs face technical challenges to maximize the amount of usable material (since the grinding process produces alot of particles that are too fine to be used). Coarser grogs are thus more difficult to manufacture. Thus, as you might expect, grogs can be expensive.

Simplistically, grog additions improve drying properties simply because the clay shrinks less and because the individual grog particles terminate micro cracks before they become big cracks. But the porosity of a grog's particles, their surface texture and their shapes are also important in the dynamics of how it affects clay body working and drying properties. The more grog that is added to a body more its plasticity will be impacted (finer grogs have a larger impact). While it might seem that adding a grog with a wide range of sizes to a clay body will produce the maximum benefit, this is not normally the case. Generally, the highest percentage of the largest particles that can be tolerated should be employed, this has the greatest reducing effect on the shrinkage and the least reducing effect on the plasticity. Amazingly, plastic modelling and pottery throwing bodies can still feel quite smooth when they have 20-40 mesh grog particles as long as the body is very plastic. Often silica sand is incorporated with a grog addition to supply another specific range of particle sizes.

It is possible to achieve a pressing or non-plastic forming body with almost zero shrinkage by mixing a body with 90% or more grog. The heavy refractories industry commonly uses a 50% 4-16 mesh, 10% 20-36 mesh, 40% 40-60 mesh mix of grog and a deflocculated slip to bind them together for drying. This principle can be extended to almost any grogged clay body.

Grog is also used to increase pore space in the matrix to enable quicker venting of water vapor during drying and gases of decomposition during firing. A sculpture clay body, for example, typically has 15-25% grog (but can have much more).

Since grog is typically prefired, its does not normally undergo a firing shrinkage (unless the body in which it is a part is fired to a temperature higher than the grog was initially fired at). This means that the more that is put into a recipe, the less the clay shrinks during firing. The effect can be quite dramatic. For example, Plainsman Clays makes a clay body that normally has a fired shrinkage of 5.5%, but with an addition of 15% 20-48 grog and 15% 70 mesh silica sand the fired shrinkage drops to 2.5% while maintaining the same degree of vitrification. Fired properties of grog-containing bodies are also affected by the hardness, color, porosity and impurity content of the grog particles.

It can be tricky to select a commercial grog since their designations can be confusing and they can contain much more fine material than expected. Generally it is best to get samples so that the right material can be selected by comparison testing.

http://digitalfire.com/4sight/material/grog_828.html

Molecular Formula of Grog:

K20 0.00255923	Al2O3 1.00000000	SiO2 2.07307402
Na2O 0.00372399	Fe2O3 0.00721504	TiO2 0.06702375
CaO 0.00418827		
MgO 0.00581732		

Percentage Analysis

53.23 % SiO2
43.58 % Al2O3
0.10 % K2O
0.10 % Na2O
0.10 % MgO
0.10 % CaO
0.49 % Fe2O3
2.29 % TiO2

99.99 % TOTAL

NOTES:

Grolleg

-- kaolin from England –
Silica/Alumina ratio: 2.2:1
Equivalent Molecular Weight: 276.258

A blended English china clay, combining moderate plasticity, low titania content and relatively high flux content, low shrinkage and white fired color. It is excellent for making translucent throwing or casting porcelains. The pottery community uses many Grolleg based porcelains.

Its chemistry is different from a typical North American kaolin, it contains some fluxing oxides (e.g. it has almost 2% K2O). Thus porcelain bodies employing it require slightly less feldspar to vitrify.

For use in plastic porcelains there is dilemma that body formulators face: This material has a much lower plasticity than materials like #6 Tile and Sapphire kaolin. Thus porcelain bodies employing it require additions of a plasticizer like bentonite, in some cases up to 5%. Since bentonites having the necessary plasticity are also exceptionally high in iron, North Americans must balance the advantages of using a white burning and more costly material like this against the low plasticity that makes the addition of dirty plasticizers necessary. The low TiO2 content is a key factor for its usefulness in making translucent bodies and even 5% bentonite having 5% iron content will only increase iron in the body by 0.25%. However if plasticity and whiteness are important and translucency is secondary, you might find that more plastic kaolins are better for plastic bodies.

Glazes: While the chemistry difference between this and more typical kaolins is certainly worth noting for bodies, it is still likely close enough to the theoretical 1 alumina and 2 silica to be used in glazes that call for kaolin or china clay. However there may be exceptions where the titania in other kaolins could be detrimental to the development of a color (titanium can turn celedons to a greenish tint).

http://digitalfire.com/4sight/material/grolleg_kaolin_831.html

Molecular Formula of Grolleg:

K20 0.055646	Al2O3 1	SiO2 2.201645
Na2O 0.004407	Fe2O3 0.012118	TiO2 0.001102
CaO 0.004962	LOI 1.850133	
MgO 0.020385		

Percentage Analysis

47.89 % SiO2
36.92 % Al2O3
1.90 % K2O
0.10 % Na2O
0.30 % MgO
0.10 % CaO
0.70 % Fe2O3
0.03 % TiO2
12.07 % L.O.I.
____
100.01 % TOTAL

NOTES:

Hawthorn Bond Clay

-- fire clay, very common, the base for the IUS shop stoneware --
P.C.E. 31-32
Silica/Alumina ratio: 2.5:1
Equivalent Molecular Weight: 266.713

A popular buff firing plastic Missouri fireclay of fine particle size. It fires a light color with approximately 10% shrinkage at cone 10. Ground to 35 mesh.

Val Cushing recommends it as a substitute for Pine Lake Fireclay and with 15% Lizella red as a substitute for PBX Fireclay.
Jim Robinson has done much work with this material and observes that it is variable and shivers common glazes.

http://digitalfire.com/4sight/material/hawthorne_bond_839.html

Molecular Formula of Hawthorn Bond Clay:

K2O 0.04120000	Al2O3 1.00000000	SiO2 2.46010000
Na2O 0.00700000	Fe2O3 0.02600000	TiO2 0.06880000
CaO 0.01520000	P2O5 0.00160000	SO3 0.00110000
MgO 0.04710000		

Percentage Analysis

55.40 % SiO2
38.22 % Al2O3
1.45 % K2O
0.16 % Na2O
0.71 % MgO
0.32 % CaO
0.08 % P2O5
1.56 % Fe2O3
2.06 % TiO2
0.03 % SO3

99.99 % TOTAL

NOTES:

Helmar Kaolin

-- kaolin clay, used for wood firing slips and clays –
Silica/Alumina ratio: 2.2:1
Equivalent Molecular Weight: 286.072

A kaolin deposit near Helmer, Idaho (US) that has been developed and promoted by Michael Wendt since the mid seventies. Helmer clay is used primarily for its 'flashing' properties in wood firing. Mr. Wendt prepares it using a wet process that removes soluble and iron particulate impurities.

Plainsman Clays sells the same material under the name "Troy Clay". Plainsman hammermills the raw product to about 40 mesh, a finer grade than the one from Mr. Wendt.

http://digitalfire.com/4sight/material/helmer_kaolin_845.html

Molecular Formula of Helmar Kaolin:

K20 0.0161	Al2O3 1.0000	SiO2 2.2485
Na2O 0.0037	Fe2O3 0.0233	TiO2 0.0406
CaO 0.0248	LOI 2.1224	
MgO 0.0184		

Percentage Analysis

47.21 % SiO2
35.64 % Al2O3
0.53 % K2O
0.08 % Na2O
0.26 % MgO
0.49 % CaO
1.30 % Fe2O3
1.13 % TiO2
13.37 % L.O.I.

100.01 % TOTAL

NOTES:

Ilmenite

-- colorant, source for iron and titanium --
Equivalent Molecular Weight: 152.000

Usually granular. Like rutile, ilmenite is quite variable in nature. You can tell the difference between granular rutile and granular ilmenite by doing a smear test against an abrasive surface (i.e. an unglazed white tile). The rutile will be tan or brown, the ilmenite will be black or dark brown. Likewise, under a microscope the ilmenite will be an opaque black whereas the rutile crystals will be somewhat translucent or transparent.

Ilmenite can be used in small amounts (-1%) to produce dark brown specks in bodies and specialized glazes. It also is used in combination with rutile to develop characteristic rutile break glazes; it seeds crystals in titania glazes.

You should consider testing each batch of this material you get by mixing it with a boron frit and firing a button of it high enough to create a pool of glass. Variations in chemistry will be immediately evident.

http://digitalfire.com/4sight/material/ilmenite_863.html

Molecular Formula of Ilmenite:

Fe_2O_3 1 TiO_2 1

Percentage Analysis

66.65 % Fe_2O_3
33.35 % TiO_2

100.00 % TOTAL

NOTES:

Iron Chromate

-- colorant –
Equivalent Molecular Weight: 759.660

A dense compound of iron and chromium. It is very refractory in oxidation, even with 50% borax and zero-alumina Ferro frit 3134 it does not melt. It is used in glazes to produce gray (with feldspar), brown (with zinc), red (with tin) or black depending on the base glaze and percentage and other coloring oxides present. Often used in underglazes, engobes and clay bodies.

Highly toxic in absorption, inhalation, and ingestion.

http://digitalfire.com/4sight/material/iron_chromate_871.html

Molecular Formula of Iron Chromate:

Fe_2O_3 1
Cr_2O_3 3

Percentage Analysis

25.93 % Fe_2O_3
74.07 % Cr_2O_3
____
100.00 % TOTAL

Comments:
$Fe_2(Cr_2O_7)_3$ - actually Iron Dichromate
Potential Health Hazards:
potentially carcenogenic

NOTES:

Kona F-4 Feldspar

-- flux, sodium feldspar –
Silica/Alumina ratio: 5.9:1
Equivalent Molecular Weight: 547.100

Shipped from Spruce Pine, North Carolina. No longer available. Minspar 200 (formerly NC4) has virtually identical chemistry to F-4 and should be a good substitute.

This material is prized as a porcelain ingredient because of its low iron content. It is used in casting and throwing porcelains of all types. At cone 6 for example, it is possible to make a vitreous body using 50-60%. However to get enough plasticity in such bodies, it is necessary to use ball clay or bentonite which can darken the color. If high plasticity is not essential, Macaloid and plastic kaolins can be used.

Another similar material is Nepheline Syenite.

http://digitalfire.com/4sight/material/f-4_feldspar_303.html

Molecular Formula of Kona F-4 Feldspar:

K20 0.2791	Al2O3 1.0416	SiO2 6.1516
Na2O 0.5649	Fe2O3 0.0016	LOI 0.0608
CaO 0.1560		

Percentage Analysis

67.54 % SiO2
19.41 % Al2O3
4.81 % K2O
6.40 % Na2O
1.60 % CaO
0.05 % Fe2O3
0.20 % L.O.I.
____
100.01 % TOTAL

NOTES:

Kyanite

-- refractory material, reduces shrinkage in clay bodies –
Silica/Alumina ratio: 1.1:1
Equivalent Molecular Weight: 172.785

Kyanite is a super-duty refractory material with very high resistance to thermal shock. It is widely employed in insulating brick, kiln furniture, refractory shapes, etc. and in body formulations used in porcelain, tile bodies, and casting mixes. The material reduces fired shrinkage, increases mechanical strength and thermal shock resistance and allows products to be made with thinner walls, better resistance to dunting, deformation and chipping. Kyanite's long jagged particles tend to form an interlocking no-shrink crystal matrix (like a felt) in bodies fired to low heat (potters use it up to 30% in raku bodies).

Its large grain sizes make an excellent high temperature grog. It is volume stable and has excellent hot load strength. Because of its expansion characteristics it makes an excellent crack filler.

It is found in large deposits in India, Africa and the USA. American kyanite occurs in association with quartz, from which it must be mechanically separated by grinding. Indian kyanite is processed from surface boulders, and can be calcined in lump form and graded in coarser sizes. American kyanite is said to be the most consistent and Indian the most pure.

Kyanite is available in varying grain sizes down to 325 mesh and in calcined-to-mullite form. The decomposed mullite form is volume-stable with temperature increase, while the raw form of kyanite displays definite expansion during heatup. Depending on grain size, this phenomenon permits the use of kyanite in clay formulations to counteract the shrinkage of the clay body during firing (see also Spodumene). Kyanite has proven invaluable in cements, ramming mixes, and mortars for this purpose.

http://digitalfire.com/4sight/material/kyanite_951.html

Molecular Formula of Kyanite:

K_2O 0.00552868	Al_2O_3 1.00000000	SiO_2 1.10176199
Na_2O 0.00552868	Fe_2O_3 0.01088487	TiO_2 0.02591624

Percentage Analysis

38.30 % SiO_2
59.00 % Al_2O_3
0.30 % K_2O
0.20 % Na_2O
1.01 % Fe_2O_3
1.20 % TiO_2

100.01 % TOTAL

NOTES:

Lepidolite

-- flux, glassformer, source of alumina, similar to a feldspar –
Silica/Alumina ratio: 2.9:1
Equivalent Molecular Weight: 343.200

It has a lower fusion point than most high temperature feldspars. The fluorine content can cause problems with glaze bubbles and surface pitting.

It is tricky to establish a formula weight and analysis for this material. Here are some of the factors:
-LOI varies, but we have assumed 5% water in this example.
-Lepidolite does not actually contain Li_2O, it has to absorb oxygen from the atmosphere or other materials during firing since the Li is bonded to F.
-Fluorine is bonded to potassium so oxygen has to be absorbed to create K_2O.
-For both Li and K only 1/2 of a molecule per input molecule of lepidolite will be yielded.
-In a complete oxidation firing all of the fluorine will volatilize and none will be in the final glass. However in real world conditions none of these is likely to happen completely, and in a reduction firing none may happen at all. In this case we are assuming it is all LOI.

http://digitalfire.com/4sight/material/lepidolite_963.html

Molecular Formula of Lepidolite:

K20 0.0235	Al2O3 1.0270	SiO2 3.0188
Na2O 0.0160	Fe2O3 0.0021	TiO2 0.0014
MgO 0.0089	MnO2 0.0053	
Li2O 0.9517	F 0.3882	

Percentage Analysis

55.57 % SiO2
32.09 % Al2O3
0.68 % K2O
0.30 % Na2O
0.11 % MgO
8.72 % Li2O
0.10 % Fe2O3
0.14 % MnO
0.03 % TiO2
2.26 % F
____
100.00 % TOTAL

NOTES:

Limestone

-- source of calcium, not generally used in glazes or clay –
Equivalent Molecular Weight: 100.000

The analysis here is a sample of an actual material, it would not be appropriate to provide a theoretical $CaCO_3$ since limestone contains many impurities and there are many commercial calcium carbonate products that are processed to greater purity.

http://digitalfire.com/4sight/material/limestone_970.html

Molecular Formula of Limestone:
CaO   1

Percentage Analysis

100.00 % CaO

____

100.00 % TOTAL
Comments:
typically fairly pure $CaCO_3$ - calcium carbonate or whiting.

