BÖTTGER'S EUREKA! : NEW INSIGHTS INTO THE EUROPEAN REINVENTION OF PORCELAIN*

Nicholas Zumbulyadis, Independent Scholar (Retired, Eastman Kodak Research Laboratories, Rochester, NY)

Introduction

The opening of Europe's first porcelain manufactory in Dresden, in January, 1710 represented the successful culmination of efforts to unlock the secret of Chinese porcelain, a quest that had gone on for at least 800 years. By royal decree, on the 6th of June 1710 the manufactory was moved from Dresden to the Albrechtsburg in the city of Meißen. Developed initially as a medium of artistic expression, porcelain quickly became one of the most widely used composite materials ever invented (1). The objective of the present paper is to fill in new details about the invention of European porcelain by examining the plausibility of an early 19th-century account in the light of recent analytical data together with archival material.

Porcelain was first discovered in China, with the earliest recorded pieces dating to the T'ang Dynasty (618-907 AD). While it is generally believed that this discovery was accidental, Chinese porcelain does have compositional similarities to earlier, dense, high-temperature stoneware from 200 BC to 200 AD. These wares are known as protoporcelain, a term used more frequently in China than in the West (2).

According to tradition, the earliest examples of porcelain arrived in Europe from China towards the end of the thirteenth century with the return of Marco Polo from his legendary voyage. One cannot be certain that this was the first encounter of Europeans with porcelain since Chinese porcelain objects dating to 900 AD were excavated in Samarra, Iraq. The porcelain specimens Marco Polo brought back must have displayed properties puzzling to the people of the Middle Ages. They were probably white, definitely vitreous, (and hence, unlike European pottery, nonporous) and translucent. By the middle of the 15th century porcelain objects from the Far East had found their way into Italian collections by way of the Middle East, mostly through the exchange of diplomatic gifts. Later, during the 16th and 17th centuries, when Portuguese and Dutch traders brought back large quantities of porcelain from China, Europeans became widely appreciative of porcelain's unique resistance to thermal shock.

The problem of producing true porcelain perplexed potters and alchemists for several centuries. Islamic potters, trying to imitate the white appearance of porcelain, introduced tin oxide into the transparent glaze as an opacifier. They were thus able to produce a ceramic surface that was an ideal canvas for further decoration. This approach ultimately led to materials known in Europe as Italian maiolica, French faience, or Delftware. Alchemists, both in 13th-century Persia and later in Southern Europe, attempted to introduce the property of translucency into the clay by mixing it with ground glass (3). In 1575 Grand Duke Francesco Maria de' Medici of Florence, himself an alchemist, produced a translucent material by co-melting kaolin-containing clay from Vicenza and glass. Known as Medici-porcelain, this material (one of many variants of what is now called soft-paste porcelain or fritware) was produced until 1586 (until 1620 in Pisa), with very few pieces surviving today. While used to produce objects of great beauty and elegance, none of these materials possessed porcelain's resistance to thermal shock.

One of the earliest attempts to break away from these purely phenomenological approaches was made by the English potter John Dwight (founder of the Fulham pottery), who sought to improve German salt-glazed ware by firing it at higher temperatures to bring about vitrification of the clay body (4). It was, however, Johann Friedrich Böttger (1682-1719), an alchemist in pursuit of the philosopher's stone, together with Ehrenfried Walther von Tschirnhaus (1651-1708) and their circle of laboratory assistants and kiln builders, who finally succeeded in reinventing porcelain in Europe. Böttger was both a prisoner and in the employ of Prince-Elector Augustus the Strong (5) and charged with making gold to finance the profligacy of his master. In 1706 Tschirnhaus gradually nudged Böttger towards working on porcelain.

While the story of the European reinvention of porcelain has been told countless times, the exact circumstances of this invention are still shrouded in mystery. Popular histories focus mostly on the colorful characters and salacious details. Only two scholarly Böttger biographies exist, the first by Carl August Engelhardt dating to 1837 (6). The second was published recently by Klaus Hoffmann in 1985 (7). Hoffmann explicitly makes the point that there is no body of work that specifically examines Böttger's chemical activities (8). The purpose of this paper is to take a first small step in the direction of filling in this gap. It is definitely not the author's intention to rekindle the centuries-old debate on the relative merits of the contributions of Böttger vs. Tschirnhaus to the reinvention of porcelain (see, however, the references cited in the concluding remarks for a synopsis of this debate, particularly those of Pietsch and Ufer).

