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## **The effects of reduction atmospheres upon feldspathic glazed porcelain forms**

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THE EFFECTS OF REDUCTION ATMOSPHERES  
UPON FELDSPATHIC GLAZED PORCELAIN FORMS

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## INTRODUCTION

The investigation of reduction atmospheres was an attempt at exploring the design concept of random multiplicity, that is, the chance juxtaposition of marks, colors, textures, and patterns. •Through the study of Chinese, Japanese, and Islamic ceramics as well as design philosophy, it became apparent that reduction could be a means of realizing this objective. The following is an account of reduction procedures employed in pursuit of this goal.

THE EFFECT OF REDUCTION ATMOSPHERES  
UPON FELDSPATHIC GLAZED PORCELAIN  
FORMS

For centuries, clay and fire have united to form utilitarian and sculptural objects. From the early bon-fired wares to the elegant Sung vessels, fire has played an important role in the production of ceramic objects.

In the beginning, the ancient potters discovered that the primary function of fire is heat and this important by-product renders clay impervious in water; yet the wares produced were too porous to hold liquids for any period of time.<sup>1</sup> As their knowledge and skill increased, they discovered that increased temperatures not only rendered clay vitreous but produced glassy, ash deposits on the surfaces of the wares. It was only a matter of time until they controlled this effect and produced ash glazed vessels. This is the first major utilization of a reduction process. That is, the only means of successfully producing a sufficient ash build-up on the surfaces of vessels is to employ a semi-sealed firing chamber. This inhibits efficient air intake into

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<sup>1</sup>Otto Natzler, "Natzler Glazes," Craft Horizons, July 1964, p. 39.

the chamber thereby inducing reducing conditions. This initial, conscious attempt at reduction firing is the first instance where the process may be thought of as possessing aesthetic qualities. It is a fact that earlier ceramic wares were fired in bonfires producing reduction effects but these surfaces do not possess aesthetic qualities. That is, they are referred to as natural curiosities displaying the accidental, natural product of the fire rather than a conscious effect induced by the craftsman.<sup>2</sup> It is this element that separates the early reduction effects from the later and it is obvious that the ancients considered these fire effects as defects because they were eliminated as soon as their skill permitted. Therefore, the conscious firing of ceramic objects under reducing conditions emerged simultaneously with the advent of ash glazed wares. From this initial exploitation of the fire, the process has been continually explored. For example, the Sung potters masterfully extracted from reduction fires the beautiful color mutations of iron and copper while the Iga potters of Japan successfully mastered textural changes producing bloated, cracked, iridescent wares.

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<sup>2</sup>John Dewey, Art as Experience (New York: Capricorn, 1958), p. 48.



On the other hand, the Islamic potters chose to pursue the effects of low-fire reduction and produced magnificent lustre overglazes.

Many noted authorities believe these ancient craftsmen developed these effects because they were a natural result of the way their kilns were fired. "When potters relied entirely on wood or other solid fuel, reduction was a natural occurrence."<sup>3</sup> This statement is true inasmuch as reduction is a natural product of fire but it is not exclusive to solid fuel. Liquid fuel is in a reduced state upon entering a firing chamber and if there is insufficient oxygen within the chamber, reducing conditions will occur. The only difference between the two fuel sources is their efficiency of combustion. If there is sufficient oxygen intake for the total combustion of the fuel, an oxidation atmosphere will prevail.

With this knowledge, fire may be broken down into the two elements of oxidation and reduction. These states of the fire are continually in harmony, neither one a natural state unto itself. To explain further,

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<sup>3</sup>Daniel Rhodes. Clay and Glazes for the Potter (New York: Chilton, 1971), p. 171.

fire has several states and it is in continual change. If it is reduced into its component parts, or its pre-burn state, the evolution of the changes may be understood. First, heat is required to initially decompose a fuel source into the component parts of carbon and hydrogen. This initial breakdown of the fuel results in reduction, the primary state of the fire. The second state occurs when the component parts combine with oxygen resulting in combustion producing carbon dioxide and water. This chemical change results in oxidation and produces heat and light, the third and final state of the fire. All three states are necessary and neither one occurs independent of the others. What is essential is to know exactly where within a kiln chamber these series of reactions are occurring. It is the control of the positions of these reactions that determines the atmospheric conditions within a kiln. Fire seeks change and moves in the direction that will enable change. No state is permanent. One state changes to the next in a cyclic motion. The heat of the reaction decomposes the fuel which in turn liberates the elements that combine with the oxygen to produce the heat. Each state of the fire derives itself from the previous one resulting in a cyclic, harmonious rhythm. What this states is that

the intensity of the reduction is directly proportional to the distance the component elements of the fuel must travel to change to an oxidation state. Therefore, within a kiln chamber, the intensity of the reduction decreases as the distance from the initial decomposition of the fuel increases. It is for this reason that glazes react differently as their firing positions are rotated within the kiln chamber, and it is also this property of the fire that allows for multiple atmospheres within a firing chamber. For example, it is possible to produce oxidizing atmospheres employing reduction flames as well as simultaneously firing a kiln in an oxidizing and reducing atmosphere or firing a portion of the kiln chamber in reducing conditions while the remaining portion fires in oxidation. All of these conditions are produced by manipulating the position at which the fuel is permitted to change from a reduced to an oxidized state. The cyclic action of the fire is inevitable, but it may be controlled by either prolonging or inducing a particular state, and by so doing, control atmospheric conditions.

