

## ISSUES OF SCUM: TECHNICAL ANALYSES OF EGYPTIAN MARL C TO ANSWER TECHNOLOGICAL QUESTIONS

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### INTRODUCTION

The Egyptian ceramic fabric called Marl C in the Vienna System has recently received attention in a number of studies (BADER 2001; BADER 2002; CYGANOWSKI 2003). However, several issues remain regarding the exterior coating on the surface of Marl C vessels, variously called a slip, self-slip, or scum, and the very noticeable argillaceous inclusions within the fabric. For the exterior coating, information was needed on what the coating is, how it develops, and what terms might most appropriately be used to describe it. The principal question for the argillaceous inclusions was whether they were natural to the clay or added as a tempering material. In order to understand better these two features of the Marl C fabric and any technological features associated with them, a series of technical analyses were performed. Petrographic analysis of Marl samples provided information on how the exterior surface was related to the vessel matrix and also established the distribution of the argillaceous inclusions. Scanning electron microscopy (SEM) was used to obtain images of the exterior layer to investigate its consistency, while the instrument also provided images of the inclusions to characterize their attributes. Additionally, the SEM analysis acquired chemical data to investigate differences in composition between the sherd and both the surface layer and the argillaceous inclusions. Further, elemental maps could be taken to assess if the movement of elements contributed to the exterior surface. Finally, non-destructive X-ray fluorescence spectrometry (XRF) was employed to examine compositional differences between the exterior and interior surfaces of sherds from Marl C vessels. These techniques proved quite effective in providing information to determine the origin of both the white surface layer and the clay-like inclusions in the fabric.

### MARL C SURFACE LAYER

The vessels manufactured of Marl C are produced from a calcareous clay with various amounts of sand and limestone added as temper. The appearance of the limestone suggests the vessels were fired between 750°C to 1000°C giving them a grey-white surface and a red fracture (NORDSTRÖM and BOURRIAU 1993: 180–181). A whitish layer appears on the exterior surface of closed vessels and both surfaces of open vessels (BOURRIAU *et al.* 2000: 131; BADER 2002: 30; GRIFFITHS and OWNBY 2006: 67). Based on observations of a white surface on modern pots after drying, this layer is believed to be the result of soluble salts migrating to the surface of the vessel as the clay dries before firing. This layer becomes fixed on the surface when the vessel is fired, and can range from a very light to a thick coating (up to 0.5 mm).

NOLL'S (1981) study was the first to employ scientific techniques to examine white surface layers on ancient Egyptian pottery. Through analysis by X-ray fluorescence with energy dispersive spectrometry and X-ray diffraction, the composition of these coatings was determined to be made of a quartz-rich clay, gypsum, and calcite (CaCO<sub>3</sub>) (NOLL 1981: 115). The calcite substance appeared to also contain calcium sulphate, while other coatings included salt and phosphorus. An analysis of the white pigment proved that calcite played a primary role, and gypsum (CaSO<sub>4</sub> 2H<sub>2</sub>O) and calcium sulphate (CaSO<sub>4</sub>) were used for both pigmentation and binding (NOLL 1981, 134). More importantly, NOLL noted that the calcite and sulphur could react creating calcium sulphate, leading to the discovery of gypsum in association with calcite. While these results offered the first real analysis of the chemical composition of white coatings, the difficulty was in knowing whether these coatings were deliberately applied slips or the light surface layer currently under discussion. Furthermore, the pottery was analyzed

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before the Vienna System of fabric classification had been created, thus the samples were not given designations beyond Nile clay or Marl clay pottery.

In the same volume, DO. ARNOLD (1981) discussed the presence of a light, whitish surface layer on the Marl clay pottery. Do. Arnold believed that the movement of salts during drying followed by firing created the layer. Furthermore, observations by H. and J. Jacquet of pottery manufactured in Tunisia showed that a whitish coating developed when the clay was mixed with seawater. This seemed to confirm the importance of salt in creating these surfaces. The main problem in applying this to Egyptian Marl clay pottery was the fact that there were examples (especially in the Pre-dynastic and New Kingdom periods) of Marl clay vessels without a white surface. Thus, DO. ARNOLD (1981: 172) suggested several scenarios in which either the clay utilized in the Middle Kingdom contained more salt, salt water was mixed with the clay, or a sand coating had prevented proper drying of the vessel. Additionally, she argued that the white surface layer served as an impermeable barrier to prevent leakage of the liquids in the containers, and would therefore have been intentionally created by the potters' selection of materials (DO. ARNOLD 1981: 172).

