

THE SCIENCE OF EARLY BRITISH PORCELAIN

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PORCELAIN, A TRANSLUCENT, WHITE CERAMIC, WAS first produced in China in the 6th century A.D..¹ Europeans became aware of this exotic material through travellers such as Marco Polo, and early pieces of Chinese porcelain, known to have been imported into Europe, date from the 14th century.²

Porcelain was an exotic and luxurious material, which was highly valued for its sensuous qualities and at this time, pieces were owned by the richest and most powerful members of society, who placed it in mounts of precious metal for display. As trade with the East expanded, increasing quantities of porcelain were imported, and awareness of this desirable material spread. By the 1700s, porcelain was associated with the fashionable pastimes of drinking tea, coffee and chocolate and was in great demand by the growing middle class. Large quantities were imported from the Far East into Europe and porcelain collecting became a mania in some circles. The production of porcelain was regarded as a potential source of great wealth to whoever could master its secrets.

Chinese porcelain from the imperial factories of Jingdezhen,³ was made from a mixture of two raw materials: *kaolin*, a refractory white-firing clay, and *petuntse*, or porcelain stone, a rock composed of mica, feldspar and quartz. The alkalis of the porcelain stone had a strong fluxing effect so that, fired at temperatures in the range 1250–1300°C, the porcelain body matured to a material that was largely glassy, with its strength and rigidity provided by a network of fibre-like crystals of the compound *mullite*. Chinese porcelain stone differs from, for example, Cornish china stone, which performs a similar role in firing, but does not have the high mica content of the Chinese material. Mica confers additional plasticity and green strength to the unfired Chinese porcelain body. Chinese or *hard paste* (high firing) porcelain has a relatively strong body in the unfired and fired states; it also has a wide firing range and is relatively stable in the kiln. It is white, due to the low contents of iron and titanium oxides in the raw materials, and is translucent, due to its high glass content. These properties allowed the production of very fine white ceramics, which were ideal grounds



Figure 1. White porcelain figure of Kuon Yin, marked 'Torino'. Like many examples of 18th century Italian porcelain, analysis shows that this is a silica-rich body, unusual in the wider European context. British Museum.

Table I. Typical English Porcelain Bodies					
Factory	Chelsea	Worcester	Bow	Coalport	Limehouse
Period	1745-49	c.1760	1755-60	1825	1745-48
Body	Glassy	Soapstone	Bone Ash	Bone China	Clay-rich
SiO ₂	62.8	72.3	51.2	43.0	72.4
TiO ₂	0.2	<0.2	0.3	<0.2	0.8
Al ₂ O ₃	4.9	3.4	5.6	13.6	10.7
FeO	0.2	0.4	0.3	<0.2	0.5
MgO	0.3	11.0	0.6	0.5	0.7
CaO	20.1	1.9	23.2	17.4	7.1
Na ₂ O	0.8	1.4	0.6	1.6	2.8
K ₂ O	5.3	3.3	0.6	1.6	3.0
P ₂ O ₅	0.3	0.3	15.3	21.2	<0.2
PbO	4.4	5.7	0.4	<0.3	1.0
SO ₂	0.2	0.2	1.9	<0.2	<0.2
Weight per cent. Analyses by SEM-EDXA from refs. 14 (col. 3), 15 (col.5) and unpublished. Total iron as FeO. Errors typically c. 5% relative for oxides greater than 10%, c.10% relative for oxides greater than 2%.					

for painted decoration.

