# gemstones & glazes

by Ryan Coppage, PhD

Gemstones give us inspiration for glaze design: from green emeralds and red rubies, to blue aquamarines and golden beryls, we unintentionally emulate these gemstones in our glaze formulations. Knowing this, we can begin to design glazes to reflect the faceted gem specimens we see in museums.

## Defining the Terms

***Beryl:*** A beryllium aluminum silicate gemstone base that allows for golden, blue, red, pink, and green semi-precious gems.

***Corundum:*** A crystalline form of alumina, $Al_2O_3$, that is best known in the form of both rubies and sapphires.

***Crystal Field Theory:*** A theoretical model that describes the splitting of d orbitals by anion neighbors in a coordination environment around a transition metal, absorption of light as a function of those energy differences, and the presence of transmitted or reflected wavelengths of light that are not absorbed by the metal center.

***d-Orbital Splitting:*** When transition metal atoms are surrounded by a material, which inadvertently splits the energy levels of the orbitals.

***Oxidation States of Metals (Upper, Lower, Intermediate):*** The charge of the metal colorant, which is effectively the atomic number of the metal (protons) minus the number of electrons; thus, if a metal is missing 2 electrons, it will have a charge of +2. This charge dictates the color and can be controlled (and changed) by the firing environment. Iron appears blue in small quantities (or black, in large ones) with a +2 oxidation state (reduction firing) and amber/red/brown with a +3 oxidation state (oxidation firing).

**2** Heliodor and aquamarine, left, and Gold Beryl glaze (top right) and Babu Celadon glaze (bottom right).

## Gemstone Color

Typically, a gemstone family possesses a base formula—just as a glaze has a base formula. The base formula is clear or milky without metal impurities to provide it with color. A perfect example of this is beryl, beryllium aluminum cyclosilicate, with the repeat formula $Be_3Al_2(SiO_3)_6$. Additionally, another common and ideal example is corundum, a crystalline form of aluminum oxide with the repeat unit $Al_2O_3$. These are bare, clear gemstones in their raw form. In order for them to possess color—the variety of colors that we are timelessly drawn to—they must have a small metal impurity, which controls the color and intensity of color in the gemstone.

**1** Aquamarine (beryl), which is light blue due to $Fe^{2+}$ impurities.

When a small impurity of metal is present in one of these gemstone bases, like beryl (1), it is suspended in the glaze matrix and is surrounded by those repeat formulas. The electronegativity and structure of the gemstone base around each metal center interact with the d-orbital electrons of the metal, causing the energy levels to separate and split via crystal field theory. This difference in energy levels can then allow for absorption of light—absorption in the visible spectrum, wherein we see all of the light that is not absorbed after it reflects back, resulting in reflected color.

Crystal field theory has long been studied and used to explain gemstone color—specifically to characterize how rubies and emeralds both have chromium impurities, but are so contrasting in appearance. Therein, glazes work effectively the same way as gemstones and allow for inspiration from natural mineral colors, such that we can recreate vibrant color profiles on our ceramic surfaces.

## Beryl, Color, and Glazes

As far as gemstones are concerned, Beryl exists as a nearly perfect glaze base. When beryl has an iron impurity, it possesses either a gold color as heliodor or a soft blue as aquamarine (2). Interestingly, the only difference in color is the charge of the iron. It is $Fe^{2+}$ for blue aquamarine and $Fe^{3+}$ for the gold/amber colored heliodor. By using a clear base with a small iron impurity in both oxidation and reduction atmospheres, heliodor and aquamarine gemstones can be emulated in glaze form (like Gold Beryl glaze or Babu Celadon glaze, respectively), purely dependent on firing conditions. Using 2% red iron oxide in a cone 6 oxidation firing produces the $Fe^{3+}$ heliodor amber celadon color and using 2% yellow iron oxide through a reduction firing yields the $Fe^{2+}$ blue celadon colors.

For the rock hounds out there, manganese is notorious for producing pinks and raspberry colors in morganite and red emerald, though the effect is incredibly rare. Normally, manganese dioxide is a component of brown/black slips, but it is used in somewhat higher weight percentages. While red emerald is very difficult to reproduce in a glaze (volunteers??), morganite can be recreated in a glaze by adding 0.5–1.0% manganese dioxide to Fa's Crystalline Base glaze and firing to cone 6 (3). Notably, when adding more than 2% manganese dioxide, the color shifted more mauve, transitioning to a soft brown with a pink tint. Only at these very small concentrations was a soft pink visible. Additionally, note that the crystalline base runs, but also forms small pink crystals, which can be grown or further developed with more complicated firing schedules.

