COLORANTS AND OPACIFIERS

Listed by commonest usage

Material	Notes	Color 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, blue-greens, 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 (Fe_2O_3 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 form – avoid skin contact)
	Resources: Celadons: see v.27 no.1 (Dec. '98)Studio Potter magazine, Robert Tichane's *Those Celadon Blues,* historic works: *Ice and Blue Clouds*. Cultures famous for celadons: Asian (China, Korea, Japan, Vietnam, Thailand, etc.)		
Copper (Cu): **In slip: 2-8%. In glaze: rarely used above 5%. Excess may give metallic pewter.**			
	Fluxes at low-fire temperatures 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.	copper carbonate ($CuCO_3$ 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 ($CuSO_4$ pale turquoise crystals, soluble, avoid skin contact)

Material	Notes	Color properties	Sources
		+ 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" 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.	
	Resources: **Studio Potter magazine v.8 no.1** . **Clay Times** v.4 # 6 Nov/Dec. '98 Pt 1 and Jan./Feb. '99 v.5 no. 1 pt. 2 article on firing Cu reds by Pete Pinnell, Robert Tichane, *Copper Red Glazes.* Cultures notes for copper reds: Asian ceramics. Alkaline turquoise copper colors: Egyptian and Middle-Eastern ceramics. Colorant in transparent turquoise glazes.		

Cobalt (Co): **In slip .25 - 2%. In glazes .25 - 1%.**

Material	Notes	Color properties	Sources
	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 = purple	cobalt carbonate ($CoCO_3$ lavender raw) cobalt oxide (CoO black raw) May spot unless sieved well. cobalt sulfate ($CoSO_4$ lavender crystals raw) SOLUBLE. Hazardous.
	Cultures known for use of cobalt decoration: Chinese Ming dynasty, various SE Asian ceramic traditions. Colorant in "Emily Purple" high-fire glaze.		

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

Material	Notes	Color properties	Sources
	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 Mn-Al 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.*** (See Hamer on Mn).	+ high alkaline fluxes (K, Na, Li) and low alumina 1-3% MnO_2 = 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 (MnO_2) manganese carbonate ($MnCO_3$).

Material	Notes	Color properties	Sources
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%) = chrome-tin 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 (Cr_2O_3 green raw).Chrome oxide has slight skin contact, inhalation, and ingestion toxicity. iron chromate ($FeCrO_4$ brown-greys) 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 up 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 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% TiO_2 + 50% Gerstley Borate.	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. May give Cr-Sn pinking or halos if the particular batch of rutile has slight Cr impurities. Varies.	granular rutile (produces specking) powdered form, light or dark (less or more Fe) forms. Tan, grey-brown to dark brown raw.
Ilmenite (Fe +Ti)			
	Mineral that contains iron and titanium oxides. 51% FeO• 49% TiO_2. Available in powdered or granular form. Granular form used to make black-brown specks in clay or glazes. Varies in composition.	Colors similar to rutile, but more iron. Granular ilmenite - produces black specking	powdered ilmenite granular ilmenite Black in raw state.

Material	Notes	Color properties	Sources
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 blue-greys. 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-purple	nickel oxide (NiO green raw, Ni_2O_3 black raw) nickel carbonate ($NiCO_3$)
Vanadium (V): In **slip 5-20%** vanadium stain. In **glazes 5-10%** vanadium stain.			
	Expensive. Weak colorant best made into yellow w/Sn or Zr or blue stain w/Zr. Works at all temps. and atmospheres. Stains tend to be refractory.	Warm yellow in commercial stains.	vanadium pentoxide (V_2O_5) commercial stains
Praseodymium (Pr): In **slip 5-20%** Pr stain. In **glazes 5-10%** Pr stain.			
	Fritted with zirconium and silica to make yellow stains that are stable over a wide temperature range (to cone 10) and in oxidation or reduction. Unaffected by glaze composition. Color may be bright, light value yellow toward yellow-greenish. A weak colorant.	Yellow (sometimes toward a cool yellow-green yellow) in commercial stains	Commercial stains
Cadmium (Cd) and Selenium (Se):			
	Poisonous. Used for low-fire reds. Heavy metals w/the toxicity of lead. Fugitive if fired too high (above 010 – 06) or too slowly. Cool rapidly to preserve colors. Weak resistance to food acids. May fume in firing. Not for food ware. New "inclusion" stains have made more stable red and orange stains. Toxic as raw materials. Treat like lead.	Orange and yellow colors Cd colors, w/Se bright reds.	most stable sources in stains. New "inclusion" stains by are a zirconium-encapsulated cadmium and/or selenium that is stabilized. These stains give bright color up to high temperatures. Encapsulation reduces toxicity, but the mfg. do not guarantee food safety. **Do not ball mill** encapsulated stains.
Erbium: **8-10 %** in **glazes**			
	This is a lanthanide rare earth oxide (from Wikipedia.org: The lanthanide (or lanthanoid) series	Transparent pink.	Erbium oxide (Er_2O_3) (pink powder)

