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SECTION 1
Understanding Materials
A Natural Frit

As a crystalline mineral precipitated from molten rock over geologic time, feldspar is definitely not a designer material. Feldspar is sometimes called a natural frit and is composed entirely of crystals, but a commercial frit is made up of a finely ground glass manufactured with a specific composition. More energy is needed to melt crystals than glass, so to give it time to melt, feldspar requires a somewhat slower firing, most often to higher temperatures. While a frit can be manufactured with any desired ratio of flux, alumina, and silica, with feldspar what you mine is what you get. Thus feldspar is a sort of good-news bad-news story.

The good news is that the natural laws controlling how silicon, aluminum, and oxygen link to form the feldspar crystal ensure that the ratio of silica and alumina in pure feldspar is fixed.* More good news is that the flux elements exist in a fixed ratio to the alumina and silica.

Part of the bad news, however, is that nature permits sodium and potassium to occupy that flux amount in infinitely variable proportions to one another. The amount of either in a given feldspar depends entirely on what was handy when the feldspar precipitated from the molten rock in the earth’s crust. Virtually every alkali feldspar deposit on earth has at least some difference in analysis.

In scientific terms, albite and microcline/orthoclase can form a solid solution. That is, an alkali feldspar can theoretically vary from 100% sodium to 100% potassium as its flux constituent. Soda feldspars actually tend to have at least 30% of their flux as potassium, while potash feldspars usually have at least 15% of their flux as sodium.

The rest of the bad news is that feldspar most commonly occurs as a rock, usually along with mica, quartz, and other minerals. In a feldspar mine, the rock is ground to a powder and sophisticated techniques are used to separate the minerals. How well and how consistently mining companies clean and concentrate the feldspar that artists use has virtually nothing to do with artists and focuses on the folks who buy 100-ton rail-car loads of feldspar to make literally millions of tons of glass per year. Quality control good enough to make beer bottles may not be as good as we would like in the studio, but who is ultimately the bigger end user of feldspar—studio artists or folks molding beer bottles? Feldspar is ultimately an industrial mineral and we have to accept that its quality is controlled by what’s good enough for industry.
* (Note the difference in the ratio of silica and alumina between feldspars, spodumene, and nepheline syenite. There is less silica in the latter two. The crystal structure explains this. This also explains the differences between potash feldspars to nepheline syenite and spodumene.)

**Making Adjustments in the Glaze Lab**

Commercial frits have generally consistent analyses. Naturally occurring feldspars are less consistent and subject to change over time. While all raw materials should be tested before use, this needs to be a requirement before using each new batch of feldspar in the studio.

When feldspar is added to a clay body, it helps to melt very fine quartz into a glass phase that provides strength in the fired body. The amount of feldspar needed in a stoneware body depends entirely upon the flux level of the clays composing the body. For a fixed recipe of clays, various amounts of feldspar are tested to achieve a body with the desired level of vitrification from a given firing cycle.

The difference in silica content between Custer and G-200HP feldspars (see graph on previous page) is enough to change glaze fit. While these two potash feldspars can generally be substituted one-for-one, if one wants precise control of glaze chemistry, then a more accurate substitute for Custer is G-200HP plus 3% silica. When an existing feldspar disappears or a new one enters the market, some substitution such as this is likely to be necessary to achieve consistent results.

Time is also a factor. The landscape varies and as industry excavates from one mine to another the composition of feldspar changes along with it. The feldspar you were using five or ten years ago is most likely not exactly the same as what you are using today, even if it is the same brand name. Fusion button tests of the new and old material will guide you in whether and how to substitute other materials to accommodate the new feldspar’s chemistry. To start:

1. Get a full chemical analysis of the new and old feldspars, if they are available.
2. Fire fusion buttons (a few grams of feldspar pressed into a small mold such as a crucible) of both materials side by side to get a visual indication of the differences in the two materials. Note color changes, melting temperatures, opacity, and surface effects.
3. Adjust recipes as these differences indicate and fire recipe tests to confirm that the adjustments are correct.

