The Art of Ceramics
The Blend of Art and Science in Technology
N. Claussen (Editor)

CERAMICS IN ART

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Ceramic art consists of a variety of made things that connect the activities of producing art with the activities of using and appreciating art as illustrated in Fig. 1. Perhaps the most important activity in the production process is **Design**, the process of conceiving and visualizing an object, of forming a plan, of contriving an arrangement of parts in a work of art. Design is required not only for the whole object but also for each of the production activity processes (e.g., materials selection) and use activity processes associated with an art object. As a result, identifying essential characteristics of the design process is a necessary component for understanding ceramics in art.

While our focus is on the overall object indicated in Fig. 1, there is a corresponding design element associated with every component in the production and use process. Each of these design processes will fit into the pattern we describe here. Indeed, in my view the design process is essentially similar for technical ceramics and for all the other made things that comprise most of our surroundings as it is for ceramic art. All design processes must begin with some goal or purpose more or less explicitly defined. Following the track blazed for historians of technology by Walter Vincenti (1990) and for engineers and managers by Stuart Pugh (1991), G. Teguchi (1987) and Dan

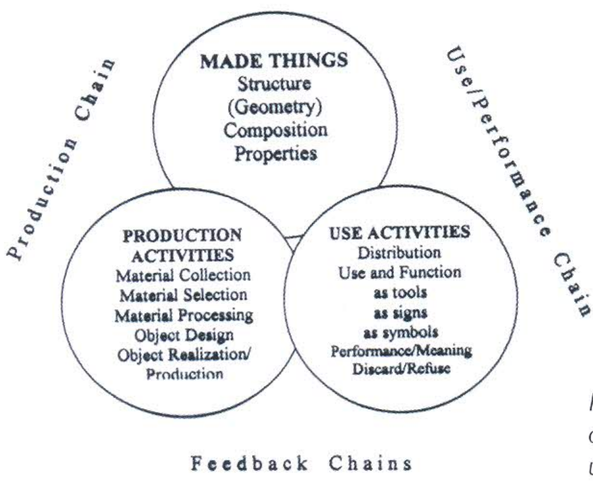

FIGURE 1 - Many activity groups contribute to the production and use of ceramic art.

Clausing (1994) we propose that design is mostly a matter of choosing between imperfect alternatives and consists of the following components:

- Purpose and goals
- Normal configuration
- Normal expectations
- Operational principles
- Design tools
- Performance characteristics

The science of materials is on one hand a search for structure and for explanations of structure, theories of structure. What is it, what are its properties? On the other hand science is a search for operational principles as to the origin of structure and its influence on properties. How did it arise, how does it work? The premise of this essay is that the place to start in developing connections between ceramic art and ceramic science is by asking questions about operational principles, questions focusing on How does it work? Ceramic objects are purposefully designed and manufactured to have both utilitarian purpose and also to function as works of art, that is to please our senses and excite our thoughts and emotions. Every object created by humans is to some extent a work of art. The designer and creator of a ceramic object has but a limited number of variables with which to work but each has a wide range of possibilities. The composition, the outer form and the inner structure fix the properties of an artifact and determine its performance as a work of art for a particular audience within a given social and cultural context. Physics and chemistry can measure the properties and attributes of a ceramic but standing by themselves they tell us nothing about ceramic as art.

When we attempt to rationalize ceramics as art, we ask the question: how does it work? This aspect of any object or machine has been described by Michael Polanyi as the *operational principle*, that is "how its characteristic parts...fulfill their special function in combining to an overall operation which achieves the purpose" (Michael Polanyi, p. 318, *Personal Knowledge*, University of Chicago Press, 1958). This has much in common with David Pye's "Essential Principle" of design, which is "purely a matter of arrangement" (p. 21, *the Nature and Aesthetics of Design*, London, 1978).

One of the wonderful capabilities of ceramics is the ease with which clay can be shaped into an infinite variety of forms and shapes. The operational principle is that the small particle size platy hydrous aluminum silicate particles (Fig. 2) mixed with water have lubricating water films between the particles which allow the particles to slide over one another at moderate pressures and subsequently retain their shape as a result of capillary forces. An understanding of the forces involved and control of the attractive/repulsive forces between particles allows one to manipulate and form a clay body. The downside of this

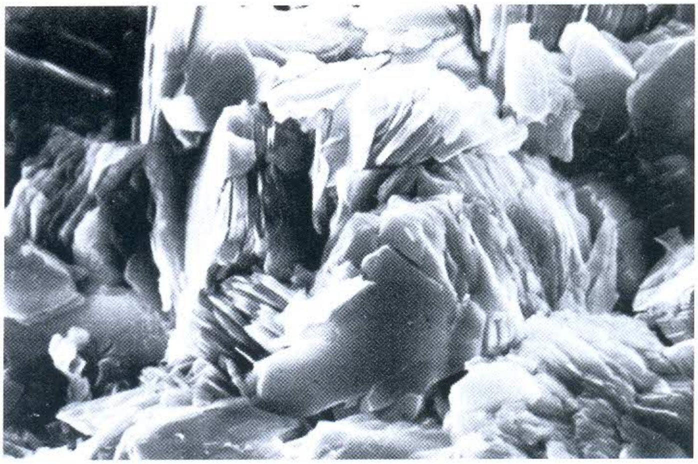

FIGURE 2 - The individual particles of kaolin are fine platelets with a thickness less than 0.5 μm (3700X).

easy plasticity is that removal of the thin water films between particles on drying gives rise to drying shrinkage which may be substantial. Additions of temper and use of fibers to create a composite allows us to control this behavior.

Since the time of classical Greece and the development of black-on-red and red-on-black wares, ceramic shapes have been used as a ground for painted scenes. With the development of white bodies, the use of decorative painting on ceramics has become common. The interaction of order and disorder, energy and entropy, in the formal aspects of ceramic art does have deep and important relationships to science. However, the interpretation, analysis and deconstruction of the formal aspects of ceramic art is a topic I shall leave to colleagues in art and art history. I add the thought that the tactile feel of ceramics that combines utilitarian function with the joy of holding and sensing is a special and important characteristic of ceramics.