The high prestige and considerable value attached to porcelain by Europeans meant that increasing efforts were made to produce it, and these are generally considered to have begun with Francesco I de' Medici (Grand Duke 1574-1587), who established a short-lived production in Florence. Medici's difficulty, and those of many later would-be manufacturers, was the lack of a white-firing kaolin with an appropriate flux from which to make the body. He was thus obliged to make a body rich in lime and silica, minimising the content of clay with its discolouring iron and titanium oxides.⁴ Porcelains of this type, which matured to glass-calcium silicate assemblages, had low firing temperatures and narrow firing ranges, coupled with poor thermal shock resistance. Losses during firing could be prohibitive and the ceramics were also more inclined to fracture during use. The manufacture of such low firing, *soft paste* bodies, with relatively low clay content, was the strategy adopted in most European attempts to manufacture porcelain prior to the discovery of sources of kaolin (china clay). European kaolin was first utilised commercially in Saxony by Johann Friedrich Böttger (1682-1719) from about 1710.^{5,8}

Suitable sources of kaolin were not exploited until the 1760s in France and Britain, however, and throughout most of the 18th century, most porcelain made in these countries, including the products of factories such as Bow, Chelsea and Chantilly, was soft paste.

EUROPEAN PORCELAIN BODIES

In France, successful soft paste porcelains were produced from the late 17th century at St Cloud, near Paris. By 1740, factories had been established at Chantilly, Mennecey, and Vincennes. The bodies of French soft-paste porcelains are very consistent in composition.⁶ They are rich in silica (SiO₂ = 70-75%), alkalis (Na₂O + K₂O = c. 6%) and lime (CaO = c. 14%). Body formulations are known from the notebooks of Jean Hellot (1685-1766), academician, chemist and technical director of the factory at Vincennes (which moved to Sèvres in 1756) and involved the production of an intermediate glassy frit from components including soda, sand, gypsum and lime.⁷

In central Europe, there was early success with kaolin-rich formulations. Böttger's initial recipe

appears to have involved the use of kaolin with a small amount of gypsum as a flux, and produced a body very rich in mullite. Later, he changed to an improved formulation using kaolin and feldspar.⁸ The technique of hard-paste porcelain of the Böttger-type spread to other centres, such as Vienna, but rather slowly, as the production methods were closely guarded and technological transfer usually depended upon luring a key worker to another location.

A different approach again appears to have been adopted in Italy. Bodies examined from the manufactory at Capodimonte,⁹ and our own limited analyses of examples from the Doccia, Cozzi, Turin and Le Nove factories suggest that these were quartz-rich bodies (c. 80 – 85% SiO₂), with low lime (fig. 1).

EARLY ENGLISH DEVELOPMENTS

The earliest attempts to manufacture porcelain in England that can be regarded as approaching success were by John Dwight of Fulham (d.1703), who in 1672 took out a patent for the manufacture of 'transparent earthenware commonly known by the names of Porcelane or China & Persian ware'. Copies of Dwight's notebooks, plus analysis of materials excavated from his pottery at Fulham, indicate that he made a white stoneware based upon ball clay, sand and an alkaline glass frit.¹⁰ In terms of microstructure, Dwight's whiteware bodies come close to Chinese porcelains from the classic locality of Jingdezhen. In spite of favourable comments by contemporary observers such as Robert Hooke, Dwight's ware was not a commercial success. This is likely to be due to a number of factors. Dwight relied upon a potassium-rich salt vapour glaze, which was thin and imperfect, unlike the thick smooth feldspathic glazes on Chinese wares. The high temperatures required for his Chinese type body were at the limits of English kilns at that time; failures would have increased the cost of what was already a labour-intensive material.

After Dwight, no attempts to manufacture porcelain commercially in England appear to have been made until the 1740s, but there is evidence that knowledge of his general approach, of mixing clay with a glass flux, was known beyond his immediate circle. In the following decades, the method of manufacture continued to be discussed. A Jesuit missionary, Pere d'Entrecolles, sent detailed letters from China detailing the methods of porcelain manufacture at Jingdezhen in 1712 and 1722. These were published in 1735 in J. B. Du Halde's *Description Géographique de l'Empire de la Chine* (English edition 1738). In 1739 the French chemist, René Antoine Ferchault de Réamur (1683-1757),



