The Practice of Stoneware Glazes

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Translated by Brother Anthony

‘You will never be freed from the need to be autodidacts.’

--Philippe Lambercy, potter, addressing his pupils.

Contents

Introduction

There are as many ways of glazing pottery as there are potters, for nothing can be more personal than the choice of initial materials, the preparation and the application of glazes. Yet there is one common denominator to all that enormous variety and that is Nature, the sole source of the minerals that are subjected to processes of transformation that, obviously, are not going to vary from one workshop to the next.

Therefore this book simply proposes one way among many of approaching stoneware glazes; it is clearly marked by the workshop whose methods it summarizes, methods that are inevitably fragmentary and always capable of improvement. At the same time, it offers a collection of diagrams that indicate all the possible fusions of the principal minerals that usually compose stoneware glazes.

Still, readers should not expect to find here a complete theoretical compendium. This book will only prove useful insofar as its suggestions are translated into practice. We should stress at the outset that the kiln is to glazes what the wheel is to forms. No one would ever think of learning to turn pots by reading a book without, above all, having a wheel! It is not so very different where glazes are concerned. In the end, the education comes from taking finished work from the kiln, time after time, and learning from the results, the bad as much as the good.

The first section sets the beginner to work, supplying step by step the basic knowledge needed. The potter is taught first how to select materials and is introduced into the complex world of glazes by way of recipes that are easy to make. The number of materials we propose may surprise the already practiced potter. But experience shows that it is better to obtain the maximum by means of the minimum than the contrary! Readers might at first think that the more materials one employs, the more one becomes capable of producing fine results, whereas in fact an initial mastery of a small number of elements leads much further than a disorderly array of many. Besides, there is nothing preventing practiced potters from bringing new materials into their research, once they have acquired a fuller depth of understanding.

As a result, when it comes to the various oxides that give color to glazes, we have only dealt with iron oxide, to which we felt it was important to consecrate a separate chapter. That one oxide offers an extraordinary variety of colors, on account of different reactions that are almost never described in glazing manuals.

The really advanced potter will probably be able to skip most of the first part, going directly to the section dealing with fusion diagrams. A number of the diagrams, those we have studied in greater depth, are accompanied by commentaries. In so doing, we indicate the route we ourselves have followed in order to obtain a number of classic glazes. The diagrams will allow potters to situate more precisely their own particular glazes and recipes in the whole universe of possible glazes, and perhaps suggest directions for further research.

Recipes 1

Four recipes for a first firing
The art of purchasing raw materials

Recipe: a list of raw materials, indicating the quantity of each, used in making a glaze.

Glazes resulting from a single recipe may yield very different results. There is no universal recipe guaranteed to result in a glaze of a particular appearance.

Generating a glaze

The success of a glaze depends on conjugating many variable factors, each as important as the others. They are:

The composition of the glaze
The raw materials
Their granulation (particle size after grinding)
The thickness of the applied glaze
The nature of the base (the clay body)
The source of calories (firing by combustion or electricity)
The size of the kiln
The fluctuations in the heating curve during the firing
The final temperature
The duration of the firing
Variations in the kiln atmosphere (oxidizing or reducing)
The curve of the cooling process

Firing in one's own kiln

This list reveals the importance of the kiln. The art of glazing is best served by a homogeneous machine (kiln), simple to control, as polyvalent as possible regarding the speed of the rise in temperature and variations in atmosphere. Today, gas-fuelled kilns correspond best to these requirements.

Readers will readily understand how important it is to fire tests in their own kiln, under the conditions that normally apply in their personal, ongoing artistic activities. The aim of the first firing proposed here is to obtain the two 'triangles' of experimental results presented in what follows. Only the test shards will not be enough to fill a kiln, so we suggest the following:

Four recipes with which to glaze the pots filling an initial kiln

Chart 1

	1	2	3	4
Chalk	13	10	8	7
Talc		10	10	8
Feldspar	50	60	55	54
Kaolin	12	10	3	12
Silica	20	10	22	13
Iron oxide	5		2	6
Result (in reduction)	dark brown	white	green	brown
Result (in oxidation)	dark brown	beige	light brown	black

Weights are in grams. Maximum firing temperature: 1280º. This temperature is the standard firing temperature for all the glazes to be studied in this book. The indications of color can only be very approximate.

These glazes, which are best fired in a reducing atmosphere, can also be superimposed (applied one on top of another). Tested in a dozen different workshops, they have always yielded results differing in appearance but satisfying in terms of fusion and union with the clay bodies, although prepared using raw materials of varying origins. It should be stressed, however, that in each case the raw materials were correctly chosen, each being in fact what its name indicated. This is not always so sure, whether we are talking about the suppliers or the labelling practiced in individual workshops. Hence the text that follows.

The anarchy of nature

You cannot buy all these powders, most of them white, just like buying sugar. When you buy sugar in a store, you do not usually stop and wonder if you can trust the owner. With minerals, it is very different. It so happens that nature is our only supplier, and nature is nothing like a great supermarket with everything classified in a strict order according to what it is made of. The following paragraphs are intended to help guide the potter's choices and purchases.

Raw materials: detailed labelling

Before you buy anything, the first precaution to take is to ask your suppliers for detailed chemical descriptions (technical cards) of their products, always hoping that the cards will correspond as closely as possible to the products described. If your supplier is an intermediary, you may do better to go to the direct source, the originating quarry.

The descriptions here of these technical cards allow the reader to discover the notation for each of the oxides that compose the different minerals. We should recall that the numbers following each element's symbol refer to the number of atoms in each molecule, so that Al_2O_3 corresponds to 2 atoms of aluminum combined with 3 atoms of oxygen.

These oxides are generally written in a conventional order; they represent what remains of a mineral in the fired glaze; all that disappears, as smoke or vapor during the firing is totalized as Lost in Firing (LF). This is the commonly recognized order:

LF	Lost in firing
SiO_2	Silica or Silicon oxide
Al_2O_3	Alumina or Aluminum oxide
Fe_2O_3	Ferric iron oxide
P_2O_5	Phosphorus oxide
TiO_2	Titanium oxide
CaO	Calcium oxide or lime
MgO	Magnesium oxide
K_2O	Potassium oxide
Na_2O	Sodium oxide

These last two are known as alkalis.

Some technical cards may indicate other components (salts of sulphur, chlorine, etc.) in very weak proportions. These can be ignored. All values will be indicated as percentages of each oxide.

The beginner may be surprised to find more than expected indicated on these cards. This serves as a reminder of how complex nature is; it only very rarely supplies a mineral with a fixed composition, such as we find in a quartz crystal, for example. But no one crushes crystals to make a glaze. We have to make do with more commonly found rocks, each loaded with what are often (wrongly) termed 'impurities' in the course of its own geological history. For it is often to such 'impurities' that the potter owes great discoveries!

We can now go back to the four initial recipes, and indicate their composition as percentages of the minerals comprising them, it being understood that they will melt correctly using other components with the same total.

	Chalk	Talc	Feldspar	Kaolin	Iron oxide	Silica
LF	43.66	6.2	0.5	12.58	0.3	0.13
SiO_2	0.13	57.8	74.5	47.28	0.5	99.6
Al_2O_3	0.7	2.8	13	37.04	0.2	0.25
Fe_2O_3	0.02	0.8	0.17	0.85	99	0.02
P_2O_5	0.03			0.03		
TiO_2		0.1	0.04	0.14		
CaO	54.6	0.3	0.03	0.09		
MgO	0.75	31.9	0.08	0.06		
K_2O		0.1	11.50	1.41		
Na_2O			0.18	0.08		

We shall see later how to use these cards. For the moment, we should review the composition of some of our most basic minerals, using information obtained from various suppliers.

Chalk (Calcium carbonate)

	A	B
LF	43.66	43.62
SiO_2	0.13	0.33
Al_2O_3	0.7	0.35
Fe_2O_3	0.02	0.03
P_2O_5	0.03	
CaO	54.6	55.4
MgO	0.75	0.06

These two products come very close to being pure chalk, 100 grams of which would provide 56 grams of CaO to a glaze, while 44 grams would disappear as carbon dioxide (CO_2) during the firing.

A potter can easily check the quality of a sample of chalk, it being readily dissolved in acid. To do this, take a glass vessel large enough to contain the frothing produced by the reaction and into it place 0.1 litre of water to which you add a teaspoonful or so of hydrochloric acid. Into this is poured one gram of chalk.

Once the reaction is over, a solid deposit may remain; you should check that no chalk is left behind by adding a few drops more of acid. Such a deposit can be dried, then weighed, indicating the percentage of impurities present in the sample. In an acceptable sample, this should not exceed 1%.

We have explained this process because it forms the initial analytical reflex of a potter wishing to detect and measure the proportion of chalk present in a rock encountered by chance, a marl for example.

Talc (Magnesium silicate)

	A. Luzenac (OOS quality)	B. Spluga (Italy)
LF	6.2	17
SiO_2	57.8	45
Al_2O_3	2.8	1.8
Fe_2O_3	0.8	2

TiO_2	0.1	
CaO	0.3	0.7
MgO	31.9	33
K_2O	0.1	0.1
Mineralogical analysis		
Chlorite	13.9	26
Dolomite		2
Magnesite		17

What we find on the market under the name of talc may be a mixture of various magnesian minerals. That is why it is essential that the mineralogical analysis should figure on the technical label. Your choice should focus on the product with the lowest proportion of chlorite, a magnesium silicate that tends to produce blistering in glazes when it is present in high proportions.

The strong Loss in Firing in the second sample should be noted. It is explained not only by the presence of chlorite but also that of magnesite, which is not a silicate but a carbonate of magnesium, lost as carbon dioxide during the firing.

Feldspars

The name ‘feldspar’ covers an infinite range of different substances. In this great family, silica and alumina combine either with potassium (orthose) or with sodium (albite), or with both alkalis together (anorthoclase etc.), or with calcium (anorthite). Here, we will only mention the alkaline varieties most commonly used.

An analysis of a series of these varying minerals prepared by the Feldspar Society of Southern France provides greater detail. The compositions in question are various mixtures prepared using raw minerals taken from the quarry.

This table becomes extremely significant when we compare the very different contents in silica, alumina, and alkalis. This provokes two comments:

1. None of these compositions is exclusively potassium- or sodium-based, but each tends more or less toward orthose or albite.
2. The variations in silica content are considerable. In reality, we are dealing here with a collection of minerals located at different points in the transition from feldspars to pegmatites, these latter being richer in silica.

For our initial recipes, we will take feldspars, either orthose or albite, that are poorest in silica and come closest to the indications found later in the summary chart.

Document provided by the Feldspar Society of Southern France

Reference:	P 3	P 5	P 10	3 MA	SPS
LF	0.8	0.8	0.8	1	0.8
SiO_2	79.2	74.6	73.2	70.1	70.9
Al_2O_3	12	15.3	16.15	17.5	17.3
Fe_2O_3	0.27	0.19	0.22	0.28	0.18
TiO_2	0.15	0.1	0.1	0.15	0.1
CaO	0.75	0.7	0.7	1	0.85
MgO	0.15	0.1	0.1	0.1	0.1
K_2O	0.95	1.7	1.7	1.35	1.45
Na_2O	5.7	6.7	7	8.5	8.3

Reference	SPE	CE	ICE 8	ISA 10	ICE 10

LF	0.6	0.8	0.4	0.3	0.2
SiO_2	68.55	75.55	71.1	68.85	68.2
Al_2O_3	19.2	13.8	16	17.1	17.7
Fe_2O_3	0.15	0.27	0.25	0.11	0.1
TiO_2	0.05	0.15	0.1	0.1	0.05
CaO	0.7	0.8	0.6	0.6	0.45
MgO	0.1	0.05	0.1		
K_2O	0.9	4	8	10.45	10.30
Na_2O	9.8	4.5	3.3	2.5	3

Kaolin

Here are the technical cards for kaolin specimens of various origins:

	1.	2.	3.
LF	8	12.5	12.5
SiO_2	66	47	47.2
Al_2O_3	22	38.2	36.8
Fe_2O_3	1.2	0.8	0.82
TiO_2	0.3	0.1	0.15
CaO	0.1	0.1	0.13
MgO	0.2	0.2	0.32
K_2O	0.15	1	0.82
Na_2O	0.15	0.1	0.09

Here again we note the variations in silica and of alumina. This is because within a deposit, silica may mix with kaolinite, the name given to pure kaolin (PF 14%, SiO_2 46.5%, Al_2O_3 39.5%).

Kaolin, the basis of numerous kinds of clay, is plastic and shrinks on drying. If it forms a large proportion of a glaze, it may make the raw glaze shrink and scale. This problem is solved by previously calcining the kaolin to the usual biscuiting temperature (950° nb. all temperatures are quoted as degrees Celsius / centigrade), and it is possible to purchase calcined kaolin from specialized suppliers. Once calcined, kaolin loses its plasticity and thus its shrinkage. When mixing the glaze, you will of course have to take account of the LF, found by re-weighing the 100 grams of kaolin after calcination.