The most obvious intersection of science and ceramic art lies in the visual impact of ceramics, with the interactions of ceramic and light. These interactions depend on composition and on the internal structure, equally important with external form. As with form, the operational principle of ceramic art is that interest and impact are developed by creative tension between order and disorder. Perfect harmony is equally as boring as "white" noise; it is as unpalatable as complete randomness.

The opportunity that presents itself in ceramic art for developing visual interests above and beyond form results from the fact that (in contrast to metal and wood) pure glasses and crystals are colorless, transparent media which we can modify in a thousand ways to interact with visible light. One visual effect available in ceramics is an enormous range of colors that can be produced. There is available a complete spectrum of possibilities from the clearest Venetian cristallo or modern Steuben glass to black opacity and all shades in between. We understand pretty well how these colors originate in the electronic arrangements of atoms and molecules. I shall pass over this topic and focus the following discussion on visual effects resulting from the arrangements of various phases in a glass or ceramic and how these can be achieved and used to create aesthetic interest and impact.

The visual appearance of reflected light from a ceramic or through a partially transparent glass or ceramic is illustrated in Fig. 3. The first interaction is with the surface from which a small fraction of the incident light ranging

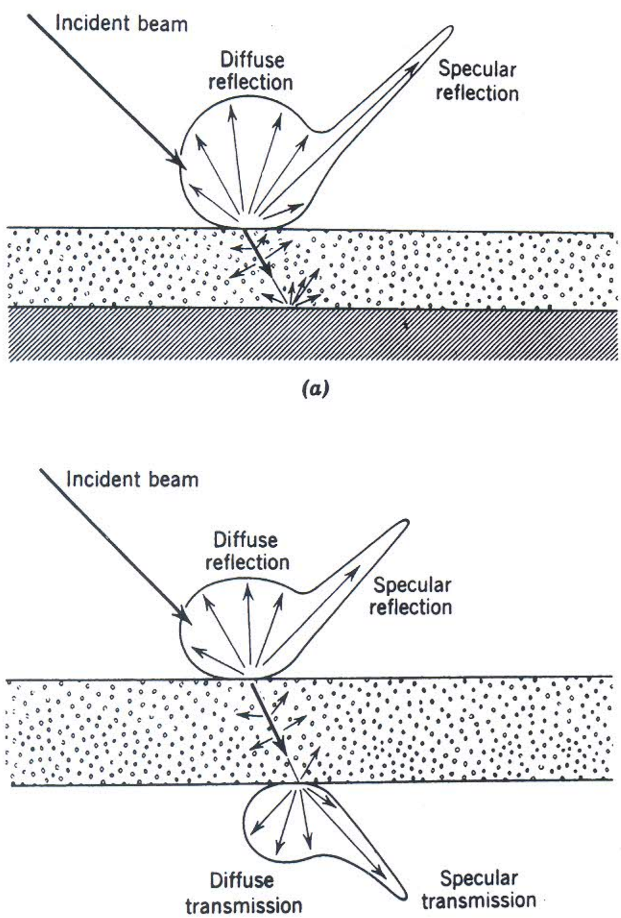

FIGURE 3 - Specular and diffuse reflections and transmission result from surface and internal reflections and light scattering of a glaze or enamel.

from 4% for a soda-lime glass to 10% for a high lead crystal composition is reflected. The brilliant spectral reflectivity of high lead glazed Mexican village pottery (Fig. 4) can be gradually transformed into a velvety surface by the development of surface roughness (Fig. 5). This can be accompanied by forming crystals in the body and surface of a matter glaze, by sand blasting or by the natural surface roughness of unglazed ware (Fig. 6). Louis comfort Tiffany used thin iridescent coatings on some of his glass objects (Fig. 7) to create a velvety visual effect in contrast to the usual smooth coating. He

FIGURE 4 - The smooth high lead glaze of Mexican pottery gives rise to high specular reflectance.

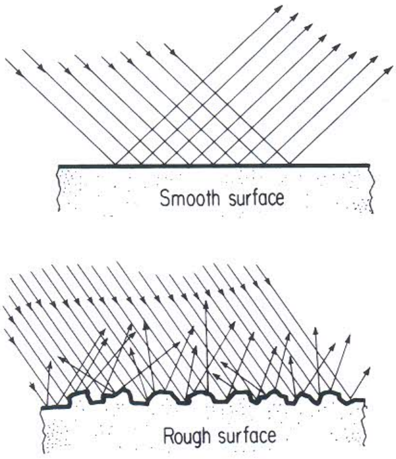

FIGURE 5 - Reflections from surfaces of increasing roughness.

FIGURE 6 - "La Danseuse" is a soft paste porcelain without glaze made at Vincennes in 1752 after a design by Francois Boucher (Courtesy of Musée National de Céramique, Sèvres, France, #20-069).