**3** Morganite, left, and Fa's Crystalline Base glaze plus manganese dioxide, right.

## Emeralds and Rubies

The most notable gemstone in the beryl family is the famous emerald, for which movies have been made, plenty of jewelry fabricated, and millions of dollars spent—all for some chromium impurity in a chunk of beryl. Because of the nature of beryl, chromium impurities produce a very vibrant emerald green color (4). The chromium oxide is green, and in a regular glaze base, chromium produces an emerald green at 0.2% content. When that same chromium impurity is present in corundum (crystalline alumina), a vibrant red is produced that we all associate with rubies (4). The difference here is the environment around the chromium, how the gemstone environment interacts with the d-orbitals of the chromium, and how much the energy levels split and affect light absorption.

The same series of colors can be replicated in a non-alkaline, highly fluid glaze base. At 0.15% chromium oxide and no tin oxide, a very literal emerald green can be produced. Upon the addition of both chromium oxide and 5–6% tin oxide to that same base, we have changed the crystal field of the glaze base to more closely resemble that of corundum, resulting in a vibrant ruby red.

**4** Emerald and ruby, left, and the corresponding Emerald/Ruby glaze with chromium oxide (top right) and chromium oxide with 6% tin oxide (bottom right). **Note:** All of the color sample yunomi were made with Laguna cone 6 Frost porcelain. *All images of gemstones samples: Courtesy of the Lora Robins Gallery of Design from Nature.*

## Limitations

Ultimately, not all gemstones can be reproduced as glazes. We are limited to the upper and lower oxidation states of metals for oxidation and reduction firing conditions. Intermediate oxidation states are more difficult and would require an uncanny degree of precision. My personal inspiration comes from trips to the natural gemstone exhibit at the Smithsonian National Museum of Natural History in Washington, DC. The most vibrant gemstones are those containing antimony, arsenic, and even lead/manganese that are on display at the Smithsonian Mineral Gallery. If only they weren't toxic!

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**EMERALD/RUBY**

Cone 6 Oxidation

| | |
|---|---|
| Gerstley Borate | 21.0 % |
| Whiting | 20.0 |
| Nepheline Syenite | 16.0 |
| EPK Kaolin | 11.0 |
| Silica | 32.0 |
| | 100.0 % |
| Add: Chromium Oxide | 0.2 % |
| For Red: | |
| Add: Tin Oxide | 6.0 % |

This is a fluid glaze that runs if thick, but does not craze. Note that chromium reds do not form in extremely thick/alkaline glaze bases.

**FA'S CRYSTALLINE BASE**

Cone 6 Oxidation

| | |
|---|---|
| Spodumene | 4 % |
| Talc | 4 |
| Zinc Oxide | 27 |
| Ferro Frit 3110 | 50 |
| Silica | 15 |
| | 100 % |
| Add: Manganese Dioxide | 1 % |
| Titanium Dioxide | 1 % |

This glaze runs. It also forms small crystals that can be further developed with a more complex firing schedule.

**BABU CELADON**

Cone 10 Reduction

| | |
|---|---|
| Whiting | 20 % |
| Potash Feldspar* | 40 |
| EPK Kaolin | 10 |
| Silica | 30 |
| | 100 % |
| Add: Yellow Iron Oxide | 2 % |

*I suggest G200 or Custer as the most potassium-rich feldspar substitutes. Both are approximately 10:3 $K_2O$:$Na_2O$ and are predominantly potassium oxide feldspars.

**GOLD BERYL**

Cone 6 Oxidation

| | |
|---|---|
| Gerstley Borate | 21 % |
| Whiting | 20 |
| Nepheline Syenite | 16 |
| EPK Kaolin | 11 |
| Silica | 32 |
| | 100 % |
| Add: Red Iron Oxide | 2 % |

A highly fluid glaze that runs if thick, but doesn't easily craze. Apply lightly. Performs best on porcelain.

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