In BADER's (2001) study of the Marl C vessels from Tell el-Dab'a additional features of this white surface layer were noted. In particular, with vessels having inscribed lines in the clay before firing (i.e. the so-called fish plates and vessels with pre-firing pot marks); the white surface was seen in the grooves but did not feature any "pools" of colour to suggest a slip. The characteristics of the surface were not consistent with being a slip and it appeared the white layer formed after the vessels had been incised during drying and firing. However, BADER (2001: 23) did note that some vessels featured "drips" that indicated an additional white slip may have been applied. This last fact complicates matters and suggests careful examination of the surface must be made to determine whether it is a "naturally" formed white layer or an intentionally applied coating. Finally, BADER (2001: 23–24) suggested that the white surface layer was not found only on storage vessels and in fact may not serve to seal the pores

in the vessel wall. Although considerable thought has been given to this white layer on Marl pottery with many good suggestions put forth and some studies made to investigate possibilities for its formation, additional analytical work is needed to clarify the processes at work and to directly study the Marl pottery that features this white surface so clearly.

The presence of a white surface layer on pottery caused by the manufacturing process is not unique to Egyptian ceramics. In fact, examples of pottery with a white surface utilized for painted decoration comes from the American Southwest (ABBOTT 2008). This pottery, known as Buff Ware, was produced by the Hohokam from roughly 650 to 1400 AD and features quite intricate designs in red paint on a buff background. Petrographic analysis had shown the buff surface was not a slip. Therefore, an experimental study was undertaken to determine how this surface had developed. Test tiles were prepared from clays believed to be similar to those employed by the Hohokam. The clays were mixed with varying amounts of calcium carbonate ( $\text{CaCO}_3$ ) and salt ( $\text{NaCl}$ ) before being fired at different temperatures. The tiles made did not exhibit a white surface before firing. The results showed that between 800°C and 850°C a thick white surface developed on the tile made from a calcium rich clay to which calcium carbonate and salt had been added. This surface was created when the small-grained calcium carbonate dispersed in the clay, assisted by the added calcium carbonate and salt, reacted with the iron in the paste resulting in a bleaching effect. An earlier study by WEISMAN (1987) had suggested that adding calcium carbonate alone would not result in the development of the surface, but rather it required the fine naturally occurring calcium in a carbonate-rich clay. The reaction between the calcium and iron occurred at around 800°C, while the ferric chloride ( $\text{FeCl}_3$ ) resulting from the reaction of the salt and iron volatilized at this same temperature. Therefore, a white surface would only develop when a calcareous clay with a calcium content between 6% and 9%<sup>1</sup> was tempered with limestone (calcium carbonate), salt was added, and the vessel was fired above 800°C.

A much earlier study of Mesopotamian pottery with a white surface was conducted by MATSON

<sup>1</sup> The authors do not say if this is in weight % as oxides, but presumably the figure is based on an analysis of the clay that would have provided results as %wt for oxides. The same probably applies to the other cited studies below.

(1971). MATSON noted that the presence of chlorides on the vessel surface due to capillary action resulted in a white surface upon firing. The reaction of the chlorides with iron produced ferric chloride that volatilized at 800°C. Additionally, the calcium ferrosilicates within a vessel would become olive to yellow in colour above 1000°C. This temperature could be lowered depending on the salt content in the clay, whether existing naturally or supplemented by salts introduced by the potter. In tests of fired briquettes, those with salt added showed increased bleaching of the surface with rising temperature. Typically, between 800°C and 900°C a white surface would develop due to the additional salts reacting with the calcium rich ferruginous clays. This description appears similar to the processes occurring in the Hohokam pottery (ABBOTT 2008), indicating once again that a chemical reaction occurs with calcium, salt, and iron around 800°C to produce a white surface.

In a study of modern Egyptian pottery from the town of Ballas, MATSON (1974: 136) suggested the white surface layer developed as the vessel dried due to the evaporating moisture bringing soluble salts to the surface. Using a scanning electron microscope, measurements of elements were taken on the surface and core, revealing that more calcium, relative to silica, was on the surface, while the concentration of iron was unchanged (MATSON 1974: 137). The presence of a small amount of sulphur in the layer suggested that soluble calcium sulphate (CaSO<sub>4</sub>) played a role in forming the white surface. However, in a second sample analyzed, the iron amount was less on the exterior and no sulphur was present. In this case, it was suggested a loss of iron due to the volatilization of ferric chloride (FeCl<sub>3</sub>) had produced the layer when the vessel was fired above 800°C. MATSON (1974: 137) describes the white surface formed due to calcium and sulphur as much whiter than the more yellowy colour of the layer resulting from the reaction of calcium and iron. This study suggested several processes, one with sulphur and one without, were involved in the creation of the exterior white surface due to soluble salts in the paste (MATSON 1974: 138).

