

A CASE FOR THE PRODUCTION OF THE EARLIEST COMMERCIAL HARD-PASTE PORCELAINS IN THE ENGLISH-SPEAKING WORLD BY EDWARD HEYLYN AND THOMAS FRYE IN ABOUT 1743

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Kiln-firing of analogue Bow first patent porcelains demonstrates that such wares ('A'-marked porcelain group) are hard-paste (*pâte dure*). These ceramics have a biaxial starting composition comprising refractory China clay and lime-alkali glass cullet, a high-firing Si-Al-Ca body and glaze, demonstrate resistance to thermal stress, exhibit a micro-texture showing marked recrystallisation of the porcelain body (calcium plagioclase and two glassy phases), and display both good translucency and a sub-conchoidal fracture. Manufactured commercially in east London *circa* 1743–1745, they predate Chelsea soft-paste porcelain by some twelve months or more, William Cookworthy's hard-paste porcelain by a quarter of a century, and represent the earliest Anglo-American response to Meissen and the Asiatic.

Key words: Bow porcelain, William Cookworthy, Meissen, Chelsea porcelain, hard-paste porcelain, *pâte dure*, Cherokee clay.

SINCE THE LATE 1930s, when the 'A'-marked porcelains were recognised as a coherent group, there has been a reluctance to accept these wares as the products of the 1744 Bow patent manufactured by Heylyn and Frye in east London. This hesitancy has been based in part on a general state of denial within English ceramic circles of the veracity and efficacy of this 1744 ceramic patent filed in London on 6 December, 1744 by Edward Heylyn and Thomas Frye, two of the proprietors of the Bow porcelain manufactory. Consequently a variety of factories other than Bow, some likely to prove to be more fictitious than real, have been proposed as a source for these technically and artistically brilliant ceramics. Although the 1744 patent details in remarkable clarity the nature of the raw materials required, the proportions necessary for body and glaze, and the manner of manufacture of such porcelains, these specifications have been variously declared as vague, experimental, cautious, hesitant, uncertain, tentative, not worth the paper they are written on, and nothing but a sea of troubles. Ramsay et al. (2006) have demonstrated that these prevailing negative views and notions have been predicated on misleading concepts and interpretations. These include an erroneous version of the patent (Chaffers 1863), an incorrect recipe for the glass frit specified in the patent (Church 1881, 1885) which was employed by Burton (1902) during his failed attempts to make analogue Bow first patent wares, deductions from the patent taken out of con-

text (Tait 1959), and an unsubstantiated claim by Watney (1963, 1973) that the patent recipe using Cherokee clay (*uneka*) was almost certainly unworkable. Because of this general reluctance to accept the Heylyn and Frye 1744 patent, ceramic commentators over many years have been poorly placed to recognise and accept the porcelains that are derived from this set of specifications. Moreover Watney (1963, 1973) further proposed that this patent might have been entered merely to monopolise the use of the *uneka* clay so as to allow the patentees, Heylyn and Frye, more time in which to develop a hard-paste formula. What Watney failed to recognise is that these patent specifications, as will be shown in this discussion, are themselves a hard-paste formula.

The aim of this contribution is to examine the concept of hard-paste porcelain and based on our previous research including the firing of analogue Bow first patent wares (Ramsay et al. 2001, 2003, 2004a, 2006), to demonstrate that the products of the 1744 patent are hard-paste. Built on the notion that the 'A'-marked group represents Bow first patent porcelains and that Bow was producing these commercial, hard-paste wares by c.1743, a re-evaluation of the significance of the Bow porcelain manufactory and its ceramic output has now been underway for the last six years.

HARD- AND SOFT-PASTE PORCELAIN

Savage and Newman (1976) recognise three types of porcelain, namely true porcelain, artificial porcelain, and bone china. Alternative names employed for true porcelain are hard-paste porcelain or *pâte dure* in France and *porcelaine royale* at Sèvres. In the case of artificial porcelain, synonyms recognised by Savage and Newman (1976) are soft-paste porcelain, *pâte tendre*, *porcelaine de France*, and frit porcelain. Porcelain of this kind is claimed by these writers to be made with powdered glass as a substitute for the feldspathic rock regarded as being used in true porcelain.

Singer and Singer (1963) record that hard porcelain has come to cover a wide range of bodies and primarily such types are regarded as a high-quality, dense body of which one type is known as true Continental hard porcelain comprising largely potash aluminosilicates. This body was developed as a copy of Chinese porcelains for tableware and artware. However as will be shown below this theoretical Chinese recipe is but one of many Chinese formulations and there is no unique composition which characterises Asiatic wares as a whole.

Godden (2004) comments that there are two basic types of porcelain namely hard- and soft-paste. He notes that Chinese and Japanese were of the 'true' or hard-paste type, as were porcelains from Meissen and from most European factories. In contrast early Vincennes or Sèvres porcelain of the period 1745 – 1772 (together with other early French factories such as Saint-Cloud, Mennecy, and Chantilly) were of the artificial or soft-paste type. Likewise most 18th century English concerns were also of the artificial variety. Godden (2004) lists the features typically associated with hard-paste and these include a white and glittery surface, a cold feeling on being touched, a brittle nature with conchoidal fractures visible on chipped surfaces, a physical hardness traditionally verified with the use of a steel file, and a hard glaze with a tendency for the on-glaze enamels to lie on the surface rather than to sink in. In reality Godden notes that there are numerous exceptions to the above rules and that with practice it is apparently possible to differentiate by eye and touch between hard-paste and soft-paste porcelain. Godden then points out that there is a school of thought that suggests that these terms relate only to the firing temperature employed, with hard-paste wares undergoing a 'hard' fire at temperatures of 1,300 – 1,400°C and soft or artificial English wares being subjected to a 'soft' fire at around 1,200°C.

The term or concept of hard-paste porcelain appears to have originated with Alexandre Brongniart in that such wares required a hard fire as recounted by Honey (1962),

Such 'true' porcelain is white and translucent and shows a conchoidal, or shell-like, fracture; it was called hard-paste by Alexandre Brongniart apparently because it requires a 'hard fire' (that is to say, a high temperature in the kiln) to fuse it, but the name is customarily taken to refer to its characteristic hardness to the file. 'Soft-pastes' are imitations of true porcelain made of ground-up glass of various composition mixed with white clay or other substances; they fuse at a low temperature and are glazed with easily fusible lead glazes.

However the visual distinction between hard- and soft-paste porcelain bodies is in a number of instances difficult as noted by Antoine d'Albis (1999), who asks,

Was there a connoisseur of the day who could have distinguished between Böttger's whites and the white of Saint-Cloud?

D'Albis further notes that the scientific fraternity of former years, distinguished between the two by placing a cup made of soft-paste inside a cup made of hard-paste porcelain and then heating both to a high temperature inside a kiln. Inspection after cooling would demonstrate that the soft-paste body had melted whilst the latter would have remained intact and thus be credited with the term 'genuine porcelain,' a term that finds parallels with the English, who refer to true hard-paste porcelain comprising kaolinite clay and a feldspathic flux (*petuntse*).

Consequently one of the major distinguishing features between hard- and soft-paste porcelains is the temperature at which sintering and partial vitrification of the body is achieved. Singer and Singer (1963) state that firing temperatures for hard porcelain range between cone 9 (1,280°C) and cone 16 (1,460°C) (Table 1). Fleming and Honour (1979) regard hard-paste porcelains to have been fired between temperatures of 1,250 – 1,350°C, while soft-paste bodies reach maturity at temperatures distinctly below 1,250°C (Table 1). Kingery (1986) states that soft-paste bodies are fired at temperatures of around 1,100°C while early Böttger porcelain required temperatures in the order of 1,355°C. In the case of early Chinese porcelain, temperatures of between 1,250 and 1,300°C are estimated (Kingery 1986). Miller (1998) regards soft-paste bodies to have been fired at temperatures less than 1,250°C, while hard-paste por-

Table 1. Criteria used by various authors to differentiate between hard- and soft-paste porcelains.