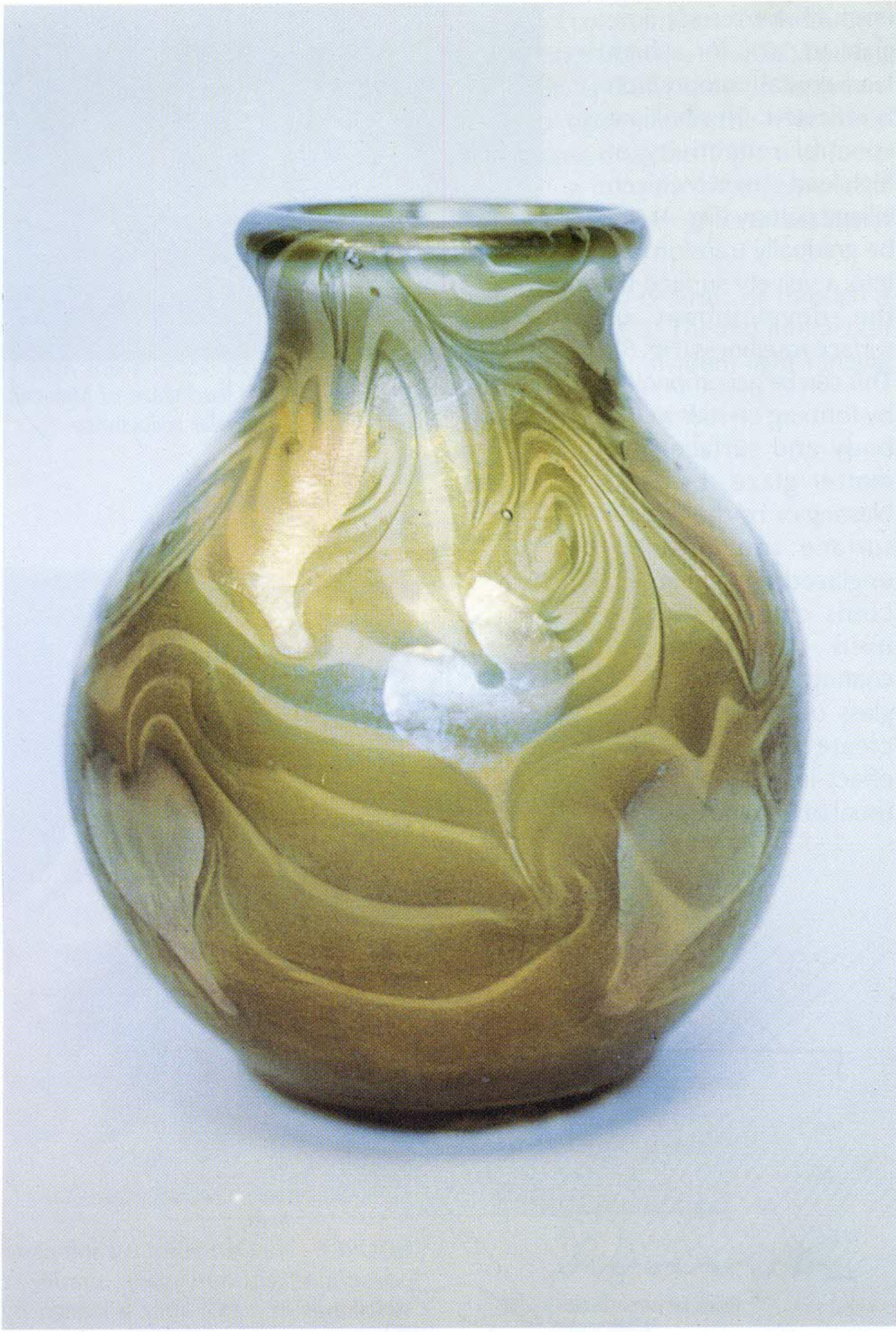

FIGURE 7 - A Tiffany vase, circa 1915, with trailed green decoration, silver punts, and an iridescent coating.

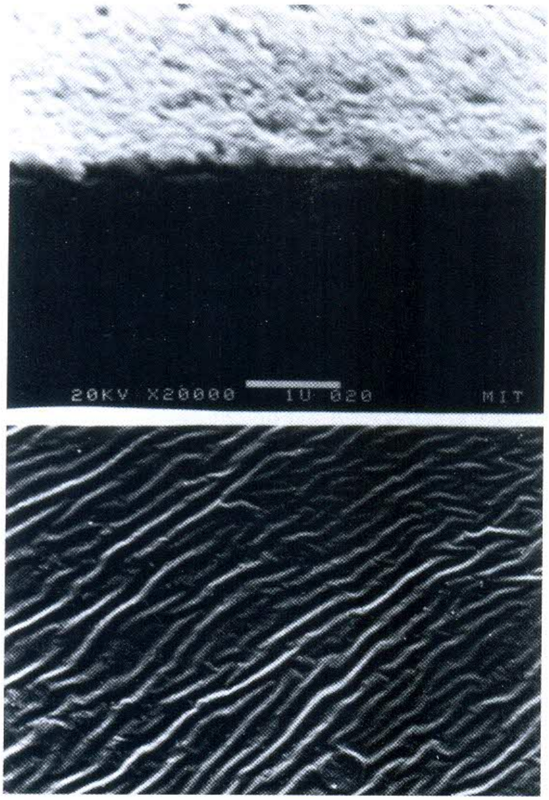

FIGURE 8 - Heating and reheating a tin oxide coating gives rise to buckling. The velvety surface is a result of superplasticity of the very fine particle size coating.

found that repeated heating and cooling gave rise to buckling of the polycrystalline surface oxide film as shown in Fig. 8. This is one of the first practical applications of what we now call superplasticity.

Chinese porcelains were the ceramics first developed as a suitable white ground for decorative designs and painting. It is generally thought that imports of Tang dynasty white porcelain inspired the development of both tin-opacified white glazes and hard white "frit porcelain" which consists mostly of ground quartz with a bonding phase formed from clay and premelted glass frit. Beginning in the tenth and eleventh centuries these became the basis of Islamic and then European luxury ceramics. Underglaze painting with a clear overglaze became the preferred structure for Yuan and Ming Chinese wares and for tens of thousands of wonderful Iznik tile (Fig. 9). A cross section of the glazed surface of an Iznik tile with an underlying white body is shown in Fig. 10.

FIGURE 9 - Iznik tile with underglaze polychrome decoration illustrating bright clear colors under a brilliant lead alkali glaze with wonderful interlocking symmetries (Musée National de Céramique, Sèvres, France, #18.024, donated by M. Charbonne).

