Scientific Analysis of Glazed Tile from the Seljuq Palace of Kubad-Âbâd, Lake Beyşehir, Turkey

Ian C. Freestone, Zehra Yegingil, and Rüçhan Arık

ABSTRACT The palace of Kubad-Âbâd was built on the instructions of the Seljuq Sultan Alâeddin Keykubad I. Excavations have recovered large quantities of decorated glazed wall tile, typically in the familiar "star and cross" pattern. We have analyzed fifty tiles, using inductively coupled plasma–atomic emission spectrometry for major elements and inductively coupled plasma–mass spectrometry for trace elements. Selected tiles were subjected to petrographic thin-section analysis and to scanning electron microscopy–energy-dispersive x-ray spectrometry for technological analysis of glazes and pigments. All the tiles are stonepaste bodies coated with an alkali-silica glaze. Black underglaze decoration is typically executed in crushed chromite. Turquoise is due to copper, and deep blue colors are due to cobalt; in some cases the cobalt pigment was mixed with fine-grained quartz to minimize bleeding into the glaze. Luster-decorated star-shaped tiles have tin-opacified glazes, but most glazes are translucent. The tiles were subdivided into visual types based upon shape, technique, motif, and color. Typically four–six tiles of each type were analyzed by inductively coupled plasma spectrometry. Each type of star tile can be matched compositionally to a single cross type in terms of major and trace elements. Each star-cross pair forms a compositional group, which can be distinguished from other star-cross groups and from the monochrome tiles. Each group is distinguished in terms of decorative style, decorative technique, body recipe (clay:glass:quartz), and the elemental composition of the clay used. The compositional groups represent individual commissions, as tiles were ordered for different rooms in the palace. The differences in style, technique, and technology among the groups suggest that they were produced by more than one group of tile makers. Archaeological evidence suggests that some, perhaps all, of the tiles were made in the vicinity of Kubad-Âbâd. However, at least one tile group has a very different body composition and was made using a calcareous clay, whereas the others were made using kaolinitic clays. This group may have been imported.

Introduction

The Seljuqs introduced Islam to much of Anatolia and from their capital, Konya, ruled over a large part of the region from the eleventh through thirteenth centuries. The Seljuq period was culturally rich and inventive. In particular, the reign of Sultan Alâeddin Keykubad I (1220–37) saw the undertaking of many major building and infrastructure projects, including the Royal Palace at Konya and the palace of Kubad-Âbâd.

Kubad-Âbâd is situated on the southwestern shore of Lake Beyşehir, which is in Central Turkey, about 100 km west of Konya. According to the Seljuqid chronicler Ibn-i Bibi, the palace complex of Kubad-Âbâd was constructed under the supervision of the hunting vizier and architect Sadeddin Köpek, in accordance with the orders of Keykubad I. No inscription stating the construction date of Kubad-Âbâd has been found, but a mosque inscription dated 1234 in the neighboring village indicates that a considerable settlement developed around the complex at that time (Oral 1949).

Zeki Oral, then director of the Konya Museum, undertook excavations between 1949 and 1952 (Oral 1959). The first scientific excavations were undertaken by Katharina Otto-Dorn of Ankara University (Otto-Dorn and Önder 1966, 1967; Otto-Dorn 1969). She started the cleaning and unearthing procedures at the ruins of the largest building, which she called the "Great Palace," and brought out almost all its remaining tile and stucco decoration, some of which were *in situ*. She also surveyed and cleaned the interior of a second large building, called the "Small Palace," where some tile, fragmentary stone carving, and reused classical or Byzantine stelae were found.

The current program of excavation was initiated by Rüçhan Arık in 1980 with the permission and support of the Turkish Ministry of Culture and Tourism (Arık 1992, 2000). A large part of the palace complex is now exposed, including the remains of a bathhouse and various work areas.

The decorated wall tile discovered at Kubad-Âbâd is outstanding in both quality and quantity and is widely cited in the literature. The figurative decoration of the tiles shows a rich and varied range of influences from the Islamic world and beyond.