Author	Porcelain type	Firing temperature	Raw materials	Glaze	Mineralogy	Physical appearance	Chemistry	Notes
Hobson (1905)	Soft-paste	1,100 – 1,150°C	Small amount of white clay substance fluxed with a glass or frit	A very fusible glass made with red lead, nitre, sand etc, with the body fired first and the glaze fired subsequently at a lower tempt. Glaze scratched with steel blade	Not specified	Fracture of the body is saccharoidal or granular. Colours sink into the body and become incorporated with the softer glaze, gaining in durability and luster	Not specified	Body easily scratched with a penknife or file
Singer and Singer (1963)	Hard-paste	1,350 – 1,450°C	China clay mixed with <i>petuntse</i> +/- a little silica sand	<i>Petuntse</i> +/- lime. Body and glaze usually fired together	Not specified	Conchoidal fracture, colours stand out dry and hard	Not specified	Body harder than a penknife. Body and glaze bonded together
	Hard porcelain	Between cone 9, 1,280°C and cone 16, 1,460°C	European hard-paste porcelain composed chiefly of kaolin, quartz, and K feldspar	Various glazes	Variable amounts of glass, quartz, mullite +/- cristobalite	Typically high-quality, dense body. Continental hard-paste white, vitrified, translucent.	Continental hard-paste SiO ₂ 58–73, Al ₂ O ₃ 18–36, K ₂ O 1–8, CaO 0–4 wt%	The most translucent porcelains lack free quartz in the body. Discoloured by impurities
Weiss (1971)	Soft porcelain	Low-fired bodies of high translucency	Mixtures of a large proportion of glass frit, used together with smaller quantities of clay, quartz, and possible whitening	Typical glaze comprises litharge (PbO), quartz, potash, and soda	Not specified	Typically vitreous, white, and translucent	Variable	Subdivided according to the raw materials. Most vitrified in the biscuit firing (< cone 11) and then glost-fired at a lower temperature
	Hard-paste	>1,350°C	Kaolin + various fluxes including feldspar, alabaster, micaceous sand	High-firing	Melilite (<i>stic</i>), quartz, glass	Hardness 6–7, dense, white, translucent, resonant	Not specified	
Fleming and Honour (1979)	Soft-paste	Typically much <1,250°C	Various including white clay and ground glass	Low-tempt glaze, often lead-based	Not specified	Not specified	Not specified	
	Hard-paste	1,250 – 1,350°C	Kaolin + China stone	High-tempt glaze applied before firing	Fused to a glassy matrix	Not specified	Not specified	

Author	Porcelain type	Firing temperature	Raw materials	Glaze	Mineralogy	Physical appearance	Chemistry	Notes
Kingsley (1986)	Soft-paste French porcelain	~1,100°C	Calcareous clay, limestone, glass frit containing silica, gypsum, soda ash, sea salt, potassium nitrate	Low-tempt lead-based glaze	Tridymite/cristobalite, wollastonite set in a glassy matrix	Sugary texture	Low alumina ~2 wt%	
	Hard-paste Böttger porcelain	~1,355°C	Colditz clay, or purer kaolin clay from Aue fluxed with alabaster	High-firing lime, quartz, clay. Al ₂ O ₃ ~ 19 wt%	Mullite set in a high-lime glassy matrix, nearly quartz free	Smooth fracture	High alumina ~30 wt%, SiO ₂ 61.5%, CaO 6.3 %, K ₂ O 0.3%	Whiteness and translucency desired by Europeans
	Hard-paste Chinese porcelain	1,250 – 1,300°C	Quartz, feldspar, sericite, +/- kaolin	High-firing	Mullite, glassy matrix, quartz	Smooth fracture	High alumina	
Miller (1998)	Soft-paste	<1,250°C	Various with kaolin typically low or absent	Low-firing and sits on the surface	Not specified	Translucent granular surface	Not specified	
	Hard-paste	Up to 1,400°C	Typically kaolin, China stone, quartz	High-firing and bonded to the body	Not specified	Translucent, granular surface	Not specified	
Owen (2002)	True (Chinese) porcelains	Single high-tempt firing ~1,400°C	Contains natural ingredients only – China stone, China clay	Usually a lime-alkali glaze capable of withstanding very high tempts	Not specified	Not specified	Not specified	
	Artificial or soft-paste	Initial firing ~1,250°C	Contains some man-made ingredients (fritted mixtures of various compounds)	Glazed at a lower tempt with early porcelains containing lead	Not specified	Not specified	Lead-based glazes on early porcelains vary from 10 – 55 wt% PbO	
Godden (2004)	Soft-paste	About 1,200°C	Includes crushed glass, bone ash, silica, various clays, chalk, soapstone	Has a warm friendly feel and is relatively soft	Not specified	Broken surface tends to appear granular and lacks a conchoidal fracture, can appear stained	Not specified	
	Hard-paste	>1,300°C	China clay (kaolin) with China stone (<i>petuntse</i>)	Contains <i>petuntse</i> , lime and potash	Not specified	Surface may appear cold, glittery, tends to be brittle	Not specified	Identification tends to rest with experience and feel

celain requires temperatures up to 1,400°C depending on the clay/flux mix. Possibly the most extreme temperature divide is that employed by Weiss (1971) where he places the lower boundary for hard-paste porcelains at greater than 1,350°C (Table 1). Likewise Owen (2002) suggests that Chinese hard-paste porcelains undergo a single kiln-firing of around 1,400°C. We note that such a high temperature threshold of 1,350 – 1,400°C would exclude many Oriental hard-paste wares fired in the region of 1,280 – 1,350°C and based on the various temperature estimates given in Table 1 a broad defining boundary of around 1,250°C offers a convenient thermal divide between soft- and hard-paste porcelain bodies.

Resistance to thermal shock or thermal stress (rapid changes in temperature) has traditionally also been used to differentiate Oriental porcelains from soft-paste wares. D'Albis (1999) records that this feature was employed by Jussieu and Duhamel du Monceau, who set about to verify the claims made by Pierre Joseph Macquer that he had fired hard-paste porcelains using material found at Saint Yrieix. Likewise, Thomas Briand claimed that his porcelains exhibited before the Royal Society of London on 10 February, 1743 were both resistant to thermal shock and were refractory in nature (Mountford 1969). Assuming the veracity of Briand's claims one can deduce that his porcelains would have contained considerable amounts of refractory China clay and on this basis there is but one group of porcelains known to have been manufactured at this time in London that conforms to these properties (Daniels 2007), namely Bow first patent porcelains.

The reason for this greater resistance to thermal shock shown by hard-paste porcelain bodies has been explained by Kingery and Vandiver (1986). Low-firing bodies containing free-silica derived from quartz sand or crushed flint, develop outer rims of disordered cristobalite (a high-temperature silica polymorph) at temperatures > 870°C (Hamer 1975). This cristobalite on cooling to around 200°C reverts to another crystalline form with a volume change similar to quartz. Consequently density and hence volume variation during initial heating and cooling results in incipient fractures extending out from the silica grains into the remainder of the body. These incipient fractures act as loci for subsequent heat-induced stress and such fractures migrate rapidly through the ceramic body resulting in rupture. In contrast, high-firing bodies develop siliceous melt rims (not cristobalite) around any quartz grains in the body. This melt phase on cooling forms a glass typically lacking

associated stress fractures leading into the surrounding body or matrix. This absence of stress fractures between glassy rims and matrix in high-fired wares confers greater strength to the porcelain body. In the case of essentially biaxial bodies such as Böttger's porcelain from Meissen or Bow first patent bodies, this silica conversion problem rarely exists as both recipes lack the addition of a free-silica phase, other than minor silica impurities associated with the China clay used. Regardless, both bodies, because of their high-firing characteristics, would tend to form siliceous glassy rims rather than cristobalite around any remnant free-silica particles present that escaped the washing process and consequently both bodies display excellent thermal stress resistance. Singer and Singer (1963) observe that bodies with very high quartz contents may have excess quartz in the fired body, which under prolonged firing may result in cristobalite appearing. Because of cristobalite's higher expansion coefficient, this may lead to reduced thermal shock resistance.

Sandon (1989) regards the presence of kaolin clay and the method of firing as key discriminators between hard- and soft-paste porcelain. Hard-paste bodies are matured in a low-temperature glaze kiln and the glaze is subsequently applied to the immature, underfired body, whereupon both body and glaze are fired together at a higher temperature to maturity. This feature is found with both Meissen porcelain and William Cookworthy's porcelain and is the method inferred by us to have occurred in the firing of Bow first patent wares (Ramsay et al. 2004a).

Microtexture of the porcelain body has also been used as a discriminant between hard- and soft-paste porcelains. Church (1898) gives a detailed description as follows,

If we bring in the microscope to aid us in the discrimination of these differences and resemblances, we shall find that all the hard porcelains, as well as the stonewares which come nearest to them, have a common and distinctive structure which never occurs in the glassy, phosphatic and siliceous pastes, fired at a lower temperature, which simulate them in outward appearance.