Iron oxide

	1.	2.
LF	0.5	0.4
SiO_2	5.4	0.04
Al_2O_3	1	
Fe_2O_3	90	99.5
CaO	0.9	traces
MgO	0.2	

We have devoted a separate chapter to iron oxides. In practice, all you have to do is procure red, ferric iron oxide as pure as possible. Synthetic iron oxides are available on the market that are extremely rich in Fe_2O_3 (over 95%).

Silica

LF	0.13
SiO_2	99.6
Al_2O_3	0.25
Fe_2O_3	0.01

There is no problem in obtaining good quality silica. It can be found under a variety of names: silica, quartz, sand etc. It too should be as pure as possible, tending toward 100% of SiO_2.

Summary table

	LF	CaO	MgO	K_2O	Na_2O	Al_2O_3	Fe_2O_3	SiO_2
Chalk	44	56					< 1	
Talc	6		32				< 1	58
Orthose	0.5			10		17	< 1	71
Albite	0.5				10	17	< 1	71
Kaolin	14					39.5	< 1	46.5
Iron oxide							> 95	
Silica							< 1	99

Comments

The potter must obtain raw materials with percentages as close as possible to those indicated in the table above. You should specify grains sized between sieve mesh 200 and 300, since minerals with too coarse a texture will have difficulty combining during firing, while too fine a grain size can cause problems when glazing (shrinkage, scaling).

The decision to begin by selecting minerals which are, if not completely pure, at least as simple as possible and above all of a known composition, was made with a precise intention—to achieve by the shortest path the melting together of many different mixtures at a temperature (1280º) determined in advance, and to dispose of a method of correction. We shall see later, very concretely, to what extent this melting depends on the relationship between silica and alumina, and how the melting point varies according to the variations of the other oxides present in the glaze. As a result, the more potters know about their materials, the easier it becomes to establish relations of cause and effect, discover the function of a given oxide in the formation of a given glaze. This training will subsequently enable us to include in our research rocks that do not figure in commercial lists but that we discover and collect during our own geological rambles. It is this aspect of the potter's work that constitutes one of the main characteristics of true craftsmanship.

As we end this first part, we must warn the potter against the temptation of being a perfectionist in the choice of basic materials. No matter how carefully they are produced, there will always be a certain gap between the technical cards and the real composition of the raw materials stored in any pottery. It should be remembered that, although it is possible to analyze with great precision a specimen of a product, it is never possible to guarantee that the specimen will be absolutely representative of an entire run of that product. For example, the list of feldspars quoted above comes with the following reservation: 'These figures are given as an indication, they do not represent a guarantee.' No one is obliged to do the impossible, and sometimes the state of a mineral deposit no longer allows a particular quality to be obtained. In that case, the producer will send out a corrected description of the product with each new delivery. But the individual potter does not always benefit from such dispositions, normal at the industrial level. Most of the time we depend on retailers who do not necessarily update the technical information in their catalogues. As a result, the potter should take as far as possible the precaution of buying and stocking enough of one delivery of a product to avoid such inconveniences. Similar precautions should be taken when we discover for ourselves a natural substance that interests us.

Recipes 2

Panoramic overview of stoneware glazes by mixing natural silicates
Notation by triangle
Making, glazing and firing test shards
Interpreting the fired tests

Mixtures of silicates will always yield silicates

Recipes for glazes made by mixing natural silicates

The most accurate term to define a stoneware glaze is a silicate: a network of silica holding in its meshes, just as a sponge holds water, the various oxides that modify its melting point and its appearance.

The mineral world is constantly manufacturing silicates of the most varied kinds, just as it subjects them to endless metamorphoses. For example, the breakdown of feldspars, aluminous and alkaline silicates, gives us kaolin, a hydrous silicate of alumina.

The first series of experiments that follow are composed of mixtures of natural or reconstituted silicates, yielding stable and coherent glazes. Above all, they will set before our eyes a kind of table of contents of the main types of stoneware glaze, on the basis of which it will be possible to make one's own choices and undertake a particular line of research.

In the present method, only the raw materials described in the previous chapter will be used. Thus the oxides of zinc and barium are omitted. Among the host of silicates produced by natural processes, silicates that include those two oxides are quite exceptional; there is nothing to prevent the potter employing them later, if desired.

Choice of silicates

The first silicate to be chosen is feldspar, either orthose or albite, it does not matter at the moment. Three other natural silicates will then serve as models and will be reconstituted—ochre, wollastonite and diopside. (nb. All weights are indicated in grams.)

Ochre

This is a familiar mineral, composed of silica, alumina, and iron oxide. In nature its composition is varied, and we will limit ourselves to one that best defines its essence. We can reconstitute it by mixing the following:

Iron oxide	160g
Kaolin	400g
Silica	240g

This mixture should be passed three times through a sieve of 100 mesh in order to obtain a homogeneous mixture.

Wollastonite

This silicate of lime can be reconstituted by:

Chalk	150 gr
Silica	90 gr

Mix by sieving in the same way as above.

Diopside

This secondary form of granite is a silicate of lime and magnesium, reconstituted here by:

Chalk	100gr
Talc	130gr
Silica	60gr

The same method of mixing by sieving is employed.

Note: If you possess a grinding mill, the mixtures can be made by placing the powders and a few grinding balls in a cylindrical plastic box inside the jar of the mill. Turn for one hour. Such a grinding mill will be indispensable when a potter wishes to compose glazes with materials that do not combine closely enough if merely sieved together.

Notation of experiments by triangle

We are going to mix our silicates by groups of three, in every possible combination, the unit of weight being the gram and the combination of the three components always totalling 10 grams.

The four silicates chosen are distributed as follows:

Ochre Ochre

1. 2.

Wollastonite Feldspar Diopside Feldspar

Figure 1 (p25)

The doses of each of the three silicates will be as follows:

Ochre

Feldspar Wollastonite
or Diopside

Figure 2 (p25)

The following graphic, which superimposes the 3 triangles of Figure 2, gives both the identity (code) for each mixture and the doses in grams of each component mineral.

Ochre

Wollastonite Feldspar
or Diopside

Figure 3 (p26, needs corrections)

Example:

Code:	A 10	C 6	E 3	F 5
Wollastonite or Diopside	0	2	3	0
Feldspar	0	2	4	5
Ochre	10	6	3	5

For the benefit of people who might find the figure hard to follow, the following table lists all the codes of the figure, together with the doses for each. However, arranging the fired test shards in the shape of the triangle permits a far better visualisation of the processes by which glazes are formed.

a=Code; b=woolastonite or diopside; c=feldspar; d=ochre

a	b	c	d	a	b	c	d	a	b	c	d
A	10	0	0	A1	9	0	1	A2	8	0	2
B	9	1	0	B1	8	1	1	B2	7	1	2
C	8	2	0	C1	7	2	1	C2	6	2	2
D	7	3	0	D1	6	3	1	D2	5	3	2
E	6	4	0	E1	5	4	1	E2	4	4	2
F	5	5	0	F1*	4	5	1	F2*	3	5	2
G	4	6	0	G1*	3	6	1	G2*	2	6	2
H	3	7	0	H1*	2	7	1	H2*	1	7	2
I*	2	8	0	I1*	1	8	1	I2*	0	8	2
J*	1	9	0	J1*	0	9	1				
K	0	10	0								
A3	7	0	3	A4	6	0	4	A5	5	0	5
B3	6	1	3	B4	5	1	4	B5	4	1	5
C3	5	2	3	C4	4	2	4	C5	3	2	5
D3	4	3	3	D4	3	3	4	D5	2	3	5
E3	3	4	3	E4	2	4	4	E5	1	4	5
F3*	2	5	3	F4*	1	5	4	F5	0	5	5
G3*	1	6	3	G4	0	6	4				
H3	0	7	3								
A6	4	0	6	A7	3	0	7	A8	2	0	8
B6	3	1	6	B7	2	1	7	B8	1	1	8
C6	2	2	6	C7	1	2	7	C8	0	2	8
D6	1	3	6	D7	0	3	7				
E6	0	4	6								
A9	1	0	9	A10	0	0	10				
B9	0	1	9								

In this table, the codes marked by an asterisk indicate the mixtures producing results most directly useful for the potter. This may help those who do not have enough time to weigh out and mix the full series.

Making test shards

When the potter intends to use new glazes, each new composition should be tested on several different clay bodies. The body has a considerable influence on the behavior of a glaze, depending on whether it is more or less rich in iron oxide (red or white clays), in free silica (not combined with alumina as it is in kaolin), or in alkalis. Of course, it is hardly possible to employ a great number of different clays, but a potter ought at least to dispose of one red and one white clay. There are also white, porcelain clays available on the market which are strongly recommended for certain kinds of glaze, particularly celadons.

Potters have different ways of making the test shards. The main thing is to test each glaze on a vertical surface, to see if, and how much, it is inclined to run on firing.

Figure 4 (photo p28)

The picture above shows a way of shaping test shards on a wheel, which is especially rapid. The slight forward slant of the pieces offers a better guarantee of stability in the kiln.

The thickness of the clay is equally important. Between body and glaze there will form a zone of transition during the firing, combining aspects of both and helping bond the two. If the clay body is too thin, the transition zone of the inner surface connects with that of the outer, making the whole much more fragile and cracking the glaze.

Once the clay has dried, the shards should be biscuited to 950º in an oxidizing atmosphere, unless, of course, your glaze is destined for work that is single-fired. However, this latter technique is very challenging, especially when the glaze needs to be applied thickly or lacks plasticity.

Weighing and sieving

Figure 5 (photo p29)

1. Scales sensitive to 1/100 of a gram.
2. List of weighings. Each combination should be crossed out as soon as it is done. This allows for sudden interruptions.
3. Small, clearly numbered cups into which the powders are poured once weighed.
4. Sieve, composed of a simple plastic cylinder with a nylon screen (100 mesh) forming a cup-shaped pouch held in place by a tight collar. You should ensure that all the minerals intended for use in your tests pass through mesh 100 without difficulty.
5. Sheet of strong, glazed paper to take the mixed powder as it passes through the sieve. Each test mixture should be sieved 3 times.
6. Stainless steel spoon used in weighing and also in glazing the test shards.

Glazing

(See figures 6 and 7 photos p31)

The glazing of each test shard must be done in the same way as the glazing of a pot. The quantity of water used in each case should be carefully measured. Stir the mixture using a small brush until you obtain a smooth cream. The layer of glaze should be too thick rather than too thin. If too thin, you will end up with nothing but the transition zone. The best method is to double-glaze one portion of the test shard.

On the unglazed back of each shard write, using a brush dipped in a suspension of iron oxide, the identity of each test. For example:

▲ 1 A4 R

refers to code A4 of the first triangle fired in a reducing atmosphere.

Firing

When filling the kiln, you may be tempted to distribute the test shards everywhere there is room. This is not wise, and may make a comparison between your fired specimens confusing. All should rather be grouped in a zone of the kiln where the regular temperature corresponds accurately with that of your final pyrometer.

There are some necessary points to be made concerning the firing.

Heat

When carbon and oxygen combine, heat is given off. This reaches its height when one atom of carbon combines with two of oxygen. When this condition is achieved, i.e. when you provide just enough air (neither more nor less) to a given quantity of gas to allow the reaction $C + O_2 = CO_2$ to occur, the atmosphere is said to be 'neutral.' This provides the quickest rise in temperature.

Oxidation

This 'neutral' atmosphere is never rigorously present in the kiln. The quantity of air supplied is always slightly above or below the theoretical norm. Therefore, when firing in oxidation (**essential when biscuiting**) you provide a safety margin by letting slightly more air than necessary enter the kiln.

Reduction

If the quantity of air is reduced, or the volume of gas entering is increased, only part of your fuel finds the oxygen needed to produce CO_2. The rest of the carbon atoms will have to make do with a single oxygen atom, forming CO, carbon monoxide.

This carbon monoxide serves as the reducing agent. Unstable, it seeks out a second oxygen atom to stabilize its structure. Not finding one in the hot gas in the kiln, it takes one from the materials constituting the pots, especially those ready to give up their oxygen without too much difficulty, iron oxide in particular. Whence the term 'reduction,' referring to the removal of oxygen from the oxides in the pots.

It should be noted that any CO unable to find a balance in this way burns as it leaves the kiln with a flame that gives off little heat. The sight of such a flame can to some extent serve to indicate the degree of reduction present in a kiln.

Mistakes in firing

Success with glazes depends to a large degree on a right understanding of the mechanics of combustion. Experience is essential here. Still, we might indicate a few errors that must be avoided.

During an oxidizing firing, allowing an excessive quantity of air into the kiln will only cool it down, slowing the rise of temperature and resulting in a pointless waste of fuel.

The same slowing down can be provoked in reduction by too much cold gas; beginners are surprised when advised to reduce their gas pressure to obtain a quicker rise in temperature!