NOTES:

Lincoln 60 Fire Clay

-- fire clay from Lincoln, California –
Silica/Alumina ratio: 2.7:1
Equivalent Molecular Weight: 313.203

Lincoln fireclay has a smooth and very pleasant feel and is used as a major ingredient in many commercial west coast USA stoneware and middle and high fire pottery clay and sculpture bodies.It provides excellent drying properties considering its high plasticity. It sieve analysis varies considerably by batch.

27% water is required to make the material plastic enough to work whereas a typical plastic pottery clay body is 20-22%.

Although this material is called a fireclay by many, it is not. It matures around orton 10, reaching zero absorption at that point.

The ZAM stoneware pottery clay body has been made for many years by various manufacturers on the west coast and it employs Lincoln. It is:

15 Hawthorn fireclay
10 Lincoln fireclay
40 Goldart
15 Ball clay
10 Silica
7 Feldspar
3 Redart
8 Grog or Sand

Another example is Soldner's Raku which is:
50 Lincoln fire clay
30 sand, all mesh
20 talc

http://digitalfire.com/4sight/material/lincoln_60_fireclay_971.html

Molecular Formula of Lincoln 60 Clay:

K_2O 0.0252	Al_2O_3 1.0000	SiO_2 2.7271
Na_2O 0.0167	Fe_2O_3 0.0429	LOI 1.9367
CaO 0.0107		
MgO 0.0429		

Percentage Analysis

52.29 % SiO_2
32.55 % Al_2O_3
0.76 % K_2O
0.33 % Na_2O
0.55 % MgO
0.19 % CaO
2.19 % Fe_2O_3
11.14 % L.O.I.

100.00 % TOTAL

NOTES:

Lithium Carbonate

-- flux, can be used in place of lead in mid range glazes, reduces glaze expansion and promotes crystallization –
Equivalent Molecular Weight: 74.000

Lithium Carbonate is the best source of lithium oxide for glazes. It is slightly soluble. It is unusual to see more than 5% lithium carbonate in glaze. Because of the low expansion of Li2O, high lithium glazes tend to shiver.

There are certain basic properties of lithium which are of interest in ceramics. Since lithium has a very small ionic radius in comparison to the other alkali metals, it has a higher field strength. Low expansion coefficients are generally imparted to ceramic compositions containing lithia. Lithium carbonate is a very strong flux (also true of lithium fluoride). In contrast, other lithium compounds may be quite refractory: lithium zirconate and lithium aluminum spinel are examples.

There is comparatively little published information on the use of lithia compounds in ceramics. Laboratory investigations indicate that small additions of lithium will react with quartz during firing and eliminate the alpha-beta quartz transition in the cooling cycle. Lithia imparts low thermal expansion coefficients to glasses and also promotes devitrification in glass systems. Smaller amounts act to smooth the glass surface.

Lithium exhibits many properties that are similar to the more common alkali metals sodium and potassium. In many respects is also shows similarities to the elements of the alkaline earth group, especially magnesium.

In addition to being soluble, lithium carbonate produces gases as it decomposes and these can cause pinholes or blisters in glazes. There are many preferred insoluble lithium frits available and incorporating one of them to source the Li2O instead is a classic application of ceramic chemistry calculations. The resultant glaze will be more fusible and will have better clarity and fewer defects.

http://digitalfire.com/4sight/material/lithium_carbonate_975.html

Molecular Formula of Lithium Carbonate:
Li2O 1

Percentage Analysis

100.00 % Li2O

100.00 % TOTAL

NOTES:

Lithospar

-- flux, glassformer, source of lithium –
Silica/Alumina ratio: 5.4:1
Equivalent Molecular Weight: 589.500

Has lower lithium than petalite, spodumene and lepidolite.
While the term lithium feldspar is commonly used in the ceramic industry, there is no such thing (for example, in references that list various types of feldspar, no lithium material appears). The lithium ion is too small to be a part of the feldspar crystal structure.

http://digitalfire.com/4sight/material/lithospar_977.html

Molecular Formula of Lithospar:

K_2O .18	Al_2O_3 1.24	SiO_2 6.73
Na_2O .38		
CaO .05		
Li_2O .39		

Percentage Analysis

69.03 % SiO_2
21.59 % Al_2O_3
2.90 % K_2O
4.02 % Na_2O
0.48 % CaO
1.99 % Li_2O
____
100.01 % TOTAL

NOTES:

Lumnite Cement

-- high temperature cement (also known as calcium aluminate cement), primarily used in homemade castable refractory recipes –
Silica/Alumina ratio: 0.3:1
Equivalent Molecular Weight: 157.100

Molecular Formula of Lumnite Cement:

CaO	0.9648	Al_2O_3	0.7274	SiO_2	0.2074
MgO	0.0352	Fe_2O_3	0.0730	SO_3	0.1033

Percentage Analysis

7.69 % SiO_2
45.76 % Al_2O_3
0.88 % MgO
33.39 % CaO
7.19 % Fe_2O_3
5.10 % SO_3

100.01 % TOTAL

NOTES:

Magnesite

-- opacifier, source of magnesium carbonate --
Magnesite is used in pottery bodies, glazes, and glass. Magnesite is used in low fire glazes to produce opacity and matteness.

Dolomite and talc are more practical sources of MgO for most higher temperature applications.

In glaze melts it is an active flux at higher temperatures (2150C+), and it produces elasticity, a lower expansion coefficient and smooth buttery surfaces. At lower temperatures it is a refractory and will matte glazes and make them crawl due to its high shrinkage and contributions to the surface tension of the melt.

Magnesium carbonate by itself is very refractory, and is used to make bricks for the cement and metal industries. It is 'dead burned' in rotary kilns, then reground, sized, and dry pressed using organic binders.

http://digitalfire.com/4sight/material/magnesite_1000.html

NOTES:

Magnesium Carbonate

-- high temperature flux, creates a smooth, matte finish –
Equivalent Molecular Weight: 84.320

Molecular Formula of Magnesium Carb:
MgO 1

Percentage Analysis

100.00 % MgO

100.00 % TOTAL
Comments:
$MgCO_3$ - natural Magnesite

NOTES:

Magnesium Oxide

Equivalent Molecular Weight: 40.304

Magnesium oxide or Periclase is a synthetic pure MgO mineral produced in electric arc furnaces by sintering Magnesite powder. Magnesium oxide is very refractory, and is used in the manufacture of bricks and crucibles for the metal processing industries, thermocouple insulation, etc.

Its low comparative cost, thermal conductivity and electrical resistivity properties at elevated temperatures make this material valuable for heating unit insulation. Crucibles and shapes, thermocouple insulation, infrared glass are other applications.

Slightly soluble in water, soluble in acids.

http://digitalfire.com/4sight/material/magnesium_oxide_1001.html

Molecular Formula of Magnesium Oxide:

MgO 1

Percentage Analysis

100.00 % MgO

100.00 % TOTAL

NOTES:

Magnesium Sulfate

-- glaze suspender, natural Epsom Salts --

Equivalent Molecular Weight: 246.480

Molecular Formula of Magnesium Sulfate:

MgO 1

Percentage Analysis

100.00 % MgO

100.00 % TOTAL

Comments:

MgSO4•7 H2O natural Epsom Salt

NOTES:

Manganese Dioxide

-- colorant –
Equivalent Molecular Weight: 86.930

Above 1080C, half of the oxygen disassociates to produce MnO, a flux that immediately reacts with silica to produce violet colors in the absence of alumina, browns in its presence. Thus if it is being used in glazes fired below 1080C it should be considered as MnO_2, if above it should be taken as 81.5 MnO and 18.5 LOI.

In glazes it will behave in a refractory manner, stiffening the melt. Because to the expulsion of oxygen at 1080, glazes using manganese should avoid this temperature range to reduce the chance of blistering and ruining of the glaze surface.

This material is available as a pure material or as a ground ore (pyrolusite). Thus while generically it is pure MnO_2 the actual name-brand materials may only be 75% MnO_2.

Manganese dioxide is the key to Rockingham brown wares which are made by employing about 3% iron oxide and 7% manganese in a transparent lead glaze of a recipe such as: Feldspar 28, Kaolin 14, Flint 4, Lead bisilicate 40, Whiting 4.

Manganese browns have a different, often more pleasant character than iron browns.

Manganese oxides can occur in a number of less common forms: (i.e. Mn_2O_3, Mn_3O_4, Mn_2O_7).

http://digitalfire.com/4sight/material/manganese_dioxide_1008.html

Molecular Formula of Manganese Dioxide:
MnO_2 1

Percentage Analysis

100.00 % MnO

100.00 % TOTAL

Comments:
MnO_2
Potential Health Hazards:
TOXIC-avoid inhalation-wear a NIOSH approved dust mask when handling dry material

NOTES:

Molochite

-- refractory material, not normally used in glazes, reduces thermal shock in clay bodies, shelves --
P.C.E. 34
Silica/Alumina ratio: 2.1:1
Equivalent Molecular Weight: 233.710

Molochite is made by firing raw low-iron kaolin to very high temperatures to bring about maximum conversion of the clay crystal to crystalline mullite (usually 95%+). The latter has high mechanical stability and resistance to thermal shock.

Molochite is available in a wide range of sizes (from 8 to 325 mesh) and in dedusted form. It is a very uniform material. It can be used as a very white firing porcelain grog and aggregate material. However, its chief use is in the investment casting industry, where successive coats of increasingly coarser molochite slurry are applied onto wax models. After drying, the wax is melted out and the molten metal poured in.

Since molochite is used for mechanical purposes in most applications, its chemistry is not usually a consideration (although it will have the chemistry of a calcined kaolin of course).

Not to be confused with "malochite" or "malachite" which is a green copper mineral.

http://digitalfire.com/4sight/material/molochite_1034.html

Molecular Formula of Molochite:

K2O 0.0427	Al2O3 1.0000	SiO2 2.0723
Na2O 0.0038	Fe2O3 0.0149	TiO2 0.0024
CaO 0.0043		
MgO 0.0059		

Percentage Analysis

53.26 % SiO2
43.62 % Al2O3
1.72 % K2O
0.10 % Na2O
0.10 % MgO
0.10 % CaO
1.02 % Fe2O3
0.08 % TiO2

100.00 % TOTAL

NOTES:

Mullite

-- refractory material, not normally used in glazes, reduces thermal shock in clay bodies, shelves --
Silica/Alumina ratio: 1.5:1
Equivalent Molecular Weight: 383.060

Mullite is a mineral of long interlocking needle-like crystal structure that is very resistant to thermal shock failure (has a low thermal expansion). It is also has a low thermal conductivity and is very refractory thus the theoretical formula (of 71.8% alumina and 28.2% silica)bears little resemblance to the real world material (we have provided a typical non-theoretical analysis). It is found rarely in nature, it is named after a deposit on the Isle of Mull in Scotland. However, it can be synthesized by calcining kyanite, bauxite or alumina/kaolin mixtures of proper Al_2O_3:SiO_2 ratio.

On a scale of lowest to highest thermal expansions at 2000F (where fused silica is almost zero and quartz is 1.5%), mullite is about one third of the way. It has a lower expansion than fused alumina (0.9%) and stabilized zircon (0.8%).

Mullite crystals can also be formed within special purpose porcelains by incorporating similar minerals into the recipe and firing to the necessary temperature and heating curve to decompose them into mullite. These include andalusite (cone 13), kyanite (cone 12), sillimanite (cone 20). The resulting bodies display low thermal expansion and a useful in spark plugs, laboratory ware, etc. and in thermal shock resistant refractories.

Firing of ordinary stoneware bodies provides the necessary temperature and adequate kaolin to produce mullite crystals from the decomposition of kaolinite (kaolinite looses some silica and the remaining higher alumina reorients itself to a higher melting compound). The resulting lattice of crystals is potentially much stronger than the simple glass-weld bonds of low-fire ceramics.

The chemistry of mullite depends on the parent material. Impurities tend to be TiO_2, Fe_2O_3, Na_2O, K_2O.

http://digitalfire.com/4sight/material/mullite_1054.html

Molecular Formula of Mullite:

Al_2O_3 2 SiO_2 3

Percentage Analysis

46.91 % SiO_2
53.09 % Al_2O_3

100.00 % TOTAL

Comments:
The theoretical formula for mullite is $3Al_2O_3 \bullet 2SiO_2$ - It often contains small traces of TiO_2 and Fe_2O_3

NOTES:

NC-4 Feldspar

-- flux, glassformer, sodium feldspar --
Silica/Alumina ratio: 6.1:1
Equivalent Molecular Weight: 557.254

NC-4 feldspar is a high quality sodium / potassium / calcium aluminum silicate ground to 170, 200 and 250 mesh, for ceramic applications. Carefully beneficiated and controlled for quality, NC-4 feldspar offers high alkali content and low iron oxide content per unit of alumina. Its various grinds are tailored for specific applications.

Now called Minspar 200.

http://digitalfire.com/4sight/material/nc-4_feldspar_1068.html

Molecular Formula of NC-4 Feldspar:

K20 0.2437	Al2O3 1.0359	SiO2 6.3569
Na2O 0.6162	Fe2O3 0.0022	LOI 0.0280
CaO 0.1401		

Percentage Analysis

68.51 % SiO2
18.95 % Al2O3
4.12 % K2O
6.85 % Na2O
1.41 % CaO
0.06 % Fe2O3
0.09 % L.O.I.
____
99.99 % TOTAL

Comments:
a soda feldspar - 200 mesh

NOTES:

Nepheline Syenite

-- flux, glassformer, naturally occurring material that is similar to a sodium feldpar --
Silica/Alumina ratio: 4.4:1
Equivalent Molecular Weight: 450.500

Nepheline Syenite is an anhydrous sodium potassium alumino silicate. Although feldspar-like in its chemistry, mineralogically it is an igneous rock combination of nepheline, microcline, albite and minor minerals like mica, hornblende and magnetite. It is found in Canada, India, Norway and USSR. Thus it does not have a simple theoretical formula like soda feldspar (we have provided representative chemistry of a Canadian nepheline syenite).

Nepheline Syenite has been a standard in the ceramic industry for many years, and is very popular for its whiteness. Nepheline syenite melts lower than feldspars. For example, it is possible to make a very white vitreous medium temperature porcelain (as low as cone 4) by mixing a plastic kaolin with nepheline syenite and silica (up to 50% nepheline will be needed).

Like feldspar, nepheline syenite is used as a flux in tile, sanitary ware, porcelain, vitreous and semi-vitreous bodies. It contributes high alumina without associated free silica in its raw form and fluxes to form silicates with free silica in bodies without contributing free silica itself. This stabilizes the expansion curve of the fired body. It is an excellent tile filler and melter, especially for fast firing. Nepheline syenite is valuable in glass batches to achieve the lowest melting temperature while acting as a source of alumina.