The present project involves the detailed investigation of a sample of tiles from a range of contexts at Kubad-Âbâd. Although the total number of tiles analyzed is only about fifty, as far as the authors are aware it is the most comprehensive and systematic scientific study of Islamic tile from a single site so far undertaken, and the only detailed study of Anatolian Seljuq tile, apart from the analysis of a small number of tile bodies by Smith (2006). The results have exceeded expectations, and the information that they provide about tile production for the palace complex points toward some very interesting conclusions.

Materials and Methods

Tile fragments were sampled from several areas of the site, including the Great Palace, the bathhouse, and a builder's yard where materials appear to have been stored. However, it should be borne in mind that they represent a relatively small sample of the contexts in which tiles have been found and in which they were used as decorative elements of the palace complex.

The tiles analyzed may be categorized into three basic forms: polychrome decorated eight-pointed stars, polychrome and bichrome decorated crosses, and monochrome turquoise blue rectangular tiles. In addition to form, the polychrome tiles could be categorized into macroscopic types on the basis of their colors, decorative motifs, and techniques, as shown, for example, in figures 1 and 2.

Selected tiles from each macroscopic type were sampled for the preparation of thin sections, which were examined using polarized light microscopy (PLM). Polished cross-sections were examined in a CamScan Maxim 2040 scanning electron microscope (SEM) by backscattered imaging. Quantitative analysis of glazes and inclusions was carried out by energy-dispersive x-ray spectrometry (EDS) using the attached Oxford Instruments ISIS spectrometer. Selected tile bodies were also examined using a PANalytical x-ray diffractometer with an accelerator detector (XRD). Powdered samples of 200 mg were removed from the bodies of all tiles and analyzed for major and trace elements by inductively coupled plasma–atomic emission spectrometry (ICP-AES) and plasma mass spectrometry (ICP-MS) at Royal Holloway University of London, using HF-HNO_3 dissolution, under the direction of Dr. J. N. Walsh. Silica contents were determined by difference.

Technology

Microstructure of Tile Bodies

All tile bodies are comprised mainly of poorly sorted angular particles of quartz, typically up to 0.5 mm in diameter (fig. 3). These are ceramic bodies of the stonepaste type, which were characteristic of many high-quality ceramics in the Islamic world. As outlined by the Iranian author Abū'l-Qāsim in about 1301, stonepaste bodies were produced from a mixture of about 80% crushed quartz with around 10% each of clay and crushed glass (Allan 1973). The production of a ceramic body low in clay produced a pale ground that was favorable for polychrome decoration.

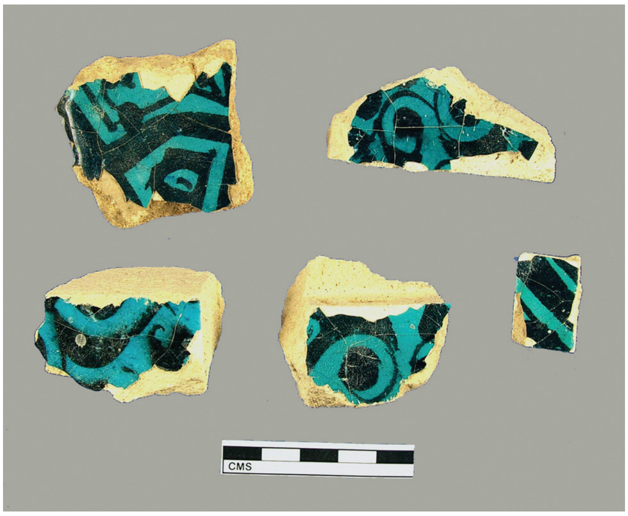

Figure 1. *Tile samples from Kubad-Âbâd: blue glaze over underglaze chromite black.*

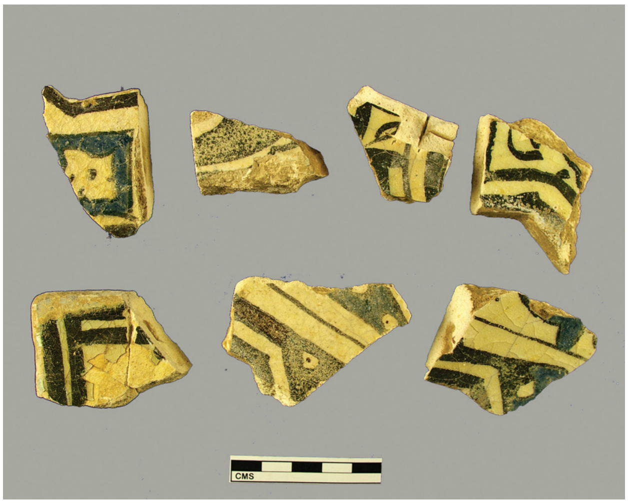

Figure 2. *Tile samples from Kubad-Âbâd: geometric decoration under a clear glaze.*