If the atmosphere at the burners is too poor in oxygen, the flame will be smoky, soft and bright. Finding no available oxygen, free carbon passes through the kiln as smoke. That is not only a waste of fuel, it can provoke faults in glazes.

This last mistake must especially be avoided when biscuiting.

Below 1000º, the firing can be as rapid as possible, within the limits imposed by the ability of the wares, the kiln walls and the firing supports to resist. While biscuiting, 3 – 4% of excess oxygen should be the upper limit.

Analysing atmospheres

Figure 8 (p33 translate)

Nowadays, atmosphere analysers are perfectly accessible in price and simple to use. All that they have to show is the percentage of carbon dioxide (CO_2) and oxygen (O_2) present.

Above (Figure 8) is a diagram representing a firing in reduction, in which the percentages of carbon dioxide and oxygen in the kiln are combined with a curve representing an average pattern of temperature rise when firing glazed pieces.

Examining the fired experiments

Ongoing research is dependant on a minute reading of the results of each firing. It is worth insisting once more on the fact that the reading of these results will be much easier if all the test shards have been fired correctly, all at the same temperature and in the same atmosphere, and are then arranged in triangles according to their respective codes.

The same mixtures are bound to result in differently nuanced results from one workshop to the next. For that reason, we can only offer a general description of the first series of experiments. Attention must be paid in turn to the melting, the color, and the homogeneity of the resulting glazes.

Ochre

Wollastonite
or Diopside

Feldspar

Figure 9 (p34)

Melting

As shown in Figure 9, it is possible to indicate within a triangle a variety of zones in which melting is more or less complete.

Zone 1 includes the glazes with a correct melting point, almost all of them usable for pottery. The feldspar located at the point of the triangle can in fact melt alone but it is only used as such in higher temperature firings.

At the far extreme from this first series, zone 4 shows a small group of compositions that have not melted. That is hardly surprising, seeing that wollastonite melts at 1544º and diopside at 1391º.

By their composition, the mixtures in zone 3 are close to certain kinds of ferruginous clays. Easy to vitrify, they are best considered as vitrified slips and can usefully play that role applied underneath other glazes.

Zone 2 reveals plainly a phenomenon important in every form of melting. This zone includes the compositions the most easily melted of the entire triangle, especially along the line linking wollastonite, or diopside, to ochre. It is sufficient to mix these minerals, neither of which will melt alone, to have them melt. This is the natural phenomenon known as ‘eutexy’ to which we shall often be referring in the following pages.

Melting point of a few minerals in their pure, unmixed state:

Alumina	Al_2O_3	2020º
Silica	SiO_2	1707º
Lime	CaO	2570º

Iron oxide	Fe_2O_3	1565°
Magnesium oxide	MgO	2800°
Kaolin	$2\ SiO_2\ Al_2O_3\ 2H_2O$	1545°
Wollastonite	$CaO\ SiO_2$	1544°
Talc	$3MgO\ 4SiO_2$	1500° approx
Diopside	$0.5MgO\ 0.5CaO\ SiO_2$	1391°
Ochre	$Fe_2O_3\ 1.4Al_2O_3\ 7SiO_2$	1600-1700°
Orthose	$6SiO_2\ Al_2O_3\ K_2O$	1220°
Albite	$6SiO_2\ Al_2O_3\ Na_2O$	1220°

Color

These two initial triangles can be considered as a map, on a very large scale, of all the stoneware glazes that can be made using our seven basic oxides: CaO, MgO, K_2O, Na_2O, Al_2O_3, Fe_2O_3, SiO_2. This is particularly clear when we list the different colors, all of them the result of iron oxide being affected by changes of composition and of firing atmosphere. From this large-scale map, the potter will have to begin a detailed survey of a particular region, working to bestow on it the finest qualities possible. But these initial results already herald the main families of stoneware glazes, in particular those of the first triangle, fired in reduction. This is summarized in the following diagram:

Code	Family of glazes
F, G, H, I, J	Transparent colorless to opaque white
F1, F2, G1, G2, H1, I1	Transparent green-blue, iron blues, celadon
J1	Shino red
H2, I2, G3, H3, E4, F4	Various browns
E3, F3, D4	Temmoku (black)
D5, B6, C6, B7	Iron reds

In an oxidizing atmosphere, this same initial triangle offers less varied and less clearly defined colors. In particular, the blue-greens, typical products of reduction, are replaced by olive hues.

You will notice, mainly on the line between feldspar and ochre, certain badly blistered tests, a first encounter with a phenomenon linked to the decomposition of ferric oxide (Fe_2O_3) which ultimately will give us the glazes known as ‘oil-spot’ to be studied later.

In addition, we should note that the glazes as a whole appear here to be less fluid than in reduction.

In the second triangle fired in reduction, the magnesia introduced by the talc produces an obvious change in the colors. The transparent ones tend to become more opaque, bluish greens veer toward a yellowish green. (cf. Plate 2)

Homogeneity

A glaze may be homogeneous or heterogeneous. These terms are borrowed from mineralogy, where a rock crystal for example may be said to be identical at every point, and therefore homogeneous, whereas a block of granite, made up of several distinct minerals, is said to be heterogeneous. Likewise, there may be features in a glaze that are distinct from the vitrified mass, either the juxtaposition of different forms of glass, crystals of different sizes, or nucleations, depending on the processes undergone during the formation of the glaze.

Thus, in the first triangle, in reduction, we find among the iron reds the formation of fine crystals of hematite, while in compositions closer to wollastonite can be seen mixtures of different silicates.

But this heterogeneity can be seen most obviously in the second triangle. In addition to zones sprinkled with grains of iron oxide, magnesia gives rise to crystals, varying in size, of yellow diopside; this is particularly developed in oxidation, where the whole glaze takes on a lemon-yellow tone. (cf. Plate 3)

Glazes of the ‘oil-spot’ variety might also be included among the heterogeneous variety. They are found best formed in the second triangle, in oxidation.

Exercises

The exercises proposed below can be performed after firing triangles 1 and 2. They will increase the number of usable glazes available, and give a fuller insight into the role of certain minerals in the melting process.

Correction by the addition of kaolin

Glazes that are too fluid can be fired at a temperature slightly lower than 1280º. They can also be used to take advantage of certain cooler zones in the kiln, if any. But they can be corrected by adding between 5% and 20% of kaolin; that is to say, between 0.5 and 2 grams of kaolin are added to the 10 grams of mixed minerals that need this correction.

Using less iron oxide

Since we have reconstituted our ochre, we have the possibility of varying the level of iron oxide, especially, which brings about modifications of fusion and color.

If iron oxide is completely eliminated from some compositions that are highly fusible in reduction (for example, C2, D2, E2, D3, E3 in the first triangle) we obtain a new quality of transparent, colorless glazes that no longer run. This reveals the way in which iron oxide in reduction forms an eutectic with the kaolin of the glaze.

Replacing silicates

New triangles, or portions of triangles, can be made by replacing the silicates at the three points with other minerals of the same category:

Orthose can be replaced by albite.

Wollastonite or diopside can be replaced with a mixture of wood ash and silica in the following proportions: wood ash 100, silica 60.

Reconstituted ochre can be replaced with a natural ochre that is not mixed with chalk, or with a red clay equally free of chalk (use the acid test) enriched by additional iron oxide if necessary.

Before firing all the tests for such a new triangle, you are advised to make a few specimen tests first.

Transitions between two test shards

When reading the triangles, we sometimes find striking contrasts between two mixtures that stand very close together—for example, between D4 and E4 in the wollastonite triangle or between G2 and F3 in the diopside triangle. You might wish to divide the distance between such points by 5 or 10; this will provide you with a good variety of transitional compositions. For example:

	D4					E4
Woolastonite	3	2.8	2.6	2.4	2.2	2
Feldspar	3	3.2	3.4	3.6	3.8	4
Ochre	4	4	4	4	4	4

Conclusion of Part 1

The initial recipes and the two first triangles will permit readers to take a few steps. For some, it will be enough. But for those wishing to go further, this first method has its inconvenient sides, the main one being the way all the components vary at once as we pass from one test to the next. That makes it hard to identify the function of each oxide in the process of the glaze. Now it is precisely knowledge of that, or at least what we can know about that function, that allows us to advance. In addition, when we want to modify or improve a test sample, it is usually the quantity of a single oxide that has to be modified. In order to do that, we have to provide ourselves with a less limited method.

Formulae

From recipe to formula
Establishing the formulae of one’s raw materials
From formula to recipe
Exercises

Formula: the proportion, expressed in moles, of the oxides making up a fired glaze.

All that melts is not a silicate.

From recipe to formula

So far, we have made do with recipes, rather like a housewife making a cake by following her cookery book. Now a recipe has either been communicated to you by some other person, who perfected it, or it emerges at the end of your own research. What matters then is how to undertake that research in the best conditions, with a minimum of fumbling and a maximum of knowledge possible.

The ideal would surely be to be able to represent to oneself in advance how the flame is going to transform the mixture of raw materials one is about to entrust to it. That would at least have the advantage of allowing you to avoid at least the worst errors. We are going to see that this kind of foresight is at least partially attainable.

The work of the fire

To begin with, let us note this: a very close mixture of the ingredients of a future glaze can never be anything more than the juxtaposition of raw materials. In a microscope, all you would see would be grains of silica beside grains of chalk, talc, feldspar, and kaolin, for example. Even the finest grinding can never replace the work done by the flame. That work consists of transforming those different minerals into a silicate defined previously as a network of silica enclosing various oxides. To form that skeleton of the glaze, the flame uses not only the free silica supplied initially but equally that contained in the kaolin, the feldspar, or the talc. The fire is going to dissociate the raw materials, group oxides by category, and with them compose the glaze.

A game of musical chairs

If you have ten people walking around nine chairs while the music plays, then all trying to sit down when it stops, you end up with one being the loser. You might compare that to the work of the fire. The chairs represent the network of silica; the players are the oxides which, at the moment the music stops, that is, at the end of the firing, must already be installed inside the network. Only in a glaze that is meant to be balanced and stable, all the players have to find their place. Then there have to be enough chairs, that is, enough silica. How can we ensure in advance that balance, that stability? How can we dose our raw materials in such a way that the fire will make of them a silicate worthy of the name? By counting in advance the players and the chairs, that is, the molecules of the oxides. How is that to be done?

A fruit salad

A cook goes to market to buy fruit to make a fruit salad. The vendor turns out to have the curious habit of only selling fruit in baskets of three—three melons, three grapefruit, three apples, three apricots, three plums. Under such conditions, obviously the cook will only buy a single basket of melons or grapefruit, while buying several baskets of the other fruits, the smaller the fruit, the more baskets are needed. Back home, the cook will then make the fruit salad by following a recipe, taking perhaps just half a melon, one grapefruit, three apples, six apricots and three plums.

Let us call each of the fruits **molecule** and the group of three fruits in each basket a **mole**; obviously the weight of each basket will vary depending on the variety of fruit it contains. That weight we shall call **molar mass**.

Apart from this difference of vocabulary, the mathematical difficulties confronting the potter in concocting glazes are no greater than those of the cook making a fruit salad!

Scales that count

Naturally, a mole contains more molecules than there were fruits in the various baskets. It is actually quite a large number, something like 6023 followed by twenty zeros! What needs to be remembered is not that number, but the fact that the mass of the molecules represented by it varies according to the nature of each oxide. For example, if I weight out 60 grams of silica, I shall have a mole of that oxide. While a mole of iron oxide (Fe_2O_3) will weigh 160 grams.

Thus the potter counts in moles, using scales, the components of a glaze and writes out the formulae in advance as if they were already fired, before ever translating them into recipes.

The identity card of a glaze

Recipes can vary to an infinite extent because of the host of materials nature makes available to us. The formulae, however, are very similar on account of the oxides composing them. In this study, there will only be 7 oxides and they will always be noted in the following order:

_.__CaO		
_.__MgO	_.__Al_2O_3	_.__SiO_2
_.__K_2O	_.__Fe_2O_3	
_.__Na_2O		

There we have the identity card common to all our glazes. The figures preceding each symbol will indicate later the particular identity of each, the multiples or subdivisions of each mole of the different oxides.

When no figure precedes it, a symbol represents a mole.

The two oxides K_2O and Na_2O will most of the time be grouped under the symbol KNaO, given the very frequent simultaneous presence of both alkalis in our feldspars.

The arrangement in three columns should be noted. That to the left contains the oxides with basic function, that to the right contains silica, with acid function. The central column brings together alumina and iron oxide, both substances known as amphoteric, capable of becoming either basic or acidic during firing.