Figure 2. Fragment of a Chelsea cream jug marked with a raised anchor (Eccles and Rackham 1922, no. 6). Victoria and Albert Museum.

wrote of his attempts to produce porcelain involving the devitrification of a glass starting material. That an understanding of the principles involved in producing a vitrified ceramic body were becoming understood is revealed in an important manuscript dated 1732 in the British Library, a deposition by two witnesses to the process adopted by Richard Holt (fl.1722-30) in the manufacture of "artificial stone".¹¹ This was a stoneware intended to replace decorative marble in architecture, and which was a precursor of the Coade Stone which was so successful late in the century. It involved the addition of glass to clay to act as a flux.¹² Thus, by about 1740, there existed sufficient understanding of the principles of the behaviour of ceramic bodies during firing to act as a general guide in attempts to manufacture porcelain, even the approach taken was not as systematic as that adopted by Wedgwood a few decades later. For experimentation there certainly was. Between 1744 and 1750, porcelain was made at least eight factories in England: Bow, Chelsea, Limehouse and the 'Girl on a Swing' factory, in and around London; Bristol; Derby; Longton Hall and Newcastle-under-Lyme, both in Staffordshire. In the next decade, new factories began at Vauxhall, Worcester, Lowestoft and Liverpool. Between them, these factories used at least four major soft paste porcelain body types, as well as variants upon a number of these.