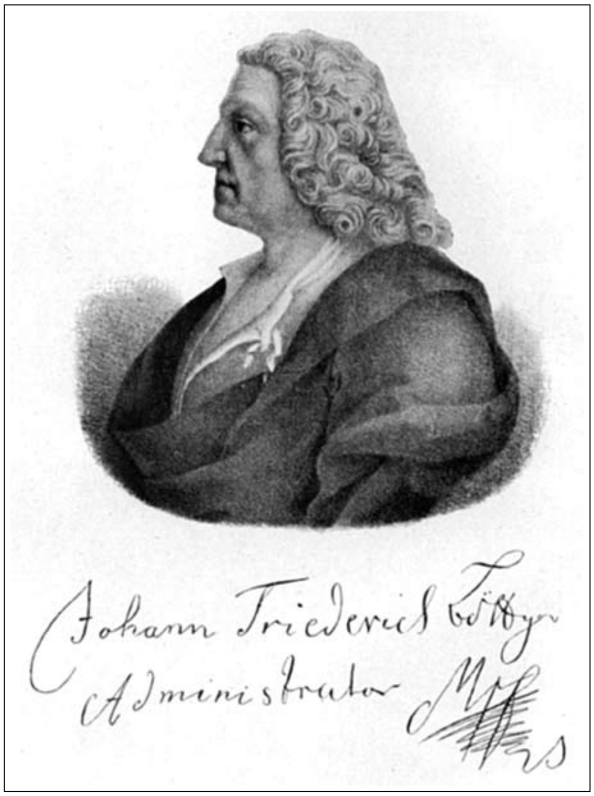

Figure 1. *Engraving of Johann Friedrich Böttger*

The Basics of Porcelain Chemistry

In this section a brief review of the chemistry of porcelain will be presented. The chemical composition and heat treatment protocol followed during the manufacturing process give porcelain its unique properties and set it apart from all other ceramic materials. Certain aspects of the manufacturing process are of key significance to the reconstruction of the circumstances that led to the reinvention of porcelain.

The starting material for porcelain is a mixture of approximately 50% kaolinite, 25% quartz, and 25% feldspar. Kaolinite [$Al_2Si_2O_5$ $(OH)_4$], a white-burning clay, is structurally a phyllosilicate which can intercalate water molecules between its layers, thus acquiring its unique plasticity. Kaolin (from Chinese, *kao-ling*, meaning mountain ridge) and quartz constitute the basic body, what the Chinese poetically described as the bones, of porcelain. Feldspar [$KAlSi_3O_8$] (*petuntse* and also called the flesh of porcelain by the Chinese) plays a very special role during the final thermal processing step. The components are finely ground, thoroughly mixed, and after an elaborate hydration step acquire the necessary plasticity to create shapes of almost arbitrary complexity. The objects are subjected to an initial firing at 850-1000°C which renders them dimensionally stable yet absorbent. They are glazed by being dipped into aqueous slurry of the starting materials containing a higher proportion of feldspar.

The formation of porcelain occurs during the second heating to 1450°C. At this temperature feldspar softens and acts as flux, forming a eutectic with kaolin and quartz. Upon cooling, porcelain forms as a composite. It consists of a vitreous silica-rich continuous phase with needle like crystals of mullite (9) embedded in it. The continuous phase gives porcelain its translucency; the mullite crystals, because of their exceedingly small thermal expansion coefficient, provide the resistance to thermal shock. Feldspar is not the only substance that can act as a flux. Calcium sulfate in the form of gypsum was actually the flux material used by Böttger in his experiments, as well as commercially by the Meissen Manufactory during Böttger's lifetime. Calcium carbonate and calcium phosphate behave similarly.

How could anybody come up with these starting materials and conditions in order to duplicate the manufacturing process of porcelain during the first decade of the 18th century, when analytical chemistry was virtually unknown? The contemporaneous primary sources are silent on this matter. The official biographers speak only in generalities about Böttger's diligence, inventiveness, and methodical approach. There is, however, a remarkably detailed but little known early 19th-century account that comes from a totally unexpected source.