Some ceramic artists use chemistry to adjust clay and glaze recipes before testing. Others rely entirely on testing. The method chosen may say something about an artist’s working style, but not the results, both methods work equally well.
Lifespan of Feldspars

Bernard Leach used Varcoe feldspar in a clay body recipe he published in *A Potter's Book* in 1940. Have you ever heard of that feldspar? Not likely. Varcoe and Sons was sold to English China Clays, Ltd., and Leach's feldspar disappeared from the market.


Currently there are five common feldspars available in the US: G-200 HP (“HP” for high potassium), Custer, Minspar 200, Nepheline Syenite, and Talison Spodumene (formerly Gwalia). The relatively subtle differences in their chemical compositions are shown on page 3.
SECTION 2
Studio Application
CHAPTER 1

In the Studio: Practical Physics

Mesh Size
by John Britt

Defining the Terms

**Mesh Size**—A count of the number of strands per inch in a screen that is used to grade the particle size of the material. Theoretically, in a 100-mesh material sample, approximately 95% of the particles should pass through a 100-mesh sieve (this means that 1–5% of the particles will remain in the pan). A larger mesh-size number indicates smaller particles so 100-mesh particles are larger than 200-mesh particles. In ceramics, mesh sizes generally range from 25 to 325 mesh, smaller particles are referred to in microns.

**Micron**—A unit of length one-millionth of a meter or one twenty-five thousandth of an inch.

**Particle Size**—Also called grain size. It is relevant in terms of how long the particle will take to dissolve in a glaze melt and also in terms of plasticity, shrinkage, and strength of a clay body.

**Sieve**—A device with a screen or mesh bottom used to separate out coarse or unwanted particles. Most glazes are sieved twice through an 80-mesh sieve. Can be done dry or wet.

Potters often buy whatever selection of materials suppliers provide without thinking about the consequences or even the potential artistic possibilities. Using the correct particle size and distribution for the job you are doing requires some basic knowledge of material properties followed by some creative experimenting.

Size Matters

Size, on many levels, makes a big difference in both clay bodies and glazes. For example, if you have a glaze recipe that calls for 30% silica and you used 325-mesh silica, it would create a smooth and glossy glaze, but if you used silica sand (40 mesh), you would have a rough and crusty glaze.

Mesh sizing originally referred to the number of threads per linear inch of mesh, which presumed the same number of holes. Of course, thread size caused variance so uniform international standards measured in micrometers have been adopted. So a 100-mesh sieve has 100 square holes per inch which measure 0.152 mm (or 152 microns). Theoretically, in a 100-mesh sample, 95% of the particles should pass through a 100-mesh sieve. A higher mesh size number indicates smaller particles so 100-mesh particles are larger than 200-mesh particles. If you continue to add more and more threads to a sieve, eventually you will clog all the holes. So anything beyond 325–500 mesh is usually described in microns.

Because the sieve hole is a square, the size of the diagonal is larger than the width and length. Larger particles can make it through the diagonal and that is why you often sieve several times.

Describing a material as 100 mesh is not very precise as you don’t know the size of the 95% of particles that passed through the sieve. A more precise notation has been established which uses -/+ signs. So a particle that is “-80/+100” means that 95% of the particles passed through(-) the 80 mesh sieve but were retained(+) by the 100-mesh sieve. In ceramics, grogs are often listed more precisely as 12–48, (or -12/+48) which shows the range of particle size.

Today, because our grinding technology is vastly improved, the particle size (expressed as mesh size) is much different than it was just 50 years ago. For example, 50 years ago the standard silica for glazes was 200 mesh, which meant that 95% of the particles passed through a 200-mesh sieve. We do not know exactly how fine 95% of the particles were, we just know that they passed through the 200-mesh sieve. But now that same 200-mesh silica is much finer because our grinding ability is so much better. So the 95% of the particles that passed through the sieve are much finer and that affects the melting of those particles. Using 200-mesh silica now may be closer to using 325 mesh back in the day. Knowing the particle distribution may help and is generally available from many suppliers. For example, Minspar 200 lists that 87% of particles are finer than 30 microns; 72% are finer than 20 microns; 40% are finer than 10 microns; and 19% smaller
than 5 microns. The graph below shows the variation in particle size of a sample of Minspar 200, ranging from 100 microns to less than 1.0 micron, with the vast majority between 3 and 50 microns.

