GLAZES
UNCOVERED

Sofie Goethals

Lannoo

I want to thank you for buying this book. It makes me very happy, because I'm really looking forward to showing you around the wonderful world of glazes!

Glazes are not paint. When you glaze, you're doing much more than just brushing some colour onto your piece. There are many, many variables that can influence the end result. Unless you understand and control these variables, that result will be completely out of your hands. I strongly believe this is something many ceramists don't fully appreciate when they start working with clay. And until they do, they gradually find glazing more and more frustrating: something that often goes wrong. Something beyond their understanding. Something scientific, something hard.

I do have a scientific background myself. I worked in a university laboratory for more than 12 years, and I can't deny that this background helps a lot. Yes, I studied a lot of chemistry during my education. Yes, I have a lot of practice in setting up experiments. I'm good at problem-solving and am curious by nature. However, that doesn't mean only people like me, who studied chemistry at university, can make their own glazes. Quite the contrary!

Do you need to already have some basic knowledge before you read this book? Absolutely not. Is making good glazes hard work? Absolutely yes! Do you need to practise, test and experiment a lot? For sure! Glazing is just like working with clay. Be honest: the first time you stood at the potter's wheel, you didn't turn out any masterpieces, did you? (Neither did I.) Think about the first time you sculpted, or worked with clay sheets; that didn't go perfectly either, did it? You had to do it again, and then again, and then again and again, before you got better.

It's exactly the same with glazing. Developing glazes, improving them, understanding them, applying them right, mastering them: These are all things you can learn. It takes time and effort. But it pays off! I hope this book inspires you and makes you eager to start testing your own glazes. Some chapters are more difficult than others, I admit. If you find yourself reading one that you don't think you're ready for, go ahead and move on to the next one. You might find that after you get some hands-on experience, you'll be able to come back to that chapter and find it a lot easier. I structured this book in a way that seemed logical to me, but of course that might not be the right way for you.

Would you rather just go over the photos of the samples? That's fine! Or just start using some of the base recipes? That's fine, too! The most important thing is to use this book in a way that works for you. I wish you all the best for the glorious glaze adventure ahead. Learn, experiment and enjoy!

Sofie

SO
GO
KERAMIEK

TABLE OF CONTENTS


THE PERIODIC TABLE OF THE ELEMENTS

CHAPTER 1

THE BASICS

WHAT IS GLAZE?

You bought this book, or maybe you received it as a gift, so you're probably a ceramist, or potter, or you just like working with clay and/or glaze – or maybe you want to start. You might have some knowledge already, maybe even a lot. You may have done some glazing already, or maybe you're about to start. Either way, I'm pretty sure you handle glazed tableware every day, so you probably know what glaze is. But like any journey, it's best to start at the beginning. What is glaze?

A GLASSY LAYER THAT COATS CERAMICS

Glaze is the glassy layer that coats ceramics. It's made up of three primary components that all need to be there, in a defined proportion, for the glaze to melt properly. Under the right conditions glaze will, if heated enough, melt on a ceramic object, bond to it and, when cooled, become inseparable from it.

THE LIQUID IN BUCKETS OR JARS IN YOUR WORKSHOP

The term "glaze" is used both for the shiny surface on your favourite breakfast bowl and the liquid, also known as a suspension, that you have in the buckets or jars in your workshop.

THE WHITE, SWEET STUFF

Of course, the white, sweet stuff that I pour over my cinnamon rolls is also called glaze. But if that's the glaze you're interested in, you've got the wrong book! So pass this one on to a friend who's interested in ceramics and find yourself a nice cookbook. There's absolutely nothing in this book that you can eat (however tempting some of it may look).

WHY DO WE GLAZE?

There are plenty of reasons to put glaze on ceramic objects.

HYGIENE

A fully glazed piece is hygienic. Its surface is smoother than unglazed ceramics, so it's easier to wash, whether you do that by hand or with the dishwasher. Likewise, decorative work is also easier to clean when it's encased in a layer of glaze. It's just a lot easier to remove dust and dirt from a glazed piece than from unglazed clay.

Even the types of clay without grog (the small, fired particles of clay that reduce shrinkage and add hardness) can be finished very finely, but will still have small pores and irregularities. But glaze covers those right up. Whether it's a glossy or a matte glaze, which will have more texture than glossy, a glazed piece is better suited for washing than unglazed work–and that makes them more hygienic.

