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Sang De Boeuf Glaze: Its Chinese Historical References And Local Reduction Experiments in Electric Firing Kilns

By John M. Matthews*

The *sang de boeuf* glaze is a copper-red glaze that is fired in a reduced atmosphere. This glaze, or a similar produce, is the object of an intensive research by numerous present-day potters. This current study is concerned with the Chinese historical references to this glaze, with the main direction of the monograph being taken toward the establishing and recording of experimentation relative to this particular glaze. Although, upon several occasions, the author has approached a solution, he has never actually realized it. Nevertheless, it is hoped that this record may prove to be beneficial to others seriously interested in finding a solution to this ancient ceramic mystery.—J.M.M.

I

Many of today's outstanding potters have long been seeking a glaze which will approach, if not rival, the *sang de boeuf* glaze which Chinese potters of the Ming Dynasty exemplified so well. As yet, there has been little success derived from the unlimited trials of these modern potters, and the subject itself knows no national boundaries. Widely varied approaches have been taken, and these methods have differed so greatly as to prevent the casual observer from detecting similarities in these experiments. Indeed, for this reason, the ambiguity of the title itself, *sang de boeuf*—a French phrase describing a Chinese developed product—seems most adequately to fit the development of this specific glaze. In lieu of such vast experimenting upon this glaze, one is amazed to discover that Chinese ceramists who initiated it enjoyed a simplicity and paucity of materials which, when employed with empirical methods, developed the famed *sang de boeuf*. Its permanent characteristics—this of the K'ang Hsi *sang de boeuf* glaze[1]— are (a) a brilliant red, varying in depth and sometimes entirely lost in places, but always red and without any of the grey or grey-blue streaks which emerge on the *flambé* and modern imitations; (b) the faint crackle of the glaze; (c) the stopping of the glaze at the foot rim.[2] Père d'Entrecolles, a Jesuit missionary to China, wrote two letters containing information about Chinese glazes, the first in 1712 and the

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1. Edward Dillon, *Porcelain*, p. 103.
2. W. G. Gulland, *Chinese Porcelain;* cf. notes from R. L. Hobson, p. 142ff.

second in 1722. In his first, he refers to the red that is made from copperas (crystals of sulphate of iron[3]); however, in his second, he corrects himself as having reported his data somewhat inaccurately, if not wholly incorrectly, about the red glaze produced at Ching-tê-chên:[4]

> I was mistaken when I said in my previous letter that the red glaze called Yu-li-hung was made with the red color from copperas, such as is used for painting red colour on the fired white glaze. This red glaze is made from granulated red copper, and the powder of a certain stone or flint that is a little reddish in colour, pounded together in a mortar, and mixed with a boy's urine and with the ordinary white glaze. I have not been able to learn the preparation of these ingredients, and those who know this secret are very careful not to divulge it. The mixture is applied to porcelain that has not been fired, and no other glaze is necessary, but they have to be careful during the firing that the red colour does not run to the bottom of the vase. I am assured that for this red glaze they use no Pe-tun-tse in the porcelain paste, but they employ with the Kaolin a yellow clay prepared in the same manner as Pe-tun-tse. It is likely that such a clay is more suitable for developing this particular colour.[5]

"So bright as to dazzle the eyes . . . the clear red of the sky after rain . . . the color of the blood of an ox, or simply ox-blood"—these and other phrases have but slightly indicated the awesome hue, endowed with such magical charm as to have enticed poets and authors to translate the beauty of *sang de beouf* into an abstract literary phraseology. But neither the Eastern nor Western writer has ever been successful in capturing the intense thrill that excites the casual or the initiated observer who gazes upon an article so glazed, for the term denotes a beautiful shade of ruby red which, instead of being clotted, is perfectly clear and more like wine than like blood. The *Lang-yao*[6] of the K'ang-hsi Dynasty, which is considered to be the *sang de boeuf* proper, exemplifies a brilliant red of crimson tone, permeating a vitreous enamel that is crackled throughout and strewn under the surface with innumerable little points. The red is rarely uniform,[7] so that when looking for identifiable characteristics of *sang de boeuf*, the Chinese connoisseur examines the foot of the glazed vessel, which to him indicates the different periods of manufacture: *i.e., ping-kuo-ti,* "bases of apple-green (crackle)"; *mi-sê ti,* "bases of rice colored (crackle)"; or *pai-tz'ŭ-ti,* "bases of plain white porcelain."[8]

By no means was the *sang de boeuf* the only monochrome glaze perfected in China. Single color wares existed in an almost unlimited variety, some of the best known types being the *clair de lune*, turquoise blue, apple green, celadon, mirror black, powder blue, tea dust, and coral red

3. W. Burton, *Porcelain, A Sketch of Its Nature, Art and Manufacture*, p. 94.
4. This spelling, a name of a town located in the Kiangsi province, varies from time to time. Since its establishment in the Sung Dynasty, it has been the focal point of Chinese ceramics. *Ching-te-chen* is the spelling most commonly used afer 1920.
5. Burton, *op. cit.*, p. 94.
6. Gulland, *op. cit.*, p. 140; cf., E. S. Duncan, *The Collector's First Handbook on Antique Chinese Ceramics*, p. 39.
7. S. W. Bushell, *Oriental Ceramic Art*, p. 537.
8. *Ibid.*, p. 303.

made with iron. Within these monochromes were other varieties, the aesthetically pleasing products of mis-fired kilns. In general during the K'ang-hsi era, the term *Chi-hung*[9] came to be applied to reds, exclusive of the separate varieties, having such special names as *Chiang-tou-hung, Pao-shih-hung, Hung-mien,*[10] mule's liver, horse's lung,[11] pigeon's blood, liver color, peach bloom, and *sang de poulet,*[12]—a few indications of the almost limitless variety achieved. There are three distinct kinds of *Chi* reds, however, known as *hsien-hung* (blood red), *chu-sha-hung* (cinnabar red), and *pao-shih-hung* (ruby red.[13]) All of these were achieved through the use either of gold, iron, or copper, with copper being the most common ingredient and also the one in which current potters are most interested. To be sure, the confusion of these many terms is simple; and the understanding of them, nearly incomprehensible even to the Chinese themselves.