Since nepheline syenite can be slightly soluble, in pugged bodies it can be responsible for stiffness changes during aging (although admittedly many other factors can also contribute to this). It can more challenging to maintain stable deflocculated slurry bodies using nepheline syenite than with feldspars. However, the place where you may note the solubility of nepheline the most is in glaze slurries containing significant percentages, they can gel over time and the addition of more water to thin the slurry can wreak havoc with application performance.

Because of its sodium content, high nepheline syenite glazes tend to craze (because of the high thermal expansion of Na_2O). Also, since nepheline syenite has more alumina than most feldspars, substituting it into recipes means that on one hand a lower melting temperature is achieved while on the other a more viscous melt results because of the extra alumina.

http://digitalfire.com/4sight/material/nepheline_syenite_1069.html

Molecular Formula of Nepheline Syenite:

K_2O 0.2199	Al_2O_3 1.0302	SiO_2 4.5548
Na_2O 0.7125	Fe_2O_3 0.0018	LOI 0.1753
CaO 0.0563		
MgO 0.0113		

Percentage Analysis

60.72 % SiO_2
23.31 % Al_2O_3
4.60 % K_2O
9.80 % Na_2O
0.10 % MgO
0.70 % CaO
0.06 % Fe_2O_3
0.70 % L.O.I.

99.99 % TOTAL

NOTES:

Newman Red Clay

-- naturally occurring red clay, source of iron --
P.C.E. 19-20
Silica/Alumina ratio: 4.7:1
Equivalent Molecular Weight: 465.096

In 2003 this material became unavaiable. There were problems with consistency and lack of compatibility with light colored materials also produced at Gladding, McBean & Co. However as of Mar 2004 it was again available. The reintroduction was accompanied by a new data sheet on which the numbers only add up to 92.8? In addition the material is much more expensive and is more coarsely ground (some 30 mesh grit) so some companies began using substitutes. In March 2006 is was again unavailable.

Newman is a red burning, low plasticity, low dry strength fireclay useful in both plastic and casting bodies to impart red color. It has powerful staining abilities (beyond what its percentage of iron suggests). For example, even if diluted to 50% in a recipe the body can still fire bright red in oxidation. Newman clay has a very fine particle size coupled with some large impurity particles in the plus 50 and even plus 30 mesh range. The crude material color is bright orange. Not surprisingly, bodies containing it complement it with ball clay and feldspar.

Coming up with an economical substitute for this material is a tricky task both because of its unusual properties and unique combination thereof. There is no other commonly available smooth refractory red burning clay material in North America. Thus some have suggested substituting various low and mid-fire red clays to impart color to clay bodies (i.e. Carbondale Red, Redart). However this is not practical since these materials flux the body producing a more vitreous and browner fired result. Even if feldspar is removed from the body to compensate the red coloration is still compromised to brown. Some have suggested mixes of fireclays mined in the same area (i.e. IMCO 400, 800, Lincoln Fireclay). However these are not nearly refractory enough either (they are not really fireclays) and they have far less iron. Other refractory red clays are not fine grained like Newman and contain iron speckle or other impurities (e.g. Plainsman Firered). Also, Newman has a high firing shrinkage, substitutes will likely be lower (this is not a bad thing of course unless continuity of fired dimensions are important).

Understandably any substitution strategy is going to have to involve a mix of materials, including iron oxide and could be more costly (it is messy, but so was Newman). It is also going to involve understanding various tradeoffs. We have compounded a series of mixes to replace Newman (both from physical properties and chemistry perspectives) and have compared their merits by inserting them in place of Newman in a body recipe calling for 50%. We have evaluated color, absorption and fired shrinkage over a range of temperatures, drying shrinkage and drying performance, particle size distribution, etc. So far one mix of materials has proven quite similar to the character of the color, the maturity, the smoothness and the nature of the plasticity. It is code number L3179H and has Imco 400 Fireclay - 67, Silica - 27, Iron Oxide Red: 3, Iron Oxide Yellow: 3. The mix of red and yellow iron were used to duplicate the raw color, you can use straight red iron.

http://digitalfire.com/4sight/material/newman_red_clay_1071.html

Molecular Formula of Newman Red Clay:

K20 0.0436	Al2O3 1.0000	SiO2 4.6760
Na2O 0.0166	Fe2O3 0.2291	TiO2 0.0584
CaO 0.0043	LOI 1.9222	
MgO 0.0261		

Percentage Analysis

60.38 % SiO_2
21.92 % Al_2O_3
0.88 % K_2O
0.22 % Na_2O
0.23 % MgO
0.05 % CaO
7.87 % Fe_2O_3
1.00 % TiO_2
7.45 % L.O.I.

100.00 % TOTAL

NOTES:

Nickel Carbonate

-- colorant –
Equivalent Molecular Weight: 118.720

Used as a colorant in ceramic glazes and glasses.
Watch out for glaze blistering, this generates a lot of gases of decomposition.

http://digitalfire.com/4sight/material/nickel_carbonate_1073.html

Molecular Formula of Nickel Carbonate:
NiO 1

Percentage Analysis

100.00 % NiO

____

100.00 % TOTAL
Comments:
NiCO3 green Nickel Carbonate
Potential Health Hazards:
can cause allergic skin reactions

Nickel Oxide (Black Nickel Oxide)

-- colorant –
Equivalent Molecular Weight: 165.000

http://digitalfire.com/4sight/material/nickel_oxide_green_1967.html

Molecular Formula of Nickel Oxide:
NiO 1

Percentage Analysis

100.00 % NiO

____

100.00 % TOTAL
Comments:
Ni2O3 black Nickel Oxide
Potential Health Hazards:
can cause allergic skin reactions

NOTES:

Nytal (talc)

-- flux, used in low fire clay bodies and some glazes –
Silica/Alumina ratio: 309.6:1
Equivalent Molecular Weight: 111.163

New York talc has been mined around Gouverneur, New York since 1870. The area around the town is very rich in minerals, especially talc, a wide range of talcs can be found within a small area. Amazingly the material is no longer available (it has been plagued by controversy about whether or not it contains asbestos and whether the talc itself is a hazardous fibrous aluminum silicate like asbestos).

The RT Vanderbilt website recommends VanTalc (from Montana) as a substitute however its chemistry is quite different (it has almost no CaO (closer to theoretical which has zero CaO) and its iron content is much higher).

Nytal 99 and Ceramitalc HDT are pressing grades of talc for use in ceramic wall tile and artware. They have been standards in the ceramic industry for many years because of their white firing, reliability and wide deflocculation curve. They are "certifiable" for non-toxic purposes in an ever growing health conscious market. Both products develop high uniform thermal expansion and low moisture expansion to prevent crazing in bodies that can be safely fired at rapid cycles. Nytal 99 produces bodies with somewhat lower shrinkage than Ceramitalc HDT, otherwise they are similar.

Nytal 100 is used as an auxiliary flux in vitreous bodies such as electrical porcelain and sanitaryware. Recommended for cordierite development in refractory specialties, and to impart strength and resistance to delayed crazing in semivitreous dinnerware. Nytal 100HR and Ceramitalc 10AC have special use in art pottery and hobby casting slips. All three grades perform well in dry pressing, ram-pressing and in the making of good casting slips.

Nytal is offered in various particle sizes. White talcs are usually thought of as soft materials, but this contains an appreciable amount of other silicate minerals which can be somewhat abrasive.

Density Mg/m3 2.85
pH at 10% solids 9.4

Abrasiveness (Einlehner M/M2 loss, 174,000 revolutions) 175-300

http://digitalfire.com/4sight/material/nytal_talc_1090.html

Molecular Formula of Nytal:

Na_2O 0.0061	Al_2O_3 0.0033	SiO_2 1.0217
CaO 0.1669	Fe_2O_3 0.0011	MnO_2 0.0022
MgO 0.8270	LOI 0.3338	

Percentage Analysis

55.20 % SiO_2
0.30 % Al_2O_3
0.34 % Na_2O
30.00 % MgO
8.42 % CaO
0.16 % Fe_2O_3
0.17 % MnO
5.41 % L.O.I.

100.00 % TOTAL

NOTES:

Ocmulgee

-- dark clay –
Silica/Alumina ratio: 4.2:1
Equivalent Molecular Weight: 464.110

A sandy, coarse, iron bearing sedimentary clay. Used in brick and pipe manufacture.

http://digitalfire.com/4sight/material/ocmulgee_red_clay_1095.html

Molecular Formula of Ocmulgee:

K20	0.0635	Al2O3	1.0000	SiO2	4.1906
Na2O	0.0271	Fe2O3	0.1874	TiO2	0.0701
CaO	0.0308	LOI	3.4341		
MgO	0.0916				

Percentage Analysis

54.23 % SiO2
21.96 % Al2O3
1.29 % K2O
0.36 % Na2O
0.80 % MgO
0.37 % CaO
6.45 % Fe2O3
1.21 % TiO2
13.33 % L.O.I.

100.00 % TOTAL

NOTES:

OM-4 Ball Clay

-- a very common ball clay –
P.C.E. 32
Silica/Alumina ratio: 3.5:1
Equivalent Molecular Weight: 374.796

Old Mine #4, Mayfield, KY.
A fine-grained ball clay with excellent plasticity and strength. Old Mine #4 is an "industry standard" based on its popularity in both casting and plastic formed bodies. It is also widely used as a suspension aid in glazes.

OM#4 ball clay is variable in nature and tends to be more vitreous than some of the more refractory ball clays that are available. It has some soluble salts which can give a brown coloration to the surface, so barium carbonate may be needed to precipitate these.

Physical Properties
===================
Water of Plasticity*: 37.0%
% Dry Shrinkage*: 6.5
Dry M.O.R., psi:* 825
pH: 4.4
C.E.C., meq/100g: 11.0
Specific Surface Area, sq metre/g: 24.4
Soluble sulfur+: Low

P.C.E.: 32

Particle Size, Microns: 20 10 5 2 1 0.5 0.2
(% finer than) 99% 97% 93% 81% 72% 56% 35%

Fired Properties
================
Cone 5 10

Total Shrinkage: 13.0% 14.5%
Absorption: 10.0% 1.0%

Shipped from Mayfield, KY

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*Extruded, 50% ball clay, 50% flint
+Low-trace to 150, Med-150-400, High-450+
**50% Clay, 50% Nepheline Syenite

http://digitalfire.com/4sight/material/om_num_4_ball_clay_1098.html

Molecular Formula of OM-4 Ball Clay:

K20 0.04390000	Al2O3 1.00000000	SiO2 3.48840000
Na2O 0.01200000	Fe2O3 0.02590000	TiO2 0.05620000
CaO 0.02660000	LOI 2.60050000	
MgO 0.03710000		

Percentage Analysis

55.90 % SiO_2
27.20 % Al_2O_3
1.10 % K_2O
0.20 % Na_2O
0.40 % MgO
0.40 % CaO
1.10 % Fe_2O_3
1.20 % TiO_2
12.50 % L.O.I.

100.00 % TOTAL

NOTES:

Pearl Ash (Potassium Carbonate)

-- flux, source of potassium, highly soluble –
Equivalent Molecular Weight: 138.210

This is the only material in ceramics that can deliver K2O in the exact amount required without bringing other oxides with it, however it is water soluble. The most common source of K2O in glazes is feldspar and normally all of the oxides that feldspar supplies are also needed in glazes (so it is rare that pure and much more expensive K2O is needed). Sometimes this is used to modify the color in glazes.

In the manufacture of frits, pearl ash can be an important source of potassium.

http://digitalfire.com/4sight/material/pearl_ash_1137.html

Molecular Formula of Pearl Ash:
K20 1

Percentage Analysis

100.00 % K2O

100.00 % TOTAL

Comments:
Potassium Carbonate K2CO3
Potential Health Hazards:
CAUSTIC and soluble - avoid skin contact and inhalation of mists.

NOTES:

Petalite

-- flux, feldspar like material, contains lithium but reacts similarly to nepheline syenite, has low expansion so it is often used in flameware clay bodies –
Silica/Alumina ratio: 8.2:1
Equivalent Molecular Weight: 599.386

Petalite is a lithium aluminum silicate mineral (more simply a lithium feldspar) that is commonly used in clay bodies. It is valuable because it provides an insoluble source of lithium (lithium carbonate is soluble) and has the highest Li2O:Al2O3 ratio of any natural mineral. Lithium is a strong alkaline flux and is effective over all temperature ranges. It and imparts lower expansion and gives unique color response to copper and cobalt in glazes. Some commercial versions have a chemistry that fairly closely matches the theoretical chemistry given here.

Petalite is most prized for its mineralogical properties. It is especially valuable in imparting thermal shock resistance to clay bodies because it has almost zero expansion when heated above 700C. Bodies with 60%+ petalite can take a direct flame and rapid water cooling without failure. To make a plastic clay body mix petalite with as much ball clay as needed. For a casting body, use as much kaolin as needed to achieve the desired casting properties. Bentonite can be added to either type of body to increase the petalite proportion.

One serious problem with low expansion petalite bodies is that it is very difficult to achieve glaze fit. All common glazes will craze. This is compounded at lower temperatures where the limited low-expansion silica and alumina necessary for melting raises glaze expansion. For some low-expansion bodies, it is almost impossible to match a glaze. Flame ware bodies can be made with 50-60% petalite.

Petalite can be used to create low expansion glazes. It is suitable for white and transparents as well because of the low iron content. It does not present the frothing problems sometimes associated with spodumene and helps improve brightness. One formula suggested by Val Cushing is petalite 76.9, talc 14.2, whiting 3.4, kaolin 5.5. This glaze is claimed to have an expansion of 0.8 x 10 -6 and fires cone 9 to 12 with a silky surface.

Spodumene and lepidolite also provide insoluble sources of lithium. However, spodumene is more refractory, thus producing more porous fired results. If a body's range needs to be extended, spodumene can thus be added in preference to silica. Petalite is slightly more refractory than lepidolite.

P.C.E.: 15
P.C.E. 45% petalite:55% F4 Feldspar: 4
P.C.E. 45% petalite:55% Nepheline Syenite: 2

A petalite clay body can be made by combining petalite and ball clay or kaolin in proportions that provide a good compromise between high petalite content and necessary plasticity.

A substitute for petalite can be made from 25% feldspar and 75% spodumene.

http://digitalfire.com/4sight/material/petalite_1114.html

Molecular Formula of Petalite:

K20 0.01940000	Al2O3 0.95150000	SiO2 7.77029999
Na2O 0.03940000	Fe2O3 0.00120000	F 0.00480000
CaO 0.01090000	LOI 0.11760000	
MgO 0.06000000		
Li2O 0.87030000		

Percentage Analysis

77.86 % SiO_2
16.18 % Al_2O_3
0.30 % K_2O
0.41 % Na_2O
0.40 % MgO
0.10 % CaO
4.34 % Li_2O
0.03 % Fe_2O_3
0.02 % F
0.35 % L.O.I.