HARDNESS

Glazed work is harder than unglazed or semiglazed work, but only if the glaze is free of what we call "glaze flaws." There must be no crazing (see chapter 8, "Identifying problems and their solutions"), otherwise your glaze will actually work against you.

And if you only glaze the interior of a ceramic object, the result will be more fragile than one glazed both inside and out.

AESTHETICS

But the biggest reason to glaze ceramics might just be the beauty of it. Glazing gives your work your own aesthetic signature and character, a look that's all yours. You can choose one colour or multiple colours, overlapping or not. You can work with patterns, like stripes or circles, and even paint with glaze. The possibilities are truly endless.

WATERPROOFING

Although waterproofing is often cited as an important reason to use glaze, it's not the glaze that makes a piece watertight – that comes down to the clay and the firing temperature. A glaze can make a piece more watertight, but will not prevent the piece from absorbing water if the clay was not fired at a high enough temperature (see elsewhere in this chapter, as well as chapter 5, "Getting consistently Good Results").

THE RIGHT GLAZE FOR THE RIGHT TYPE OF CLAY

When you first dive into the wondrous world of ceramics and glaze, you will very quickly run into terms like "earthenware," "stoneware" and "porcelain." You'll see them on packages of clay, jars of ready-made glaze, and bags of glaze powder.

When I started out in ceramics, all these terms were a complete mystery to me–I didn't know what clay I should use, let alone what was the right glaze.

Usually, clay is going to be fired twice: the first firing (or "bisque firing") turns the clay into ceramic ware; the second firing (or "glaze firing"), generally at a higher temperature, puts the glassy coat on. This, too, I only learned after I was elbows-deep in clay (what kind, I still didn't know). In this section, I'll explain the differences between each type of clay.

EARTHENWARE CLAY AND GLAZE

Earthenware is clay that has been fired at "low" temperatures. By that we mean a maximum firing temperature of generally 1180 °C, or pyrometric cone 5 (see chapter 6, "Kilns, temperature and heatwork"). That might sound pretty hot to you, but in ceramics it's really not. The kiln temperature for a normal glaze firing for earthenware clay is going to be somewhere between 1000 °C and 1180 °C. Many ceramists who fire earthenware clay do so at around 1080 °C or cone 04.

Vase thrown with red earthenware clay. This piece has only had a bisque firing, which has given the initially yellow-ochre clay a warm red colour. This colour will turn an even darker red after the glaze firing. The hotter the firing, the darker the colour.

Pros and cons

Earthenware clay is often associated with terracotta, that familiar orange-red clay of the garden-variety flowerpot. But that's not the whole story–earthenware clay can also be white after firing. You usually can't tell the type of clay just from the colour (regardless of whether it's been fired or not). A lot of industrial tableware is made from earthenware clay; it's cheap, and because it can be fired at low temperatures it saves on energy costs.

But along with these advantages, earthenware clay also has some disadvantages.

Earthenware clay normally stays porous after firing, so ceramics made out of this type of clay may absorb water. That's a big disadvantage for functional wares: Plates and cups will soak up the water used to wash them, and a vase will absorb the water you put in it. That will create unhygienic conditions just ripe for bacterial growth and mould–not to mention unsightly water spots on your counters and cabinets. Additionally, intensive use can cause crazing (hairline cracks) in the glaze.

Earthenware clay is not as strong as other types of clay because it doesn't fully vitrify. Vitrification is the process by which free quartz, or silica (see elsewhere in this chapter), in the clay melts and fills in the pores between the individual particles of clay. That makes these clay particles start to melt, too, and makes them attach to each other more strongly, leaving very little space between the individual particles. The higher the firing temperature, the more vitrification occurs and the stronger the finished product. Having said that, a completely vitrified piece will be brittle and very fragile. With earthenware clay (unlike stoneware; see below), it's a very fine line between a strong piece and an extremely brittle piece. That's why we don't fire earthenware clay all the way to the vitrification point, but that's also why it always remains at least a little porous and doesn't get as strong as stoneware or porcelain.