Chemically, several compounds can exist in clays that will migrate to the exterior surface of a vessel when the water within the clay is evaporating (GRIMSHAW 1971: 558; RICE 1987: 88). Typically, these are called soluble salts and consist of

calcium sulphate, magnesium sulphate, potassium sulphate, sodium sulphate, and sodium chloride (GRIMSHAW 1971: 276; RICE 1987: 336). All of these components can produce a whitish surface on a vessel upon firing. While calcium sulphate is not typically present in clay in large amounts, it can be formed during firing (GRIMSHAW 1971: 280). This is due to the release of sulphur when the heat breaks down pyrites (ferric sulphide, FeS<sub>2</sub>), which can react with calcium concentrated on the surface to produce calcium sulphate (CaSO<sub>4</sub>). If the atmosphere is oxidizing and free sulphur becomes available, this is likely to occur and can produce a whitish surface (GRIMSHAW 1971: 276, 927). Soluble magnesium sulphate (MgSO<sub>4</sub>) can be naturally present in the clay and migrate to the surface during drying creating a white surface even in very low amounts of less than 0.05% (GRIMSHAW 1971: 281). Clearly, sulphur is vital for the production of the layer whether during drying or firing. If the sulphur content is greater than 1% then a white surface will occur, while an amount between 0.2% and 0.5% will result in an uneven whitish surface that is thicker on exposed edges due to the evaporate processes that concentrated it in these areas (GRIMSHAW 1971: 926). Typically, the surface is dominated by calcium sulphate, but magnesium and alkali sulphates can still be present in small amounts (GRIMSHAW 1971: 925). Surprisingly, marl clays are not known to naturally possess large quantities of soluble salts (GRIMSHAW 1971: 42).

Another possibility for forming the white surface is that identified for the Hohokam and Mesopotamian pottery involving the reaction of decomposed calcium carbonate, iron, and salt (NaCl) at temperatures above 1000°C (RICE 1987: 88; GRIMSHAW 1971: 278, 280, 920). This results in the formation of calcium ferrosilicates that reduce the red colour and give an olive-greenish to yellow colour on the surface (RICE 1987: 336). This is because the iron has now become apart of the mineral lattice by substituting for aluminium; a process that occurred when the clay entered a liquid phase during firing (GRIMSHAW 1971: 703). However, this event occurred only on the vessel surface due to the migration of finely disseminated calcium carbonate and sodium to the exterior during drying (GRIMSHAW 1971: 925). These components act as a flux to form liquids at lower temperatures resulting in a liquid phase on the surface where

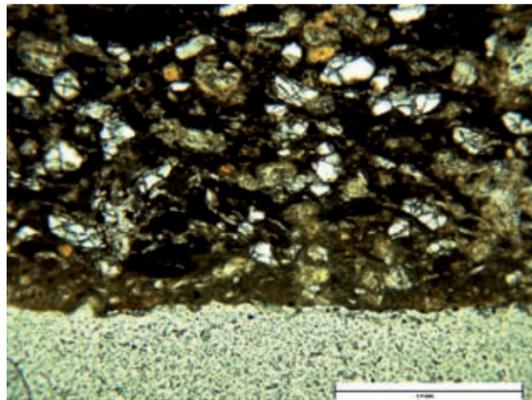


Fig. 1

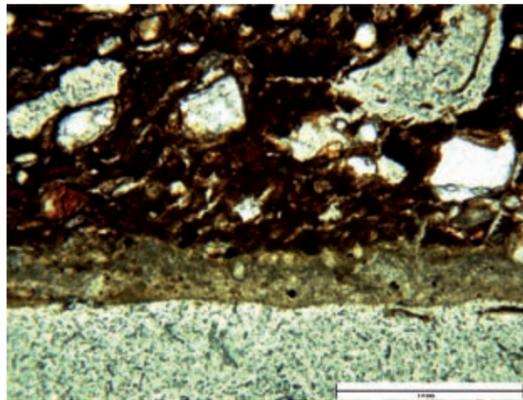


Fig. 2

the clay is directly exposed to the heat, while the clay in the interior has yet to reach this point (GRIMSHAW 1971: 275, 701, 720). Thus, when the calcium ferrosilicates are formed, they incorporate the iron preventing a reddish colour appearing, while the white colour is due to the presence of the calcium on the surface (MANIATIS *et al.* 1981: 268).

This process may explain the olive colour on the Marl C sherds, and why the interior does not exhibit a dramatic colour change. Relevant to this scenario, was BUTZER's (1974: 381) observation that calcareous clay pottery produced by modern Egyptian potters was fired to temperatures between 900°C and 1000°C to give a buff colour. However, as previously mentioned a white surface can appear due to sulphates. Therefore, the possibility for the development of a white surface layer is between two reactions both involving the migration of elements towards the surface. The first occurs with sulphur to produce calcium and magnesium sulphate, and the other involves calcium, iron, and sodium that produce a bleaching effect. Perhaps the crucial difference is that the last process requires a temperature above 800°C, while the former does not.