99.99 % TOTAL

NOTES:

Plaster

-- plaster of paris, we normally stock Number 1 Pottery Plaster at the IUS studio –
Equivalent Molecular Weight: 290.299

There are many different types of plaster and they vary mainly in setting time, strenth, absorbency. Manufacturers provide instruction booklets on how to mix and use their materials. For example, common precautions with reference to pottery plaster are: Don't stack pallets 3 high to avoid hard chunks, use before the shelf life of 120 days expires (if longer then extend mixing time), don't mix at higher than 105 degrees for proper set.

USG Pottery #1 (2000 psi) is an example of an all around material. It is normally mixed at a 70 consistency (70 water to 100 plaster). Jiggering benefits from a plaster with more surface hardening additives (i.e. USG's "Puritan"). For carving USG "Moulding Plaster" works well. USG Ultracal (5000 psi) and Hyrdostone (10,000 psi) are very hard materials and ideal for case molds where hardness and the expense of absorbency are required (they require much less water).

The optimum hardness and absorbency of the final product are best achieved with the proper water to plaster ratio. Manufacturers recommend that you weigh the water, add the plaster to the water, soak for 2-3 minutes, then mix well using a propeller mixer. It is important not to mix in air bubbles, but to agitate in such a way that the air bubbles break at the surface during mixing.

Gypsum cements are not the same as pottery plasters. They are designed for optimum surface hardening, dimensional stability, and very low expansion.

An continuous plaster mixing machine as available from: Hoge Warren Zimmermann Co., 40 West Crescentville Rd., Cincinnati, OH 45246 FAX 513-671-3514

http://digitalfire.com/4sight/material/plaster_1124.html

Molecular Formula of Plaster:

CaO 1	SO3 1
	LOI 1

Percentage Analysis

36.38 % CaO
51.93 % SO3
11.69 % L.O.I.

100.00 % TOTAL

Comments:
basic plaster of paris

NOTES:

Plastic Vitrox Clay

-- white burning plastic feldspar --
Silica/Alumina ratio: 11.0:1
Equivalent Molecular Weight: 844.785

A California feldspathic earth, usually packaged under the label PVC for "Plastic Vitrox Clay", that is similar in makeup to Cornwall Stone but fires whiter. It is preferred by many for use in white clay or glaze formulas where kaolin or a "white clay" is called for.

Typical empirical analyses are SiO_2 75.56%, Al_2O_3 14.87%, Fe_2O_3 0.09%, CaO 0.22%, MgO 0.20%, Na_2O 0.29%, K_2O 6.81% and CaO 1.00%, K_2O 5.00%, MgO 0.50%, Na_2O 0.90%, TiO_2 0.10%, Al_2 $_{>}O_3$ 12.70%, SiO_2 76.50%, Fe_2O_3 0.50%
A well-behaved casting slip for cone 8 or lower can be made of 1 part PV to 3 parts talc and 2 parts ball clay. A simple cone 6 glaze can be made of 1 part PV to 1 part borocalcite ($2CaO.3B_2O_3.5H_2O$).

http://digitalfire.com/4sight/material/plastic_vitrox_1126.html

Molecular Formula of Plastic Vitrox Clay:

K20 0.45133900	Al2O3 1.00000000	SiO2 10.97583800
Na2O 0.04478900	Fe2O3 0.01271300	TiO2 0.00505100
CaO 0.07526500	LOI 1.15381400	
MgO 0.27050000		

Percentage Analysis

78.03 % SiO2
12.07 % Al2O3
5.03 % K2O
0.33 % Na2O
1.29 % MgO
0.50 % CaO
0.24 % Fe2O3
0.05 % TiO2
2.46 % L.O.I.
____
100.00 % TOTAL

NOTES:

Portland Cement

Silica/Alumina ratio: 5.1:1
Equivalent Molecular Weight: 86.000

A relatively high-temperature calcinated mix of clay and lime which hardens quickly after wetted with water and left to air-dry. Unlike most "natural" clay cements, however, Portland's bonding deteriorates under time, stress and weathering. Like all clay cements, Portland, behaving as a calcined calcareous earth, will fuse readily when fluxed and will melt at much lower temperatures than its required high calcinating temperatures. A simple brown glaze, for example, can be obtained at 900º ;C from a thick solution comprising equal parts of Portland and hydroboracite or minium.

http://digitalfire.com/4sight/material/portland_cement_1134.html

Molecular Formula of Portland Cement:

CaO	0.9574	Al2O3	0.0632	SiO2	0.3218
MgO	0.0426	Fe2O3	0.0135	LOI	0.1430

Percentage Analysis

22.50 % SiO2
7.50 % Al2O3
2.00 % MgO
62.50 % CaO
2.51 % Fe2O3
3.00 % L.O.I.
____
100.01 % TOTAL

NOTES:

Pumice

-- flux, glassformer, variable volcanic material –
P.C.E. 19
Silica/Alumina ratio: 11.5:1
Equivalent Molecular Weight: 809.723

Molecular Formula of Pumice:

K_2O 0.12738406	Al_2O_3 1.00000000	SiO_2 11.46650207
Na_2O 0.11465292		

Percentage Analysis

85.05 % SiO_2
12.59 % Al_2O_3
1.48 % K_2O
0.88 % Na_2O

100.00 % TOTAL

NOTES:

Pyrax HS (Pyrophyllite)

-- clay body additive to lower expansion and increase thermal shock –
Silica/Alumina ratio: 9.9:1
Equivalent Molecular Weight: 738.674

Principle use in rapid fire ceramic wall tile bodies. It lowers firing temperature, produces low moisture expansion bodies with good craze resistance, increases thermal shock resistance, and greatly increases firing strength in vitreous bodies. It promotes development of mullite when substituted for an equivalent amount of feldspar or quartz. Pyrax RG refractory grade pyrophyllite is used in insulating firebrick, metal pouring refractories, alumina-silcia monolithic refractories, ramming mixes, gunning mixes, castable mixes and kiln car refractories.

http://digitalfire.com/4sight/material/pyrax_hs_1153.html

Molecular Formula of Pyrax:

K20 0.1802	Al2O3 1.0000	SiO2 9.9482
Na2O 0.0480	Fe2O3 0.0096	TiO2 0.0096
	LOI 0.9431	

Percentage Analysis

80.89 % SiO2
13.80 % Al2O3
2.30 % K2O
0.40 % Na2O
0.21 % Fe2O3
0.10 % TiO2
2.30 % L.O.I.

100.00 % TOTAL

NOTES:

Pyrophyllite **(Pyrax)**

-- clay body additive to lower expansion and increase thermal shock –
P.C.E. 26
Silica/Alumina ratio: 5.7:1
Equivalent Molecular Weight: 81.150

Pyrax is chemically similar to a clay, it is a hyrated aluminum silicate. But Pyrax has the appearance of a talc. Many properties of Pyrax are quite similar to talcs. Pyrax has a neutral pH and due to the presence of quartz, is highly abrasive.

Density Mg/m3 2.8
pH at 10% solids 6.9
Abrasiveness (Einlehner M/M2 loss, 174,000 revolutions) 450-500

Pyrax is available as types A, B and WA. They vary in particle size and thus bulk density and color.

-325# -10micron -5micron -2.5micron
Pyrax A 90 50 28 13
Pyrax B 95 50 27 11
Pyrax WG 87 44 28 15

Pyrax HS Used in wall tile bodies. It lowers firing temperature; produces low moisture expansion bodies with good craze resistance; increases thermal shock resistance; and greatly increases firing strength of vitreous bodies. It promotes the development of mullite when substituted for an equivalent amount of feldspar or quartz.

Pyrax RG Refractory grade used in insulating firebrick, metal pouring refractories, ramming mixes, gunning mixes, castable mixes and kiln car refractories.

http://digitalfire.com/4sight/material/pyrax_pyrophyllite_1154.html

Molecular Formula of Pyrophyllite:

K20 0.0017	Al2O3 0.1751	SiO2 1.0000
Na2O 0.0026	Fe2O3 0.0020	TiO2 0.0041
	LOI 0.1261	

Percentage Analysis

74.01 % SiO2
22.00 % Al2O3
0.20 % K2O
0.20 % Na2O
0.39 % Fe2O3
0.40 % TiO2
2.80 % L.O.I.

100.00 % TOTAL

Comments:
NOTE: alkalies listed as total - split evenly between Na & K.
Pyrotrol brand of pyrophyllite used as typical analysis. Blend of pyrophyllite and andalusite ores.

NOTES:

Pyrotrol

-- Andalusite/Pyrophyllite Ore, see pyrophyllite **--**
P.C.E. 26
Silica/Alumina ratio: 5.7:1
Equivalent Molecular Weight: 81.150

The Pyrotrol group of mineral products offers a controlled blend of milled Andalusite/Pyrophyllite ores designed to control strinkage in whiteware ceramic applications. Pyrotrol reduces thermal expansion, stabilizes shrinkage, widens firing range and reduces warpage.

Alumina content is controlled to meet certain specifications. Pyrotrol produces an excellent kiln car wash and is an inexpensive coating material for facebrick production.

This material is dry milled and magnetically separated.

The analysis shown is an average.

http://digitalfire.com/4sight/material/pyrotrol_2270.html

Molecular Formula of Pyrotrol:

K2O 0.0017	Al2O3 0.1751	SiO2 1.0000
Na2O 0.0026	Fe2O3 0.0020	TiO2 0.0041
	LOI 0.1261	

Percentage Analysis

74.01 % SiO2
22.00 % Al2O3
0.20 % K2O
0.20 % Na2O
0.39 % Fe2O3
0.40 % TiO2
2.80 % L.O.I.

100.00 % TOTAL

Comments:
NOTE: alkalies listed as total - split evenly between Na & K.
Brand of pyrophyllite. Blend of pyrophyllite and andalusite ores.

NOTES:

Quartz

-- glassformer, source of silica –
Equivalent Molecular Weight: 60.000

Unlike silica glass, the quartz phase of silica is subject to inversion and accompanying volume and form change when fired through 573C. Room temperature quartz is called alpha quartz, beta quartz exists only above 573C.

Quartz sand is often used in bodies as grog for texture and to increase thermal expansion. Powdered quartz is used in glazes and bodies also. Quartz of very fine particle size (-400 mesh) will typically enter the feldspathic melt or convert to cristobalite during firing if fluxes are lacking, coarse powdered grades help to 'squeeze' glazes into fit. Intermediate sizes (200-300 mesh) seem to be best however, since their greater surface area exerts more compressive squeeze per unit.

Crystalline silica is used in agriculture, paving, brick and tile, concrete, cleansers, foundry casting, ceramics and pottery, paint, glass, soaps, fiber glass, electronics, plaster, sandblasting, industrial effluent filtration, drinking water filtration, hazardous waste control.

http://digitalfire.com/4sight/material/quartz_1171.html

Molecular Formula of Quartz:
SiO_2 1

Percentage Analysis

100.00 % SiO_2

100.00 % TOTAL

Comments:
Another name for flint or silica.
Potential Health Hazards:
free silica -wear a NIOSH approved dust mask when handling dry material

Red Iron Oxide

-- colorant, flux, at IUS we use synthetic Red Iron Oxide **--**
Equivalent Molecular Weight: 169.680

Synthetic red iron oxide is the most common colorant in ceramics and has the highest amount of iron. It is available commercially as a soft and very fine powder made by grinding ore material or heat processing ferrous/ferric sulphate or ferric hydroxide. During firing all irons normally decompose and produce similar colors in glazes and clay bodies (although they have differing amounts of Fe metal per gram of powder). Red iron oxide is available in many different shades from a bright light red at a deep red maroon, these are normally designated by a scale from about 120-180 (this number designation should be on the bags from the manufacturer, darker colors are higher numbers), however in ceramics these different grades should all fire to a similar temperature since they have the same amount iron. The different raw colors are a product of the degree of grinding.

In oxidation firing iron is very refractory, so much so that it is impossible, even in a highly melted frit, to produce a metallic glaze. It is an important source for tan, red-brown, and brown colors in glazes and bodies. Iron red colors, for example, are dependent on the crystallization of iron in a fluid glaze matrix and require large amounts of iron being present (eg. 25%). The red color of terra cotta bodies comes from iron, typically around 5% or more, and depends of the body being porous. As these bodies are fired to higher temperatures the color shifts to a deeper red and finally brown. The story is similar with medium fire bodies.

In reduction firing iron changes its personality to become a very active flux. Iron glazes that are stable at cone 6-10 in oxidation will run off the ware in reduction. The iron in reduction fired glazes is known for producing very attractive earthy brown tones. Greens, greys and reds can also be achieved depending on the chemistry of the glaze and the amount of iron. Ancient Chinese celadons, for example, contained around 2-3% iron.

Particulate iron impurities in reduction clay bodies can melt and become fluid during firing, creating specks that can bleed up through glazes. This phenomenon is a highly desirable aesthetic in certain types of ceramics, when the particles are quite large the resultant blotch in the glaze surface is called a blossom.

Iron oxide can gel glaze and clay slurries making them difficult to work with (this is especially a problem where the slurry is deflocculated).

Iron oxide particles are very small, normally 100% of the material will pass a 325 mesh screen (this is part of the reason iron is such a nuisance dust). As with other powders of exceedingly small particle size, agglomeration of the the particles into larger ones can be a real problem. These particles can resist break down, even a powerful electric mixer is not enough to disperse them (black iron oxide can be even more difficult). In such cases screening a glaze will break them down. However screening finer than 80 mesh is difficult, this is not fine enough to eliminate the speckles that iron can produce. Thus ball milling may be the only solution if the speckle is undesired.

Red iron oxides are available in spheroidal, rhombohedral, and irregular particle shapes. Some high purity grades are specially controlled for heavy metals and are used in drugs, cosmetics, pet foods, and soft ferrites. Highly refined grades can have 98% Fe_2O_3 but typically red iron is about 95% pure and very fine (less than 1% 325 mesh). Some grades of red iron do have coarser specks in them and this can result in unwanted specking in glaze and bodies (see picture).

High iron raw materials or alternate names: burnt sienna, crocus martis, Indian red, red ochre, red oxide, Spanish red. Iron is the principle contaminant in most clay materials. A low iron content, for example, is very important in kaolins used for porcelain.