Clay Bodies
Although clays are described as 200 mesh, many are actually much finer than 325 mesh (40 microns). For example, in a 200-mesh sample of EPK, approximately 55-65% of kaolin particles are less than 2 microns, while approximately 81% of ball clay particles are less than 2 microns and many can be as low as 0.1 microns or 400 times smaller than 325 mesh.

Porcelain bodies are often difficult to throw because the particles (kaolin, feldspar, and silica) in the body are all approximately 200 mesh or less, making it a homogenous clay body. Stoneware bodies, however, are a mix of various clays and particle sizes. They contain fire clays, which are 25–50 mesh; ball clays, which are 200 mesh; and then grogs, which can be 12–80 mesh.

Grog is often added to sculptural bodies to give them strength and reduce shrinkage. Val Cushing lists a proportion of: 12% fine grog, 3% medium grog, and 15% coarse grog, for a total of 30%. This is how you can produce non-shrinking sculptural clay bodies. In a plastic clay body this proportion of mixed mesh-size grog helps fill all the voids and avoids micro-cracking around larger particles.

Grog is often listed by the largest particle size, for example 30 mesh. This tells you the size of the largest particle but not the smallest. Some grogs are listed as 30–80 mesh, meaning that the largest particles are 30 mesh and the smallest are 80 mesh.

Glazes
Melting particles in glazes can be compared to dissolving sugar in tea. The particle size of the sugar makes a big difference in the amount of sugar that will dissolve into the tea and thus how sweet it is. For example, two sugar cubes will not dissolve as easily as the same weight of crystallized sugar and certainly won’t dissolve as easily as
Materials and Glazes

the same weight of powdered sugar. This is because there is more surface area per weight in the fine particles and they enter the melt easier. In glazes, the same principle applies; 325-mesh silica will go into the melt easier than the same amount of 200-mesh silica.

Mesh size can be related to other properties, like solubility. For example, nepheline syenite has two grinds available to potters, 270 mesh and 400 mesh. Theoretically the 400 mesh would go into the glaze melt better than the 270 mesh. But because it is slightly soluble, using the finer 400 mesh (more surface area) will also cause the glaze slurry to deflocculate quicker and the glaze will settle out and hard pan more easily. So there's a trade off.

The mesh sizes in some materials are kept large to create specific effects, like granular ilmenite or granular rutile. These create intentional speckles used in glazes like Jackie’s Speckled Lavender. Other materials, like silicon carbide, are specific sizes to encourage cratering in glazes. Some sculptural low-fire glazes may specify sand in the glaze to add texture. In the case of Bleeding Cake, the sand is used to get a surface that looks like Red Velvet Cake.

Colorants

Mesh size can make a big difference with colorants. For example, when making a blue celadon, if you use 100-mesh black iron oxide (an old-school way of mixing blue celadon with a coarse grind) you might get speckling. This can be corrected by ball milling the colorant in a small amount of the glaze for several hours then adding it to the whole batch. But by simply changing the colorant to synthetic red iron oxide (a very fine type of iron at 325 mesh) which goes into the melt more easily without ball milling, you get no speckling.

Routinely putting glazes through a ball mill (approximately 2 hours) is also a good way to smooth out a glaze batch by slightly grinding the particles, but grinding glazes for too long (beyond 4 hours) will reduce the particle/mesh size too much and cause the glazes to crawl. The most efficient grinding is when there is just enough material in the ball mill to fill all the voids and just cover the grinding media. If ball milled too long, the small particles in the glaze will shrink excessively when they melt and cause crawling. Ball milling is usually done wet with glazes but can be done dry.
SECTION 3
Recipes, Research, and Techniques
Defining the Terms

Aromatic Compounds: Organic hydrocarbon chemicals, so called because many have a sweet smell, evaporate rapidly, and contain benzene rings. Typical aromatic compounds are benzene and toluene.