To trace the development of the history of the red glaze which led to the *sang de boeuf* necessitates a beginning in the Sung and Yuan Dynasties. Underglaze red had reached a high point of its development before, or at least as early as, the Sung Dynasty (A.D. 960-1279), but at this time, its use was limited to decorative areas, rather than to a monochrome glaze. Correctly, the red of this period was a transmutation ware named *Chün yao,*[14] not the *sang de boeuf* proper. Two events important to the ceramic industry of China occurred within these Dynasties, one being the invention of porcelain; the other, the establishment by imperial decree of a manufactory at Chang-nan-chên, afterwards called Ching-tê-chên, after the Emperor King-tê (1004-1007 A.D.), who was responsible for the manufactory and for the making and dating of pieces produced there for the palace.[15] Previously, during the T'ang Dynasty (A.D. 618-906), the only monochromes in use were blue, black, white, and brown, and before the T'ang, the only colored glazes found were celadons and pale sea-green colors.[16] In the Yuan Dynasty, porcelain with the underglaze red continued to be produced, but not of a quality to attract connoisseurs, particularly those connoisseurs of the Ming Dynasty,[17] for it is in the Ming Dynasty (A.D. 1368-1643) that one first encounters the monochrome red glaze. The reign of Hsuan Tê marks the first era of its perfection.[18] John A. Pope, noted authority on the Ming Dynasty ceramic wares, substantiates this conclusion:

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9. S. W. Bushell, *Description of Chinese Pottery and Porcelain (Being a Translation of the T'ao Shuo)*, fn. 2, p. 5.
10. Gulland, *op. cit.*, p. 140.
11. Burton, *op. cit.*, p. 135.
12. Gulland, *op. cit.*, p. 139; 361.
13. Wu Lai-hsi, "Underglaze Red Porcelain," *T'ien Hsia Monthly* (March, 1936), p. 248.
14. Dillon, *op. cit.*, p. 71.
15. C. Monkhouse, *Chinese Porcelain*, p. 17.
16. Li Ch'iao-p'ing, *The Chemical Arts of Old China*, p. 71.
17. Wu Lai-hsi, *op. cit.*, p. 246.
18. E. L. Hobson, *The Wares of the Ming Dynasty*, p. 62.

I know a number of pieces decorated with red designs on the white porcelain which may well date before 1400, but at the moment I can't think of a single solid red piece or a fragment of one that could reasonably be given such an early date.[19]

A pair of bowls in the Franks collection, bearing the Yung-lo mark (A.D. 1403-1424), affords one a sound basis from which to determine the beginning of a true reduction-red glaze.[20] In addition, the reign of Hsuan Tê (A.D. 1426-1435) was noted for its underglaze copper-red, of which, however, no specimens are now extant. They are only known to connoisseurs of the present day by means of descriptions and by twelve pictures in the famous album of Hsian Yuan-p'ien.[21] It was these wares which were so well recognized in the second half of the Ming Dynasty. It is true that the Hsuan Tê Dynasty wares are somewhat easy to identify, for after the time of Yung-lo, it became mandatory for Imperial wares to bear the name of the reign on each piece. In spite of this convenience, however, dating and naming of particular pieces has become difficult, because of many excellent forgeries which bear falsified dates on the bottoms of the pieces. Lesser wares, those articles made for use other than in the palace, were signed not only with the name of the reign but also with the makers' marks and other marks of commendation. The blue and white ware of the Hsuan Tê was very much valued, but not nearly as highly prized as the red ware perfected in this reign. Most of the pieces making use of red show it confined to smaller areas of decoration, such as to fish, peaches, or dragons, rather than in the monochroming itself. Other articles which made use of the cinnabar red (*Chu sha hung*) *en toto* were mostly small objects used on the Altar of the Temple of the Sun, red being the symbolic color of the Sun. It was also in this reign that the style or form of decoration changed from the architectural treatment to the decorative; hence, the fish, peaches, and dragons—although there was an extensive concentration on form and glaze carried along from the previous reigns as well as from those of antiquity.[22] It is possible, too, that the development of a red glaze during this reign might correctly be related to the appointment of a director whose title was *Ying-tsao-so Ch'ang*,[23] who may have enjoyed the opportunity of controlling the reasearch and development of the potteries, since prior to this period, each pottery had been independent. It follows, then, that the red glaze was lost, probably because in the first year of the reign of the successor to Hsuan Tê (A.D. 1436), the office of the director of the Imperial manufactory was abolished. Official records for this period indicate that it was necessary to levy soldiers, so that the manufacture of porcelain consequently was

19. J. A. Pope, personal letter, dated May 6, 1955.
20. Monkhouse, *op. cit.*, p. 25.
21. Duncan, *op, cit.*, p. 35.
22. L Ashton and B. Gray, *Chinese Art*, p. 273.
23. S. W. Bushell, *T'ao Shuo*, p. 57.

stopped in order to release people for civil duties. Therefore, it is possible to observe that the best known pieces of ceramic ware of the Dynasty—those bearing the use of the red glaze in decoration—are the fish stemcups alluded to by Carter[24] and Bushell,[25] and other sources. This red is thought to have been produced by the mixing of precious stones from the West, reduced to powder, into the clear glaze. The red, thus produced, rose in relief, because the glaze was as transparent and as thick as lard, causing its surface to become marked like the skin of a chicken or the peel of an orange.[26]

After the Hsuan Tê reign, the secret of the production of the glaze was lost. At any rate, there is no record of the use or the re-use of the color in the following period. Hsuan T'sung, the successor to Hsuan Tê, evidently encouraged no advancement in the technology of the glaze or of ceramics in general, and it was during his rather degenerate rule that the production of ceramics declined through mass production methods. Upon his death in 1465 A.D., a great emperor came to power and, in spite of the mass production techniques which were still in use, succeeded in elevating the final product to a position of distinction. This emperor was Ch'eng-hua (A.D. 1486), who goverened the quality of the work to the extent that at least the products were still thin and translucent, yet the art of his decorators declined alarmingly. Nevertheless, Ch'eng-hua is ranked alongside the Hsuan Tê Dynasty with respect to ceramic production in underglaze reds.

Cheng Yao was the ware produced in the imperial factories of Chente (A.D. 1506-1521). The paste in these products was fine, the body varying in thickness. The color was blue or polychromatic, *Chi-hung* (deep red) being used for the best color.[27] Bushell notes that in the reign of Cheng-te, blue and red underglazes were combined with over-glaze decoration, although not with much skill or success until the time of Wan-li (A.D. 1573-1619).

During the next two periods of rule—Chia-ch'ing (A.D. 1522-1566) and Lung-ch'ing (A.D. 1567-1572)—there lived a man who, almost without exception, is referred to as Mr. Ts'ui. He was probably one of history's most successful imitators in his art, and his work often passed for original Hsuan Tê, duplicating with extreme dexterity the color, style, and form of his model. Also, at the time of the Mongol occupation in the Chia-ch'ing reign, pottery making had nearly come to a standstill, but with the re-establishment of the Ming Dynasty, the old kilns at Ching-tê-chên were renewed. However, the subsequent re-development of the red glaze baffled the potters, following the Hsuan Tê and Ch'eng Hua periods, and

24. D. Carter, *Four Thousand Years of China's Art*, p. 283.
25. S. W. Bushell, *T'ao Shuo*, p. 58.
26. *Loc. cit.*
27. Li Ch'iao-p'ing, *op. cit.*, p. 85.

in the sixteenth century, underglaze experiments were virtually abandoned in favor of overglaze red enamel with a red color, derived from iron crystals, being the only red that was successfully fired.