#### Petrographic Analysis

A petrographic comparison of a Marl C sherd and a Nile clay sherd with an applied white slip high-

lighted the distinct differences between the two white surfaces (OWNBY *forthc.*).<sup>2</sup> Under the microscope, the Marl C surface appeared as a greyish area on the edge of the sample that blended into the matrix (Fig. 1). Inclusions in the matrix were observed within the greyish area suggesting the surface was irregular and integrated with the body of the vessel. However, the white slip on the Nile B2 vessel was a clearly separate layer attached to the surface of the vessel (Fig. 2). The slip lacked inclusions identified in the fabric of the sample. A Marl A sherd from Giza also exhibited a faint whitening of the exterior surface of the vessel. The thin section of this material confirmed that this feature was a greyish area toward the edge of the sherd containing quartz and limestone inclusions found in the vessel matrix. These distinct features of the exterior surface layer on Marl pottery were noted in a petrographic study by PAPE (1991: 67–68).<sup>3</sup>

The current petrographic examination of the surface layer on Marl vessels from Giza confirms the term “slip” in these cases is not applicable. Additionally, in a thin section of a sherd with a self-slip, defined as when the potter smooths the exterior with the same materials used to form the vessel, the edge would appear as a finer layer of optically oriented clay and not as a different coloured region (RICE 1987: 151). Thus, the term self-slip is also not appropriate for the

<sup>2</sup> The sherds were a part of a study of fabrics from the Giza Plateau Mapping Project generously supplied by Dr. Anna Wodzińska.

<sup>3</sup> PAPE (1991: 67–68) believed the white surface was produced due to the reaction of salts and iron to give a bleaching effect.

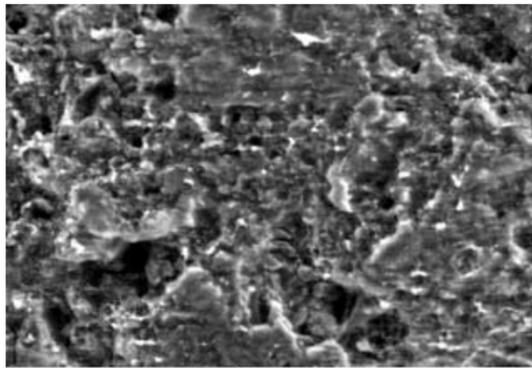


Fig. 3

surface on these samples. Rather, the term “scum”, which implies a deposit that develops during the manufacturing process, seems appropriate (GRIMSHAW 1971: 925). Finally, the petrographic analysis confirmed that the Marl C sherd had been fired above 850°C, due to the decomposition of the limestone temper (GRIMSHAW 1971: 713). Conversely, the Marl A sherd lacked decomposed limestone indicating a lower firing temperature and its exterior surface was less well developed.

#### SEM Analysis

To characterize further the white surface seen on Marl sherds, scanning electron microscopy was performed. Initially, the same Giza Marl C sample was analyzed as a whole object by SEM-EDS (energy dispersive spectrometry).<sup>4</sup> Images of the scum revealed that it is not as uniform and smooth as it appears in hand specimen (Fig. 3). Rather, the scum is uneven and crusty with some areas containing a more developed layer than others. In fact, this type of irregular surface would appear smooth and white due to the effect of scattered light. Elemental maps were created of the polished cross-section of the sherd to ascertain the degree of movement of calcium and salts to the exterior surface from the interior core through evaporative processes.

<sup>4</sup> Typically, for SEM analysis samples are prepared as polished sections embedded in blocks of resin. Analysis of whole objects should be considered qualitative rather than quantitative (POLLARD and HERON 1996: 49).

Surprisingly, this type of analysis did not show any significant movement of elements such as calcium, sodium, sulphur, or chlorine toward the surface. This may have been due either to difficulties in the instrument detecting the fine movement of elements (this type of analysis is only semi-quantitative, rather than being fully quantitative), the scale at which the analysis took place, or problems arising from post-depositional alterations to the composition. An examination of the cross-section of the Marl A sherd also failed to detect any differences between the centre and edge to indicate the movement of elements.

The next step was to establish the elemental differences between the core matrix composition and the white surface layer. This was also performed on the same whole sherds with polished cross-sections. Elemental readings were taken from approximately 2 mm<sup>2</sup> areas of the core of the section and of the exterior and interior surfaces. Both the Marl C with its thicker surface and higher firing temperature (>850°C) and the Marl A with its light surface layer and lower firing temperature (<800°C) were examined (Table 1). The Marl C scum had a higher amount of calcium, iron, and sulphur, while there was no significant disparity in sodium. This data appears consistent with the process involving calcium ferrosilicates producing the scum causing an increase in iron and calcium on the surface. The Marl A surface exhibited an increased concentration of calcium, magnesium, sodium, and sulphur relative to the matrix composition. The iron levels did not show a major difference. Therefore, the lighter scum on this sample was probably due to the movement of sulphates to the surface rather than a reaction between calcium, iron, and salt. There is the possibility that had the firing continued above 800°C, the Marl A sample would have exhibited the thicker scum composed of calcium ferrosilicates due to the decomposition of the limestone inclusions and the naturally high level of calcium in the matrix.<sup>5</sup> Future X-ray diffraction analyses of these samples should help to clarify the chemical structure of

<sup>5</sup> The composition of the Giza Marl sherds was determined by XRF analysis, and revealed that the Marl A sherd had a higher calcium concentration than the Marl C sherd (OWNBY forthc.)