Simeon Shaw's Account of the Porcelain Invention

Simeon Ackroyd Shaw (1785-1859), an author and schoolmaster, was born in Lancashire, England. He came to Staffordshire, the center of English pottery manufacturing, to work as a printer for the "Potteries Gazette and Newcastle under Lyme Advertiser." In the 1820s and 1830s Shaw ran a number of academies for young gentlemen and was the author of several books, among them "The History of the Staffordshire Potteries," published in 1829, and "The Chemistry of Pottery," published in 1837. "The History of the Staffordshire Potteries" is one of the earliest chronologically based surveys of the area's development from the late medieval period to the state of the industry in Shaw's own times. Buried in the "History" and without any reference to a source or document lies a surprisingly detailed description of Böttger's invention (10):

> …While Reaumur was thus employed in France, Baron De Botticher was equally busily engaged in Saxony, and first produced the white kind of real porcelain in Europe. The Baron professed Alchemy, or the secret of the Philosopher's Stone, for transmuting metals into Gold; and having exhibited to his dupes several specimens, by some means they were shewed to the King of Poland. To gratify the cupidity of this monarch, by compulsory divulgement of this secret, an order was issued for his incarceration in the castle of Koningstein, where he unremittingly continued making experiments. While pursuing this useless research without opportunity to destroy or mal-appropriate whatever was produced, he found in one of his crucibles, what completely answered his purposes; the intense heat he employed to fuse some of his materials, rendered the crucibles themselves of similar appearance to the white Chinese porcelain;(very probably because of accidentally employing some materials in quality like those used in China;) he carefully repeated the process, and produced white porcelain; which caused Dresden to become the seat of the art..

Shaw is just as specific about the location as he is about the experimental details, Königstein, an impregnable fortress at the eastern corner of Saxony, about 20 miles from Dresden (curiously, Shaw uses a quasi-Dutch spelling, Koningstein). The specification of this location establishes the time frame, which must coincide with Böttger's second incarceration there from September 5, 1706 until September 22, 1707 to prevent his falling into the hands of the invading Swedish army.

To assess the plausibility of Shaw's account we must answer three questions: First, is the transformation described by Shaw chemically possible? Second, could it have actually taken place? and Third, is Shaw's account consistent with the known timeline of other, well documented events associated with the reinvention of porcelain? What follows is an examination of all three questions, albeit in reverse order. A fatal objection could be raised immediately. It is known that no kilns or ovens were allowed at Königstein because of the danger of fire. This well documented fact may have led scholars to dismiss Shaw's statement right from the outset, ending all further discussion. We shall see that this is actually a spurious objection.

Milestones in the Invention of Porcelain

Europe's first porcelain manufactory began its operations in 1710 in the castle of Albrechtsburg in the city of Meissen. Its founding followed Böttger's famous Memorandum to the King, dated March 28, 1709, where he announced that he can produce "good white porcelain **with the appropriate glaze and decoration;"** in other words, a finished, commercializable product. Based on this document the influential art historian Ernst Zimmermann in 1909 declared March 28, 1709 as the official date of Böttger's invention. Careful reading of the memorandum actually shows that it is a defensive document, intended to mollify a Saxon government growing impatient with Böttger's failure to deliver on his promises of transmutation, rather than a triumphant announcement of success in making porcelain. Nevertheless, Zimmermann's view prevailed until 1962, when a page of a laboratory notebook dated January 15, 1708 was discovered in the Meissen archives (11). The document is shown in Fig. 2. A transcript and commentary were published by Mields in 1967 (12).

The text describes a set of experiments involving the firing of mixtures of clay from Colditz with alabaster (calcium sulfate) as the flux. The quality of the ensuing porcelain for different clay to alabaster ratios is indicated in notes on the margin written in Medieval Latin. The document appears to be describing a matrix of optimization experiments. Mields attributes the authorship of the notebook page directly to Böttger because of a comparison of the handwriting to letters in the Dresden archives known to be by Böttger's hand (13). The contents of this document suggest that the basic formulation for porcelain must have already been known to Böttger and his circle of collaborators prior to January, 1708. This is confirmed by Paul Wildenstein (1682-1744), one of Böttger's assistants. Wildenstein describes how, during the last days of December 1707, Böttger showed a small unglazed porcelain teapot to Augustus the Strong and demonstrated its resistance to thermal shock by pulling it out of the white-hot oven and throwing it into a pail of cold water (14). More significantly, on November 20, 1707 Augustus had already issued a decree assigning Böttger the task of creating several factories that made use of Saxony's mineral resources (15). If one rejects Shaw's account, one must conclude that the invention of porcelain took place in Dresden, after Böttger's return from Königstein, sometime during October/ November, 1707. Böttger's main preoccupation during those two months was, however, the construction with the assistance of Balthasar Görbig (1672-1739) of more efficient ovens for the high-temperature firing of large porcelain objects. Actual work in ceramic chemistry was left to two of his assistants, Wildenstein and David Köhler (1683-1723). It is unlikely that Böttger and Tschirnhaus would have left any work more challenging than the refinement of known experimental conditions to their assistants. To this end Wildenstein and Köhler used a most unusual apparatus, an extraordinary invention of Tschirnhaus. As we shall see, this apparatus resolves the conundrum of being able to carry out high temperature experiments at Königstein without access to kilns.