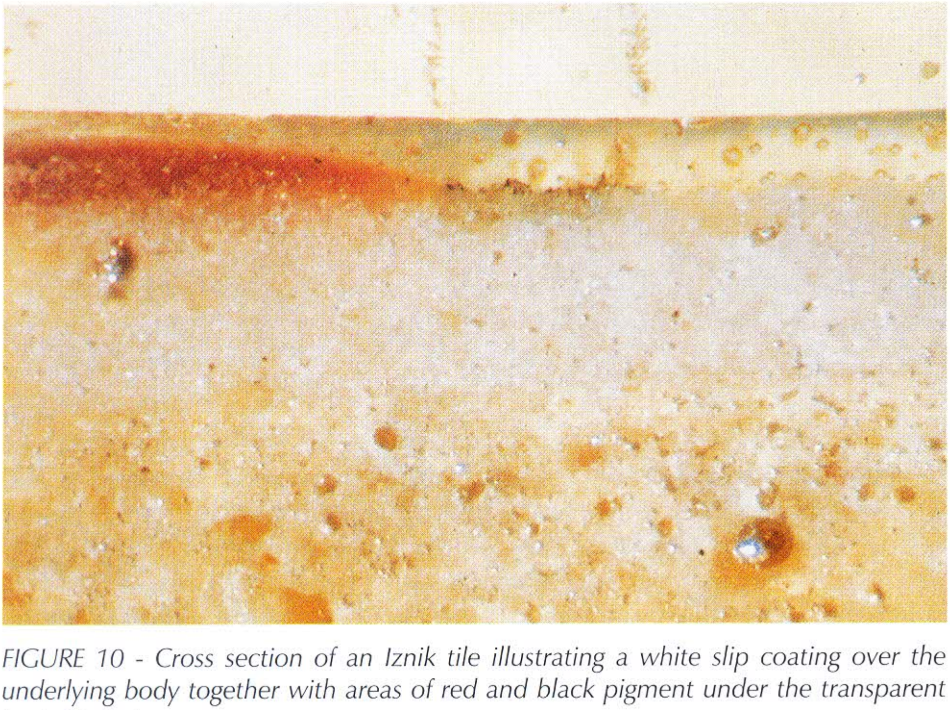

FIGURE 10 - Cross section of an Iznik tile illustrating a white slip coating over the underlying body together with areas of red and black pigment under the transparent lead alkali glaze.

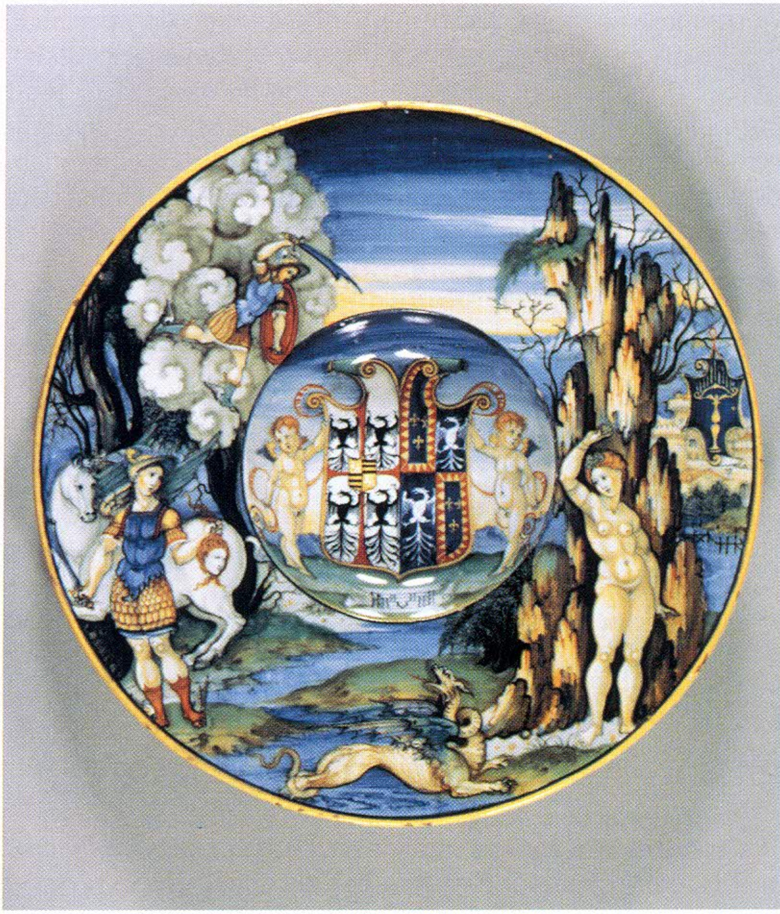

FIGURE 11 - Istoriato maiolica bowl with a scene from the story of Perseus and Andromeda painted by Nicola da Urbino ca. 1525 (Courtesy of the Museum of Fine Art, Boston, Otis Norcross Fund, Cat. No. 41.105).

Narrative paintings in overglaze decoration on a white tin-opacified ground became the basis for *istorioto* maiolica (Fig. 11) in Renaissance Italy. A cross section (Fig. 12) shows how scattering from the tin oxide layer produced a depth that enhanced the detailed painting made brighter by the reflectance of an overlying lead silicate coating. Controlled light and color through control of microstructure allowed unique visual effects to enhance formal decoration. This sort of maiolica was the leading European high-tech ceramic for two

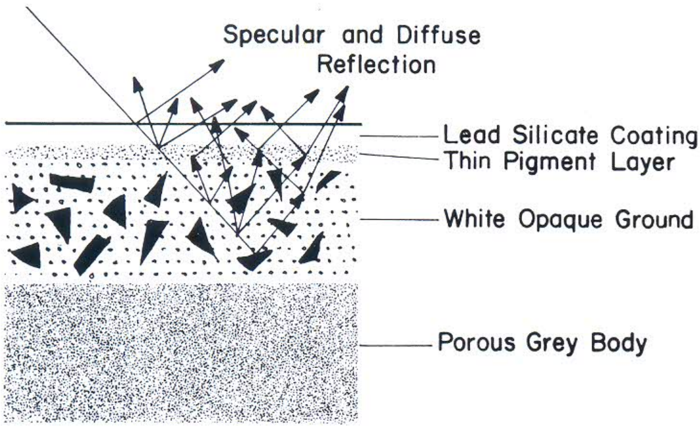

FIGURE 12 - Cross section of a glaze of istoriato ware illustrates the scattering from the tin-ozide opacified ground layer through the thin layer of pigment coated with a lead silicate layer .

TABLE 1 - Design of Renaissance Maiolica.

PURPOSE
- Creation of Wealth. Quality of Life
OPERATIONAL PRINCIPLES
- Incorporate pictorial, social, and cultural identifiers in luxury ceramics
NORMAL CONFIGURATION
Decorated tiles, pharmacy jars, plates, etc.
PERFORMANCE CHARACTERISTICS
- Permanence
- Aesthetics
- Functional
- Social and cultural identifier
- Ease of manufacture
- Moderate cost

TABLE 2 - Performance characteristics of Renaissance Maiolica.