Sample	Location	Na <sub>2</sub> O %	MgO %	SO <sub>3</sub> %	CaO %	Fe <sub>2</sub> O <sub>3</sub> %
Marl C	Centre	1.7	3.0	0.1	14.2	8.1
Marl C	Exterior	1.8	3.2	0.4	17.1	10.2
Marl C	Exterior	1.9	2.8	0.2	12.5	8.8
Marl C	Exterior	1.5	3.0	0.5	15.2	8.6
Marl C	Interior	2.6	2.6	0.4	18.5	10.2
Marl C	Interior	2.4	3.0	0.4	20.0	10.7
Marl C	Interior	3.0	2.3	0.3	15.7	12.6
Marl A	Centre	2.6	2.2	2.4	16.9	7.4
Marl A	Exterior	3.5	2.7	2.8	17.2	7.4
Marl A	Exterior	2.8	3.3	4.9	20.7	8.1
Marl A	Exterior	3.0	3.5	3.5	19.8	8.0
Marl A	Interior	4.7	2.2	1.1	16.5	7.9
Marl A	Interior	4.0	2.5	1.5	16.0	9.3
Marl A	Interior	2.7	1.8	0.6	25.7	9.3

(Note: the scum on the exterior of the Marl A sherd was noticeable, but this was not the case for the interior)

Table 1 Giza Marl C and Marl A SEM compositional data

the white surface layers and confirm if the processes just discussed were indeed responsible for their development.

#### Non-Destructive XRF Analyses<sup>6</sup>

During a study of the utility of non-destructive XRF analysis to determine the composition of Marl C sherds from Kahun, additional data was acquired on the elemental differences between the scum and the composition of the matrix, as determined from the interior surface that had did not exhibit a white surface (OWNBY 2005). Several elements showed a disparity between their concentrations on the exterior and interior surfaces of the jar sherds (Table 2). The increased amount of calcium in the exterior scum on the Marl C sherds was expected. The increased amount of sulphur on the exterior may relate to the presence of calcium sulphate (CaSO<sub>4</sub>) that contributed to the scum. The elevated concentration of magnesium may also indicate the development of magnesium sulphate (MgSO<sub>4</sub>) on the surface. However, the amount of iron and sodium on the interior surface was greater than on the exterior surface. These data suggest that for these

samples, the formation of sulphates was the primary means by which the white surface developed. Surprisingly, samples with no apparent scum could still have a high amount of sulphur at the surface, but usually for these samples the calcium value was low. Conversely, some samples with a thick scum had a low amount of sulphur but quite a high concentration of calcium on the exterior surface (i.e. >10wt%). Clearly, calcium plays the primary role in the colouring of the surface.

#### Summary of Analyses of Marl C Surface Layer

The results of the analyses performed indicate the white surface layer on Marl pottery is a scum that formed due to the movement of elements during drying and reactions that occurred through firing. Two processes appear to have played a role in the development of the scum. While soluble salts are involved in both processes, only in the process that produces calcium ferrosilicates does the temperature have to be above 800°C. The petrographic examination confirmed that the Giza Marl C vessel was fired above 800°C and the SEM analysis of the sample showed a

<sup>6</sup> This work was carried out in order to assess the utility of non-destructive XRF analysis in separating the chemically similar Marl C1 and Marl C2 sherds. While the resulting data could not statistically separate the two subfabrics, data from experimentally produced sherds

with very different compositions were correctly separated by fabric. Future in-field analysis by non-destructive XRF should recognize the limitations of the technique for fabrics with very similar compositions.