One method of producing synthetic iron oxide is by burning solutions of Ferric Chloride (spent pickle liquor from the steel industry) to produce Hydrochloric Acid (their main product) and Hematite (a byproduct). 100% pure material contains 69.9% Fe.

http://digitalfire.com/4sight/material/iron_oxide_red_874.html

Molecular Formula of Red Iron Oxide:
Fe2O3 1

Percentage Analysis

100.00 % Fe2O3

100.00 % TOTAL

NOTES:

RedArt

-- common red clay, low firing, source of iron --
P.C.E. 13
Silica/Alumina ratio: 6.6:1
Equivalent Molecular Weight: 623.754

Redart is a red firing earthenware of moderate plasticity and low shrinkage. It fires light orange to dark red depending on firing temperature from cone 06 to 3. It fires much stronger and denser at cone 04 than 06 and achieves its best color/strength compromise at cone 02 and gives deep red color and stoneware properties at cone 1. It is airfloated to 200 mesh and is very clean and has a long firing range. This is a very popular ingredient in clay bodies made across North America and it has been available for many years.

This material is quite high in iron thus the powder is a deep red color and quite messy to work with. Redart is also used by potters in glaze recipes, sometimes up to 60%.

Redart can be used as a primary component in plastic modeling and throwing bodies, however some plastic additions of ball clay will be necessary. It can be used as a casting body without any additions, although it is desirable to diversify recipes to achieve better consistency and less dependence on the quality of one material alone.

While redart can be used as a source of iron in high temperature bodies, it will produce brown rather than red coloration. This is because the fluxes are intimately mixed with the iron and fuse it to a darker color. To get red in oxidation or reduction at higher temperatures you must use refractory clays with iron or iron bearing fireclays. However there is good reason not to use low fire reds as fluxes in high fire bodies: The fluxes in the red clays don't dissolve cristobalite like feldspar does, the result can be thermal expansion related ware failure.

This material is mined from a large deposit and the company is confident in its consistency and long term availability.

Sample body recipes for low fire terra cotta:

Redart Casting mix #1062
----
10 Kaolin
50 Redart
25 Nepheline Syenite
15 Large Particle size kaolin
33.7 Water
0.15 Soda Ash
0.65 N Brand Sodium Silicate

For redder color you can replace the kaolin with more Redart but dry strength will be lower. You can even use straight redart for casting.

Redart very plastic throwing body #3322A
----
40 Redart
40 Banta Red Clay
10 Talc
10 Ball clay

This body has remarkably good plasticity yet its drying performance is also very good. It is melting by cone 4 and is quite vitreous by cone 02. Talc in low fire bodies can really improve drying while not reducing plasticity as much as other fillers, talc also increases the thermal expansion for better fit to commercial glazes.

http://digitalfire.com/4sight/material/redart_1191.html

Molecular Formula of RedArt:

K20 0.26829687	Al2O3 1.00000000	SiO2 6.64660405
Na2O 0.04037338	Fe2O3 0.27390906	TiO2 0.08263658
CaO 0.02548391	P2O5 0.00744474	LOI 1.64780667
MgO 0.23851792		

Percentage Analysis

64.28 % SiO2
16.41 % Al2O3
4.07 % K2O
0.40 % Na2O
1.55 % MgO
0.23 % CaO
0.17 % P2O5
7.04 % Fe2O3
1.06 % TiO2
4.78 % L.O.I.

99.99 % TOTAL

NOTES:

Rutile

-- colorant –
Equivalent Molecular Weight: 82.579

Rutile is the mineral name for natural crystals of titanium dioxide. In nature rutile is always contaminated by up to 15% other minerals (especially iron but also things like tantalum, niobium, chromium and tin). The term 'rutile' is thus generally understood to refer to the brown powder into which these minerals are ground and industry accepts up to 15% contaminants and yet still calls it rutile (below 85% titanium is called ilmenite). Rutile is considered an impure form of titanium whereas ilmenite is considered as $FeTiO_3$. Grades of rutile are sometimes named after one of the impurities (e.g. Niobian Rutile). Rutile is used in many industries (e.g. welding rods, paint) and ceramic uses are minor in comparison (for this reason bags of rutile might have labels like "Welding Rod Titanate"). Rutile is often sourced by companies in the titania and zircon supply business. The are large reserves of rutile in the world and any supply shortages are thus related to other factors.

Rutile is available in light calcined ceramic grade powder (very fine particle size), dark uncalcined powder, and granular form. Either grade of powder can be ground very fine (e.g. 325 mesh). In glazes it is generally better to use the ceramic grade since the decomposition of raw rutile during firing can be a source of glaze imperfections like pinholing and bubbles (even larger amounts of the ceramic grade, e.g. 8%, can also cause problems).

Rutile produces many crystalline, speckling, streaking, and mottling effects in glazes during cooling in the kiln and has been used in all types of colored glazes to enhance the surface character. It is thus highly prized by potters, many attractive variegated glazes are made using it. Many potters would say that their living depends on their rutile supply!

This material can be inconsistent in the amount of iron and impurities producing variations in color and surface character, thus manufacturers will blend ores from different deposits (Ferro in the US blends various Australian materials in addition to material from Florida). For example, one major American supplier, TAM (now Ferro), relied on a high quality Sierra Leonian rutile deposit until 1995 when political problems in the country cut the supply. Since then no other substitute has provided the same quality. Considering that it is the metallic coloring impurities in rutile that are the subject of its variation and that the function of rutile in glazes is most often partly or mainly as a colorant, it is easy to see that visual consistency variations can be expected when using this material in ceramic glazes. Large users of rutile will often track batch numbers from the manufacturer and test when the number changes. If serious differences are detected another batch may be requested. Failing this the situation can sometimes be dealt with by adjusting the amount of rutile in the recipe or firing differently. In more serious situations adjusting the recipe and employing other materials like iron and titanium might be needed. In any case, it is important to understand the base glaze and the mechanisms by which rutile imparts the desired visual effect. Buying large amounts of a batch that works well is thus a good idea with a material like rutile.

Rutile is very refractory in oxidation, even a mix of 50% borax alumina-free frit like Ferro 3134 will not melt rutile in a crucible. In reduction, the improvement in melting will depend on the amount of iron present.

In ceramic glazes rutile is more often considered a variegator than a colorant. As little as 2% can impart significant effects in stoneware glazes. It is normally used in combination with a wide range of metal oxide and stain colorants to produce surfaces that are much more visually interesting. In glazes with high melt fluidity (e.g. having high boron), large amounts of rutile (e.g. 6-8%) can be quite stunning. The rutile encourages the development of micro-crystals and rivulets. Since rutile contains significant iron its use in combination with other colorants will often muddy the color that they would otherwise have or alter it if they are sensitive to the presense of iron. Even though rutile generally makes up less than 5% of stoneware glazes that employ it, they are often called 'rutile glazes' in recognition of its dramatic contribution.

Excessive rutile in a glaze can produce surface imperfections. In addition, when rutile is employed in higher percentages (e.g. 5%+) a given percentage might work well whereas a slightly higher amount can look drastically different. Such situations are vulnerable to chemistry changes in the supply of rutile. Thus people will often do a line blend trying a range of percentages to determine an optimal amount.

In glazes rutile can be quite sensitive to the presence of opacifiers. While an unopacified glaze glaze might appear quite stunning, the addition of a zircon opacifier will usually drastically alter its appearance and interest because the variegation imparted is dependent on the glaze having depth and transparency or translucency. Strangely rutile and tin, another opacifier, can produce some very interesting reactions and it is quite common to see tin in amounts of up to 4% in rutile glazes. In these cases the tin appears to react in the crystal formation rather than opacify the glaze.

Rutile powder, although its color makes it appear to be a very crude ground mineral, normally contains 90%+ titanium dioxide. However this does not mean that you can use a 90% titanium:10% iron mix and get the same result in a ceramic glaze (obviously line blending would be needed to match the amount of iron). The mineralogy and significant other impurities in rutile are a major factor in the way it acts in glazes and are not easily duplicated using a blend of other things. Sometimes the special effects that rutile produces in glazes are also partly a product of a coarser grade (larger particle size). These likewise cannot be easily duplicated by more refined materials. Unfortunately the trend at some mining operations (at least in Australia) is to fine grind the rutile on-site, making it more difficult for ceramic operations to obtain the coarser grades.

Although rutile will normally stain a glaze brown or yellow, its crystallization effects can significantly lighten the color of iron glazes. Higher amounts of rutile in stoneware glazes will often contribute glaze imperfections.

Granular rutile is sometimes used in bodies and glazes to impart fired speckle.

Rutile is used for special effects in leaded glazes and can form up to 15% of the recipe.

Rutile can be used as a tone modifier to soften the more potent colorants.

http://digitalfire.com/4sight/material/rutile_1204.html

Molecular Formula of Rutile:

Fe_2O_3	0.0032	SiO_2	0.0111
Cr_2O_3	0.0011	TiO_2	1.0000
V_2O_5	0.0032	ZrO_2	0.0061

Percentage Analysis

0.81 % SiO_2
0.62 % Fe_2O_3
96.76 % TiO_2
0.91 % ZrO_2
0.70 % V_2O_5
0.20 % Cr_2O_3

100.00 % TOTAL

NOTES:

Silica (Flint)

-- glassformer –
Equivalent Molecular Weight: 60.000

The term 'silica' can be misleading. It is important to understand the difference between 'silica mineral', 'silicates', and 'silica glass'. Quartz is the best example of a natural mineral that is almost pure silicon dioxide (it is the most abundant mineral on planet earth). Other ceramic minerals like feldspar and clay contain some 'free silica' (accessory quartz). However these also usually contain 'silicates', that is, SiO_2 chemically combined with other oxides to form crystalline minerals. Other silica-containing rocks and minerals are andalusite, barite, beach sand, bentonite, calcite, diatomaceous earth, kaolin, limestone, mica, pyrophyllite, talc, tripoli, rutile, wollastonite, zeolite, zirconium sand, vermiculite, granite, and sandstone. Silica is also available as a silicate glass (in frits).

Pure silica minerals (like quartz) have high melting points. In ceramic bodies and glazes other oxides are added to complement it, they form silicates with it or occupy the network between particles of quartz. In the latter case silica is considered a 'filler' (e.g. porcelain clay bodies). It is interesting that some special purpose (and expensive) clay bodies replace the silica filler with calcined alumina, this greatly increases body strength and reduces thermal expansion.

Individual particles of quartz have a high thermal expansion (and associated contraction) and significantly change their volume as they pass up and down through 'inversion' temperature points during firing. This can cause a form of body cracking called 'dunting' where the silica does not get dissolved in the feldspar glass melt. The cracking occurs as microcracks radiate out from each microscopic particle of quartz and propagate into larger cracks. High quartz bodies are usually unsuitable for ovenware and ware that must tolerate sudden temperature changes. However this behavior is advantageous to glaze fit since it puts the 'squeeze' on the glaze to prevent crazing. At the same time silica in glazes tends to dissolve and form low expansion silicates that reduce glaze expansion and also prevent crazing. In both cases, silica powder of small grain size is advantageous.

High temperature bodies tend to have up to 30% silica whereas low fire ones have much less or none (because of its refractory nature). However in recent years many companies substitute kyanite, pyrophyllite or similar minerals for part of the quartz to minimize thermal expansion (see article in Studio Potter vol 28 #1 by Peter Sohngen). Apparently very fine grades of silica aid in cristobalite formation in stoneware bodies (cristobalite is a form of silica that goes through it's inversion at about 200C).

High temperature glazes can have 40% or more silica at times, if enough flux is available to react and form silicates.

http://digitalfire.com/4sight/material/silica_1245.html

Molecular Formula of Flint (325m):

SiO_2 1

Percentage Analysis

100.00 % SiO_2

____

100.00 % TOTAL

Potential Health Hazards:
free silica-wear a NIOSH approved dust mask when handling dry material

Silica Sand

-- refractory material, used like grog in clay bodies --

Often used in clay bodies instead of grog or to augment grog. However the particle size is often round and the angular shaped particles of grogs are usually more suited to clay bodies. In addition, the thermal expansion behavior of the quartz will contribute to dunting (grogs are available that have almost zero thermal expansion). Also used as a lubricant on kiln shelves to prevent ware from sticking and enable it to move while shrinking.

Many sizes and particle shapes of silica sand are available. Colors can range from white to brownish, the latter containing iron. Small amounts of iron or contaminating products can darken the sand considerably. Many industrial silica sands are not suitable for ceramics because of the level of impurities they contain.

Silica sand is used as a source of SiO_2 in the glass industry and for a wide range of things in others.

http://digitalfire.com/4sight/material/silica_sand_1246.html

NOTES:

Silicon Carbide

-- refractory material, used in kiln posts and shelves, sometimes used in glazes to achieve localized reduction, also may be used in crater glazes --
M.P./°C 2700
Equivalent Molecular Weight: 40.070

Silicon Carbide is a non oxide ceramic and is used in a wide range of products that must perform in thermally (heat shock) and mechanically demanding applications. It is employed in both abrasives and wear resistant parts for its hardness; in refractories and ceramics for its resistance to heat and low thermal expansion; and in electronics for its thermal conductivity and other properties. The only materials harder than SiC are boron carbide and diamond.

SiC parts can be fabricated in a variety of ways. Hot pressed and reaction bonded parts are usually porous, non-homogeneous and less thermally conductive and shock resistant. By contrast single crystal SiC has optimal properties but is very expensive to make. CVD furnaces, on the other hand, can be used to make solid pure SiC parts that are uniform and dense. Surprisingly, 100% SiC powders can also be cast using the traditional slurry deflocculation and plaster casting method (provided that a very fine grade SiC powder is employed). SiC cast parts separate best from completely dry molds and special measures may be needed to get the dispersant to mix in properly. SiC casting mixes can also contain some plastic clay to affect better suspension and enable using a coarser grade of material (for refractory setters, for example). Items need to be fired to 1500C.

In ceramics the most common use of SiC is for high heat duty kiln shelves. But this material is increasingly being used to make a wide range of products having low expansion, high heat endurance and resistance to abrasion.

SiC powder has some curious uses in ceramic glazes. It is employed to make crater and foam glazes. The silicon part takes up available oxygen to make SiO_2 and the carbon combines with oxygen to make CO_2 that creates the blisters and bubbles. This mechanism is also useful to create reduction effects in oxidation firings. The carbon that silicon carbide particles release acts to reduce metallic oxides like iron and copper (however larger amounts of SiC increase the danger of blisters in non fluid melts). Additions of tin oxide will aid color development, especially for copper reds.

http://digitalfire.com/4sight/material/silicon_carbide_1250.html

Molecular Formula of Silicon Carbide:
SiO_2 1

Percentage Analysis

100.00 % SiO_2

100.00 % TOTAL

NOTES:

Silver Nitrate

Cost/lb: $224.00
-- colorant --
Equivalent Molecular Weight: 153.880

Silver nitrate is highly soluble and forms Ag+ ions when dissolved in water. This ion transfers to ware as adhered material and when fired and reduced the Ag metal gives a gold sheen.