PERMANENCE - Easy maintenance - Fade-Corrosion and fracture resistant	**SOCIAL AND CULTURAL IDENTIFIER** - Depiction (classical story) - Personal devices - Extraordinary object
AESTHETICS - Depth of image - Form - Surface reflectance - Color brilliance - White ground - Translucence - Drawing precision	**MANUFACTURE** - Raw materials required - Ease of shaping - Ease of drying - Ease of glazing - Ease of painting - Ease of firing - Finishing required
FUNCTIONAL - Impermeable - Washable - Thermal shock resistant - Impact resistant - Non-poisonous	**REASONABLE COST**

hundred years, and is still made today. Its properties, structure, performance and design need to be seen as interrelated.

On a grand scale the purpose of these designs is to enhance the quality of life by incorporating culturally and socially important pictorial identifiers in luxury ceramics. Performance characteristics that have to be considered in creating the formal design and internal structures include (Table 1) permanence, aesthetics, functional characteristics, social and cultural identifiers and - always important - ease of manufacture and moderate costs. These characteristics include a large number of properties, each of which should be optimized for the most effective overall performance (Table 2).

The genius of the Italian Renaissance potter and artist as ceramic designers is that every one of these two-dozen performance characteristics is excellent with the exceptions of impact and thermal shock resistance that are merely satisfactory.

Control of visual effects is even more important in monochrome ceramics such as the Song Dynasty celadon jar illustrated in Fig. 13, a class of wares long admired by connoisseurs. This wheel-thrown blue green vessel has a molded dragon encircling the neck and lotus petals carved and incised over the horizontal throwing rings of the body.

The visually exciting translucent jade-like depth of the glaze arises in

FIGURE 13 - Song Dynasty celadon jar on display at the Boston Museum of Fine Arts (No. 35-734, courtesy of the Boston Museum of Fine Arts).

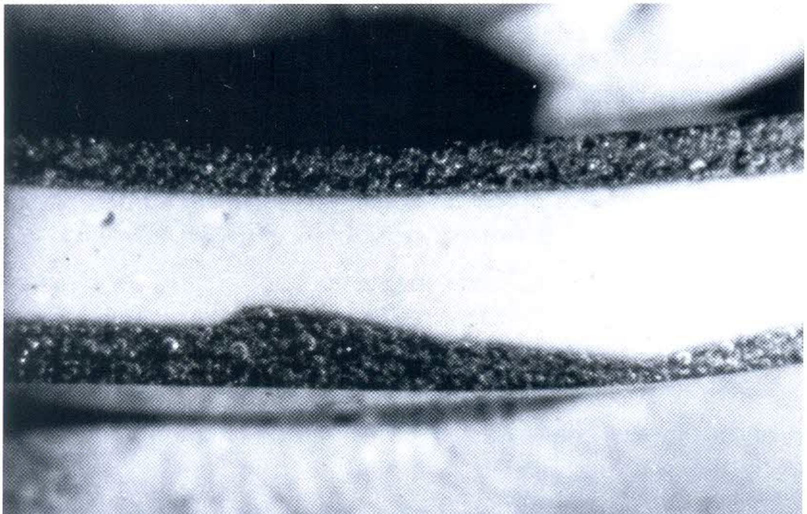

FIGURE 14 - A cross section of a celadon glaze illustrates the bubble structure and also shows how thickness variations over an incised pattern and give rise to subtle variations in the depth and color.

part from a combination of a dense concentration of bubbles about a tenth of a millimeter in diameter and undissolved quartz grains about the same size (Fig. 14). These features exist in concert with fine crystals of anorthite and wollastonite, which give the glaze the soft silky luster and translucent depth which connoisseurs find so attractive. Anorthite (refractive index n=1.58) and wollastonite (n=1.61) in an alkaline glaze (n=1.5) are not strong scattering particles so they create a pleasing translucent depth rather than opacity. There is another important factor; compositional variations such as illustrated in Fig. 15 result from the layered application of the glaze. The variations on a tenth of a millimeter scale, a similar size scale as the bubble structures and undissolved quartz crystals are just at the limit of resolution of the human eye (which is about 0.07 mm at a viewing distance of 20 centimeters) creating a level of uncertainty in the visual image, which seems to be a key factor in elevating these ceramics to a status above less interesting compositions.

These same features are seen in another group of glazes, Jun ware made in a wide region of northern China beginning in the northern Song Dynasty (960-1127 A.D.), (Fig. 16). Jun ware was made with a long firing time and

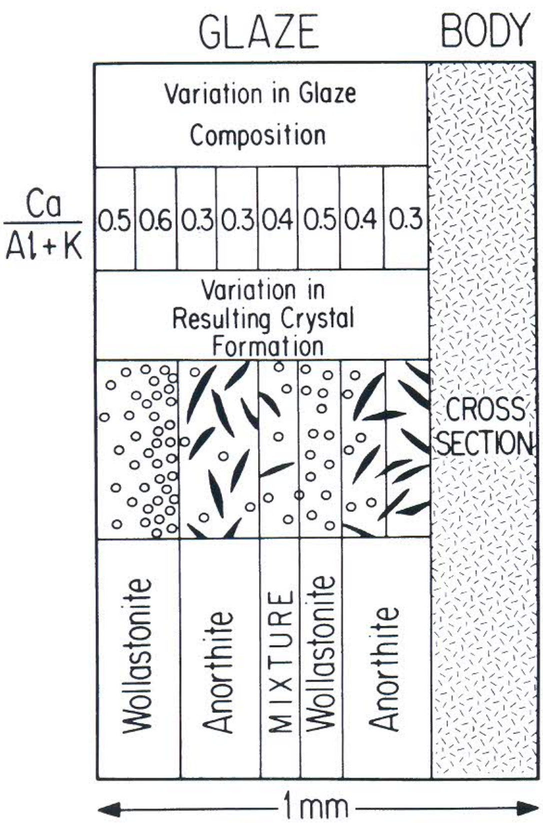

FIGURE 15 - Compositional variations in the glaze give rise to areas with higher and lower concentrations of wollastonite and anorthite to produce a jade-like texture.