After the early seventeenth century, during the reign of Wan-Li (A.D. 1573-1619), there began to appear new glazes and new ideas in ceramic ware, but, for the most part, the bulk of the work of this period was confined to reproductions of ancient shapes and colors. Wan-Li wares today are numerous; however, they display less refinement in material as well as in manufacture than do previous wares, which observation may be explained partially by the fact that the mines which supplied porcelain to Ching-tê-chên were worked out by this time. After Wan-Li's death in 1619, a period of approximately twenty years ensued before much again was recorded about porcelain. The Ming Dynasty ended with the expulsion of the emperor by the Manchu Tartars in 1644, and the last imperial dynasty of China, the Ching (A.D. 1644-1911), had its inception.

In the history of ceramic art, the K'ang Hsi period (A.D. 1662-1722) is of outstanding importance. No other emperor, before or since, has been known to have shown as keen a personal interest in the production of new varieties of fine porcelains as did K'ang Hsi. His attempts at furthering this industry included his trying to transplant the manufacturing from Ching-tê-chên to Peking, but obstacles of practical natures soon forced him to abandon his project. Yet, his interest in the art never flagged, and, as a consequence, to his period belong some of the finest and costliest varieties of all time. It is interesting, indeed, that K'ang Hsi porcelains are also much rarer today than ceramics of the T'ang and Sung Dynasties, insomuch as those that have survived have had to do so above ground, and not, as was the custom in earlier days, underground, buried with the dead. Furthermore, in this period the use of copper sub-oxide to obtain a red *sous couverte* (underglaze) was also revived. In combination with this reduction fire-glaze, the oxidation fire-glaze was obviously nearly as successful in beauty as its counterpart. This is the glaze that was known as the apple-green ware, the oxide of copper having not been reduced to the basic metal, copper. Some of the most famous of the K'ang Hsi porcelains, in addition to the *sang de boeuf* and apple-green, are *famille verte, famille noire,* peach bloom, powder blue, turquoise blue, peacock green, celadon, mirror black, dead-leaf brown, Nanking yellow, millet yellow, *flambé, imari,*[28] and the other best known porcelain, the blue and white, which in this period reached a degree of perfection to make it famous throughout the world, but which, like celadon, was no new invention of the era, nor even a rediscovery or redevelopment like the *sang de boeuf.*

28. Duncan, *op. cit.,* p. 38.

II

The ill-defined boundaries of the legacies of the Ming potters are somewhat exasperating; it is consequently quite difficult in a study of specific Chinese porcelain pieces to date ceramic wares, particularly single-color wares. To date the year exactly from which the *sang de boeuf* originated would be probably impossible, but by the strictest type of examination and reliance upon the research of the most recognized authorities, one derives the name from Lang Ting-tso, the famed viceroy of the Two Kiangs—provinces of Kiangsi and Kiangnan—around the time of the accession of K'ang Hsi. The earliest form of this *Lang-yao* must be associated with a period (c. A.D. 1654-1668) that otherwise is known to have been quite sterile in the annals of Chinese porcelain, immediately suggestive of doubt as to the authenticity of these dates. The *sang de boeuf* glaze, which is only properly identified with the K'ang Hsi period, was an imitation of the Hsuan Tê sacrificial red, and it is to Lang-ting-so, viceroy of Kiang-si, who derived this red from copper compound, that the ceramic world is greatly indebted. The K'ang Hsi reign, as well as the Yung Cheng reign (A.D. 1723-1736) under the supervision of Tsang Ying-hsuan (superintendent of the Porcelain Factories in 1681)[29] made extensive use of the *sang de boeuf* glaze in addition to other reds of this period. Cinnabar red, for example, was still being produced in the Ch'ing Dynasty.[30] Still, another theory holds that Tsang Ying-hsuan assumed office in 1683, and that after an interval of sixty years, a renaissance set in, so that it is from this date that one may ascertain the last great stage of development in Chinese porcelain.[31] Despite such confusion on this particular subject, it remains that at the close of the K'ang Hsi period, the porcelain industry in China had developed to such an extent that Ching-tê-chên had grown into a city of over one million inhabitants, almost all of whom were employed in the three thousand porcelain factories.[32]

The secret of the *sang de boeuf* glaze was a carefully guarded one, and it would seem to have been lost altogether to the world toward the end of the K'ang Hsi period. Later efforts to obtain the same glaze effects, though often successful in producing large areas of brilliant red, have usually been streaked with alien tints, such as grey or bluish grey, and have invariably been marred by the inability of potters to control the flow of the glaze which overruns the foot rim and, consequently, has to be removed by grinding methods. Certainly these factors were closely controlled in the time of K'ang Hsi, and it appears with a further great deal of certainty that no one since, with the exception of the potters of the

29. Wu Lai-hsi, *op. cit.*, p. 259.
30. Monkhouse, *op. cit.*, p. 39.
31. Wu Lai-hsi, *op. cit.*, p. 251.
32. Dillon, *op. cit.*, p. 96.

Yung Cheng period (A.D. 1723-1795), has ever been able to control all of these various elements successfully. It has, of course, been suggested by Gulland that ". . . the brush and the fire seem to have worked together to bring about the desired effect, the colouring is far too evenly placed to be due to chance transmutation in the furnace . . . ."[33] So it remains that the K'ang Hsi, Yung-cheng, and Ch'ien-lung reigns all excelled in the manufacture of porcelain wares, and even after 1796, all types of wares continued to be made; but, while some were of fine quality, there was a general decline of technical excellence and a noted lack of inspiration necessary to the production of a great work. Yung-Cheng ruled from 1723-1735, after his father's death in 1722. The finest colors of the previous reign, such as the powder-blue, coral-red, and soufflé red (a red coloring blown on the ware through a fine gauze), were continued and improved, and it is of the utmost interest to discover the ancient underglaze red once more making its appearance. It was also at this time that Jesuit missionaries were expelled from China by Imperial edict for befriending the brother of the emperor who was the rightful heir to the reign. It was for this reason that Père d'Entrecolles was unable to procure additional information about the secrets of the *sang de boeuf* and other glazes. Nevertheless, the secrets of this glaze return to obscurity during this period, and in their place was brought to perfection the *Chi-hung*, or sacrificial red. By the time of the succeeding reign, even this single color is known to have lost something of its purity and transparency, however. Nevertheless, Burton places some of the finest *sang de boeuf* and *flambé* glazed pieces, extant in European collections, within this period.[34] The validity of this *sang de foeuf*, however, is highly questionable, for by this time most technical information was, in all likelihood, too obscure for the production of a real *sang de boeuf*. Hobson says:

> There are, however, specimens of a more or less anaemic underglaze red which point to its survival through the first half of the sixteenth century; and we have reason to believe that the underglaze red was revived with some success in the Wan Li period.[35]

Even so, these results were not comparable to the fine underglaze reds of the fifteenth century.

Copper red was the subject of much enthusiastic experimentation, and the finest work of *Lang Yao* (*sang de boeuf*) and of peach bloom exhibit a rare degree of perfection. For the most part, these pieces are rare indeed, for the copper red was found to be too difficult, and iron red took over in the Ch'ing Dynasty.[36] However, Ashton and Gray refer to a glaze which is quite possibly that of the *sang de boeuf*, for it possesses many of the characteristics essential to the authentic *sang de boeuf*:

33. Gulland, *op. cit.*, p. 361.
34. Burton, *op. cit.*, p. 128.
35. Hobson, *op. cit.*, p. 29.
36. S. W. Bushell, *Oriental Ceramic Art*, pp. 536-37.