The peculiarity of structure consists in the presence of a vast number of small, straight-ended slender rods called belonites, (crystallites) and of many minute granules called spherulites, both rods and granules having been formed out of the original materials, but not pre-existing them: embedded in a clear or nearly clear paste, the binding material or cement (glassy melt

phase). This observation helps us to a classification, which, if necessarily imperfect from the very mixed and capricious products with which one has to deal, does, at least, recognize the main characteristics of the different types.

Church is arguing here that hard-paste porcelains show a degree of recrystallisation and retexturing not found in lower fired, soft-paste wares.

Owen (2002) emphasises the use of at least some man-made ingredients (eg. fritted mixtures of various compounds) in artificial (soft-paste) porcelains. These wares are fired in a biscuit kiln (~1,250°C) and then subsequently glazed in a lower temperature glost kiln. In contrast, Owen argues that true (Chinese-type) porcelains contain only 'natural ingredients' (eg. China stone and China clay), which are given a single high-temperature (~1,400°C) firing during which the glaze fuses to the body. Glazes associated with these bodies are typically of an alkali-lime type. We suggest that such a distinction between soft- and hard-paste wares based on the presence or absence of man-made ingredients might possibly be artificial. An example is provided by the use of man-made slaked alabaster in early Meissen hard-paste porcelain. However Owen's contention that recourse to a single, high-temperature firing for both body and glaze in hard-paste porcelains is in concert with numerous other commentators such as Sandon (1989) as a key characteristic of hard-paste porcelains.

The assumption of the necessary presence of a high-firing, or refractory kaolinitic China clay in the body of hard-paste porcelains has been universally accepted by Western ceramic experts (Watney 1963, 1973; Rado 1969; Savage 1970; Sandon 1989; Young 1999; Hillis 2001; Owen 2002; Godden 2004). This Western belief in the importance of China clay can be traced back to the writings of the Jesuit priest, François Xavier d'Entrecolles.

D'ENTRECOLLES AND THE USE OF KAOLINITE CLAY BY THE CHINESE

A major influence on Western thinking as to the composition of Chinese hard-paste porcelains were two letters written by François Xavier d'Entrecolles, who resided and worked at Jingdezhen (*Ching-tê-Chên*) and wrote accounts of Chinese ceramic practices in 1712 and 1722. These letters were in turn published in Paris in 1717 and 1722 and then incorporated in Jean-Baptiste Du Halde's *The General History..... of the Empire of China, Chinese*

Tartary, Corea and Thibet, with the English edition appearing in 1736.

Based to a large degree on d'Entrecolles' writings, the concept of composition has tended to dominate Western thinking with respect to both Asiatic and European hard-paste porcelains. The notion of Chinese 'true' hard-paste porcelain has been widely accepted in the literature as comprising a mixture of China clay (refractory kaolin clay), and feldspathic rock, or *petuntse*. Savage (1970) in discussing true porcelain states,

In China it was made from kaolin (china clay) and a fusible feldspathic rock termed 'pai-tunt'zū, the latter usually written in the form employed by 18th-century French missionaries, who called it 'petuntse.'

Fleming and Honour (1979) define hard-paste (*pâte dure*) or true porcelain as,

...made from KAOLIN (white china clay) and a feldspathic rock called china-stone or PETUNTSE (chemically, silicate of potassium and aluminium) which when fired at a high temperature (1250 –1350 °C.) fuse(s) to a glassy matrix.

Young (1999) comments that the porcelains of China and Japan were high-fired, being fired between 1,300 and 1,400°C and that at these temperatures the two principal components of hard-paste are kaolin (China clay) and *petuntse* (China stone) fused to form a hard and vitrified white body. Likewise Godden (2004: 18) defines true or hard-paste porcelain as comprising China clay and China stone fused at or above 1,300°C; the related glaze comprising *petuntse*, lime, and potash. Possibly the most recent summary of the current thinking on Chinese 'true' hard-paste porcelain can be found with Carswell (2000: 20) where he writes,

Until relatively recently it had been generally thought that (Chinese) porcelain was a combination of two basic materials: kaolin (white china clay) and petuntse (pulverized porcelain stone). This was based on the observations of a French Jesuit, Père d'Entrecolles, who visited Jingdezhen in the early eighteenth century..... Two decades or so ago it began to be questioned whether the kaolin/petuntse combination was true, and a series of international conferences on ceramic technology in China have concluded that the formula is far more complex, not only varying at different periods and kiln sites but more recently being revealed to have a major divide between north and south China.....

Wood (2000) comments as follows,

Perhaps the greatest differences that have emerged from analytical studies of Chinese high-fired ceramics, in terms of their fundamental compositions, are those established between wares from the north and south of the country – with northern wares being rich in clay and the southern wares rich in quartz.

What has become apparent from compositional studies of Chinese porcelains over the last 25 years, with the opening up of the country to Western researchers and a more ready access to Western analytical techniques by Chinese scholars, is that the long-standing Western notion that Chinese ‘true’ hard-paste porcelains comprise but kaolin and a feldspathic flux is far too simplistic and fails to recognise the breadth in starting materials used, the geographical spread of kiln sites, the evolution of various types of body with time, and the variety of resultant fired porcelain bodies.

The earliest Chinese porcelains to have emerged were probably made during the Sui (581 – 617 AD) or the early Tang (618 – 906 AD) Dynasties. It appears that porcelain evolved from the high-fired northern white wares that were developed in the fifth or sixth century and were produced in the northern kilns of Hebei, Henan, Shaanxi, and Anhui provinces located north of the Yangtze River. Wood (2000) notes that the first porcelains to appear were during the Sui-Tang transition in the late 6th to early 7th centuries and these can be regarded as unusually pure versions of the more abundant northern stonewares, which reappeared in the north in quantity during the 6th century after a puzzling gap of some 1,600 years. Apparently, relatively pure sedimentary porcelain clays were combined with various fluxes thus producing tough, dense, white porcelain, which at times showed a translucency (Wood 2000).

Those clays from North China, which are relatively pure, approach the composition of kaolinite and were blended with variable amounts of quartz and feldspar thus approaching in composition the Western concept of ‘true’ hard-paste porcelain. Yanyi (1987) records that Ding white porcelain bodies comprise Lingshan refractory clay, 10–20 % feldspar and quartz, as well as small amounts of calcite and dolomite. Likewise Gongxian high-fired white wares comprise Gongxian clay blended with feldspar, whilst elsewhere such as in the Henan and Shaanxi provinces, less pure clays containing fluxes in their own right were mixed with purer more refractory clays to produce a suitable body. In short, the various porcelains produced from

the northern provinces of China reflect the nature and purity of the local raw materials and the resultant ceramic body is the product of the variable use and blending of clays (some of which are relatively pure kaolinites), feldspar, quartz, calcite, and dolomite and broadly these high-fired wares can be regarded as clay or clay-feldspar in composition as reflected in their typical high Al₂O₃ contents. What is apparent is that the Western concept of a kaolinite-feldspar recipe does not apply in all cases.

In contrast by 500 AD in South China glazed stonewares had been in production for two millennia (Chen et al. 1999). Yanyi (1987) in an important contribution based on the analytical results and deduced recipes obtained from numerous kiln wasters throughout China, states that the occurrence of significant deposits of porcelain stone in southern China formed the basic material of the high-firing body by the 10th century AD and led to the discovery of porcelain in the south. The main centre for this development appears to have been in the vicinity of Jingdezhen where at various 10th century sites, porcelains made from what is inferred porcelain stone are intermixed with grey-bodied, ash-glazed stonewares (Xinyuan & Kun 1980).

Porcelain stone has apparently been confused in the past with China stone (*petuntse*) and porcelain clay or China clay and as Yanyi (1987) has pointed out; this has resulted in considerable confusion, both among experts and in the literature. Porcelain stone is most likely derived from hydrothermally altered acid igneous rocks comprising intrusives, lavas, and fragmentals – both pyroclastic and epiclastic, which have undergone phyllic alteration. This resultant secondary or alteration assemblage comprises quartz, sericite +/- pyrite (Edwards & Atkinson 1986) and where the alteration merges with potassic alteration the assemblage quartz, orthoclase, biotite +/- albite, sericite, anhydrite, sulphides may develop. Subsequently these altered igneous assemblages, or porcelain stone, if lightly weathered may still contain some feldspar, either primary or secondary. However if such rock is exposed to prolonged weathering then any remnant feldspar will break down to kaolinite and the assemblage will then comprise quartz, sericite +/- kaolinite. Consequently the final mineralogy of porcelain stone will vary depending on the degree and type of hydrothermal alteration and the intensity of subsequent weathering or regolith development. Wood (2000) records that such rocks occur in the coastal provinces of southern China and include Jiangsu, Zhejiang, Fujian, and Guangdong.