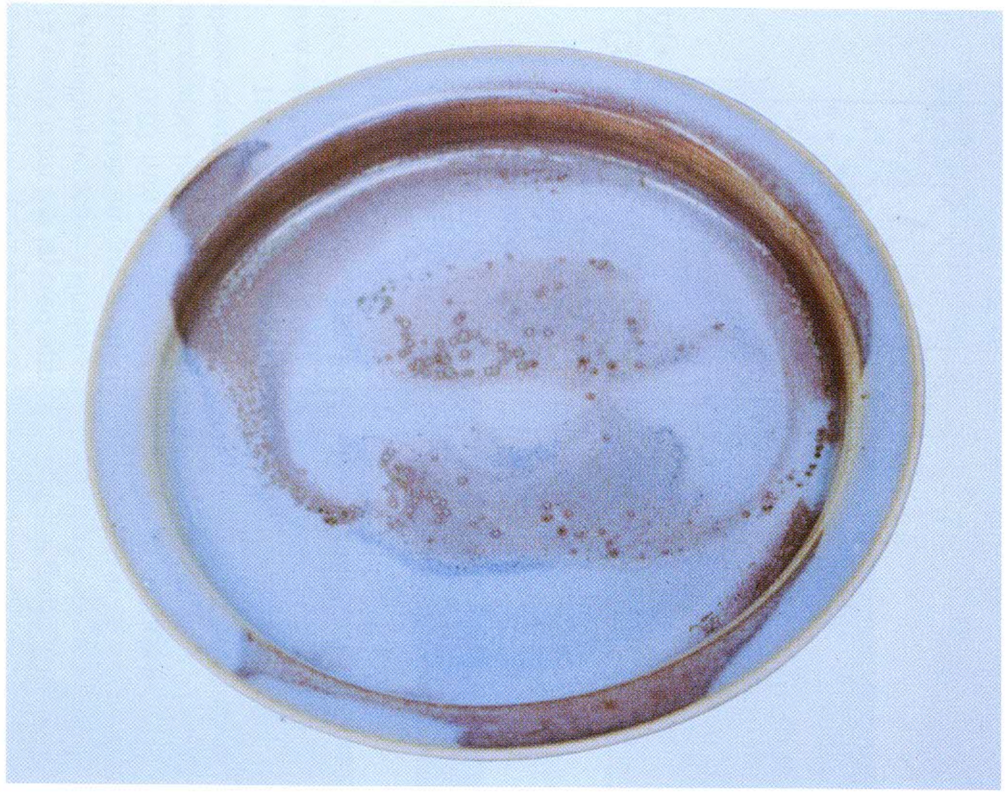

FIGURE 16 - The best jun ware has a glaze which is blue or lavender with an opalescent lustrous cloudy appearance. The brushed decoration contains copper as a colorant. (Victoria and Albert Museum, Eumoro Jopoulos Collection, C.845-1936. Courtesy of the Board of Trustees of the Victoria and Albert Museum).

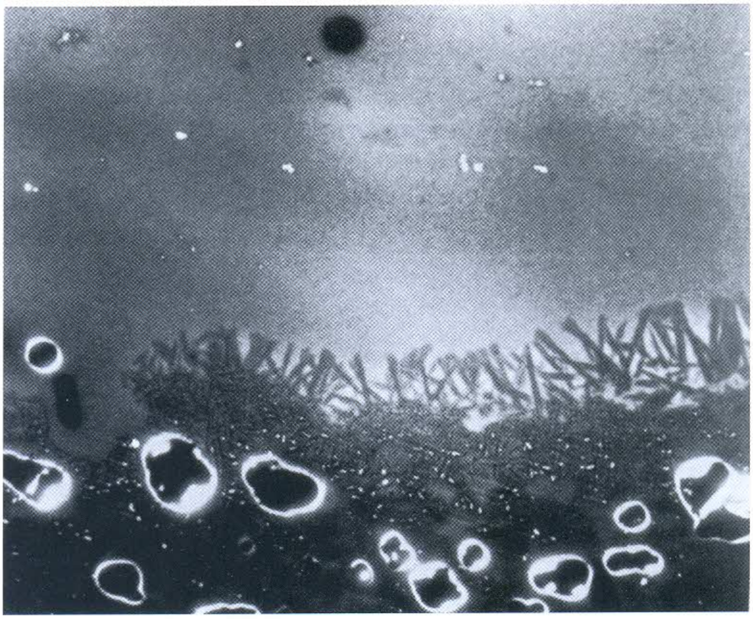

FIGURE 17 - A cross section of the jun glaze shows the growth of anorthite crystals from the body which gives rise to a reflective white ground for the glaze (800X).

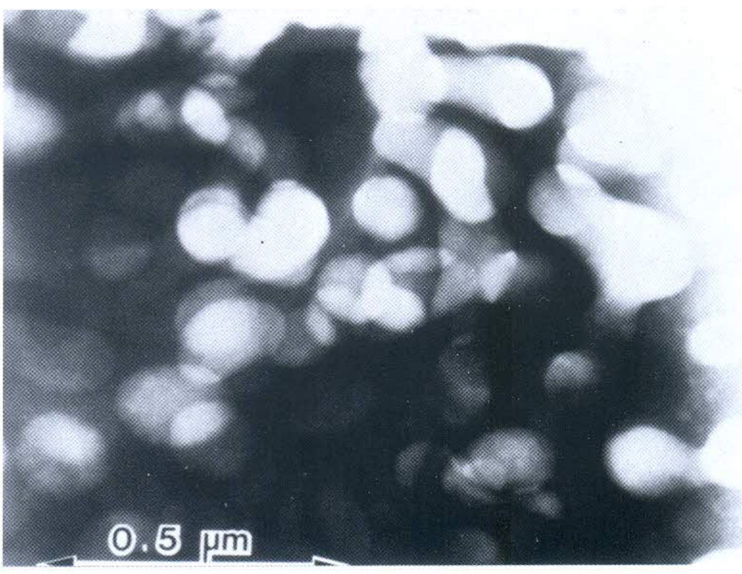

FIGURE 18 - The blue opalescence in jun glazes is caused by an emulsion that forms on a very fine scale as shown at 80,000X with transmission electron microscope.