Luster: Extremely thin films of metals fired onto the surface of ware. The effect is due to the interference of incident and reflected light. Precious metal preparations and resinate lusters, in their unfired state, are complex mixtures of up to 40 components with different chemical and toxicological properties. Their toxic and ecological effects vary from product to product.

Noble Metals: As distinct from base metals, these metals do not corrode or oxidize in the presence of moist air or most acids. Most are precious due to their rarity in the earth’s crust, and include gold, platinum, palladium, iridium, and silver.

Organic Compound: Any of a large class of chemical compounds in which one or more atoms of carbon are covalently bonded to atoms of other elements, most commonly hydrogen, oxygen, or nitrogen.

Solution: A homogeneous mixture of two or more substances, which may be solids, liquids, gases, or a combination of all.

Suspensions: A heterogeneous mixture of a fluid containing solid particles large enough that they will settle out if left long enough without agitation.

Resinate: A salt of a resin acid (terpenoid acids produced by conifers).

Polymer: A polymer is a chemical compound or mixture of compounds consisting of repeating structural units created through a process of polymerization.

Bismuth oxide: An amphoteric oxide that acts as a flux in ceramic fusions. It is usually introduced in small amounts as a modifier of colorings and is a low-melting-point metal. The nitrate form dissolved in resin and oil deposits a mother-of-pearl luster on glazed ware and is also used as a carrier for other luster colors. The organic materials burn out at 1292°F–1472°F (700°C–800°C), below the melting point of the metal.

Lusters have been described as transmitting the same effect as the light reflected from a thin layer of oil on water. This diffraction of light is produced via the deposition of a very thin film of metal on a ceramic surface—be it glass, earthenware, or porcelain. Knowing what these materials are and how they behave is the key to making them work.

Reduced Lusters vs. Resinate Lusters

Lusters were first in evidence on glass in Egypt in the 4th century. By the 9th century, luster was being used on ceramics. Reduced luster—also known as pigment luster, smoked luster, Arabian or Persian luster—was first used in Iraq in the 9th century. A pigment, based on an iron-bearing clay and containing copper or silver, is brushed onto a fired glaze surface and then refired in a reducing atmosphere. After firing the pigment/clay paste is washed off, leaving behind a thin film of metal, which we call luster. The interactions between the clay paste/pigment, temperature, length of reduction, and base glaze are all important. Most notably the base glaze has to accept and develop the luster from the pigment. The glaze can be either lead- or alkaline-based frits that are non-toxic and non-soluble. They are typically low-temperature glazes as the glaze needs to soften between 1112–1292 °F (600–700 °C) in order to bond with the thin film of metal deposited. Other sources of metallic deposition are possible with luster glazes, resinate lusters, and fuming. The widespread use of electric kilns, together with the increasing interest in and use of overglaze techniques necessitates a focus on resinate lusters.

Resinate lusters are made up of solutions and suspensions of metallic resinate combined with solutions of polymers and thickening agents to aid application by brush and machine. The colors result from metallic oxide films bonded onto the glazed surface by a flux, specifically bismuth oxide, which must be fired to a low temperature otherwise it would burn out. This is the same luster film as produced by reduced luster—the main difference being
the method of application and firing technique employed. Whereas reduced lusters are either clay paste or water based and fired in a reducing atmosphere, resinate lusters are oil/resin based and are fired in an oxidizing atmosphere. The localized reduction is performed by the carbon produced from the resin (usually pine oil) base. Resinate lusters are a product of the ceramic industry, developed as glaze application and controlled firings were standardized for mass production. Resinate lusters are also known as oxidation or commercial lusters.