The use of porcelain stone in the south of China may have commenced with the Yue kilns in Zhejiang province which produced high-fired wares with dense bodies dating to the Eastern Han dynasty of 221 BC – 220 AD (Yanyi 1987). Apparently the Yue kilns were not the only ones to employ porcelain stone in producing high-fired wares with Yanyi (1987) recording the Longquan kilns in Zhejiang, the Southern Song Guan kiln in Hangzhou, the Jizhou kilns in Jiangxi, the Hutian and Xianghu kilns of the Jingdezhen district, the Imperial factories of the Ming and Qing Dynasties, the Dehua kilns in Fujian and the kilns in the Jianyang district and various kilns in Anhui and Jiangsu as all actively employing porcelain stone as a key raw material. The actual development of porcelain out of these high-firing wares may have been known by Tang potters but it was apparently not until the Song Dynasty (960 – 1279 AD) that a translucent, high-firing ceramic, known to the West as porcelain, first appeared.

Apparently a porcelain body, where porcelain stone is used (quartz and sericite), has a narrow vitrification temperature and by the Yuan Dynasty (1280 – 1367 AD) in the south, kaolinite commenced to be added to the paste in order to broaden the range at which vitrification and sintering occurs and thus minimising the tendency for various vessels, especially larger ones, to become pyroplastic and deform (Yanyi 1987). From this time onwards porcelain stone was blended with kaolinite to make the porcelain body in the Jingdezhen region, with a concomitant increase in the Al_2O_3 content. Ren (1983) has demonstrated at least three sources for kaolinite in the Jingdezhen region, these being Mingsha, Xingzi, and Linchuan. Calculations by Yanyi (1987) has indicated that during the Yuan Dynasty some 10 – 20 wt% kaolinite was added to the Jingdezhen porcelain body with minor increases occurring during the Ming Dynasty (1368 – 1643 AD) and again in the Qing Dynasty (1644 – 1912 AD). This addition of kaolinite resulted in an increase in the range of firing temperatures, reduced the incidence of deformed wares, and increased both the strength and quality of the body and associated glaze.

In a note of caution Wood (2000) states that during the Yuan and Ming Dynasties the identity of this clay-rich additive and its physical properties are still being debated. However by the Qing Dynasty (1644 AD) kaolinite clay was now a major ingredient of the Jingdezhen porcelain body with its contribution rising to 40 – 50%. Wood (2000) further notes that kaolin was very much a Jingdezhen material and that it

saw little use at kiln sites such as Dehua in Fujian province, whilst porcelain kiln sites in both Korea and Japan appear to have managed with minimal or zero use of kaolin, where porcelain stone (in part kaolinised) alone was used. Yanyi (1987) states that porcelain stone on its own is both plastic and fusible and consequently is able to combine the properties of the more familiar Chinese recipe recognised in the West comprising kaolinite and feldspar. Consequently early porcelains from southern China made using porcelain stone tend to be siliceous, reflecting the abundance of silica in the recipe, and low in Al_2O_3 , reflecting either the absence or low levels of an aluminous clay such as kaolinite. In contrast porcelains derived from North China tend to be dominated by sedimentary or transported clays and consequently can be termed ‘clay’ or ‘feldspar-clay’ porcelains with associated high Al_2O_3 contents (Yanyi 1987). This compositional divide between north and south was apparently first recognised by Sundius and Steger (1963).

It now appears that the Western concept of ‘true’ hard-paste Chinese porcelain is based more on an accident of both timing and geographical location. Had d’Entrecolles visited Jingdezhen two or three hundred years earlier his description of what constituted Chinese hard-paste porcelain would have differed considerably from that observed by him in the early 18th century. Likewise had d’Entrecolles worked in Northern China instead during the early 18th century, again his description of Chinese porcelain would have departed from what he recorded to the south. Possibly the most succinct and incisive summary of current thinking on the composition of Oriental ‘true’ hard-paste porcelains rests with Wood (2000) where he states,

kaolin is an ‘optional extra’ in the East rather than the very basis of porcelain production as in the West.

THE DEVELOPMENT OF HARD-PASTE PORCELAIN IN EUROPE

The discovery of hard-paste porcelain in Europe is credited to Ehrenfried Walther von Tschirnhaus and Johann Friedrich Böttger at Meissen in 1709. Böttger’s porcelain or ‘fine transparent white porcelain’ was first produced commercially by 1713, yet for the period dating from ~1709 till Böttger’s death in 1719, if not into the very early 1720s, the paste recipe had little in common with that used in the Orient, other

than that clay of variable purity (initially Colditz clay and then subsequently a purer clay termed Schnorr's kaolinite clay, from Aue) was used. During this early period the flux employed was a ground and calcined alabaster ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) from Nordhauzen. Estimations of the firing temperature in the system SiO_2 – Al_2O_3 – CaO indicate $\sim 1,400^\circ\text{C}$, however the presence of very minor impurities in the clay in the form of Na_2O (0.1 wt%) and K_2O (0.3 wt%) is likely to have depressed the firing temperature to a little over $1,350^\circ\text{C}$ (Schulle & Ullrich 1982, 1985; Kingery 1986). Kingery (1986) observes that Böttger's porcelain for this early period does not contain as much quartz as found in Chinese porcelain and was not derived from a triaxial paste (quartz, feldspar, kaolin). Hence Kingery suggests that although widely regarded as hard-paste, Böttger's porcelain should be referred to as an entirely new composition, which resulted in high-firing white porcelain. Schulle and Ullrich (1985) regard the resultant body as not dissimilar to Chinese Ding ware while Menzhausen (1990) uses the term 'Böttger porcelain' to describe the wares for the period ~ 1713 – ~ 1720 . By the early 1720s a potassium feldspar (orthoclase) flux replaced the calcined alabaster flux and this allowed for a slight lowering of the firing temperature (Kingery 1986), nevertheless this later porcelain apparently had a lower quartz content than other hard-paste porcelains of Europe and that of the Chinese (Kingery 1986).

THE DEVELOPMENT OF HARD-PASTE PORCELAIN IN ENGLAND

Hard-paste initiatives in Britain

In England the first production of a commercial hard-paste porcelain body is widely credited to William Cookworthy, an apothecary living in Plymouth, who in 1768 enrolled his specifications for,

A kind of porcelain newly invented by me, composed of moorstone or growan and growan clay.

This important development of a hard-paste body using in part, growan clay (kaolinite) is universally accepted as representing the first high-fired, hard-paste body in English ceramic history (Burton 1906; Eccles & Rackham 1922; Mackenna 1946; Watney 1963, 1973; Sandon 1989; Spero 1998; Young 1999; Hillis 2001; Godden 2004). Cookworthy appears to have based his hard-paste porcelain recipe on the writings of d'Entrecolles and from both his patent wording and the work of Wood and Cowell (2002) it

has been concluded that William Cookworthy manufactured a range of ceramic bodies using these Cornish raw materials, namely growan, moorstone (or porcelain stone – an altered granite rich in quartz, feldspar, sericite +/- kaolinite) and growan clay. Cookworthy's glazes were made from related materials fluxed with limestone, which had been burnt with fern leaves. Based on these discoveries Cookworthy founded 'The New Invented Plymouth Porcelain Company' in 1768 and commenced to produce commercial hard-paste wares until the concern was moved to Bristol in 1770 and finally sold to Richard Champion in 1774. As noted, Cookworthy appears to have produced a variety of hard-paste bodies (Table 2) ranging from one-rock bodies comprising partially kaolinised porcelain stone derived from St. Stephens in Cornwall through to bodies comprising the addition of prepared kaolinite clay (Wood & Cowell 2002).

Recent work on wasters obtained from the Devon kiln site of Bovey Tracey (Owen et al. 2000) has identified three highly siliceous and aluminous sherds typical of true porcelain (Table 2). Two of these sherds are similar in composition with SiO_2 63%, Al_2O_3 31%, K_2O 3.8%, and Na_2O 1.1 wt%, whilst the third is more siliceous and less aluminous with K_2O 2.6 wt% and similar Na_2O content to the former two sherds. Compositionally all three are regarded by Owen et al. (2000) as typical of so-called 'true porcelains.' They further note that on the one hand these excavated sherds do not necessarily prove that they originated from Nicholas Crisp's concern at Bovey Tracey yet on the other hand these sherds compositionally match no other known British porcelains and furthermore show evidence of being unfinished or kiln damaged. From this they conclude that these wasters represent pastes fired, if not also mixed at Indeo House, Bovey Tracey. These workers state that it is difficult to establish whether there was a direct relationship between Nicholas Crisp's 'true porcelain' c.1767 of the Indeo pottery, Bovey Tracey and that of William Cookworthy at Plymouth and Bristol. They conclude that the compositional dissimilarity between the Si-Al sherds recovered from Bovey Tracey and Cookworthy's Plymouth/Bristol samples, coupled with the compositional heterogeneity of both Crisp's and Cookworthy's 'true porcelains' suggests that both individuals experimented with a variety of 'true' porcelain pastes. Recently Daniels (2007) has suggested that based on evidence contained in correspondence between Cookworthy and Thomas Pitt, there are grounds for suspecting

Table 2. Oxide analyses for various porcelain bodies, glaze, and clay.