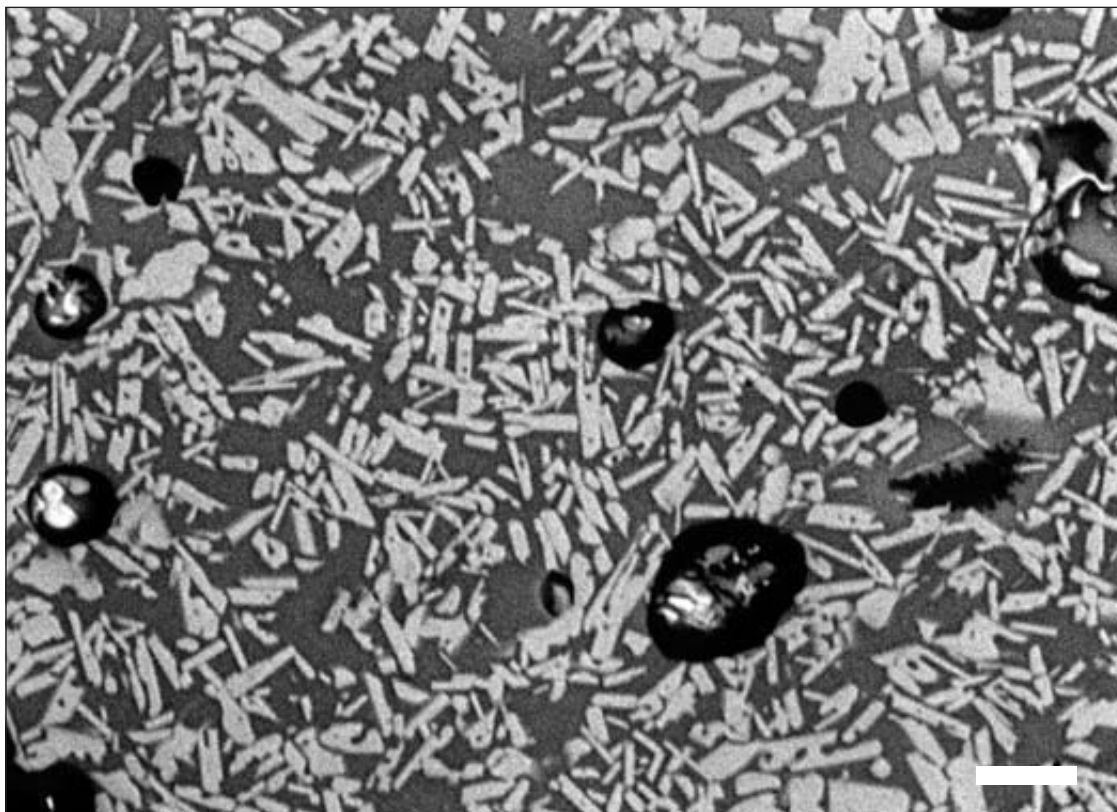


Figure 3. A cross section of the Chelsea raised anchor jug (fig.2), seen in the scanning electron microscope. The elongate crystals are of calcium silicate and they sit in a matrix of glass. The origin of the translucency of such a glassy body is readily appreciated. The white scale bar (lower right) is 0.01 mm long.

account outlines some of the characteristics of the soft paste porcelain bodies utilised in England in the 18th century, grouped according to their major compositional type.

Glassy Porcelain

ENGLISH PORCELAIN BODIES

Recent archaeological excavations of 18th century porcelain manufactories¹³ coupled with the ability to handle very small samples in the scanning electron microscope, with its attached X-ray micro-analyser (SEM-EDXA), have allowed the analysis of both sherd material from excavations and museum specimens.¹⁴⁻¹⁹ Archaeology is revealing factories that were previously inferred on the basis of limited contemporary references in advertisements and so on, such as those at Limehouse and Isleworth. Analysis is revealing similarly little known body compositions and throwing light on their inter-relationships and evolution. Meanwhile, historical research on archival material and records continues to expand our understanding of production in this important period.^{20,21}

Analytical work has recently added a fourth body type to the three previously recognised – glassy, soapstone and bone ash pastes. The following brief

Chelsea is generally seen as the earliest successful commercial soft paste porcelain body produced in England, from about 1745. The early Chelsea formulation is clearly similar to the approach adopted in France, based upon a glassy frit, and early English and French glassy porcelains are similar in composition with 60-75% silica (SiO_2) and 10-25% lime (CaO). However, they differ in minor components, notably the alkalis, soda (Na_2O) and potash (K_2O). The French bodies contain higher soda, which is a reflection of the raw material components employed in the crystal glass industries of the two countries – in France these were based on soda-rich plant ashes but in England, potash. Higher alumina (Al_2O_3) in Chelsea porcelain may reflect a higher clay content but may equally reflect the use of alum in the paste, a component which is documented, for example, by Hellot.²⁰ Early Chelsea porcelain typically consists of calcium silicate crystals in a glass matrix (fig.2,3), and may contain minor amounts of quartz. While only a