Here is a glaze formula (see diagram 18 later in this book):

Basic	Amphoteric	Acidic
0.7 CaO	0.55 Al_2O_3	4 SiO_2
0.1 MgO	0.04 Fe_2O_3	
0.2 KNaO		
1.0		

We should stress already that such an identity card indicates nothing more than the proportion of oxides within a glaze, a proportion that remains the same no matter the quantity of glaze we mix. As can be seen, the basic oxides add up to one mole. This is a convention allowing us at once to check if the formula is that of a silicate, i.e., returning to the musical chairs image, if there are sufficient chairs for all the players to be able to sit down at the end of the music. In theory, all that is needed is one chair for each player, that is, one mole of silica for each mole of basic oxides. That can happen in nature; wollastonite ($CaO\ SiO_2$) is an example, or in the laboratory under certain conditions. But in the potter’s kiln, the music is too fast, the rise in temperatures is too rapid, so we have to increase the number of chairs, that is, increase the dose of silica. Therefore, for safety’s sake, we never go below 1.5 moles of silica for a mole of basic oxides.

This minimum is all the more important because a mixture of oxides can melt without in fact a silicate being present. The result will then lack stability over time. For example, lime (CaO) not in combination with silica will sooner or later fall victim to decomposition by some kind of acid—even vinegar will do.

Putting our raw materials into their baskets

Suppose now that we imagine a potter equipped with the formula for a glaze. That formula can only be transformed into a recipe if, for a moment, the potter takes the role of the fruit vendor by putting the materials into their baskets, translating the technical cards into moles.

This is how it is done. First, the percentages of the various oxides indicated on the cards have to be divided by the molar masses corresponding to each. Here is the list:

SiO_2	60
Al_2O_3	102
Fe_2O_3	160
TiO_2	80
CaO	56
MgO	40
K_2O	94
Na_2O	62

These divisions will provide a provisional formula noted in the same order as that of a glaze. The total of the basic oxides in such a formula will not be equal to one mole. It is when we bring it to unity that we establish the definitive formula. We will offer now some completed examples of this transformation.

Establishing the formula of a feldspar

In this first example, exceptionally, we are going to calculate to four decimal places.

Technical card		divisor	moles
SiO_2	69.7	60	1.1616
Al_2O_3	17.5	102	0.1715
TiO_2	0.1	80	0.0012
Fe_2O_3	0.35	160	0.0021
CaO	0.3	56	0.0053
MgO	0.3	40	0.0075
K_2O	2.5	94	0.0265
Na_2O	7.5	62	0.1209
	99.25		

We then write the provisional formula as for a glaze:

0.53 CaO		
0.0075 MgO	0.1715 Al_2O_3	1.1616 SiO_2

0.0235 K_2O 0.1209 Na_2O 0.1602	0.0021 Fe_2O_3	0.0012 TiO_2

By dividing now all these values by the total of basic oxides we arrive at the definitive formula in which that total approaches unity:

0.033 CaO 0.0468 MgO 0.1654 K_2O 0.7546 Na_2O 0.9998	1.0723 Al_2O_3 0.0130 Fe_2O_3	7.2509 SiO_2 0.0074 TiO_2

In order to find the molar mass of this feldspar, the total of the oxides on the technical card is divided by the same divisor:

$$99.25 \div 0.1602 = 619{,}538$$

Needless to say, this kind of avalanche of decimal places, no matter how flattering for a perfectionist assisted by a calculator, is hardly necessary. Above all, the calculations we have just made demonstrate clearly that the minor oxides can be omitted; which is not to say that the fire will ignore them. But their role will be minimal and will have only an insignificant influence on the fusion. Moreover, we can make do with two decimal places. All that is needed is to avoid rounding figures off before the last stages of the calculation. Now we can again calculate the formula of the same feldspar, taking these simplifications into account:

Technical card		divisor	moles
SiO_2	69.7	60	1.1616
Al_2O_3	17.5	102	0.1715
K_2O	2.5	94	0.0265
Na_2O	7.5	62	0.1209

Provisional formula:

0.0235 K_2O 0.1209 Na_2O 0.1474	0.1715 Al_2O_3	1.1616 SiO_2

This formula corresponds, of course, to the total of 99.25 on the technical card. The definitive formula (divisor: 0.1474):

0.18 K_2O 0.82 Na_2O	1.15 Al_2O_3	7.9 SiO_2

or simply:

KNaO	1.15 Al_2O_3	7.9 SiO_2

Mass molar: 99.25 ÷ 0.1474 = 673

The formula and molar mass of a talc

Technical card		divisor	moles
LF	6.2		
SiO_2	57.8	60	0.963
Al_2O_3	2.8	102	0.027
TiO_2	0.8		
Fe_2O_3	0.1		
CaO	0.3		
MgO	31.9	40	0.797
K_2O	0.1		
	100		

Provisional formula:

0.797 MgO	0.027 Al_2O_3	0.963 SiO_2

Definitive formula (divisor: 0.797)

MgO	0.03 Al_2O_3	1.2 SiO_2

Molar mass: 100 ÷ 0.797 = 125.4

Formula and molar mass of a chalk

Technical card		divisor	moles
LF	43.66		
SiO_2	0.13		
Al_2O_3	0.7		
Fe_2O_3	0.02		
P_2O_5	0.03		
CaO	54.6	56	0.975
MgO	0.70		
	99.84		

Provisional formula: 0.975 CaO
Definitive formula: CaO
Molar mass: 99.84 ÷ 0.975 = 102

Formula and molar mass of a kaolin

Technical card		divisor	moles
LF	12.58		

SiO_2	47.28	60	0.766
Al_2O_3	37.04	102	0.363
Fe_2O_3	0.85		
P_2O_5	0.03		
TiO_2	0.14		
CaO	0.09		
MgO	0.06		
K_2O	1.41		
Na_2O	0.08		
	99.56		

Provisional formula:

0.363 Al_2O_3	0.788 SiO_2

Definitive formula, with alumina brought to unity:

Al_2O_3	2.17 SiO_2

Molar mass: 99.5 ÷ 0.363 = 274

Practical conclusion regarding the purchase of materials

The molar masses which have just been calculated are different, sometimes markedly different, from those usually indicated in manuals; this is inevitable. The authors find themselves obliged to give the masses of minerals considered to be absolutely pure, something rarely found in reality. But for potters capable of transforming their technical cards into formulae, these theoretical indications permit a more judicious choice of raw materials. Their formulae should be as close as possible to those indicated in the table below:

Mineral	PF	Formula after firing	Mass
Chalk	44	CaO	100
Talc	6	MgO 1.3SiO_2	126
Orthose	0	K_2O Al_2O_3 6SiO_2	558
Albite	0	Na_2O Al_2O_3 6SiO_2	525
Kaolin	36	Al_2O_3 2SiO_2	258
Silica	0	SiO_2	60

Note: The loss in firing of actual materials may well differ from those indicated. For example, if what is sold as talc includes chlorite, the loss in firing will be more than 6.

From formula to recipe

Now the potter is able to work out the recipes for glazes using the formulae and real masses of the materials.

First, the materials composing the glazes have to be selected. Since we have limited ourselves here to a minimum number of minerals, the choice is soon made.

The table below should make the choice easier. The formulae and masses are those of the technical cards that have just been studied. In an appendix can be found a similar table involving a larger number of components.

Figure 10 (p52 needs translating)

Calculation

A series of examples of increasing complexity will now serve to illustrate the method of calculating recipes.

Recipe A

Although not a glaze, we may begin by coming back to the reconstitution of wollastonite, with its formula $CaO\ SiO_2$. Since there is a mole of each oxide, no calculating is needed; all that is needed is a mole of chalk (100g) and a mole of silica (60g).

Recipe B

This time, we can reconstitute diopside, with its formula:

$$\begin{array}{ll} 0.5\ CaO & SiO_2 \\ 0.5\ MgO & \end{array}$$

First comes half a mole of CaO, provided by chalk, with its mass of 100, giving us 0.5 x 100 = 50g.

The half mole of MgO is provided by talc, with its simplified formula $MgO\ 1.2\ SiO_2$ and with mass 125. As a result, talc will at the same time provide a proportional quantity of silica. In order to obtain the 0.5 MgO required, we shall also gain 0.5 x 1.2 = 0.6 SiO_2 and a weight of talc of 0.5 x 125 = 62.5g.

Since the formula of diopside demands a mole of silica, we still have to provide:
1 – 0.6 = 0.4 SiO_2 x 60 = 24g.

In order to avoid any error, the calculation can be written in the following manner:

Formula ►	0.5 CaO 0.5 MgO	SiO_2	Recipe ▼
Chalk	0.5 CaO		0.5 x 100 = 50g
Talc	0.5 MgO	0.5 x 1.2 = 0.6	0.5 x 125 = 62.5g
Silica		1.0 – 0.6 = 0.4	0.4 x 60 = 24g

Recipe C

Here is a glaze, of the celadon family (cf. Diagram 1), with first its formula:

$$\begin{array}{lll} CaO & 0.5\ Al_2O_3 & 3SiO_2 \\ 0.04\ Fe_2O_3 & & \end{array}$$

For the CaO, we take a mole of chalk, 100g.

In this case, the 0.5 Al_2O_3 can only be supplied by kaolin which at the same time supplies a proportional quantity of SiO_2 equal to 0.5 x 2.17 = 1.085 SiO_2. The quantity of kaolin needed will be 0.5 x 274 = 137g.

For the iron oxide, we shall need 0.04 x 160 = 6.4g.

For silica, the formula demands 3 SiO_2. We already have 1.085 SiO_2 thanks to the kaolin. We still need 3 – 1.085 = 1.915 SiO_2, so the weight of the additional silica will be 1.915 x 60 = 115g.

Finalized calculation:

Formula ►	CaO	0.5 Al_2O_3 0.04 Fe_2O_3	3 SiO_2	Recipe ▼
Chalk	CaO			1 x 100 = 100g
Kaolin		0.5 Al_2O_3	1.085 SiO_2	0.5 x 274 = 137g
Iron oxide		0.04 Fe_2O_3		0.04 x 160 = 6.4g
Silica			3 - 1.085 = 1.915 SiO_2	1.915 x 60 = 115g

A rule for the order of operations in calculating formulae

Although the previous examples do not make this clear, it is very useful to follow the following rule when calculating glaze recipes:

Always move from the more complex minerals toward the simpler ones.

That gives, in the order of priorities:

Feldspar (3 oxides)
Kaolin and talc (2 oxides)
Chalk, iron oxide, silica (1 oxide)

For, clearly, if you begin with kaolin instead of feldspar for example, you find the feldspar introducing more alumina than you need.

When weighing sample quantities, it is already clear that the recipes emerging from our calculations involve a total weight of minerals far superior to the ten grams or so needed to glaze a couple of test shards. It is easy to reduce the total quantity, to 10g say, simply remembering that a formula does not change so long as the proportions of each mineral remain the same.

For the next recipes, we will simply provide the finalized calculation:

Recipe D

Formula ►	0.5 CaO 0.5 MgO	0.55 Al_2O_3	3 SiO_2	Recipe ▼
Chalk	0.5 CaO			0.5 x 100 = 50g
Talc	0.5 MgO		0.5 x 1.2 = 0.6 SiO_2	0.5 x 125 = 62.5g
Kaolin		0.55 Al_2O_3	0.55 x 2.17 = 1.19 SiO_2	0.55 x 274 = 150.7g
Silica			3 – (0.6 + 1.19) = 1.21 SiO_2	1.21 x 60 = 72.6g

Recipe E (temmoku family)

Formula ▶	0.64 CaO 0.36 KNaO	0.58 Al_2O_3 0.15 Fe_2O_3	3 SiO_2	Recipe ▼
Chalk	0.64 CaO			0.64 x 100 = 64g
Feldspar	0.36 KNaO	0.36 x 1.15 = 0.414 Al_2O_3	0.36 x 7.9 = 2.84 SiO_2	0.36 x 675 = 243g
Kaolin		0.58 – 0.414 = 0.166 Al_2O_3	0.166 x 2.17 = 0.36 SiO_2	0.166 x 274 = 45.5g
Iron oxide		0.15 Fe_2O_3		0.15 x 160 = 24g
Silica				1.8 x 60 = 108g

Recipe F

Formula ▶	0.4CaO 0.4 MgO 0.2 KNaO	0.3 Al_2O_3 0.02 Fe_2O_3	3.5 SiO_2	Recipe ▼
Chalk	0.4 CaO			0.4 x 100 = 40g
Talc	0.4 MgO		0.4 x 1.2 = 0.48 SiO_2	0.4 x 125 = 50g
Feldspar	0.2 KNaO	0.2 x 1.15 = 0.23 Al_2O_3	0.2 x 7.9 = 1.58 SiO_2	0.2 x 675 = 135g
Kaolin		0.3 – 0.23 = 0.07 Al_2O_3	0.07 x 2.17 = 0.15 SiO_2	0.07 x 160 = 3.2g
Iron oxide		0.02 Fe_2O_3		0.02 x 160 = 3.2g
Silica			3.5 – (0.48 + 1.58 + 0.15) = 1.29 SiO_2	1.29 x 60 = 77.4g

Exercise 1

Establish the formulae for the following 4 initial recipes:

	1.	2.	3.	4.
Chalk	13	10	8	7
Talc		10	10	8
Feldspar	50	60	55	54
Kaolin	12	10	3	12
Silica	20	10	22	13
Iron oxide	5		2	6

Correct solution for recipe 3:

Chalk	8 ÷ 100	= 0.08 CaO		
Talc	10 ÷ 125	= 0.08 MgO		0.096 SiO_2
Feldspar	55 ÷ 675	= 0.08 KNaO	0.0937 Al_2O_3	0.644 SiO_2
Kaolin	3 ÷ 274	=	0.0109 Al_2O_3	0.0237 SiO_2
Iron oxide	2 ÷ 160	=	0.0125 Fe_2O_3	
Silica	22 ÷ 60	=		0.3666 SiO_2

Provisional formula:

0.08 CaO 0.08 MgO 0.08 $KNaO$ 0.24	0.1045 Al_2O_3 0.0125 Fe_2O_3	1.1303 SiO_2

Definitive formula (divisor 0.24):

0.33 CaO 0.33 MgO 0.33 $KNaO$	0.43 Al_2O_3 0.05 Fe_2O_3	4.7 SiO_2

Exercise 2

Put into formulae whichever recipes for the first two triangles seem most interesting to you. In the following chapter, we indicate ways of correcting or pursuing further recipes once they have been converted into formulae.