As it was essential for early potters to explore a means of controlling the fire to produce oxidation effects, so it is also necessary to investigate the

means for producing reduction effects. Initially, the reduction process was discovered through the procedures employed to fire the kilns. Philosophical ideals supported the further intense investigations into this process. These investigations provided potters with the knowledge of reduction characteristics and eliminated the accidental production of these unusual mutation effects. It was this deliberate elimination and the employment of reduction characteristics as decorative elements that imparted aesthetic qualities to the ancient works. Likewise, it is the discovery of reduction characteristic effects and the elimination of the accidental that the following research is herewith concerned.

My initial exploration of a reduction atmosphere consisted of investigating sustained temperatures. Reduction will arrest a kiln's rate of temperature increase thereby extending a glaze's work heat time. This condition was reached by closing the damper sufficiently to permit the necessary amount of oxygen needed to maintain a temperature equilibrium of 2300°F. Throughout a series of firings, the duration of the work heat was increased by one half hour increments. As the duration of the work heat increased, the glazes either ran excessively or devitrified. From these first reduction

attempts, it was discovered that stalled reducing conditions promote flowing and devitrification. These effects are a direct result of extending a glaze past its firing range. By adding alumina and silica to the glaze batch, it became possible to extend a glaze's range to coincide with any length of work heat time. The most significant benefits of stalled reduction atmospheres are as follows:

1. Fewer fluxes are necessary to induce a melt.
2. A flux with a high melting point and normally not employed as a major melt contributor becomes excessively active thereby permitting a more frequent use.
3. Glaze flowing occurs, promoting particle separations that impart crystal development, texture transformations, and color mutations.

At present, a two hour work heat is sufficient to induce these effects. Increasing the duration of the work heat only necessitates the addition of alumina and silica to the glaze batch while a decrease in time inhibits the effective use of high melting

fluxes.

The most interesting feature of a reduction work heat is its varied effect on glossy and matte glazes. At present, it appears that the effect of the atmosphere is related to the density of the silicate formed. If a surface is extremely hard, it is impervious to the atmosphere. Flowing and particle separations occur but the result is identical to oxidation. On the other hand, alumina and silica matte glazes change drastically. Extreme color mutations occur along with slight texture transformations. It is this property of silicates that allows for the simultaneous firing of both reduction and oxidation effects. Control is obtained by varying the silicates' density.

The second step in the investigation consisted of exploring the effects of increasing intensities of reduction after silicate formation but prior to total glaze flowing. A series of firings were conducted in which the primary air was continually decreased. The results, although somewhat similar to the previous experiments, were quite startling. As could be expected, the dense glazes were unaffected by these atmospheric changes. However, devitrified glazes changed drastically

in color and texture. As the reduction intensified, so did the crystallization and devitrification. Smooth, waxy glazes became one rough, solid mass of crystals. Glaze colors became diluted as if mixed with a black pigment. It became necessary to continually extend and intensify the soaking period of a firing to revive the hue. It is now known that an oxidation period in relation to the intensity of the reduction is imperative in order to return a glaze to its brilliant character. If this is not done, glazes will either be coated and impressed with carbon or diluted in terms of color saturation.

In addition to color and texture mutations, the elimination of primary air produced an extreme flame within the firing chamber that induced crawling and skinning in certain silicates, specifically glazes containing excessive amounts of either iron or barium oxide. At present, the reason for these effects is unknown. Even with extended re-oxidation periods, the effects remained.

At this point, open-ended saggars were used to protect the wares from the flame but allow for a continued exposure to the atmosphere. Saggars eliminated the crawling in addition to glaze pinholing, but a most

interesting transformation occurred with the devitrified glazes. Matte glazes that normally were severely pin-holed transformed into runny, glassy silicates. These results indicate that a clear distinction exists between the atmosphere and the flame. It appears to be the flame that imparts skinning, crawling, crusting, and glaze separations while the atmosphere is responsible for matteness, crystallization, and color mutations. Exceptions do occur. At times carbon has been present in saggar fired ware due to settling, but generally, it is absent if a sufficient re-oxidation is employed. Particle separations occur due to a glaze flowing but stable silicates generally retain a uniform consistency. Further experimentation with saggars was indicated but a durable clay body that will withstand multiple firings has not yet been found.