It is possible to dry blend the nitrate and carbonate forms and putting these into a glaze to get a better gold sheen.

100 grams of Carbonate is equivalent to 123 grams Nitrate.

http://digitalfire.com/4sight/material/silver_nitrate_1255.html

Molecular Formula of Silver Nitrate:

Percentage Analysis

% TOTAL

Comments:
AgNO2 Light sensitive-deteriorates quickly. Causes skin discoloration-blindness if splashed in eyes!
Potential Health Hazards:
EXTREMELY HAZARDOUS-wear eye and skin protection when handling.

NOTES:

Soda Ash

-- common source of sodium for glazes, soluble, deflocculant, used in soda firing as a fuming agent
Equivalent Molecular Weight: 106.000

In ceramics, a common use of soda ash is as a soluble deflocculant in ceramic slips and glazes. It works well in combination with sodium silicate to produce slips that do not gel too quickly and whose rheology can be adjusted for changes in the hardness of the water. Higher soda ash in proportion to sodium silicate will produce a slip that gives a softer cast (stays wet longer). The total soda ash and sodium silicate amount should be tuned to create a slip that will eventually gel if left to stand. This thixotropic behavior will prevent it from settling.

Sodium carbonate is the preferred deflocculant for thinning glaze slurries.

Soda ash is not normally used as a source of Na_2O in glazes because it is soluble. It is used as a source of sodium in frits and glass. Its solubility makes it an ideal flux for Egyptian paste glazes.

http://digitalfire.com/4sight/material/sodium_carbonate_1263.html

Molecular Formula of Soda Ash:
Na_2O 1

Percentage Analysis

100.00 % Na_2O

100.00 % TOTAL

Potential Health Hazards:
caustic-avoid contact with skin or eyes or inhalation of mists

NOTES:

Sodium Silicate

-- used as a deflocculant in casting slips, reduces the amount of water needed to make a slip liquid –
Equivalent Molecular Weight: 696.402

The most popular deflocculant used in casting slips for many years. It is nearly always used with soda ash (when employed alone it can make a slip 'stringy' and thixotropic). The material is effective, reliable and inexpensive. However, it attacks the plaster in molds much more than more modern deflocculants and it is easier to over-deflocculate a slip with sodium silicate.

There are potassium based deflocculants that are similar to the corresponding sodium ones. They can be employed where the presence of sodium is undesirable. Soda ash is more suitable for deflocculating glazes. In addition, a wide range of organic deflocculants are available as alkali salts of pyrogallic, humic or tannic acids. They have long working ranges and can increase the apparent plasticity of the clay. As noted, their use prolongs mold life compared with sodium silicate and soda ash and they are less prone of over-deflocculation. Tetramethylammoniumhydroxide is also an organic compound that is used where residues from inorganic salts cannot be tolerated. It is a strong base that can even attack glass and quartz.

http://digitalfire.com/4sight/material/sodium_silicate_1275.html

Molecular Formula of Sodium Silicate:

Na_2O 1.0000 SiO_2 3.3280

LOI 24.1198

Percentage Analysis

28.70 % SiO_2
8.90 % Na_2O
62.40 % L.O.I.

100.00 % TOTAL

Comments:
alkaline material - wear eye protection and gloves when handling. Avoid contact with skin.

NOTES:

Spodumene

-- flux, glassformer, similar to lithium based feldspar, similar to petalite –
Silica/Alumina ratio: 4.3:1
Equivalent Molecular Weight: 478.683

The name is from the Greek spodos, meaning burnt to ash. Spodumene is a silicate mineral often referred to as lithium feldspar. Its mineral form is characterized by hard needle-like grains of brilliant white color. It is used in ceramics as a source of lithia.

Lithia is a very powerful flux, especially when used in conjunction with potash and soda feldspars. As one of only a few natural lithium source materials, spodumene is a valuable component in glass and ceramic/enamel glazes (Li_2O reduces thermal expansion, melting temperature and viscosity of the glaze melt).

Spodumene is only slightly soluble (in contrast to lithium carbonate). Because spodumene is a natural combination of silica, alumina and lithia it melts better than a chemically equivalent mixture of lithium carbonate, kaolin and silica. Since almost all raw glazes contain kaolin and silica it is normally fairly easy to juggle recipe ingredients in a ceramic chemistry calculation program to introduce spodumene to replace lithium carbonate.

Some types of spodumene do contribute to the formation of bubbles in the glaze slurry. Spodumene is a little more readily fusible than petalite since it is higher in lithium.

http://digitalfire.com/4sight/material/spodumene_1287.html

Molecular Formula of Spodumene:

K_2O 0.0604	Al_2O_3 1.1759	SiO_2 5.0701
Na_2O 0.0048	Fe_2O_3 0.0691	
Li_2O 0.9348		

Percentage Analysis

64.88 % SiO_2
25.54 % Al_2O_3
1.21 % K_2O
0.06 % Na_2O
5.95 % Li_2O
2.35 % Fe_2O_3
____
99.99 % TOTAL

NOTES:

Strontium Carbonate

-- flux, similar to calcium and barium, color responses are similar to barium but not toxic –
Equivalent Molecular Weight: 147.630

Strontium Carbonate is a slightly soluble source of SrO used in glazes.

There is disagreement about when it decomposes (data sheets vary from 1075-1100C, one even indicates 1340C) as follows:

$SrCO_3 \rightarrow SrO + CO_2$

The 'Ceramic Industry Materials Handbook' states that it starts to disassociate as early as 800C in a purely oxidizing atmosphere, whereas a CO_2 atmosphere might delay break-down until around 1220C. This information is supported by the fact that when the more stable calcium and barium carbonate are added to bodies, pinholing and blistering are greater than bodies containing strontium. Wikipedia says it melts and decomposes at the same time, 1100C.

Strontium carbonate is often recommended as a substitute for barium to produce matte glazes. Use about 75% as much and test first to make sure color response is the same. However strontium is not a substitute for barium as a precipitator of soluble salts in clay bodies because it combines with SO_4^{--} ions in the water to form a compound that is not nearly as insoluble as $BaSO_4$.

Viscous zirconium silicate glazes can be smoothed with the addition of strontium carbonate.

Strontium is considered a safe material. Some people confuse SrO with Strontium 90, an isotope released from atomic reactions, but they are not the same thing.

Strontium carbonate produces gases as it decomposes and these can cause pinholes or blisters in glazes. There are many strontium frits available and incorporating one of them to source the SrO instead is a classic application of ceramic chemistry calculations. The resultant glaze will be more fusible and will have better clarity and fewer defects.

http://digitalfire.com/4sight/material/strontium_carbonate_1609.html

Molecular Formula of Strontium Carbonate:

SrO 1

Percentage Analysis

100.00 % SrO

____

100.00 % TOTAL

Comments:
$SrCO_3$ - natural Strontianate

NOTES:

Superpax

-- opacifier, similar to zircopax (but cheaper) –
Equivalent Molecular Weight: 183.280

http://digitalfire.com/4sight/material/superpax_2144.html

Molecular Formula of Superpax:
SiO_2 1
ZrO_2 1

Percentage Analysis

32.77 % SiO_2
67.23 % ZrO_2

100.00 % TOTAL

Comments:
Contains traces of Iron Oxide and Titanium Dioxide, in actuality, Superpax is only 92-94.5% $ZrSiO_4$

NOTES:

Talc

-- flux, used in low fire clay bodies, reduces expansion and increases thermal shock resistance --
Silica/Alumina ratio: 338.8:1
Equivalent Molecular Weight: 118.217

Talc is the most common mineral in the class of silicates and germinates and is the softest of all minerals. Talc is also called steatite – or, in chemical terms, magnesium silicate hydrate. It is the main component of soapstone. Its crystals usually develop massive, leafy aggregates with laminar particles. Ground talc is called talcum.

Talc is the softest mineral, with a Mohs hardness of 1. Its silicate layers lie on top of one another and are bound only by weak forces (residual van der Waals forces). This gives it its characteristic greasy or soapy feeling – hence the name "soapstone". In its pure form, talc is colourless or appears white, and often it has a mother-of-pearl sheen. When it contains other substances, it can also appear light grey, green, yellow or pink.

No talcs have the theoretical chemistry (although some can be very close), the most common impurities are CaO (up to 8%), Al2O3 (up to 6%) and Fe2O3 or FeO (up to 2%). Along with dolomite, and to a less extent magnesium carbonate, it is an important source of MgO flux for bodies and glazes. Dolomite and magnesium carbonate have high loss on ignitions which can produce glaze bubbles, blisters and pinholes, talc is much less of a problem in this respect.

Some textbooks claim that talc is used as a low fire body addition to encourage conversion of excess free quartz to cristobalite to increase body expansion which reduces crazing. Ron Roy has argued that his testing indicates that cristobalite does not form at cone 04 or below. Thus, while the exact mechanism by which talc increases body expansion may not be completely evident, clearly glazes fit talc bodies and craze on non-talc ones.

Amazingly, talc is also used to produce low expansion ceramics, for example thermal shock resistant stoneware bodies. In these it acts as a low expansion flux that reduces body expansion by converting available quartz mineral, mainly in kaolin, to silicates of magnesia. Cordierite bodies used in kiln furniture and flameware (an a host of other applications e.g. catalytic converters) employ a high percentage of talc and extend this concept so that all free quartz is used up. Such bodies tend to have a narrow firing range because all the silica needs react before the body distorts.

Thus talc is truly a curious material. By itself it is a refractory powder; yet in amounts of only 1-3% in middle temperature stoneware bodies it can drastically improve the maturity and melting! Yet cone 06-04 ceramic slips containing up to 60% talc can often be fired to cone 6 without melting or even deforming. Nothwithstanding this, other 50:50 talc:ball clay bodies will completely melt and boil at cone 6! In glazes at middle temperature raw talc is refractory, its presence tends to create opaque and matte surfaces, yet if supplied in a frit it can create wonderfully transparent glossy glazes. At cone 10 it is a powerful flux but also can be used in combination with calcium carbonate to create very tactile magnesia matte glazes (the MgO forms magnesium silicate crystals on cooling to give both opacity and a matte silky surface).

Talcs vary alot in their iron content (some talcs have almost zero iron, others are much higher), so if you are making a body high in talc be aware that the reason it is not firing as white as you would like might be because of the talc, not the clays.

The soapstone form of talc was first used by Indians who carved it. Coarse grade talc is used in roofing preparation. Finer grades are used in rubber, paint, steel marking pencils, soaps, lubricants, tailor's chalk (or French chalk), pigments, and it is used for talcum powder.

http://digitalfire.com/4sight/material/talc_1620.html

Molecular Formula of Talc:

Na_2O 0.0034	Al_2O_3 0.0033	SiO_2 1.1180
CaO 0.1464	Fe_2O_3 0.0015	MnO_2 0.0018
MgO 0.8502	LOI 0.4239	

Percentage Analysis

56.80 % SiO_2
0.28 % Al_2O_3
0.18 % Na_2O
29.00 % MgO
6.94 % CaO
0.20 % Fe_2O_3
0.13 % MnO
6.46 % L.O.I.

99.99 % TOTAL

Comments:
Finer grind (325 mesh) for higher fired strength than coarser talcs. Analysis for

NOTES:

Tenn. #10 Ball Clay

-- ball clay –
Silica/Alumina ratio: 2.9:1
Equivalent Molecular Weight: 329.943

A low organic, low residue Ball Clay with unparalleled white-firing characteristics due to its high kaolintic content. This medium-grained, uniquely clean Ball Clay is especially suited for refractory and fast-firing applications.

http://digitalfire.com/4sight/material/tennessee_num_10_ball_clay_1630.html
Molecular Formula of Tenn. #10 Ball Clay:

K2O 0.0211	Al2O3 1.0000	SiO2 2.9004
Na2O 0.0320	Fe2O3 0.0208	TiO2 0.0620
CaO 0.0234	LOI 2.1792	
MgO 0.0244		

Percentage Analysis

52.80 % SiO2
30.90 % Al2O3
0.60 % K2O
0.60 % Na2O
0.30 % MgO
0.40 % CaO
1.01 % Fe2O3
1.50 % TiO2
11.90 % L.O.I.

100.01 % TOTAL

NOTES:

Tile-6 Clay

-- highly plastic, fine grained kaolin --
Silica/Alumina ratio: 2.2:1
Equivalent Molecular Weight: 279.797

6 Tile is an airfloated kaolin with bright firing properties yet highly plastic. It thus offers high green strength for superior jiggering and wet processing properties.

Particle size, % < 2 microns 54-65
Mean particle size (microns) 1.0-1.3
325 mesh screen residue, % max 1.0

pH, 20% solids 6.7-7.5
Strength (dry M.O.R.)
-psi 100% clay 900 min
Cone 10 absorption, % 5-8
Moisture, % max 3.0

Color (fired), cone 8 100% clay
-brightness, % MgO 80.3
-whiteness index 22.9

Color (fired), cone 8 50:50 clay/nepheline syenite
-brightness, % MgO 60.8
-whiteness index 25.9

http://digitalfire.com/4sight/material/tile_num_6_kaolin_1641.html

C.E.C. (meq/100 g.) 8.5

Molecular Formula of Tile-6 Clay:

Na2O 0.00159900	Al2O3 1.00000000	SiO2 2.21724000
CaO 0.02054900	Fe2O3 0.00587000	TiO2 0.04750200
MgO 0.03843300	LOI 2.05898200	

Percentage Analysis

47.60 % SiO2
36.44 % Al2O3
0.04 % Na2O
0.55 % MgO
0.41 % CaO
0.34 % Fe2O3
1.36 % TiO2
13.26 % L.O.I.

100.00 % TOTAL

NOTES:

Tin Oxide

-- opacifier –
Equivalent Molecular Weight: 150.700

Tin oxide is a white or off-white powder produced by oxidizing molten high grade tin metal. It is typically quite pure, some manufacturers have grades up to 99.999% purity.