Material	Notes	Color properties	Sources
	comprises the 15 elements with atomic numbers 57 through 71, from lanthanum to lutetium. The lanthanide series is named after lanthanum.). Produces pale, translucent pink. Has application in glass coloring, as an amplifier in fiber optics, and in lasers for medical and dental use. The Erbium ion has a very narrow absorption band coloring erbium salts pink. It is used in decorative glassware to neutralize discoloring impurities such as ferric ions and produce a neutral gray shade. David Pier has researched this colorant in glazes and says, "Erbium oxide's density means it is absolutely essential that you use CMC gum. Erbium oxide gives its best pink color at concentrations of 8-10%, but it is difficult to get more than 8% to fully dissolve in the melt. It has given a more lavender color in the presence of iron traces in reduction."		
Uranium (U):			
	Largely unavailable. Used for low-temp. reds, oranges, and yellows (e.g. famous Fiesta Ware "radio-active orange"). Oxidation only.	+ Pb (lead) = yellow, red, or orange + alkaline flux (Na, K, Li) = lemon yellow Fugitive over cone 010.	uranium oxide sodium urinate
Antimony (Sb):			
	Seldom used, except + Pb to make Naples yellow, or w/rutile and Ti for yellow body stain. TOXIC. Used in the brick industry to bleach red clay surface to buff color.	Yellow with lead (Naples yellow) Unstable above cone 2	antimony oxide (Sb_2O_3).

Opacifiers

A base glaze is generally thought of as an un-colored coating of completely melted glass. Depending on the materials and amounts, it may be gloss and transparent. Many satin glazes are a bit frosty due to crystal formation causing the matt surface and also breaking up the light refraction, and refractory matts are often translucent or opaque due to unmelted particles suspended in the glaze. Some glazes, like Chun or Jun glazes, are frosty due to trapped bubbles in the glaze. Use of minerals (like bone ash) that release gas during firing in a viscous glaze melt encourages this frostiness from trapped bubbles.

Adding certain materials to a transparent gloss glaze will make it opaque either through the suspension of intern particles in the glaze (e.g. tin) or by encouraging the formation of crystals (e.g. titanium). 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. Slow cooling promotes crystal growth in glazes.

Particle size influences the amount of opacity from a material: smaller particles produce more opacity. Most commercial opacifiers are available in small particle size. Screening an opaque glaze well to disperse the opacifier thoroughly helps. Some manufacturers of frits melt opacifiers in with commercial frits for better dispersion.

Material	Notes	Color properties	Sources
Tin (Sn): up to 10% in glazes			
	Historic opacifier. Increases surface tension, so high Sn glazes may tend to crawl where thick. An inert opacifier that remains suspended in the glaze. Unaffected by cooling rate. Expensive.	Usually white, very opaque. +5% Sn + small amounts of CrO or Cr fuming = pink. Use of 4% SnO or less + zirconium opacifier will make a dense white w/o Cr-Sn pinking issues.	tin oxide (SnO) chrome-tin pink stains
Zirconium (ZrO_2) : 5-12% in glazes			
	Modern opacifier, often used in the form of zirconium silicate ($ZrSiO_4$). Produces harder glaze than Sn or Ti. Less strong opacity than tin (general rule: 1 Sn = 1.5 Zr opacifier) because it's more soluble in glaze. Produces a more translucent white than tin, and a slightly shinier surface. Acts as both an inert particle suspended in the glaze and a re-crystallized opacifier. Refractory, often used in kiln wash. Low coefficient of expansion: counters crazing. Increases glaze viscosity, surface tension, and > 10% mechanical hardness. Best results in glazes high in Ca and low in boron.	White, opaque	All below are brand names for zirconium opacifiers: Zircopax: all temps., 12-15% = dense white Ultrox: all temps., stronger than Zircopax. 6% = white Superpax: stronger than Zircopax Opax: best at lower temps
Titanium (Ti)			

	Causes re-crystallizion during cooling to produce matts, broken or mottled color. Slow cooling needed for crystal formation. Usually an antique white, yellowish-buff color. Refractory. If using as wash, add flux, e.g. over temmoku to produce a pale golden crystalline surface, test 50% TiO2 + 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)

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