> The single-colour glazes (of the Ch'ing dynasty A.D. 1644-1911) include the well-known *Lang Yao*, *sang de boeuf*, a brilliant crackled blood-red, the glaze under the base a translucent crystalline green . . .[37]

The one characteristic listed above which might eliminate this particular glaze from the distinctive and exclusive *sang de boeuf* category, however, is that concerning the crackled blood-red appearance, generally conceded not to be a *sang de boeuf* element; however, some K'ang Hsi pieces were also known to have been crackled, and for this reason, it is impossible to conclude that the glaze referred to by Ashton and Gray was not a true *sang de boeuf*.

During the Chia-ch'ing reign (A.D. 1796-1820) and the Tao-kuang (A.D. 1821-1850), the porcelain industry developed very slightly,[38] although there was a greater perfection of technical beauty during the latter of these two periods.[39] One family still held the secret of the old glazes when M. Scherzer visited Ching-tê-chên in 1883, but even though their pieces simulated the appearance of the older products of this glaze, their work lacked the finish or refinement of the old wares. Burton admonishes that ". . . sometimes, however, they are sold as the original older pieces they are made to resemble."[40] For this reason, he seriously cautions the modern collector about the possibilities of the imitation of these older wares. Because of civil war and foreign aggression during the last Ch'ing Dynasty reign, all Chinese industry tended to decline, and that of the porcelain industry is not to be excepted.[41]

The possibilities of obtaining a contemporary duplicate or revival of the *sang de boeuf* glaze have unfortunately divorced themselves from any contact between the East and the West. Nicholas clearly explains this problem:

> . . . Strange as it may appear, although the commercial intercourse between China and the western nations since those dates 1712-22 has been continuous and increasing, we today do not know that way the Chinese and Japanese produce many kinds of the porcelain, which may be seen in almost every good ceramic collection. In view of this fact, it has been surprising that some of the great pottery producing nations, like England or France, have not long ago sent out to China and Japan, expert agents to obtain a knowledge of the secrets of the manufacture of the Celestials.[42]

Principally, it is said that all attempts to reproduce this beautiful color in the West have failed, because it is so difficult to seize the *exact moment*—a few seconds, more or less, in the duration of the firing are sufficient to ruin the beauty of the fugitive tint. Nevertheless, this costly porcelain has claimed the earnest attention of the modern potter. The first real success

37. Ashton and Gray, *op. cit.*, p. 328.
38. Li Ch'iao-p'ing, *op. cit.*, p. 88.
39. Monkhouse, *op. cit.*, p. 38.
40. Burton, *op. cit.*, p. 137.
41. Li Ch'iao-p'ing, *op. cit.*, pp. 88-91.
42. G. W. Nichols, *Pottery—How It Is Made, Its Shape and Decoration*, p. 85.

was achieved by a Japanese potter at the end of the last century. He was able to make admirable "copies" of the color, but he failed to reproduce adequately the paste and glaze of the originals.[43] And in China and other countries, many potters are constantly attempting to work with the difficult copper glazes, the *flambé* and the *sang de boeuf*, but, as yet, without successfully rivaling the older and reverent Chinese K'ang Hsi *sang de boeuf*.

III

The processes of developing glazes, for the Chinese, was an empirical matter pertaining to the use, through simple means, of those general materials which were at hand. The *sang de boeuf* was achieved during periods when the "secret" methods were known; however, the formulation of the glaze, as such, was not the only operation necessary for the development of the rich, red color. The placement of the glaze on the piece, the placement of the piece within seggars in the kiln, and the firing and cooling of the kiln itself, all had a function in the production of this glaze. Many formulae from which experimental data can be established are readily available to the research student. Most would seem to be of such exceeding simplicity that, at first, a mistake would appear to be an unwarranted blunder—this, however, is not the case. For example, in the Chi-hung[44], when instructed to make use of pure copper strips, it is assumed that one should secure the copper from the furnaces of the silver manufactory whose copper contained certain impurities, especially silver oxide. Then, again, when one is told to make use of a certain kailin or quartz, there is no indication of the fact that the particular substance to be used was to be found near a mineral spring which could well have contained iron compounds. In an additional case typical of the over-simplified directions given by the Chinese potters, one finds that the glaze on the porcelain stem wine cups decorated with red fish was made by pulverizing the "red precious stones from the West" into a paste (*Hsi hung pao shih*) and by applying this paste in turn to the form. The red thus described as being so bright as to dazzle the eyes was erroneously thought to have been derived from rubies. Mu Lai-hsi, realizing the reverence with which this legend had been accepted by the Chinese, suggested that it, nonetheless, is not factual. At the risk of committing heresy, he suggested the possible use of red garnet or cornellian.[45] With reference to the expected result of the red stones, Mr. Wu explains:

> It is difficult to surmise what the effect aimed at in the introduction of ruby dust in the copper glaze could be, except to retard the changes going on, so that when they are finally terminated when the tempera-

43. A. I. Andrews, *Ceramic Tests and Calculations*, p. 178.
44. G. R. Sayer (translator), *T'ao Lu*, p. 25.
45. Wu Lai-hsi, *op. cit.*, p. 253.

> ture of the porcelain drops below a certain point, these changes would not have passed beyond the stage in which the glaze would still retain the brilliant red colour, with the minute particles of metallic copper standing out in relief on the surface.[46]

A. L. Hetherington, in consultation with Sir Herbert Jackson, remarks:

> The presence of these substances [the alumina and silica which comprise the chief chemical component of the red stones] in excess in a copper glaze will tend to retard or even to prevent the copper coming out, or "striking" as it is technically called. Alumina, therefore, in some excess, and to some extent this is true of silica also, would counteract a super-abundant quantity of copper which otherwise might have produced the undesirable opaque effect. Some such explanation as this is the only one which provides a scientific foundation for this oft-quoted tradition.[47]

In some of the more recent Chinese formulae there is an addition of pegmatite, controlling the crazing or crackling of the glaze on the piece, or, of still more importance, the lack of the glaze razing, since this ingredient affects the different expansion and contraction between the body and the glaze. (According to the amount added, the extent of the cracking can be controlled.) It is through the addition of similar substances that the Hsuan Tê Dynasty glazes produced a direct correlation to the expansion and contraction of the body and the glaze, resulting in the complete fitting of the glaze to the glazed article.