Lusters, then, can be redefined as precious-metal-based organic compounds dissolved in a solvent base and combined with resins. Gold and platinum lusters consist of precious-metal-containing organic compounds combined with other organo-metallic fluxes and resins.

**Working with Resinate Luster**

Luster takes on the surface qualities of the ware that it is applied to. On surfaces with gloss glazes, luster will be shiny, on matte glazes it will be satin matte, and on
vitrified bisque it will be very matte. As the luster bonds at the softening temperatures of the substrata, there is a wide firing range, which encompasses glass, earthenware, bone China, stoneware, and hard and soft porcelain (this refers to the glaze types used). Lusters can be fired from 1202°F (650°C) for glass through to 1562°F (850°C) for hard-glazed porcelains.

Luster is oil based so that it will adhere to a glossy surface. However, the surface has to be scrupulously clean. Any grease, sweat, and oils from the skin, or lint or dust will repel the adhesion of the luster. The two most common methods used for cleaning the surface of the ware are wiping the surface with an alcohol impregnated cloth or using detergent and very hot water until the water sheets off the pot. It is then dried with a lint free cloth and no further skin contact with the pot is permitted.

Application
When applied, all lusters appear brown and lacquer-like, with their color achieved in the firing process. In order to visualize the end result while working, a permanent color chart can be made for each glaze typically used (1). This is simply a test tile with luster brush strokes applied and labelled, that is fired, then the tile is turned 90 degrees, the brush strokes are repeated, and the tile is fired again. This provides a readout of one and two layers of luster plus many variations of colors when luster is applied over luster. Different color glazes will also influence the luster colors due to their transparent nature.

Lusters can be applied by brush, sponge, and stamping. Some people advocate airbrushing for certain effects, but I do not recommended this as lusters are based on organic solvents. German squirrel hair flat shaders, mainly No. 10 (the old ¾ inch size) are used for brush application. Broad areas of luster are achieved by laying down the luster in long quick strokes, taking care not to overlap drying areas as otherwise these would be more intense in color. If a very even surface is required, the brushed-on luster can be lightly padded or pounced with a small sponge or cotton ball wrapped in a square of silk held tight with a rubber band. This will even out the brush strokes but will also lighten the luster considerably as excess luster is pulled off. Multiple layers of luster, fired between each layer, can be used to intensify color responses.

Other methods of application are pen work, flow technique, and dipping (2). The batik pen (commonly known as the Tjanting) is used solely for resist. The flow technique is achieved by putting a quantity of luster thinners on the surface and quickly adding drops of luster before manipulat-

Luster and resist applicators from top to bottom: ¼-inch German squirrel hair flat shader; ¾-inch, No. 10 German squirrel hair flat shader; Tjanting (batik pen) used for resist detail; Kemper Gold pen/fluid pen used for pen work/writing with luster and gold.

ing the flow of the luster by positioning/angling the work, causing the luster to flow. A number of resists can be used for specific effects (see below). Other abstract surface effects can be achieved with random application of salt, dispersing agent, glass cleaners, mineral spirits, alcohol, as well as marbleizing fluid. Partial removal with crumpled plastic kitchen wrap, rubber stamps etc. can produce different textures.

Brush Care
Keep luster brushes for luster use only, as other mediums will contaminate the brushes. To clean brushes, put a small amount of luster essence or citrus solvent into two small glass jars, and fill one jar with a small amount of methylated spirits (denatured alcohol). Swish the brush in the first bottle, blot it on a tissue, then swish it in the second bottle of luster essence, and blot it again. Swish it in the methylated spirits jar and blot it once again. Finally work a detergent into the bristles and rinse the brush exceedingly well under warm running water. Blot it on a tissue and dry it flat.