Eutectics

Making things melt that will not melt alone
Making glazes by mixing eutectics and feldspars
Nothing ‘makes things melt’: fusion is a phenomenon rooted in relationships

A mixture of oxides always melts more readily than any of those oxides alone. The eutectic is the most fusible mixture.

Eutexy

CaO	2570°
MgO	2800°
Al_2O_3	2020°
Fe_2O_3	1565°
SiO_2	1707°

If we began by looking at the melting points of the main oxides used in glazes, it would seem impossible for any of them to melt in our kilns. The temperatures are all far higher than those at which stoneware is fired.

Fortunately, the problem is only apparent, not real. A natural phenomenon comes into play that lowers the temperatures as soon as the oxides are mixed together. This is the phenomenon known as ‘eutectics’ from the Greek meaning ‘melts easily.’ Eutectics are always present to a greater or lesser extent, depending on the proportions in which oxides are mixed. The feldspars, orthose and albite, are good examples for they melt at 1200° and 1220° respectively. (These are the temperatures for pure samples, not the qualities found on the market which usually melt at slightly higher temperatures.)

Eutectics

Certain specially favored combinations break all the records, so to speak. Thus a mixture of 58% of albite and 42% of orthose melts at 1160°. This is what is meant by an eutectic.

Their melting point is lower than that of the more fusible oxide in the mixture. Here are two eutectics that play a decisive role in stoneware glazes:

CaO	$0.35\ Al_2O_3$	$2.48\ SiO_2$	Fusion: 1165°
MgO	$0.5\ Al_2O_3$	SiO_2	Fusion: 1330°

Needless to say, these minimal temperatures are only obtained if the components of the mixtures reproduce the formulae exactly. That kind of precision is never obtained in a workshop, given the rapidity of our firings and an inevitable margin of imprecision and impurity in the composition of our raw materials. That is nothing to be worried about; the temperatures will simply be slightly higher, that is all. In addition, the formulae for stoneware glazes are never identical to those of a single eutectic. It is important to realize that several eutectics work together in the melting of a glaze, and that that too has an influence on the melting point.

Obtaining glazes by mixing eutectics and feldspars

First stage: the triangle

$MgO\ \ 0.5\ Al_2O_3\ \ SiO_2$

$CaO\ \ 0.35\ Al_2O_3\ 2.48\ SiO_2$

Feldspar (orthose or albite)

Figure 11 (p62)

Here we use the method of a triangle with at its summits two eutectics and a feldspar.

1. Eutectic: CaO 0.35 Al_2O_3 2.48 SiO_2. This is made using chalk, kaolin and silica.
2. A feldspar, orthose or albite or a mixture of both, or else a nepheline syenite, for those who use that mineral.
3. Eutectic: MgO 0.5 Al_2O_3 SiO_2. Here the reconstitution will be made using a mixture of talc, which introduces more silica than is needed but it does not matter, and alumina calcined and ground as finely as possible, sieve mesh 200 minimum. The molar mass of Al_2O_3 is equal to 102. The same alumina is used, mixed with an equal weight of kaolin, to coat the plates on which pieces stand in the kiln

.

Each mixture is mixed thoroughly by passing three times through a 100 mesh sieve; the test samples will then be weighed out as described previously.

This triangle forms the starting point for the exploration of white glazes, both shiny and mat.

Second stage: correcting a glaze

‘Making a cross’

The method with a triangle can only offer an initial approach; many of the glazes resulting from the previous exercise will need to be corrected, adjusted. This gives us the opportunity here to show how that is done.

The importance of the relationship between silica and alumina in developing a glaze has already been made very clear. Their relationship will appear in a very obvious way when we come to the fusion diagrams. But for the moment we are going to exploit it to correct a particular glaze.

If we take our example from the tests in the preceding triangle, we need to begin with a formula, which might be:

0.21 CaO 0.6 Al_2O_3 2.3 SiO_2
0.55 MgO
0.24 $KNaO$

This formula will be modified in four different ways, first by increasing, then by decreasing the silica by half a mole. Then the same is done with the alumina. The result is the following model:

	+ 0.5 SiO_2	
- 0.05 Al_2O_3	formula to be corrected	+ 0.05 Al_2O_3
	- 0.5 SiO_2	

We must stress that these corrections are made to one oxide at a time. This is always the case with corrections. By modifying a number of quantities at the same time, an improvement is sometimes found but without any indication of its precise cause, and so we lose a useful element of information.

By comparing the four new test shards after firing with the original glaze, at the center of the cross, it can usually be seen in which direction the desired improvement should be sought.

Sometimes a result leaves one perplexed. For example, you might have thought that by increasing the dosage of silica or alumina, both having very high melting points, you would be sure to improve too fusible a glaze, or that on the contrary reducing them would improve a glaze that was too hard. Yet the very opposite can happen. Once again, it will be easier to understand this apparent contradiction after we have come to the fusion diagrams. The more sugar you put in your coffee, the sweeter it becomes; that is logical. But the phenomena of eutectics are not governed by that kind of logic!

Third stage: introducing iron oxide

Once everything is complete, the glazes resulting from this last triangle can be the objects of a new, extremely interesting exercise. If you produced the glazes of the two initial triangles at the beginning of this book, you will have realized to a considerable extent what a variety of colors can be obtained by using iron oxide.

The causes of these variations will now become clearer as we vary the dosage of iron oxide in our new glazes. People often simply add coloring oxides as a percentage of the mixed glaze. However, we intend in what follows to include the iron oxide in the formula, since that will later enable us to make some useful comparisons.

Series 1	(Celadon or iron blue type)	0.04 - 0.06 Fe_2O_3
Series 2	(Temmoku type)	0.13 – 0.15 Fe_2O_3
Series 3	(Iron red and oil-spot type)	0.2 – 0.25

Here the reading of your tests will show clearly the role of the basic oxides in the development of the colors. For example, it will be clear that, in reduction, celadons appear in compositions with a high proportion of calcium, that the alkalis lead to ‘kaki’ red, and Mg to browns, to say nothing of all the transitions that are possible with variations in the mixtures of CaO, MgO and KNaO.

The oxides of iron

The influence of kiln atmospheres and glaze components
on ferric oxide
Types of ferruginous glazes

$$6Fe_2O_3 \overset{2\ Fe_2O_3\ Al_2O_3\ {}_2\ SiO_2}{<=>} 4Fe_3O_4 + O_2$$

Iron’s mobility

If iron fascinates the potter on account of the wide range of colors it makes available, that is because it is so mobile during firing. Its main characteristic is the ease with which oxides of iron give up or take back oxygen in reversible reactions known as chemical equilibria, that are conventionally represented by the sign <=>

In all the exercises proposed in this book we use red iron oxide, Fe_2O_3, the richest in oxygen. Once incorporated into a glaze, the oxide undergoes a series of modifications during firing. Very briefly, we can say that the agents of these modifications are, first, the atmosphere in the kiln and, second, the other components making up the glaze.

Modification of Fe_2O_3 in a reducing atmosphere

In the presence of CO, hematite (Fe_2O_3) loses part of its oxygen and turns into ferrous oxide, in the reaction:

$$Fe_2O_3 + CO \Leftrightarrow 2\ FeO + CO_2$$

In this chemical equilibrium, the ferrous oxide can turn back into ferric oxide when additional oxygen becomes available. Ferrous oxide begins to form above 570º, the temperature below which it decomposes.

Modification of Fe_2O_3 in an oxidizing atmosphere

In an oxidizing, oxygen-rich atmosphere, ferric oxide decomposes above 1210º and turns into black magnetic ferric oxide Fe_3O_4 in a reaction with the formula:

$$6\ Fe_2O_3 \Leftrightarrow 4\ Fe_3O_4 + O_2$$

This reaction can easily be made visible by firing to full stoneware temperature a small crucible containing ferric oxide. After firing, it will have shrunk and turned into a dense block of black magnetic oxide.

The passage from ferric to magnetic sets free a quantity of oxygen, provoking the phenomenon known as ‘oil-spot’ that is described later.

Modification of Fe_2O_3 by components within the glaze

By lime

Very many components of stoneware glazes contain lime (CaO). It can even represent the entire basic mole, as we shall see later in the first fusion diagram. Now in an oxidizing atmosphere, ferric oxide Fe_2O_3 combines with CaO to form a particularly fusible combination termed calcium ferrite, that melts at 1203º while CaO alone melts at 2570º and ferric oxide at 1565º.

Here again, this reaction can be verified by firing a suitable mixture of chalk and iron oxide in a small crucible or stoneware bowl.

By magnesia

The same phenomenon is found with MgO, that combines with ferric oxide Fe_2O_3 to form a ferrite of magnesium, from as low as 350º. This reaction, known as solid solution, occurs even before fusion. In both these examples, Fe_2O_3, being amphoteric as we know, plays the role of an acid.

By alumina

In addition, various combinations occur between Fe_2O_3 and Al_2O_3, both being amphoteric, with alumina playing the role of an acidic material while the iron oxide becomes basic. These iron aluminates likewise begin to form at relatively low temperatures.

If we calcinate a small quantity of iron oxide mixed with alumina, in a reducing atmosphere at full stoneware temperature, we obtain an orange powder, not black, as might have been expected. The color of a terra cotta flower pot, as well as of certain kaki glazes fired in reduction, seems to be due to this reaction.

By lime and silica

The mixture CaO 4FeO $5SiO_2$ melts at 1030º, another reaction making it easy to understand why certain stoneware glazes become so fusible with the addition of iron oxide when fired in reduction.

By alumina and silica

Figure 12 (photo p71)

Another eutectic, well-known to stoneware potters for the dramatic effect it produces, is what can be called the pyrites-eutectic. Its composition is :

$2FeO\ Al_2O_3\ 2SiO_2$

It only forms in reduction, as soon as the iron oxide finds itself in the company of kaolin or clay. Contrary to common belief, the pyrites do not melt in the clay but together with it. You can demonstrate the presence of this eutectic very clearly by firing a small amount of ferric oxide placed on top of a piece of light brick. In reduction, the brick will be literally devoured by the eutectic effect whereas in oxidation, as we saw preciously, it will remain intact under a layer of black magnetic oxide. (cf. Figure 12)

Summary table

	In oxidation
Above 1210º	$6\ Fe_2O_3 <=> 4\ Fe_3O_4 + O_2$
1203º	$CaO\ \ Fe_2O_3$
Above 350º	$MgO\ \ Fe_2O_3$
	In reduction
Above 570º	$Fe_2O_3 + CO <=> 2\ FeO + CO_2$

1030°	$CaO\ 4FeO\ 5SiO_2$
1210°	$2FeO\ Al_2O_3\ 2SiO_2$

Practical consequences

The reactions just described have not included any mention of the medium in which they occur, i.e. the other components of the glaze. It should be obvious that once they occur, the results establish new relationships with their immediate environment. The development of a glaze occurs in successive stages, right up to the end of the firing and even on into at least the early part of the cooling.

This glimpse of the varying behavior of iron oxide, although apparently theoretical, is going to provide some useful insights for the practice of our glazes.

What follows offers information about various types of classic glaze. But here again, you need to remember that from one to the other, you can experience every kind of transition. Later, in the notes accompanying the fusion diagrams, we will indicate a list of the standard compositions of these glazes.

Glazes with a low concentration of iron oxide (0.02 – 0.06 Fe_2O_3)

Greens, blues, celadons

In this family, we find glazes ranging from light green (bottle-green) to blue. They may be transparent or opaque. This is the group that includes true celadons and the glazes are much more interesting when fired in reduction.

If you are using a red, ferruginous clay for the bodies, the quantity of iron oxide in the glaze will have to be diminished accordingly.

We recommend a lengthy period of grinding in a ball-mill (2 or 3 hours) for these mixtures, in order to ensure a regular diffusion of the very small quantity of iron oxide; passing through a sieve will not be sufficient to avoid having your glazes speckled by little brown spots.

In order to obtain well developed colors, it is important to know that ferric oxide needs a relatively long time to surrender to oxygen and become ferrous. Over-rapid firing is therefore to be avoided. Likewise, brief intervals of a strongly reductive atmosphere have been found ineffective; above 1000° a moderate but constant reduction will prove far more effective.

Shino reds

These glazes, the color of polished terra cotta, always take the unprepared potter by surprise. You might think that you would obtain a stronger red by adding more iron oxide but what happens in fact is that these glazes contain a high proportion of alumina, which produces an aluminate of iron in the course of a slow, strongly reduced firing; this migrates, rising to the surface where it forms a thin layer. This phenomenon of migration is explained by Gibbs’ formulation of the laws governing tensio-actives, that modify the surface tension of liquids. Whenever a substance diminishes a fluid’s surface tension, like soap in water, it tends to form a concentration on the open surface. Here it is the aluminate that serves as a tension modifier. If you rub away the surface of the glaze with an abrasive, the red color vanishes at once. A loss of color is likewise produced by increasing the proportion of silica in the glaze, since it serves to prevent any diminution of the surface tension.

Beige glazes

Certainly, in this group of glazes with only minimal iron, the best results seem to be obtained in reduction, where the ferrous oxide gives more pronounced colors. But in oxidation, small quantities of iron can prove interesting as a way of ‘breaking’ certain kinds of white, those produced by magnesia especially.

Glazes with a moderate concentration of iron oxide (0.13 – 0.15 Fe_2O_3)

Temmoku

These brown-black glazes can be obtained in both reduction and oxidation, although the first is more traditional. The difference lies in the origins of their colors. In reduction, this proves to be the pyritic eutectic formed between the ferrous oxide and kaolin ($2\ FeO\ Al_2O_3\ \ 2SiO_2$) in a glaze containing lime and feldspar just as it begins to melt (1210º). In oxidation, on the other hand, the color is given by the calcium ferrite $CaO\ Fe_2O_3$. Here it is important to avoid any excess iron, which would make the glaze begin to bubble.

Glazes with a high concentration of iron oxide (0.2 – 0.25 Fe_2O_3)

‘Oil-spot’ glazes

We have just seen that a temmoku can be obtained in oxidation when the dosage of CaO and Fe_2O_3 permits the formation of a calcium ferrite. If we now increase the proportion of iron oxide in a suitably composed glaze, in which the same ferrite can form, the surplus Fe_2O_3 will decompose into Fe_3O_4 and set free oxygen, that will form bubbles in the glaze. If the pressure of the oxygen is sufficiently high and the glaze does not have too strong a surface tension, the bubbles are able to burst, bringing the magnetic oxide thus formed to the surface by convection. On encountering the oxygen present in the kiln atmosphere, the iron oxide reverts to the ferric variety and at the end of the firing we shall have a black glaze patterned with spots of rust.

If the glazed pots are to emerge from the kiln with a regular surface sheen, without blisters or scarcely-burst bubbles, the firing will need careful discernment. We saw that the decomposition of ferric oxide into magnetic oxide begins at 1210º. Obviously, then, if there is any tendency toward reduction below that temperature, the formation of oxygen bubbles, the appearance of the desired effect, would be hindered. On the other hands, if the atmosphere were too strongly oxidizing above 1210º, the magnetic oxide formed would immediately become ferric again on account of the reaction of chemical equilibrium, and there would be no end to the bubbling.

As a result, the following points will need to be observed:

In the absence of a cone for 1210º, put a cone for 1200º in the kiln; once that has fallen, allow the temperature indicated on the pyrometer to rise by a further 10º.

Until this temperature is reached, never allow the atmosphere to drop below about 2% of free oxygen.

Once you have reached 1210º, keep the atmosphere neutral (no free oxygen) or even very slightly reducing (0.5 – 1% of CO).

As the final cone is falling, return to about 2% of oxygen to provoke the re-oxidation of the spots of Fe_3O_4, that will then continue during the first phases of cooling.

All these indications are offered to help potters in their research. It is each potter’s experience alone that will have the final say.

Iron reds

If you fire an oil-spot glaze in reduction, the result will be entirely different. No calcium ferrite will be able to form. Instead there will be a supersaturation of iron oxide, which will crystallize in specks varying in size depending on the concentration of Fe_2O_3 and yielding the great variety of what are commonly called iron reds. The color here is given by the re-oxidation of the crystals as they cool. It can be improved by a brief moment in an oxidizing atmosphere at the very end of the firing.

Introduction to fusion diagrams

Treasure islands
Description and use of diagrams
Exercises: first applications
Additional notes

You can only land on an island if you know where it is. But a map of the ocean is not enough, you need to know how to use a compass.

Introduction

When a mixture of minerals is heated, while their proportions are varied, as well as the temperatures and atmospheres in the kiln, we have already begun to see that a host of things happens along the way. Their number increases according to the initial complexities of the substances employed.

For more than a century, scientists in many countries have been working to understand these kinds of topics. Among the results they have obtained, expressed in what are often termed ‘phase diagrams’, there are a large number that can be of interest to the stoneware potter. Unfortunately, it is not always easy to gain access to these documents and, above all, a special training is needed to be able to decipher the diagrams (see figure 13).

What we will present in the last part of this book is a kind of pre-selection of these documents for the benefit of potters, making accessible some of the data that determine the fusion of glazes.

If an explorer wishes to land on a particular island but has no nautical charts, his chances of success will be slim. The sixty fusion diagrams that follow point, so to speak, to sixty islands on which potters can choose to land. Treasure islands, indeed, containing much buried treasure, but the potter will still have to find where it is hidden. For, using another image, there is a great difference between choosing the route for a walk on a map and successfully completing it. A number of parameters intervene that were not indicated on the map. In the domain of glazes, that means it is possible, for a given temperature, to locate the fusion zone for any particular group of components but that the quality of the glazes belonging to that zone depends on all the different factors that have been described in the opening pages of this book.

Figure 13 is an example of a phase diagram, covering the system CaO - Al_2O_3 - SiO_2, established by E. F. Osborn and A. Muan, taken from the book Phase Equilibrium diagrams of Oxide Systems, Volume 1, published by the American Ceramic Society and the Ed. Orton Ceramic Foundation. This is a voluminous collection which has been our principal basis in establishing the following fusion diagrams.

The structure of the diagrams

Relations between SiO_2 and Al_2O_3

These diagrams begin with the fact, gradually discovered by experience, that fusion is a matter of relationships, a phenomenon which does not depend on a single oxide that might be termed a ‘flux,’ but on the relationships that all the components establish one with another. In reality, for any given number of oxides, there are always several possible relationships leading to fusion at any one temperature. In particular, if we modify the proportion of silica and alumina of a glaze without changing anything in its basic mole, we discover that it is possible to keep that glaze inside its fusion zone. Only the relationship between the alumina and the silica must not be chosen arbitrarily.

It is precisely this fusion zone that the diagrams are going to circumscribe, so determining in advance, for any given basic mole, all the possible relationships between SiO_2 and Al_2O_3 that are capable of leading to the fusion of the whole. SiO_2 will be added in quantities equal to ½ mole each time, while Al_2O_3 will be reduced by stages of 0.05 moles.

Figure 14 (p81)

Point A indicates the two values 0.4 Al_2O_3 and 2 SiO_2.

The temperature curve

Imagine a mountaineer eager to study a mountain by walking around it at an altitude of 1,300 m. To do that, he will follow the 1,300 m contour on his map and ignore all the others. You could go so far as to imagine a map with only that one contour marked on it. That is what our diagrams will be, because we always work at the conventional stoneware firing temperature of 1280 - 1300º.

Figure 15 (p82)

The shape outlined on the grid indicates the limits of the zone of possible fusion for the system CaO - SiO_2 - Al_2O_3. By following the edges of the shape, we see the possibilities of fusion at 1280 - 1300º while within it fusion occurs at lower temperatures.

You will note the break in the line at the level of 1.5 SiO_2. That does not mean that no fusion is possible below that value. But as we saw earlier, 1.5 SiO_2 marks the safety limit beyond which silicates form only imperfectly.

Needless to say, it would be possible to trace other contours on this grid, inside or outside the one indicated, corresponding to higher or lower temperatures, as can be seen in Figure 16, an extension of Figure 15:

Figure 16 (p83)

As can be seen, the different zones extend away from a central point corresponding to the eutectic of the system CaO - Al_2O_3 - SiO_2 which melts at 1165º and corresponds to the formula CaO – 0.35 Al_2O_3 – 2.48 SiO_2 . This was used previously in our research into glazes by mixing eutectics and feldspars.

The above figure is more like the map of the ocean bed than that of a mountain, since the contour lines surround not a summit but a point of maximum depth. In a sideways section, we obtain:

Figure 17 (p84)

This likeness to a lake suggests the following image. In firing glazes, the line between well-fired and insufficiently-fired cannot be drawn with a ruler or a compass, any more than the line between the wet and the dry along the edge of a lake or pond can; yet that does not prevent the geographer drawing a map! Before your feet enter the water, you may encounter a zone that is merely damp, then increasingly muddy. If you advance further, sometimes it only takes a few steps and sometimes many more before you are out of your depth. So it is for the potter too. By taking a few steps on either side of the theoretical line, you discover what is the best possible state of fusion for the materials you are using. How is what we shall see later.

The Table of Contents of the diagrams

The shape and extent of our ‘lake’ will obviously vary according to the composition of the basic mole, which is subject to infinite variations.

Here we have limited ourselves to all the possible combinations of CaO, MgO and KNaO, by steps of one tenth of a mole. This will give us a repertoire in the shape of a triangle with summits occupied by one mole of each of the three oxides

Figure 18 (p85)

Here, for example, point 20 is covered by the diagram where the basic mole consists of 0.5 CaO 0.3 MgO 0.2 KNaO.

It will be noted that the points surrounding the mole of MgO are not numbered. That is because they correspond to compositions that are not fusible a 1280 – 1300º.

Feldspar and frit

Figure 19 (p86)

Frit zone feldspar zone

On figure 19, which corresponds to diagram 47, you will note the vertical line marking 0.6 Al_2O_3. A similar line will be found on a number of other diagrams at differing levels of alumina, corresponding each time to the quantity of KNaO in the basic mole. The lines divide each diagram into two zones.

In the zone to the right, the alkalis will be introduced by a feldspar, in which alkalis and alumina are theoretically considered to have the same molecular value. In the zone to the left, it will only be possible to work with an alkaline frit having a low level of Al_2O_3.

In the initial stages, you will ignore compositions that demand use of a frit, while remembering that this rarely explored area offers rich prospects.

Purchasing a frit can be problematic, since suppliers are not always prepared to communicate their formulae. What is needed is something close to the following:

0.8 KNaO	0.05 Al_2O_3	2 SiO_2
0.2 CaO		

How to use the diagrams

The sixty fusion diagrams provided here may be disconcerting at first sight. To employ the image of the explorer again, if he has a map showing an ocean with sixty islands, where should he land first, and for what reasons? For the potter, the choice will largely depend on the level of experience, whether you are at the beginning of your research or already using a series of glazes with formulae you know or can calculate. All we can do is propose a general method, in the form of exercises that each can adapt, depending on what is needed.

Some of the exercises may seem to take rather a long time. They are basically intended for beginners, to whom they will act as a reference later, on account of their pedagogical value. They might provide material for team work in a training session or a school.

The principal of the section

Before beginning the exercises, here is a generally useful way of approaching any diagram in order to gain an initial impression of the possibilities it offers.

We already saw that the passage from not-melted to melted cannot be indicated by a simple contour. In practice, we explore sections selected at very different points of the diagrams, as here:

Figure 20 (p.87)

Exercise 1: Scanning

Here we propose a scan of diagram 18, which introduces all the basic oxides in frequently encountered proportions. You may calculate each of the intersections, or only those marked on this figure, depending on the time available.

Figure 21 (p88)

In order to shorten the time spent weighing, you can prepare a certain quantity of the composition corresponding to 0.20 Al_2O_3 SiO_2. This is carefully mixed using sieve mesh 100. To this mixture, the molar mass of which we know, can then be added the required extra quantities of kaolin and silica to provide the remaining components.

For each formula, prepare about 30 grams of glaze, divided into 3 parts. The first will serve to test the glazing qualities. To the remaining two, add 1% and 6% of iron oxide. To complete the test, the same sample will be fired in both reducing and oxidizing atmospheres.

Note: Each potter will find a way of marking the test shards. We suggest:

18	0.45	4.5
1Fe		R

This corresponds to: Diagram 18, 0.45 Al_2O_3 4.5 SiO_2, 1% iron oxide, fired in reduction.

Exercise 2

We choose 3 diagrams in which the basic moles are clearly distinct, such as diagrams 1, 40 and 45.

Figure 22 (pp89 –90)

Practice the method of selected sections. Then make the chosen results react with various levels of iron oxide.

Exercise 3

Choose on each of the diagrams a point on the right-hand part of the traced line, mid-way between the extreme values of SiO_2. (For example, in diagram 30 you might choose 0.7 Al_2O_3 and 4 SiO_2). Add 0.04% of iron oxide to the formulae. This exercise reveals the role of the basic mole in the diversification of the colors obtained with iron oxide. Fire in both atmospheres.

Exercise 4

Here we introduce into a diagram a glaze with an already known composition. The glaze can come, for example, from the recipes or triangles at the start of this book.

Usually the basic oxides in these glazes will go to two decimal places. This difficulty is easily overcome by comparing the closest diagrams. For example, if the basic mole is made up of 0.65 CaO 0.12 MgO 0.23 KNaO, you will compare diagrams 18 and 26.

This exercise will prove useful once you have situated a given glaze within its ‘family’ and want to develop it and above all correct its melting point. Locating it in one of the diagrams will show in this latter case in which direction the correction should go.

This exercise is also possible using iron oxide. You simply need to recall that in a reducing atmosphere, the fusion zone will be slightly broader than that indicated in the diagrams.

Additional notes

The notion of a flux

Figure 23 (p92)

Potters often refer to a substance as a ‘flux.’ But reference to the diagrams will show that this is an improper expression. For example, look at Figure 23 (diagram 27), and choose two points A and B corresponding to two compositions well removed from the fusion zone. To make these melt, we have in one way or another to bring them closer to the line traced in the diagram. For point A, we might reduce the quantity of SiO_2, which will seem a normal thing to do, since silica is an oxide with a high melting point. But we might equally well increase the quantity of Al_2O_3 to a considerable extent, although alumina is even more refractory than silica. If we now move to point B, the corrections will have to go in the opposite sense—diminishing the quantity of alumina, which seems ‘normal,’ but increasing the quantity of silica, which does not, yet it works! Once again, we see that it is not this or that substance in itself that makes a glaze melt, but this or that proportion in the relationship between the various components.

The influence of the firing time on fusion

We mentioned near the beginning of this book that the final appearance of a glaze depends in part on the length of the firing time. That is particularly true as far as fusion is concerned. The longer a firing takes, the more time reactions have to take place in, so that a glaze can melt better in a slow firing than in a quicker one, assuming that the final temperatures remain the same. That explains why a quite lengthy stage during which the firing is prolonged without a rise in the temperature can assist in the fusion of a glaze.

Fusion and atmosphere

An oxidizing atmosphere can affect the viscosity of certain glazes and raise their melting point slightly. For that reason, when working with the diagrams using an electric oven or firing in oxidation, you are advised to remain a little way inside the marked fusion zone.

Fusion and iron oxide

Many of the glazes you discover by means of the diagrams will later serve as the basis for ferruginous glazes. It must be obvious, for the reasons exposed in the chapter on iron oxides, that the fusion of those glazes will be more or less increased by the addition of iron, especially in a reducing atmosphere.

Fusion and fluidity

It is important not to confuse these two terms. A perfectly melted glaze may well have sufficient viscosity and surface tension not to run. That explains why you can work inside the limits of the fusion zone with several diagrams, especially those including high levels of MgO. The methods based on a use of sections will be the best guide.

Correcting a glaze

Previously, we proposed the method using a cross to correct a glaze. That correction was mainly concerned with fusion, not the other qualities that might be desired in a glaze. Sometimes, you might find yourself modifying the basic mole in seeking a particular result, that is, moving to another diagram or working somewhere between two diagrams. This way of correcting can produce valuable solutions, even if they do not always correspond to what was being sought. That is why it is good to learn to dialogue with the fire, and accept its suggestions rather than expect impossible solutions.

Superimposing glazes

The technique by which two glazes are superimposed offers rich possibilities. There are times when it is obligatory, to obtain certain iron blues, for example, where a suitable transparent glaze is superimposed on a glaze rich in iron oxide. There is always a risk that two superimposed glazes will run, although neither does when used alone, because a eutectic forms between them. Here, once again, only experience can tell which glazes can be superimposed without running.

Unknown regions

Faced with these sixty diagrams, we have had the impression of being tourists holding the map of a whole continent. We are far from having explored it entirely. The occasional comments that accompany these maps are bound to be fragmentary and relative. For example, we have identified certain zones where particular kinds of glaze develop, iron blues or oil-spot for example, but nothing assures us that other similar zones do not exist elsewhere too.

Moreover, in this continent, or archipelago of glazes, there probably lie unknown lands, unexplored areas. That can stimulate our research. They exist in any case for every potter, and if you are weary of certain landscapes, the diagrams offer the possibility of finding new horizons without going too far astray. We should mention again how little use has so far been made of frits in stoneware glazes.

Passing from the initial triangles to the diagrams

The tests made using the initial triangles already offer possibilities for renewal, as we have often seen during training sessions introducing the development of glazes. A glaze can be transplanted from a triangle into its own diagram, then the quantities of Al_2O_3 and SiO_2 are varied, as well as the amount of iron oxide, and fired in both atmospheres.

Rapid firing

We have tested in a fiber-lined kiln samples from each diagram with 0.04 Fe_2O_3 in the formula. Our intention was to check whether all the different basic moles melted well in a rapid firing (4 hours). The results were conclusive; all the compositions had melted correctly. We also tested the ability of the kiln to perform in reduction. For that, we decided to rise to 1000º in one hour, reserving the remaining three hours to reduction with up to 9% of CO_2. Here the results were uneven. Samples of the same glaze were more or less reduced, depending on their place in the kiln. In addition, certain glazes depending on micro-crystals, such as the iron reds, did not develop on account of the too rapid cooling. It is to be hoped that these kilns will become as regular and as supple in their programs as they are economical in their use of energy.

Plates

Exploring a quarry of oligoclase. In standard lists, this rock is said to be a mixture of albite and anorthite with a predominance of the former. In fact, its composition is more complex and the full analysis, transposed into the potter’s formula is

0.307 CaO	0.787 Al_2O_3	5.170 SiO_2
0.216 MgO	0.129 Fe_2O_3	0.006 P_2O_5
0.204 Na_2O	0.054 TiO_2	
0.272 K_2O		

Such is nature, hostile to our classifications and more or less desirable, depending on points of view. This quarry would have been valued highly, were it not for the presence of that iron oxide, that condemns its stones to surface highways. The potter quickly recognizes another side; some dust gathered under the crushers yields a brown glaze marked with small oil-spots in an oxidizing atmosphere. Diagram 42, to which this mineral belongs, shows that its formula is located near the edge of the zone for this type of glaze.

Plate 1

The Blanot pottery kindly produced for this book the four initial recipes as well as a few application of them. All the examples were fired in reduction.

Above: Test shard for the initial four recipes.

Below: The superimposing of recipe 3 on recipe 2, with a decorative trail of molten wax made prior to the application of the second glaze, gives this jug its shiny green glaze, that must not be confused with a celadon, which is quite different in composition and appearance. (cf Plate 4)

The bowl is glazed with recipe 1 on the exterior. Glazed to normal thickness, this glaze produces a temmoku. Used thinly, the silica and alumina of the body turn it brown. The inside is recipe 1 with an ornamental dab of iron oxide added.

The plate is recipe 4 on top of recipe 2 with lines of wax reserve.

Plate 2

Above: Symmetrical presentation of the lower right sections of the two initial triangles. Their common axis being at the center, the order of the shards to the right is reversed. Fired in reduction. This picture shows the role of magnesia, absent on the left-hand side.

Below: The right-hand section of the picture above, fired in oxidation. The ‘oil-spot’ phenomenon will be noted.

Plate 3

Two glazes from diagram 59 are here superimposed, with the addition of 0.04 Fe_2O_3. The quantities of alumina (1.45) and silica (5) allow the application of Gibbs’ observations for the surface tension of the red glaze, but not the white where the alumina content is lower (1.25) and the silica content higher (8) for the same amount of iron oxide.

In the red glaze, the high level of silica means that the alkalis have to be introduced by means of nepheline syenite, whereas a feldspar can be used for the white.

Plate 4

These celadons on porcelain are located in diagram 1, with a dosage of 0.55 Al_2O_3 0.02 Fe_2O_3 and 3 SiO_2. They correspond to the most classic kinds of celadon.

Plate 5

François Lanusé produced these iron blues on a Berry clay. They are from diagram 25, with 2% of iron oxide. The blue has gained in intensity through firing the pots more than once (the pot in the foreground has been fired twice, that behind three times). But one result is an increase in the number of the number and volume of bubbles within the glaze. This phenomenon of bubbling is very common in iron blues. This kind of work shows clearly that the success of a glaze is not just a matter of its formula.

Plate 6

Oil-spot glaze from diagram 43.

Plate 7

White magnesian glaze from diagram 39, superimposed on zones of oil-spot glaze. The large spots are produced by a glaze located between diagrams 43 and 48. The small spots are from glaze E3 from the second of the initial triangles. This latter is not, strictly speaking, an oil-spot glaze, but it gives off a small quantity of oxygen which is revealed by superimposing the white glaze.

Diagrams

Sixty fusion diagrams
Zones of the classic glazes

Enjoy and trip and happy discoveries!

Diagram 1

The first diagram contains a eutectic that is especially important for a large number of stoneware glazes: CaO $0.35\ Al_2O_3\ 2.48\ SiO_2$. It melts at 1165º and if you fire in reduction a white clay shard glazed with it, the result is a shiny, highly fusible glaze, pale green in color in account of the traces of iron oxide almost always present in its components. By progressively increasing the alumina from this eutectic point, the glaze will harden while preserving its brilliance so long as you remain inside the line of the diagram. Beyond that limit, it will gradually become opaline until it attains the specific quality of celadons, whose diagram this supremely is. To strengthen the color, which is close to that of emerald green jade, you should include in the formula 0.02 Fe_2O_3 so as to achieve a formula within the following limits (cf. figure (p126) zone A) :

CaO 0.4 to 0.6 Al_2O_3 2.5 to 3.5 SiO_2
0.02 Fe_2O_3

As can be seen, all the alumina is introduced by the kaolin, which is going to make the glaze very plastic, with a strong shrinkage on application which may cause blemishes in firing. In that case, it will be necessary to introduce the kaolin in its calcined form, not raw, or if needed a mixture of the two, in order to ensure that the glaze is sufficiently adhesive.

The very small addition of iron oxide will generally require a thorough milling (2-3 hours) of the mixture in order to obtain a regular color without speckles.

There exist a variety of colors among the celadons. The most delicate nuances are obtained on a porcelain or white clay body devoid of titanium. The slightest trace of this oxide, that is usually present in stoneware clays, will be enough to turn to an olive gray the emerald green of this strictly calcic glaze. There is a strange optical phenomenon, as yet unexplained, which makes the same celadon appear greenish-yellow in bright light and greenish-blue in shadow.

The glaze also turns olive-green when the proportion of iron oxide is increased. If you wish to intensify the emerald color, the only solution will be to increase the thickness of the glaze. That cannot always be done in a single operation, it may be necessary to re-glaze a fired piece. In that case, we recommend working with a thick glaze mixture on pots still as hot as possible, in order to ensure a rapid evaporation of the water.

But celadons are not the exclusive reserve of this first diagram. Beside chalk, it is possible to introduce the alkalis of a feldspar, which will provoke a change in the texture and color of the glaze. By increasing the alkalis, which goes hand in hand with an increase in Al_2O_3, you tend toward a shiny surface and a grayish green color. By introducing magnesia, which is not favorable for celadons, you move into olive-browns.

Celadons require a continuous reduction from about 1050º, passing gradually from a neutral atmosphere to 9% Co_2 at the end of the firing; all the last stages suffer if subjected to a too rapid rise in temperature.

We still have to stress that this first diagram, like a few others, (see figure (p126), left) can lead to a very heterogeneous set of glazes. This phenomenon occurs when we dose the silica at the minimum quantity possible. This yields glazes too fragile to be used on pottery destined for household use. We find two kinds of heterogeneity, depending on the quantities of alumina. The first (zone B) includes very little alumina and give rise to nucleations of wollastonite. The other (zone C), richer in alumina, produces nucleations of anorthose, which is a feldspar with a calcitic basis. In both these varieties the iron oxide, added in the same proportion as for the celadons, divides itself unequally between the nucleations and the base of the glaze, causing a stronger heterogeneity. These glazes are not easy to obtain, on account of the narrow margin within which they form. (cf. Plate 2)

Diagrams 25 and 33

The zone included in diagrams 25 and 33 is especially polyvalent. In a constantly reducing atmosphere, it is capable of producing glazes as diverse as celadons, iron blues, temmoku, and iron reds, without of course counting all the intermediate stages between those principal types. Here again, far superior to any arbitrary classification, patient experimenting will show the best way forward. The following examples, all relating to diagram 33, may help find the best direction.