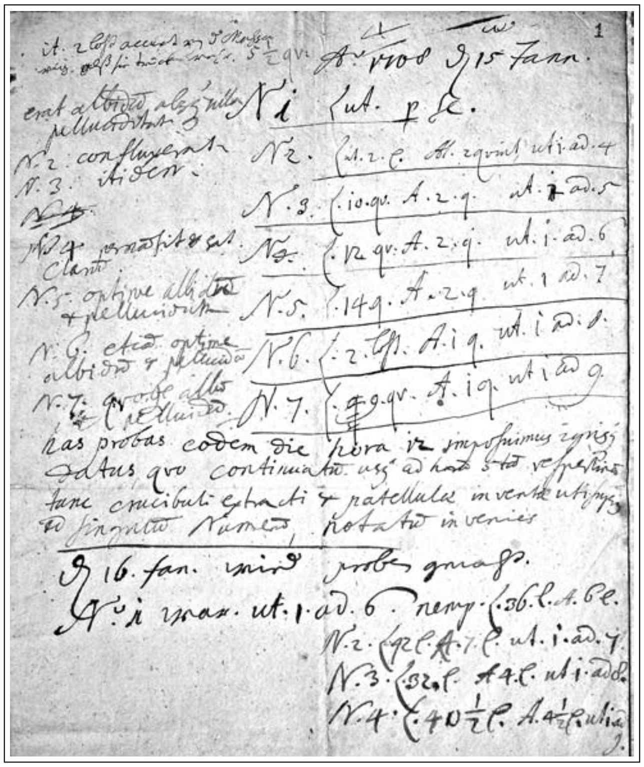

Figure 2*. Laboratory notebook page dated January 15, 1708 recording the results from a series of experiments with different clay/flux ratios (image courtesy of Staatliche Porzellan-Manufaktur Meissen Historical Collections, reproduced with permission).*

Experimentation at Königstein?

Tschirnhaus, a mathematician, physicist, and mineralogist, was born in Kieslingswalde (today Sawnikowice in Poland) and died in Dresden. During 1675 he worked with Robert Boyle (1627-1691), Isaac Newton (1643-1727), Christiaan Huygens (1629-1695), and was introduced to Gottfried Wilhelm Leibniz (1646-1716), with whom he maintained a lifelong scientific correspondence. Besides his contributions to mathematics (theory of polynomials), Tschirnhaus is perhaps best known for his invention of large parabolic mirrors (1686) and burning lenses (1687) to create very high temperatures. In 1687 he was able to melt asbestos for the first time, a substance regarded since antiquity as infusible. Tschirnhaus was also the first to observe the phenomenon of eutectic formation. In 1699 he reported to the French Academy of Sciences (16) that, while chalk and quartz cannot be fused at the temperatures available to his burning mirrors, a finely ground mixture of the two ingredients could be made to flow. Based on a written record by Leibniz, Tschirnhaus became interested in porcelain as early as 1675. In 1694 he used a burning lens to melt a shard of Chinese porcelain and showed that metal oxides can be made to adhere to porcelain at high temperatures. Specifically, he found that gold under such conditions gives porcelain a purple color, an observation he communicated to Leibniz.

A two-stage burning lens built by Tschirnhaus is shown in Fig. 3. It can be seen today at the Physikalisch-Mathematischer Salon as part of the Staatliche Kunstsammlungen, Dresden. The instrument is 2.5 m in height, and the two lenses are 50 cm and 26 cm in diameter. On the basis of Tschirnhaus' accounts of the substances he could bring to a molten state, the highest documented temperature is about 1600 °C. The solar energy could be

***Figure 3**. Two-stage burning lens apparatus built by Ehrenfried W. v. Tschirnhaus, in Kieslingwalde around 1690; reproduction (image courtesy of Staatliche Kunstsammlungen Dresden, Mathematisch-Physikalischer Salon, Photographer: Michael Lange, Dresden, reproduced with permission).*