Sherd #	Fabric	Scum	Na <sub>2</sub> O %	MgO %	SO <sub>3</sub> %	CaO %	Fe <sub>2</sub> O <sub>3</sub> %
7638IIIi	Marl C1	None	8.0	2.1	1.3	6.4	6.5
7638IIIe	Marl C1	Yes	4.6	6.3	3.6	12.3	6.1
7676i	Marl C2	None	3.7	2.2	2.0	7.8	7.5
7676e	Marl C2	Light	2.7	3.4	3.9	13.6	6.2
7682i	Marl C1	None	3.9	1.7	7.8	5.3	7.3
7682e	Marl C1	None	2.3	1.7	18.5	7.2	7.3
44771i	Marl C1	None	4.7	2.4	2.8	7.5	7.9
44771e	Marl C1	Light	3.5	3.2	4.2	10.5	5.4
44780i	Marl C2	None	2.6	2.5	1.5	9.5	6.6
44780e	Marl C2	Light	2.3	2.7	3.0	12.8	6.6
44788i	Marl C2	None	3.0	2.5	2.3	7.3	6.5
44788e	Marl C2	Light	1.6	2.8	1.1	10.3	6.0
44790i	Marl C1	None	1.5	2.2	0.5	2.4	6.4
44790e	Marl C1	None	2.1	2.3	3.6	6.4	6.3
44797i	Marl C1	None	3.0	2.2	0.9	10.3	5.7
44797e	Marl C1	Yes	2.7	3.0	2.1	9.2	5.3
44804i	Marl C1	None	4.7	2.9	2.0	7.2	5.7
44804e	Marl C1	None	3.3	2.7	8.7	13.7	6.4
44817i	Marl C1	Yes	4.4	3.0	3.4	12.6	5.2
44817e	Marl C1	Yes	3.2	3.0	6.7	14.2	5.5
44818i	Marl C1	Yes	2.5	3.3	0.4	9.9	6.5
44818e	Marl C1	Yes	2.5	3.2	2.1	13.6	6.1
44850i	Marl C1	None	3.7	2.2	1.6	8.0	8.7
44850e	Marl C1	Yes	2.3	3.8	1.9	11.3	7.2
44863i	Marl C1	None	1.6	2.7	1.0	7.2	6.4
44863e	Marl C1	None	1.8	2.9	6.4	8.9	6.4
44868i	Marl C1	None	2.1	2.4	0.6	6.5	5.7
44868e	Marl C1	None	3.1	3.3	3.3	10.0	6.1
44869i	Marl C2	None	3.0	2.0	1.0	4.3	6.9
44869e	Marl C2	None	2.1	2.9	4.2	9.3	6.6
44871i	Marl C1	None	3.9	2.6	3.5	8.9	6.0
44871e	Marl C1	Yes	2.8	3.4	6.8	13.3	5.2
44876i	Marl C1	None	2.5	2.5	1.6	8.4	6.9
44876e	Marl C1	None	1.7	3.2	2.1	8.2	5.6
44880i	Marl C2	None	3.0	2.6	9.8	7.3	7.3
44880e	Marl C2	Light	2.0	3.7	1.4	6.4	6.3
44883i	Marl C1	Yes	3.2	2.3	9.8	10.6	6.9
44883e	Marl C1	Yes	4.1	2.3	10.7	13.2	5.4
44905i	Marl C1	None	4.0	2.3	0.5	5.2	7.2
44905e	Marl C1	Yes	3.4	3.1	3.8	9.0	5.1
44920i	Marl C1	None	3.5	2.9	0.6	5.8	8.9
44920e	Marl C1	Light	1.6	2.8	7.6	10.3	7.7
44931i	Marl C1	None	4.9	2.6	0.6	5.7	7.7
44931e	Marl C1	Yes	1.6	5.1	3.1	13.4	7.2
44933i	Marl C1	None	4.5	2.0	13.1	6.1	7.0
44933e	Marl C1	Yes	4.3	2.8	10.4	13.3	6.9
44984i	Marl C1	None	3.2	2.1	0.8	4.2	6.5
44984e	Marl C1	Yes	2.5	3.0	5.4	13.2	5.8

(Note: Due to the technique and issues discussed in the Appendix, only the concentrations for samples with totals between 80% and 100% are listed. These are considered more accurate. If more than one determination was available, they were averaged.)

Table 2 Marl C XRF data; amount of scum and major elemental concentrations on the interior (i) and exterior (e). All sherd numbers preceded by "UC"

thick surface rich in the elements calcium and iron. Therefore, it seems likely that the scum on this vessel formed due to the reaction of calcium and iron, which was facilitated by the addition of limestone temper that decomposed upon firing. The Giza Marl A sample with lighter scum and

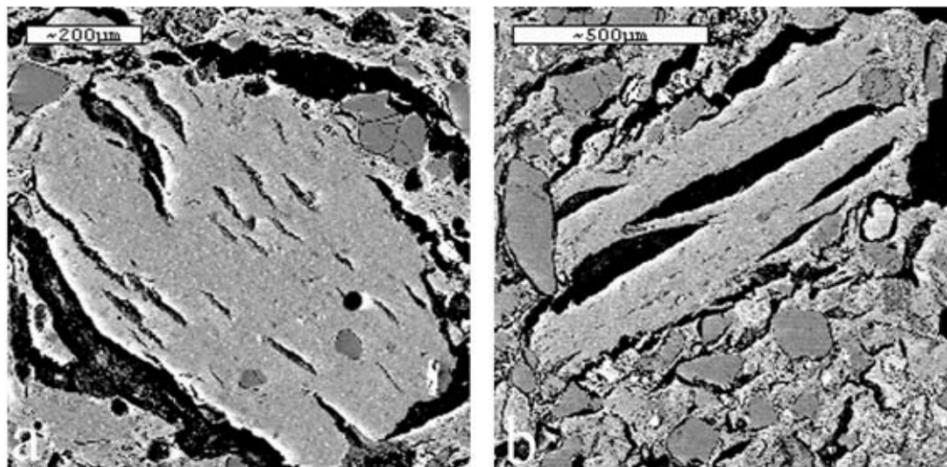


Fig. 4

fired below 800°C had an increased amount of calcium, magnesium, sodium, and sulphur on its surface. Thus, the presence of salt and calcium and magnesium sulphates probably produced its scum. The XRF data suggested that for the Kahun Marl C vessels the scum was composed of calcium and magnesium sulphates. For future studies, the identification of decomposed limestone, either visually or petrographically, that suggests a high firing temperature may be all that is needed to establish which process resulted in the surface scum.