	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO ₂	63.5	64.9	68.1	44.8	74.1	64.3	61.8	59.0	70.0	72.3	63.42	63.0	82.6
TiO ₂	<0.2		0.1	0.01			trace	trace					0.4
Al ₂ O ₃	19.5	21.1	11.7	38.4		21.7	22.9	30.6		23.1	30.75	30.6	8.3
FeO	0.3		0.6	0.04*			0.02	0.03		0.4*		0.5	0.4
MgO	1.2	1.3	1.0	0.03	2.4	1.7	0.02	0.02		0.3	trace	0.3	0.3
CaO	6.1	5.6	13.6	0.06	10.4	5.6	7.5	5.0	15.0	0.3	0.53	0.3	5.2
Na ₂ O	4.2	4.5	2.2	0.06	8.3	4.1	7.7#	5.3#	15.0#	0.7	3.64	1.1	0.5
K ₂ O	3.6	2.6	2.2	0.33	4.8	2.4				3.0	1.66	3.8	2.0
P ₂ O ₅	0.5			0.02								0.3	
PbO	0.4		0.4										0.5
SnO ₂	trace												
LOI				16.24									
Total	99.3	100.0	99.9	100.00	100.0	99.8	99.94	100.0	100.0	100.1	99.98	99.9	100.2

1. 'A'-marked body (Freestone 1996: Table 1, analysis 1)
2. Average 'A'-marked body (Ramsay et al. 2004a: Table IV)
3. Glaze composition from an 'A'-marked cup (Ramsay et al. 2003)
4. Kaolinite clay, Macon County, NC (Ramsay et al. 2001: Table 1, analysis d)
5. Glass frit used in firing analogue Bow first patent porcelain (Ramsay et al. 2004a: Table II)
6. Analogue Bow first patent body (Ramsay et al. 2004a: Table IV)
7. Theoretical Bow first patent porcelain body with 1 clay : 1 glass ratio (Ramsay et al. 2001: Table 2)
8. Theoretical Bow first patent porcelain body with 2 clay : 1 glass ratio (Ramsay et al. 2001: Table 2)
9. Glass composition used in calculating the theoretical compositions 7 and 8 (Ramsay et al. 2001: Table 2)
10. William Cookworthy hard-paste porcelain body made at Plymouth (Tite & Bimson 1991). The body is deduced to have been made entirely from china clay rock, i.e. one rock body – see Wood and Cowell (2002)
11. William Cookworthy hard-paste porcelain body (Wood & Cowell 2002). The body is deduced to have been made from a 50:50 mixture of washed kaolinite clay and less altered porcelain stone still rich in Na feldspar
12. Bovey Tracey 'true porcelain' sherd (Owen et al. 2000: Table IV, BT5)
13. William Reid Si-Al-Ca sherd from Brownlow Hill, Liverpool (Owen & Hillis 2003: Table 1)

* total iron as Fe₂O₃

combined Na₂O and K₂O

LOI loss on ignition

that Crisp was firing hard-paste bodies using Cherokee clay before Cookworthy.

Based on excavated ceramic wasters from the lowest stratigraphical level from Warmstry House, Worcester Owen (1998) has identified abundant tan coloured Si-Al material (SiO₂ 75.3%, Al₂O₃ 19.8%, TiO₂ 1.5%, K₂O 1.7 wt%), which he tentatively equates with a type of high-firing 'stone china.' Owen (1998) comments that compositionally such a body presaged the development of British hard-paste porcelain by nearly two decades and the investigation of various types of 'stone china' (*sensu lato*) and their relation to early hard-paste porcelains (*sensu stricto*) would be a fruitful avenue of research.

Wasters recovered from the Brownlow Hill site demonstrate that William Reid and Co. were experi-

menting with three major recipe types namely, phosphatic, Si-Al, and Si-Al-Ca bodies (Owen & Hillis 2003). Visual examination of the analyses of the Si-Al-Ca sherds provided by Owen and Hillis (Table 1, Nos. BH7, BH18, BH19, BH20) indicates that William Reid was using a recipe comprising crushed silica, ball clay (probably from Dorset or Devon), and mixed glass cullet (lead and calciferous-alkali glass) apparently in an attempt to replicate the Bow first patent specifications. Of note is that in these Brownlow Hill sherds remnant relics of calciferous-alkali glass frit are not preserved in contrast to that for Bow first patent porcelains (Freestone 1996; Ramsay et al. 2004a). Owen and Hillis (2003) suggest that this indicates that either the firing temperature was higher for the Brownlow Hill sherds than that required at

Bow or that calcite (limestone) was the main source of calcium. William Reid (as with Limehouse) replaced refractory China clay with ball clay and the glaze used was a lead glaze. In the pure system $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-CaO}$ (Osborn & Muan 1960) the theoretical temperature for the composition of the measured melt of the Brownlow Hill Si-Al-Ca sherds is 1,400°C (Owen & Hillis 2003). However in this case the presence of additional fluxing agents will reduce the necessary vitrification temperature considerably, though as noted by Owen and Hillis, this effect cannot be quantified without experimental data. In the case of early Meissen porcelain the presence of very minor K_2O (0.3wt%) and Na_2O (0.1wt%) in the paste recipe was enough to lower this theoretical temperature nearly 50°C (Schulle & Ullrich 1982, 1985; Kingery 1986).

Excavations from the Limehouse factory site in Duke Shore (Tyler et al. 2000) have recovered two compositional porcelain groups, namely Si-Al and Si-Al-Ca bodies (Freestone 1993; Owen 2000). Owen comments that the Si-Al group has a composition and glaze comparable to true porcelains produced in England some two decades after the closure of Limehouse. However instead of the use of a China clay, the Limehouse proprietors relied on ball clay as deduced from the distinct presence of TiO_2 and a flint glass frit as indicated by the lead content in the analysis. Owen continues that such sherds are not unique as based on the personal correspondence of Richard Pococke in 1750, where he states that Lund's Bristol produced a type of yellowish ware, termed 'stone china' made from a pipe clay and flint-rich recipe. This ware in turn apparently finds its equivalent in compositionally and aesthetically similar sherds recovered from Warmstry House in Worcester (Owen 1998).

Analytical results reported by Paul Bemrose for a number of sherds recovered from an archaeological excavation at Pomona, Newcastle-under-Lyme (Bemrose 1973) showed that the samples fell into two broad divisions with one group of nine samples having Al_2O_3 contents of around 15wt%, CaO not in excess of 1wt%, and modally the presence of the mineral mullite. Bemrose describes this group in a table listing three of the analyses as *proto porcelain* but in the body of the text states that these wares were in reality a type of stoneware.

A feature of this recent work on wasters recovered from Bovey Tracey, Brownlow Hill, Warmstry House, Limehouse, and Pomona is that relating to the presence of siliceous-aluminous-calcic (SAC)

and siliceous-aluminous (SA) groups. The latter assemblage, which tends to crystallise mullite ($3\text{Al}_2\text{O}_3\cdot 2\text{SiO}_2$) rather than Ca plagioclase, has been regarded as representing 'true porcelain' (Owen & Hillis 2003; Owen et al. 2000). The resultant mineralogy in the siliceous-aluminous group (presence of mullite) in turn reflects the starting materials utilized. Our view is that a range of compositions can arrive at a hard-paste body (Singer & Singer 1963), and that there is a degree of circular arguing for the presence of mullite to define a hard-paste body. By marginally increasing the Ca flux content in the body of the porcelain ware the bulk composition will migrate from the mullite field to the anorthite field within the silica-mullite-anorthite compatibility triangle of the $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-CaO}$ phase diagram (Osborn & Muan 1960).