STONEWARE CLAY AND GLAZE

Stoneware is generally fired at temperatures between 1200 and 1300 °C, or cone 5½ and up. Unlike earthenware clay, stoneware clay can be vitrified to a high degree over a wide temperature range without becoming brittle. That gives it a low porosity, so it absorbs much less water (that is, as long as it is fired at a sufficiently high temperature): In other words, it doesn't have the disadvantages of earthenware clay described above.

White stoneware clay being thrown on the potter's wheel.

PORCELAIN CLAY AND GLAZE

Porcelain is clay that can be fully vitrified, which gives it its translucent, very white appearance. To attain these properties, porcelain is typically fired at temperatures above 1300 °C (cone 10), although there are some types that can be fired within the temperature range of stoneware. Most stoneware glazes will also work well on porcelain clay.

Liquid porcelain being poured into a plaster mould. After pouring, a thin layer of porcelain remains in the mould. When dry, the mould can be carefully removed and the piece can then be finished as desired.

KNOW YOUR CLAY

Before you even start thinking about glazes, it's critical that you know what kind of clay you're working with (or want to work with). As I've described, this choice determines the glaze you will need and the temperature at which you'll have to do the second firing. Clay and glaze go hand-in-hand.

An earthenware glaze is any glaze that's suitable for use on earthenware clay. It must melt at a fairly low firing temperature. If the glaze's melting point is too high (as with a stoneware glaze), you can't use it on earthenware clay. It won't melt, or won't melt enough, and the result will be unusable. But if you raise the firing temperature enough to melt the glaze, then the earthenware clay will start to melt, too. That process starts with bloating (see chapter 8, "Identifying problems and their solutions"), and will eventually leave you with an unrecognisable blob of solidified clay at the bottom of your kiln!

Stoneware clay, on the other hand, needs a stoneware glaze that will melt within a temperature range of 1200-1300 °C. Using an earthenware glaze on stoneware clay is an equally bad idea. In this case, the glaze will melt so strongly at the higher firing temperature that it will run right off the piece. And it can be so fluid that it can cause other glaze problems, like pinholes or craters (see chapter 8, "Identifying problems and their solutions").

That's why you always need to know what clay you're working with before you get to glaze firing!

All the recipes provided at the end of this book are stoneware recipes, which should ideally be fired at cone 7, meaning in the range of 1200–1240 °C. The temperature you need to set to fire at cone 7 depends on a huge number of variables, including type of kiln, the age of the spirals, the firing curve, and your kiln's insulation. You can read all about these factors in chapter 6, "Kilns, temperature and heatwork." But in general, unless I give a different indication in the text, you can assume that the glaze samples throughout this book were fired at cone 7.

That's enough about clay for now–let's get back to glazes!

THE BASIC BUILDING BLOCKS OF EVERY GLAZE

All glazes are made up largely of minerals obtained from mines or quarries. These are, in essence, specific rocks ground very finely. To understand glazes, we have to look more closely at them, down to the atoms and molecules present in these minerals. Virtually every glaze (whether for earthenware, stoneware or porcelain) consists of three basic components, or building blocks, and you will find them in every glaze recipe. You will need them in any glaze you make. To get to know these materials and understand glazes, we have to immerse ourselves in the world of chemistry. Now, I understand that for many lovers of clay, chemistry is not per se, your favourite subject. But there's no getting around it.

In this chapter, we're going to go deeper into these components. This will be important for understanding what a glaze is made of. The better you understand the various components, the easier it will be to categorise them and the sooner you will understand glaze recipes. The knowledge I will give you here will be essential for your getting down to work with glazes. So don't skip this chapter!

But don't worry, we're not going deep-sea diving straight away; we're first going to do some snorkelling on the surface. There's plenty of beautiful things to discover in the shallows, too. So let's go!

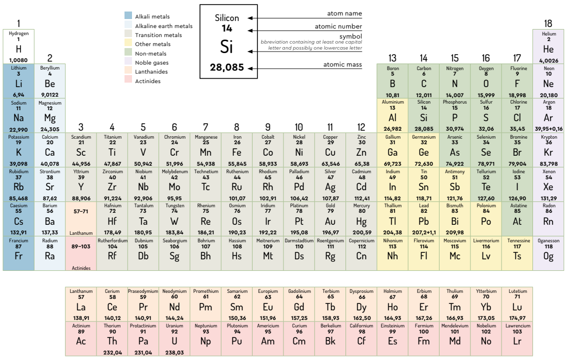
CHEMISTRY CRASH COURSE FOR CERAMISTS

In the following sections, I have no choice but to hit you with a few terms from the field of chemistry. I'm aware that not everyone had chemistry in school, and some who did still have nightmares about it. That's why I'm going to try to explain only the basic terms we need in only the necessary level of detail–I promise, just enough so that you don't run away screaming when you get to the later chapters in this book!