Working with Resist
My preferred method of working is with resist so as to limit my exposure to luster. I spend a lot of time being precise with the resist, so that 90% of my time is spent in applying inert resist and only 10% in actually applying the luster. This reduces my exposure to the organic solvents in the luster.
Most resists, apart from waxes, will work as luster resist. Latex, white poster paint, adhesive tapes, masking lacquers, stickers, white-out pens, and proprietary luster resists can all be used. I prefer to use Fay Good’s black luster resist as this resist can survive several firings without having to be cleaned off and reapplied.

I sketch my drawing onto the glazed surface with a non-permanent, black overhead-projection pen. I then go over this, adding detail with a Tjanting filled with the black luster resist that I have adjusted to flow through the tip. After the resist dries, I apply an even layer of luster in the areas required just the same as for any other painting technique. I then fire to 1472°F (800°C) in approximately 5 hours. I don’t subscribe to the fast firing techniques because glaze softening takes time as well as temperature.

After the first firing, I continue adding layers of luster to deepen the color, firing between each layer. I add further resist to help the layering effect that I am after. After the final luster layering, I will either add pen work with a gold pen, or use raised enamel for accent. I remove the resist by gently cleaning the surface with liquid dish soap. Do not use any abrasive cleaners as they will scratch the surface.

Toxicity and Safety

Finding out precisely which of the solvents have been utilized is not easily done, as there is a degree of secrecy within the industry. There are no safe organic solvents. These toxic substances are unstable, poisonous compounds and these toxins can enter the body through skin absorption, ingestion, and inhalation. Though some of the materials that produce these toxins are essential to the creation of ceramics, it is not necessary to stop working with them to remain healthy. However it does mean that a raised awareness and new work habits are essential. So it is best to assume the worst-case scenario. This must take into account the health risks associated with a high concentration of noxious fumes, their flammable nature as well as being irritants to eyes, skin, and respiratory tract. The noxious fumes are present during both application and firing.

Proper ventilation and safe work practices will prevent the inhalation of fumes. Be sure to use either dilution, local, and/or personal ventilation while working with resinate luster. Immediately remove any luster from the skin with methylated spirits or other alcohol and then wash the area with soap and water. Do not bite fingernails, put brushes into your mouth, eat, drink, or smoke while working with lusters. Do not bring food or drink into the decorating workplace. Noxious fumes are present in the firing of lusters as the media burns out. Do not enter a kiln shed/area/room without a respirator while firing lusters—this can be very damaging to the lungs. Under no circumstances should a kiln used to fire lusters be placed inside a dwelling.

Lusters contain all or some of the following toxics in varying proportions (formulas vary per color): Turpentine, O-dichlorobenzene, cyclohexanol, cyclohexanone, methyl cyclohexanol, di-iso-octylphthalate, camphor, white spirit, xylene, tetrahydrophthalene, isophorone, tetrahydrofururyl alcohol. Classifications for solvents used in commercial luster production: Aromatic hydrocarbons, hydrocarbons with a low content of aromates, hydrotreated aromatic hydrocarbons (tetraline), alcohols and ketones (propanoles, butanoles, butanones, and diacetone alcohol), terpenes (turpentine oil and etheric oils).

For a comprehensive account of Johanna DeMaine’s approach to health and safety, read the article in conjunction with “Health and Safety and Overglaze” available at http://overglaze.info. Additional information, bibliography, and recommended reading at http://johanna.demaine.org.
SECTION 4
Troubleshooting
It's All About the Gas

Blistering is a glaze problem that occurs when a low-viscosity glaze traps a gas within it. Glaze blisters always have these two components. First, some sort of gas is trapped within the melted glaze. Second, the glaze is “thin,” meaning it’s been heated to the point that its consistency is watery rather than viscous.

Obviously a glass, which is a liquid, must first form. Then gases trapped within that glass expand due to the rising temperature in the kiln.

A very thick, viscous glaze may contain many bubbles of gas, but the viscosity of the glaze—it’s resistance to flow—will limit the expansion of the gas bubble. However, if the glaze is thin and watery, the bubble can expand greatly, in the process thinning the glass covering it.