Since continued experimentation with saggars was halted, the research was redirected to include the effects of reduction on glazes in their pre-melt state. The first attempts were the incorporation into existing firing schedules of low fire, body reductions at 1641°F, 1940°F, 1154°F, and 1168°F. The results were all consistent. Color mutations minimally occurred but were generally insignificant. The oxidation climb



from 1168°F to 2300°F eliminated any effects. It is now known that reduction of glazed porcelain wares is only effective above the initial melt of the silicate and must be continued throughout the firing. Otherwise, a loss of the effects will occur. This rule is only true for fluid, glossy glazes and does not apply to devitrified silicates. This latter group seems to more readily retain the effects of low-fire reductions and therefore allows for a more diverse combination of atmospheres.

The glazes used in this research became visibly active by bubbling at approximately 2232°F. Reduction was begun at this temperature and continued until 2300°F where both holding and smoking reductions were employed. Drastic changes in the form of color and texture mutations occurred in both matte and gloss glazes. For example, glossy, copper-green glazes transformed into intense reds while matte, iron yellow glazes darkened to either a gold or brown-green. Attempts were made using soaking, oxidation atmospheres to return matte silicate color to its previous brilliance. Even after employing a two hour oxidation period, color remained diluted. It was found that a glaze's color could be restored to its original brilliance by refiring the ware in oxidation

to cone 04. Firing above this point returned the glaze color to its oxidation state.

Concurrent with the previous experiments were firings employing climbing reductions from 1940°F. Results were compared with the previous experiments and no major distinctions were evident between the two schedules other than severe bloating of the clay body accompanied the introduction of reduction at 1940°F. It appears that an initial glaze melt is essential to protect the clay body from the deleterious reducing atmospheres.

From this point, two basic methods of reductions that allowed for increasing atmospheric temperatures were explored. First, a reduction was induced by simply closing the damper sufficiently to create the presence of flame within the flue. This adjustment also created backpressure at both the burner intake ports and the spyholes. The rate of temperature increase was severely diminished. This procedure promoted reduction as well as a small amount of flame within the firing chamber.

The second method was that of increasing the gas pressure and decreasing the primary air until a flame was present within the flue. This procedure eliminated backpressure but created an extreme flame within the

firing chamber. As a result, the effects mentioned earlier attributed to the flame were intensified. A constant temperature increase within the firing chamber was also possible. The most interesting comparison between the two procedures was the vast difference between the extent of the reduction effects produced. The first firing procedure created sporadic results while the second produced more dramatic regular mutations.

At this point, duplication of previous firing schedules were run with fairly consistent results. Duplications of firing conditions are possible within limits. Variations occur due to atmospheric conditions outside the kiln, wind velocity and direction, but if careful control is maintained, duplication is possible.

The most interesting firing procedure investigated was the final one. It was a product of several firing procedures and knowledge accumulated throughout the research. The procedure consisted of employing a reduction flame in an oxidation atmosphere. This was achieved by closing the primary air and opening the damper. A reduction flame was present but there was sufficient air within the kiln chamber to allow total combustion. The results were extremely

interesting. Portions of the ware were massively flame licked and reduced while other sections were oxidized. For example, some copper glazes were red and green depending on where the flame licked the vessel. These results indicate a multitude of effects are possible with this procedure.

Considerable exploration is necessary in the areas of both low-fire and cooling reductions as well as extended holding reductions within the firing schedules. The possible combinations are endless.

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PLATE I. Porcelain Bottle. Red to Green Reduction Glaze with an Orange Peel Texture, Crackle Pattern, and Impressed Carbon.



PLATE II. Porcelain Bottle. Iron Red Reduction Glaze  
with Flowing, Crystals, and Iridescence.



PLATE III. Porcelain Bowl. Rutile Reduction Glaze  
with Flowing and Crystals.





PLATE IV. Porcelain Bowl. Red Reduction Glaze with  
Fire Mark, Flowing, Mattiness, Melt Fissures,  
Impressed Carbon, and Crackle Pattern.



PLATE V. Porcelain Bottle. Copper Blue Reduction Glaze with Fire Mark, Impressed Carbon, and Circular Separations.



PLATE VI. Porcelain Bottle. Green Lava Reduction Glaze  
with Flowing and Impressed Carbon.



PLATE VII. Porcelain Bowl. Copper Blue Reduction.  
Glaze with Flowing and Crystallization.



PLATE VIII. Porcelain Bottle. Yellow Reduction Glaze with Flame Lick Pattern, Flowing, Crystals, and Kiln Incrustations.



PLATE IX. Porcelain Bottle. Red Reduction Glaze with  
Flowing and Feathering.



PLATE X. Porcelain Bottle. White to Black Lava  
Reduction Glaze with Fire Mark and Copper  
Blush.



PLATE XI. Kiln used for the research.



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