Atom

The smallest of the building blocks that make up our world is the atom. The periodic table of the elements, also known as Mendeleev's table, gives us the 118 atoms known to man.

This table (see the figure below, also provided as a pull-out reference card at the back of this book) is over 150 years old but still absolutely in use today. And I will refer to it frequently in this book. But the good news is, you don't have to memorize the whole thing. Of the 118 elements, there are about 20 that are relevant to ceramists.



periodic table

Atoms are always indicated by an upper-case letter, sometimes followed by a lower-case letter. Every atom has an atomic number. On the periodic table, the atoms are grouped in columns. The first two groups are particularly relevant to us as ceramists: these are the "alkali metals" and the "alkaline earth metals." But other groups are also important to us; for example, almost all the colours we will need as ceramists are found in the group "transition metals."

An atom is made up of protons, neutrons and electrons. Compared to protons and neutrons, electrons weigh almost nothing. This weight is important, and we'll go into that in great detail in chapter 7, "Going deeper."

An example of an atom in the second column (the alkaline earth metals) is calcium. This element is written as: "Ca."

Molecule

Atoms bond with each other to stay stable. This is because most of them are not stable on their own. We won't really get into the different types of molecular bonds; you won't need to know them to understand this book. The most important thing to know is that when atoms bond with each other they form molecules, which are made up of multiple atoms. These may be all atoms of the same kind, but atoms usually combine with different atoms. In a chemical formula, the number next to the atom indicates how many of that atom there are in that molecule.

Take whiting, an example of a glaze material. The chemical formula is $CaCO_3$*. We call this "calcium carbonate," and we see that a molecule of it contains one calcium atom (Ca), one carbon atom (C) and three oxygen atoms (O).*

Carbonate

Any molecule that ends in a CO_3 group is called a carbonate. In glaze chemistry, there are several glaze components that have such a group.

Whiting, $CaCO_3$*, is a perfect example.*

Oxide

Molecules that contain one or more oxygen atoms are called oxides. Some glaze materials are in themselves oxides, like zinc oxide (ZnO) or copper oxide (CuO). Others are available in the carbonate form, like whiting.

Fired glazes are always complex and disordered combinations of oxides. Under the influence of heat, materials that start out as a carbonate break down. Take whiting (calcium carbonate), for example, which breaks down into:

$$CaCO_3 \rightarrow CaO + CO_2$$

The calcium oxide CaO remains in the fired glaze. Long before the end of the firing process (at around 700°C), the CO_2 has left the kiln in the form of the well-known greenhouse gas.

WHAT IS MELTING?

Before we go deeper into components and materials, we first have to answer a fundamental question: what is melting?

Melting is simply the breakdown of molecular bonds under the influence of heat in our kiln. A glaze is a complex compound of many different chemical bonds, which we will learn more about later. A glaze doesn't have a single melting point: it has a melting range. Glazes that have just been applied to a piece begin their journey in the kiln as a powdery solid. During the firing, the viscosity (meaning the thickness; honey, for example, is a viscous liquid but water is not) will decrease until the solid glaze material becomes a liquid and, in theory, all the solid particles have been dissolved into that liquid. The more chemical bonds that are broken under the influence of the various oxides in the mixture and the heat in the kiln, the less viscous the glaze becomes. Take this last point with a grain of salt–at the highest temperatures, glazes in the kiln are theoretically liquid, but in practice are extremely viscous, many times thicker than honey. If the kiln is not turned off, the glaze will continue to melt until it ultimately becomes so fluid that it runs off the piece onto your kiln shelf, and that's bad.

In the next section I'll give you an overview of the three basic components that make up virtually every glaze and which, under the influence of heat, will melt in the kiln.