focused down to an area of about 10-15 cm^2. There is little doubt that burning lens equipment played a major role in Böttger's work. This is hardly surprising, since Tschirnhaus, the leading Saxon scientist of his time, was assigned by Augustus in 1704 to supervise Böttger's experiments closely. The earliest evidence comes from Johann Melchior Steinbrück (1673-1723), who was initially at Böttger's private service, and later was charged with the day-to-day administration (*Inspektor*) of the Meissen Porcelain Manufactory. In 1717 he submitted a lengthy report to Augustus summarizing the events leading to the founding of the Manufactory in 1710 and its development in the following seven years under his supervision. In his report Steinbrück recounts that Tschirnhaus was a proponent of the use of burning lenses in ceramics experiments. Böttger, in response, raised the curious objection that the lenses caused melting of the substances that altered their "essence" (a puzzling concern coming from somebody attempting transmutation). Nevertheless, Steinbrück writes, at the end Böttger did make use of such a device for his invention (17). It is conceivable that the absence of ovens at Königstein encouraged Böttger to change his mind. Similarly, Wildenstein complains in his Petition (18) about how his own eyesight was damaged from the use of burning lenses when he and Köhler were testing mixtures of clays and fluxes for porcelain. A less well known document in the Meissen manufactory archives and dated to 1743 (19) also refers to experiments with burning lenses both for the development of red stoneware (a project that was being run in parallel) and for porcelain. A passage from the document states that "Tschirnhaus' burning lenses were used to test not only the red clays, some of the white clays tested would soften and become porcelain-like."

But it is Karl Berling who gives us the most direct evidence. In the Introduction to the History of the Meissen Manufactory published in 1911 on the occasion of the 200th anniversary of the Manufactory, Berling states almost in passing that Böttger used this equipment for ceramics experiments while in Königstein. He writes (20):

> …and Böttger seems to have been more fortunate than his master [i.e. Tschirnhaus] in working with the burning glass of the latter. On the Königstein he succeeded in making Dutch ware, a sort of Delft fayence, and in the last months of the year 1707 he brought forth in Dresden red stoneware.

We have so far established that Shaw's account is consistent with the known timeline of events leading to the manufacture of commercially viable porcelain, and that high-temperature experiments on the Königstein even without the use of ovens were feasible and had in fact taken place. We shall now turn to the pivotal question of whether the transformation described by Shaw is chemically possible.

Crucible Chemistry and Porcelain

The one passage in Shaw's account that is most important to the chemical history of porcelain states (10):

> …the intense heat he employed to fuse some of his materials, rendered the crucibles themselves of similar appearance to the white Chinese porcelain…

The passage describes the observation of an unexpected event, thus vividly capturing a moment of discovery. To what extent is this description realistic?

In January, 1702, as Böttger prepared to start his transmutation experiments for Augustus the Strong, he gave councilor of mines Gottfried Pabst von Ohain (1656-1729) a list of chemicals and equipment he would need for his experiments (21). Included in this list were Hessian crucibles, a most remarkable type of stoneware, first invented during the late Middle Ages in the village of Grossalmerode near Kassel in Hessen. These

Figure 4*. Hessian crucibles from ca. 1607-1610 excavated at Jamestown with evidence of copper smelting, which may have been used in attempts to produce brass (image courtesy zof the APVA Image Bank, reproduced with permission).*

thin-walled crucibles are 2-20 cm in height and have an astonishing resistance to thermal shock. They were the favorite tools of metallurgists, goldsmiths, assayers, and of course alchemists the world over. Their characteristic triangular shape allows for convenient pouring in all directions. Hessian crucibles have been found across continental Europe, from Portugal to Norway, and also in Great Britain and the British colonies of the New World. The examples of Hessian crucibles shown in Fig. 4 were indeed excavated in the Settlement of Jamestown, Virginia, the first English speaking settlement in North America. According to Hudgins (22) they were used by early settlers for cementation experiments (a step in the production of brass) around 1607-1610.

The factors behind the heat resistance of Hessian crucibles became clear only very recently through the work of M. Martinón-Torres, Th. Rehren of the University College London, and I. Freestone of Cardiff University (23, 24, 25). They used scanning electron microscopy and X-ray powder diffraction to detect both mullite (see Fig. 5) and quartz in Hessian crucibles, together with iron oxide. Just as with porcelain, the resistance of Hessian crucibles to thermal shock can thus be attributed to the presence of mullite. By examining the crystal morphology Martinón-Torres et al. (24) conclude that most, but not all of the