Another "secret" of Chinese ceramic production was the painting of cobalt blue or copper red glazes on the crude paste without absorption of certain elements of the glaze and without the glaze spreading over the paste to cause it, ultimately, to run off the foot of the piece, a phenomenon exceedingly difficult for present day potters to control. *Hua-shi* is another chemical used by the Chinese that is reported to be a medicate used by Chinese doctors. In the 1722 letter of Pére d'Entrecolles, there is the notation of a different substance used in the red glazes–*Hua-shi* (a soapstone or steatite, a silicate of magnesia).[48] Whether or not this was used in the body or in the glaze is another disputed question, although it is generally known today to be used occassionally as a body flux. Many of the Chinese copper-red pieces used light celadons with crackles and high feldspar glazes over the glaze, a vital clue to one who investigates the production of these glazes, for it indicates that the copper-red is an underglaze color that must be protected from the atmosphere of the kiln by another glaze which is unaffected by the same process.

In a description-comparison of the Hsuan Tê red with a Ch'ing copy, one finds that the red of the Hsuan Tê was excellent in the daylight and still brilliant when the light was less direct at dusk, though this may seem to be impossible. The principle underlying this is a simple one. In the

46. *Loc. cit.*
47. Hobson, *op. cit.*, p. 29.
48. Dillon, *op. cit.*, p. 131.

Hsuan Tê red, one finds, according to Wu Lai-hsi, that the raw clay was first glazed with a clear glaze which essentially produced a mirror-like background upon which was placed the red coloring.[49] Then, another clear glaze coating was given to the entire piece, and the article was fired once more, thereby intensifying the light by the fact that it was reflected from the background rather than absorbed by it as in the Ch'ing copies. In the *sang de boeuf* glaze, the responsible element for the red coloring is copper initiated into the glaze by various compounds of the copper family. It is the peculiarity of copper oxide to produce its complement in color (which would be red) when fired in a reducing atmosphere. Littlefield explains:

> If copper-bearing glazes are fired in an atmosphere which is deficient in oxygen, the copper will give some shade of red. We speak of an oxygen-deficient atmosphere as being a reducing atmosphere.[50]

There are, as well, some references made to specific compounds of copper, disregarding other possibilities from similar copper compounds. For example, Dillon refers to the color of the *sang de boeuf* as being given only by the red sub-oxide of copper.[51] On the other hand, one finds many other references to the copper's being received from other sources. However, since a sub-oxide of copper will tend to release the extra atom of oxygen more easily, giving the metallic copper which is necessary to produce the red color, this might be better than other compounds of copper which would have additional oxygen atoms to lose. Because of the necessity of the loss of atoms of oxygen, compounds holding extra oxygen atoms would require additional reducing agents to change the copper to its metallic state, thereby offering substantial validity for the use of the sub-oxide of copper. Many techniques in kiln firing are possible because of the differences of the glaze, the reducing agent, the kiln, the firing time, the firing immediacy, as well as the personal preference of the individual who is doing the firing, regarding the best or most expedient time for reduction.

Traditional methods of producing reds of copper require control and manipulation of the kiln atmosphere, with varying schedules for admitting excesses and deficiencies of oxygen. While atmosphere manipulation is undoubtedly the method *par excellence* for obtaining copper reds, it is possible to accomplish attractive results by adding a reducing agent to the glaze batch. For an electric kiln, Leach suggests obtaining a reducing atmosphere without damage to the electric heating elements by inserting thin pieces of wood into the kiln chamber. There are several reducing agents possible for use in glaze batches; all agents, however, provide the glaze with the needed carbon element which robs the copper compound of its additional oxygen atom, thereby reducing the copper to its metallic

49. Wu Lai-hsi, *op. cit.*, pp. 260-61.
50. E. Littlefield, "Local Reduction Copper Reds," *Ceramics Monthly* (December, 1953), p. 16.
51. Dillon, *op. cit.*, p. 42.

state. Only silicon carbide has been used in the various formulae investigated in this study. Additional agents, the success of which could be determined through experimentation, are metallic aluminum, pure silicon, carbon, pine cones, resin, cedar sticks, and moth balls, the last four being specifically concerned with artificial reduction. If silicon carbide is used, it should be of fine grain size. That designated as FFF and which is sold in hardware stores as an abrasive powder is of sufficient fineness. Silicon carbide of much smaller grain size gives equally satisfactory results, but it is more difficult to obtain and shows no advantages over the easily obtainable FFF grade. The optimum amount of silicon carbide to be used in the glaze batch has been found to be approximately equal to the amount of the copper compound employed, though there are exceptions to this general rule. Larger quantities of silicon carbide will not adversely affect the color, but will greatly increase the amount of gaseous material released and may thus cause excessive bubbling. To prevent the copper from becoming oxydized, one may apply a clear overglaze on top of the glaze holding the copper compound, preventing oxygen from contacting the reduced copper. The formation of the gaseous oxides of carbon is the one drawback to the use of silicon carbide as a reducing agent, however. It is necessary to allow the gases to escape, and this can only be accomplished by providing a glaze of sufficient fluidity to allow ready passage for gas bubbles. A glaze that is too viscous, in the molten state, however, may run off the ceramic piece. Advantages to local reduction with silicon carbide technique are found in the firing of copper red wares in an oxidizing atmosphere, a method which allows copper red and greens or blues to appear on the same piece, thereby making decorative pattern possible.[52] Using yellow ochre with water, a paste that is resistant to oxygen consuming particles may be applied to wares that are to be fired in an atmospheric reduction kiln to achieve the same effect.

In experimenting to produce a local reduction red glaze—that is, a glaze which contains the reducing agent itself—, it is important to investigate reduction possibilities not dependent upon atmospheric manipulation. Such a procedure would mean that, because of the inability to control the atmosphere of an electric kiln without harming the kiln or its heating elements, it would be possible to effect a reduction fire without these harmful conditions having to exist. In discussing local reduction glazes, Littlefield suggests:

> The nature of the glaze in which the above materials, copper, silicon carbide, and tin oxide, are used will naturally have an effect on the kind of red resulting. In general, soda has been found preferable to potash in the choice of alkalies, although this is at variance with the opinions of several researchers . . . . In reds obtained by controlling the kiln atmosphere, ferric oxide (red iron oxide) is sometimes used

52. F. C. Ball, "How to Get a Copper-Red Glaze by the Surface Reduction Method," *Ceramic Industry*, LVIII (June, 1952), p. 117.