GLASS FORMER

The first basic component in a glaze is the glass former. This is a compound that is chemically able to form a glass. Glass is a non-crystalline solid–meaning, a chemically disorganised (i.e., non-crystalline, i.e., amorphous) jumble of molecules that don't get the time during the cooling phase to reorganise themselves nicely into a lattice. In other words, glass happens when the very viscous liquid cools down "rapidly" into a solid.

There are many different types of glass, but for glazes there are really only two glass formers you need to know: these are silica = SiO_2 and boron = B_2O_3. But silica (also known as quartz) is always the primary glass former; by that I mean that it is always going to be present in any glaze. Boron might be there too, but it's optional. We'll look at this in more detail later in this chapter.

The glass former is the most critical part of the glaze. Without glass former, no glass, and that means no glaze. It's impossible to make a glaze without adding this component.

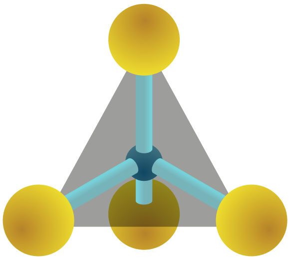
Silica

Silica, or quartz, is the most important glass former used in glazes. Chemically, we indicate quartz like this: SiO_2. A silicon atom bonds with two oxygen atoms. But this molecule does not occur in nature by itself.

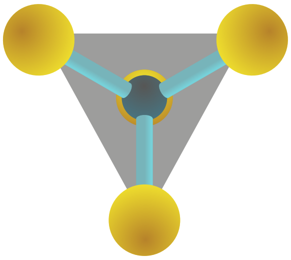
Silicon is a small atom, with space to surround itself with four oxygen atoms. The oxygen atoms pile on small silicon like a little atomic family in a happy little group hug. This molecule is called a silica tetrahedron, and looks something like a pyramid with the oxygen atoms at the corners and the silicon atom tucked away in the middle.

But these oxygen atoms aren't satisfied with being part of a silica tetrahedron; in fact, they've all got space for not just one silicon friend, but two. So they start looking for an extra silicon atom to bond with, one which will also be looking for three more oxygen atoms. So the 3D structure of silica is quite intricate and complex.

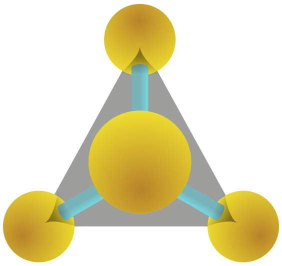
The situation I just described is that of unmelted quartz, which has arranged itself nicely into a lattice. When the kiln is fired, silica (along with the rest of the glaze components) transition from a solid to liquid form. In this viscous liquid, the bonds between the molecules are broken, and when that happens, a clear molecular structure can no longer be determined. A cooled glaze is an unorganised network of silicon and oxygen atoms (and also contains many other atoms and molecules like the fluxes and the stabiliser, which we will look at later in this chapter.) And it's this chaos that is vital to the definition of glass and glaze! During firing, more and more particles of the components melt into the glaze. In a perfect world, they would all be in solution at the top temperature. Upon cooling, the mixture becomes thick and syrupy so fast that the atoms don't have time to organise themselves back into the nice lattice structure that they had before firing. If they could, then they would form a crystal rather than a glass. The amorphous, chaotic structure of quartz after cooling means that quartz glass has properties of a liquid, but is actually a solid.



FRONT VIEW



BOTTOM VIEW



TOP VIEW

The 3D structure of a single silica tetrahedron with four oxygen atoms (yellow) surrounding one silicon atom (blue). This triangular pyramid shape is the building block of quartz. It is not found in this form in nature because it is not stable; this is because the oxygen atoms still have room to bond with another suitable atom.

Quartz or silica is abundantly present in our Earth's crust. Approximately 27% of the Earth's surface is made up of one form of silicium or another. You can find it in many rocks and minerals.

Because glazes are made primarily from ground stones, we find silica in a great many glaze components. So when you add a glaze component, you might also be getting some silica as a "bonus". You can determine whether a component contains the glass former silica by looking at the chemical analysis, which we will come back to (see chapter 7, "Going deeper").

Pure silica or quartz has a high melting point, approximately 1700 °C. If you have a kiln, check how high of a temperature you can set. You'll probably find you're about 400 °C. short of being able to melt silica in its pure form.

Boron oxide

As already noted above, along with the primary glass former silica there's another glass former: boron oxide. Chemically, we write it like this: B_2O_3.