slow cooling, evidenced by transformation of quartz particles to form cristobalite. While the body is a straw color, reaction at the glaze body interface occurs to form a layer of anorthite crystals within which iron containing particles go into solution. This provides a white ground for the glaze (Fig. 17). In these glazes a blue iridescence results from a liquid-liquid phase separation much like an oil-vinegar emulsion but on a very fine scale (Fig. 18). The spinodal phase separation is accompanied by areas of fine white wollastonite precipitation (Fig. 19), which give what Chinese connoisseurs have described as a "white clouds in a blue sky" appearance. The bubble structure and the white clouds occur on a submillimeter scale (Fig. 20) just as the limit of resolution of the human eye, creating an interest and vitality going far beyond that of a purely monochrome glaze. In the bowl illustrated, the brushed design is done with copper that appears purple when combined with the iridescent blue. In a constitution diagram the phase field of emulsion formation and spinodal decomposition for these glaze compositions is illustrated in Fig. 21. Jun glaze compositions lie just along the boundary of emulsion formation at 1200 °C; celadon glaze compositions have a higher alurnina content. We have to be impressed at the way Chinese potters were able to control compositions and

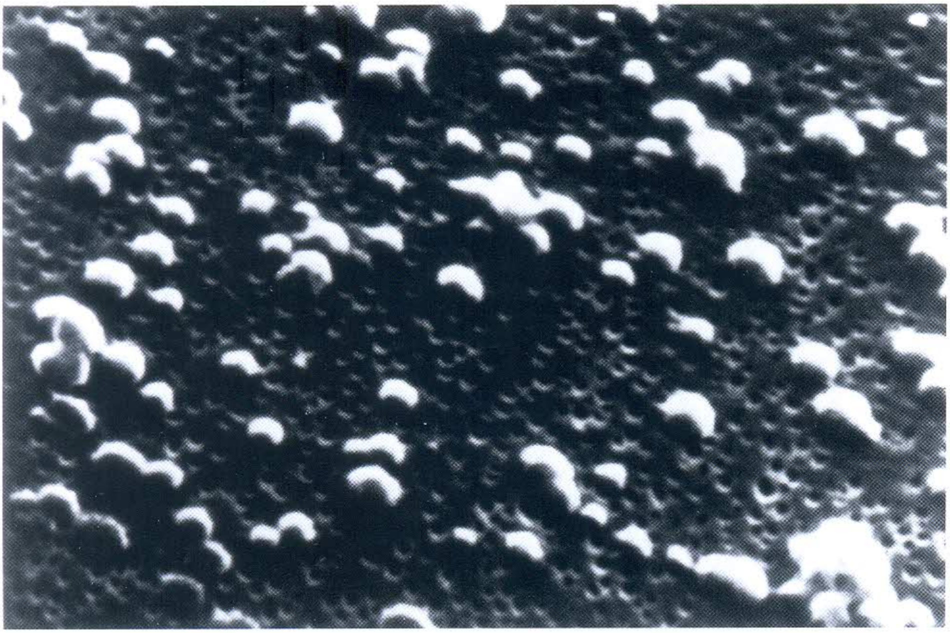

FIGURE 19 - The white cloud effects in jun ware glazes are caused by regions of white particles of wollastonite. The emulsion shown in the previous figure appears as etch pits interspersed between the crystalline precipitates.

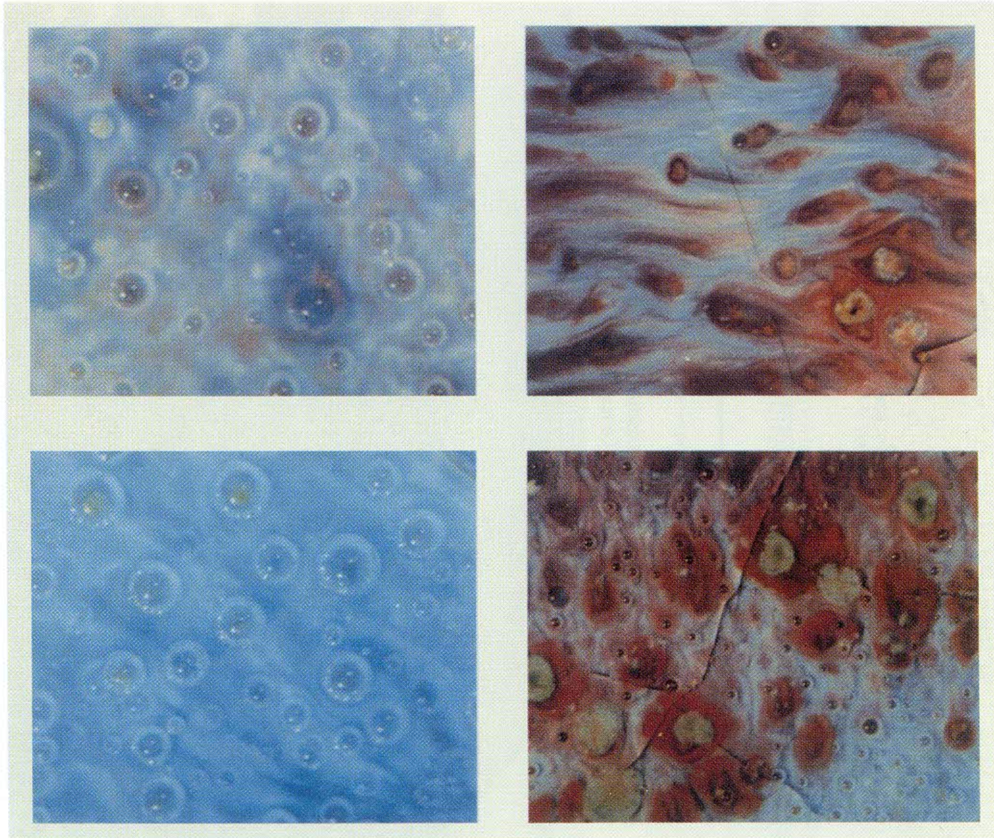

FIGURE 20 - Viewed at 10X magnification a variety of textures are seen in a jun ware glaze just as the limit of resolution of the human eye.