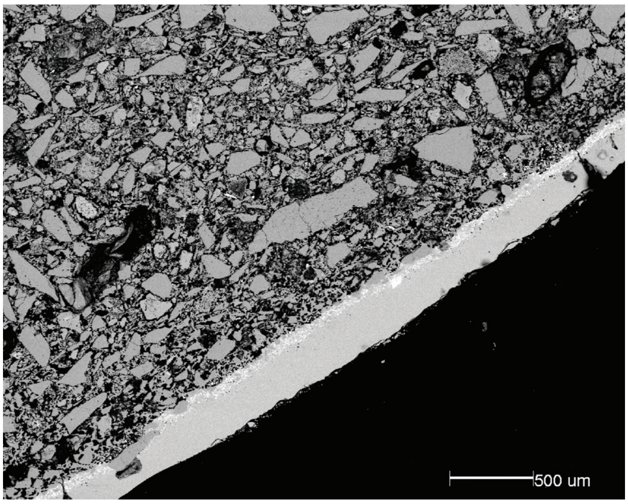

Figure 3. *SEM backscattered image of tile showing quartz-rich body, alkaline glaze, and layer of chromite pigment (white) at base of glaze.*

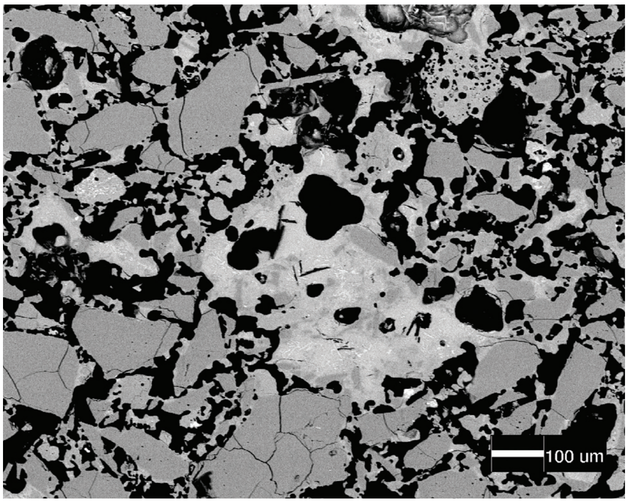

Figure 4. *SEM backscattered image of tile body with relatively high glass content. The mottled area in the center of the field is a relict particle of glass, partially devitrified. Quartz grains (gray) are interconnected by threads and filaments of glass.*

PLM showed the quartz in all samples to have low numbers of vacuoles and inclusions, and to be largely monocrystalline, so that most of the tile fabrics could not be readily subdivided on the basis of the petrographic criteria adopted by Mason (1991, 1995, 2004). The absence of composite grains of quartz and feldspar, as well as the monocrystalline nature of much of the quartz, leads us to assume that the quartz was derived by crushing quartz pebbles, as documented by Abū'l Qāsim. One small group of tiles (calcareous clay group, below) differs in that it contains small amounts of feldspar and small grains of red-brown iron oxide in the matrix. Although present at a low level (ca. 1%), it was possible to confirm the presence of feldspar in these tiles and its absence in others by XRD and SEM-EDS. The feldspar is fine grained, and no evidence could be seen that it shares an origin with the larger quartz grains. It therefore seems probable that it was a component of the clay added to make the unfired body material plastic.

The interstitial material in the tiles shows considerable variation. In some tiles it appears to be composed largely of unfused clay material, whereas in others, lime-rich glassy areas are apparent (fig. 4). These represent the minor components, clay and glass, in the stonepaste recipe. This textural evidence suggests either (1) there was substantial variation in the firing temperatures of the tiles, or (2) the relative amounts of clay and glass included in the body recipe varied significantly.