Tin oxide has long been used to opacify glazes (make transparents opaque) at all temperatures. Hand decorated tin glazed earthenware of the 1700/1800s is the most famous use of tin in glazes (delftware-England, faience-France, maiolica-Italy). While many potters are keeping this tradition alive today most now use zircon based opacifiers instead. Thus any discussion about the use of tin oxide as an opacifier ends up comparing it with zircon products:

-Twice as much zircon is required to produce the same level of opacity.
-Like zircon, tin melts at very high temperatures and thus does not go into solution in typical glaze melts.
-Zircon will stiffen the glaze melt more than tin.
-Zircon will likely produce a harder glaze surface.
-Zircon will reduce the thermal expansion of the glaze more than tin.
-The quality of the white color is different (tin tends to be more of a blue white, zircon a yellowish white).
-Tin is very expensive, this is likely the main reason for its much more limited use as an opacifier today.
-Zircon tends to have less of an effect on the development of metal oxide colors (e.g. tin reacts with chrome to make pink).
-Tin can react with titanium and rutile to variegate the glaze.
-If gloss is an issue, silica might have to be reduced to compensate for the silica introduced by a zirconium silicate opacifier being substituted for tin.
-While there are other products that produce varying degrees of opacity, none are as neutral and non-reactive as tin and zircon. Other opacifiers also tend to variegate the glaze.
-Copper red glazes require tin, with iron in oxidation tin makes a warmer shade of brown than zirconium does.

http://digitalfire.com/4sight/material/tin_oxide_1642.html

Molecular Formula of Tin Oxide:
SnO_2 1

Percentage Analysis

100.00 % SnO_2

100.00 % TOTAL

NOTES:

Titanium Dioxide

-- opacifier –

Equivalent Molecular Weight: 80.000

TiO_2 occurs in many silicates in nature, accounting for over 1% of the earth's crust. Thus it is manufactured using a variety of materials and processes.

Although titanium is the strongest white pigment known for many uses, in ceramics the whiteness (and opacity) it imparts to glazes is due to its tendency to crystallize during cooling. While titanium dioxide is used in glazes as an opacifier, it is not as effective and easy-to-use as tin oxide or zircon. It can be used as an additive to enliven (variegate, crystallize) the color and texture of glazes (rutile works in a similar manner). In moderate amounts it encourages strong melts, durable surfaces and rich visual textures.

Titanium is available both as raw and surface treated products. Non-pigmentary grades flow more freely in the dry state. Self opacified enamels are made by adding titanium during smelting to super saturation. Upon firing the enamel, the titanium crystallizes or precipitates to produce the opacity. Titania is also used in dry process enameling on cast iron appliances for its effect on acid resistance, color and texture. In glass, non-pigmentary titanium dioxide increases refractive index, intensifies color.

http://digitalfire.com/4sight/material/titanium_dioxide_1644.html

Molecular Formula of Titanium Dioxide:

TiO_2 1

Percentage Analysis

100.00 % TiO_2

100.00 % TOTAL

NOTES:

Ultrox

-- opacifier, similar to zircopax –
Equivalent Molecular Weight: 183.280

Three types are available: Ultrox, Ultrox 500W, Ultrox 1000W.

Ultrox opacifiers are claimed to assure uniformity of glaze opacity, texture and color over a wide range of temperatures and compositions. They reduce the expansion of glazes and tend to reduce crazing. They increase the resistance of glazes to chemical attack and widen the firing range. Ultrox melts at 4000F and has a coefficient of thermal expansion of 42 x 10-7, a hardness of 7.5 Moh and index of refraction of 2. It is composed of 65% ZrO_2 and 35% SiO_2 in a formula of ZrO_2:SiO_2.

Ultrox is used for the production of both white and color glazes for sanitary ware, wall tile, glazed brick, structural tile, stoneware, dinnerware and special porcelains. It is used in amount of 12-20% of the glaze batch.

-Ultrox has an average particle size of 2 microns.
-Ultrox 500W has an average particle size of 1 micron and thus provides greater whitening power. It lightens color appreciably and thus requires more stain.
-Ultrox 1000W has an average particle size of .5 micron and provides the maximum reflectance and opacity.

Ultrox has an extremely high melting point and low uniform thermal expansion and can thus be slip cast or pressed to produce zirconium silicate refractories (for use in glass melting furnaces, foundries, refractory porcelains, washes for refractory slabs, refractory cements). Compositions of Ultrox alone can approach the theoretical density of zircon.

Coefficient of thermal expansion: 42 x 10 -7
Hardness: 7.5 Moh's scale
Index of refraction: 2

Ultrox products are relatively non-hazardous based on plant operating experience. Avoid inhalation of dust. May cause eye irritation on repeated contact.

http://digitalfire.com/4sight/material/ultrox_1665.html

Molecular Formula of Ultrox:

SiO_2 1
ZrO_2 1

Percentage Analysis

32.77 % SiO_2
67.23 % ZrO_2

100.00 % TOTAL

NOTES:

Veegum

-- glaze hardener, binder --
Silica/Alumina ratio: 93.8:1
Equivalent Molecular Weight: 167.686

Veegum is not a 'gum', rather it is a fine particle mineral called 'smectite' (bentonite and hectorite are members of the smectite group). It is a complex colloidal and extremely plastic magnesium aluminum silicate. It is an off-white insoluble flake magnesium aluminum silicate that swells to many times its original volume when added to water. Its aqueous dispersions are thus high viscosity thixotropic gels at low solids. Veegum is not subject to attack by microorganisms. Various grades are classified according to viscosity and ratio of aluminum to magnesium content.

Density (Mg/m3): 2.6
Viscosity (after shear mixing, 5% dispersion): 250 cps +/- 25%
Moisture: 8% max
Bacterial Count: less than 1000 per gram. No E. coli, S. aureus, Salmonella sp., P. aeruginosa at time of shipment.

It is very important to properly hydrate the powder, mix it in water before adding other ingredients (different grades of Veegum hydrate at different rates). Do not underestimate the time needed, in 25C water it could take 120 minutes using a propeller mixer! Using hot water or a higher energy mixer can drastically cut the time needed. It is also important to use the same water temperature, mixing time and energy and viscosity each time it is used to get consistent behavior in the slurry.

Veegum T is used as an in-mix suspending agent and surface hardener for glazes. It is also suitable for use as a spray-on surface hardener before decorating (mix it with water and put a light layer on dried ware).

VGT is employed as a plasticizing agent for nonplastic formulations such as high alumina or zirconia bodies, and as a nonmigrating binder in extruded bodies. The material is clean and therefore does not affect fired whiteness.

VGT has a high pH of 8.5 and yet acts as a flocculant, contributing to the workability of porcelain. 1.5-2.0% added to a porcelain, that is otherwise a little to short for modeling or throwing, will transform it into a plastic material.

Veegum CER is a mixture of Veegum T and medium viscosity sodium carboxymethylcellulose that gives optimum surface hardening of unfired ceramic glazes for safe handling of the ware. It serves as hardener, suspending agent and viscosity stabilizer in glazes.

Veegum Pro is Veegum treated with amine to improve dispersability. Veegum Pro hydrates readily in hot or cold water to form high viscosity dispersions. Recommended for use where a minimum amount of water is required and/or only slow type mixers are available.

Other Grades: F, HV, K, S728, HS

Since this is a mineral family it is very difficult to supply a chemistry. We recommend using the bentonite chemistry (it is possible in INSIGHT to label a recipe line as Veegum yet specify bentonite as the material database look-up value).

http://digitalfire.com/4sight/material/veegum_1672.html

Molecular Formula of Veegum CER:

K_2O	0.0012	Al_2O_3	0.0116	SiO_2	1.0885
Na_2O	0.1361	Fe_2O_3	0.0012	LOI	3.1348
CaO	0.0987				

MgO 0.7230
Li_2O 0.0410

Percentage Analysis

38.99 % SiO_2
0.71 % Al_2O_3
0.07 % K_2O
5.03 % Na_2O
17.38 % MgO
3.30 % CaO
0.73 % Li_2O
0.11 % Fe_2O_3
33.68 % L.O.I.

100.00 % TOTAL

Comments:
Veegum CER is a mix of Veegum (inorganic complex colloidal magnesium aluminum silicates) and sodium carboxymethylcellulose (CMC) 24.84%.
Use 1.0 to 1.5% of dry weight of glaze in water for dispersion.

NOTES:

Vermiculite

-- refractory material, used in kiln insulation and sometimes used in clay bodies, can be purchased at gardening supply stores –
Silica/Alumina ratio: 10.4:1
Equivalent Molecular Weight: 133.611

Clay-making mineral of the ideal form (Mg, Ca)$_x$(Si$_{8-x}$ Al$_x$(Mg, Fe)$_6$O$_{20}$, 8H$_2$O of varying typical analyses.
Hardness 1.6 Density 2.3-2.7 Water insoluble
Used principally in refractory materials for purposes of insulation.

http://digitalfire.com/4sight/material/vermiculite_1674.html

Molecular Formula of Vermiculite:

CaO 0.26182876	Al2O3 0.10431009	SiO2 1.09000918
MgO 0.73566779	LOI 0.72666583	
Li2O 0.00250344		

Percentage Analysis

49.00 % SiO2
7.96 % Al2O3
22.20 % MgO
10.99 % CaO
0.06 % Li2O
9.80 % L.O.I.
____
100.01 % TOTAL

Comments:
only an approximate analysis

NOTES:

Volcanic Ash

-- flux, glassformer, variable volcanic material –
Silica/Alumina ratio: 10.7:1
Equivalent Molecular Weight: 792.700

Pumicite is composed of minute particles of volcanic glass. Pumicite is easily processed due to its fine in nature. Deposits resulted from volcanic eruption blowing large quantities of material into the air which settled in layers, sometimes in thicknesses which compressed to 30 feet or more. Volcanic ash particles are non-crystalline due to the quick cooling during formation. This material thus takes on the unique melting properties associated with a glass.

The chemistry is similar to granite or ryolite. Raw color varies and deposits can be found over wide areas of the central and western areas of North America. Volcanic ash materials vary widely in their chemistry, it is impossible to formulate a representative analysis, the one shown here may not be similar to your native material.

Some types of volcanic ash are balanced enough chemically that they can be used in amounts to 50% or more of the glaze batch. Most require the addition of fluxes and kaolin to form a glaze with reasonable firing and suspension properties.

More sample formulas of two well known materials:

Pinatubo:
Ca0 5.6%
Mg0 2.7
K20 1.6
Na20 4.4
Fe203 5.6
Ti02 .8
Al203 16.1
Si02 61.9

http://digitalfire.com/4sight/material/volcanic_ash_1689.html

Molecular Formula of Volcanic Ash:

K20 0.6619	Al2O3 0.8971	SiO2 9.5590
Na2O 0.2288	Fe2O3 0.0602	TiO2 0.0538
CaO 0.0958	LOI 1.6746	
MgO 0.0135		

Percentage Analysis
72.48 % SiO2
11.55 % Al2O3
7.87 % K2O
1.79 % Na2O
0.07 % MgO
0.68 % CaO
1.21 % Fe2O3
0.54 % TiO2
3.81 % L.O.I.
____
100.00 % TOTAL

Comments:
Typical volcanic ash - very approximate
NOTES:

Water

-- source of all life on earth –
Equivalent Molecular Weight: 18.015

Molecular Formula of Water:
LOI 1

Percentage Analysis

100.00 % L.O.I.

100.00 % TOTAL

Comments:
H2O

NOTES:

Whiting (Calcium Carbonate)

-- flux, main source of calcium in glazes, excess calcium produces matte glazes –
Equivalent Molecular Weight: 100.000

Whiting has traditionally been a source of CaO in raw glazes and glass (however whitings also typically contain some dolomite as a contaminant). Whiting is generally inexpensive and there is a large calcium carbonate industry worldwide for non-ceramic uses of this mineral. Well known deposits are the chalk cliffs of England, France and Belgium. Marble and calcite ores are abundant in many places.

Inexpensive non ceramic grades of whiting tend to lack the quality and consistency needed for use in glazes (especially for industrial use). Also whiting produces a very large volume of gases while decomposing, it loses more than 40% by weight. While these gases should be gone well before 1100C (and therefore should not disturb the glaze melt), in low or fast fire they can contribute to imperfections and faults in the glaze surface. With the advent of faster firing schedules in recent years whiting has been replaced by wollastonite and frits as a source of CaO in many applications (CaO oxide is advantageous in fast fire because it does not lower the melting point as much as the alkalies). Since LOI is a good indicator of variation in chemistry it may be practical to do an LOI test on shipments by firing a specimen of powder in a thin bisqued bowl to confirm the consistency of shipments.

There are many alternate no-LOI sources of CaO (e.g. wollastonite, frits) and incorporating one of them to source the CaO instead is a classic application of ceramic chemistry calculations (it is dealt with in the lessons section of the INSIGHT software manual).

In low-fire bodies, calcium carbonate is sometimes added in small amounts as a filler to reduce fired shrinkage and act as a whitener. It is also common to see 5% whiting included in porous earthenware body recipes to prevent moisture expansion (which causes glazes to craze).

http://digitalfire.com/4sight/material/calcium_carbonate_173.html

Molecular Formula of Whiting:
CaO 1

Percentage Analysis

100.00 % CaO

100.00 % TOTAL

NOTES:

Wollastonite

-- source of calcium, reduces firing shrinkage and thermal shock resistance –
M.P./°C 1540
Silica/Alumina ratio: 48.5:1
Equivalent Molecular Weight: 121.110

Wollastonite is a naturally occurring calcium metasilicate. It is the only commercially available pure white mineral that is wholly acicular (needle-like crystals). Wollastonite is available in fine particle size powders as well as fibrous 'high aspect ratio' products (20:1). This material has a very unusual texture, it does not flow at all (a hand full can be picked up with fingers downward). Wollastonite's unique qualities were first recognized in 1822 by an English scientist, Sir William Wollaston. However as a commercially available raw material wollastonite has only been available since the 1950s. Explosive market growth took place during the 1980s and 90s and major industrial sectors have adopted the material.

Deposits are mined mainly in US, China, India, Mexico, Canada, and Finland. They vary in purity; some require almost no beneficiation; others may require removal of up to 80% impurities such as garnet, diopside, limestone, and dolomite (e.g. by magnetic separation, froth flotation, optical sorting). Synthetic wollastonite is also made by combining quicklime with quartz, calcium carbonate and calcium hydrate.

No commercial products have the theoretical chemistry shown here.

Example of Typical Data:
Appearance: Brilliant White
Shape: Acicular
Molecular weight: 116
Specific gravity: 2.9
Refractive Index: 1.63
pH (aqueous solution): 9.9
Water solubility (gms./100cc): 0.0095
Density (lbs./solid gallons): 24.2
Bulking balue (gal./lbs): 0.0413
Moh's hardness: 4.5
Coefficient of expansion: (in/in/degree C): 6.5 x 10 -8
Melting point: 1540
Nyad 325 on 325# sieve: 1.0

The fibrous form of wollastonite can be very beneficial in bodies. In low fired ceramics wollastonite reduces drying and firing shrinkage and drying and firing warpage. It also promotes lower moisture and thermal expansion in the fired product. It fires with no LOI and its fibers help vent out gassing. These factors have made it a valuable component in tile bodies, especially for fast fire. Vitreous and semi vitreous bodies can also show reduced shrinkage with small additions (2-5%), however wollastonite becomes a stronger flux as temperatures go above 1100C.

Wollastonite exhibits a slight solubility in water, but slips containing it can become more alkaline (potentially affecting rheological properties).