> to replace the tin oxide, but in the local reduction procedure iron has proved to have no value. One may spray (or paint in pattern) a solution of copper sulphate or copper nitrate on a piece of bisque or green ware and then apply a glaze containing silicon carbide and tin oxide but no copper. Or, copper oxide may be mixed with a clay slip and applied to the ware after which a glaze containing silicon carbide and tin being carried by the glaze. When either the copper or the silicon carbide is in the slip, it is necessary to use greater percentages than when they are in the glaze; three to five per cent is recommended.[53]

H. Black employs an underglaze red copper pigment. Using twenty per cent of this underglaze pigment added to a white basic slip or Albany slip, he discovered that by changing the glaze over the same slip, one could achieve a different effect in the reduction.[54] In the Western world, a counterpart to the development of the red glaze in China is realized in thirteenth century stained glass windows.[55] In their case, the art was lost, and only in a measure ever developed again. As with the Chinese glaze, the stained glass secret was to seize the *exact moment* in the firing when the copper was first reduced and, in a minute state of division, suspend these particles in the floccular masses in the glass. Once melted, the glaze not only then formed an impervious cover to prevent the smokey flames from discoloring the paste below, but it no longer was sensitive to the action of the gases that surrounded it. Similarly in the local reduction experiments, once the silicon carbide has been melted, it no longer serves a function as the ingredient necessary to the reduction of the copper element; *i.e.*, the carbon is thus spent, and, therefore, no source remains for any further development once the silicon carbide is affected. So, in agreement with an atmospheric reduction firing, it is necessary for carbon to be present at the exact moment the glaze begins to flow. Naturally, the amount of copper used affects the glaze color, there being little difference from the extent of one-half of one per cent to two percent of copper carbonate. With smaller amounts than this, however, 1/16 to 1/8 of one per cent, there is a tendency toward developing a more pink than red cast to the glaze.[56] Also, when these glazes were experimentally fired without reduction, the amount of copper was so slight that there was virtually no green or blue color discernible. This "clear glaze" is usually the one used over a local reduction glaze to keep additional oxygen atoms from contacting the copper atoms, thereby allowing for a perfect fit of the protective glaze to the underglaze which holds the ingredients necessary for the production of the red color.

The experiments in Tables I-IV following are low-fire glaze formulae ranging from cone 03 to cone 06. The "X" series of glazes were developed

53. Littlefield, *op. cit.*, pp. 17-18.
54. H. Black, "Opening the Door to Copper-Red Glazes," *Ceramics Monthly* (January, 1953), p. 10.
55. Dillon, *op. cit.*, p. 43.
56. Ball, *op. cit.*, p. 117.

from the formulae in Table I, being theoretical abstract formulae. In the case of M-14 and M-15, slight variations on basic formulae were developed, using small additions or reductions of zinc oxide, tin oxide, copper carbonate, and silicon carbide, thereby increasing the brightness of the red color and/or diminishing the intensity of the copper blue or green. None of the test tiles fired in the test kiln resulted in a completely red glaze, although some resulted in nearly complete red reduction, *e.g.*, M-2 and M-3. Most of the test tiles were fired on a porcelain body clay at low fire temperatures which matured the glaze but not the clay body. However, like effects could be produced on a low-fire clay body which has been previously fired with a white body slip coating on the tile or ceramic piece. The white backing of slip enables the color to become brighter because of the reflecting characteristic of the white body. In addition, one may presume that a slower firing schedule which could be maintained in the regular kiln firing would enhance the red color effect achieved in the faster firing test kiln because of the additional time during which the glaze would adjust and react to the reducing agent (silicon carbide).[57] Also, the irregularities of the glaze surface would have opportunity to even themselves out, producing a more regular top surface, the roughness of which is due to the gaseous elements of the glaze and clay body inadequately escaping through the glaze itself. During the short period of the time of fire in the test kiln, there is not sufficient time for all these gases to escape before the glaze is colled to a solid, thereby leaving the glaze pitted or bubbly as the case may be.

Three glazes, M-11, M-12, and M-13, listed as copper-red local reduction glazes, involved the use of Ferro frits and O. Hommel alkaline frits, but did not produce as effective a red color as did the other glaze experiments, and, as a consequence, did not warrant further experimental inquiry. The M-14 and M-15 formulae are deviations on the M-2 and M-3 formulae, respectively, with variations concerning only the coloring oxides and the reducing agents which do not effect the base formula in any way. M-14-A and M-15-A were different from their originals only in the case of an addition of 0.5 grams silicon carbide in the M-14-A, and .10 grams silicon carbide in the M-15-A, neither addition making any noticeable improvement on the original formula.

The experimental glaze series, M-X-1, M-X-2, M-X-3, and M-X-4, produced generally good results, but none effected more than a partially reduced product. Detailed information on each of these glaze experiments follows:

M-X-1, cone 06. This is a feldspathic glaze derived from a general abstraction of several of the low fire glazes listed in Table I, which makes use of both lead carbonate and borax as fluxing agents. An additional ele-

57. A. L. Hetherington, *Chinese Ceramic Glazes*, pp. 63-64.

ment, tin oxide, was added to aid the general brightness of the red color. One half of one per cent of copper carbonate and silicon carbide was added to the glaze, supplying the necessary elements for the production of the red color. It was found that a smaller percentage of both of these elements promoted a better red color, while any amount in excess of this, produced a more liverish red—not necessarily undesirable. The base formula: PbO, 0.54; K_2O, 0.16; Na_2O, 0.3; Al_2O_3, 0.1; B_2O_3, 0.6; and SiO_2, 3.1. Batch formula:

Lead Carbonate	46.44
Potash Feldspar	55.60
Borax	114.60
Potassium Carbonate	.83
Silica	150.00
Tin Oxide	3.6
Copper Carbonate	1.8
Silicon Carbide	1.8

It is suggested that the last two ingredients, copper carbonate and silicon carbide, be separated from the main body of the glaze which is ground separately, then divided into two parts, one of which is to be ground with the copper carbonate; and silicon carbide, being an abrasive, is added after the additional grinding, since it would be harmful to the mortar and pestle or the ball mill, whichever is used. In applying these two glazes, the one with the copper and silicon carbide is applied to the clay body, and then the clear glaze is placed over it in a very light application, which protects the copper and the silicon carbide from the aerial oxygen in the oxidizing atmosphere that would add a sufficient amount of oxygen atoms to the reduced copper, thus changing it back to its original state and producing a green glaze, rather than the intended red. An over-sufficient amount of the clear glaze would cause the entire glaze to become too fluid and eventually to run off the piece; therefore, it is necessary to experiment with the proper amount of clear and colored glaze on the piece to determine the proper amount to be applied. This is true of all of the experimental glazes as well as of the other glazes attempted in these experiments.

M-X-2, cone 06. This glaze is predominantly the same as the M-X-1, with the exception that zinc oxide was added to promote a brighter color, changing the non-reduced copper color from a green to a more blue color. Both the base formula and the batch formula are the same, with the exception that one per cent of zinc oxide was added to this formula; so no formulae will be given for this glaze, which can be procured from the previous glaze formula.

M-X-3, cone 06. This is another general abstraction derived in the same manner as the M-X-1 and M-X-2 glaze formulae, and is also a feldspathic glaze rich in sodium, but is a non-lead glaze. The base formula: K_2O, 0.3; Na_2O, 0.7; Al_2O_3, 0.3; SiO_2, 1.9; with additions of 1% tin oxide, 1% zinc oxide, .3% copper carbonate, and .3% silicon carbide. Generally, the amount of the reduction agent should be similar to the amount of coloring oxide added; in some cases, however, it may exceed this slightly, but by doing so it produces a brownish red color rather than the desired red. The batch formula for the M-X-3:

Potash feldspar	166.80
Sodium Bicarbonate	117.60
Silica	6.00
Tin Oxide	2.90
Zinc Oxide	2.90
Copper Carbonate	.87
Silicon Carbide	.87

As with the other formulae, it needs to be divided into two parts, one with the addition of the copper carbonate and silicon carbide, the other being left clear to protect the first glaze from the onslaught of the aerial oxygen of the oxidizing atmosphere. The oxidized copper color of this glaze is a delicate light green.