Although it has been suggested that John Dwight, working in the late 17th century failed to manufacture porcelain (Tite et al. 1986; Hillis 2001) it might appear that the body of his fine white stoneware or 'porcelain' (Al_2O_3 11.6–18.0 wt% and K_2O 2.24–5.35 wt%) fell within the compositional range of yingqing porcelains of the Yuan Dynasty (Tite et al. 1986), with both tridymite and mullite recorded. Likewise firing temperatures for Dwight's white stoneware have been estimated by Tite and co-workers to have been in excess of 1,200°C and for two samples (FP20 and FP27) possibly greater than 1,250°C. Whilst Dwight may have experienced problems applying low-temperature glazes the implication drawn is that he did produce a high-fired, translucent body, though not in commercial quantities.

Bow first patent porcelains

In 1937 a small coherent group of hitherto unattributed porcelains, called the 'A'-marked group on account of the typical presence of an 'A,' either inscribed or painted on the base of most items, was recognised (Elliot 1939). Arthur Lane (1958) in discussing this enigmatic ceramic group noted that members appeared to have contained some kaolin clay, that the glaze was close-fitting, the body had a modified conchoidal fracture and was harder in composition than English soft-paste porcelains and softer than hard-paste German wares. Lane tended to an Italian attribution for this group, however he noted that the 'A'-marked group pieces differed considerably from any of the identified Italian porcelains in the fineness of their potting.

In 1971 Charleston and Mallet published a seminal work on this porcelain group. Here they recognised and described twenty eight 'A'-marked items as well as providing a partial chemical analysis of the body of a so-called high-style decorated teapot from the collections of the Victoria and Albert Museum (V&A C207–1937). Possibly the most significant contribution that arose out of Charleston and Mallet's work was the proposal that the group was of British origin, not Continental, based in part on the depiction of a cricket scene contained within one of four vignettes contained on a covered sugar bowl now housed in the Melbourne Cricket Club Museum (Ramsay et al. 2004b). Additional support for an English origin of this group is to be found in the presence of numerous scenes taken from the English operetta *Flora* by John Hippisley and first performed in April 1729. Based on the chemistry of the porcelain body Charleston and Mallet (1971) note that if the porcelain material produced under the 1744 Bow patent of Heylyn and Frye was a kind of modified hard-paste, then its formula might have borne some resemblance to that of the 'A'-marked group of porcelains.

Subsequent work by the Ramsays and co-workers (Ramsay & Ramsay 2006; Ramsay et al. 2001, 2003, 2004a,b, 2006), largely based on the ceramic patent filed in London in December 1744 by Edward Heylyn and Thomas Frye, has both recognised the products of this patent as being the hitherto enigmatic 'A'-marked group and has proposed that this patent document represents an unrecognised landmark in the history of Anglo-American porcelain development. A key feature of the patent specification is the description and location of the material or earth used in the manufacture of the porcelain body and its associated glaze. These specifications state that the earth, or *uneka*, is the produce of the Cherokee (*sic*) nation in America, being very fixed, strongly resisting fire (refractory) and menstua (dissolution), is extremely white, tenacious, and glittering with mica. The patent specification then continues requiring the earth to be washed and the associated sand (quartz grains) and mica, being of no use, to be removed (Table 2).

Based on the wording of the Heylyn and Frye 1744 patent, analogue first patent porcelains have been fired using refractory Cherokee clay (Ramsay et al. 2001, 2004a) and as a result of the high kiln temperatures recorded during the firing of these analogue wares, coupled with the physical properties and micro-texture of the resultant porcelain body, it

has become apparent that such porcelains are hard-paste and not soft-paste (Table 2). These results support the observations of Daniels (2007) who is the first to recognise the link between the Vincennes Privilege signed on 24 July, 1745 and 'A'-marked porcelains. This privilege provides a time-marker for Bow first patent porcelains because by this date there is reference made to these inferred ceramics by the French, who had recognised their superior composition which, in contrast to their own soft-paste wares and that of Chelsea could alone compare with Meissen porcelains.

Bow first patent porcelains as hard-paste

Based on our observations and the firing of analogue Bow first patent porcelains we list the key features that lead us to the notion that the products of the 1744 patent of Heylyn and Frye are hard-paste.

Composition with 50% or more refractory China clay.

Based on the 1744 patent specifications the body of Bow first patent porcelains comprises 50% or more refractory clay (...*strongly resisting fire*). Both from the description provided in the patent (*white, tenacious, and glittering with mica*) coupled with the location of where the clay was most likely sourced by the Bow proprietors in Macon County, North Carolina (Ramsay et al. 2001) it is possible to ascertain that the clay or *uneka* utilised in the Bow first patent was a refractory China clay (Table 2). Other workers to various extent have also concluded that the clay referred to in the 1744 patent or as found in the body of 'A'-marked wares, the products of this patent, is a China clay (Binns 1898; Dillon 1904; Hurlbutt 1926; Lane 1958; Freestone 1996). Contemporary documents of the day which state that there was a ceramic concern producing porcelain using China clay or interested in the use of clay from the Carolinas include the 1744 patent itself, the letter dated 27 July, 1745 by William Cookworthy to his friend Dr Richard Hingston, and the account by Dossie (1758). More recently, correspondence dated 14 December, 1744 (one week after the Bow first patent was filed) refers to the patent itself, Aldermen, China ware, and fine earth from Carolina (Bridge & Thornton 2006).

High-firing composition. Ramsay et al. (2004a) have demonstrated that analogue Bow first patent porcelains fired using China clay from the Carolinas and a lime-alkali glass flux in a ratio of 1:1 are high-fired

with a 'heat-work' level of Orton cone 9–90° deflection at 150° per hour (~1,279°C). We suggest that where the percentage of China clay is increased to a 2:1 mix (Table 2), as stated as a possibility in the 1744 patent, the required threshold temperature would increase and may exceed 1,300°C. Patent specifications state that up to 80 wt% clay may be used while chemical analysis of porcelain bodies obtained from various 'A'-marked examples to date demonstrate that the China clay component may reach ~70 wt% of the body. Consequently it is reasonable to assume that the attendant firing temperature was higher for those bodies with >50 wt% clay than that recorded for the analogue body with a 1:1 clay:glass mix. It is this high-firing feature (>1,250°C) more than any other that characterises Bow first patent porcelains and defines them as hard-paste. This aspect finds parallels with the claims by Thomas Briand of February 1742/43 made before the Royal Society of London.

Introduction of an amorphous flux. As with Meissen porcelain, Bow first patent porcelains have a biaxial composition comprising two end members. With Meissen the calciferous flux was initially calcined alabaster but by around 1721 a potassic flux in the form of ground orthoclase was introduced. In the case of Bow first patent porcelain the flux comprised an amorphous crushed lime-alkali glass cullet (Table 2). We have inferred that with time the Bow proprietors appear to have commenced buying in bulk lots of second hand cullet based on the very low lead levels found in one or two members of Bow first patent wares (Ramsay et al. 2004a). This suggests to us that during the sorting process minor amounts of lead glass (flint glass) were inadvertently added. The traditional European view is that porcelains containing a glassy frit must as a consequence be soft-paste, however we contend that this view involves circular arguing (Ramsay & Ramsay 2006) and it is largely of little consequence whether the flux is added in a crystalline or non-crystalline (amorphous) form. What is of more significance in defining whether the porcelain body is a soft- or hard-paste are the other components, be they a low-firing ball clay or marl or a high-firing refractory China clay.

Biaxial composition and resistance to thermal stress. Based on the work of Kingery and Vandiver (1986) and the specifications contained in the 1744 patent we conclude that Bow first patent porcelains, as is the case with Meissen porcelain, have a biaxial composition. With Bow this is a refractory China clay and lime-alkali glassy frit or crushed cullet lacking any ap-

preciable amount of, if any, added free-silica. Hence on theoretical grounds discussed above coupled with data obtained from analogue first patent porcelains, it can be demonstrated that these wares are resistant to rupture during rapid temperature changes.

Mineralogy. The bulk composition of Bow first patent porcelains plots within the silica-mullite-anorthite compatibility triangle in the system $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-CaO}$ (Osborn & Muan 1960). This general Bow composition comprises $\text{SiO}_2 \sim 71$ wt%, $\text{Al}_2\text{O}_3 \sim 22\%$, $\text{CaO} \sim 7\%$ (Table 2) as compared with early Böttger porcelain with $\text{SiO}_2 \sim 63$ wt%, $\text{Al}_2\text{O}_3 \sim 31\%$, $\text{CaO} \sim 6\%$ (Kingery 1986). Studies on the mineralogy of a Bow first patent body (Charleston & Mallet 1971; Freestone 1996) and an analogue body of Bow first patent porcelain (Ramsay et al. 2004a) have recognised the presence of Ca plagioclase and glass lacking mullite. Although mullite is traditionally regarded as a key indicator mineral of 'true' hard-paste porcelains (Kingery 1986; Owen & Hillis 2003; Owen et al. 2000) our view, as noted above, is that hard-paste porcelains can be arrived at via a number of compositions and minor variations in bulk composition and firing conditions can result in the crystallisation of Ca plagioclase. If necessary qualifiers can be attached to these various porcelain types such as Böttger hard-paste (Si-Al-Ca) porcelain (Menzhausen 1990) where mullite is the key mineral, or Bow hard-paste (Si-Al-Ca) porcelain where Ca plagioclase dominates.