Glaze chemistry is a factor in blister formation because glaze chemistry controls glaze melting point as well as glaze viscosity. Obviously, the timing of melting matters. Low melting point glazes in mid- to high-fire applications are most likely to blister. That’s because the later in the firing a glaze melts, the greater the odds are that problematic gases will have escaped being trapped in the glaze.

Before considering the glaze, it’s critical to understand what is meant by gas. To begin with, the term gas is general rather than specific.

The gas trapped by a melting glaze may be any form of vapor:
• It can be air that was caught against the clay body as the glaze was applied over it.
• It can be oxygen given off by thermal decomposition of a glaze ingredient such as iron oxide.
• It can be a molecule of carbon dioxide given off, also by thermal decomposition, of a carbonate such as whiting.
• In the case of extremely low-melting-point glazes, it can even be water vapor given up by decomposition of clay body or glaze ingredients.

Short of firing in full vacuum with ingredients that do not off-gas upon heating, it is impossible to totally prevent gases from being trapped within a glaze. In that case, what’s to be done? Ultimately, the answer is to change the glaze so it remains viscous enough that it does not blister, even though many gas bubbles may be trapped within it. Naturally it’s also advisable to attempt to reduce the amount of gases trapped in the glaze.

The first step in modifying glaze viscosity usually involves the addition of kaolin or ball clay to the glaze recipe. Both are mainly kaolinite, a mineral made of equal parts of alumina and silica. Since most glaze recipes have between 3 to 15 or more times as much silica as alumina, adding clay quickly raises the proportion of alumina in the glaze.

This is important because alumina makes a glaze viscous. However, adding too much clay, (hence too much alumina), can produce a glaze that is refractory; in other words, one...
that will not melt. Reasonably viscous glossy glazes typically have between 5–15 times as many moles of silica as alumina. An alternative is to reduce the quantity of glass formers and fluxes in a glaze recipe while leaving the alumina the same. Recall that boron is a glass former, as is silica, but boron melts at a lower temperature. If blistering is a glaze problem, boron should be used sparingly at higher glaze firing temperatures.

Choosing the Right Materials
It should go without saying that the traditional methods of minimizing bubble formation in glazes may help minimize glaze blisters. In particular, wetting the surface of work to be glazed prior to application of water-based glazes will help reduce air trapped between glaze and body. Likewise, use of a surfactant or wetting agent such as soap in the glaze slurry helps reduce air bubbles trapped under the applied glaze.

Use of frits as the source of glaze fluxes may help to prevent blistering of glazes that melt at low temperatures. This is because frits contain no carbonates that can decompose upon heating to release carbon dioxide gas. Obviously, this gas can become trapped within a glaze if the melting temperature of the glaze is lower than the decomposition temperature of the carbonate present.

However, frits can still trap gases from other sources. Use of frits in a glaze recipe is no guarantee of blister-free firings. Testing is still necessary to determine whether frits reduce or eliminate glaze blisters from a given recipe. Some argument is made that overfiring is the cause of blistering. Certainly, blisters would not appear if the ware had been fired to a peak temperature low enough that the glaze would have remained viscous. However, firing temperature alone is not the root cause of blistering. A high firing temperature simply reveals the glaze’s susceptibility to this fault.

A truly overfired glaze, if from a well-formulated recipe, will flow uniformly—even flow off the pot—but without

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**LOI Isn’t Important? Think Again!**
The LOI (loss on ignition) of many common studio materials can affect your glazes, possibly even causing blisters. When choosing materials for your glazes, it’s helpful to know when they are gassing and when they are melting in order to prevent or correct blistering. Note that some late gassers overlap early melters.

What’s happening in the kiln:
- **1400°F**: Frit begins melting. This happens well before calcium carbonate and dolomite finish gassing and before talc starts to gas. Gerstley borate stops gassing.
- **1500°F**: The calcium carbonate and talc have stopped gassing before the Gerstley borate melts.
- **1550°F**: Gerstley borate suddenly starts to shrink.
- **1600°F**: Gerstley borate is bonded to the ceramic.
- **1600–1650°F**: The talc is going through the final stages of gassing as Gerstley borate is suddenly melting.
- **1650°F**: Gerstley borate bubbles a lot then totally melts.
- **1700°F**: Gerstley borate is a transparent glass. Frit 3124 is still slowly softening but still not bonding to the tile. (Ferro frit 3110, 3195, and 3134 all melt sooner than Ferro frit 3124).