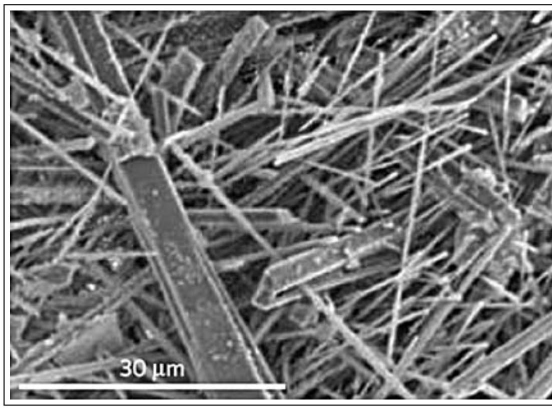

Figure 5. *Electron micrograph of mullite needles from a flux-rich region within a Hessian crucible (image courtesy of M. Martinón-Torres reproduced with permission).*

mullite (26) comes directly from the decomposition of kaolin during processing at an estimated temperature of 1200-1400°C, rather than through the action of a flux. All the ingredients for porcelain with the exception of a sufficient quantity of a flux are therefore present within the crucible body. Böttger could have indeed transformed all or part of a crucible into a porcelaineous body in the manner Shaw describes. He would only need to add a calcium salt like calcium carbonate or calcium sulfate (27) under the higher temperatures afforded by a burning lens apparatus as part of some transmutation experiment. Calcium salts were commonly found in the alchemist's tool kit for purifying and assaying silver or gold by a process known as cuppelation.

Concluding Remarks

In the light of the evidence presented here, Shaw's account appears plausible and indeed likely. Böttger could have gained several key insights from this observation that later guided his work and that of Tschirnhaus and their laboratory assistants upon Böttger's return to Dresden. Shaw's account is also consistent with the archival evidence presented in Ref. 14 and 20, that the basic formulation of porcelain was known to the team of Böttger and Tschirnhaus as early as the latter months of 1707, in contradistinction to opposing claims first voiced by Bussius in 1719 (28). The observation would have pointed to the need for higher temperatures. Neither the small laboratory ovens described by Johann Rudolf Glauber (1604-1668) nor the larger more efficient ones by Johann von Löwenstern Kunckel (1630-1703) could reach the temperatures needed for porcelain production (29). The observation would have also established the flux material. Pabst von Ohain, in notes written on May 29, 1706 was already speculating that the secret of Chinese porcelain possibly lay in the use of a calcareous flux (30).

Most significantly, the observation would have led Böttger and Tschirnhaus to consider clays with properties similar to those of clay used in the production of Hessian crucibles. The use of clay from nearby Colditz for making heat resistant containers and bricks for ovens that could withstand high temperatures was already well established. In fact, upon his return from Königstein, Böttger contended that he knew how to make crucibles that would surpass the Hessian ones in performance. A crucible manufactory was one of the several enterprises he proposed to Augustus. Böttger did bring in Meister Johann Just Gundeloch, one of the last surviving Hessian crucible manufacturers from Grossalmerode, to verify his contention. It was ultimately decided not to build such a factory—based purely on economic considerations (31).

In conclusion, Simeon Shaw's little noticed passage is proven plausible and significant in understanding the process leading to the reinvention of porcelain in 18th century Europe. An important challenge for future research would be to identify the source for Shaw's insight.

ACKNOWLEDGMENTS

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REFERENCES AND NOTES

* This paper is based on a presentation at the 236th National Meeting of the American Chemical Society, Philadelphia, PA, August, 2008, HIST 006.

1. To appreciate how multifaceted the role of porcelain in our society is, the reader need only consider that as heat resistant high voltage insulators, porcelain components are found on virtually every utility pole. At the same time, a Vienna teapot from ca 1720, made essentially of the same material, was sold at a recent Sotheby's auction well in excess of its pre-auction estimate of $215,000.
2. For a discussion of protoporcelain ware from the Han Dynasty see N. Wood, *Chinese Glazes: Their Origins, Chemistry, and Recreation*, University of Pennsylvania Press, Philadelphia, PA, 1999, 21-23.
3. This attempt to introduce the "essence" or "form" of porcelain into the clay is entirely within the alchemistic tradition. For a discussion of the ideas of the alchemists see F. S. Taylor, *The Alchemists: Founders of Modern Chemistry*, Collier Books, New York, 1962, 12-21.
4. During the 1650s John Dwight (1635-1703) worked for Robert Boyle, which might explain why he embraced a chemical rather than alchemistic approach. He was granted a patent on April 17, 1672 for making "transparent Earthen Ware" which, nevertheless did not rise to the level of true hard paste porcelain. Dwight's move away from the use of glass frit is pointed out by Honey; see: W. B. Honey, *Dresden China*, Tudor Publishing Company, New York, 1946, 7.
5. Augustus the Strong (1670-1733), Prince Elector of Saxony (r. 1694-1733) and King of Poland (r. 1697-1704 and again 1709-1733).
6. C. A. Engelhardt, *J. F. Böttger, Erfinder des Sächsischen Porzellans,* Verlag von Johann Ambrosius Barth, Leipzig, 1837, (reprinted by the Zentralantiquariat der Deutschen Demokratischen Republik, Leipzig, 1981).
7. K. Hoffmann, *Johann Friedrich Böttger: Vom Alchemistengold zum weißen Porzellan,* Verlag Neues Leben, Berlin, 1985.
8. Eine detaillierte Darstellung der chemischen Experimentiertätigkeit Böttgers muβ jedoch einer Spezialstudie vorbehalten bleiben." (A detailed presentation of Böttger's experimental work must be left to [a future] specialized research on the subject); Ref. 7, p 187
9. Mullite has the nominal composition $3Al_2O_3.2SiO_2$ and is the only chemically stable intermediate phase in the SiO_2-Al_2O_3 system. Its high temperature strength and resistance to thermal shock and chemical attack make mullite one of the most versatile engineering ceramics.
10. S. Shaw, *History of the Staffordshire Potteries*, Praeger Publishers, (reprint of the1829 ed.), New York, 1970, 196.
11. Staatliche Porzellan-Manufaktur Meissen, Historische Sammlungen P 44 Blatt 1.
12. M. Mields, "Eine Versuchsaufzeichnung von Johann Friedrich Böttger zur Porzellanerfindung aus dem Jahr 1708," *Ber. Dtsch. Keram. Ges.,* **1967**, *44*, 513-517. A transcript and English translation of the document in pdf-format are available from the present author upon request.
13. An alternate view holds that the document is by the hand of Dr. med. Johann Jakob Bartholomaei (1670-1742), Böttger's personal physician, who on January 6, 1708 was also assigned to help him with his ceramics work.