Chemistry of the Bodies

Major element analyses of several of the tile groups are presented in table 1. As stonepaste fabrics, the bodies are significantly higher in silica than clay-based ceramics, and SiO_2 contents (by difference) lie between 85% and 93%, the mean value being about 90%. Even so, the alumina concentrations, at around 6% Al_2O_3, are higher than those reported for most medieval stonepaste ceramics, a characteristic of Anatolian stonepaste also noted by Smith (2006). A comparison of iron and aluminum oxides in Kubad-Âbâd tiles with those of stonepaste vessels reported by Mason (2004) (fig. 5) very clearly demonstrates that the tiles typically have lower Fe_2O_3, but higher Al_2O_3, than the vessels from other regions. Exceptions are the vessels attributed by Mason (2004) to the Kashan production center in Iran, which also have high Al_2O_3. These high alumina contents might be expected to relate to relatively high amounts of interstitial clay in the Kubad-Âbâd tiles, a characteristic shown by the Kashan wares (Mason 2004).

Given their high alumina contents, the low Fe_2O_3 contents of the Kubad-Âbâd wares (see fig. 5) are surprising. High iron oxide contents are characteristic of many clays, and the high alumina contents of Kubad-Âbâd tiles might

Table 1. *Mean compositions of selected tile types from Kubad-Âbâd. Silica by difference.*

	Monochrome Turquoise	Cobalt Underglaze	Turquoise Cross	Luster Star	Silhouette Cross	Vessel
n	4	4	4	6	4	1
SiO_2	88.04	86.19	90.54	88.90	91.20	88.68
Al_2O_3	6.85	6.50	6.52	6.24	4.61	5.43
Fe_2O_3	0.51	0.93	0.12	0.37	0.32	0.22
MgO	0.56	0.67	0.39	0.50	0.44	0.74
CaO	0.76	2.86	0.69	1.54	1.22	1.23
Na_2O	1.79	1.18	0.66	1.17	1.22	2.38
K_2O	1.07	1.30	0.70	0.87	0.67	0.92
TiO_2	0.28	0.23	0.24	0.25	0.19	0.23
P_2O_5	0.14	0.13	0.14	0.15	0.11	0.15
MnO	0.02	0.03	0.01	0.02	0.02	0.02

n = number of analyses

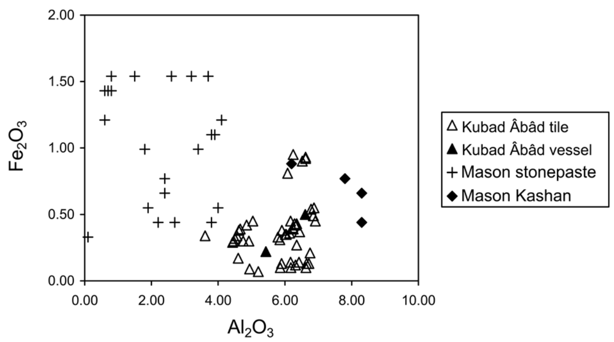

Figure 5. *Iron and aluminum oxide contents of stonepaste tile and vessel bodies from Kubad-Âbâd, compared with those from Egypt, Syria, and Iran, analyzed by Mason (2004). Note the relatively high alumina and low iron oxide of the Kubad-Âbâd samples.*

have been expected to impart high iron oxide. Figure 5 indicates that the tiles from Kubad-Âbâd have lower iron oxide contents than many other stonepaste ceramics, and certain tiles have exceptionally low Fe_2O_3, at around 0.1%. The low Fe_2O_3:Al_2O_3 ratios of the tiles show that the clays used are likely to have been white-firing kaolinitic clays, and this composition has been confirmed by spot analyses of interstitial clay rich areas by SEM-EDS, which indicate the presence of fine grains with high Al_2O_3:SiO_2 ratios, characteristic of kaolinite. This finding is in contrast to many other stonepaste production centers, which appear to have used pale-firing calcium carbonate–rich clays, as suggested by the presence of several percent CaO in the body compositions (Mason 2004; Redford and Blackman 1997). Only one small group of the Kubad-Âbâd tiles (group 2, below) has high CaO; the majority has CaO contents of about 1% or less.