At higher temperatures the powder form is valuable as a source of CaO flux in glazes (and bodies). The other main raw source of CaO is whiting but it releases a high volume of gases of decomposition which produce suspended micro-bubbles that demand slow firing to clear. Also, since wollastonite sources silica as well, glaze recipes employing it do not need as much raw silica powder. Further the SiO2 and CaO react more readily to form silicates. Thus wollastonite is used as a major flux in high temperature sanitaryware and electrical insulators.

In glass and fiberglass making wollastonite melts more readily (lower energy costs) and microbubble generation is lower than limestone-sand mixes.

Wollastonite has the ability to seed crystals (in glaze melts of sympathetic chemistry), and can be valuable to create special effects which depend on devitrification (crystallization during cooling). Since CaO tends to devitrify in high temperature slow cooled glazes wollastonite can be employed to make faster cooled lower CaO content ones exhibit the same effect.

Wollastonite is also used in stain and frit formulations to supply CaO in a more easily melted form.

Mineralogy vs. Chemistry, Wollastonite vs. Calcium Carbonate:
Wollastonite is an excellent demonstration of the fact that we must consider ceramic chemistry is a relative science and it is one piece in the glaze puzzle. The mineralogy of materials is another important factor to consider. For example, the melting temperature of a frit or glass is predictable, but since raw minerals are most often crystalline, the bonds holding the molecular structure together are more complex. The melting temperature of minerals of similar or even identical chemistry, for example, can be vastly different.

To demonstrate we took a reliable cone 6 calcium matte glaze (Wollastonite - 34.0, Ferro Frit 3134 - 21.0, Kaolin - 45.0) and used the above technique to calculate an equivalent recipe employing whiting to source the CaO. We fired the two glazes side-by-side on upright tiles and in a flow tester to cone 6 (picture shown below).

You might expect these glazes to fire the same since they have the same chemistry. Not so. The wollastonite version runs much more on the flow tester. This is because the wollastonite melts at a lower temperature than whiting or is more easily dissolved in the melting frit glass. Also, the entrained bubble population is much higher in the whiting version (whiting has an LOI of 45%). Additionally the wollastonite version is a silky pleasant matte, the whiting version is glossy. The former more fluid melt gives the crystals much more freedom to grow during cooling.

In simply looking at the glazed tiles one might easily assume that the transparent glossy whiting version is melting more than the matte wollastonite one, however the opposite is clearly the case. This is a good reminder that ceramic calculations need to be viewed in perspective. They excel in ongoing predictions of how changes to existing material amounts in a recipe will affect fired properties. They are much less reliable as absolute indicators of properties of unknown glazes. Always remember that glazes are made of materials that have a chemistry, mineralogy and physical properties and you cannot ignore any of these.
http://digitalfire.com/4sight/material/wollastonite_1705.html

Molecular Formula of Wollastonite:

Na2O 0.0042	Al2O3 0.0208	SiO2 1.0094
CaO 0.9513	Fe2O3 0.0019	MnO2 0.0002
MgO 0.0445	LOI 0.1466	

Percentage Analysis

50.06 % SiO2
1.75 % Al2O3
0.21 % Na2O
1.48 % MgO
44.05 % CaO
0.25 % Fe2O3
0.01 % MnO
2.18 % L.O.I.

99.99 % TOTAL

Wood Ash

-- flux, has been used in glazes for centuries –
** Variable Material!

Wood ash has been used in glazes since primitive times. When mixed with a clay and feldspar it assists melting and produces the classic variegated and often coveted ash glaze surfaces. Part of the attraction of ash glazes is that each type of ash has a very different chemistry and even ash from the same source is not consistent. People practicing this art thus are always seeking a 'vintage batch'. However many people have managed to control their ash by meticulous attention to consist processing and sourcing.

Ash can be processed wet or dry. In wet processing the often black and non-homogeneous ash is put into water and the unburned carbon material floats and is discarded while the ash itself settles to the bottom. When dried to a powder this material can be quite light in color. However ash is caustic (corrosive to skin and lung tissue). The water used to process it is potentially very caustic. Ash is therefore a hazardous material to work with, so care is needed when handling it. In dry processing the raw ash is simply coaxed through a sieve that catches most of the unburned material and impurities. This form of processing leaves the soluble caustic K_2O and Na_2O components in the ash and therefore it will be a better flux (of course using any soluble materials in a glaze can lead to problems with slurry flocculation or deflocculation). Dry processing is best if you are making your own ash and therefore have control to make sure the burning process is complete.

Many books for potters deal with the subject of preparing and formulating ash glazes. Generally the key to success is to process a large batch of ash and use a minimum of it developing a recipe tuned to it. When the chemistry of the ash is unknown triaxial blending techniques with feldspar and clay are usually best to zero-in on a good mix (some people also mix ash and a low fire red clay). If the chemistry is known then you can compare the ash to target formulas for the temperature you work at and add materials to supply oxides that are absent or deficient (this in turn dilutes the ones that are in excess).

Since it takes a lot of wood to make a little ash it can be challenging to find a consistent source. When an ongoing supply of ash is available you can get an idea of its consistency by asking about their wood supply and the process that creates the ash. Also, it is important that the wood not be too dirty since the dirt does not decompose, its small proportion in relation to the wood can be a large proportion related to the ash.

http://digitalfire.com/4sight/material/wood_ash_2138.html

Equivalent Molecular Weight: 84.100
Molecular Formula of Wood Ash:

K_2O 0.0805	P_2O_5 0.0204	SiO_2 0.0289
Na_2O 0.0197	LOI 1.2	
CaO 0.8122		
MgO 0.0876		

Percentage Analysis

2.06 % SiO_2
9.01 % K_2O
1.45 % Na_2O
4.20 % MgO
54.14 % CaO
3.43 % P_2O_5
25.70 % L.O.I.

99.99 % TOTAL

Comments:
Apple wood ash analysis This is at best a rough approximation for your average ash.

Potential Health Hazards:
caustic-avoid contact with skin or eyes

NOTES:

XX Sagger Clay

-- characteristics between a ball clay and a fire clay, common in wood firing clay bodies, American deposits of saggar clay are smooth, whereas English deposits are very course --
Silica/Alumina ratio: 3.3:1
Equivalent Molecular Weight: 349.520

A fine grained secondary clay which fires to a light cream with 13% shrinkage at cone 10. This ball clay is considered to be very effective in salt firing and it is claimed that it works well in flashing (i.e. wood firing).

http://digitalfire.com/4sight/material/sagger_xx_ball_clay_1211.html

Molecular Formula of XX Sagger Clay:

K20 0.03351900	Al2O3 1.00000000	SiO2 3.29643000
Na2O 0.01676500	Fe2O3 0.01536100	TiO2 0.07437000
CaO 0.03107500	LOI 1.89944300	
MgO 0.02583300		

Percentage Analysis

56.64 % SiO2
29.17 % Al2O3
0.90 % K2O
0.30 % Na2O
0.30 % MgO
0.50 % CaO
0.70 % Fe2O3
1.70 % TiO2
9.79 % L.O.I.
____
100.00 % TOTAL

NOTES:

Yellow Banks #101

-- ball clay, also called #401 --
M.P./°F 2275
Silica/Alumina ratio: 5.4:1
Equivalent Molecular Weight: 517.869

Molecular Formula of Yellow Banks #101:

K20 0.00106152	Al2O3 1.00000000	SiO2 5.42637618
Na2O 0.27523631	Fe2O3 0.15124096	TiO2 0.06121417
CaO 0.08370823	LOI 1.76292777	
MgO 0.14547844		

Percentage Analysis

63.12 % SiO2
19.74 % Al2O3
0.02 % K2O
3.30 % Na2O
1.14 % MgO
0.91 % CaO
4.68 % Fe2O3
0.95 % TiO2
6.15 % L.O.I.
____
100.01 % TOTAL

Comments:
Now called #401
It can be obtained from: United Clays (formerly Yellow Banks Clay Products, Inc.)
Industrial Park, PO Box 29, Huntingburg, Indiana, 47542. Phone (812)683-2179.

NOTES:

Yellow Ochre

-- colorant, can be flux at high temps, source of iron, iron bearing clay --
Silica/Alumina ratio: 5.7:1
Equivalent Molecular Weight: 1660.682

A natural clay material containing yellow iron oxide. Used as a colorant to produce iron tan, yellow and red-brown in slips and glazes.

http://digitalfire.com/4sight/material/yellow_ochre_1714.html

Molecular Formula of Yellow Ochre:

CaO 0.18170000	Al2O3 1.00000000	SiO2 5.65360001
MgO 0.08490000	Fe2O3 6.38030001	MnO2 0.19530000
	LOI 9.42440001	

Percentage Analysis

20.45 % SiO2
6.14 % Al2O3
0.21 % MgO
0.61 % CaO
61.35 % Fe2O3
1.02 % MnO
10.22 % L.O.I.

100.00 % TOTAL

Comments:
Fe2O3•xH2O - approximate analysis as it often contains small amounts of clays and other materials.

NOTES:

Zinc Oxide

-- flux, opacifier, produces smooth surfaces in small amounts as a flux, in percents over 25% it can create crawling in glazes –
Equivalent Molecular Weight: 81.380

Zinc oxide is a fluffy white to yellow white powder a very fine particle size coupled with high surface area. It is made using one of two processes that produce different densities. The French process vaporizes and oxidizes zinc metal, the American process smelts a coal/zinc sulfide mix and oxidizes the zinc fumes.

Ceramic grades normally employ a larger particle size.
It is soluble in strong alkalies and acids.

It can be an active flux in smaller amounts. It generally promotes crystalline effects and matteness/softness in greater amounts. If too much is used the glaze surface can become dry and the heavily crystalline surface can present problems with cutlery marking. Other surface defects like pitting, pinholing, blistering and crawling can also occur (because its fine particle size contributes to glaze shrinkage during drying and it pulls the glaze together during fusion). Calcined zinc oxides are available and apparently produce less glaze surface defect problems. You can calcine zinc on your own in a bisque kiln, fire it at around 815C. Calcining a mix of zinc and kaolin produces a more workable powder. However calcined zinc tends to rehydrate from atmospheric water (and get lumpy in the process).

Zinc oxide is thermally stable on its own to high temperatures, however in glazes it readily dissolves and acts as a flux. Zinc oxide sublimes at 1800C but it reduces to Zn metal in reduction firing and then boils at around 900C (either causing glaze defects or volatilizing into the atmosphere). Note that electric kilns with poor ventilation often have local reduction.

While it might seem that zinc would not be useful in reduction glazes, when zincless and zinc containing glazes are compared it is often clear that there is an effect (e.g. earlier melting). Thus some zinc has either remained or it has acted as a catalyst.

The use of zinc in glazes is limited by its price, its hostility to the development of certain colors and its tendency to make glazes more leachable in acids (although zinc itself is not considered a hazardous substance).

Zinc oxide is used in glass, frits, enamels and ferrites. Zinc oxide is also used in large quantities in the rubber and paint industries; in insulated wire, lubricants, and advanced ceramics.

http://digitalfire.com/4sight/material/zinc_oxide_1718.html

Molecular Formula of Zinc Oxide:
ZnO 1

Percentage Analysis

100.00 % ZnO

100.00 % TOTAL

NOTES:

Zirconium Dioxide

-- opacifier –
Equivalent Molecular Weight: 123.219

Zirconium Dioxide or zirconia (ZrO_2) is a metallic oxide either processed from the mineral Baddeleyite (zirconium oxide) or extracted from zirconium silicate sand. While there is an abundance of raw material (mostly from Australia and South Africa), processes to extract the ZrO_2 are varied and expensive (e.g. fusing, leaching, plasma arc, dissolution and precipitation). Purities range from 75 to >99%. Each process produces zirconias that have their own unique properties. Considerable tonnages of zirconia are used each year (10s of 1000s of tons), far more than hitech materials used for similar purposes.

The form in which zirconia crystals exist changes with temperature (monoclinic to 1170C, tetragonal to 2370C, cubic to melting at 2880C).

In ceramics zirconia is used for a number of things:

-It is employed in stain formulations to stabilize and assist certain colors.
-It is added to non-oxide ceramics as a sintering aid (to help glue the particles together).
-Added to body and glaze formulations to promote hardness.
-Used in crucilbles, nozzles and valves to resist the attack of molten metals.
-Used as an opacifier in glazes and frits (makes transparents white). Opacifying power is similar to zirconium silicate (6-9% for semi-opacity, 10-15% for full opacity).
-Used as a whitener in porcelains.

Zirconia has other interesting uses also:

-Its hardness and resistance to heat make it suitable for use in abrasives, cutting tools and engine parts.
-It is useful as a medical implant material because bone will form a bond with alumina matrixes that have porosity.
-Its ionic conductivity makes it valuable in sensors and fuel cells.

Partially Stabilized Zirconias (PSZ)
are made by adding small amounts of lime, yttrium or magnesia to create a multi-phase matrix (all three crystal types) that has a higher strength.

http://digitalfire.com/4sight/material/zirconium_dioxide_1720.html

Molecular Formula of Zirconium Dioxide:

ZrO_2 1

Percentage Analysis

100.00 % ZrO_2

100.00 % TOTAL

NOTES:

Zircopax

-- one of the most common opacifiers –
Equivalent Molecular Weight: 183.280

Zircopax is a brand name version of zirconium silicate or zircon (see Zircon for more information). Zirconium prices are have increased rapidly in recent years, reflecting the world supply situation.

It is often used for semi-opaqueness (finer materials like Superpax provide more opacity). In North America, the most popular zirconium opacifiers fall under the brand names of Zircopax, Superpax and Excelopax. These vary according to particle size, the finer the size the greater the scattering of light (and thus the better the opacification). In addition, the finer sized materials contain a little extra silica for maximum whiteness.

Of course, the amount of zircopax in a glaze determines the opacity. Small amounts (1-3%) may give no noticeable difference but are sometimes employed to improve glaze hardness. Since zircopax is refractory, the more that is added the more the degree of glaze melting is going to be affected. Up to 15% or more might be needed to fully opacify a glaze. If higher amounts are needed the glaze formulation may need to be adjusted to reduce the amount of SiO_2 or increase flux (to melt the glaze better).

Zircopax affects glaze melt viscosity, surface smoothness, thermal expansion and color development and can be implicated in a range of glazes faults associated with these. Please read the page on zircon for more information.

Zircopax can be used to whiten porcelain bodies, especially for casting, but of course, translucency is lost.

http://digitalfire.com/4sight/material/zircopax_1724.html

Molecular Formula of Zircopax:

SiO_2 1
ZrO_2 1

Percentage Analysis

32.77 % SiO_2
67.23 % ZrO_2

100.00 % TOTAL

Comments:
A coarser opacifier than Superpax or Superpax A. Contains traces of Iron Oxide

NOTES: