An investigation into a range of idiosyncratic crystalline glazes and aesthetically compatible forms

by

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A thesis submitted in partial fulfilment of the requirements for the degree

DOCTOR OF CREATIVE ARTS

School of Contemporary Arts

UNIVERSITY OF WESTERN SYDNEY

Bankstown Campus, Sydney

July, 2002

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PLEASE NOTE

The greatest amount of care has been taken while scanning this thesis,

and the best possible result has been obtained.
Dedication

This work is dedicated to Mary, Sam, Tom, Rosie and Zara.
Acknowledgements

I would like to thank Ted Seccombe for his assistance in my early research with crystalline glazes and Peter Deck for his ongoing dialogue and critical discussions concerning the aesthetics of crystals, glaze quality, faults and how to overcome them.

Thanks also to my principal supervisor Dr Denis Whitfield for his encouragement, support, critical appraisal and regular promptings to complete the writing. Lastly, thanks to my mother, Mary, who nursed me through a lengthy convalescence, during which time I completed the writing of this work.
Statement of Authentication

The work presented in this thesis is, to the best of my knowledge and belief, original except as acknowledged in the text. I hereby declare that I have not submitted this material, either in whole or in part, for a degree at this or any other institution.

[Signature]
Abstract

This study documents the evolution of a unique body of ceramic work which straddles the areas of science and art. The author establishes the framework and context for the development of a range of ceramics incorporating crystalline glazes and forms. A personal aesthetic sensibility for the work is defined with reference to ceramics in general and specifically to the historical and contemporary development of glazes within this genre.

The author describes a research methodology to comprehensively test a range of base glazes while controlling many of the variables involved in their production. The technical aspects of glaze composition, firing, chemistry and application and their interrelationships are examined. The results of experimental work are then discussed with reference to the causal relationships involved. The author then explains how his aesthetic judgement is responsible for the resulting glazes and ceramic forms which exhibit a strong visual and tactile presence.

The study articulates the stages of contemplation, design and development in the creation of a unique body of work which is cognisant of the decorative qualities of crystalline glazes. The forms are simple and uncomplicated, and the work is concerned with the pinnacle of the craft of ceramics at every level.
Pioneer Pottery by Michael Cardew (1969). Locally, there was Ivan McMeekin’s Notes for Potters in Australia (1976) which was an invaluable guide to local raw materials. These were staple references for potters starting out but there was little other information available. The Potters’ Society of Australia had begun publishing its quarterly magazine *Pottery in Australia* in 1962, and a handful of dedicated early practitioners wrote articles on aspects of studio pottery in Australia when materials were scarce and knowledge about pottery was generally scant. These references were also useful because they showed examples of the works of these potters, which provided some benchmark for aspiring potters. They showed that there were potters making work and experimenting with local materials. In a country as geologically diverse as Australia, and with clay being the most common mineral on earth, ceramic materials were surely in abundance.

I had majored in Geology at Macquarie University as part of my BA degree and began sourcing local clays and materials after purchasing geological maps of my area from the Department of Minerals and Energy. I discussed clays with the local brickworks manager and brought samples from Clarence, Meadow Flat, Sunny Corner and Lithgow for testing. The samples were crushed, slaked, sieved and dried to throwing consistency. Test pieces were made, shrinkage rates measured and glazes applied. I developed a usable stoneware body by combining several clays that gave a reliable throwing body. However, its iron content was such that it would spot most light-coloured glazes I used with it.

Much of the time was spent winning my own materials and testing samples of these for different effects. Limestone was obtained from the marble quarry and crusher at Cow Flat near Bathurst. Crushed blue metal dust which gave a beautiful speckled iron glaze in reduction, came from the quarry towards Orange. The ash from yellow-box trees formed a good glaze over darker-bodied clays.
Which type of kiln to build was a difficult decision. Peter Rushforth’s advice was ‘find out what you want to produce and then build the kiln that will do this for you to give you these specific effects’.

Initially I fired with wood using a Dutch-oven style fire-box and a single chamber of stacking space. After initial difficulties in reaching temperature and a series of modifications, this produced good results. The amount of ash deposit could be controlled to an extent by the size of the bag wall but all pots had some degree of flashing where they were unglazed.

Subsequently I built a smaller gas kiln after a plan from Ivan Englund that appeared in an article in Pottery in Australia (1978, Vol. 17 No. 2). This kiln was efficient and relatively easy to fire without the constant stoking and collecting of timber for the wood kiln. I also liked the qualities of glaze and I developed a range of ware that incorporated this richness.

Developing an oeuvre

My major interest in ceramics lies in the effects of the fire; effects that are uniquely ceramic and which cannot be produced by the brush or any other method. It is as Joan Miro (Erben 1992, 74) said:

To make ceramics, you must tame the fire.

I am not a painter or decorator. Rather, I am searching for particular qualities of glaze that have individuality in these days of mass information and globalised generic knowledge and goods. Every known glaze can be analysed and duplicated once it is there for others to see. Wood’s (1980) study of oriental glazes has revealed the exact formulae of the most beautiful of the Chinese glazes from the Sung Dynasty (960-1279 AD). He has been able to emulate the qualities of the copper reds, the celadons of jade

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1 In personal communication in 1976.
green and blue, the oil-spot, hare’s fur, the chun glaze and the breaking saturated iron glazes on which the tenmoku are based.

These glazes are now in the repertoire of most experienced potters and are duplicated freely the world over. Computer-based glaze programs are now readily available and can convert the chemical analyses of materials from America or England to those combinations of materials that most closely approximate it within Australia. Information can also be obtained about any of these glazes within several minutes through the Internet, Wood’s book or a variety of other sources. Even though the composition of materials varies from place to place, the general parameters of knowledge on these glazes are constant and enough information can be gleaned to begin experimentation in the desired area.

For many years I worked in reduced stoneware and developed my own chun and iron glazes in combination with rutile and wax-resist decoration. This allowed for a unique range of effects that could be manipulated by varying the thickness of the chun to range in colour from clear (thin application) to purple-blue through to white where it was thickly applied. The firing conditions had to be precise with just the correct amount of reduction, otherwise the results were undesirable and the colours muted. In the early 1980s I developed these glazes to a reliable consistency and continue to produce variations of them today. However, I had begun to be dissatisfied with my own work. I realised I needed to put time into glaze research and to develop new forms and possibilities. I now felt the force of Dewey’s statement (1977, 15) that:

If the artist does not perfect a new vision in his process of doing, he acts mechanically and repeats the same old model fixed like a blueprint in his mind.

At around this time in 1990, John Olsen moved to the Bathurst area and we met through mutual artist friends. Olsen was interested in the art courses being run through Charles Sturt University, especially Painting and Drawing subjects that were being taught in the Julian Ashton tradition by my late friend, artist David Wilson. Olsen and I began a
collaboration that spanned seven years. The work that resulted from this joint effort severely challenged my own sense of aesthetics.

Olsen wanted to use the opportunity to produce a new body of work that was intellectually rigorous and used themes of national importance. He wanted to do something new and did not care if it was going to ‘disappoint his friends... One may be wrong, but there is nothing more enervating than trying to repeat the past. I think it is better to be totally wrong and free’. These themes related to an earlier body of his work, Journey into the You Beaut Country (Hart 2000, 123), that involved his initial visit to Lake Eyre in flood in 1962. To fulfil this vision I had to develop new forms and surfaces that represented the essential quality of the earth. Slips were developed that could be applied as thick as toothpaste and remain on the pots. He wanted glazes that crawled and ran and showed glaze faults as part of the whole Zen philosophy of the work.

Several exhibitions of the work ensued. It was well received and subsequently sold well with several pieces being acquired by the National Gallery of Australia. We planned to begin work on replacing his Opera House mural, Salute to Five Bells, in ceramic tiles. The original mural was done by Olsen in 1972 after he received the commission to paint it from the Sir William Dobell Foundation (Hart 2000, 111). Olsen painted the mural directly onto marine plywood, but owing to the positioning of the mural in the northern foyer of the building, it was exposed to direct sunlight that caused the paint to lift and flake off. Over the twenty-year period since the mural was completed, the surface had become a conservator’s nightmare. It had to be screened from the sun by a heavy curtain and could only be exposed to the public in the evening. Olsen had talked often of replacing the whole mural in ceramic tiles as a way of overcoming the ongoing problems with it. This would be a huge task, as the mural measured twenty-two metres in length by three metres in height. Lloyd Martin, the then Opera House Manager, had set aside the finances to enable the project to be undertaken and Olsen commissioned me to manage the production of the tiles and the entire process. This task included making the
tiles, developing the glazes, assisting with the painting, firing, transporting and fixing the mural in place in the Opera House.

This was to be a huge and exciting challenge for us both and the planning had begun. The contracts were drawn up and signed and I commenced the tile-making. Because of Olsen’s stroke in December 1997, he lost sight in one eye, his confidence was shattered and he felt unable to continue. We never completed the project, even though several maquettes had been finished and sold.

With the death of the mural project, my own work began to blossom. Working with Olsen had given me a new confidence and impetus with my own work, which had become stagnant and largely secondary to this collaborative project. I had been using raku techniques to explore the qualities and the patina of decay on the surfaces of pots, low-fired, textured and softly lustred with the nitrates of silver and bismuth. This body of work was aesthetically fresh and challenging to the wider audience. Most of the awards I have won in ceramics have been with pots made in this genre.

However there were difficulties with raku. The relative softness of raku ware, the high loss rate of pots in firing and the lack of surface stability over time caused me to abandon it as a means of working. I could not sustain the loss rates caused because of technical difficulties with clay bodies. I did enjoy, however, the involvement and spontaneity of the medium, the immediacy of the technique and the sense of intuition involved in the process.

I decided that I was ready to move into a new area of work. It takes a conscious decision to commit to a body of research that requires time, effort and financial burden without the promise of anything at the end. Essentially, once you embark on a new course of action there is no going back, although you do not know where it will end. There is also the question of the aesthetic merit of the work, as anything you make to exhibit and sell is open for critical attention.

\[2\text{ In personal communication, 1993.}\]
The focus for my research has been to develop something unique (as yet unseen) that has critical merit and aesthetic qualities which remain related to function. Why choose crystals, when for many years I had denigrated the ostentatious, garish, flamboyant and questionable aesthetic characteristics that crystal-glazed pots demonstrated?

This interest in developing idiosyncratic glazes has led me to examine a range of crystalline glazes. The best work I have ever done in ceramics has been as a result of *pentimento* (the happy accident) and the development of my ideas in crystal glazes is an example of such serendipity. After some experimentation with glazes that contained zinc oxide, I found interesting areas on several pots, especially in firings where the soak had been lengthened. This term refers to the amount of time spent at the top temperature of the firing, usually planned to even out the heat in the kiln but also to allow time for the glazes to mature fully. An extended soak period, in conjunction with ‘firing down’ to slow the cooling process of the glazes, similarly improved glaze quality. Shiga’s Tomato Red glaze (see Glossary) is a good example here, even though it contains no zinc. Excellent crystals form by firing to a full cone ten and slowing the cooling in that top temperature range.

The slower cooling of zinc glazes showed a clear crystal development. The crystals were smaller and showed a softer contrast between the crystal and the background. I was able to take these areas and elaborate on them. The interesting results of each firing became the basis for the next series of experiments and the creative and intuitive processes began. Developing an acceptable range of crystalline glazes had become an aesthetic challenge.

This extensive research project included all the essential characteristics that are familiar to potters. It involved detailed record keeping, accurate measurement of glazes, t-shaped test tiles to examine the differing effects of glaze on vertical and horizontal surfaces, thousands of possible glaze recipe variations, adjusting firing schedules, discussions
with other potters, reading and researching and gleaning information from any source available - and many, many firings.

1997 was the first year of serious experiments with crystalline glazes and the outcomes were disastrous. The glazes ran onto the shelves. The pots were blistered, pinholed and either overfired or underfired. There was very little to be positive about. Most pots made in this period were smashed. Each firing, however, produced something that pushed me onwards. This may have been a small effect on part of a pot or a particular glaze that showed a certain quality. This result then became the focus for the next firing, so that eventually a small repertoire of interesting glazes could be duplicated and developed onto a pot's surface.

Slowly some possibilities started to emerge. The particular results I sought contained glaze characteristics of a softer, more muted range of crystals that lay in a background of secondary crystals of contrasting, harmonising or complementary colours. It seemed that the possible variations attainable were immensely diverse and could be manipulated by altering the colourants, the firing cycle or application methods.

Pottery is not only about the technical aspects of glazes, nor is it about the forms that display these glazes. Rather, it is about the union of both the form of the pot and the glazed surface which combine in such a way that neither dominates the other. A pot is about an aesthetic harmony that exists between the form and the surface. Many aspects of both of these elements need careful aesthetic consideration in the making process. The weight of the pot is important. Its sense of proportion, the relationship of the width of the lip of a bowl to its foot and the fullness of the shape in between are critical, as the smallest variation in proportion can change the whole dynamic balance and tension within the form.

Similarly, with the glazed surface, many a potentially beautiful pot has been destroyed by using an inappropriate glaze on it. Further decisions need to be made in the making stage which determine the optimal shape for a pot for use with a decorative glaze and
how the two can work harmoniously together and still be a vessel eminently suited for use on the table. Herein lies the challenge.
Chapter 1

Introduction

We are all on the edge of realisation; each day brings us closer to the Reality – not of Death, but of the realisation of something within that is authentic and human...to make a work of art that is authentic and human, that is always just out of reach.

D. Wilson (1997)³

1.1 The aim of this study

This is a hybrid study which incorporates scientific testing and analysis. Aesthetic judgements are brought to bear on objective results, and from this information, ceramic forms are designed and created which best complement and enhance the qualities of the ceramic glazes developed.

The purpose of this study is twofold: firstly to develop an idiosyncratic range of crystalline glazes that reflect a personal aesthetic sensibility which will be clearly defined and described, and secondly to design and create a series of ceramic forms which, in combination with the glazes, will constitute an original body of ceramics.

The technical phase of the first process will see glazes being developed through the procedures of rigorous scientific testing. Materials will be measured out in predetermined combinations and quantities and will be fired under controlled conditions in both gas and electric kilns.

The results of this exhaustive testing process will be examined and the glaze results will be assessed for certain characteristics of crystals, colour combinations, primary and secondary crystal development and size. A clear definition of the desirable qualities in

the glaze results will be delineated which will be a selection of glaze effects that defines my preferred sensibility. It will represent an aesthetic selection of scientific findings of the glaze tests. Furthermore, the combinations of glaze materials and the firing cycles will be manipulated in an attempt to obtain these desired qualities in the glaze results.

The decorative nature of the newly developed crystalline glazes will be foremost in the design and creation of a body of ceramic forms. The forms will be created to fully complement the glazes. This combination of glaze and form in ceramic objects will be described and defined as an aesthetic for the crystalline-glazed vessel. It will also be argued that these vessels constitute a legitimate art form.

Any development in ceramics occurs within the contemporary aesthetic and cultural climate of the day, utilising the latest information, technology and skills that are available at the time. Potters working in the twenty-first century have more equipment, technology and information available to them than potters at any earlier time. The Internet, with its ready dispersal of information on any area of ceramics, has made readily available a wealth of knowledge on virtually every type of glaze known to humankind. Ceramics bulletin boards and chat lines provide answers to myriad questions and problems incurred on the way. The beauty and mystery of the glazes of the ancient Chinese potters, whose secrets I dreamed of discovering for twenty years, are now at the fingertips of anyone interested in finding them. Much of this knowledge has become generic, and every potter has potential access to the information. The documentation of ceramic processes throughout history has never been more thorough nor more readily available.

This study thus documents the processes involved in the development of a new range of high temperature crystalline glazes that exhibit the glaze qualities as defined by the author, in conjunction with a body of utilitarian ceramics that best display the qualities of these glazes in aesthetic unity.
The significance of this study will be in its discovery and explanation of a range of methods to control the various qualities of crystalline glazes. Even though these glazes have been in commercial use since the 1880s, nowhere in the contemporary literature is there reference to the degree of complexity in surface quality of the glazes. This study aims to develop a comprehensive understanding of the multiple variants which can be manipulated to produce a range of personalised glazes and contribute to the quantum of knowledge on crystalline glazes.

1.2 Defining a personal aesthetic

Art without tradition is like a flock of sheep without a shepherd: art without innovation is like a corpse.

W. Churchill (1954, 93)

The claim of any work of art to beauty and artistic integrity centres on its ability to convey meaningful visual messages. There must be both a depth and breadth to the work which transcend the relative superficiality of the technical aspects of its creation. The work needs to be informed by parameters of philosophy, design, craftsmanship, technical strength and utility, and genuine spiritual aspirations, all of which relate to the whole body of ceramics, seen in the entire ceramic tradition that has gone before.

William Morris (1834-1896), the nineteenth-century British writer, craftsman, artist and social reformer, railed against the impact of mass-produced goods from the industrialised world, and its consequent effect of reducing demand for hand-made crafts in the United Kingdom. Morris’s main treatise concerned notions of art and beauty in society; he claimed that an aim of art was to increase people’s happiness by giving them beauty. Beauty would enhance their leisure, give them hope and bodily pleasure in their rest, and prevent them growing weary of their rest (Naylor 1996, 138). This beauty was to be achieved by revitalising traditional crafts, so that individuals had access to the wares of craftspeople at reasonable prices. Morris also spoke of the sensuous pleasure
derived by the craftspeople as they worked, and believed that this level of work satisfaction should be part of all labour.

Like Morris, Soetsu Yanagi (1889-1961) also took a stance against the shoddy and poorly designed goods which appeared in Japan during the Industrial Revolution. The machine-made substitutes for hand-crafted work were standardised and monotonous, cold and ill-fitted to serve as companions in daily life. He concluded that in bringing cheap and useful goods to the average household, industrialisation had been of service to humankind - but at a cost to the heart of warmth, friendliness and beauty. Yanagi (2nd Ed.1976, 122) claims that no machine can compare with the flexibility and creativity of a person's hands. Machinery can give speed, power, complete uniformity and precision, but it cannot give creativity, adaptability, freedom and heterogeneity.

Notions of aesthetics have cultural biases. In Japanese ceramics, Yanagi (1976, 123) refers to the terms of shibui, wabi and sabi. These refer to the beauty of irregularity and the love of a certain roughness, behind which lurks a hidden beauty. Certain tea-bowls with these qualities have the beauty of the imperfect, a beauty that deliberately rejects the perfect. It is a beauty that lurks within, not a beauty that is displayed before the viewer by its creator. Creation here means making a piece that will lead the viewer to draw beauty out of it for him or herself, thus making an aesthete of the viewer.

While I fully understand and appreciate the Japanese notions of restraint, austerity and unevenness in beauty, and also the humility and warmth of usage in the everyday ceramic objects in the daily rituals and ceremonies of the household, I am particularly conscious of the symmetrical nature and influence of early European ceramics, particularly the Greek ceramics from the Golden Period of 600-400 BC which combine form, function and decoration.

It is this sense of ceramic tradition that is important to my work. I am drawn to the utility of ceramics and also to the decoration created specifically by the fire and not by the brush. My interest lies in the uniqueness of glazed ceramic surfaces, in their propensity
to change subtly where differences in thickness occur on the pot, or where the glaze creates a special effect which is aesthetically pleasing. It is within this dimension of glaze quality and its relationship with the form of the pot where the intended innovation for this study will lie. My preferred forms are uniform and symmetrical.

In matters of beauty, there is a clear antithesis between East and West. Greece has dominated western art for more than two thousand years, and the ideal of Greek beauty is founded on the symmetry of the human body. The oriental aesthetic, however, found the beauty in the irregularity nature, outside the human form.

My knowledge of ceramic form comes from long experience at the wheel and also, more importantly, from the observation of pottery's form and function as used throughout history, especially with a sensitivity to the material. People's daily habits and actions also add to this equation. I am attempting to infuse my pots with a heightened sensuality that is denied to ceramics that merely function as utility objects. I dislike the connotation that functionalism denies ornament and decoration. Function should not merely be discussed in terms of design and ergonomics, but in the way the pot can be part of a ritual and add depth and meaning to life. This is why touch is so crucial. A purely visual analysis denies the tactility of the craft, and too much criticism is based on the eye and not the hand.

The tastes of ceramic collectors or curators who acquire ceramic objects for public collections are not necessarily an authoritative discernments. Nor is work which sells successfully necessarily a measure of aesthetic worth. Most publicly collected work reflects community taste or the standards of the time. Exhibited ceramic work often escapes the rigours of the genuinely perceptive critical assessment which is familiar to the world of the painter or the sculptor.
John Olsen said of art criticism:

I think a good critic is a kind of sensitive adjudicator who comments on what the rules may be and how they have been invented by different creators. I think good criticism not only informs the public but it informs the artist. And the artist needs some sort of articulator who can perceive what is important and what is not (Sullivan 1994, 106).

Peascod (1992, 4) claims that community tastes and standards are defined by educational systems. Political pressures have also been used to espouse the virtues of design as a desirable educational goal, with the resultant message that design is the whole essence of ceramics.

Ceramics has its particular uniqueness in that its utility has been seen as the cornerstone of craft practice. Our response to the pot and the dialogue we have with it are personal to our own sense of social and material existence. Their surfaces have been used as a canvas for important messages or the recording of aspects of life and culture. Pots have accompanied all forms of human existence as cooking and eating vessels, funerary urns, canopic jars, sacred chalices and storage vessels to hold the accoutrements of the deceased for transportation to the next life.

Aspects of form and surface are also linked to our notions of qualities of beauty. The form of the pot, the way it feels in our hands, its weight, thickness, balance, the feel of the glaze to the touch, its relationship to function, its dimensions, the size of the foot and its proportions are all elements which must be contemplated in the making process. The glaze quality and its compatibility with the form of the pot are also important considerations. There is the intuition of the maker and the unexpected and inexplicable alchemy that occurs in the fire that make the ceramic process so alluring. It is that magical quality of the pots, essentially indescribable, where notions of beauty meet language in the deep recesses of the mind, that motivates the potter to continue. For me, beauty in ceramics reflects a strong and lengthy contemplation of these factors. But
beyond all of the technical considerations, there is a transcendence that can elevate the pot to attain qualities of beauty which are universally recognised.

In the development of this new body of work all of the above considerations are brought to bear. I adopt a highly disciplined approach to all aspects of the processes of making, bisque firing, glaze preparation, application and firing. As the clay is being prepared for throwing, there are many decisions being made, as the form and thickness of the pot will influence the quality of the crystals in the glaze. The form is critical, as the slightest variation in the proportions of the pot, the relationship of the width/height of the foot, belly, neck or lip of the pot can render a potentially beautiful pot into one which lacks merit because its balance and proportion are not right. My work is totally dependent on the relationship between form, surface and function.

Aesthetic judgements on the qualities of the glazes are also being made. These concern the desired shape of the crystals, the colours of both the crystals and the background, the use of secondary crystals and the growth of haloes around the crystals. Even though the qualities of glazes are carefully and scientifically planned, it is the unexpected outcomes discovered on opening the kiln, the *pentimento*, that really excite.

The essence of beauty in ceramics lies in the understanding of both form and glazed surface. These reflect the craft skills involved in the making process, the hard-won knowledge of form and proportion and glaze chemistry, and a virtuosity derived from long practice in using the fire as a tool to obtain the surface effects required.

With ceramic surfaces, many glazes have crystalline qualities. My view is that crystalline glazes *per se*, in their crudest and most common form, are a novelty only, and antithetical to originality. This thesis takes the use of crystalline glazes as a starting point, and proceeds through a carefully documented process of experimentation to develop a palette of soft and muted glazes. The variety of specific features achieved, haloes, secondary crystals, colour relationships and tactile qualities create an
harmonious unity with the specific ceramic forms chosen, and together they represent the notion of beauty I explore in this thesis.

1.3 What are crystalline glazes?

Any glaze containing crystals, whether they are microscopic or large, visible crystals, is technically a crystalline glaze. Micro-crystalline glazes occur most frequently as matt glazes. In the stoneware range of temperature they commonly contain large quantities of alumina, barium, calcium or magnesium, which cause very small crystals to appear on the glazed surfaces and give them their rougher-textured matting qualities. Crystalline mattness can also be caused by underfiring, where the glaze does not melt (i.e., a complete homogenous melt is not achieved), or by firing too rapidly, where the glaze does not have enough time to mature. In both of these conditions, the surfaces develop microscopic crystals. At lower temperatures, matt qualities (crystalline) are achieved by introducing a vigorous crystal-former such as rutile to the glaze (Sanders 1974, 87).

Another type of crystalline glaze is the aventurine glaze. These are low-fired glazes with minute crystals in suspension. They are readily visible to the naked eye and create surfaces which sparkle and reflect light. Lead-based glazes with the addition of 8-15% iron will result in the formation of aventurine crystals. These glazes were first developed by the Chinese potters in the late Ming Dynasty period (1369-1644 AD).

Macro-crystalline glazes are the focus of this study. These include zinc silicate crystals on the ceramic surface that are separated and easily distinguishable as individual crystals or clusters of crystals. Macro-crystalline glazes contain zinc ortho-silicate crystals to which other metal oxides have been added for colour. These crystals are clearly evident in the glaze and are usually fired to between cones 9 and 12. The basic crystalline glaze consists of silica, fluxes and crystal formers. Crystals form when a number of minerals
interact with silica in a low-alumina glaze. Fluxes that promote crystal growth are zinc, sodium, potassium, barium, magnesium and lithium (Parmelee 1973, 113).

Crystalline glazes must have very low viscosity for the crystals to form and grow. Crystal formation depends on the glaze recipe, the thickness of application of the glaze, the heat work done in the kiln and the shape of the glaze surfaces.

1.4 The historical development of crystalline glazes

In the 7000-year history of the use of fired clay by humans, high-temperature crystalline glazes first appeared only relatively recently as oil-spot glazes in the Sung Dynasty in China (AD 960-1279). The glazes produced in this period were unique because of their characteristic circular, brown and light-grey crystals on a black background. The crystals vary in size and colour intensity according to the firing conditions. These glazes have been extensively studied and reproduced (Wood 1980, 47), and are shown to include between 5% and 10% magnesium and calcium in combination with adequate silica. This forms the primary crystal as a magnesium silicate under firing conditions with a long soak period within the cone 10 range of the firing.

Image 1: Example of oil-spot glaze by Paul Davis (Davis, 1995).
The earliest specific studies in glazes containing zinc silicate crystals were conducted in France during the 1850s. The ceramic chemists, Charles Lauth and G. Dutailly, working in the factories of the National Porcelain Factory in Sevres, were largely motivated by the recent European discovery of the secret of making porcelain, previously known only to the Chinese. The western discovery of porcelain fuelled a yearning to emulate some of the renowned characteristics of Chinese pots, particularly those of the Sung Dynasty, which have influenced generations of potters throughout the world. The new porcelain was the primary vehicle for crystalline glazes and the two French chemists were at the forefront of experimentation in this area. They understood that glazes with an excess of zinc oxide and silica would produce crystals under certain firing conditions. Although crystallinity was initially seen solely as a glaze fault, the unique decorative possibilities of crystalline glazes soon became apparent and experimentation continued. Lauth and Dutailly developed the following base recipe (expressed in proportional quantities by weight) for crystalline glazes in their research at the Sevres porcelain factory (Illsley 1999, 19):

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
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<tbody>
<tr>
<td>Pegmatite (a felspar)</td>
<td>55.6</td>
</tr>
<tr>
<td>Sable (sand)</td>
<td>16.0</td>
</tr>
<tr>
<td>Crai (whiting)</td>
<td>12.1</td>
</tr>
<tr>
<td>Kaolin</td>
<td>4.4</td>
</tr>
<tr>
<td>Oxide of zinc</td>
<td>18.0</td>
</tr>
</tbody>
</table>

At this factory, whole ranges of wares were designed and made specifically for crystalline glazes. Similar developments occurred in Denmark, Germany and the United States owing to the high level of interest in their unique qualities and the potential commercial advantage that these glaze types offered the ceramic manufacturing companies.

In the latter part of the nineteenth century many ‘art potteries’ flourished in the Art Nouveau period (1880-1920). These factories employed artists, designers and chemists
who were responsible for the production of ranges of individual ceramic products, much of the style of which was influenced by the Art and Crafts movement. The English social and aesthetic movement founded by William Morris which emphasised the importance of crafts and the dignity of labour in a rapidly industrialising world (Illey 1999, 28).

From 1880 the Royal Copenhagen Ceramics Company experimented extensively with crystalline glazes and the possible artistic merit in these so-called glaze defects. They mounted the first exhibition of crystal-glazed ware six years later. In 1889, the French Ceramic Manufacture de Sevres mounted its own exhibition and was soon joined by other porcelain manufacturers such as Rorstrand, Meissen and Berlin, and by the ceramic workshops of Alexander Bigot, August Delacherche and Pierre Adrien Dalpayrat.

Image 2: Crystal-glazed pot from the Royal Copenhagen Factory, circa 1900 (Illey 1999, 23).

In the United States two women were in the forefront of crystalline glaze development. Maria Longworth Storer and Adelaide Alsop Robineau first produced crystalline glazed vases. Storer founded Rookwood Pottery of Cincinnati in 1880 and began researching
aventurine glazes, first exhibiting this work in 1889. Robineau (1851-1929) made her first successful crystalline vase in 1904. She worked in collaboration with Frederick Herbert Rhead and later Taxile Doat and developed a wide variety of some of the most beautiful and interesting crystalline glazes ever seen. Her experiments covered zinc silicate, flowing matt, fixed matt, molybdenum crystals and reduced crystal glazes. She attempted to produce moulded ware on a semi-industrial basis, but continued with hand-thrown vases of the same aesthetic form and colours into the next decade. She eventually achieved elusive red and black crystal glazes (Ihrman 1984, 96-99).

Adelaide Alsop Robineau’s significant contribution to the study of crystalline glazes, achieved by her lifetime documentation of her extensive research, is largely responsible for bringing the glazes into the realm of the independent potter’s studio. Her research notes supplemented the first definitive text on crystalline glazes by Taxile Doat in 1905 entitled *Grand Feu Ceramics*. This was translated and published in (in the United States) 1916 by Samuel Robineau, brother of Adelaide.

Although studio potters have never ceased to experiment with them, from the 1930s through to the 1980s the commercial production of crystal glazes dwindled. The reasons for this are thought to lie in the political upheaval in Europe from the first World War and changing aesthetic tastes in pottery. During this half-century, little development of note is recorded. Since 1980 there has been a growing interest in crystalline glazes, especially in the United States and Britain where there are many devotees and collectors of crystal-glazed pots. There are, however, just as many detractors, owing to questions of personal taste and, more generally, aesthetics.

Ilsley (1999, 34) suggests that the resurgence of interest in macro-crystalline glazes since 1980 is clearly because of the great technological advances in controlling the kiln and to the persistence of a handful of dedicated practitioners. He sees the electronic programmer as having made it possible for many more potters to venture into crystals; the technology generally has opened up an endless vista of experimentation with an infinite variety of possibilities.
1.5 The aesthetics of crystalline glazes

In creating works from clay, the potter has to manipulate form and surface quality. It is the combination of both of these elements which determines whether a pot has aesthetic merit. The potter faces the intellectual problem of designing and creating works which embrace this aesthetic challenge. The essence is to produce pots in which the form and surface quality find a level of understated harmony, a sympathy for each other, where the two elements combine in a seeming unconscious way to become a single entity. The qualities of this pot transcend the individual elements and technical considerations that have been the essence of its making, where the object has a power to move others as a statement of universal beauty and harmony.

Gwynn Hanssen Pigott (1996, 61)

Crystal-glazed pots have attracted much attention since they first appeared in exhibitions in the 1880s, not only because of their technical challenge, but for the beauty and depth of their glazes. Their startling gem-like glitter and rarity were enhanced by the fact that no two pieces were exactly alike in the disposition, size and colouring of their crystals.

Crystalline glazes can have an elegance that gives them an aura of preciousness akin to rare metals, enamels and gemstones. They suggest a connection with natural phenomena such as holograms, starry skies, frosted windows, geodes, lichen on rocks or fractals. They are at once both mysterious and sensuous.

Several writers have linked crystal formations in glazes with fractal images. In 1918 the French mathematician Gaston Julia (1893-1978) advanced his complex theory of mathematical sequences as potentials for geometric patterns. In 1970, Gaston’s nephew, Benoît Mandelbrot (2000), elaborated on his uncle’s work and invented the concept of fractals as images of extraordinary beauty which arise out of simple mathematical function. Their distinguishing feature is the property of self-similarity, whereby an
arbitrarily small region of a fractal looks like the entire fractal. Crystal formations can have similar qualities.

![Image 3: Detail of crystalline-glazed surface (Peter Wilson, 2000).](image)

1.6 Characteristics of crystals

For a full discussion on the aesthetics of crystalline glazes, the specific characteristics of the glaze must be examined. A crystalline glaze is composed of crystals and the background or sea within which they float. The crystals themselves have a finite number of manifestations from circular shapes (equiaxed), large flowery forms, battle-axe shapes, Maltese cross forms, needle shapes (acicular) and combinations of these. The crystals can have haloes of different colours surrounding them and growth rings within them, and can come in any variety of colours. The background colours can be manipulated in comparison to the crystal itself and the development of secondary
crystals and their colours can be controlled to a lesser extent. These are all factors that can be determined and manipulated by the potter and a conscious decision can be made as to which type of crystal shapes to use in the glazes. These results are determined by the glaze chemistry and the firing procedures.

Image 4: Images of various crystal shapes (Peter Wilson, 2000).

Image 5: Detail of a dense agglomeration of crystals (Peter Wilson, 1999).

The background colours of the glaze are usually paler, transparent hues of the crystal itself. The crystals tend to form in a random manner of agglomeration where the glaze is
thicker. This is most often towards the bases of pots as the glaze flows under the pull of gravity. They also form most densely where the glaze pools in the bottom of concave bowl forms. Crystal formation is dependent on many factors, but a major one is the form of the pot and whether the surface is vertical, oblique or horizontal. Crystals tend to form less frequently on vertical surfaces than on flat or oblique surfaces, as the low viscosity of the crystalline glaze causes excessive running at high temperature. The crystals develop best where the glazes can pool and where the glaze run is restricted. For my preference, however, the crystals formed under these conditions are often less visually attractive.

1.7 Form and crystal development

Crystalline glazes are unique in that they are inherently decorative surfaces. Special consideration needs to be given to the form of the pots in order to exhibit their decorative qualities in the best possible manner.

Crystalline glazes are a form of decoration. The question as to whether the finished pot is of aesthetic significance depends upon the potter’s and the critic’s understanding of the harmony that exists between form and glaze. Daniel Rhodes (1980, 136) states that a unique glaze by itself does not ensure aesthetic significance. It is an expression of the potter’s skill and aesthetic sensitivity to know which forms are best suited to the use of crystalline glazes and which glaze is the most appropriate.

This question of appropriateness of glaze and form is a lengthy discussion with strong individual notions of aesthetic choice and preference.

According to Dann (1991, 36), crystalline glazes look inappropriate on square, angular or complex forms where the crystals have to navigate corners or grooves. The glazes are also a poor choice for rough, primitive, or abstract-expressionist forms. Objects need an unbroken surface on which to display crystals.
Deck (1996, 20) takes the approach that since crystalline glazes are complex decorative surfaces, the forms should be equally complex. He prefers to use thrown and altered forms with additions of handles and other decorative pieces to complement his crystal glazes.

My own view is that much of the crystal-glazed ware currently on view is crass, ostentatious and garish. Large flowery crystals covering a form, or crystalline glazes on particularly busy, complex forms, are unattractive. The viewer’s eye is confused and has nowhere to settle to contemplate the individual piece which has a decorative glazed surface on a form that is inherently complex. My own aesthetic preference (see 1.2) is for glazes which are softer and which use colours that harmonise rather than contrast. The negative space around the crystal is the primary area of interest for me. I prefer to develop a secondary crystal in this space, of a different colour to the primary crystal, which can have a halo or growth rings for interest. I prefer my forms to be simple and sculptural, undistracted by unevenness, texture or complexity in any way. In this way, the purity of the decorative glazed surface is unimpeded by the form. Each piece is like a sculpture, beautifully balanced with a subtle yet decorative surface.

The exteriors of rounded, open bowl-forms provide an excellent surface for the crystals to be shown to their advantage. Similarly, round vases, necked-vases, bottles and spherical forms generally show the full potential of crystal development in these glazes. Rounded forms, because of their convex shapes, tend to be more suited to crystalline glazes, as the nature of these shapes allows the glaze to run smoothly without pooling (which can be an unattractive feature of crystalline glazes). A straight form or a curving organic one with clean lines is more harmonious with the decorative nature of the glaze and the circular shapes of the crystals. All of the work should be finely thrown and finished because the form needs to support the complexity of the glaze. My tendency is towards pots and glazes that are understated rather than bold and ostentatious.

Creber (1997, 30) points out that, for her, forms with smooth flowing surfaces tend to be best suited for crystalline glazes. She claims that pronounced throwing lines, incisions,
additions or alterations to the surface or the form should be kept to a minimum or avoided, because the extremely fluid crystalline glaze gathers in the crevices or texture marks creating an unevenness or disjointed quality to the growth of the crystal patterns.

The vases, urns, bowls, platters, jugs and other items of domestic ware produced by the National Porcelain Factory at Sevres in the late nineteenth century were glazed with crystalline glazes. The crystalline glazes were considered to be just another glaze, albeit an inherently decorative one, but it does not appear that any special aesthetic consideration was given to the forms of these wares.

The form of a pot will influence the general pattern of crystal development. On vertical areas, especially on the lips of thin bowls, the fluid glaze will flow down the walls of the pot leaving the rim totally denuded of crystal development. This phenomenon will occur even when the glaze is applied more thickly to allow for this effect of gravity. Another
factor influencing this result is the thickness of the rim and its saturation level when the glaze is applied. Thicker areas of the bisqued pot will retain a greater amount of glaze.

Image 7: Crystal development on vertical surface on a bowl rim, 140mm h. x 180mm w. (Peter Wilson, 2000).

On flatter areas within platters or the interiors of bowls, the glaze can tend to pool. This can lead to the development of large macro-crystals that coalesce, or in other cases where the glaze is thickly applied, it may look roughly textured and opaque, which detracts from the overall quality of the pot. In both cases, the thickness of application of the glaze is crucial to the finished quality of crystal development.

On oblique surfaces, the type of crystal development depends on the angle of the surface, with flatter surfaces leading towards a larger crystal, while with surfaces closer to the vertical, smaller crystals develop.
The low viscosity of crystalline glazes has caused potters to consider redesigning the forms of their pots so that the glaze runoff can be minimised. The bases of pots can be modified to stop the flow of glaze off the piece. A special foot or base is made as part of the design of the pot to catch or slow the flow of glaze off the pot. Here, the foot can be slightly undercut providing a barrier and an angular change of direction against which the molten glaze will be compressed and hence collect. This design alteration, combined with a slightly thinner application of glaze to within approximately 50mm of the pot’s base, tends to reduce to a minimum the amount of glaze runoff.
1.8 Crystals and colour

The crystals themselves vary widely in their shape, size, growth patterns and colour, and each of these variables can be controlled. The author’s prime area of interest is not the development of crystals *per se*, but a much broader view of the glazed surface that encompasses both crystals and the negative space around the crystals. This includes the growth of haloes around the crystals, growth rings within crystals, secondary crystal growth of either a contrasting or complementary colour, the size and shape of the crystals and crystal placement on the pot.

Image 9: Crystal development which includes primary crystals, haloes, secondary crystals (Peter Wilson, 2001).
The colour of the crystals and the background is determined by the manner in which crystals form in the firing. After the glaze has been fired to maturity (the zone of nucleation) and then cooled to the crystal-growing temperature (zone of crystallization) between 1020-1120\(^0\) C, ionic bonds of zinc silicate crystals (willemite)\(^4\) form around certain molecules which are related to some colourants in preference to others. The crystals continue to grow while the kiln remains within this temperature range. This selective crystal development of molecules in the molten glaze explains the colour differentiation between the crystal and the glaze itself.

The glaze colour is influenced by the amount and combination of colourants used in it. Seemingly small changes in the amount of colourant can dramatically alter the colour characteristics of the glaze. Small changes in the amount of titanium dioxide added to the glaze can also dramatically alter the glaze colour. In this case, the crystals may remain the same colour with increasing amounts of titanium, but the ground will become increasingly opaque and creamier.

---

\(^4\) Willemite

Willemite is an extremely rare mineral as it occurs in nature. It fluoresces brilliant green. **Willemite** (Carter and Sweet 1997, 79)

<table>
<thead>
<tr>
<th>Property</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour:</td>
<td>ranges from beige, pale grey or pale blue on larger crystals transparent to translucent</td>
</tr>
<tr>
<td>Transparency:</td>
<td>dull to greasy</td>
</tr>
<tr>
<td>Lustre:</td>
<td>hexagonal</td>
</tr>
<tr>
<td>Crystal system:</td>
<td>Hexagonal prisms to 3mm, terminated by small pyramids and pinacords (exceptionally to 10cm)</td>
</tr>
<tr>
<td>Crystal habits:</td>
<td>crystals, radiate fibrous, granular, massive and crusty aggregates imperfect on 0001 – perfect on 1120 conchoidal to splintery</td>
</tr>
<tr>
<td>Morphology:</td>
<td>5.5</td>
</tr>
<tr>
<td>Cleavage:</td>
<td>white</td>
</tr>
<tr>
<td>Fracture:</td>
<td>ZnO 72.96%, SiO(_2) 27.04%溶 soluble in HCl; fuses with difficulty into a white enamel; shines in a blowpipe flame secondary metamorphic</td>
</tr>
<tr>
<td>Hardness:</td>
<td>Crystal habit and its fluorescence Named in 1830 after King Willem II (1772-1843) of the Netherlands</td>
</tr>
<tr>
<td>Streak:</td>
<td>5.5</td>
</tr>
<tr>
<td>Chemical composition:</td>
<td>5.5</td>
</tr>
<tr>
<td>Chemical properties:</td>
<td>5.5</td>
</tr>
<tr>
<td>Genesis:</td>
<td>5.5</td>
</tr>
<tr>
<td>Distinguishing features:</td>
<td>5.5</td>
</tr>
<tr>
<td>Origin:</td>
<td>5.5</td>
</tr>
</tbody>
</table>
The author's preference here is for circular crystals, for several reasons. Only the circular crystals can develop growth rings within them and haloes around them. They also form in a particular colour that allows for a range of possible harmonising or contrasting colours to be developed as a background in conjunction with them. The other forms of crystals, such as needles, starbursts or Maltese crosses, do not exhibit these qualities.

These glaze characteristics can be controlled by manipulating several elements, including the form of the pot, the glaze recipe and the firing conditions. Each of these elements will be assessed and discussed in detail.
Chapter 2

Methodology

An artist may experience innumerable influences in a lifetime and yet be captive to none of them. From the Italian fresco painters to Titian, Rubens, Brueghel, Constable, Turner, Van Gogh, Cezanne, Streeton, Wakelin, Nolan and Boyd - but of one thing I feel personally certain, whatever the influences, an artist must forget them when he starts to paint – once a picture comes to life, it dictates the terms of its own creation.

L. Rees (Hawley 1993, 16)

Chapter 1 set out an historical perspective and defined a personal aesthetic position based partially on observations and the influences of the work of others and that work which has gone before. This chapter will describe the method of formulating a series of line-blended glaze tests on previously researched base glazes. These tests, which incorporate colourants used both individually and in combination, have led to the development of a palette of glazes from which individual glaze characteristics have been selected for their aesthetic qualities.

2.1 Glaze formulation and chemistry

This study translates the research of the author, an artist, into a text-based form and draws on the technical aspects of glaze formulation that relate specifically to studio-based ceramic activity. The methods that have been adopted for glaze testing and analysis throughout this thesis are those that are most commonly used by ceramicists working within the context of studio practice the world over. The glaze recipes are calculated using the glaze-recipe method as used by DeBoos (1978, 1989), Daly (1995), Hopper (1993) and others.
Either of two other related methods of glaze formulation and recording could have been adopted for use in preference to the glaze-recipe approach and these would, theoretically, be more accurate. These are the Seger molecular formula method and the percentage analysis method of glaze calculation.

The Seger molecular formula calculation is a precise method of calculating the composition of each glaze. Whitfield (1982, 22) explains that in using this method, the glaze components are expressed in terms of the ratio of molecules present in the fired glaze. If the ratio of molecules present is then converted to a ratio of weights by multiplying the proportion of each molecule present by the molecular weight of that molecule, it is transformed to a percentage analysis. This is the second possible method for glaze notation that could have been used in this study.

Currie (1985, 107) states that a knowledge of molecular formula of glazes helps the ceramicist with an understanding of the principles of glaze technology, which then enables the prediction of effects, the extrapolation and interpolation of results and the ability to search in a systematic way for desirable results.

Whitfield (1982, 22), however argues that the percentage analysis method offers more information on the nature of the composition of glazes as well as providing insights into the causal relationships between specific materials in the glaze. He uses the specific example of a glaze written in both molecular and percentage analysis formulae and concludes that more information can be gleaned from the latter approach. Wood (1980) also adopts the percentage analysis method as his preferred approach in discussing the re-formulation of centuries old Chinese glazes. He states that the molecular formula method is more suited to the refined raw materials available today and generally not suited to descriptions of the impure raw materials that the Chinese potters used because of its unnecessary complexity. His preferred way of replicating these glazes is with similarly impure natural substitutes for the original ones adopting the percentage analysis approach in finding the appropriate raw material.
Currie (1985, 107) admits that there are distinct disadvantages of this molecular formula which relate to the information that is issued by the suppliers and rock-milling companies. The difficulty being that in using many raw materials, molecular analysis is not always available or reliable, as variations in the material can occur naturally from within different parts of the same mine. The sophisticated equipment required for exhaustive scientific analysis is normally unavailable to the studio ceramicist. The main concern for studio-based practitioners is the consistency of materials across different batches of supply.

Ironically, in his later book, Currie (2000, 15) disregards molecular formula in favour of the recipe-data method, stating also that it is not necessary to understand Seger formula. Understanding the influence of different recipes of materials, glass, flux, glaze stiffeners, colourants and opacifiers on the fired glaze is important and is the approach adopted by most studio ceramicists.

The aesthetic qualities of glazes are more important to studio practitioners than the molecular analysis of glaze materials and the scientific explanation of the glaze chemistry involved. Technical virtuosity doesn’t necessarily interpret into exciting art. Good ceramic art comes from a thorough familiarity with all of the materials, the clay, the glaze materials and the firing processes as well as the craft skills involved. This thesis draws on the knowledge of the relationships of glaze materials and chemistry with specific reference to studio-based ceramic activity. The glaze-recipe method of glaze formulation is sufficiently precise to give the studio ceramicist the necessary control and understanding of glaze outcomes.

The glaze formulation and testing procedure adopted for this study utilized duplicate test tiles glazed with six crystalline base glazes and line-blending. They were then fired in both gas and electric kilns. The electric kiln, which fired to stoneware temperatures, had an electronic programmable controller. This allowed the glaze tests to be compared for thickness of application, the composition of each recipe, firing conditions, kiln
atmosphere, temperature and firing cycle. The tests and the results were systematically recorded.

2.2 Clay

After initial testing, two clay bodies were chosen for the tests. Preliminary trials on a variety of stoneware clays had excluded all but the fine, white firing bodies, as any coarseness was shown to adversely affect crystal growth. Darker or buff-coloured bodies were excluded because the palatte of colours in the finished glazed surface became muddied. Other factors that were important were availability, reliability in the kiln, shrinkage rates, warpage and price. The cost of expensive porcelain (at $45 per block) could not be justified because its translucency was not a required quality. The three commercial bodies chosen for the tests were Keane’s White Stoneware No. 7, Feeney’s White Stoneware and Johnson Brothers white porcelain (JB3) (see Table 1). All of these clays are dense porcellaneous-type stoneware bodies.

<table>
<thead>
<tr>
<th>Clay</th>
<th>Shrinkage when fired to cone 11</th>
<th>Fired</th>
<th>Throwing properties</th>
<th>Cracking/dunting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeney’s White Stoneware</td>
<td>16.5%</td>
<td>White</td>
<td>excellent</td>
<td>Care needed to avoid dunting</td>
</tr>
<tr>
<td>Keane’s White Stoneware</td>
<td>14.5%</td>
<td>White</td>
<td>good</td>
<td>Care needed in bisque kiln with the placement of large pots</td>
</tr>
<tr>
<td>JB3</td>
<td>15%</td>
<td>White</td>
<td>good</td>
<td>Care needed to avoid dunting and cracking in bisque</td>
</tr>
</tbody>
</table>

Table 1: Clay properties
While all three clays could be used with crystalline glazes, Keane’s and Feeney’s clays were selected for their greater reliability in the kiln. Both clays produced similar results. Feeney’s clay was more reliable with larger pots above twenty kilograms in weight, whereas Keane’s clay tended to be more suited to smaller pots.

![Image 10: T-shaped test tiles for glaze tests, 50mm h. x 35mm w. (Peter Wilson, 1998).](image)

It was necessary to have a vertical and a horizontal surface to test the glazes because of the differing effect these surfaces have on crystal development. To this end a T-shaped die was made for the extruder and test tiles were made using both clays (see Image 10).

### 2.3 Glaze ingredients

The main ingredients used in high temperature glazes to promote crystal growth are: *alkaline frits*, especially Ferro frit 4110⁵. This is the primary glass former for crystalline glazes in this country. It has a wide firing temperature range:

⁵ Ferro Frit 4110: A frit is a manufactured compound that has been fired to a molten state, then cooled and ground to a powder. Using a frit in a glaze simplifies glaze preparation. One single, convenient material is added rather than having to weigh out and add several ingredients. Its chemical composition is: (www.potters.org.subject.htm)

Na₂O 15.31; K₂O 2.54; CaO 6.13; Al₂O₃ 4.26; B₂O₃ 2.68; SiO₂ 69.15
- **silica.** This combines with zinc oxide and fritted glass to form a glaze.

- **zinc oxide.** This was calcined (or densified) to prevent the otherwise thick coating of glaze from cracking or lifting off the glazed pot, which is what happens when colloidal zinc oxide is used. This is the primary crystal-forming material when combined with silica at high temperature, cones 9-12. Calcining avoids the cracking of the thickly applied glaze because of the high shrinkage rate associated with the zinc oxide. Calcining is done by firing standard zinc oxide (colloidal) on a clean kiln shelf in a normal biscuit firing, or alternatively, it can be purchased in its densified form, (calcined).

- **alumina.** This was introduced as bentonite in very small quantities which increased the suspension of the mixed glazes and causes the dry glaze to adhere to the pot prior to firing. More than 5% of alumina increases the viscosity of the glaze which affected the crystal development.

- **titanium dioxide.** This is a crystal seeding material which enhances crystal growth and provides a wide range of colour variations that affect the primary colourants. It should be used in amounts less than 10%.

The test glazes were made in small batches of about 100g or less dry weight. The workspace was kept clean and free from contaminants. The ingredients were accurately weighed out and mixed with a small amount of water to make a slurry. The slurry was passed through an 80 screen mesh twice to break up any coarse particles and to mix ingredients thoroughly. Water was added to the screen to push the slurry through using a kidney or brush. More water was subsequently added and the glaze was applied according to thicknesses as described for each glaze type.

The addition of a flocculent such as magnesium sulphate (Epsom Salts) in the proportion of 0.25% of the total weight of the glaze retards the settling of ingredients in the glaze and also allows the glaze to be stirred more easily after it has settled. This addition has no effect on the glaze quality. The use of up to 2% of bentonite as a flocculant in the glaze mix reduces the amount of water required to make the glazes. More importantly, it creates a near perfect suspension of glaze ingredients prior to application.
All ingredients were dry weighed and then thoroughly mixed. Dry glaze can be prepared in any quantity and stored, but water is only added to the approximate amount of glaze needed for the pots to be glazed. This practice was adopted for two reasons:

- glazes tend to settle in the bottoms of containers, even though flocculants like Epsom Salts are added.
- a change to the ingredients occurs while the glaze is mixed and it loses its efficacy if it is left to stand for any length of time. This can result in the glaze not forming crystals. One suggestion to explain this phenomenon is that one or more ingredients go into solution over time.

The glazes were mixed to a light creamy consistency for application to the ware. It is mixed in the ratio of dry glaze to water 1:1.6. The glazes were then sieved again through an 80 mesh screen. The test tiles were dipped to cover all of the horizontal and vertical surfaces to a thickness of around 1.5mm. Then half of the tile was brushed with the same glaze to a thickness of 3mm. Comparisons of thickness of glaze application can then be made.

2.4 Application of the glaze

The test tiles and subsequently the pots were cleaned with a damp sponge to remove dust. The glaze was constantly stirred to keep ingredients from settling. Glaze can be applied by dipping, brushing, pouring or spraying. It is important to get the correct thickness of glaze on the pot. Because the glazes flow readily under gravity at top temperature, there must be enough glaze to allow for this and to still develop crystals. Several coats of glaze may be required to build up an adequate glaze thickness. Crystalline glazes consist almost entirely of insoluble materials that make them easier to apply thickly. However, when insoluble materials dry, they have little dry strength and require careful handling.
When glazing a bowl shape, care must be taken or the glaze will run and pool on the inside. Creber (1997, 47) points out that the glaze should be applied heavily on the rim area of the bowl, allowing it to get thinner as it gets closer to the middle, so that at the bottom there is only a thin application. When the piece is fired, there should be an even layer of glaze all over as the glaze flows.

For items such as vases and covered jars, standard functional-ware glazes were used on the inside. Crystalline glazes need to be seen and are hence wasted on the invisible interiors of closed pots. Two glazes in particular were used in this body of work in this respect (Table 2).

<table>
<thead>
<tr>
<th>Glaze</th>
<th>Parts by Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cones 8-10</td>
<td></td>
</tr>
<tr>
<td>Potash felspar</td>
<td>52</td>
</tr>
<tr>
<td>Wollastonite</td>
<td>22</td>
</tr>
<tr>
<td>Zinc oxide (colloidal)</td>
<td>5</td>
</tr>
<tr>
<td>Silica</td>
<td>18</td>
</tr>
<tr>
<td>Bentonite</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Potash felspar</td>
<td>40</td>
</tr>
<tr>
<td>Silica</td>
<td>30</td>
</tr>
<tr>
<td>Whiting</td>
<td>20</td>
</tr>
<tr>
<td>Kaolin</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 2: Functional-ware glazes used in conjunction with crystalline glazes.
2.5 Glazes

The base glazes selected for initial testing are shown in Table 3.

<table>
<thead>
<tr>
<th>Glaze No.</th>
<th>Ingredients</th>
<th>Parts by weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Frit 4110</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>Zinc oxide</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Silica</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Bentonite</td>
<td>1.5</td>
</tr>
<tr>
<td>2.</td>
<td>Silica</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Whiting</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Zinc oxide</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Frit 4110</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Lithium carb.</td>
<td>5</td>
</tr>
<tr>
<td>3.</td>
<td>Potash felspar</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Silica</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Whiting</td>
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<tr>
<td></td>
<td>Zinc oxide</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Frit 4110</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Lithium carb.</td>
<td>5</td>
</tr>
<tr>
<td>4.</td>
<td>Soda felspar</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Barium carb.</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Zinc oxide</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Silica</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Bentonite</td>
<td>1</td>
</tr>
<tr>
<td>5.</td>
<td>Frit 4110</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>Silica</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Zinc oxide</td>
<td>27</td>
</tr>
<tr>
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<td>Bentonite</td>
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</tr>
<tr>
<td>6.</td>
<td>Potash felspar</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Barium carb.</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Zinc oxide</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Silica</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Lithium carb.</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Bentonite</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 3: Base glaze recipes
2.6 Firing

All test tiles and pots were bisque fired to $1020^\circ$C. Firing beyond this temperature decreased the porosity of the clays, affecting their capacity to develop glaze thickness. The bisque-firing cycle adopted is shown in Table 4.

<table>
<thead>
<tr>
<th>Temperature $^\circ$C</th>
<th>Rate of rise per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-150</td>
<td>40</td>
</tr>
<tr>
<td>150</td>
<td>Hold for 2 hours</td>
</tr>
<tr>
<td>150-650</td>
<td>90</td>
</tr>
<tr>
<td>650-1020</td>
<td>130</td>
</tr>
</tbody>
</table>

Table 4: Bisque-firing schedule.

2.7 Glaze firing

Oxidising or neutral atmospheres in the kiln were shown to provide optimum growing conditions for crystals. To achieve a non-reducing atmosphere in the gas kiln, an oxygen probe was used to monitor the firing. This instrument is a pyrometer, but is also able to measure the presence or absence of oxygen in the chamber. Once the kiln reaches $600^\circ$C, the pyrometer will accurately measure the atmosphere, reading excess oxidation through neutral to heavy reduction. If reduction occurs at over $1000^\circ$C, white smoke starts appearing at the flue outlet, emanating from the zinc oxide volatilising out of the glaze. If this is maintained to the end of the firing, few crystals form and a blue tinge to the glaze generally results. The oxygen probe is an excellent kiln tool to optimise fuel economy and the control of atmosphere-sensitive glazes such as crystalline and copper reds. This level of atmosphere control is unable to be assessed by the naked eye.

Several firing cycles were adopted because it was found that the base glazes matured at different temperatures and special crystal effects could be achieved by varying the crystal-growing soaking phase of the firing cycles.
Each of the glazes used was extremely sensitive to its optimum maturation temperature. As little as $5^\circ$C difference from this optimum temperature caused the pot either to be underfired, resulting in a heavily matted surface with no background, or to be overfired, causing blistering with a few crystals only and excessive running. The glazes based on potash felspar have a wider firing range than the glazes based on Frit 4110, even though they fire at lower temperatures.

The gas kiln is much more difficult to fire than its electric counterpart. Every change in the gas settings must be made individually, and the problems of firing with LPG are always present. These problems include a loss of pressure and hence temperature, if left unchecked, at critical stages of the firing. This occurs through the gas bottles freezing because the gas is being tapped off too quickly. If this occurs unnoticed during critical periods in the firing, the crystal-growing soak period for example, the whole firing can be lost if the temperature drops below 1020$^\circ$C where the glaze freezes. Firing with gas requires a vigilance that is unnecessary for firing programmable electric kilns. The potter’s presence here is only required if assisted cooling is required from top temperature down to the zone of crystallization.

Electric kilns tend to lose their firing efficiency as the elements age. Because of a continuous fall-off in element performance with use, pyrometric cones and reference to previous firing records are important to assess rates of rise. Clarkson (1994, 42) and Ilsley (1999, 77) both suggest that the rate of rise for the last 200 degrees should be at least at 100 degrees per hour. If the firing is slower than this, the effect is to increase the length of time in the zone of nucleation. The glaze becomes too fluid and the glaze run-off is increased leaving only a very thin layer of glaze for the crystals to grow in. Also the clay body may leach and fuse into the glaze which could mean no crystal growth at all, or a few small but faint crystals.

The aspects of the firing that were under examination in this study were the rate of rise of the kiln, the top temperature, the amount of time spent at the top temperature, the rate
of cooling, the temperature at which the kiln was held for crystal growth and the length of time the kiln was held at this crystal growth temperature.

Four variations of a glaze-firing cycle were developed to produce optimum results. These varied in the cooling and soaking phases of their cycles to examine a range of possible crystal effects (see Tables 5-8).

<table>
<thead>
<tr>
<th>Temperature °C</th>
<th>Rate of temperature change per hour in °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-400</td>
<td>90</td>
</tr>
<tr>
<td>400-1150</td>
<td>120</td>
</tr>
<tr>
<td>1150-1285</td>
<td>80</td>
</tr>
<tr>
<td>1285</td>
<td>Hold 0.25 hour</td>
</tr>
<tr>
<td>1285-1090</td>
<td>500</td>
</tr>
<tr>
<td>1070</td>
<td>Hold 2.5 hours</td>
</tr>
</tbody>
</table>

Table 5: Glaze-firing schedule A, Cone 10-11.

<table>
<thead>
<tr>
<th>Temperature °C</th>
<th>Rate of temperature change per hour in °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-400</td>
<td>90</td>
</tr>
<tr>
<td>400-1150</td>
<td>120</td>
</tr>
<tr>
<td>1150-1270</td>
<td>80</td>
</tr>
<tr>
<td>1270</td>
<td>Hold 0.25 hour</td>
</tr>
<tr>
<td>1270-1090</td>
<td>500</td>
</tr>
<tr>
<td>1070</td>
<td>Hold 2.5 hours</td>
</tr>
</tbody>
</table>

Table 6: Glaze-firing schedule B, Cone 9-10.
<table>
<thead>
<tr>
<th>Temperature $^\circ$C</th>
<th>Rate of temperature change per hour in $^\circ$C</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-400</td>
<td>90</td>
</tr>
<tr>
<td>400-1150</td>
<td>120</td>
</tr>
<tr>
<td>1150-1268</td>
<td>80</td>
</tr>
<tr>
<td>1268</td>
<td>Hold 0.25 hour</td>
</tr>
<tr>
<td>1268-1100</td>
<td>500</td>
</tr>
<tr>
<td>1100</td>
<td>Hold 1 hour</td>
</tr>
<tr>
<td>1080</td>
<td>Hold 1 hour</td>
</tr>
<tr>
<td>1060</td>
<td>Hold 1 hour</td>
</tr>
</tbody>
</table>

Table 7: Glaze-firing schedule C, Cone 9-10

<table>
<thead>
<tr>
<th>Temperature $^\circ$C</th>
<th>Rate of temperature change per hour in $^\circ$C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-400</td>
<td>90</td>
</tr>
<tr>
<td>400-1150</td>
<td>120</td>
</tr>
<tr>
<td>1150-1280</td>
<td>80</td>
</tr>
<tr>
<td>1280</td>
<td>Hold 0.25 hour</td>
</tr>
<tr>
<td>1280-1080</td>
<td>500</td>
</tr>
<tr>
<td>1080</td>
<td>Hold 1 hour</td>
</tr>
<tr>
<td>1060</td>
<td>Hold 0.5 hour</td>
</tr>
<tr>
<td>1080</td>
<td>Hold 1 hour</td>
</tr>
<tr>
<td>1060</td>
<td>Hold 0.5 hour</td>
</tr>
</tbody>
</table>

Table 8: Glaze-firing schedule D, Cone 10-11.

In an attempt to develop an understanding of the range of possible glaze colour outcomes, the following colourants were used individually and then in combinations: cobalt carbonate (CoCO$_3$), copper carbonate (CuCO$_3$), red iron oxide (Fe$_2$O$_3$), manganese dioxide (MnO$_2$) and nickel oxide (NiO). Titanium dioxide (TiO$_2$) was also
used in amounts up to 10% to produce a variety of different colour responses to added
colouring oxides.

To ascertain its effect on secondary crystal formation, magnesium silicate in the form of
talc was added to the glaze test batches in amounts to 10%.

In Table 9, glaze test formulae are listed with their colourants being shown in their parts
by weight within each variation. These are the specific amounts from variation A to F.
For example, glaze no. 1.1, variation E contained the following ingredients as tested on
each of the six base glazes: 1% CuCO₃ + 2% MnO₂ + 6% TiO₂ + 5% talc.

For test glazes 1.1 (as marked by their colourants, CuCO₃ and MnO₂), there were six
base-glazes, each being tested for six variations on the line-blend, that is, thirty-six
possible outcomes for glazes 1.1 as fired in the electric kiln to schedule A. As there are
twenty-four possible colourant combinations, this amounted to a total of 864 tests
completed for this preliminary series as fired to schedule A (Table 5). As well, these
tests were completed also for firings to schedules B, C and D. The most interesting
results from the electric kiln (as marked in the comments section) were duplicated in the
gas kiln.

This series of tests were then repeated for a lower cone 9-10 firing as listed in schedule
B (Table 6), schedule C (Table 7) and schedule D (Table 8).

<table>
<thead>
<tr>
<th>Glaze No.</th>
<th>Base Glaze</th>
<th>Variation A</th>
<th>Variation B</th>
<th>Variation C</th>
<th>Variation D</th>
<th>Variation E</th>
<th>Variation F</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>1-6</td>
<td>1 CuCO₃, 1 MnO₂</td>
<td>2 MnO₂, 1 CuCO₃</td>
<td>3 TiO₂, 2 MnO₂, 1 CuCO₃</td>
<td>6 TiO₂, 2 MnO₂, 1 CuCO₃</td>
<td>5 Talc, 6 TiO₂, 2 MnO₂, 1 CuCO₃</td>
<td>10 Talc, 6 TiO₂, 2 MnO₂, 1 CuCO₃</td>
<td>Colour combinations unpleasant</td>
</tr>
<tr>
<td>1.2</td>
<td>1-6</td>
<td>2 CuCO₃, 3 MnO₂</td>
<td>4 MnO₂, 2 CuCO₃</td>
<td>3 TiO₂, 4 MnO₂, 2 CuCO₃</td>
<td>6 TiO₂, 4 MnO₂, 2 CuCO₃</td>
<td>5 Talc, 6 TiO₂, 4 MnO₂, 2 CuCO₃</td>
<td>10 Talc, 6 TiO₂, 4 MnO₂, 2 CuCO₃</td>
<td>Colour combinations unpleasant</td>
</tr>
</tbody>
</table>

49
<table>
<thead>
<tr>
<th>Glaze No.</th>
<th>Base Glaze</th>
<th>Variation A</th>
<th>Variation B</th>
<th>Variation C</th>
<th>Variation D</th>
<th>Variation E</th>
<th>Variation F</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.3</td>
<td>1-6</td>
<td>CoCO₂ 0.5</td>
<td>4 CuCO₃</td>
<td>3 TiO₂</td>
<td>6 TiO₂</td>
<td>5 Talc</td>
<td>10 Talc</td>
<td>Glazes 1, 5 1.3E and F good</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CoCO₂ 0.5</td>
<td>0.5 CoCO₃</td>
<td>4 CuCO₃</td>
<td>4 CuCO₃</td>
<td>6 TiO₂</td>
<td>6 TiO₂</td>
<td>good</td>
</tr>
<tr>
<td></td>
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<td>0.5 CoCO₃</td>
<td>0.5 CoCO₃</td>
<td>4 CuCO₃</td>
<td>4 CuCO₃</td>
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</tr>
<tr>
<td>1.4</td>
<td>1-6</td>
<td>CoCO₂ 0.5</td>
<td>3 MnO₂ 0.5</td>
<td>5 Talc</td>
<td>6 TiO₂</td>
<td>6 TiO₂</td>
<td>5 Talc</td>
<td>Glazes 1, 5 1.4D good</td>
</tr>
<tr>
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<td></td>
<td>CoCO₂ 0.5</td>
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<td>6 MnO₂</td>
<td>4 MnO₂</td>
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<td>CoCO₂ 0.5</td>
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<td>3 TiO₂</td>
<td>4 MnO₂</td>
<td>0.5 CoCO₃</td>
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</tr>
<tr>
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<td>1-6</td>
<td>Fe₂O₃ 1.5</td>
<td>3 TiO₂ 1.5</td>
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<td>0.5 CoCO₃</td>
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<td>0.5 CoCO₃</td>
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</tr>
<tr>
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<td></td>
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<td>Fe₂O₃ 3</td>
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</tr>
<tr>
<td>1.6</td>
<td>1-6</td>
<td>NiO₂ 1.5</td>
<td>3 TiO₂ 1</td>
<td>6 NiO₂</td>
<td>2 NiO₂</td>
<td>5 Talc</td>
<td>2 NiO₂</td>
<td>Glazes 1, 5 1.6B good</td>
</tr>
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<td>3 TiO₂ 1</td>
<td>6 TiO₂</td>
<td>5 Talc</td>
<td>10 Talc</td>
<td>6 TiO₂</td>
<td>Colour combinations unpleasant</td>
</tr>
<tr>
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<td>TiO₂ 6</td>
<td>Fe₂O₃ 5</td>
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<td></td>
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<td>Fe₂O₃ 10</td>
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<tr>
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<td>1-6</td>
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<td>3 TiO₂ 1</td>
<td>6 TiO₂</td>
<td>5 Talc</td>
<td>10 Talc</td>
<td>6 TiO₂</td>
<td>Glazes 1, 5 1.8E good</td>
</tr>
<tr>
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<td></td>
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<td>CoCO₃ 1</td>
<td>6 TiO₂</td>
<td>6 TiO₂</td>
<td>6 TiO₂</td>
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<td>CoCO₃ 10</td>
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</tr>
<tr>
<td>1.9</td>
<td>1-6</td>
<td>CuCO₃ 4</td>
<td>3 TiO₂ 4</td>
<td>6 TiO₂</td>
<td>5 Talc</td>
<td>10 Talc</td>
<td>6 TiO₂</td>
<td>Colour combinations unpleasant</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>CuCO₃ 5</td>
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<td>CuCO₃ 4</td>
<td>CuCO₃ 10</td>
<td>CuCO₃ 1</td>
<td>CuCO₃ 1</td>
<td>CuCO₃ 1</td>
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</tr>
<tr>
<td>2.0</td>
<td>1-6</td>
<td>CuCO₃ 3</td>
<td>3 TiO₂ 3</td>
<td>6 TiO₂</td>
<td>5 Talc</td>
<td>10 Talc</td>
<td>6 TiO₂</td>
<td>Glazes 1, 5 good 2.0D.E</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CuCO₃ 3</td>
<td>CuCO₃ 3</td>
<td>CuCO₃ 6</td>
<td>CuCO₃ 3</td>
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<td>CuCO₃ 10</td>
<td>CuCO₃ 1</td>
<td>CuCO₃ 1</td>
<td>CuCO₃ 1</td>
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</tr>
<tr>
<td>2.1</td>
<td>1-6</td>
<td>CuCO₃ 4</td>
<td>3 TiO₂ 4</td>
<td>6 TiO₂</td>
<td>5 Talc</td>
<td>10 Talc</td>
<td>6 TiO₂</td>
<td>Glazes 1, 5 2.1E good</td>
</tr>
<tr>
<td></td>
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</tr>
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<td>CuCO₃ 4</td>
<td>CuCO₃ 4</td>
<td>CuCO₃ 10</td>
<td>CuCO₃ 1</td>
<td>CuCO₃ 1</td>
<td>CuCO₃ 1</td>
<td></td>
</tr>
</tbody>
</table>
Table 9: Preliminary glaze tests fired to schedule A, Cone 10-11

The results of this initial series of tests provided the basis for a much greater freedom to explore controlled colour possibilities. Once repeatable colour combinations were discovered, different firing cycles and further additions of colourants and manipulations formed the groundwork of experimentation to achieve a greater diversity. If an interesting result occurred on part of the test tile as listed in the comments, the thickness, base glaze and colourants/additives were recorded for elaboration in the next series of firings, with an intuitive response as to how to further develop the qualities that were sought. This was done by making small changes to the colourants or the amounts of titanium or talc. Pots were made and fired to elaborate the selected glazes onto a larger surface, to see the development of the crystals on oblique surfaces as well as on horizontal and vertical surfaces.

It was found that some glazes, notably base glaze numbers 2, 3, 4, and 6, were overfired in the cone 10-11 firings (schedules A and D, Tables 5 and 8 respectively). These glazes were fired to cone 9-10 as shown in schedule C in Table 7.
<table>
<thead>
<tr>
<th>Base glaze/s</th>
<th>% Addition of colourants</th>
<th>Firing schedule</th>
<th>% Talc addition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, 5</td>
<td>7. CoCO₃ 1, TiO₂ 6</td>
<td>A, D</td>
<td>Up to 10% for each variation provided interesting results</td>
</tr>
<tr>
<td></td>
<td>7. CoCO₃ 0.1, MnO₂ 0.1, TiO₂ 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. CoCO₃ 1, MnO₂ 4, TiO₂ 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. CoCO₃ 1, MnO₂ 4, TiO₂ 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. CoCO₃ 0.5, CuCO₃ 2, TiO₂ 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. CoCO₃ 3, TiO₂ 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. Fe₂O₃ 7, TiO₂ 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2, 3</td>
<td>1. CoCO₃ 1, TiO₂ 6</td>
<td>B, C</td>
<td>Up to 10% for each variation provided interesting results</td>
</tr>
<tr>
<td></td>
<td>2. CoCO₃ 0.1, MnO₂ 1, TiO₂ 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. CoCO₃ 1, MnO₂ 4, TiO₂ 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. CoCO₃ 1, MnO₂ 4, TiO₂ 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. CoCO₃ 0.5, CuCO₃ 2, TiO₂ 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6. CoCO₃ 3, TiO₂ 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. Fe₂O₃ 7, TiO₂ 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4, 6</td>
<td>1. CoCO₃ 0.25, TiO₂ 5</td>
<td>B, C</td>
<td>Unsuitable</td>
</tr>
<tr>
<td></td>
<td>2. CoCO₃ 0.5, TiO₂ 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. CoCO₃ 0.1, TiO₂ 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. CoCO₃ 0.5, CuCO₃ 2, TiO₂ 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. CuCO₃ 3, TiO₂ 5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 10: Successful glaze tests by firing schedule and colourants

Some possibilities slowly started to emerge as summarised in Table 10. The particular results sought contained glaze characteristics of a softer, muted range of crystals that lay in a background of secondary crystals of contrasting, harmonising or complementary colours. It appeared that the possible variations attainable were diverse and could be manipulated by altering the colourants, the firing cycle or application methods.
2.8 Setting procedures

The work was stacked densely in the kiln to maximise the use of the available setting space, with particular care being taken to set the ware correctly. Appropriate setting procedures were adopted. One such method involves making a base-width collar and saucer, measured and thrown when the pot is finished to catch glaze runoff and protect the shelves from glaze. Another method involves cutting soft, insulating fire-brick to the base width of the pot and setting the pot and brick pedestal on a small saucer (see Image 11).

![Image 11: Pot-setting procedure](image)

After bisque firing, the foot rim of the pot and the top of the pedestal surface are ground flat and smooth on a clean flat kiln shelf to ensure a close fit.

The pot was then glazed and the base wiped free of any glaze up to five millimetres from the base lip of the pot. A liberal coating of a kiln wash (50 parts calcined alumina and 50 parts kaolin) was then applied to the top of the pedestal and it is placed in a bisqued
catch tray that collects the run-off glaze. The pot was then placed onto the pedestal and the tray, and stacked into the kiln.

After firing, the pedestal was separated from the pot by a gentle tap along the join with a cold chisel and hammer. The pot was then positioned upside down in a chuck on the wheel; with the wheel in motion, an angle grinder with a masonry disc was used to carefully grind down and even out the foot of the pot. The foot of the pot was then hand-finished by polishing with a medium to fine grade carborundum stone.
Chapter 3

Results and Discussion

In nature, small crystals form where cooling occurs rapidly, usually on the earth’s surface. Larger crystals develop where cooling takes place over a longer period of time, usually beneath the earth’s surface.

C. Klein (1989, 38)

With the methodology firmly established for testing a series of base glazes on test tiles under four tightly controlled firing schedules in both gas and electric kilns, the results and their implications for the future development of glazes and ceramic forms are assessed with aesthetic considerations foremost in terms of glaze quality, tactility, colour combinations, crystal characteristics (number and size) and secondary crystal development. My research shows that macro-crystal formation in glazes depended on four factors and this chapter will be divided into sections to discuss each of these in detail:

- the glaze recipe
- the thickness of application of the glaze
- the firing conditions
- the form of the pot

Other factors were shown to influence the quality and character of crystal formation. These are sub-categories of the factors listed above and will form part of the discussion.
3.1 Glazes

The glaze fluxes that are used for crystalline glazes include alkaline frits, barium carbonate, zinc oxide (which must be calcined so that it is in its pure form), sodium, potassium, magnesium and lithium. A fluid glaze with a low viscosity is thus formed, between cones 7 and 11, in which the oxides move freely. There should be minimal clay content in the glaze, as this increases viscosity and inhibits crystal development. When cooling starts, motion within the glaze slows down and the ionic bonds form as crystallites. These act as nuclei around which larger crystals may form. The slower the cooling rate, the larger the crystals may be. Some oxides display stronger colour characteristics than others. An excess of zinc in a fully fired glaze combines with silica to form large crystals of zinc silicate or willemite. Smaller secondary crystals of different shape may also occur in the same glaze (Clarkson 1992, 27-31).

The clay content of any of the glazes used was less than 2% of the total glaze weight. This was sufficient to bond the glaze to the bisqued body and reduce the friability of the glaze once applied. In base glaze 4, the bentonite content was 1%. Bentonite was used in preference to kaolin for its properties of flocculation. It does this by virtue of its extremely fine particle size and its ability to remain in a colloidal suspension, thickening up the glaze slop and making it more difficult for the non-plastic particles to settle (De Boos et al. 1984, 36).

The glazes had a component of up to 10% of titanium dioxide which, as well as being an opacifying agent, is also a seeding agent for crystals to develop (Creber 1997, 47). The results showed the amount of titanium used in the glazes did alter the glaze quality. With increasing amounts of titanium to a maximum of 10%, the background glaze became creamier and more opaque and the crystals stood starkly on this ground. Pinholing in the glaze was also more likely to occur. Glazes without titanium, by contrast, were transparent in colour and the crystal was a paler tone.
Where talc ($\text{MgSiO}_3$) was used in conjunction with titanium in amounts up to 10%, it also affected the surface quality of the fired glaze, in particular base glaze 5. This occurred in three ways:

- the amount of secondary crystals increased proportionally with the amount of talc added to the glaze to a maximum of 10%
- the background crystals were a matt glaze texture as compared with the crystals themselves being gloss
- haloes formed around the crystals.

The talc appears to alter the surface tension in the glaze and this is clearly evident in the immediate area around the halo. The haloes were often a different colour to the crystal and the background. The talc addition softened the background colour (the secondary crystals) to a muted cream/gold colour in most cases. In all cases the talc addition softened the overall impact of the glazed surfaces into a range of harmonising colours.
its absence there was a strong contrast between the crystal and the background; the larger the amount of colourant, the more pronounced the contrast.

The cone 10-11 gloss glazes (base glazes 1 and 5), which contained up to 6% titanium dioxide, responded to the addition of talc (up to 10%) by breaking up an even and opaque cream background into a mottled surface of secondary crystals. My suggestion is that the magnesium silicate molecules of the talc are incorporated into the free zinc silicate molecules in the melt to nucleate and form secondary crystals (see Image 13).

![Image 13: Detail of crystal development with titanium dioxide and talc additions (Peter Wilson, 2000).](image)

Base glazes 2 and 3, when fired lower to cone 9-10, responded in similar ways to the combination of titanium dioxide and talc. When these glazes were fired higher to Schedule A, cones 10-11 (Table 5), the secondary crystals disappeared and the glazes became transparent and ran excessively.

Additions of talc to the crystalline matt base glazes 4 and 6 created muddy brown responses which destroyed crystal growth, ran excessively and were unworthy of note. Here the amount of titanium dioxide was the critical factor affecting the results. With quantities greater than 5%, the results were an unpleasant brown/black. Below that
amount the slightly darker coloured background (see Table 11) provided a good contrast to the crystals from copper or cobalt colourants.

Image 14: Detail with 6% titanium addition only; no magnesium silicate (Peter Wilson, 2000).

<table>
<thead>
<tr>
<th>Base glaze/s</th>
<th>% Addition of colourants</th>
<th>Firing schedule</th>
<th>% Talc addition</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frit 4110</td>
<td>48</td>
<td>A, D</td>
<td>Up to 10% for each variation</td>
</tr>
<tr>
<td>Zinc oxide 25</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silica 18</td>
<td>18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bentonite 1.5</td>
<td>1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. 5</td>
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<td></td>
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<tr>
<td>Frit 4110</td>
<td>46</td>
<td></td>
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</tr>
<tr>
<td>Silica 21</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zinc oxide 27</td>
<td>27</td>
<td></td>
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</tr>
<tr>
<td>Bentonite 1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base glaze/s</td>
<td>% Addition of colourants</td>
<td>Firing schedule</td>
<td>% Talc addition</td>
</tr>
<tr>
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<td>-----------------</td>
</tr>
<tr>
<td><strong>No. 2</strong></td>
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<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>Whiting</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zinc oxide</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frit 4110</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1. CoCO₃ 1, TiO₂ 6</td>
<td>B, C</td>
<td>Up to 10% for each variation</td>
</tr>
<tr>
<td></td>
<td>2. CoCO₃ 0.1, MnO₂ 0.1, TiO₂ 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. CoCO₃ 1, MnO₂ 4, TiO₂ 3</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>4. CoCO₃ 1, MnO₂ 4, TiO₂ 6</td>
<td></td>
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<tr>
<td></td>
<td>5. CoCO₃ 0.5, CuCO₃ 2, TiO₂ 5</td>
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<tr>
<td></td>
<td>6. CoCO₃ 3, TiO₂ 5</td>
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<td></td>
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<tr>
<td></td>
<td>7. Fe₂O₃ 7, TiO₂ 4</td>
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<td></td>
</tr>
<tr>
<td>Whiting</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zinc Oxide</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frit 4110</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>LiCO₃</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1. CoCO₃ 0.25, TiO₂ 5</td>
<td>B, C</td>
<td>Brown, muddy responses, without crystals, runs excessively</td>
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<tr>
<td></td>
<td>2. CoCO₃ 0.5, TiO₂ 5</td>
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<td>3. CoCO₃ 0.1, TiO₂ 5</td>
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<td></td>
<td>4. CoCO₃ 0.5, CuCO₃ 2, TiO₂ 5</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>5. CuCO₃ 3, TiO₂ 5</td>
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<tr>
<td><strong>No. 4</strong></td>
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<td></td>
</tr>
<tr>
<td>Soda F’par</td>
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</tr>
<tr>
<td>BaCO₃</td>
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<td>Zinc oxide</td>
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<td>Silica</td>
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</tr>
<tr>
<td><strong>No. 6</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Pot. F’par</td>
<td>35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BaCO₃</td>
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<td></td>
</tr>
<tr>
<td>Silica</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LiCO₃</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bentonite</td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 11: Results of glaze responses by percentage of colourant, firing schedule and base glaze
Crystalline glazes appear to have the unique and interesting property of the preferential absorption of colourants. This means that a colourant added to a base glaze may ultimately tint either the crystals or the ground. Iron and nickel lend their coloration to the ground, while the colours of copper and cobalt seem to go primarily to the crystal. While complete separation depends on the complex relationship between the amounts of colourant added to the base glaze and the degree to which potential crystallization is realised, interesting colour combinations can be achieved through preferential ionic bonding.

Many combinations of colourants were tested in order to achieve the results attained. The possibilities of combinations here are endless and are largely a question of personal preference. Small variations in the amounts of the colourant made a significant difference in the final glaze result. Similarly, small changes in the quantity of titanium dioxide additions to the base glaze, even as low as 1%, made a difference to the glaze characteristics. The glaze quality can thus be varied subtly by making small changes to the colourant/s and/or altering the amount of titanium dioxide in the glaze.

The combinations of colourants that were found to exhibit aesthetic merit are summarised in Table 11. This table relates the base glaze to the firing schedule, the percentage of colourants used and the glaze responses to talc additions.

Talc additions up to 10% to base glazes 1, 2, 3, and 5 created a new range of possibilities. However, the addition of talc to glazes 4 and 6 adversely affected the glaze, turning it to a dark-brown mud, as well as destroying crystal growth and causing excessive glaze running.

**3.2 Glaze thickness**

The thickness of glaze applied to the pot is critical to the formation of crystals. This thickness varies according to the type of glaze in question. The glazes can be brushed, poured, dipped or sprayed onto the ware. In this study, spraying offered a more precise
way of varying the glaze thickness, especially towards the base of the pot. All of the glaze types used were applied more thinly towards the base of the pot, decreasing in thickness from a point about 30 millimetres above the base. This practice compensates for the amount of glaze run, as these glazes are extremely fluid at top temperature and run excessively under gravity in the firing conditions.

Image 15: Crystalline matt-glazed bowl, 190mm h. x 213mm w. (Peter Wilson, 2001).

The bowl is glazed with base glaze No. 6, with additional ingredients CuCO$_3$ 3 parts and TiO$_2$ 5 parts, fired to schedule B or C.

**Crystalline matt glaze**

For the most effective results, the crystalline matt glaze required a thinner application of 1 – 2 millimetres of glaze thickness. If the glaze is thicker than this, the crystals will be too densely packed against one another. The crystalline surface will only show a mass of
crystals and no individual crystal development, even though the crystals themselves are defined. If the glaze is applied too thinly, crystal development may not occur at all, leaving only the background glaze, usually brown. The ideal surface is between the two extremes, where crystals develop on a ground of either harmonising or complementary colour.

<table>
<thead>
<tr>
<th>Base glaze no.</th>
<th>Optimum glaze thickness appl’n</th>
<th>Firing schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 and 6 matt glaze</td>
<td>1 to 2mm</td>
<td>B and C</td>
</tr>
<tr>
<td>1 and 5 gloss glazes</td>
<td>2 to 3mm</td>
<td>A and D</td>
</tr>
<tr>
<td>1 and 3 gloss glazes</td>
<td>2 to 3mm</td>
<td>B and C</td>
</tr>
</tbody>
</table>

Table 12: Summary of base glaze and required thickness of application.

**Crystalline gloss glaze**

The crystalline gloss glaze requires a much thicker application of between two and three millimetres (2-3mm). Allowances in thickness must be made when applying glaze according to the type of surface being glazed. Flat platter forms need much less glaze because there is little runoff on horizontal surfaces, only pooling. On vertical, thin-walled bowls, the glaze needs to be applied thickly, because runoff is at its maximum; also, once the porous bisque-surface becomes saturated with moisture from the glaze, absorption is restricted. This often requires that the surface be pre-heated with a gas flame to overcome the problem. The fluidity of the glaze will also cause it to run and flow off the vertical surface much more than from an oblique or horizontal one. These tolerances need to be observed with relative accuracy; otherwise the glaze results vary widely and are unpredictable. Indeed, much of the skill in using these glazes lies in
understanding the required thickness of glaze application as it varies from glaze to glaze and for different forms of the pots.

Image 16: Example of the glaze having been applied too thickly and showing a crystalline mass (Peter Wilson, 2000).

This vase is 400mm h. by 410mm w. It is glazed with base glaze no. 5 and fired to schedule A. The additional ingredients used are: CoCO$_3$ 1; CuCO$_3$ 4 and TiO$_2$ 5 parts.

3.3 Firing conditions

Bisque firing

The influence of the temperature of the bisque firing is critical to the porosity of the fired clay body and its capacity to hold a glaze when it is first applied. The bisque-firing schedule is detailed in Table 4. If the clay is underfired, the porosity increases but its ability to be physically handled is diminished. If, however, the clay is overfired, it is more vitreous. It is also handled much more easily, but absorbs less glaze because of its reduced porosity.
The pots made for this study were thrown very finely, especially the lips of the bowls. These were between 2 - 5mm thick depending on the size of the pot. If the bisque-firing causes a degree of vitrification in the clay, the glaze will be less readily deposited, especially on the lip and thinner parts of the pot. On firing with glazes of low viscosity, the glaze run will expose the raw clay surface, leaving a roughness around the lip.

**Glaze firing**

In the glaze firing, oxidising or neutral atmospheres provide the optimum conditions for crystal growth, with reducing atmospheres distinctly inhibiting their growth (Creber 1997, 69). Creber’s finding was substantiated. Firings were conducted in electric and gas kilns and results were equally good in both, provided that the heat differences in the gas kiln were understood. However, several important distinctions between the two kilns need to be stressed. The ease of firing with the electronically programmable electric kiln was a clear advantage and the relative evenness of temperature with which this kiln fired was an important consideration. The gas kiln showed a clear half-cone difference from top to bottom on a downdraft 0.3 cubic metre capacity LPG kiln. Even with extended soaking periods at top temperature (up to 45 minutes), this difference could not be corrected. Uniform firings are critical for crystalline glazes and the correct glazes need to be placed in the appropriate position for consistent results.

The glaze firing cycles adopted for this study strongly influenced the final results. The factors of importance here included:

- the rate of rise of the kiln to top temperature
- the top temperature
- the amount of time spent at top temperature
- the rate of cooling
- the temperature at which the kiln is held for the crystal growth stage
- the length of time the temperature is held at this soak temperature.
The rate of rise of the kiln to top temperature

There were four specific firing schedules (see Tables 5-8, pp 45-46) which required firing to between cones 9 and 11 (nominally 1268-1285°C). The time from when the glazes start to melt (around 1100°C) until maximum temperature is reached should occur as quickly as possible. Snair (1980, 22), Clarkson (1994, 42) and Ilsley (1999, 77) suggest that this temperature should be reached rapidly to fully melt all of the glaze ingredients and to ‘seed’ the crystals. The important point is whether the required amount of heat work is done in the shortest time possible. This clearly depends on the heating capacity of the kiln. With electric kilns, the older the elements, the longer the time period to reach maximum temperature.

Kilns that require a long time to reach maximum temperature may produce disappointing results. A slow climb in temperature allows interaction between glaze and clay body, permitting the glaze to absorb alumina out of the clay. The result may be many small crystals, a matt glaze or dull and rough areas. Creber (1997, 62) suggests a rate of rise of 100°C per hour is required for satisfactory results. Deck (1996, 21) also advocates a fast rate of rise of 150°C per hour, but suggests a soak of 30 minutes at cone 10 is needed to even out the temperature difference from the top to the bottom of his gas-fired kiln.

The author’s preference in this respect was determined by the firing capabilities of the kilns used in this study. This is reflected in all firing schedules (Tables 5-8), between 0-400 at 90 degrees per hour, 400-1150 (where the glaze is fully molten) at 120 degrees per hour. From there until the appropriate cone/top temperature was reached the rate of rise was slowed to 80 degrees per hour. This rate of rise to top temperature from 1150 degrees was the fastest that either of the kilns used for the study could achieve. When the appropriate cone was fully down, the kiln was soaked for 15 minutes to even out kiln temperature variations as much as possible.
With the faster firing rate advocated by Deck, the higher temperature as indicated in Table 13 must be reached for the same heat work to be done. Heat work, as measured by cones, effectively measures the amount of heat over a given time period.

<table>
<thead>
<tr>
<th>Cone</th>
<th>Temperature required at 60/hour rise</th>
<th>Temperature required at 100/hour rise</th>
<th>Temperature required at 150/hour rise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cone 8</td>
<td>1236</td>
<td>1249</td>
<td>1263</td>
</tr>
<tr>
<td>Cone 9</td>
<td>1260</td>
<td>1270</td>
<td>1280</td>
</tr>
<tr>
<td>Cone 10</td>
<td>1285</td>
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<tr>
<td>Cone 11</td>
<td>1294</td>
<td>1305</td>
<td>1315</td>
</tr>
</tbody>
</table>

Table 13: Top temperature required to achieve the same heat-work with different rates of temperature rise (in °C).

The implication to be drawn from this is that the rate of rise of the kiln, especially over the last 200 degrees, should be at least 80°C per hour or faster if possible.

Electric kilns tend to lose their firing efficiency as the elements age. Because of a continuous fall-off in element performance with use, pyrometric cones and reference to previous firing records are important to assess rates of rise. Clarkson (1994, 42) and Ilsley (1999, 77) both suggest that the rate of rise for the last 200 degrees should be quick, at least at 100 degrees per hour. If the firing is slower than this, the effect is to increase the length of time in the zone of nucleation; the glaze becomes too fluid and the glaze run-off is increased leaving only a very thin layer of glaze for the crystals to grow in. Also the clay body may leach and fuse into the glaze which could mean no crystal growth at all, or a few small but faint crystals.

The relationship between rate of rise and the crystallization process needs further investigation.
The top temperature (the zone of nucleation)

The heat work done in the kiln is critical to the nucleation process and it is determined by the rate of rise of the kiln and the temperature reached. It is measured by deformation of the nominated cone.

The zone of nucleation is the temperature range where the crystals first form, and this varies according to the glaze recipe of each glaze (Snair 1980, 26). Knowledge of these temperature zones for each glaze is important to understanding the crystallization process.

If this maturation temperature of the glaze is not fully reached, the resulting glaze surface will demonstrate the qualities of under-firing. The surface will vary from being matted with immature and textured miniature crystals, to being covered with a dense crystalline surface with a background obscured by the impacted crystals.

This process of nucleation is one of over-saturation of the molten glaze, whereby the glaze ingredients, in this case zinc oxide and silica, and the heat produce the crystals. Zinc silicate crystals grow in the matrix in much the same way as when a supersaturated solution of sugar is boiled continually and then cooled. The crystals form with the excess saturated ingredients separating from the other liquids.

If the glaze is fired to its full zone of nucleation, the crystals will develop according to the shape of the pot and the thickness of glaze application and the zone of crystallization.

The amount of time spent at top temperature

The 15-minute soak at the top temperature was necessary to ensure an evenness of temperature within the kiln at maximum heat. This was required especially for the gas kiln, which fired unevenly throughout the chamber. There was a half-cone difference
from top to bottom. To utilise this characteristic, the lower maturing glazes were placed in the cooler parts of the kiln.

Whether a soak period is needed at all is a point of conjecture. Clarkson (1992, 44) argues that, the longer the soak at top temperature, the more time the alumina and silica in the clay body have to react with the critical ingredients in the glaze and to adversely affect their balance and their ability to produce crystals.

The results showed that with the maximum rate of temperature rise (80°C) possible with each kiln to the nominated cone, a good covering of crystals was achieved. If this cone was not fully reached, the works were underfired at this temperature and the glazes exhibited a dense mass of crystals.

In conclusion, the rate of rise of the kiln is an important factor in determining the number of crystals, as is the top temperature reached and the amount of time spent in that range. If faster firings (towards 100°C per hour) had been possible, they may have revealed a different set of results.
Image 17: Example of the glaze having been applied too thickly and showing a dense crystalline mass, 740mm h. x 605mm w. (Peter Wilson, 2000).

This pot has been fired to schedule D. It is glazed with base glaze no. 6 with additional ingredients of TiO$_2$ 6; CoCO$_3$ 1; MgSiO$_2$ 10.

The rate of cooling

Once the maximum temperature is reached and the kiln temperature has been allowed to even out, the kiln is cooled to the crystal-growing soak temperature (the zone of crystallization). The soak temperature is in the desired crystal growth range for a specific glaze recipe. Cooling can be done naturally or it can be assisted. Assisted cooling is achieved by removing the bungs or opening the kiln door slightly, or using combinations of both. When the crystal growth range temperature is reached, the kiln is turned back on or the burners are relit according to whether the kiln is electric or gas. The kiln is soaked according to the desired program of the firing schedule.
Assisted cooling effectively drops the kiln temperature from its maximum to the crystal-growing soak temperature (between 1120-1020°C) in a very short time, usually around 15 minutes. A natural cool can take up to an hour.

All of the firings in this study utilised the natural method of cooling. In the electric kiln firings, the unassisted cooling periods were from between 40 to 60 minutes, depending on the denseness of the kiln stacking. With the gas kiln firings, unassisted cooling usually took 20-25 minutes.

The glaze results from both kilns were comparable, even though the rates of cooling differed considerably between them. The rate of cooling was considered a less important factor than the maximum temperature reached and the heat work achieved in the kiln.

**The crystal growing temperature (the zone of crystallization)**

The crystals grow at a temperature within a window in the cooling phase of the glaze before the glaze solidifies at 1020°C. This window of crystal growth is between the temperatures 1120-1020°C. Specific shaped crystals are determined by the temperature at which the kiln is held within the crystal-growing soak temperature. Snair (1980, 58) refers to this temperature range as the zone of crystallization.

This critical temperature range of crystal growth is linked to the fusion point of the glaze and the crystal-growing band can be predicted from here. Needle-shaped crystals develop near the hottest end of the band (1120°C); 1115 degrees produces rods that radiate out at their extremities like starbursts; Maltese-cross shapes appear at 1100°C and cooler. At 1085 degrees, circular, flower-like crystals are produced and appear like three-dimensional holograms. The explanation for this is probably related to the crystal development patterns as created by temperature differences within this zone of crystallization.
Three firing-schedules were developed to assess the differences in crystal-shape characteristics as shown in Tables 5-8:

- Kiln firing schedules A and B (Tables 5 and 6) - after reaching relevant top temperature, the kiln temperature was dropped to 1070°C and held for 2.5 hours

- Kiln firing schedule C (Table 7) - after reaching top temperature, the kiln temperature was dropped to 1100°C and held for one hour. The temperature was then dropped a further 20 degrees to 1080°C and held for one hour. Again, the temperature was dropped to 1060 and held for one hour and then the firing was shut down.

- Kiln firing schedule D (Table 8) - after reaching top temperature, the kiln temperature was dropped to 1080°C and held for one hour, the temperature was dropped a further 20 degrees to 1060°C and held for 30 minutes. The kiln temperature was then raised to 1080 and held for one hour and then finally dropped again to 1060°C. The kiln was then held for another 30 minutes then shut down.

In firing schedules A and B, the crystals that formed were round and uniform and varied between 10 and 18mm in diameter. The crystal size was dependent on the form of the pot. A longer soak period would have developed larger sized crystals.

In firing schedule C, where the kiln temperature is held then progressively dropped over three hours, the crystals were largely similar in shape and size to those in A and B, except there were some Maltese cross type crystals amid mostly round crystals.

In firing schedule D where the temperature was held then dropped, then raised and then again dropped, the crystals developed growth rings of uneven size. The thicker band of growth occurred when the kiln temperature was held for a longer period (one hour) at the specific temperature of 1080°C; the thin growth band within the crystal represented the relatively smaller amount of time (30 minutes) spent at the lower temperature of
1060°C. With each rise and fall in temperature, a ring formed around the central core in the crystal (see Image 18). The positioning and thickness of these growth rings was controllable, depending on when in the firing cycle the rises and falls occurred and on the length of time the temperature was held there.

Image 18: Detail of a crystal-glazed surface showing growth ring bands within the crystals (Peter Wilson, 2000).

The results suggest that the shape of the crystal and its characteristics are controllable by the temperature/s at which the crystal-growing phase of the kiln is held and manipulated.

The number and size of the crystals that form on the pot can be controlled. Each crystalline glaze has a zone of nucleation where the crystals first form, and a zone of crystallization, where the crystals grow. The nucleation zone typically lies in the upper end of the firing range: cone 10-11 for fully fritted glazes and lower temperatures for the
felspathic and barium-containing glazes. Recognising the *zone of nucleation* of the particular glaze is the key to controlling crystal growth. The *zone of crystallization*, by comparison, is in the temperature range between 1020 and 1120°C. The longer the time period spent in this zone, the larger the crystals will grow (Clarkson 1994, 44).

The fluidity of the glaze is necessary to allow the crystals to grow. When at its peak temperature the glaze is at its most fluid; this is when most runoff occurs. On reaching the peak, the temperature must be reduced, firstly to limit the run-off, and secondly to arrive at the *zone of crystallization*, which is approximately 200°C below peak temperature. The crystal shape is determined by the precise temperature within this zone that the kiln is held, and the length of time spent at this temperature determines the size of the crystals.

**The impact of individual ingredients**

Macro-crystalline glazes contain three main ingredients: frit (approximately 50 parts), calcined zinc oxide (approximately 25 parts) and silica (approximately 25 parts) plus a minimal amount of alumina and deflocculants. Using a frit in a glaze simplifies glaze preparation. This convenient material is added in one go rather than having to weigh out and add several ingredients to the glaze. If the frit content is increased, the peak temperature for the glaze is reduced, or alternatively it makes the glaze more fluid at the maturation temperature.

*Zinc oxide* is an active flux at middle and high temperatures. A flux acts by combining with refractory materials to significantly lower their melting temperatures. A classic example of a flux was the long-held secret for making porcelain which the Chinese potters had developed prior to the Sung Dynasty. The extremely refractory kaolin was combined with petuntse (a felspathic rock) which fluxed the kaolin and made it vitreous at stoneware temperatures.
When zinc oxide is used to excess in a glaze low in alumina and cooled slowly, zinc will produce crystals. Zinc and silica have an affinity for each other and will readily combine to form zinc silicate (ZnSiO₃). Increasing the zinc content will increase the number of crystals; too much zinc in a glaze recipe produces too many crystals, resulting in a matt glaze. A reduction in the amount of zinc oxide will decrease the number of crystals and affect the quality of the glaze.

The silica can be adjusted up or down depending on the glaze fit. The problem of crazing can be overcome by increasing the silica content in the glaze by a small amount. The progressive reduction of silica in the glaze results in increasingly matted surfaces, where the crystals are rough and unpleasant to the touch. In a crystalline glaze recipe, silica combines with zinc oxide to form zinc silicate crystals.

Alumina is added to the glaze recipe as bentonite to give viscosity, making the glaze less likely to run off the pot when melted. Used in very small amounts, it helps the glaze adhere to the pot in a uniform thickness. The alumina level should be kept low as it has a tendency to produce many crystals, resulting in a matt texture.

Titanium dioxide can be added to the glaze in quantities up to 10%. This has an opacifying effect on the glaze and it also alters the glaze substantially, even with small variations. With higher concentrations, it contributes towards secondary crystal formation on the background around the crystals in the negative space. Titanium dioxide also acts as a seed creating the nucleus for the crystals, but it is not essential for the glaze. Ilsley (1999, 61) suggests that it acts like the irritant that becomes a pearl in an oyster. Rutile is an impure oxide of titanium and contains small amounts of iron. It can be substituted readily for titanium dioxide, especially where the iron impurity is desired. Titanium dioxide when used in conjunction with up to 10% magnesium silicate (talc) in the glazes greatly enhances the development of secondary crystals. The magnesium silicate combines with the titanium, and free zinc molecules in the glaze melt to form a distinctly different crystal from the primary one. It is specifically a satin-matt crystal, in contrast to the primary crystal, which is glossy as is the rest of the surface. The surface is
then a variation between gloss and matt components. It breaks up the static cream background into a mass of small crystals and causes the development of haloes around the primary crystals. The haloes look to be created by a surface-tension differential in the molten glaze between the crystal and the background space.

*Magnesium silicate* and titanium additions also reduce the viscosity of the glaze. This is evident when the glaze reaches full temperature; its fluidity causes it to run excessively, denuding the thinner areas on the lips of bowls of glaze and crystals. A streaking effect can also occur as the glaze runs (see Image 19). The same glaze without the additions of titanium dioxide and magnesium silicate flows much less and creates crystals along rims. It is possible that by adopting a faster firing schedule, this denuded effect of the glaze run could be overcome. This is another area for further investigation.

![Image 19: Example of glaze streaks that occur in glazes with contents of titanium dioxide and magnesium silicate up to 10% of each ingredient, 140mm h. x 275mm w. (Peter Wilson, 1999). This bowl has been glazed with glaze no. 3 and fired to schedule A. The additional ingredients in the glaze are CoCO₃ 1, MnO₂ 4, TiO₂ 6, MgSiO₂ 10.](image-url)

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Image 20: Crystalline glaze without titanium and magnesium silicate and its impact on the lip of the pot, 205mm h. x 230mm w. (Peter Wilson, 2000).

This bowl has been glazed with glaze no.2, fired to schedule A, with additional ingredients CuCO₃ 3 parts.

Other minerals that promote crystal growth are oxides of manganese, sodium, potassium, lithium, calcium and bismuth. It is reported that some interesting effects can be developed with molybdenum trioxide, ammonium tungstate and vanadium pentoxide (Ilsley 1994, 62).

Tony Laverick (Ilsley 1999, 63) notes some success in using commercial glaze stains with crystalline glazes. He uses commercial stains as the primary colourant in the glaze recipe. Here, the molecule-bonding propensity of the stain in the crystal growth phase in the molten glaze is a key factor in determining the success of the stain in this respect.
<table>
<thead>
<tr>
<th>Features</th>
<th>Colourant</th>
<th>% C’ant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver crystals on tan ground</td>
<td>Manganese dioxide</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>Cobalt carbonate</td>
<td>0.2</td>
</tr>
<tr>
<td>Gold crystals on tan ground</td>
<td>Red iron oxide</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Manganese dioxide</td>
<td>2.0</td>
</tr>
<tr>
<td>Ice blue crystals on cream ground</td>
<td>Copper carbonate</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Cobalt</td>
<td>0.1</td>
</tr>
<tr>
<td>Pale blue crystals on tan ground</td>
<td>Cobalt carbonate</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Manganese dioxide</td>
<td>1.0</td>
</tr>
<tr>
<td>Mauve crystals on grey ground</td>
<td>Cobalt carbonate</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Manganese carbonate</td>
<td>2.0</td>
</tr>
<tr>
<td>Strong green crystals on paler ground</td>
<td>Copper carbonate</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>Manganese dioxide</td>
<td>1.0</td>
</tr>
<tr>
<td>White crystals on yellow ground</td>
<td>Red iron oxide</td>
<td>0.5</td>
</tr>
<tr>
<td>Royal blue crystals on dark tan ground</td>
<td>Cobalt carbonate</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>Manganese dioxide</td>
<td>1.0</td>
</tr>
<tr>
<td>Prussian blue crystals on dark tan ground</td>
<td>Cobalt carbonate</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Copper carbonate</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Nickel oxide</td>
<td>0.5</td>
</tr>
<tr>
<td>Soft green crystals on a cream ground</td>
<td>Copper carbonate</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Manganese dioxide</td>
<td>0.3</td>
</tr>
<tr>
<td>Pale green crystals on paler ground</td>
<td>Copper carbonate</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Table 14: Colourant combinations for future experimentation as suggested by Peter Ilsley (1999, 63).
Some stains form ionic bonds more readily than others. The use of commercial glaze stains has not been addressed in this study and could form part of a further investigation.

Ilsley (1999, 63) suggests a range of colouring oxides/carbonates that could be tested for future suitability (see Table 14).

**The length at the crystal-growing soak temperature (the zone of crystallization)**

The results suggest that for all firing schedules, the longer the time spent in the zone of crystallization, the larger the crystals. This was the case for all glazes, even though the crystal size for the crystalline matt glaze was generally smaller than the crystals in the crystalline gloss glazes.

While it was not the intention of the study to grow large crystals, it was observed that the size of the crystal is directly dependent on the length of time this crystalline soak period is maintained. Other factors are involved also and include the shape of the pot, the pot’s thickness the thickness of application of the glaze and the conditions under which it is fired.

**3.4 The form of the pot**

Special consideration needs to be given to the form of the pot as this will affect the extent of crystal growth. Crystalline glazes tend to be best suited to forms with smooth flowing surfaces. Forms with pronounced throwing lines, incisions or additions affect the glaze flow and alter the natural development of the crystals. Vertical, oblique and flat surfaces each create different conditions for crystal-growth owing to the fluid nature of the glazes.
The form of a pot will also influence the general pattern of crystal development. The angle of the surface will directly affect the manner in which crystals grow. On horizontal or gently sloping surfaces, crystal development is much more prolific and often the crystals coalesce as there is minimal movement in the glaze due to running. In the concave areas on the inside of bowls the glazes can tend to pool, creating an unpleasant textured quality if the glaze thickness has not been judged correctly.

Vertical surfaces cause the greatest amount of glaze run. The crystals in these areas can have a greater spread between each other. With thin-lipped, vertical-walled bowls, the area around the lip can be totally denuded of crystals because of the excessive glaze run. The thinness of the lip and its ability to hold glaze, and saturation levels in the bisqued stage would both be a factor here, as with thicker-lipped bowls this phenomenon does not occur. Warming the forms in question in a kiln prior to glazing to increase absorption levels has helped to alleviate the problem.

On oblique surfaces, the type of crystal development depends on the degree of the angle of inclination, with flatter surfaces leading towards a larger crystal, while the opposite occurs with surfaces closer to the vertical (see Image 21).
Image 21: Crystal development on vertical surface of a bowl, 155mm h. x 168mm w.
(Peter Wilson, 2001).
This bowl has been glazed with base glaze no. 3, fired to schedule C with additional ingredients CuCO$_3$ 3, TiO$_2$ 6 and MgSiO$_2$ 10 parts.

Image 22: Crystal development on a horizontal surface, 73mm h. x 590mm w.
(Peter Wilson, 2001).
This platter is glazed with base glaze no. 5 and fired to schedule C with additional ingredients CoCO$_3$ 1, CuCO$_3$ 4, TiO$_2$ 4 and MgSiO$_2$ 10 parts.
An understanding of the varying thicknesses of application required for the different slopes of the surfaces from vertical to horizontal and the range of angles in between is important for the use of these glazes.

In attempting to minimise the glaze runoff, and hence shortening the laborious grinding and finishing stages for the pots, much thought has been given to the design of the forms. The forms were modified in the earlier work to include undercut bases which provided angular barriers to slow the flow of glaze off the pot (see Image 23). The running glaze compresses when changing direction and collects there. This modification along with a thinner application of glaze up to 50mm from the base of the pot has helped to improve the result. With the undercut foot, however, I feel the form of the pot is compromised when its smoothly flowing line is harshly interrupted by an angular change of line to its foot. My preference is for the form to assume an uninterrupted line from lip to foot, and to vary the glaze thickness towards a thinner application at the base.

![Image 23: Bowl with undercut foot to prevent glaze runoff, 145mm h. x 270mm w. (Peter Wilson, 2001).](image)

This bowl has been glazed with base glaze no. 2, fired to schedule C with additional ingredients CoCO$_3$ 0.5, CuCO$_3$ 2, TiO$_2$ 6 and MgSiO$_2$ 8 parts.
The main focus of interest is not the development of crystals *per se*, nor of crystals with specific characteristics, but concerns a much broader view of a glazed surface that encompasses both crystals and the negative space around the crystals. My preference is for the tactile satin-matt surface, but also for a softer understated surface that has crystals floating in a sea of other-coloured crystals and background and also variations in colour intensity. This includes the growth of haloes around the crystals, growth rings within crystals, secondary crystal growth of either a contrasting or harmonising colour to the primary crystal, the size and shape of the crystals and crystal placement on the pot. The crystals themselves vary widely in their characteristics, and each of the variables of crystal size, shape, colour, haloes and growth rings can be manipulated to achieve a desired aesthetic quality for a glazed surface of a pot.
Chapter 4

Conclusion

It is not talent that is required but energy.

C. Pissarro (Lloyd 1979, 52)

My initial investigations into crystalline glazes began tentatively in 1997 after I became dissatisfied with my own work and felt a strong desire for creative reinvention. The path I chose led to frustration and disaster and in the first year I had precious few pots to show for my efforts. Firing after firing produced flawed pots; all had to be smashed. Despite this, each firing produced at least some small gem worthy of the effort being expended and provided me with enough positive reinforcement to continue the chase for the elusive perfect pot. I persevered, struggling to come to terms with the technical and aesthetic understanding needed to master these glazes.

Initially, I was just trying to emulate the complex language of crystalline glazes that had gone before, but as my understanding grew, this became tiresome. I began to see possibilities for the development of an idiosyncratic range of glazes. This development was achieved firstly by varying the quantities of ingredients in the glazes (largely by intuition and experimentation) to manipulate the surface qualities, and secondly, by altering the firing cycles of the kiln to orchestrate another range of possible effects.

It was clear from the outset that these glazes had special qualities and were not meant for the cups and saucers of utilitarian pottery. I set about redesigning forms that showed a sympathy and harmony for the unique decorative qualities of the glazes I was developing. The forms needed to be simple with pure lines, undistracted by the complications of surface markings or textures.
I embarked upon this study with the twin aims of developing an idiosyncratic range of crystalline glazes and an accompanying range of ceramic forms which would complement one another in an aesthetic unity.

This study documents the processes involved in the conceptualisation and development of the technical, aesthetic and critical discussions that occurred in formulating this new body of work. In the process, three solo exhibitions and two group exhibitions were held (see Appendix 2). Three articles were written on the subsequent research findings and accepted for publication in refereed scholarly journals (see Appendix 3). As well, a conference paper entitled Preliminary Investigations into Crystal Growth in High-temperature Ceramic Glazes was accepted, presented at the Australasian Ceramic Society Conference in June 2000 in Sydney and subsequently published in the journal of the Australasian Ceramic Society, March 2001. Similarly, a paper entitled Factors Affecting Crystal Growth in High Temperature Ceramic Glazes has been written and accepted for presentation at the biennial conference of the Australasian Ceramic Society Conference in October, 2002 in Perth. Subsequent publication of the article in the journal of the Australasian Ceramic Society after the conference has been assured.

Many new glazes have been discovered and ceramic forms have been developed in tandem with the glaze development. A unique body of ceramic work has evolved. A significant discovery in this process has been that, with a detailed understanding of ceramic materials and the processes involved in forming crystalline glazes, the glazed surface can be manipulated to suit a desired aesthetic quality, which includes predetermining the crystal characteristics and their relationship to the background glaze qualities. This has entailed a careful attention to detail in all aspects of the making process, and the keeping of the fullest records for the development of consistent results with crystalline glazes. The clay, the materials, the glaze composition and its application, the kiln and firing cycles all play vital parts. Many variables need to be tightly controlled to obtain consistent results.
In contemporary practice, crystalline glazes can be used on a variety of forms to best display their characteristics; between both the form of the pot and the glaze itself, there is a vast area for experimentation, and many possible future directions for investigation.

More research needs to be conducted into the rate of rise of the kiln over the last 200 degrees of the firing cycle, and the relationship this has to the quality of the crystals, the amount of glaze runoff and the subsequent ‘denuded lip’ syndrome.

Another area of possible future study includes the use of fluid crystalline glazes combined with stable stoneware glazes. Where the two glazes interface, interesting runs and integrated areas can result. Preliminary investigation suggests that, on vertical surfaces, different coloured and sized crystals will develop as the zinc and colourant contents are diluted by the flow. On horizontal surfaces, the interface between the two glazes is stronger and more complex. The tonal intensity of the two can be similar or contrasting. The glazes can be shiny against matt, shiny against shiny or matt against matt, all adding to the visual complexity.

Other areas for further investigation include combining crystalline and non-crystalline glazes, as well as exploring a range of glaze stains and other combinations of colourants as potential glaze possibilities.

Recent contemporary developments with the use of reduction in the cooling phase of the firing provide a further area for possible future research. Reduced red copper crystals have been attained in preliminary studies in North America by Leon Bush (1996, 49) and Creber (1997, 68), by drip-feeding oil in the kiln chamber after the crystallization phase has ceased and the kiln temperature has dropped to $800^\circ C$.

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6 Red crystals are considered extremely difficult to achieve under normal firing conditions. Leon Bush (1996, 49) sets out his method for obtaining them using an intuitive technique which is effectively a post-fired-reduction during the cooling phase of the kiln. The kiln is fired to cone 10 as for a normal crystal-glaze firing and the kiln is then held at $1050^\circ C$ for three hours for the crystal-growing phase. The kiln is allowed to cool naturally to $815^\circ C$ when an oil-drip at a rate of one-drop per second is introduced into the kiln through a ceramic rod (with a controlling pinch valve) through the lower peep-hole. The oil ignites immediately and a small continuous flame can be seen at the end of the tube when it is momentarily withdrawn from the kiln. At $540^\circ C$ the oil drip is stopped and the kiln is allowed to cool naturally to room temperature before opening. Spectacular red crystals will result using the formulae as shown in Table 15 in Appendix 1.
In summation

This hybrid study has combined the areas of art and science. Scientific method has been utilised to develop and test a comprehensive series of glazes. Aesthetic judgement has then been brought to bear on the results of these tests, and on the ceramic forms which have been designed and made specifically for the resultant glazes.

A new body of ceramic work has been developed which incorporates this comprehensive and new range of idiosyncratic crystalline glazes with an aesthetically harmonious series of ceramic forms. It is a unique combination of form and surface specifically because the decorative nature of the glazes can be manipulated to suit a desired aesthetic quality.

The significance of this study has been to discover the degree of control that can be developed within the crystalline glaze genre. Even though these glaze types have been in popular usage since the 1850s, nowhere in the past or contemporary literature is there any reference to the degree of complexity in surface quality of the glazes such as has been developed and highlighted in this study. I see this study as constituting an important breakthrough in its contribution to the existing knowledge of high-temperature crystalline glazes and to the development of a highly personalised and sophisticated range of glazes as yet unseen by the wider ceramic community.
Appendices

Appendix 1: Red Crystal Reduction

Spectacular red crystals will result using the formulae as outlined in Table 15.

<table>
<thead>
<tr>
<th>Red Crystal Glazes</th>
<th>% of materials</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ferro Base</strong></td>
<td></td>
</tr>
<tr>
<td>Ferro frit 4110</td>
<td>45.7</td>
</tr>
<tr>
<td>Zinc oxide</td>
<td>27.5</td>
</tr>
<tr>
<td>Silica</td>
<td>19.9</td>
</tr>
<tr>
<td>Kaolin</td>
<td>13.5</td>
</tr>
<tr>
<td>Titanium dioxide</td>
<td>5.6</td>
</tr>
<tr>
<td>Bentonite</td>
<td>0.2</td>
</tr>
<tr>
<td>Copper carbonate</td>
<td>2-3.5</td>
</tr>
<tr>
<td><strong>Pemco Base</strong></td>
<td></td>
</tr>
<tr>
<td>Pemco frit 283</td>
<td>68.4</td>
</tr>
<tr>
<td>Zinc oxide</td>
<td>24.1</td>
</tr>
<tr>
<td>Silica</td>
<td>7.4</td>
</tr>
<tr>
<td>Bentonite</td>
<td>0.2</td>
</tr>
<tr>
<td>Copper carbonate</td>
<td>2-3.5</td>
</tr>
</tbody>
</table>

Table 15: Glazes used to produce red crystals in reduced cooling
Appendix 2: Invitations to Exhibitions

L&S Gallery
62 Gorman Street, Bathurst
New South Wales 2795
(019) 562 5729

Cordially invite you and your friends
to the opening of

New Ceramics
by
Peter Wilson

6.30pm Friday 28 May 1999


PETE R WILSON
CERAMICS

22nd June - 17th July 2001
Invitation to Doctoral Exhibition 14-06-02

Peter Wilson

ceramics

"make sure the potter washes his hands"

Exhibition Opening 6.30pm 14th June
14 – 26 June 2002

To be opened by:
Pro Vice Chancellor Professor Richard Johnstone
University of Technology Sydney

To be introduced by:
Dr Dennis Whitfield Senior Lecturer
School of Contemporary Arts
University of Western Sydney

MURA CLAY GALLERY
49-51 King St, Newtown 2042
Phone: 9550 4433 / fax: 9550 1996
Email: muraclay@bigpond.com
Mon-Fri 10-5.30 Sat 10-4

Image 27: Invitation to doctoral exhibition, Mura Clay Gallery, June 14-26, 2002
PLEASE NOTE

The greatest amount of care has been taken while scanning the following pages. The best possible results have been obtained.
Appendix 3: Articles published, papers presented

Peter Wilson's Ceramics
Dublin Regional Gallery, 1 December - 15 January, 2001

In exhibiting his work recently at Dublin Regional Art Gallery, Peter Wilson chose to present one aspect of his findings: an ongoing research program that has spanned several years.

Wilson's work is distinguished by a unique firing algorithm that develops complex crystalline forms, with the temperature gradient of the kiln promoting more minor, crystal formations. Wilson has developed firing schedules that develop similar crystalline forms, which indicates that the configurations of the crystal structures in the firing schedules are similar to those of the forms he has been working on.

Wilson's work is characterized by a preference for soft, subtle forms and compositions, with a focus on the interaction of light and shadow. His use of color is often muted and subdued, with a preference for earth tones and natural hues. This approach helps to emphasize the texture and form of the ceramic pieces, creating a sense of depth and dimension.

The exhibition includes a variety of pieces, ranging from vessels to wall hangings, each showcasing Wilson's skillful use of form and color. The exhibition is a must-see for anyone interested in ceramics or contemporary art.
exists without context. Wilson spoke of the importance of understanding our visual history and the development of his sense of aesthetics. This work refers to past expressions of aesthetic choice and extends modern visions of what is possible. The visual and tactile elements are there to attract our attention and we have the choice of listening to their story or passing them off as mere decoration. The elements of this visual history are there for us to use. Form, function and surface, colour and placement, and the contrast or harmony of elements, all can be used to explore and create meanings for ourselves and move us beyond our likes or dislikes. We may regard the works individually or look further afield to understand more of their historical significance. We can often think and say things without asking ourselves what we mean. With this work, meaning cannot be conveyed in overt language; it may appear between the words we have to say. As educators we both consider the need to engage the audience in discussion of the work. At a glance you will notice the surfaces; given a dialogue, whether overt or more subtle, which extends, provokes or challenges us to develop our culture. To give the artist's work its due requires that we recognize and respect the effort imbued within it. The long hours, the frustration and the patience required in its creation can only be appreciated at a distance. We spend our life in exploration of it and the best is often that which we least expect. Much like the mystery of processes in the ceramic arts, these pots contain their own narratives written in a language complex and rich in descriptive form. Much like literary form, when you find a story, when you discover a meaning, there is pleasure in revelation, the ‘eureka’ of discovery that is its own reward and value. Sometimes, on a clear day, you can see yourself reflected in the beauty of the object you behold.

Duncan Ratcliffe

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P.O. Box 6138 SYD. His work is available at Maker's Mark, Chifley Square, Sydney.

PRELIMINARY INVESTIGATIONS INTO CRYSTAL GROWTH IN CERAMIC GLAZES

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SUMMARY:
The aim of this study was to develop a range of high temperature crystalline glazes suitable for use on ceramic wares, and to determine the factors that contribute to crystal development. Using several glaze formulae which had been developed through previous experimentation, a range of colourants and combinations thereof were mixed with the glazes and fired using several firing cycles in an attempt to maximise crystalline growth within the glazes. The results indicate that there are many variables that influence the size and quality of crystal growth. These variables fall into three main categories: the clay body, glaze (formulae, application, characteristics), and the firing cycle including atmosphere conditions within the kiln.

KEYWORDS:
crystalline glazes, zinc silicate crystals, firing cycle, crystalline glaze formulae

INTRODUCTION:
The Chinese potters of the Sung Dynasty (AD 960-1279) first developed crystal glazes in the form of oil-spot glazes but the earliest specific studies in zinc crystal glazes were conducted in France during the 1850s. The ceramic chemists working in the factories of the National Porcelain Factory in Sevres well understood that glazes with an excess of zinc oxide and silica with a small addition of titanium would produce crystals, given the correct firing conditions. They were considered as a glaze defect and the chemists wrote papers and disseminated their findings, warning others of their use.

Despite the warnings, experimentation continued and the development of crystalline glazes happened throughout Europe. Whole ranges of ware from many of the major potteries in France, England, Germany and the U.S., were designed and made specifically for crystalline glazes.

In the late twentieth century, a renewed interest has occurred in the development and use of crystalline glazes. Many studio potters around the world are now working with crystal glazes. My interest lies in understanding the process of crystallization in glazes and in developing a range of suitable forms and glazes which complement one another.

METHODS AND PROCEDURES:
T-shaped test tiles were made so that the test glaze results could be seen on vertical as well as horizontal surfaces. Crystalline glazes have a low viscosity and hence flow and run readily once they have been melted. The need to assess glaze results on vertical and horizontal surfaces had important implications for the creation of suitable types of ceramic forms that will carry these glazes.

Two base crystalline glazes, one gloss and the other matt, were developed to which the selected colourants were added in varying amounts. The base glaze recipes were:
Crystalline Gloss Glaze (Cone 10)  Crystalline Matt Glaze (Cone 10)
Frit 4110  46  Potash felspar  28
Silica  21  Barium carbonate  5
Zinc Oxide  27  Dolomite  4
Kaolin  1  Lithium Carbonate  7
Add:  
Titanium  4-8%  Kaolin  3
Add:  
Silica  33  Add:  
Titanium  3-7%

Colourants were added individually to the test glazes in increasing amounts. They were added in combination with other colourants in varying ratios. The principal colourants tested included: manganese dioxide, cobalt carbonate, copper carbonate, red iron oxide, nickel oxide and chrome oxide.

To gauge the optimum thickness of the glaze to maximise crystal development the test glazes were applied in different thickness ranging from 0.2-2mm. The test glazes were dipped and brushed onto the tiles. The tiles were then fired to cone 10 in both gas and electric kilns, (in neutral atmospheres), over a 12 hour period. They were soaked at top temperature for twenty minutes to even out variations in the kiln temperature. The kilns were then cooled quickly to 1090°C, where they were held for four hours after which they were turned off and allowed to cool slowly.

Two variations of this firing cycle were adopted in an attempt to promote crystal development:
*The first variation was to drop the kiln to 1065°C and to hold at that temperature for three hours.
*The second variation was to cool the kiln in stages by holding the kiln temperature in three bands. After the kiln had reached cone 10, (1280°C) drop the kiln temperature to 1100°C and hold for one hour. Next, drop the temperature to 1080 degrees C, and hold for one hour. Finally, drop the kiln temperature to 1060 and hold for one hour and then shut down the firing.

RESULTS AND DISCUSSION

The results indicated that there are many variable factors which influence the quality and character of crystal formation in the glazes. These included:

*the colour and type of clay body
The best crystals with the clearest definition were formed from dense, fine and light colored clay bodies akin to porcelain or a porcelainous stoneware. Dark coloured, fine clay bodies influenced the final color of the glazes through their interaction with the glaze and effectively made every glaze result dark and muddy.

Similarly, open bodied, (grog bearing), clays were too porous and the fluid glazes on melting, were absorbed into the physical structure of the body, hence losing the definition of the crystals and diminishing the overall effect. Also, because of the grog content, these clays often cause scratches or unevenness when being turned and finished and can create places for unwelcome nucleation sites for crystal development in the glaze firing.

*the base glazes
In high temperature crystalline glazes, (cone 9-10), the glazes need to be fluid with a low viscosity which enhances the growth of crystals. There is clay in the glazes as this increases viscosity and inhibits crystal development. The clay content should be at less than 3% of the total glaze weight and enough only to bond the glaze to the bisqued body and reduce the friability of the glaze once applied.

The glaze fluxes include alkaline frits, barium carbonate, zinc oxide, (this must be calcined so that it is in its pure form), sodium, potassium, magnesium and lithium. A fluid glaze is formed at between cones nine and ten, in which the oxides move freely. When cooling starts, motion within the glaze slows down, and the ionic bonds form as crystallites. These act as nuclei around which larger crystals may form. The slower the cooling rate, the larger the crystals may be. Some oxides work better than others and an excess of zinc in a fully fired glaze, combines with silica to form large crystals of willemite. Smaller secondary crystals of different shape may also occur in the same glaze. (1)

The glaze should also have a component of up to five percent (5%) of titanium dioxide which, as well as being an opacifying agent, is also a seeding agent for crystals to develop. The amount of titanium used in the glaze alters the glaze quality. In larger amounts, beyond six percent (6%), pinholing in the glaze was more likely to occur and the glaze was paler in color.

The glaze batch of dry ingredients should be mixed with water and sieved through a one hundred-mesh screen. Five grams of Epsom Salts per one kilogram of dry glaze ingredients should be added as a deflocculant to keep the glaze
from setting out in the bucket. Only enough glaze for the pieces required to be glazed should be made up and sieved as mixed glazes tend to lose their efficacy in terms of crystal development once they have been stored for any length of time.

*the quantity and combination of the colourants used in the glaze
Small variations in the amount of colourants used in the base glazes made significant differences in the final glaze result.

*glaze thickness
The glazes can be brushed, poured, dipped or sprayed onto the ware, but spraying offers a more subtle way of varying the glaze thickness especially towards the base of the pot. Glaze thickness is critical to the success of these glazes. For the most effective results, the crystalline matt glaze requires a thin application of around one half (0.5mm) millimetres of glaze thickness, whereas the crystalline gloss glaze requires a much thicker application at up to one millimetres (1mm). These tolerances need to be observed reasonably accurately otherwise the glaze results vary widely and are unpredictable.

*form
Because of the fluidity of crystalline glazes and the need to apply a much thicker layer of glaze than for normal stoneware glazes, special consideration needs to be given to the form of the pots. The bases of pots can be modified to stop the flow of glaze off the piece, or alternatively, appropriate setting procedures should be adopted. One such method involves a base-width collar and saucer for each piece to catch glaze runoff.

Forms with smooth flowing surfaces tend to be best for crystalline glazes. Pronounced throwing lines, incisions or additions onto the surface of the forms or any type of surface decoration should be kept to a minimum or avoided because glaze gathers in the crevices. Vases and bottles and spherical forms generally, because of their convex shapes, tend to be more suited to crystalline glazes as the nature of these shapes allows the glaze to run smoothly without pooling.

The form of a piece will also influence the general pattern of crystals. On vertical areas, glaze can flow down the walls of the pot in an even application. On flatter areas or interiors, the glaze can tend to pool, sometimes to a depth where it may look rough and opaque and detract from the overall quality of the pot.

*firing conditions
Oxidising or neutral atmospheres provide the optimum conditions for crystal growth with reducing atmospheres distinctly inhibiting their growth.

Similarly, the firing cycles adopted for the glaze firings for this study strongly influenced the final results. The factors of importance here included:

- the rate of rise of the kiln to top temperature,
- the top temperature,
- the amount of time spent at top temperature,
- the rate of cooling,
- the temperature at which the kiln is held for the crystal growth stage
- the length of time the temperature is held at this soak temperature.

The two glazes described here fire to cone 10 or 1280°C. The time from when the glaze started to melt (1100°C) until maximum temperature is reached should occur as quickly as possible. (1) Kilns which require a long time to reach maximum temperature, may produce disappointing results. It seems a slow climb in temperature allows interaction between glaze and clay body, permitting glaze to absorb alumina out of the clay. The result may be many small crystals, a matt glaze or dull and rough areas.

Once the maximum temperature is reached and cone 10 is over, the kiln is cooled quickly to soak temperature. The soak temperature is the desired crystal growth range for a specific glaze recipe. This cooling can be done naturally or it can be assisted. Assisted cooling can be achieved by removing the burners, opening the door slightly or combinations of both. When the crystal growth range temperature is reached, the kiln is turned back on or the burners relit according to whether the kiln is gas or electric. The kiln is soaked according to the desired program. Two programs as outlined were developed:

- drop kiln to 1065°C and hold for three hours
- cool the kiln in stages by holding the kiln temperature in three bands
Drop the kiln temperature to 1100°C and hold for one hour. Drop the temperature a further twenty degrees to 1080 degrees C and hold for one hour. Finally, drop the kiln temperature to 1060 and hold for one hour and then shut down the firing.

One to two hours soaking time gives smaller crystals, four hours or more gives larger crystals. Five to six hours produces even larger crystals, but the crystals may butt up against or overlap one another. When crowded together, their growth becomes restricted and they do not appear as grand or spectacular. It is necessary to experiment with each particular glaze to find its most favourable growth patterns. Once the most appropriate fusion temperature is determined, ten degree Celsius variations in the growth phase can be tried over a series of firings. This will provide an understanding of optimal conditions for crystal formation. (2)

Special crystal effects such as haloes (growth rings around the crystals) are achieved by raising and lowering the temperature several times throughout the soak range. With each rise and fall in temperature, a ring forms around the central core in the crystal. The positioning of these growth rings can be controlled depending on when in the firing cycle the rises and falls occur.

Similarly, specific crystal shapes can be determined by controlling the soak temperature. Once the fusion point of the glaze can be established, the crystal-growing band can be predicted. Needle-shaped crystals are achieved near the hottest end of the band. A few degrees cooler produces rods which radiate out at their extremities (3). Next are Maltese-cross shapes. Cooler still produces circular, flower-like crystals which seem three dimensional and have the appearance of holograms.

CONCLUSION
The size of crystals is influenced by three main factors – the glaze composition, the rate of cooling in the kiln and the amount of seed material in the glaze. When a crystalline glaze cools rapidly, smaller crystals tend to form. A glaze that cools slowly promotes growth of larger crystals. When many nuclei are present, growing crystals crowd each other, resulting in smaller size.
For the glazes tested it appears that a small opening of 72°C exists in which to grow crystals. In the hotter part of the growing range, zinc silicate fibres line up beside one another, producing thin, needle-like crystals. As the temperature drops into the cooler end of the growing range, the fibres fan out and the crystals become spherical(4).

It is important to determine the maximum and minimum temperature limits in the crystal growing range. If the temperature is too high, few or no crystals will form. If the temperature is too low, the glaze becomes solid.

Being able to produce crystalline glazes is a technical achievement in itself, but being able to produce a piece of pottery of aesthetic significance depends upon the artist’s understanding of the harmony that exists between form and glaze. In his book, Clay and Glazes for the Potter, Daniel Rhodes (5) expresses the view that a unique glaze, by itself, does not ensure aesthetic significance. It is an expression of the artist’s skill and aesthetic sensitivity to know which forms are best suited to the use of crystalline glazes and which glaze is the most appropriate.

To satisfy the aesthetic sensibility of the authors, forms that are as simple as possible (rounded bowls, rounded vases and jars) are preferred. As the crystalline glazes by their very nature are inherently decorative in themselves, it appears to be a contradiction to use such a glaze on a complex or inappropriate form.

In relation to glaze quality, the authors dislike large flowery crystals, their interest being in the relationship between crystal colour and background colour, the appearance and colour of haloes around the primary crystals and the presence of secondary crystals and their colour.

The development of crystalline glazes poses many technical problems. A large number of variables need to be tightly controlled to obtain consistent results.

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Kissed by Fire

Crystalline glazes have been around for a long time with the first ones appearing in China as oil-spot glazes in the Sung Dynasty (AD 960-1279). The earliest specific studies in zinc crystals were conducted in France during the 1850s. Article by PETER WILSON

Crystalline glazes have been around for a long time with the first ones appearing in China as oil-spot glazes in the Sung Dynasty (AD 960-1279). Later they appeared in Chinese porcelains in the late Ming Dynasty around 1650. They then reappeared in connection with the Art Nouveau movement in the late nineteenth century as an attempt to reproduce antique Chinese porcelains.

The earliest specific studies in zinc crystals were conducted in France during the 1850s. The ceramic chemists working in the factories of the National Porcelain Factory at Sevres well understood that glazes with an excess of zinc silicate and titanium would produce crystals. They wrote papers and disseminated their findings, warning others of these glaze defects. It is ironic that what was considered then to be a defect, has been now been developed into a highly technical artform in itself.

Despite the warnings, experimentation continued and the development of crystalline glazes happened throughout Europe. In the National Porcelain Factory at Sevres, whole ranges of wares were designed and made specifically for crystalline glazes. Similar developments occurred in Denmark, Germany and the US.

It is in the United States that Adelaide Abip Robineau made her significant contribution to the study of crystalline glazes and is largely responsible for bringing them into the independent potter’s studio. She began her work with crystals in 1904, documenting her extensive research until her death in 1929. From then until the 1970s, there was little or no additional work in the area. Since then there has been a growing interest in crystalline glazes, especially in the US and Britain, where there are many devotees and collectors of crystal glazed pots. There are however, just as many detractors.

I dislike large, flowery crystal-glazed pots. They are garish and ostentatious. My own interest in this topic began quite by accident while exploring the effects of zinc in glazes and I was surprised with the diversity of results attainable just by extending the soaking period during the firings. I am more concerned about the development of a softer surface which comprises elements of primary and secondary crystals, haloes and interesting colour formation. To this end, the addition of between five and ten parts of magnesium silicate creates interesting effects. There is a sense of unpredictability and uniqueness about these glazes which is very exciting - a pot kissed by the fire.

A unique glaze however, does not in itself ensure aesthetic significance, and mastering crystalline glazes is only one aspect of the equation, the difficulty lies in finding some sort of aesthetic balance. Daniel Rhodes says in his book, Clay and Glazes for the Potter, “...the presence of spectacular crystals on the sides of pots,
interesting though such crystals are in themselves, has in most cases, contributed as little to the aesthetic significance of the piece as it has to the function. Subtle and crystalline glazed pots could be seen as contradictory. Herein lies the challenge.

Technically the development of crystalline glazes depends on many variables, some of which include:

- The colour and type of clay body: White firing, dense porcelainous type bodies are more suited to crystalline glazes as darker bodies adversely affect the glaze colour.

- The type of surface: Crystals develop differently on vertical and flat surfaces. Forms may need to be modified to suit the glaze.

- Fluid glazes: For crystal growth, the glazes need to be fluid with a viscosity which must encourage the growth of crystals. There is minimal alumina in these glazes and fluxes which promote crystal growth include zinc, sodium, potassium, barium, magnesium and lithium. A fluid glaze is formed in which the oxides move freely. When cooling starts, motion within the glaze slows down, and period bonds form as crystallites. These act as nuclei around which larger crystals may form. The slower the cooling rate the larger the crystals may be. Some oxides work better than others. Appropriate setting procedures are required for pots before all of your shelves are lined with glazes that have run off the ware. A base-width collar and a saucer to catch glaze runoff can be useful.

- Glaze application and thickness: Glazes can be brushed, dipped or sprayed, but spraying offers a more subtle way of varying the glaze thickness, especially towards the base of the pot.

- Temperature and the length of the firing: Fire slowly up to full cone 10 in a neutral atmosphere. (60°C hour from 1100°C to cone 10), and soak for around 10 minutes to even out temperature differences within the kiln, then turn off the gas burners which are relit at 1090°C. This temperature is then maintained for 3-4 hours before it is shut off and closed up. The total firing time is around 15-16 hours.

The temperature at which the kiln is held determines the shape of the crystals such that at 1140°C needle like crystals form; at 1100°C the crystals are batte-axe shaped and at 1050°C the crystals are round. I find the glazes benefit from a longer slower firing.

- Colourant: The main colouring agents are red iron oxide, copper oxide and carbonate, cobalt carbonate, nickel oxide, manganese oxide, rutile, ilmenite and vanadium. Often two or more can be used in combination.

GLAZES FOR CRYSTAL DEVELOPMENT-
CONE 9-10:

1. Fat 4110
   - Silica 21
   - Zinc oxide (Dense) 27
   - Kaolin 1
   - Titanium 4.5

2. Pot Pelspar
   - Barium Carb. 5
   - Dolomite 4
   - Zinc Oxide 20
   - Titanium 3-18
   - Lithium Carb. 7
   - Kaolin 3
   - Silica 35

3. Fat 4110
   - Zinc oxide 25
   - Silica 20
   - Titanium 6.5
   - Kaolin 1
   - Aluminum hydrate 0.5

Other possible colourants:
CuCO₃ 1-3% light green
Fe₂O₃ 2-8% red/orange
MnO 0.5-4% beige/ivory

Peter Wilson who is a potter and lecturer at Charles Sturt University in Bathurst, NSW.

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Thanks to Peter Deck and Ted Nocombe

30 SEPTEMBER 1999 * POTTERY IN AUSTRALIA* 25

Article published in Pottery in Australia, Vol. 38 No. 3 September, 1999, by Peter Wilson
Crystalline Glazes

GLAZES – PETER WILSON looks at the history of crystalline glazes and gives some straightforward advice on how to achieve them.

A brief history

Within the 7000-year history of the use of fired clay by humans, high temperature crystalline glazes first appeared relatively recently as slip-spot glazes in the Sung Dynasty in China (960-1279 AD). Much later in France in the 1850s at the National Porcelain Factory in Sèvres, the ceramic chemists C. Lauch and G. Dutilly, inspired by the European discovery of porcelain in Meissen by Johann Berlinger in the early eighteenth century, began experimenting with high-temperature glazes containing zinc. This Western discovery of porcelain no doubt fuelled a yearning to emulate the renowned characteristics of the Chinese porcelains, particularly the translucency of those produced from the Ming Dynasty first introduced to Europe by Marco Polo via the silk road (from the Middle Ages).

The new porcelain was the primary vehicle for crystalline glazes and the two French chemists were at the forefront of experiments in this area. They understood that glazes with an excess of zinc oxide and silica would produce crystals under certain firing conditions. The unique decorative possibilities soon became apparent and experiments continued, even though the result was initially seen as a flaw – built due to the success of their work, whole ranges of wares were designed and made specifically for crystalline glazes, with similar developments occurring in Denmark, Germany, the United States and England at around the same time.

Many potteries flourished during this Art Nouveau period in the late nineteenth century but the interest in these glazes had faded by the 1930s. It is only in the past twenty years that studio potters have rekindled an interest in crystalline glazes. The developments in technology have increased the accessibility of potters to these glazes.

Crystalline glazes have been developed as a form of decoration and as a technical achievement. The question is to whether the finished pot itself has aesthetic significance, depends upon the potter’s understanding of the harmony that exists between the form and the glaze. Clearly these glazes are not meant for the cups and saucers of domestic pottery. My personal view is that much of the crystal-glazed ware currently on view is creaking in an aesthetic merit. My own preference is for glazes that are softer and use colours that harmonize rather than contrast. The negative space around the crystal is the main concern for me. I prefer to develop a secondary crystal of a different colour to the primary crystal which floats in this space. The character of the crystals, their shape and size, as well as the features of the sea in which they float, can be manipulated and controlled. I like my forms to be simple and sculptural, undistracted by unevenness.
texture or complexity in any way, and yet still related to function.

CRYSTALLINE INVESTIGATIONS

After twenty-five years of making pots I needed to develop a new direction and four years ago I began actively exploring a range of possibilities. Many of the best discoveries I have made in ceramics have been as a result of a happy accident and the development of my ideas in crystal glazes was no exception.

Following some experiments with glaze containing zinc oxide, I found interesting areas on pots, especially in firings where the soak period had been lengthened, or where I had fired down to improve the glaze quality. The slower cooling of zinc glazes showed a clear crystal development.

What fascinated me most was the selective ability of the glaze melt to choose one colourant on which to form the primary period bonds for the crystal and leave the remaining ground a different colour. I was able to take these areas of interest and elaborate on them.

I had always designated the ostentatious, garish and flamboyant qualities of crystalline glazes and yet I was drawn to them because of their unique qualities and the seemingly endless range of possibilities attainable. It then became possible to develop a range of idiosyncratic glazes within this genre by manipulating a range of elements.

TECHNICAL DETAILS

Technically, the development of crystalline glazes depends on many variables.

Clay body

White-firing, dense porcellaneous bodies are more suited to crystalline glazes. Darker bodies adversely affect the glaze colour.

Surface

Crystals develop differently on vertical and flat surfaces. Forms may need to be modified to suit the glaze.

Glaze characteristics

Crystalline glazes need to have low viscosity to encourage crystal growth. There is minimal alumina in these recipes as this increases viscosity. The fluxes which promote crystal growth include zinc, sodium, potassium, barium, magnesium and lithium. A fluid glaze is formed in which the oxides move freely. When cooling starts, motion within the glaze is slowed, and period bonds form as crystals. These act as nuclei around which larger crystals may form. The slower the cooling rate, the larger the crystals.

Setters are required for pots to protect your shelves from glazes that may run off the ware. A base width collar and a saucer to catch the glaze run-off are useful for each pot.

Titanium dioxide (up to 8%) can be added to the glaze to assist in crystal development and to increase opacity. It also aids in the development of secondary crystals. Small changes in the quantity of titanium will change the glaze colour characteristics significantly.

OPPOSITE: Blue vase, 435.5cm. Orange vase, 475cm. This page left: Blue-green tall vase, 520cm. Above right: Blue bowl, 420cm x 221cm. Bottom right: Blue bowl, 416cm x 221cm.
Glaze application and thickness

Glazes can be brushed, dipped or sprayed but the latter offers a more subtle way of varying the glaze thickness, especially towards the base of the pot, where a thinner coating of glaze will lessen the likelihood of the glaze running. The thickness of the glaze is important; it determines the amount of potential crystals that can develop. A thicker application (2-3mm) is often more desirable for good crystal development, but this can be determined by controlled experiments.