Sodium oxide concentrations in the ceramic bodies reflect the addition of glass, as specified by Abū'l-Qāsim. Soda contents in the tiles are 0.6–1.8 wt.%, averaging 1.2 wt.%, whereas those in two vessels analyzed were higher at 2.4 wt.%. Soda contents of Syrian, Egyptian, and Iranian stonepaste vessels are typically 2% or greater (Mason 2004; Redford and Blackman 1997), suggesting that the glass contents of the Kubad-Âbâd tile bodies were relatively low. Indeed, model calculations, assuming that all of the soda in the tile bodies was added in the form of glass, indicate that for some tiles the amount of glass in the body recipe did not exceed 5%. The effect of the glass in the stonepaste body is to increase the vitrification upon firing, improving the bonding between the quartz particles and increasing the fired strength. However, high strength is not a requirement of decorative wall tiles, which do not support any structure and are not subject to the compressive stresses imposed upon floor tiles. Therefore the glass content of wall tiles could be reduced to lower the cost of raw materials and reduce the labor involved in preparing and crushing the glass. Indeed, from this perspective it is somewhat surprising that the glass contents of some of the tiles appear to have been quite high.

The two stonepaste pottery vessels analyzed from Kubad-Âbâd have high alumina and low iron oxide, close to the levels in the tiles see (see fig. 5). Thus the use of kaolinitic clays was not confined to tiles but appears to have been a more general feature of Anatolian stonepaste wares. In fact, major elements appear sufficient to distinguish stonepaste wares found at Kubad-Âbâd from all other stonepaste wares so far analyzed. The Kashan products, which show some overlap with Kubad-Âbâd in figure 5, are readily differentiated in terms of other components such as sodium oxide. Furthermore, Kashan wares are readily differentiated petrographically by their high chert contents (Mason 2004).

Glazes and Pigments

Glazes are typically transparent and of the soda-lime-silica type. Colorant elements include copper, to produce monochrome pale blue (turquoise) glazes, while manganese and cobalt were used to produce purple and dark blue. Underglaze black was widely used for borders and motifs, and to produce silhouette-type decoration under copper blue glaze. In the SEM, the black appears to be due to particles of a chrome-rich spinel (chromite), composed mainly of Cr_2O_3, with subordinate Fe_2O_3, Al_2O_3, and MgO (see fig. 3). In addition, chromite particles also contain variable amounts of copper oxide, absorbed from the copper colorant in the glaze. The use of chromite as a pigment is well known in Syrian and Iranian ceramics of the medieval period (e.g., Mason et al. 2001), and its use as a ceramic pigment in the Middle East first occurred in the Neolithic period (ca. 9000–5500 B.C.E.) (Kamilli and Steinberg 1985).

Cobalt blue, although associated with specific fields in the decorative schemes, appears to be mainly dissolved in the glaze. However, one group of tiles analyzed has a well-defined underglaze cobalt pigment, comprising fine particles of cobalt-bearing iron oxide mixed with fine quartz particles. This underglaze appears to be an attempt to stabilize or fix the cobalt pigment and to stop it from bleeding into the glaze.

Tin opacification is found in the glazes of tiles with overglaze luster decoration. These glazes consist of alkali glazes

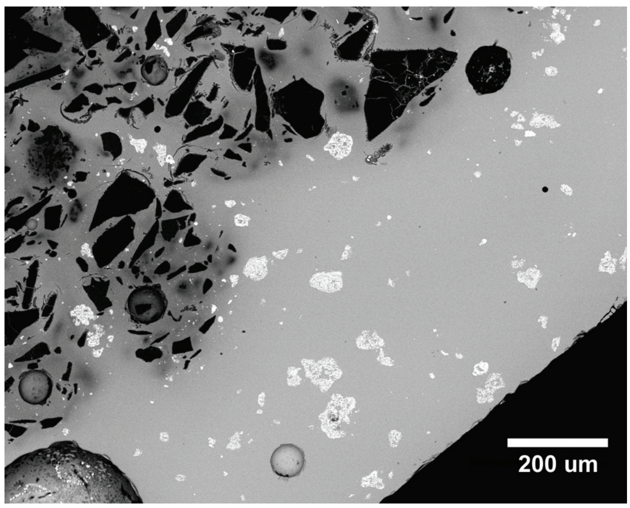

Figure 6. *SEM cross-section of luster-decorated tile, showing tin oxide particles in the glaze.*

with added lead and tin oxides, which crystallized (or failed to dissolve) particles of tin oxide during firing (fig. 6). Tin oxide was also used in an opaque white glaze that appears to have been painted over a manganese purple glaze to produce purple and white cross-shaped tiles. Tin oxide opacification was also observed in some monochrome blue tiles associated with the bathhouse, but we have analyzed only a single sample of this type. The majority of tiles analyzed in this work had colorless or translucent glazes.