Regardless of who wrote the document, it pushes the date of the actual invention to the previous year.

14. Wildenstein gives a colorful account of this demonstration 29 years after the fact in his lengthy 1736 petition for payment of salary owed to him by the Meissen Manufactory. A transcript of the text with commentary has been published by Walcha: O. Walcha, "Paul Wildensteins Eingabe," *Mitteilungsblatt Keramik-Freunde d. Schweiz*, **1958**, *42,* 17-22. The author would like to thank Dr. Pierre Beller, treasurer of the Keramik-Freunde der Schweiz, for a copy of the article. In a memorializing letter to Augustus immediately following the demonstration, Böttger states that the teapot was made with the help of Herrn von Zschirnhausen [sic] („mit Bey Hülffe des Herrn von Zschirnhausen" fertiggestellt wurde). The source for this quote is a document in Staatsarchiv Dresden, Geheimes Kabinett, Loc. 1340: J.F. Böttgers u. Consorten Angelegenheiten, Vol. II, fol. 148. I would like to thank Dr. Mathias Ullmann, Chairman of the Tschirnhaus-Gesellschaft Dresden for communicating the archival location of the document. Böttger's statement shows that the relationship between Böttger and Tschirnhaus was one of collegiality and sharing of information.
15. The full text of the decree is given in Ref. 6, p 255. The text does not explicitly enumerate the projects and uses instead the phrase "tasks known only to us" (*Uns allein bekannte Verrichtungen*). They are discussed explicitly in the Steinbrück Report of 1717 (see Ref. 17 below).
16. On July 22, 1682, at the age of 31, Tschirnhaus became the first German national to be elected to the French Royal Academy.
17. I. Menzhausen, *Johann Melchior Steinbrück Bericht über die Porzellanmanufaktur Meissen von den Anfängen bis zum Jahre 1717; Kommentar, Transkription und Glossar*, Edition Leipzig, Leipzig, 1982, 47-48.
18. Ref. 14, p 21.
19. Ref. 7, p 375. Dr. med. Christoph Heinrich Petzsch (1692-1756), the presumed author of the document, uses vivid Latin prose to describe the outcome of these porcelain experiments: "…semidiaphanam tremuli narcissuli, ideam lacteam" or "appearing milky white like a translucent fluttering narcissus."
20. K. Berling, Ed., *Meissen China*, Dover Publications, Inc., New York, (unabridged reprint of the work originally published in English in 1910 under the title *Festive Publication to Commemorate the 200th Jubilee of the Oldest European China Factory, Meissen*, by the Royal Porcelain Manufactory, Meissen), 1972, 2. It should also be mentioned that while in Königstein, Böttger received several visits from Tschirnhaus. Following the visit by Tschirnhaus, Nehmitz, and Ohain at the end of June 1707, Böttger memorialized "mit dem Herrn von Schürnhausen [*sic*] alle Veranstaltungen verabredet zu einer sehr fleißigen Arbeith." (I have agreed with Tschirnhaus upon all arrangements for a very diligent work[plan]).
21. The list is discussed in Ref. 7, pp 188-189 (page numbers refer to the actual report, not the transcript).
22. C. C. Hudgins, "Chemistry in the New World," *Chem. Heritage*, **2007**, *25*, 20-26.
23. M. Martinón-Torres, T. Rehren, and I. C. Freestone, "Mullite and the Mystery of Hessian Wares," *Nature*, **2006**, *444*, 437-438.
24. M. Martinón-Torres, I. C. Freestone, A. Hunt, and T. Rehren, "Mass-Produced Mullite Crucibles in Medieval Europe: Manufacture and Material Properties," *J. Am. Ceram. Soc*., **2008**, *91*, 2071–2074.
25. M. Martinón-Torres and T. Rehren, "Post-Medieval Crucible Production and Distribution: A Study of Materials and Materialities." *Archaeometry,* **2009**, *51*, 49-74.