Unlike silica, boron oxide melts at a very "low" temperature–"only" 570–600°C. This gives it the ability to lower the melting point as a glass former, and is why it's also sometimes called a low-temperature glass former.

Boron oxide is often used to make stoneware glazes at the lower range of the stoneware spectrum (1200-1230°C). It's also extremely useful in earthenware glazes, which are commonly made with toxic lead oxide, a perfectly good flux. More and more, lead in earthenware glazes is being replaced by boron oxide: It will give you a glaze that melts at earthenware temperatures.

But you'll rarely, if ever, find boron oxide in the classic high-temperature stoneware glazes or porcelain glazes, because these glazes are able to melt fully at high temperatures (1280–1300°C) without a lower-temperature glass former like boron oxide. So it's not only not needed, but it would cause glaze problems like dripping (see chapter 8, "Identifying problems and their solutions") and also make the glaze less hard, impermeable and long-lasting.

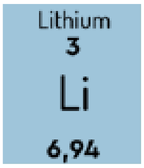
STABILISER

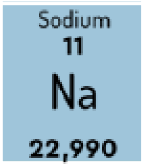
Alumina

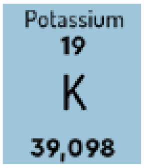
The stabiliser is a second component that you will find in virtually every glaze. The only stabiliser is aluminium oxide (Al_2O_3), generally referred to as alumina for short. Alumina is needed in almost all glazes. It increases the viscosity of the glaze at high temperatures, which prevents the glaze from running off the piece during firing. And alumina plays a major role in making glazes harder. With silica, it forms a network in the glaze. That's why in the technical literature, alumina is also referred to as an intermediary.
Alumina by itself has an extremely high melting point, somewhere above 2000 °C.

FLUX

The third and final component needed to create any glaze is called the flux. A flux lowers the melting point of a glaze so that it will actually melt at temperatures that you can achieve in your ceramic kiln. As you have read already, for most glazes that temperature is generally going to be between 1000 and 1300 °C. But here the story gets more complex, because there are a lot of different fluxes; broadly, they can be divided into two major groups.







Alkali metals

The first group of fluxes are the alkali metals, from the first column of the periodic table of the elements.

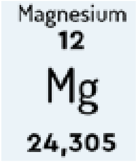
If alkali metals bond with oxygen, they are referred to as oxides. Ceramists often refer to the alkali metals as the R_2O group, with the "R" being a variable that could stand for any atom. This is because two atoms from the alkali metals group always bond with one oxygen atom within this group. The alkali metals are the strongest fluxes because they very readily react with oxygen and want to make bonds with that atom. To do this, they break bonds, like the bond between silicon and oxygen, to get those oxygen atoms for themselves. Melting is the breaking of chemical bonds under the influence of heat, as I have already described.

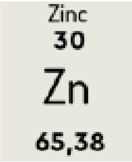
There are three alkali metals that are interesting for ceramists:

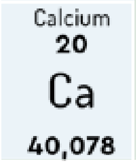
- lithium oxide (Li_2O)
- sodium oxide (Na_2O)
- potassium oxide (K_2O)

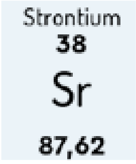
These are used in glazes, sometimes individually and sometimes in combination. Lithium oxide is a rare product, and highly sought-after because it is vital for batteries as well as in many other industries. This makes it a very expensive alkali metal. It can lower the melting point of a glaze very significantly. The two other alkali metals, sodium oxide and potassium oxide, are more common and consequently much cheaper. And these, too, are perfectly good fluxes. Excessive use of sodium oxide and potassium oxide can lead to crazing (a glaze flaw; see chapter 8, "Identifying problems and their solutions").

You will find that one or more R_2O fluxes is added to virtually every glaze. They are needed to get the glaze melting without pushing the temperature to impossible heights.









Alkaline earth metals

The second group of fluxes are the alkaline earth metals, from the second column of the periodic table of the elements. These alkaline earth metals are sometimes called RO fluxes, because with these one atom (R) always bonds with one oxygen atom.