M-X-4, cone 05. The M-X-4 abstract formula did not produce a desirable result. This was an experiment undertaken to find out the absolute necessity of having the copper red reduction glaze be basically feldspathic. The base formula: PbO, 0.7; CaO, 0.3; Al_2O_3, O.25; SiO_2, 2.0; B_2O_3, 0.5; with additions of 1% tin oxide, 1% zinc oxide, .3% copper carbonate, and .3% silicon carbide. Batch formula:

Lead carbonate	60.10
Whiting	30.00
Kaolin	64.50
Silica	90.00
Boric Acid	35.00
Tin Oxide	2.80
Zinc Oxide	2.80
Copper Carbonate	.84
Silicon Carbide	.84

Although no definite conclusion can be ascertained through one experiment, there is an indication that a non-feldspathic glaze is undesirable for the production of the copper-red glaze, since the other elements of the formula were in relation to their presence in a feldspathic formula.

The glaze formulae listed above have produced some variations of copper reds, but it should be recognized that they will not necessarily perform the same under all circumstances, and that raw materials differ.

Valid suggestions to be derived from the previously recorded experiments are listed as follows:

1. Lime is beneficial to a reduction glaze.
2. Barium oxide gives a brownish tone to the red and is, therefore, generally to be avoided.
3. Boric oxide is valuable in adjusting the fluidity of the molten glaze, but must be used with discretion if purplish tones are not wanted. When boric oxide is present, the silicon must be kept rather low to prevent a bluish opalescent effect which in combination with the copper red will give purple or red violet.
4. A small amount of zinc oxide, usually not over 5%, often has the effect of brightening the color.
5. In low fire glazes, the oxide of lead may be used in combination with other fluxes.
6. Iron may be added to assist the complex action that goes on in the production of the red color—tin oxide does the same thing.
7. Tin oxide in the glaze is an absolute necessity in the local reduction firing. A small percentage only is necessary, usually not over 1%, or sometimes, if figured as a correlative to the amount of copper, not more than double this amount.
8. One must make two batches of glaze, one with copper carbonate and silicon carbide, and one without—the latter to be used as the cover or over glaze.

Copper red glazes owe their color to cupric oxide which has been reduced to metallic copper finely divided into what is referred to as a collodial state. The red color is due primarily to the even assemblages of these finely divided particles to form a layer within a certain portion of the glaze. The formation of this band is assisted and maintained by the presence of tin or zinc oxide. In an extremely fine state of division, collodial copper seems yellow in color; when less fine, red; and when in an even coarser division, blue. The reduced copper is dissolved in the glaze and, at the beginning, is colorless. The tin or ferrous oxide present completes the reducing action. The aerial oxygen next begins its function, attacking the molten glass, oxidizing the top layer without much difficulty, thus re-establishing the copper with its lost oxygen atoms and returning it to its original green color. The aerial oxygen, now somewhat spent, continues to penetrate deeper into the glaze, but does not have sufficient strength to do much more than break up the colloidal copper to the necessary size to produce the red layer of color. The tin or ferrous oxide present in the glaze helps to stabilize the colloidal copper and to keep it dispersed, maintaining the red band of colloidal copper.

TABLE I, PART I
Empirical Formulae

Glaze	Cone	Pbo	K_2O	Na_2O	CaO	BaO	Al_2O_3	FeO	SiO_2	B_2O_3	SnO_2	Fe_2O_3	CuO	Sil. Carb.
M-2	06		.2224	.7776			.28		2.021		1%		1%	.2%
M-3	06	.5491	.1572	.2932			.1255		3.1232	.6095	1%		1%	.2%
M-4	04	.518	.0911		.2084		.128	.1829	.4278		.0642			2.0%
M-5	03		.25	.40	.35		.12		2.8	.5	2.4%	.5%	1.5%	
M-6	05	.7			.3		.25		2.1	.4	1.5%		1%	.5%
M-7	05		.25	.25		.5	.15		2.3	.5				
M-8	06		.5		.5		.1		2.5	1.0			1%	.5%
M-9	03		.25	.40	.35		.12		2.8	.5	2.4%		.5%	.5%
M-10	05		.25	.25		.5	.15		2.3	.5	1.5%		.5%	.5%
M-14	06		.2224	.7776			.28		2.021		1%		.25%	.2%
M-15	06	.5491	.1572	.2932			.1255		3.1232	.6095	1%		.3%	.2%

TABLE I, PART 2

References for Emperical Formulae

Sources of the nine experimental glazes used in Table I.

M-2	Harding Black, "Opening the Door to Copper-Rd Glazes," *Ceramics Monthly,* January, 1953, p. 9.
M-3	Same as M-2.
M-4	*Ceramic Industry,* January, 1949, p. 158.
M-5	F. Wurts, "China Red Glazes," *Keramos,* April, 1936, p. 121 and 126.
M-6	Eberhard Breitenfeldt, *Ceramic Abstracts,* IX, December, 1930, No. 12, p. 1007.
M-7	Same as M-6.
M-8	Anonymous, "Copper Red Glazes Maturing at Low Temperatures," *Ceramic Abstracts,* VII, March, 1928, No. 3, p. 122-123.
M-9	Same as M-5 with the exception of the deletion in the formula of the Fe_2O_3.
M-10	Same as M-6 and M-7.

TABLE II

Description of Experimental Glaze Tiles

Glaze	Tile Numbers	Description
		(All samples are on porcelain body unless otherwise indicated.)
M-2	M-1-C	Clear light blue, crackled, slight indication of reduction; when covered with clear glaze on right hand side of tile, the reduction effected was better.
	M-2 M-2-A M-2-B	All tiles (3) of curdled light blue color, with only minor indication of reduction. These were fired without a protective coating.
	M-3-D	Clear glaze without the copper or silicon carbide. Crackled.
	M-4	Light blue crackled glaze with slight indications of reduction-red.
M-3	M-1-B	Clear blue-green crackled glaze with minor indications of reduction-red color. On right hand side of tile, which was covered with a "foreign" clear glaze, a more dominant red color is indicated; however, the "foreign" glaze produced a brownish tinge over this area.
	M-2-D	50% partial reduction with greenish blue base glaze. Glaze with reducing agent covered with protective glaze absent of silicon carbide but containing the copper compound.
	M-3 M-3-A M-3-B	Clear blue-green crackled glaze without any reducing compound.