26. Martinón-Torres et al. did observe highly elongated mullite crystals in areas of locally high feldspar concentration. These are the crystals shown in Fig. 5.
27. The reader is reminded that calcium sulfate in the form of gypsum was the typical flux used in early Böttger porcelain.
28. On January 19, 1719, less than two months before Böttger's death, Caspar Gottlob Bussius, treasurer of the Meissen Manufactory, claimed in a report to the Manufactory Commission (roughly equivalent to today's board of directors) that the credit for the invention of porcelain should properly go to Tschirnhaus and that following Tschirnhaus' death the secret of the porcelain composition (the *Arcanum*) was illicitly given to Böttger by Steinbrück, who was at the time the private tutor of Tschirnhaus' children. Dismissed at the time, the story was revived during the early 1900s by Curt Reinhardt and Hermann Peters (see for example: C. Reinhardt, "Tschirnhaus oder Böttger? Eine urkundliche Geschichte der Erfindung des Meißner Porzellans," *Neues Lausitzisches Magazin,* **1912**, *88*, 1-162; and also P. Diergart, "Was wissen wir gegenwärtig von der Erfindungsgeschichte des europäischen Porzellans? Mit Benutzung eines Manuskriptes des Herrn Hermann Peters-Hannover," *Mitteilungen zur Geschichte der Medizin und der Naturwissenschaften*, **1906**, *5*, 534-536. The date of the laboratory notebook page shown in Fig. 2 and the account given in the Wildenstein Petition (see Ref. 14) show that Böttger, Tschirnhaus, and their assistants already knew the recipe for porcelain during the second half of 1707, about a year before Tschirnhaus' death. The timeline for Bussius' conspiratorial hypothesis is therefore wrong but has nevertheless been repeated as recently as 1998 (see e.g., M. Schönfeld, "Was There a Western Inventor of Porcelain?" *Technol. Cult.,* **1998**, *39*, 716–729). A counterpoint is offered by Ulrich Pietsch, the director of the Dresden Porcelain Collection: U. Pietsch, "Tschirnhaus und das europäische Porzellan," in P. Plassmeyer and S. Siebel, Ed., *Ehrenfried Walther von Tschirnhaus (1651–1708): Experimente mit dem Sonnenfeuer*, Staatliche Kunstsammlungen, Dresden, 2001, 68-74. For a more up-to-date account see also U. Pietsch and P. Ufer, *Mythos Meißen*, edition Sächsische Zeitung, Dresden, 2008.
29. Alchemists and early chemists typically built the ovens used in their experiments themselves. A new design to

improve oven efficiency was published by Glauber under the name *Furni novi philosophici* (first edition, in German, 1646-49). Further improvements in oven construction were made by Kunckel as reported to Prince Elector Johann Georg II in 1675 (see Ref. 7, p 260). None of these designs could produce the temperatures needed for porcelain production. This explains Böttger's preoccupation with oven design during October/November, 1707.

30. Ref. 7, p 219.
31. Ref. 17, pp 76-79.

ABOUT THE AUTHOR

Dr. Nicholas Zumbulyadis obtained his Diploma in Chemistry in 1971 from the Technical University of Darmstadt, Germany and his Ph.D. in physical chemistry from Columbia University in 1974. In March, 1976 he joined the Eastman Kodak Research Laboratories, where he worked until his retirement in June, 2005. He is the author of over 55 papers in solid state nuclear magnetic resonance as well as several patents. Zumbulyadis is also a collector of 18th-century European porcelain and the author of the book *Meissen's Blue and White Porcelain*, Schiffer Publ. Ltd., Atglen, PA, 2006, as well as related talks and articles published in art historical journals. His current research focuses on the history of cobalt blue pigments from the twin perspectives of the chemist and art historian.

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