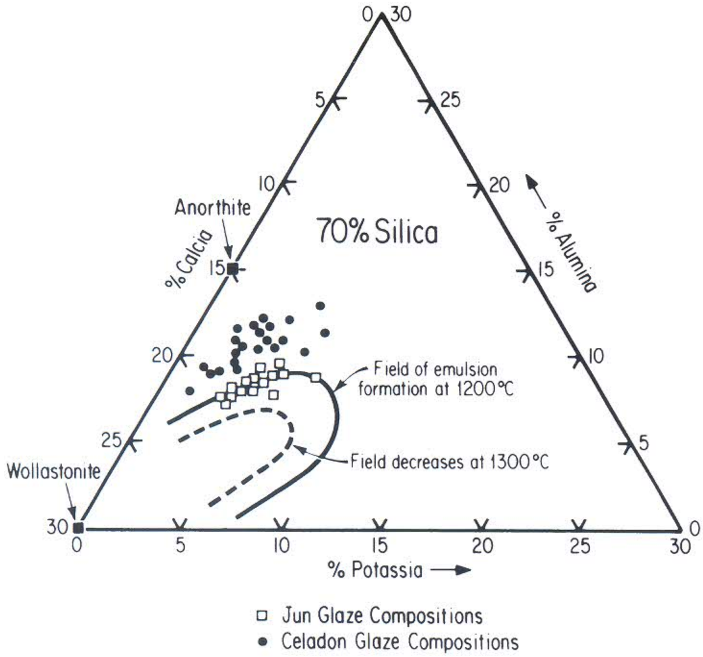

FIGURE 21 - Jun and celadon glaze compositions occur in the calcia-rich corner of the $CaO{\cdot}K_2O{\cdot}Al_2O_3{\cdot}SiO_2$ phase equilibrium diagram.

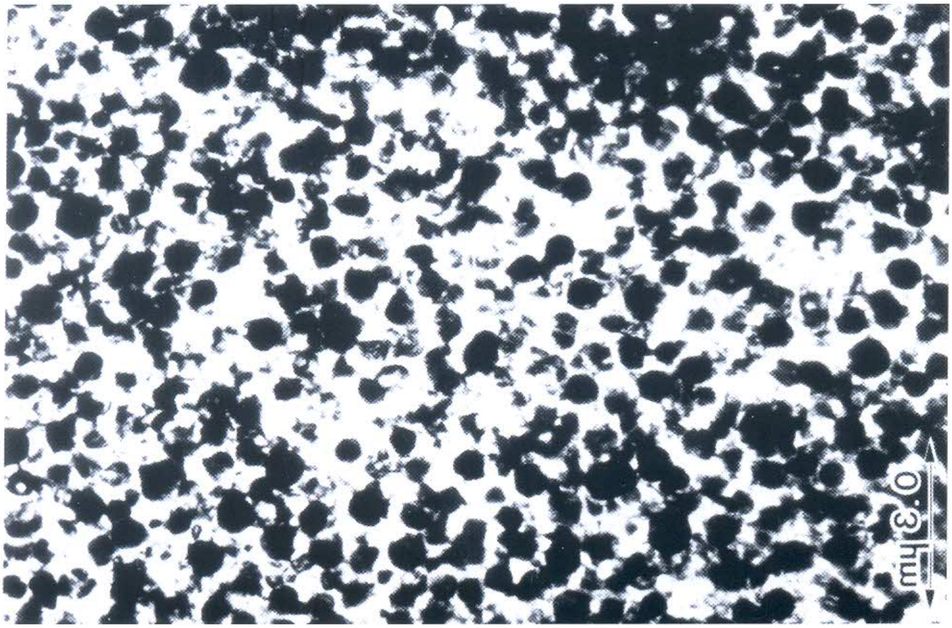

FIGURE 22 - Precipitated silver particles appear silver metallic in reflection but give a yellow scattering of transmitted light (80,000X).

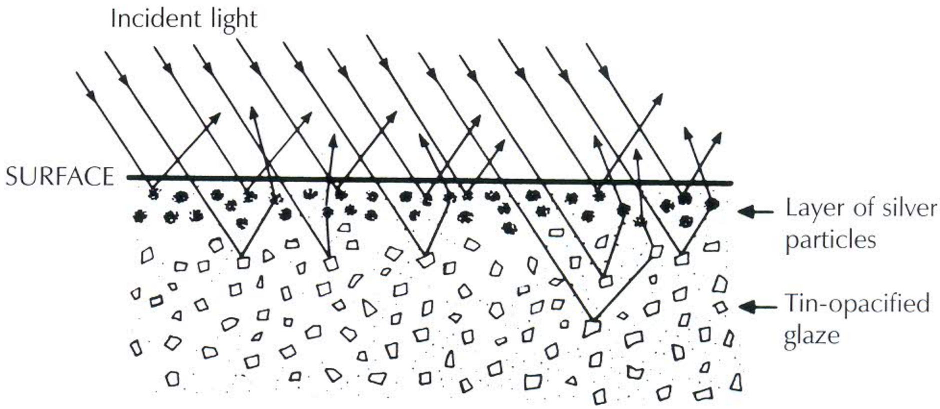

FIGURE 23 - When reflection and transmission are combined in a lustered tin glaze sample, the yellow color of transmitted light and the silver reflectance give rise to golden luster.

FIGURE 24 - The Islamic World provided many inspirations in ceramics. This lustered plate was made in Kashan and is dated 1208 A.D. by which time methods of fabricating quartz-based bodies with tin-opacified glaze and luster painting had been perfected (Victoria and Albert Museum, C5.1.1952, Kelekinn Collection, No.136. Courtesy of the Board of Trustees of the Victoria and Albert Museum).

firing behavior without the availability of an analytical laboratory or high temperature thermocouples.

In the small Tiffany vase, shown in Fig. 6, there are heart shaped reflective designs resulting from silver particles in the glass (Fig. 22). These create added visual interest because with transmitted light there is a change from metallic silver to a golden color resulting from the scattering of transmitted light by the tiny particles. This same deposition of silver particles near the surface of a tin-opacified glaze combines reflection and transmission as shown in Fig. 23 to give golden metallic luster' s such as are shown with the wonderful 13th century plate in the collection of the Victoria and Albert Museum (Fig. 24). This ceramic brings together a combination of form, formal design and exciting visual effects made possible by controlling the internal structure. The result must have also helped convince alchemists of the time that there was a real possibility of transmutation.

In all art, form and formal design play a primary role. The science-art nexus in ceramics lies in the availability of unique visual effects resulting from structure at the submicron level where the interactions of light and matter are most intense and also from structure at the submillimeter level where visual effects just at the limit of resolution of the human eye have a special importance in creating interest and wonder.