	M-3-C M-4-A	Nearly complete reduction-red. Liverish in quality, however. M-4-A less successful, difference being accounted for in the fact that the first tile was fired in a regular length firing rather than in the test, fast fire, kiln.
M-4	M-2-C	Tan, bubbly, uneven pitted glaze. Completely unsuccessful.
M-5	M-5	Semi-matt orange peel surface, speckled with darker green spots. No reduction.
M-6	M-26-A	Clear glaze with crackle, slightly tinted tan in color.
	M-26-B	Speckled light green with minor brown spots too tiny to be recorded as only the most minor reduction.
	M-6	Clear glaze, no crackle effect.
	M-5-D	Green semi-clear glaze with no reduction effect noticeable.
	M-4-C	With an additional gram of silicon carbide, the glaze turned slightly tan in addition to the green, but still no indication of any strong reduction effect.
M-7	M-25	Volcanic eruption of snowy white glaze indicating no reducing quality in the least.
M-8	M-26-D	White semi-matt orange peel surface, too opaque for any benefit.
	M-26-C	Light blue glaze covered with above glaze which clouded the entire effect. No mentionable reduction acquired.
	M-5-B	White clear smooth glaze.
	M-5-C	Light turquoise blue with only slight reduction affect. Somewhat bubbly effect on the surface. Small indication of red reduction.
M19	M-25-C	White semi-transparent somewhat bubbly, fired to cone 10 instead of cone 03 as intended.
	M-25-D	Rich maroon color though slightly clouded by too much overglaze of clear glaze. Overfired to cone 10 also, but indicates that the glaze is a much higher fire than the cone 03 as originally thought. With lighter overcoating of glaze, the color would probably have been better.
	M-28	Fired to cone 03, this glaze turned out to be very matt, which indicates that it is definitely a higher fire glaze in accordance with the M-25-C tile which was fired to cone 10. However, it is probably mature at a temperature between these two extremes.
	M-27-D	This tile indicates similar findings, in that the glaze shows no indication of a red reduction effect at all, nor is the surface texture as good as in the previous example.
	M-27-C	With only the copper and silicon holding glaze, another test was tried to determine what possible product was available without the interference of the clear glaze, since in M-25-D the only undesirable effect was the cloudiness of the clear glaze. However, again the fire was insufficient to mature the glaze and the results were: matt, medium green, no reduction indicated.
M-10	M-23-C	Clear crackled glaze, could stand a slightly higher fire, probably cone 04 or 03. Smooth pleasant texture.

	M-X-4	Soft robin's egg blue with slight red reduction effect. Texture generally good—at slightly higher fire it would smooth out better.
M-11	M-28-B	Slight reduction of brownish quality in faintly tinged green clear crackle glaze.
	M-4-D	Same as above, only slightly more green background or base color.
	M	Red clay body allowed no color indication for either green or red.
M-12	M-5-A	Slight reduction of brownish quality in faintly tinged green clear crackle glaze.
	M-A	Red clay body allowed no color indication for either green or red.
	M-28-A	Light green base color sprinkled with reddish-brown speckles, made possible by a protective glaze coating of clear base glaze.
M-13	M-28-C	50% reduction glaze backed with sea-green color. Even surface glaze without crackle. Dispersion of red particles well homogenized.
M-14	M-X-3	Beautiful blue background color with about a 25% reduction-red surfaced by bubbly texture due to insufficient firing time to allow gaseous matter to escape from the body and the glaze. Very attractive combination.
M-14-A	M-27	Same as above except that there is about a 40% reduction produced probably from the additional silicon carbide added to the preceding formula. The red is not liverish in color.
M-15	M-X-2	Slightly greenish base color glaze with semi-liver colored red reduction of about 10 to 15% of equal distribution.
M-15-A	M-27-A	Same as M-X-2, not any appreciable difference in the addition of the extra silicon carbide.
M-X-1	M-28-D	Good reduction of about 50% of the surface of the glazed area. Background area slightly darker green than other glaze samples, still a tint, however.
M-X-2	M-27-B	Slight reduction resulting in good red color, however, on very light sky-blue background.
M-X-3	M-27-C	Watery red reduction of approximately 25% of the area of the tile. Background color is very light green. Crackled glaze.
M-X-4	M-26	Matt, slightly yellowish-green color with speckled dark silicon carbide particles. Completely unsuccessful.

TABLE III

Batch Formulas of Glazes Listed in Table I
(All formulas listed in gram weight)

M-2	Cone 06
Sodium Bicarbonate	45.00
Potash Feldspar	43.00
Kaolin	5.15
Silica	12.00
Tin Oxide	1.00
Copper Carbonate	1.00
Silicon Carbide	.20

M-3	Cone 06
Potash Feldspar	10.50
Silica	32.00
Lead Carbonate	30.00
Kaolin	2.00
Borax	19.20
Boric Acid	2.00
Potassium Carbonate	2.00
Sodium Bicarbonate	2.00
Tin Oxide	1.00
Copper Carbonate	1.00
Silicon Carbide	.20

M-4	Cone 04
White lead	45.00
Whiting	7.00
Potash Feldspar	17.00
Kaolin	3.20
Flint	13.20
Tin Oxide	9.70
Iron Oxide	4.90
Silicon Carbide	2.00

M-5	Cone 03
Potash Feldspar	66.72
Potassium Carbonate	19.24
Sodium Carbonate	42.40
Whiting	35.00
Boric Acid	35.00
Flint	168.00
Tin Oxide	8.80
Iron Oxide, red	1.80
Copper Carbonate	6.50

M-6	Cone 05
Whiting	30.00
Lead Carbonate	178.60
Kaolin	64.50
Boric Acid	28.00
Flint	96.00
Copper Carbonate	3.97
Tin Oxide	5.96
Silicon Carbide	1.99

M-7	Batch formula lost.	Cone 05
Empirical formulas listed.		
0.25 K_2O	0.15 Al_2O_3	2.3 SiO_2
0.25 Na_2O		0.5 B_2O_3
0.50 BaO		

M-8	Cone 06
Potash Feldspar	55.60
Potassium Carbonate	55.20
Whiting	50.00
Flint	114.00
Boric Acid	124.00
Copper Carbonate	3.99
Silicon Carbide	1.99

M-9	Cone 03
Potash Feldspar	33.36
Potassium Carbonate	9.62
Sodium Carbonate	21.20
Whiting	17.50
Boric Oxide	17.50
Flint	84.00
Tin Oxide	4.40
Copper Carbonate	1.10
Silicon Carbide	1.10

M-10	Cone 05
Potassium Carbonate	17.25
Borax	47.75
Barium Carbonate	49.25
Kaolin	19.35
Flint	60.00
Copper Carbonate	.96
Tin Oxide	2.90
Silicon Carbide	.96

M-14	Cone 06
Sodium Bicarbonate	45.00
Potash Feldspar	43.00
Kaolin	5.15
Silica	12.00
Tin Oxide	1.00
Copper Carbonate	.25
Silicon Carbide	.20

M-14-A — Cone 06

Add .05 gram silicon carbide to M-14

M-15	Cone 06
Potash Feldspar	10.50
Silica	32.00
Lead Carbonate	30.00
Kaolin	2.00
Borax	19.20
Boric Acid	2.00
Potassium Carbonate	2.00
Sodium Bicarbonate	2.00
Tin Oxide	1.00
Copper Carbonate	.30
Silicon Carbide	.20

M-15-A — Cone 06

Add .10 gram silicon carbide to M-15

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