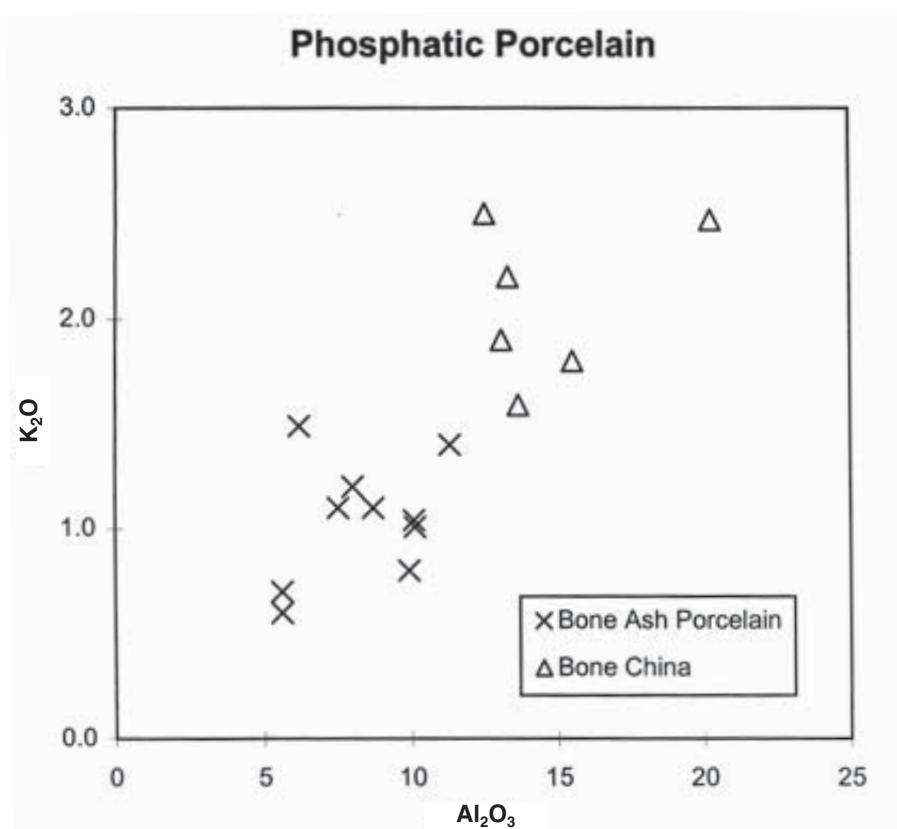


Figure 4. Graph comparing potassium oxide (K_2O) and aluminium oxide (Al_2O_3) contents of 18th century bone ash porcelain with those of 19th century bone china.

limited number of the early wares have been analysed (e.g. Table I), it appears that bodies from the earliest period (1745–49), marked with an incised triangle, have a significantly higher lead content than later raised anchor and red anchor pieces (c. 1750–1760).

At Longton Hall (Staffordshire) glassy porcelain production began with a body high in calcium sulphate, probably added either in the form of gypsum or of plaster of Paris. Middleton and Cowell have shown that bodies from the early period, from about 1751–1755 (sometimes called the ‘Snowman’ period, after the appearance of the figures made) contain large unreacted calcium sulphate particles.¹⁹ After 1755, the calcium sulphate content of the paste was reduced.

At Derby, Owen and Barkla¹⁷ have determined lead oxide contents of around 14% PbO in the glassy porcelains from excavation, making these wares among the most lead-rich of all glassy porcelains produced.

Thus, while these early glassy pastes use a broadly similar approach to that used in France, they have specific characters which indicate that the formula-

tions were not straight copies, and show developments suggesting a continuing regime of experimentation and development.

Soapstone Bodies

Steatite (talc), the ‘soapy rock’ from the Lizard, Cornwall was mined for porcelain production from 1749–1840.²¹ The geological processes which formed the soapstone produced some deposits which were white with very low iron oxides; coupled with the plastic properties of the crushed soapstone, and improvements in body behaviour (soapstone porcelain was said to be more resistant to thermal shock), it made a very good porcelain additive.

So far, we have no analyses of bodies that can be firmly attributed to the earliest manufactory of soapstone porcelain, Lund’s Bristol. From 1751, soapstone porcelain was manufactured at Vauxhall, and a few analyses given by Tite and Bimson¹⁴ indicate that it included about 30% each of steatite, glass and sand (or flint), yielding a body with about 10% magnesium oxide (MgO), derived from the steatite. There appear to be some variations in the bodies depending on the amount of lime present (possibly added in the form of glass).

Data for the Worcester manufactory^{14, 18} (Table I)



Figure 5. Teapot, marked with a letter A in underglaze blue on the base. British Museum.

show that for the first three decades of production the bodies contained 10–11% MgO but this fell with time; around 1780 the magnesia content was reduced to 7–8%. In about 1815, the Swansea manufactory was using an extreme formulation with only a few percent MgO but approximately 85% SiO₂.