Presence of a high-firing Si-Al-Ca glaze. From the wording of the 1744 patent Ramsay et al. (2004a) have concluded that Heylyn and Frye fired their porcelains in a two-step process. The first stage was to a porous biscuit body (~900°C). This was then glazed using the same components as the body but having a greater percentage of lime-alkali glass and both the Si-Al-Ca body and glaze were then fired to the top temperature to achieve a close fitting matt- to wet-looking glaze. As noted by Hurlbutt (1926) and confirmed by Ramsay et al. (2004a) Heylyn and Frye were apparently using the glaze as a crude but effective optical pyrometer. This feature of firing the body and the glaze together finds parallels with Meissen and is distinctly different from the methods used by both the French and English in firing the glaze for soft-paste porcelains. In addition the glaze used in Bow first patent wares is lead-free, another feature in accord with Meissen composition and technology.

Professor Nigel Wood (written com., 2005) makes a significant comment that one of his research students

has been working on crystalline glazes (high-zinc) and has tested a range of mixtures of China clay and lime-soda glass to make what Wood describes as a mid-temperature glaze. Apparently this student obtained good results at 1,170°C with a recipe of 70 glass : 30 clay and at 1,200°C this glaze became well matured. Wood also notes that the 1744 patent gives a number of body recipes but one glaze recipe alone. This suggests to him that unlike the Cookworthy patent, which was definitely a low-biscuit, hard-glost process, the 1744 patent proposed several high-firing body recipes but one lower temperature glaze recipe, ie one glaze recipe fits all. We note that firstly the patent wording states,

It is then to be dip't into the following glaze:-
Take unaker forty pounds..... and left of a proper thickness for the ware to take up a sufficient quantity. When the vessels, ornaments, &c, are dry, put them into the kiln in cases, burn them with a clean wood fire.....

From this quote we infer that the various wares were still porous after an initial low-biscuit firing when they were dipped in liquid glaze (...*take up a sufficient quantity*). When firing analogue 1744 patent wares (Ramsay et al., 2004a) we observed that it was difficult to get the glaze to stick to the unglazed, high-fired, porcelain surface. Likewise Burton (1921) comments in regard to William Cookworthy's method of glazing his hard-paste porcelains,

He tried to adopt the Chinese method in coating the porcelain with glaze before any firing, but he remarks that it is very difficult to distinguish the proper thickness of the coat of glaze in this way, and he preferred to bake the shaped pieces to a soft biscuit state, **so that they would suck** (our emphasis), paint them with blue if required, dip them in the glazing mixture which readily dried on the biscuit ware and fire to an intense heat to vitrify the glaze.

Secondly we note that the patent deals essentially with a 1 clay : 1 glass body and we infer that the glaze specifications refer to that body. Although the patent specifications do mention other possible clay : glass ratios for the porcelain body, these additional ratios to our way of thinking are written in a somewhat casual manner and there is no indication that the glaze specifications necessarily apply to these additional variations in body composition. Lastly our glaze composition using Cherokee clay and a lime-alkali glass fully matured at around 1,280°C (cone 9).

Microtexture. Church (1898) has argued for a distinction between hard- and soft-paste porcelains

based on the degree of retexturing and the growth of crystallites as a result of high-temperature kiln firing. This degree of recrystallisation has been replicated in analogue Bow first patent porcelains (Fig.1). Here much of the primary texture has been obliterated except for remnant particles of lime-alkali glass cullet, now greatly modified in shape with prominent reaction coronae or rims containing crystallites of calcium plagioclase (anorthite ~An₉₀). These slender plagioclase crystallites represent metamorphic recrystallisation involving reactions between the aluminous kaolinite clay and the ground lime-rich glass cullet. Depending on the rate of quenching or cooling of the porcelain body after firing, we were able to reproduce various quench-textured products, whose morphology varied from fine crystallites to plumose structures representing in part the quench spherulites recorded by Church.

Translucency and conchoidal fracture. Ramsay et al. (2004a) comment with regard to their firing of analogue Bow first patent porcelains,

The finished glazed wares were 1.5 mm thick and extremely translucent, with a soft ice-green hue covered by a clear transparent glaze which displayed slightly coarse crazing.

In addition these porcelains demonstrate a sub-conchoidal fracture. Although both the degree of translucency and the presence of a sub-conchoidal fracture do not in themselves necessitate a hard-paste body, these features are nevertheless in accord with other hard-paste porcelains.

DISCUSSION

A number of themes are combined in this account to support the contention that the earliest high-fired, hard-paste porcelains manufactured commercially in the English-speaking world were produced in east London at Bow during the period c.1743–1745 and not by William Cookworthy in Plymouth commencing from 1768. Some early English ceramic writers have recognised that early Bow may have been producing a type of hard-paste body, yet these observations have received little recent comment. Tiffin (1874) stated that early Bow is sometimes of a hard-paste but it is uncertain which group of Bow wares he was referring to. Binns (1898) both recognised that any wares made according to the 1744 specifications would have contained an inferred China clay and those wares made using a higher proportion of

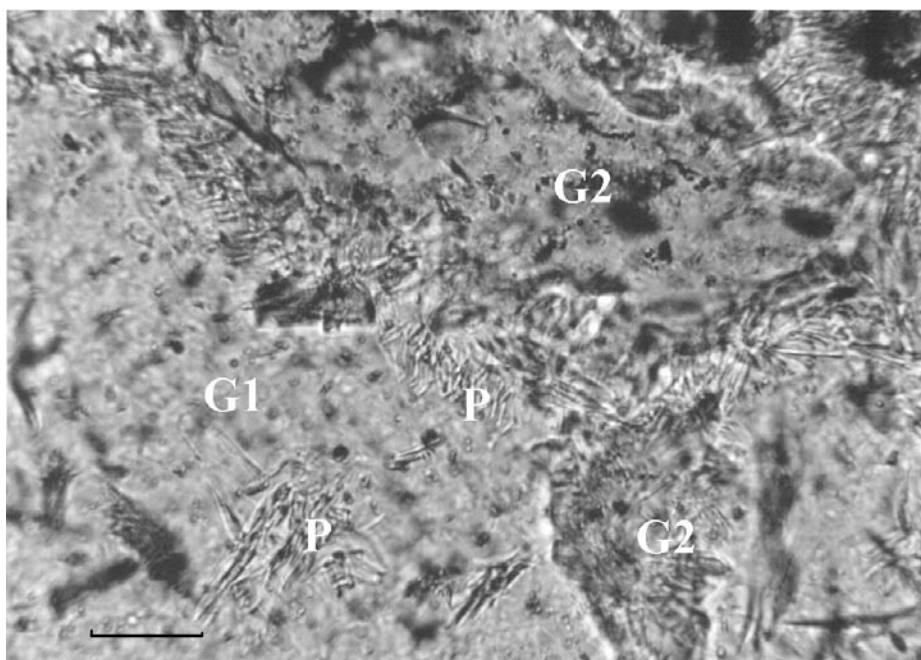


Fig. 1. Photomicrograph of porcelain body of analogue Bow first patent porcelain showing abundant calcium plagioclase crystallites (P) set in a colourless glassy matrix (G1). Irregular blebs of a slightly darker glass representing relic alkali-lime glass frit (G2) with associated reaction coronae of plagioclase crystallites. *Plain polarised light, scale bar = approx. 4.0µm, after Ramsay et al., 2004a.*

this clay would have been harder than those containing a lower proportion. Here we suspect that Binns was using the term ‘hard’ in a physical sense as related to Moh’s hardness scale rather than in the manner of a ‘hard fire’ as used by Brongniart. Both Dillon (1904) and Hurlbutt (1926) were of the opinion, based on their reading of the 1744 patent, that China clay was used in first patent Bow wares. Dillon (1904) moreover states that the use of this China clay preceded by some years the use of Cornish China clay. Thus by the end of the 19th and the beginning of the early 20th centuries there is contained in the English ceramic literature the recognition that any porcelains made at Bow during the mid 1740s would have contained refractory China clay, that the China clay used was not derived from Cornwall, and that these wares would have been ‘harder’ than more typical porcelains of that time.