#### MARL C ARGILLACEOUS INCLUSIONS

The study of the clay-like inclusions characteristic of Marl C began with SEM analysis. This is because it seemed important to first establish their character as either grog, unmixed clay or shale inclusions. The term argillaceous inclusion covers a range of inclusion types including shale/argillaceous rock fragments (ARFs), grog, and clay pellets (natural or temper). Determining between these inclusions is often difficult and a petrographic study by WHITBREAD (1986) has attempted to characterize each type. Using WHITBREAD's summary of properties for ARFs, grog, and clay pellets, backscatter electron images of the Marl C samples were examined to identify characteristic features. In particular, any cracks running lengthwise through the inclusions were noted as these may reflect how wet the material was when processed (WHITBREAD 1986: 84). A large majority of the inclusions appear to be clay pellets with only a few mineral inclusions. They

featured a prolate and stretched appearance often with cracks, and sharp to slightly merging boundaries with the matrix (Fig. 4). This suggests that some were moist and may have been distorted by the pressure applied by the potter during the process of vessel manufacture. The boundaries indicate that in certain cases they were wet enough to be integrated with the matrix, while still being dry enough to remain distinct. The variation in their appearance suggests a range between more lithified inclusions and those that were more clay-like. Therefore, a single determination as either shale inclusions or clay pellets may not be accurate. Rather, it seems appropriate to continue to refer to these inclusions as argillaceous inclusions as this term only refers to the clay component and not the degree of solidification.

The next issue is whether these inclusions resulted from a ground, dry clay with pieces that did not become mixed and acquire temper when processed, or whether they are indications of intentionally added clay temper (WHITBREAD 1986: 84–85). The nature of marl clay, typically originating as hard pieces that are broken and mixed with water, suggests the argillaceous inclusions could be the result of clay processing. The variation in the extent of lithification also seems to support this hypothesis. In order to determine if the argillaceous inclusions derived from the original clay, chemical analysis by SEM-EDS was performed to establish if the elemental composition of the inclusions and clay matrix were the same. SEM-EDS allowed for the careful analysis of

just the inclusions and a separate analysis of only the clay. A total of 25 samples were prepared as polished sections and analysed to determine the elemental concentrations in the clay matrix and in the argillaceous inclusions.

Statistical analysis was employed to assess the significance of chemical differences between the inclusions and the clay (FLETCHER and LOCK 2005). Four tests were utilized, starting with one to assess the variability within the two sets of data, those from the argillaceous inclusions and those from the clay matrix. Called an F-test, the results suggested that the variances in the two groups were different for the elements calcium, potassium, sodium, and titanium (FLETCHER and LOCK 2005: 90). Based on these results, a two-tailed Student's T-test was performed assuming unequal variances and a normal distribution (FLETCHER and LOCK 2005: 95). The results from this test revealed significant differences in the means for calcium and silica values. This is undoubtedly due to the increased calcium in the matrix because of the addition of limestone temper, while the clayey inclusions have an increased amount of silica relative to the matrix. Additionally, the inclusions had lower amounts of iron, potassium, magnesium, and manganese, but high concentrations of aluminum and titanium. Despite small differences, the data suggest that the argillaceous inclusions are in fact quite similar in their elemental composition to the surrounding clay matrix.

Although a normal distribution for the values from both data sets was safe to assume, a second significance test was run that does not require the data to show normality (FLETCHER and LOCK 2005: 97). Called the Mann-Whitney Test, it also confirmed that there were significant differences in the mean silica and calcium values, but not in the data from the other elements (FLETCHER and LOCK 2005: 97). A final test was the Kolmogorov-Smirnov test to determine if the two data sets were likely to have come from the same "source" (FLETCHER and LOCK 2005: 111). The results suggested this was probable for most of the elemental data, except the values of calcium and silica. In summary, the statistical analyses of the elemental data from the clay matrix and argillaceous inclusions support the opinion that the inclusions derive from the same source as the clay matrix and are residual components.

The hypothesis that the argillaceous inclusions are natural to the marl clay utilized to manufacture Marl C vessels was further supported by the

petrographic examination of the Giza Marl C sherd. The characteristics of the inclusions in this sample suggest they may have been inherent to the clay but did not become crushed and hydrated. This is because the size of the argillaceous inclusions ranged from fine (0.125 – 0.25 mm) to very coarse (>2 mm). The presence of fine pieces and the gradation to larger fragments makes it less likely they are temper, which would probably exhibit a narrower size range. CYGANOWSKI (2003: 27) also suggested the inclusions derived from the clay based on the examination of a corpus of Marl C thin sections. She further proposed that the size and amount of argillaceous inclusions may be used to indicate the extent to which the clay was processed for vessel production. Thus, large and plentiful inclusions would indicate the clay had not been thoroughly broken up, while a few, fine inclusions would indicate near complete pulverization of the clay for vessel manufacture.