The starting point might be the formula (zone A in right-hand diagram (p143)):

0.6 CaO 0.4 Al_2O_3 5 – 6 SiO_2
0.4 KNaO

This formula gives a transparent, colorless glaze with a slightly blue tinge if any of the components contain traces of iron. To strengthen the blue color, 0.04 Fe_2O_3 can be added. The color seems to emerge best when using a feldspar especially rich in K_2O.

Next, the formula can be modified to give (zone B):

0.6 CaO 0.6 Al_2O_3 4.5 – 5 SiO_2
0.4 KNaO

With 0.15 Fe_2O_3 this gives a temmoku. It is also possible to move in the opposite direction, passing from a temmoku to a dark blue by reducing progressively the amount of Al_2O_3 and if necessary correcting the proportion of SiO_2.

Then a new change in the formula can be made:

0.6 CaO 0.7 Al_2O_3 5 – 6 SiO_2
0.4 KNaO

Here, with 0.25 Fe_2O_3 you can obtain an iron red spangled with crystals of hematite.

As can be seen, these slight variations of Al_2O_3, Fe_2O_3, and SiO_2 make a glaze pass from one category to another. This refers us back to the general method for using these diagrams, with a gradual progression of Fe_2O_3 in a series of glazes with the same basic mole and in which Al_2O_3 and SiO_2 vary.

Now we can superimpose the first of these formulae, without any iron oxide, over the temmoku. This will give an iron blue whose intensity varies depending on the relative thickness of each layer. This use of superposition to exploit a coloring oxide by a transparent overlay is especially well suited for iron blues,

While the composition of temmokus fired in reduction is located in the zone covered by the diagrams 25 and 33, iron reds can be obtained along almost the entire line CaO – KNaO. This can be seen by establishing formulae for the reds of the first of the two initial triangles.

Likewise, the different diagrams of that same line produce glazes that give blues when superimposed over temmoku. In research to develop these blues, the correct dosage of SiO_2 is decisive. The alumina should be limited to the minimum introduced by the feldspar, unless you employ a frit, in which case even less Al_2O_3 can be used.

So far we have followed the edge, avoiding magnesian glazes. From here it is perfectly possible to extend the temmoku zone to diagrams 26 and 34. The presence of MgO may produce small crystals of diopside. The same occurs with the iron blues.

Diagram 39

Diagram 39 is located in the midst of a zone that yields ‘greasy’ white glazes particularly opaque when they are poor in lime. Very rich in MgO, these glazes require the use of talcs as poor as possible in chlorite if you are to avoid blistering. Very viscous, they do not run and offer a good base for painted iron oxide decorations. In diagram 39, the ‘lake’ representing the fusion zone is not very deep, with the result that you can go right to its center or move some way away outside of it. Use of the techniques of the sweep or the section will allow the easiest first explorations.

Diagrams 43, 48, 49, 53

This zone is the origin of our oil-spots, described in the chapter on iron oxides. Note here the average proportions of alumina and silica. Al_2O_3 will have the same molecular amount as KNaO which, multiplied by 10 or 12, gives the value for the SiO_2. The iron oxide will be limited to between 0.2 and 0.3 moles.

We should stress that all these oil-spot glazes can be used with more or less opaque superimposed glazes through which the bubbles erupt, accentuating the contrast between the spots and the surrounding glaze color.

Diagrams 55 to 60

This group of diagrams allows the realization of the glazes, mentioned in the chapter on iron oxides, known as ‘shino.’ These glazes are poor in iron (0.04 approx.) but very rich in alumina (up to 1.5 Al_2O_3), while silica is around 4.5 SiO_2. An iron aluminate that lowers the surface tension of the glaze in its liquid phase then rises to the surface. The red-brick color disappears as soon as you reduce the alumina or increase the silica. This gives you the possibility of playing with red and white on the same piece (see plate 4). The small quantity of iron oxide means that this type of glaze must be well mixed in a ball-mill. A reducing atmosphere must be maintained from 1000º until the end of the firing. We should also point out that the white glazes of this series, especially those in which the silica is located between 7 and 8 moles, are very useful for brushed decorations made with iron oxide, below the glaze or on its surface, since here there is no risk of the iron causing the glaze to run as generally happens with glazes rich in CaO. The ‘shino’ of Japan are the reference here.

Appendix

Local glazes: from rocks you find to a glaze

With a good understanding of the phenomena of fusion, any mineral can be introduced into a glaze.

(diagram page 176, lines to be added)

Vegetable ash

Orthose or
potassic pegmatite

Nepheline syenite

Mixed feldspar

Hematite

Ochre

CaO

MgO

K_2O

Na_2O

Al_2O_3

Fe_2O_3

SiO_2

Chalk
Dolomite
Magnesium carbonate
Marl
Talc
Wollastonite

Albite or
sodic pegmatite

Kaolin

Stoneware clay

Silica

(diagram page 176, lines to be added)

For pedagogical reasons, this book has mainly advised the use of classical materials that are widely available from commercial suppliers, but it remains true that at the very heart of the glaze seeker’s adventures lies the exploitation of minerals found in the local countryside.

In the table at the start of this chapter, we only indicate, among products not found on the market, vegetable ashes, marls, and different kinds of clays. The list could be extended indefinitely. Here we will limit ourselves to a few practical indications that might prove helpful to the potter in the role of ‘mineral prospector.’

If a crushing mill is not available at home or in some nearby specialized establishment, you will be well advised to limit your initial choices to minerals that are naturally fine-grained or already crushed, sufficiently fine for a final grinding in a ball-mill to suffice. We have found that quarries in which stone is crushed by machine often provide a source of ‘ready to use’ stone dust.

It is important to be sure that you will be able to obtain a sufficiently large stock of the same material, since otherwise there would be no point in beginning your research.

The next problem is how to identify the rock. You might have it analysed, but that is not always feasible and you may have to make your own identification. The geological map of your neighborhood, and guides designed to help identify rocks will prove useful, to say nothing of the information that can be obtained from local quarries. But in the latter case, people who are simply crushing stones to make roads often have no idea of the information a potter needs! In most cases, the potter will simply have to start making tests.

1. The acid test, as was done with chalk, allows us to detect CaO and measure its quantity.
2. A sample is fired to stoneware temperature, placed on a piece of brick or on a shard in case fusion occurs, as it well may in the case of a marl.
3. If no fusion occurs, make a series of tests with a progression of chalk.
4. One other useful test consists in making a progression of your rock with a feldspar or a nepheline syenite.

5. When you discover a fusible plastic mineral, a marl for example, it should be calcined in a biscuiting kiln. This helps avoid having glazes made with it peel on account of excess shrinkage.

Postface

The glaze adventurer

Ready for use in its pail, a glaze is still only a violin in its case.

If there is one kind of job that inspires dreams, it is surely that of glaze-seeker. The seeker of precious stones is obliged to leave home for sites that are often far away, while the glaze-seeker, whose dream also involves a kind of precious stone, stays put, working more or less at home. The potter knows that by the power of fire, humble materials, that are trodden underfoot by the general public, can be raised up to sumptuous metamorphoses. That in itself should be enough to make most people dream, for only very few set out on the troubled paths of the gold rush, or go off in quest of jade or turquoise. We too are caught up in our own kind of rush, fuelled by a passionate desire to play with fire, that is nowadays more and more easily brought into our homes.

From the earliest times, the potter's craft has provided a living symbol of human creative capacities. Today, when the longing to create is often left unsatisfied while the gates of pottery stand wide open, people go rushing in, for better or for worse. But there is a risk of disappointment if it is not understood that the art of glazing is the fruit of continual hard work, a long dialogue with the elements, since neither clay nor fire are slaves that readily obey our fingers and eyes.

Still, many persevere, having found in the art stimulating challenges that put them to profitable tests and keep their creativity alert. None the less, it is somehow irritating to have to say: The treasure lies within my grasp, but I cannot find a way of laying hold on it. Yet these sands in which I am wandering lost are in fact the components of the pearl I dream of!

Then you begin to imagine a kind of guide-book that might indicate, step by step, in the right order and omitting nothing, **the way**. Not **the quantity** that a visitor to the Renaissance potter Bernard Palissey demanded so stridently, exasperated by the master's technical explanations. The quantity was what he wanted—'Simply give me the recipe so that all I have to do is weigh and fire' –success guaranteed by the wording on the box, a 'ready-made glaze', a 'glaze kit' in today's terminology. No, we are not asking for that much, we know we have to 'invest ourselves' in the research process, as people say nowadays. But still, on days when everything seems too incomprehensible, we long for at least a corner of the veil to be lifted. If a book is published, we wonder hopefully if that will not be it.

In all this can be sensed aspects of what may rightly be termed a secret, that little magic word, disturbing, which has had an ambiguous destiny ever since the days of Palissey. It is a word that refers both to the technology and to the mentality of the craftsman. For even those who are prepared to recognize the secret's legitimacy cannot accept gladly its non-divulgation. Maybe they imagine that the secret is contained in the details of the dosage, when in fact to transmit a glaze is like writing a novel!

Once a seeker of glazes is fully engaged in the craft, secrets appear at every step. Even with long years of experience, you are all the time asking yourself questions about the still unexplained phenomena that occur inside the kiln. So long as you use just the simplest formulae, you can get by. But no one ever stops there. The appetite driving us onward demands increasingly solid food. It's not necessarily a matter of rare or previously unknown components, but of touch-and-go fusions of glazes, of those narrow delays in firing without which the blessed glaze destroys itself or fails to form. That's where the secrets are, the real ones, the secrets of nature that are not the same as those innocent little workshop mysteries that sooner or later end up as make-believe mysteries . . .

Once a secret of nature has been fathomed, there is no reason for hiding it. The art of glazing is constantly advancing adventure. Every authentic seeker in the end grows tired of a product that had once been dreamed of longingly and gained with much patience. A finished piece of pottery, one where the maturation of the glaze has been taken to its furthest limit possible without the piece emerging spoilt from the kiln, is still only one signpost along the way, not the finishing line of a race. The little that has so far been understood, and transmitted, of the metamorphoses observed will then serve as a kind of testimony to be passed to others, so that they in turn may venture farther still. There is no virtue in repeating the experiments that others have already done. Equally, there is no virtue in imposing (in the name of what kind of pedagogy?) on the beginner today those laborious peregrinations that form part of your own history. After all, the journey will be a long one for today's beginners too. So at least they should have before their eyes at the start a means of checking their motivation, and of thinking about the choices they have to make if they are to achieve something in themselves.

But is anyone always clearly aware of what they are going to ask of a book, can anyone always avoid the temptation of quickly looking for a clear indication of the proper dosage? Someone reading this book from that point of view will probably not be too disappointed, at least at a first glance. There are doses and recipes here. But will that reader realize sufficiently clearly that the success of a glaze often depends on more than was said about it at the outset, on certain unexpected intuitions, on a brief moment in the climate of a workshop, on a sense of things that has grown up through the years, that the potter would be hard put to to find explanations for . . . will the reader realize clearly enough that a potter sets out almost from nothing every time a new direction opens up, a direction that is not certainly going to lead anywhere, and that if it does lead somewhere, it will still be necessary to find the best possible destination for the new-born glaze, the form of pot for which it was made, for example, a matter that is not as evident as it might seem.

The author

Daniel de Montmollin lives and works in the monastic community of Taizé, not far from Cluny (S et L) in France, which was founded by Brother Roger in 1940. Br. Daniel was one of the first brothers. In 1950 he established a pottery workshop and from 1956 began to explore stoneware pottery. In 1965, he published Le Poème céramique in which he ponders on the life and work of the potter with his fundamental values. In 1972 appeared Par l’Eau et le Feu, a collection of poems inspired by his craft, and in 1976 L’Art de Cendres on his development of the use of vegetable ash in stoneware glazes. After years of further research, in 1987 he published the first edition of this present volume, which quickly became a fundamental text-book in the pottery workshops and schools of the French-speaking world. Turning again toward the inexhaustible subject of vegetable ash, he began to explore the role of phosphorus, an element that is essential for life, and which in pottery has a profound influence on the colors of glazes. This produced Pratique des Emaux des Cendres. By his work, his writings and his research, some still unpublished, Br. Daniel counts among the major figures of the present-day ceramic revival in France and beyond.

Blurb

The fruit of years of experience in a workshop with potters of differing levels, this guide is intended as much for beginners as for professionals. By a series of exercise that constitute a full working program, it enables potters to produce for themselves a full range of classic stoneware glazes, while at the same time enabling them to understand the phenomena by which these glazes are produced. A collection of sixty fusion diagrams serve to guide the potter easily and rapidly toward the mixtures of raw materials that are capable of melting at the correct temperature, while a series of brief sections show how each glaze can be explored and improved in the course of ongoing research.