Tile Groups

As outlined above, the tiles were categorized into a number of types based upon shape, technique, motif, and color. This categorization produced eight main types, each represented by four or more tiles, which could potentially form compositional groupings with some statistical meaning. Results for these types are summarized in figure 7, which shows iron and titanium oxide contents for each tile. In addition to stars and crosses, one type (polychrome underglaze) consists of stars and crosses with similar decoration and underglaze cobalt blue pigment fixed with fine quartz, and another comprises monochrome blue tiles. All tiles analyzed are shown here apart from three outliers: a cross that did not match any other pattern and two monochrome blue tiles that have a glaze visually different from the others and are from a different context on the site. The two analyzed vessels also have been omitted.

Figure 7 demonstrates two key points: (1) each "type" of tile has a characteristic composition, and (2) each type of star tile has a corresponding cross of the same composition. Comparison with the archaeological contexts from which the tiles were recovered demonstrates that stars and their corresponding crosses were from the same, or closely related, parts of the palace complex. Hence the star-cross pairs represent the tiles that decorated a specific room or area of the palace. Multivariate statistical analysis (principal components) of groups of elements, as opposed to bivariate plots of individual elements, gives the same result.

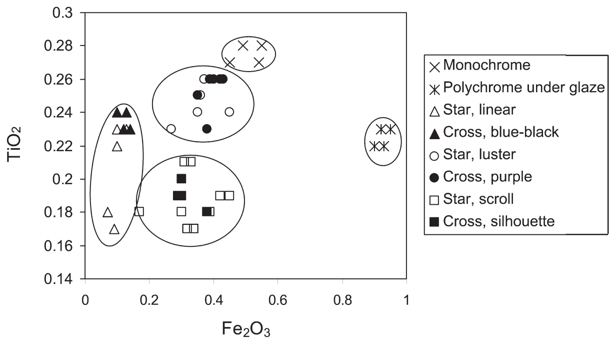

Figure 7. *Titanium and iron oxide contents of bodies of tiles from Kubad-Âbâd. Each visual type has a distinctive composition or shares a field with the corresponding cross or star. Star-shaped tiles are signified by open symbols, and cross-shaped tiles by filled symbols.*

These findings have a number of implications for the nature of tile production for Kubad-Âbâd. They demonstrate that the tiles for a room or area were made specifically to commission by a single workshop or group of tile makers and that crosses and stars were made together, from the same batches of raw materials. At least some of the tiles are likely to have been made at Kubad-Âbâd itself, as there is evidence for kilns on the site. However, the differences between the groupings in elements such as iron, titanium, and aluminum indicate that the clays added to the pastes were different.

Kaolinitic clays, which were added to the majority of body types, occur in the vicinity of Lake Beyşehir (S. Kapur, Cukurova University, personal communication, 2006) and so may not have been transported over long distances. However, at least one tile group (polychrome underglaze in fig. 7) was made with a very different calcareous clay, presumably from a very different location. There are differences in the recipes used to make the different bodies. Thus the star-cross tile group with the simplest painting style, comprising linear black and blue elements on the stars, and simple black motifs under a copper blue glaze on the crosses, also had very small amounts of glass added to the body (as indicated by a low soda content). The more labor-intensive and expensive luster-decorated tiles, with tin oxide opacification, had bodies with higher amounts of added glass, which were more vitrified. The tile group made using calcareous clay represents the only use of cobalt pigment stabilized by fine quartz so far observed in the Kubad-Âbâd tiles.

These observations indicate that the compositional groupings also reflect differences in painting style, decorative technique, and body recipe. While the possibility that these differences might all have been produced under the supervision of a single master craftsman cannot be dismissed, it seems more probable that a large project such as the Kubad-Âbâd palace complex would have needed to commission tiles from a number of workshops or masters and that the range of approaches used reflects the involvement of several different groups of tile makers in the supply of tiles to the project. They would have been directed by masters who had their own preferred body recipes and specialist decorative techniques.