#### CONCLUSIONS

This study has examined two characteristic features of Egyptian Marl C pottery, the white surface layer and the argillaceous inclusions. The analyses established that the white layer should be referred to in the literature as "scum". This scum can develop on the pottery in two distinct ways, both involving the movement of soluble salts to the surface. One process is the deposition of calcium and magnesium sulphates on the surface during drying. The other is the formation of calcium ferrosilicates on the surface during firing, a process which may be facilitated by the presence of sodium as a flux. The analyses indicate that both processes were involved in creating a scum on the surface of Marl C vessels, with the only distinction being the firing temperature resulting in a thicker surface at higher temperatures due to the formation of calcium ferrosilicates. The formation of this surface indicates the sophisticated knowledge of pottery making and firing of the Ancient Egyptians. All of the correct components in the appropriate amounts were needed for the surface to develop, in addition to the control of the firing to reach above 800°C.

On some Marl C sherds, a distinct surface scum is not present as seen from the description of Marl C sherds published by BADER (2001). Lack of a distinct scum on the surface of a Marl C sherd may arise from a small amount of evaporation having taken place through that surface during drying, or from the firing temperature reached by

that surface having been too low or too brief for a calcium ferrosilicate scum to develop.

Limestone tempered pottery fired above 800°C would have been susceptible to lime spalling after firing as the decomposed limestone hydrated. To avoid this, the potters would have either needed to add salt or fire the vessel above 1000°C (RICE 1987: 98). The addition of salt would have lowered the temperature at which the calcium ferrosilicates formed. These would encapsulate the decomposed limestone pieces preventing them from rehydrating during use. Thus, fewer resources would have been needed for firing since it would no longer be necessary to fire the vessels to 1000°C to prevent lime spalling. Ironically, the addition of salt would not only prevent spalling, but would also have resulted in the production of a surface scum due to the creation of calcium ferrosilicates at the surface where soluble calcium and sodium would be concentrated during drying. The common occurrence of decomposed limestone in the Marl C fabric confirms the high firing temperatures that may have necessitated the addition of salt, which would have also ensured a scum formed (NORDSTRÖM and BOURRIAU 1993: 180–181). While this may suggest the scum was a by-product due to methods to prevent lime spalling, there is also the distinct possibility that this surface was intentionally created. The possible presence of an added white slip on Marl C vessels was noted by BADER (2001), and may indicate a white surface was desired and could be enhanced if it did not appear naturally. The important point is to consider the possibility that the scum may have been produced deliberately.

The typically red inclusions within the Marl C fabric appear to be argillaceous inclusions resulting from the processing of the clay for manufacturing vessels. These pieces had not been completely obliterated into a uniform clay size and remained somewhat impervious to the water added during vessel production. Technologically, a certain amount of these inclusions may have been advantageous. The pore space created around them would have assisted in vessel drying and allowed the escape of gases during firing. Additionally, large inclusions with open space or weak bond around them are known to help pre-

vent crack propagation. Once again, a choice may have been made to not completely grind the clay into a fine powder as the presence of these argillaceous fragments in the clay gave desirable properties during vessel manufacture and use.

Overall, it should not be assumed that the argillaceous inclusions and scum were accidental features of Marl C pottery. The Ancient Egyptian potters had a long tradition of manufacturing marl clay vessels that undoubtedly lead to their intimate knowledge of the materials and their properties. In all probability, they intentionally selected particular clays, given that there are numerous marl clay beds along the Nile, and utilized specific recipes and firing procedures to produce the desired results. These fascinating technological practices involved in the production of Marl C pottery highlight the need to gain a more complete understanding of pottery manufacture in Ancient Egypt. The utility of technical analyses in this area of research is clear.

#### Acknowledgements

The authors would like to thank Simon Groom, Philip Connolly and Kevin Reeves for laboratory assistance at the Wolfson Archaeological Science Laboratories, University College London. Dr. Anna Wodzińska generously allowed the SEM analysis of the two Marl samples from the Giza Plateau Mapping Project. The thin sections were produced and analyzed at the Charles McBurney Laboratory for Geoarchaeology at the University of Cambridge. Prof. Thilo Rehren and Prof. Clive Orton both provided guidance for the XRF analysis, while the former also facilitated the SEM analysis. Alice Hunt from UCL kindly assisted with the SEM analysis. XRF analysis of the Kahun Marl C sherds was permitted by the Petrie Museum of Egyptian Archaeology with the assistance of Hugh Kilmister and Subhadra Das. The XRF project was conducted by M. Ownby to complete her MSc degree at University College London with the support of a Marie Curie Early Training Fellowship. A preliminary draft of this article was reviewed by Dr. Carla Gallorini, Dr. David Aston, and Dr. Bettina Bader, who provided valuable suggestions and constant feedback to encourage the project along.

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