Firing

The firing is crucial to the development of these glazes. The top temperature reached depends on the glaze recipe, but in most cases it should be cone 10-11 to ensure all the glaze materials are thoroughly melted. The rate of temperature rise over the last 200°C should be as fast as possible, 100°C/hr is advisable. The soak at top temperature should be minimised, but the kiln temperature should be even where possible. The crystal-growing soak temperature determines the shape of the crystals. The length of time the kiln is held at the crystal-growing temperature dictates the size of the crystals.

A fast rate of cooling to the crystal-growing soak temperature is desirable. All of these factors dictate the final quality of the glazed surface. The temperature at which the kiln is held determines the shape of the crystals, such as that at 1140°C, when needle-like crystals form; at 1190°C the crystals are baffle-axe shaped and at 1050°C the crystals are round.

Colours

The main colouring agents are copper carbonate, iron oxide, cobalt carbonate, nickel oxide, manganese dioxide, rutile, limonite, and zirconium. Two or more colourants can be used in combination. Small variations in the amount of colourant/s added, combined with slight alterations in titanium quantities, cause dramatic changes in the glaze colour outcomes.

FURTHER READING


Peter Wilson is a potter and lecturer in ceramics at Charles Sturt University in Bathurst, NSW, Australia. He will be visiting the UK in 2003.

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ABOVE: Detail of crystal development on green bowl.

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Glazes for Crystaline Glazes

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<tr>
<th>Material</th>
<th>Percentage</th>
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<td>Zinc oxide (dense)</td>
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<tr>
<td>Cobalt carbonate (CoCO3)</td>
<td>0.5-1%</td>
</tr>
<tr>
<td>Iron oxide (FeO)</td>
<td>2-4%</td>
</tr>
</tbody>
</table>

*Ferrite 4110 is a high expansion and high alkaline glaze. It has the following composition:

- Na2O: 15.31
- K2O: 2.56
- CaO: 4.13
- Al2O3: 4.26
- B2O3: 2.48
- SiO2: 69.15
Extended Abstract as accepted for The Australasian Ceramic Society International Conference and Exhibition in Perth, September 29-October 4, 2002.

FACTORS AFFECTING CRYSTAL GROWTH IN HIGH-TEMPERATURE CERAMIC GLAZES

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Keywords: glazes, crystalline, high-temperature

Numeric Code: 23

INTRODUCTION
Crystalline glazes were first developed commercially for the ceramic industry in France in the mid-nineteenth century. They became popular in Europe and America in the 1880s, and have been in use sporadically since then. With the developments in kiln technology over the past twenty years, there has been a renewed interest in them, especially within the studio pottery movement in the western world.

This paper sets out to analyse the factors which affect the growth of crystals in high-temperature glazes and to examine ways to manipulate these factors to develop a desired technical and aesthetic quality.

From previous experimentation it was discovered that the three important factors in determining crystal growth are: the glaze recipe, the firing cycle and the thickness of application of the glaze. Of these, the thickness of glaze application is known to be between 2 and 3mm to obtain optimal results, and therefore this factor is constant. The other two variables will be the source of the experimental procedures in this study.

EXPERIMENTAL
T-shaped test tiles were made so that the test glaze results can be seen on vertical as well as horizontal surfaces. Crystalline glazes have a low viscosity and hence they flow and run readily once they have been melted. The need to assess glaze results on vertical and horizontal surfaces has important implications for the creation of suitable types of ceramic forms to suit these glazes.

Six base crystalline glazes, both gloss and matt, were developed through previous experimentation. Colourants were added individually to the test glazes in increasing amounts and then they were added in combination with one another in varying ratios. The principal colourants being tested included manganese dioxide, cobalt carbonate, copper carbonate, red iron oxide, nickel oxide and chrome oxide.

Four different firing schedules were adopted that varied in top temperature between cone 9 to 11. Each schedule also varied in its rate of rise of kiln temperature, the length of the soak at top temperature, the rate of cooling to the crystal growing phase and length of time spent within this crystal-growing temperature range.

RESULTS AND DISCUSSION
The results indicated that within the glaze recipe and the firing schedule there were many variables which controlled the quality of the crystalline glaze.

*the glaze recipe
The glaze fluxes used included barium, zinc oxide, sodium, magnesium and lithium as well as alkaline frits. All glazes needed at least 20% of zinc oxide for crystals to develop, with the fritted glazes being glossy and requiring a hotter firing (cone 11) and the barium and lithium containing glazes being satin-matt surfaces and requiring a cooler firing (cone 9-10).

The glazes all required the presence of titanium dioxide (up to 8%) as a seeding agent to assist the nucleation of the crystals. The titanium also acted as an opacifier in the glaze and helped in the formation of secondary crystals.

*the quantity of colourants used in the glaze
Small changes in the amount of colourants used made significant differences in the final glaze result.

*firing conditions
Oxidising or neutral atmospheres in the kiln provided the optimal conditions for crystal growth with reducing atmospheres distinctly inhibiting their growth. Similarly, the firing cycles adopted for the glaze firings strongly influenced the glaze quality, i.e., the number and size of the crystals formed, the positioning of crystals on the ceramic surface, the shape of the crystals and the characteristics of the crystals themselves (growth rings, haloes). The factors within the firing cycle of significance were:
- The rate of rise of the kiln
- The top temperature
- The amount of time spent at top temperature
- The rate of cooling
- The temperature at which the kiln is held for the crystal growth stage
- The length of time the kiln is held at this crystal growth stage

CONCLUSION
The quality of the glaze is influenced by the glaze composition, the thickness of application of the glaze and the firing schedule undertaken.

The glaze composition (and its additions of colourants) affects the colour of the crystals and the background. Secondary crystals can develop in this ground if titanium and magnesium are present in the glaze, as they each form silicates which are coloured differently to the primary crystals. Their inclusion in the glaze also determines whether or not haloes develop around the crystals.

The firing schedule controls the size, shape and number of crystals on the ceramic surface.

The top temperature reached (zone of nucleation) is important as it determines the number of crystals in the glaze. The temperature at which the kiln is held for crystal growth (zone of crystallization) is significant as this determines the shape of the crystals from needle-shaped, Maltese-cross battleaxe shapes to round crystals.

The rate of rise of the kiln and the length of time spent at the top-temperature soak determine the amount of glaze that runs off the pot. This can be minimized with faster rates of kiln rise to top temperature and a reduced soak at top temperature.

The aesthetically desirable qualities of crystalline glazes (as sought by the authors) can be successfully controlled by manipulating the glaze recipe and the firing schedule.

Image 1: Example of a controlled crystalline surface of a pot by the author 300mm high x 290mm wide (2003).

GENERAL REFERENCES
Appendix 4: Final Exhibition: 14-26 June, 2002, Mura Clay Gallery, Newtown, Sydney

Image 29: Open-necked vase, crystalline gloss glaze 400mm h. x 215mm w. (Peter Wilson, 2002).

This vase has been glazed with base glaze no. 1 and fired to schedule C with additional ingredients CoCO$_3$ 0.5, MnO$_2$ 2, TiO$_2$ 5 and MgSiO$_2$ 8 parts.
Image 30: Bowl, crystalline glaze 240mm h. x 252mm w. (Peter Wilson, 2002).

This bowl has been glazed with base glaze no. 5 and fired to schedule 2 with additional ingredients CoCO₃ 1, CuCO₃ 4, TiO₂ 6 and MgSiO₂ 10 parts.
Image 31: Bowl, crystalline gloss glaze 150mm h. x 230mm w. (Peter Wilson, 2002).

This bowl has been glazed base glaze 5 and fired to schedule B with additional ingredients CoCO3 0.5, CuCO3 2, TiO2 4.5 and MgSiO3 6 parts.
Image 32: Bowl, crystalline gloss glaze 160mm h. x 292mm w. (Peter Wilson, 2002).

This bowl has been glazed with base glaze no. 1 and fired to schedule C with additional ingredients CoCO$_3$ 0.5, MnO$_2$ 2, TiO$_2$ 5 and MgSiO$_2$ 8 parts.
Image 33: Bowl with matt crystalline glaze 150mm h. x 252 w. (Peter Wilson, 2002)

This bowl has been glazed base glaze 4 and fired to schedule C with additional ingredients CoCO3 0.1, CuCO3 2 and TiO2 4.5 parts.
Image 34: Vase, crystalline matt glaze 390mm h. x 392mm w. (Peter Wilson, 2002)

This vase has been glazed with base glaze 6 and fired to schedule B with additional ingredients CoCO3 0.7 and TiO2 4.5 parts.
Image 35: Bowl, crystalline matt glaze 162mm h. x 271mm w. (Peter Wilson, 2002)

This bowl has been glazed with base glaze 4 and fired to schedule B with additional ingredients CuCO₃ 2 and TiO₂ 4.5 parts.
Image 36: Bowl, crystalline matt glaze 142mm h. x 171mm w. (Peter Wilson, 2002)

This bowl has been glazed with base glaze 4 and fired to schedule B with additional ingredients CuCO$_3$ 2 and TiO$_2$ 4.5 parts.
Image 37: Platter, crystalline matt glaze, 92mm h. x 462mm w. (Peter Wilson, 2002).

This platter has been glazed with base glaze 4 and fired to schedule B with additional ingredients CoCO3 0.5, MnO2 0.3, and TiO2 4.5 parts.
Image 38: Bowl, crystalline gloss glaze 172mm h. x 360mm w. (Peter Wilson, 2002).

This bowl has been glazed with base glaze no. 1 and fired and fired to schedule C with additional ingredients CoCO₃ 1, MnO₂ 4, TiO₂ 5 and MgSiO₂ 10 parts.
Image 39: Bowl, crystalline matt glaze 170mm h. x 355mm w. (Peter Wilson, 2002).

This bowl has been glazed with base glaze 4 and fired to schedule B with additional ingredients CuCO$_3$ 2.5 and TiO$_2$ 4.5 parts.
Image 40: Platter, crystalline gloss glaze 122mm h. x 482mm w. (Peter Wilson, 2002).

This platter has been glazed with base glaze 5 and fired to schedule A with additional ingredients CoCO$_3$ 0.5, CuCO$_3$ 2, TiO$_2$ 4.5 and MgSiO$_3$ 2 parts.
Image 41: Bowl, crystalline matt glaze 170mm h. x 355mm w. (Peter Wilson, 2002).

This bowl has been glazed with base glaze 4 and fired to schedule B with additional ingredients CuCO₃ 2.5 and TiO₂ 4.5 parts.
Image 42: Platter, crystalline gloss glaze 111mm h. x 430mm w. (Peter Wilson, 2002).

This platter has been glazed with base glaze no. 1 and fired to schedule C with additional ingredients CoCO$_3$ 1, MnO$_2$ 4, TiO$_2$ 5 and MgSiO$_3$ 9 parts.
Image 43: Vase, crystalline gloss glaze 410mm h. x 396mm w. (Peter Wilson, 2002).

This vase has been glazed with base glaze 3 and fired to schedule A with additional ingredients CoCO3 0.5, CuCO3 2, TiO2 4.5 and MgSiO2 4 parts.
Image 44: Bowl, crystalline gloss glaze 165mm h. x 177mm w. (Peter Wilson, 2002).

This bowl has been glazed with base glaze no. 1 and fired to schedule D with additional ingredients CoCO₃ 1, CuCO₃ 4, TiO₂ 5 and MgSiO₃ 10 parts.
Image 45: Bowl, crystalline matt glaze, 168mm h. x 296mm w. (Peter Wilson, 2002).

This platter has been glazed with base glaze 4 and fired to schedule B with additional ingredients CoCO3 0.5, CuCO3 2, and TiO2 4.5 parts.
Appendix 5: Review of final exhibition

Peter Wilson’s Love Affair with the Crystal

by
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School of Contemporary Arts
University of Western Sydney.
June 2002

Peter Wilson’s love affair with crystals has taken him and his work through extensive research and experimentation in a quest to find a new series of crystalline glaze effects in concert with a sympathetic repertoire of forms.

Drawn to what he describes as decoration created by fire (Wilson, 2002), Peter’s recent work celebrates his journey, culminating in a stunning range of new crystalline glazes embracing elegant and refined yet refreshingly simple vessel forms.

Writing about his work in Pottery in Australia (1999), Peter emphasized his attraction to the sense of unpredictability in the use of crystalline glazes and the importance of fire in the creative relationship. The "pot kissed by fire", his poetic description of the process, conjures images of passion, casting the kiln as boudoir where the lovers, fire and clay, tease into existence the startling gem-like surfaces of his pots.

The affair has been a long and stormy one. Five years of intense and rigorous testing, recording and refining and many discarded pots later, Peter has emerged from this tumultuous liaison in command of a new and exciting visual vocabulary of surface and form. The fruits of this passionate engagement were recently exhibited at Mura Clay Gallery, King Street, in Newtown.

The appearance of crystalline forms in the surface of a glaze was historically regarded as a fault. However, the beauty, variety and serendipitous nature of these imperfections became a source of study and development, which probably reached its peak of popularity in France in the 1880s. Possibly because of their propensity to dominate, even overwhelm the form, crystalline glazes have not enjoyed a wide following in modern and contemporary Western ceramics. Many crystalline glaze effects appear garish and ostentatious in conflict with or in total denial of the form.

Peter Wilson’s work, however, breaks new ground. His extraordinarily beautiful surfaces strike a harmonious unity with the forms of his pots. Furthermore, the surfaces he has developed are not what we have come to expect from crystalline glazes. Peter introduces surface textures, which evoke an intimate engagement with
landscape and with the spiritual and physical origins and the raw materials of ceramics.

One huge bowl features a matt-finished, dark, metallic brown base colour with a jagged surface pattern of black, irregular, pinpricked crystals. The piece has a rare patina somewhere between velvet, old leather and bronze. This majestic bowl balances defiantly on a slender foot in defiance of the implied weight of its glazed surface. Another vase, shaped rather like a huge pebble, is wrapped in a blanket of matt terracotta browns like mottled, sun-baked earth, sprinkled with tiny crystals of delicate grey blue. The surface of yet another elegant bowl recalls the textures and colours of a wheat field with creamy, yellow gold flower-shaped crystals floating on a muted grey brown ground. The matt finishes and the muted earthy colours are a fascinating departure from the accepted high gloss of crystalline glazes. These effects lend themselves readily to associations with the contemporary painted landscape of Australia, and perhaps recall Peter's collaborations with the painter John Olsen. Like Pippin Drysdale's emblematic national palette, these pieces engage with ideas, which reach beyond the boundaries of craft discourse.

Some more conventionally coloured crystals of pastel green, powder blue, pinks and soft purples sprinkle the surfaces of vessels like raindrops on a forest pool or light filtering through exotic foliage. At times these crystals resemble watercolour effects as if they have been carefully and deliberately painted, yet at the same time, the scattering of the crystal shapes appears random and spontaneous, the gesture of a playful wizard dispersing his glittering magic dust.

The vessel forms have an integrity of their own yet function as the canvas supporting the "painted" surfaces. At his best, the two elements, form and surface in Peter Wilson's work, combine in a seemingly unconscious way to become a single entity (Hanssen Pigott, 1996). It is at this point of symbiosis that the pot, according to Hanssen Pigott (1996), "transcends the individual elements and technical considerations that have been the essence of its making, "to become "a statement of universal beauty and harmony" (ibid.).

The chemistry of crystalline glazes is complex and fluid. The characteristics of crystals, their shape, size, colour, number, pattern and movement can be manipulated, to a degree, by the potter in collaboration with fire, but the chemical reactions, that produce crystal effects can also be serendipitous. In Peter Wilson's practised and sensitive hands, chemistry becomes poetry.

References
**Glossary**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>alumina</td>
<td>a component of clay (as aluminium silicate), a highly refractory material</td>
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<tr>
<td>bentonite</td>
<td>a very fine clay mineral which can be used as a flocculant in glazes</td>
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<tr>
<td>bisque-firing</td>
<td>a slow firing of ceramic ware prior to glazing to assist the ease of handling of the pot after glazing; usually to around 1000°C</td>
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<tr>
<td>bloating</td>
<td>lumps or bubbles that occur in the clay body during glaze firing which is usually due to the presence of carbonaceous material or air pockets trapped in the clay</td>
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<tr>
<td>calcined</td>
<td>the process whereby a material is fired to bisque temperatures to remove moisture content or to reduce carbonates and sulphides to oxides</td>
</tr>
<tr>
<td>carborundum</td>
<td>a hard material used for grinding the bases of pots after firing</td>
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<tr>
<td>celadon</td>
<td>a Chinese glaze which varies from grey, greens to blue caused by the addition of iron and depending on glaze composition and firing conditions</td>
</tr>
<tr>
<td>chun (jun)</td>
<td>a Chinese glaze which ranges in colour from a deep blue to pale blue and white, depending on firing conditions, thickness of application; it works best when used in conjunction with iron containing glazes</td>
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<tr>
<td>colourants</td>
<td>a variety of substances (man-made stains or naturally occurring) which, when added to the glaze give it colour; they can be used individually or in combination with one another</td>
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<tr>
<td>copper-red</td>
<td>a stoneware glaze with bright red characteristics through to a deep maroon</td>
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<tr>
<td>crai</td>
<td>a whiting (calcium carbonate) as used as a glaze flux</td>
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<tr>
<td>craze</td>
<td>a result of differential expansion and contraction rates between the glaze and the clay body whereby the glaze cracks on cooling leaving visible lines within the glaze</td>
</tr>
<tr>
<td>crystalline</td>
<td>a glazed surface which contains crystals</td>
</tr>
<tr>
<td>crystallization</td>
<td>the process where the crystals grow in the glaze</td>
</tr>
<tr>
<td>flocculant</td>
<td>a material which is added to the liquid glaze to keep the particles in suspension</td>
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</table>
densified
the same process as calcining
dunting
cracks which occur in the cooling stage of the firing, usually around 600°C
extruder
a tool for making different-shaped objects from clay by pushing the clay through a shaped die
felspar
a rock which forms from the weathering of granite; it is a flux which is added to clays to aid a lower temperature vitrification; it is also used extensively in glazes as a flux/glass-former
flux
a material when added to more refractory materials causes them to melt at lower temperatures
fractal
a mathematically-based geometric pattern which has the property of self similarity
friability
refers to an unfired glaze that is easily reduced to powder
frit
a man-made glass which is used in glaze formulation
hare's fur
a Chinese glaze, dark in colour with lighter flecks of yellow through it
insulating
the ability to contain the heat within a confined area
kaolin
a non-plastic china clay
LPG
liquid petroleum gas
lustre
a surface shine which changes with the light, ie, mother of pearl, gold, silver
oil-spot
a crystalline glaze developed by the Chinese potters of the Sung Dynasty characterised by brown crystals on a darker ground
opacifier
a material when added to a glaze makes it opaque
overfired
too much heat having been applied to the glaze causing the glazes to run excessively and spoil the desired effects
oxidation
refers to the kiln atmosphere during the firing process which contains an excess of oxygen
oxygen probe
a device which measures the amount of oxygen at any time in the kiln during firing
nucleation
the initial seeding of crystals in the glaze firing
pegmatite
a felspathic rock often used in glazes
petuntse
a felspathic rock used by Chinese potters to flux kaolin
in the manufacture of porcelain

*porcellaneous* exhibiting the qualities of porcelain, ie, fine, dense, white firing, translucent fired body

*pyrometer* a temperature-measuring device used in firing kilns

*reduction firing (gas, oil, coal, wood)* refers to the kiln atmosphere during firing whereby there is an absence of oxygen; fossil-fuels provide the major means of reduction firing

*sable* silica sand as used in glazes

*setting* refers to the way the pots are stacked into the kiln

*Shiga's tomato red* a red glaze which forms beautiful crystals under the right firing conditions as named after the Japanese potter, Shiga Shigeo who is said to have developed it

*silica* a glass-former when used in glazes

*stoneware* ceramic material which can be fired to vitrification which is usually between 1200-1300 degrees C.

*talc* a magnesium silicate used as a matting agent in glazes

*tenmoku* a saturated iron glaze which changes from black to brown depending on thickness

*titanium dioxide* a glaze ingredient which is used in crystalline glazes as a seeding compound for primary and secondary crystals to form onto and an opacifier in the glaze

*underfired* when insufficient heat has been applied to fully mature a glaze

*viscosity* refers to the fluidity of a molten glaze

*vitreous* pertaining to a glass-like state

*willemite* naturally occurring zinc silicate crystals named after King Willem II of the Netherlands (1772-1843) (Carter & Sweet 1997, 79)

*zinc oxide* a glaze flux which when it combines with silica in a glaze, can form crystals under certain conditions
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