The RO fluxes are extremely important in a glaze recipe. They are generally less powerful than the alkali metals, and only start playing a role in the melting process at higher temperatures. To a large degree, the alkaline earth metals determine how a colour (derived from a colouring oxide, which we will look at later in this chapter) is expressed in a glaze. Different colours in glaze are achieved by using different alkaline earth metals (or combinations thereof). Using different alkaline earth metals can give you glazes that look completely different, even with the same colouring oxides in similar proportions. We'll see many examples later in this chapter, in the section "Colour in your life."

There are four alkaline earth metals that are interesting for ceramists:

- calcium oxide (CaO)
- magnesium oxide (MgO)
- barium oxide (BaO)
- strontium oxide (SrO)

Also in this group is beryllium oxide (BeO), although it is rarely used because it is extremely toxic! So I've decided not to include it in this book.

Ceramists also like to add zinc oxide (ZnO) to the list of RO fluxes. Chemically speaking, zinc is not an alkaline earth metal at all; technically it's a transition metal, but it nonetheless acts like the alkaline earth metals in a glaze. So that's why you'll often see it listed in the same group.

Then there's lead oxide (PbO), which is also classified with the RO fluxes. This is another very powerful flux that in the past was commonly used in earthenware glazes. And it's true that it's pretty ideal for making these glazes melt at low temperatures. Unfortunately, in its pure form it's extremely toxic, and commercial sales of it are now prohibited. It is, however, still used in glazes in the form of a frit (see elsewhere in this chapter). But thanks in part to the strict regulations on it, it's hardly ever used by ceramists and potters who create functional ware. If you need a strong flux, there's some good alternatives to lead, like boron oxide. I'm mentioning it in this book for the sake of completeness, but I myself don't use lead in glazes.

The alkaline earth metals are important fluxes, and there will be at least one of them in more or less every glaze recipe. So, you will usually find both an R_2O flux and an RO flux in a glaze.

The eutectic point

The way a flux lowers the melting point of a glaze is not a linear process. That means that simply adding a flux won't necessarily lower the melting point of a glaze–I wish it were that simple! But the actual story is pretty complex. There is an ideal ratio between the glass former, the stabiliser and the flux to achieve the optimum (read: lowest possible) melting point. That optimal point is called the eutectic point. The eutectic point might be lower than the melting point of any of the individual substances separately. A simple example can make this clear:

Let's say we're making a mixture of silica and alumina, the glass former and the stabiliser. Both of these have an extremely high melting point (1710 °C and 2027 °C, respectively). If we combine them at a ratio of 90% silica and 10% alumina, we achieve the eutectic point for these two oxides. That's 1545 °C–still high, but much lower than either one individually!

But this example still won't give you a usable glaze, because no ordinary kiln is going to get up to 1545 °C. The eutectic point of a glaze mixture can be achieved by keeping the components of the glaze (glass former, stabiliser and flux) in the right proportion.

Eutectic points with three components are shown in phase diagrams. These are complex graphical representations mapped out in a triangle. At each corner of the triangle a substance is given, such as (in this example) silica (SiO_2), the stabiliser alumina (Al_2O_3) and the flux calcium oxide (CaO). The phase diagram shows not only the ratio between the three individual components, but also the melting point of the substance created with that ratio.