Bone Ash

A famous patent by Thomas Frye, a proprietor of the Bow porcelain manufactory, and dated to 1749, is generally interpreted as proposing the addition of calcined bone ash to a porcelain body. The whitening effect of bone ash appears to have allowed a greater component of ball clay than was possible in glassy porcelain, as bone ash porcelains may contain up to twice the concentration of Al₂O₃; in addition, some glass was added as a flux. Bow bone ash porcelain was very successful, and its successor, bone china, continues to be made today. However, there is a real and significant difference in approach between these two ceramic types. Both are

phosphatic, but whereas *bone ash porcelain* was based upon bone ash, ball clay and glass, *bone china*, which was introduced from about 1800, comprised bone ash, china clay and china stone. These fundamental differences are readily seen in the chemical compositions of the ceramics (Table I, fig. 4). Bone china has higher potash (K₂O) and alumina (Al₂O₃), reflecting the use of china stone as a flux instead of glass, and lower titanium and iron oxides (TiO₂ and FeO), reflecting the use of kaolin rather than ball clay.

The bone ash formulation was taken up by a number of 18th century factories but many of these may be distinguished by minor compositional differences in the bodies. Thus the Bow porcelains contain a percent or so of sulphate (Table I), reflecting the use of gypsum or alum, while Chelsea gold anchor (phosphatic from about 1760), Lowestoft (from 1757) and Derby (phosphatic from about 1770) lack this component.^{14,17} The porcelain of the newly discovered Isleworth factory,²² on the other hand contains higher lead and potash, possibly suggesting the addition of flint or crystal glass (potash-lead-silica) to the paste. Once again, the analyses emphasise the modification of the formula to suit the particular conditions and requirements of the specific

factory.

Clay-rich soft pastes

Perhaps the most surprising result of the recent work relates to the so-called 'first Bow patent' of Edward Heylyn and Thomas Frye. This patent, dated to 1744, specifies a porcelain body made from a mixture of *unaker*, a (?kaolin) clay from Carolina with a glass frit. In the past, this recipe has generally been dismissed as likely to have failed, but excavations of the manufactory at Limehouse, London, have revealed porcelains which correspond to such a formula, albeit based upon a ball clay rather than a kaolin.¹⁵ The analyses (Table I) suggest that the body was composed of glass to clay in the ratio of 1:3 or 1:4, and the lime-rich nature of the crown glass caused crystals of the mineral plagioclase feldspar (a calcium aluminium silicate) to form during firing. The Limehouse production was relatively short lived, from about 1745–1748, and the evidence from the discarded material on the site is that there may have been high wastage problems due to vessels slumping through over-firing. However, a substantial number of complete pieces are known in collections and advertisements from the period suggest that the manufactory was a going concern, although a short-lived one. A similar body was experimented with at another factory, on the site of the 19th century Pomona public house in Newcastle-under-Lyme, but there is no evidence for commercial production there.

Yet another clay-rich soft paste occurs in the form



Figure 6. Figure of woman playing a flute, Longton Hall porcelain. British Museum.

of 'A-marked ware', characterised by the letter 'A', incised or painted in underglaze blue on the base (fig.5). Although first recognised in the 1930s, A-marked porcelain has long been enigmatic, and even the issue of its Englishness is still not fully agreed, with Scottish or even Continental origins mooted. With 63% SiO_2 and 19% Al_2O_3 , it has some of the