The patent specifications state that this clay component could vary between 50 – 80 wt% of the porcelain body. Our analytical results support this aspect of the patent and we have shown that for members of the group so far analysed, the China clay component ranges from 50 – ~70 wt% (Ramsay et al. 2001,

2003, 2004b). In addition, the firing of analogue Bow first patent porcelains using 50 wt% China clay demonstrates that the resultant porcelain body is high-firing, resistant to thermal stress, and has a distinctly recrystallised and retextured micro-texture with abundant crystallites of the mineral calcium plagioclase (~An₉₀). Both the body and glaze are of the high-temperature Si-Al-Ca type and from our reading of the patent specifications we have concluded that body and glaze were fired together to the top temperature with the glaze being used by the proprietors as a crude but effective optical pyrometer. Lane (1958) observed that members of the ‘A’-marked group appeared to contain some kaolinite clay a feature confirmed by Freestone (1996).

In contrast to the numerous and voluminous publications on Meissen porcelain, these Bow first patent porcelains have not received the full attention they deserve since they were first recognised in 1937 as comprising a coherent and identifiable group of ceramic wares. Numerous reasons as to why this quite extraordinary group of porcelains has been partially marginalised for so long present themselves (Ramsay & Ramsay 2007a), not the least being the manner in

which the Heylyn and Frye ceramic patent of 1744 has for over a century been misunderstood, misquoted, and underestimated (Ramsay et al. 2006).

We suggest that the use of such terms as 'true' hard-paste, hybrid hard-paste, and frit porcelain has also tended to obscure the full significance of Bow first patent porcelains. In the case of 'true' hard-paste we contend that the composition reflected by this term, namely kaolinite clay and a feldspathic flux, provides a false impression of the wide ranging recipes used in the Orient in producing high-fired, hard-paste porcelains. Whilst this recipe does correctly reflect the nature of the raw materials used at Jingdezhen during the 17th, 18th, and 19th centuries, such a composition is at variance with many other recipes and starting materials used in northern and southern China as well as in Korea and Japan. Moreover this idealised composition is not in accord with the recipe initially employed by Böttger at Meissen (Colditz clay and calcined alabaster) in the production of Europe's earliest hard-paste porcelains. In other words a hard-paste body can be derived using more than one recipe (Singer & Singer 1963). Likewise the term hybrid hard-paste that Lane (1958) applied to the 'A'-marked group of porcelains may possibly be less than helpful. Hillis (2001) states that the porcelain made at New Hall from 1781 was not true hard-paste. Hillis describes such porcelain as a hybrid type in that it employed the basic hard-paste raw materials but used the usual Staffordshire sequence of a high-temperature biscuit firing followed by a lower temperature glaze firing using a lead glaze. Hillis notes that the New Hall potters had modified the traditional hard-paste formula so that translucency could be achieved at lower firing temperatures (~1,200°C), which would accept a lead glaze fired in the region of 1,100°C without crazing. He speculates that the addition of free-silica and fluxes to the paste may have achieved this. This description of hybrid hard-paste does not accord with the specifications contained in the 1744 patent. In the case of frit porcelain Ramsay and Ramsay (2006) suggest that this term is possibly associated with an element of circular arguing. Whilst numerous soft-paste French and English porcelains do have glassy frit added as an important component, the use of glassy frit in itself does not automatically result in a soft-paste body.

A further reason why these Bow first patent porcelains have tended to be overlooked is reflected in the dominant role ascribed to Chelsea over many years in regard to the quality of its soft-paste, the high standard of decoration and moulding, the assumption based on

the presence of dated goat-and-bee jugs that Chelsea was the earliest commercial concern in Britain (Sandon 1989), the notion that of all the mid 18th century English factories Chelsea porcelain alone could bear favourable comparison with Meissen (Hobson 1905; Hurlbutt 1926; Legge 1984; Dragesco 1993; Spero 2006), and the view that in some way Chelsea acted as a role model for a short period of time for other porcelain concerns (Sandon 1989). In addition it has generally been proposed that Chelsea specialised in the luxury end of the market when compared with Bow (Fisher 1965). These collective concepts have added weight and support to the belief that Chelsea alone was the pre-eminent concern of the mid 18th century in Britain (Nightingale 1881) and consequently the significant achievements of the Bow manufactory and its proprietors have been overshadowed, if not overlooked. Likewise Joan Bennett (written com. 2006) has made the subtle yet pointed observation that because Bow was located in the east end of London this might have subconsciously impinged negatively on attitudes for many years. Possibly it has been the lack of a convincing attribution for this highly significant group of Bow porcelains, which more than anything has led to a perceived reluctance to place these wares in the context of British porcelain development. As a consequence of a lack of a hitherto unequivocal attribution, these hard-paste porcelains have been unable to assume their rightful place in the history of Anglo-American ceramic evolution and hence the achievements of the Bow manufactory and its proprietors have not have been fully appreciated. Lastly we turn to the patentees themselves, Heylyn and Frye, who clearly regarded their specification as representing a hard-paste formulation. In their patent application, which was filed on 6 December, 1744 and affixed with the Great Seal of Great Britain, they state,

.....which Invention we, the Petitioners, apprehend would be of vast advantage to the kingdom, as it would not only save large sums of money that were yearly paid to the Chinese and Saxons, but also employ large numbers.....

As noted by Daniels (2007: 82) no mention is made of any large sums paid to the soft-paste manufacturers of France.

CONCLUSIONS

We contend that the Bow porcelain manufactory was producing commercial Si-Al-Ca hard-paste porcelains demonstrating remarkable compositional and

artistic expertise by at least 1743. These porcelains are in our opinion the only porcelains manufactured in Great Britain during the mid 18th century that can bear favourable comparisons with Meissen porcelain. This claim is based on the use of a refractory China clay, the method of firing the Si-Al-Ca body and glaze, the physical properties of the resultant hard-paste body, and the astonishing level of decoration lavished on these porcelains. This decoration drew artistic inspiration from the Orient, Meissen, Greek mythology, fables, the London theatre, and children's pastimes after works by Hubert François Bourguignon called Gravelot. In contrast to the extensive literature on Meissen, the significance of these seminal Bow first patent porcelains has largely been overlooked for the last 260 years with the possible exception of the French, who by mid 1745 recognised the superior compositional quality of these ceramics (Daniels 2007). We draw attention to the pioneering publications on this group by Lane (1958), Charleston and Mallet (1971), Mallet (1994), and Freestone (1996), which collectively have provided the foundations for our current research. Finally we note that in many instances compositional features of English porcelains have for too long been overlooked in favour of more subjective discussions on shape, moulding, glaze and body appearance, and decoration.

We conclude that it now may be necessary to re-evaluate our previous understanding of the Bow porcelain manufactory and its place in English ceramic history. This concern commercialized the first Si-Al-Ca hard-paste body in Britain and also developed the remarkable bone ash recipe, which continues today in its modified form known as English bone china. Moreover, current research (Ramsay & Ramsay 2005, 2007a,b; Daniels 2007) has established that Bow may have pioneered the use of a high-magnesium (steatitic) body. Consequently we suggest that it may no longer be appropriate to dismiss a Bow attribution merely on the presence of a high-magnesium body. Likewise based on the writings of Simeon Shaw (1837) there is the possibility that Bow may have early in its history employed a silica sand, ground cullet, and ball-clay recipe with a lead glaze and any such existing products are likely to have been confused for many years with Chelsea triangle period, Longton Hall, or Girl-in-a-Swing [St. James's Factory of Charles Gouyn (Dragesco 1993)] porcelains. Research in this direction is continuing. In addition this concern adapted a remarkable range of exotic and indigenous decorative elements, the first to cater for the luxury-end of the market, the first to

employ slip-casting techniques in porcelain output, demonstrated a dazzling level of entrepreneurial attainment, and the first to produce commercial hard-paste porcelains, whose compositional and artistic stature sets this manufactory apart from all other mid 18th century English rivals and which alone can compare with Meissen, the yard-stick of European porcelains.

It is apparent that over the last five or six years a remarkable revolution in our understanding of the birth of the English porcelain industry has been in progress. Central to these developments is the role of The Royal Society of London (Daniels 2007), the veracity of the 1744 patent (Ramsay et al. 2006), the pioneering position of the Bow manufactory in early English porcelain experimentation and development (Daniels 2007; Ramsay & Ramsay 2007a), and the brilliant Bow first patent hard-paste porcelains, whose significance to the Anglo-American porcelain industry has hitherto been largely overlooked.

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