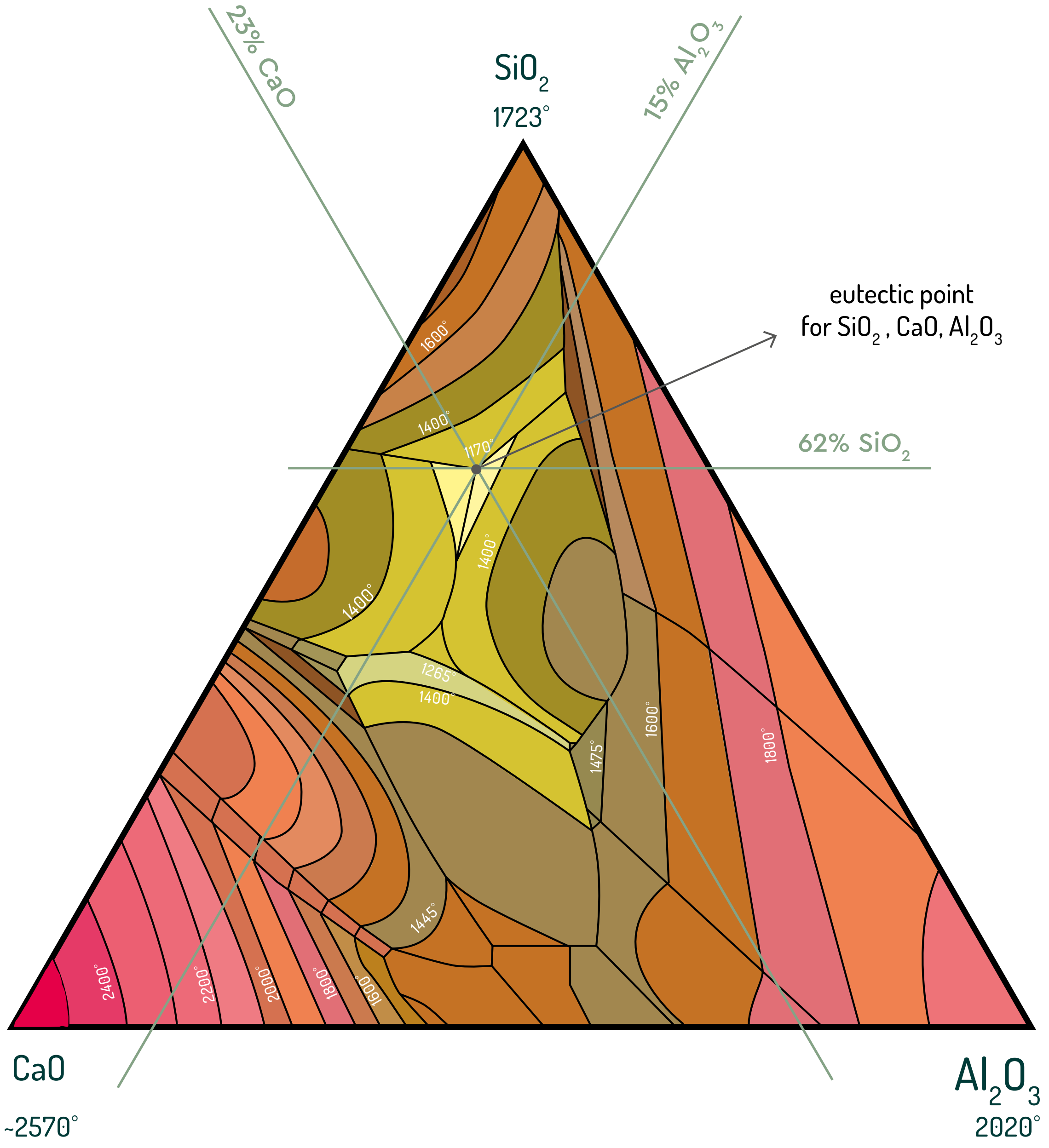
The eutectic point for the three components in our example (SiO_2, Al_2O_3 en CaO) is 1170 °C. To achieve this melting point you need 62% silica, 15% alumina and 23% calcium. Adding more calcium oxide won't lower the eutectic point–it will actually do the opposite! These three components, when combined, can never melt at a temperature lower than 1170 °C. Any adjustment to this ratio of these three components will always result in a higher melting point.

A phase diagram, even this one with only three components, is very complex material. A real glaze, which will usually contain multiple fluxes and sometimes even multiple glass formers, is many times more complicated than this example. But don't worry: while a phase diagram might be fun to get into for "glaze nerds" like me, in practice you don't really need them to develop a nice glaze.

What you should remember about eutectics is:

- it's not a linear process
- the eutectic point might be lower than the melting point of the individual components

Also be aware that the term "flux" is a little misleading. As you can see from the example above, silica and alumina can each drastically influence the other's melting behaviour, too. So it's really all about always keeping the balance between all the components in a glaze; they all play an important role. Even adding tiny amounts of colouring oxide or stain (see chapter 7, "Going deeper," as well as elsewhere in this chapter) can affect the melting point of a glaze.



Simplified examples of a phase diagram with 100% silica (SiO_2), alumina (Al_2O_3) and calcium oxide (CaO) at the corners. The lines indicate temperatures at which a mixture with a specific ratio of SiO_2, Al_2O_3 and CaO will melt. The eutectic point of 1170 °C is marked. This lowest melting point is achieved at a ratio of 62% silica, 15% alumina and 23% calcium oxide.