Eighteenth Century English Porcelain

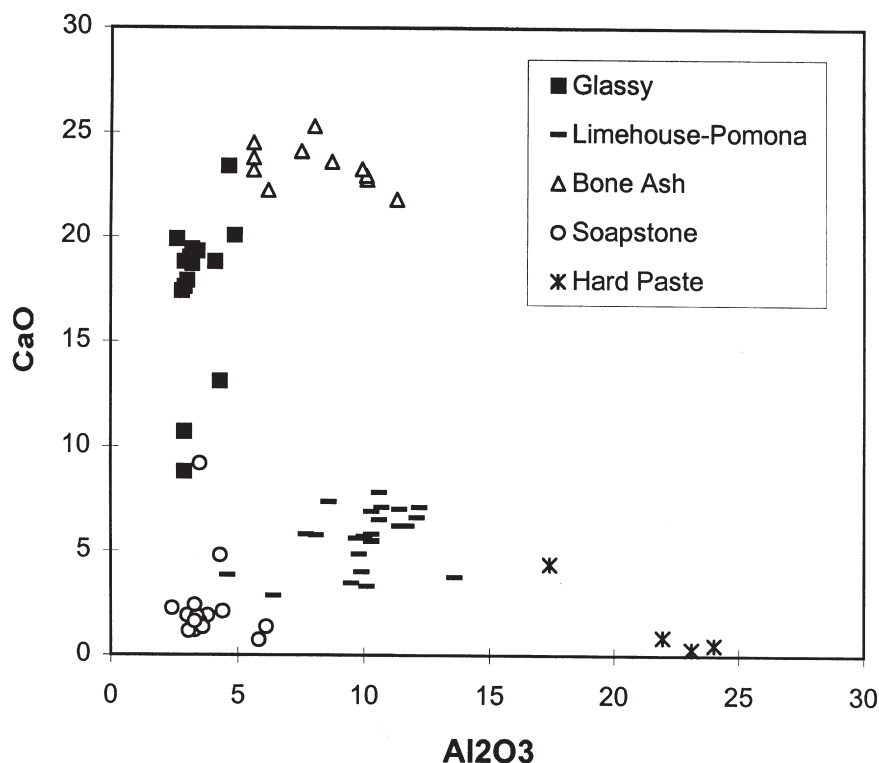


Figure 7. Graph showing the calcium and aluminium oxide contents of the major categories of 18th century English porcelain.

characteristics of a hard paste body, but its lime content is too high at around 6% CaO.¹⁶ The body consists of islands rich in plagioclase feldspar in a glassy matrix. The composition is best explained as a mixture of glass and a kaolin or china clay, a recipe defined by the first Bow patent, above. However, A-marked ware has been dated to the 1740s or 1750s on the basis of its style and this was some ten to twenty years before the use of Cornish china clay was first patented. Thus the possibility that A-marked porcelain utilised imported North American “unaker” clay as specified by the first Bow patent is a strong possibility. The relationship between A-marked ware and other products of this period remains unclear.

CONCLUSIONS

Three decades ago, Mavis Bimson demonstrated that hard paste, bone ash, glassy and soapstone porcelains could be distinguished by the removal of a small scratch of powder and the identification of the

crystals in the body by X-ray diffraction.²³ This approach has allowed many questions of attribution to be answered. For example, figures thought to be products of Longton, such as that shown in *fig. 6*, were analysed in the British Museum by Bimson to determine if they had been modelled by John Bacon at Vauxhall.²⁴ The gross differences between the soapstone bodies of Vauxhall and the glassy pastes of Longton Hall allowed assessment of this possibility, in the case shown, confirming the Longton attribution. The same type of analysis is very useful in evaluating questions of authenticity, for example, where copies have been made in bone china.

The detailed compositional information provided by materials analysis of early porcelain in the past decade or so has also begun to make a serious contribution to its study, and is proving complementary to historical and archaeological investigations. It not only allows the nature of raw materials and recipes to be assessed, but clarifies our understanding of patents and other documentary sources. Relationships which were previously only suspected, or even unanticipated, may be demonstrated, for example between Limehouse, Pomona and A-marked wares. Finally, our appreciation of the remarkable diversity of

relatively uniform soft paste porcelain body types, four may now be recognised, as shown in *fig 7*, plus a wide range of sub-varieties, associated with different factories or with different periods within the life of a single establishment.

The recent developments have been largely based upon the analysis of fragmentary and, particularly, excavated material. However, this is providing a framework of understanding which promises to allow a finer distinction between some factories and periods of production than has hitherto been possible. The major limitation is the requirement to remove a sample, but the database now established should enable many questions of attribution to be addressed by removal of a powder sample. While small powder samples are likely to provide less accurate analyses than those obtained from the coherent fragments used for most of the work reviewed here, they should be sufficient for many problems.

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