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- Magnesium Carbonate
- Gerstley Borate
- Dolomite
- Whiting
- Talc
- Ferro Frit 3124
blisters. Blisters reveal a glaze that is not viscous enough at peak firing temperature.

Soaking the kiln at peak temperature for 15 minutes or more may reduce glaze blisters by providing time for the largest of them to burst and for glaze to subsequently flow into the crater left behind. Please do not ask how I know this is not a perfect cure for the problem.

If there is one piece of information that should be available with every glaze recipe, that would be the temperature at which the glaze melts. Draw trials—that, with care, can be safely removed from a fuel-fired kiln—will provide such information.

Draw trials, however, cannot be taken safely from electric kilns, so a small electric test kiln is the best alternative. Shutting the test kiln off at different temperatures to remove and examine glaze tiles will permit determining the melting temperature of a glaze.

Armed with that information, it is possible to consider which glaze ingredients may contribute to blister formation.

There are three potential causes of bloating: over firing, “dirty” firing (reducing atmosphere in the early stages of firing), and poor clay mixing. Their cures are very different. Fortunately, they are easy to tell apart.

**Fault: Over Firing**
Overfiring is the easiest cause of bloating to recognize. Keep in mind that all ceramic bodies are intended to be formed at room temperature and then fired to durability while retaining that shape. However, if the firing is too hot, known as overfiring, the shape will be lost as the body just starts to melt.

**Fault: Dirty Firing**
Clays usually contain some organic materials which will burn in the presence of enough heat and oxygen. Some clays contain small to significant amounts of tiny crystals of pyrite, an iron sulfide. The sulfur in pyrite burns readily at moderate kiln temperatures and in a properly fired kiln has burned off by about 1300°F (700°C).

However, if the kiln is starved for air (unlikely in a well-ventilated electric kiln or a carefully tended fuel-fired kiln) the sulfur, as well as organic materials, can still be present. If oxygen gets into the kiln later in the firing, when the clay body is soft due to nearing its peak firing temperature, large volumes of gas will be generated by the combustion of the sulfur and organics and that will cause gas bloating in the ware.

**Fault: Clay Mixing**
When firing is clean and fully oxidizing until organics and sulfur are burned off, but bloating is observed, then the fault is not with the firing, but rather with inconsistencies in the clay body mixing. The fault is that flux in the clay body is concentrated in clusters, rather than being distributed uniformly throughout the body.

As any clay body approaches peak firing temperature, two features are always present in the work. There is a liquid glass phase formed from flux elements in the body melting the glass former present. There are also small bubbles of kiln gas left over as the body shrinks and becomes dense from the firing.

The glass phase, being a liquid, has almost no strength. At this point in the firing, the strength to keep the ceramic shape is supplied by the clay, quartz, and other more refractory materials in the body.
One of the primary efforts of Ceramics Monthly magazine, from the very beginning in 1953 to the present, has been to illustrate and explain the technical aspects of ceramic art so that an individual in a studio has a high chance for success. Any good ceramic-art library needs to include Ceramics Monthly, and the technical-reference shelf in that library now needs to include this book.

Compiled from years worth of technical explanation and reference material from the magazine, Ceramics Monthly’s Guide to Materials and Glazes will help you interpret results in your own studio, assess recipes from others for possible use, and pursue new ideas with knowledge and confidence.

Testing, exploration, and experimentation are at the core of artistic discovery, and this volume is a resource for understanding common ceramic materials and their characteristics. Full of practical, applicable information you can put to use every day in your studio, it will help you bring your own ideas from inspiration to reality!