Conclusions

There have been few applications of elemental techniques to the study of stonepaste ceramics from the Islamic world, as it generally has been assumed that compositional variations will have been constrained by the imposition of a standard recipe and the large amounts of inert quartz in the body. Recent advances in the understanding of stonepaste production have depended largely upon petrographic thin-section analysis (Mason 2004). However, the present study suggests that not only can differences be seen between stonepaste bodies from different regions, but that individual commissions in a single complex may be differentiated. Furthermore, groups defined by thin-section analysis may incorporate many subgroups that can be elucidated only by chemical analysis.

The use of inductively coupled plasma spectrometry, which allows the determination of all the major components of a paste, has a real advantage over techniques such as neutron activation analysis, which allow determination of a limited number of elements, because it also provides key insights into technology, such as clay type and body recipe. Coupled with detailed technological analysis, elemental analysis has the potential to be a powerful tool in investigating the production and procurement of stonepaste ceramics from archaeological excavation. Furthermore, the small sample size required for chemical analysis has the potential to allow the characterization of the complete vessels found in museum collections, which are inaccessible to petrographic study.

The analysis of tiles from Kubad-Âbâd is providing new insights into the understanding of ceramic supply and use, and the authors would advocate the adoption of similarly linked elemental characterization and technological studies elsewhere.

Acknowledgments

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References

Allan, J. W. 1973. Abū'l Qāsim's treatise on ceramics. *Iran* 11:111–20.

Arık, R. 1992. Kubad Âbâd excavations (1980–1991). *Anatolica* 18:101–18.

Arık, R. 2000. *Kubad Abad Selçuklu Saray ve Çinileri* [Kuban-Âbâd Seljulid Palace and its tiles]. Istanbul: Türkiye İş Bankası.

Kamilli, D. C., and A. Steinberg, 1985. New approaches in mineral analysis of ancient ceramics. In *Archaeological geology*, ed. G. Rapp Jr. and J. A. Gifford, 313–30. New Haven: Yale University Press.

Mason, R. B. 1991. Petrography of Islamic ceramics. In *Recent developments in ceramic petrology,* ed. A. Middleton and I. C. Freestone, 185–209. British Museum Occasional Paper 81. London: British Museum.

Mason, R. B. 1995. Criteria for the petrographic characterization of stonepaste ceramics. *Archaeometry* 37(2):307–21.

Mason, R. B. 2004. *Shine like the Sun*: *Lustre-painted and associated pottery from the medieval Middle East*. Cosa Mesa, Calif., and Toronto, Ontario: Mazda Publishers, in association with the Royal Ontario Museum.

Mason, R. B., M. S. Tite, S. Paynter, and C. Salter. 2001. Advances in polychrome ceramics of the Islamic world of the 12th century A.D. *Archaeometry* 43(2):191–209.

Oral, Z. 1949. Kubad-Âbâd Bulundu [Kubad- Âbâd is discovered]. *Anit* 10–23.

Oral, Z. 1959. Kubad-Âbâd çinileri [The tiles of Kubad-Âbâd]. *Belleten* 17(66):209–22.

Otto-Dorn, K. 1969. Bericht über die Grabung in Kobadabad 1966. *Archaeologischer-Anzeiger* 4:438–506.

Otto-Dorn, K., and M. Önder. 1966. Bericht über die Grabung in Kobadabad 1965. *Archaeologischer-Anzeiger* 170–83.

Otto-Dorn, K., and M. Önder. 1967. Kubad-Âbâd Kazıları, 1965 Ön Raporu [Preliminary report of Kubad-Âbâd excavations, 1965]. *Türk Arkeoloji Dergisi* 14(1–2):237–43.

Redford, S., and M. J. Blackman. 1997. Luster and fritware production and distribution in medieval Syria. *Journal of Field Archaeology* 24(2):233–48.

Smith, D. T. 2006. Compositional analysis of early-thirteenth-century ceramics from Raqqa and related sites. In *Raqqa revisited: Ceramics of Ayyubid Syria,* ed. Marilyn Jenkins-Madina, 221–35. New York: Metropolitan Museum of Art; New Haven: Yale University Press.