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The use of technical ceramics in early Egyptian glass-making

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ABSTRACT

We present a detailed description of the layered structure developing in the walls of Egyptian Late Bronze Age glass-making vessels, and in similar vessels successfully replicated in laboratory experiments. The analyses show that this layered discolouration and change in ceramic composition is due to the interaction of the glass batch with the vessel during firing. The formation of this visually striking and easy to recognise pattern is due to the chloride content of primary glass batches and does not occur in vessels used to re-melt existing glass. Thus, we argue that these discolourations can be used as a reliable and easy field guide to identify glassmaking waste among Late Bronze Age ceramic assemblages, hopefully increasing the currently very small number of identified LBA glassmaking workshops.

1. Introduction

Direct archaeological evidence for the production of raw glass during the Late Bronze Age is very limited, despite the abundance of glass objects from this period excavated from Mesopotamia, the Levant, Egypt, Cyprus, Crete, mainland Greece and southern Italy. This is partly due to the inconspicuous nature of glass-making waste and the lack of sufficient diagnostic criteria how to identify primary glass-making archaeologically, and partly due to the relative scarcity of excavations targeting workshop and industrial areas, compared to the more commonly excavated cemeteries, palaces and temple areas.

Current knowledge is that LBA primary glass-making at the Egyptian sites of Qantir and Amarna took place in ceramic vessels including re-used domestic pottery in Qantir (Rehren and Pusch, 2005; Pusch and Rehren, 2007a,b) and purpose-built crucibles in Qantir and Amarna (Rehren, 1997; Nicholson et al., 1997; Rehren and Pusch, 1997), fusing the raw materials at temperatures of around 900–1100 °C. This produced first so-called semi-finished, that is incompletely molten and uncoloured glass (Smirniou and Rehren, 2011), and in a second step intensely coloured cylindrical glass ingots which were then passed on to secondary workshops (e.g. Pulak, 2008) for the production of finished objects, while the used vessels and crucibles were discarded. Apart from these vessels and crucibles, and small amounts of semi-finished glass, hardly any other waste was produced in the process. So far, semi-finished glass has only been reported from Qantir (Pusch and Rehren, 2007a, 149–51) and Amarna (Smirniou and Rehren, 2011). However, it may have been overlooked elsewhere, as it is easily confused with glassy faience or white glass, and rarely present in significant quantities. Therefore, the archaeologically much more visible and abundant crucible fragments are potentially the most important indicators of Bronze Age glass-making. They can, however, also be used for the re-melting of existing glass. The simple presence of crucibles with glass attached is therefore not sufficient to demonstrate glass-making; this paper aims to present clear criteria to recognize glass-making vessels.

Fragments of crucibles and 'glassy slag' that point to primary glass production have been excavated at the New Kingdom sites of Amarna (Petrie, 1894; Nicholson, 1996), Malkata, Lisht, and Qantir (Fig. 1). The finds from Qantir–Pi-Ramesse have been comprehensively studied and form our reference point for primary glass-making during the later Ramesside period (Rehren and Pusch,

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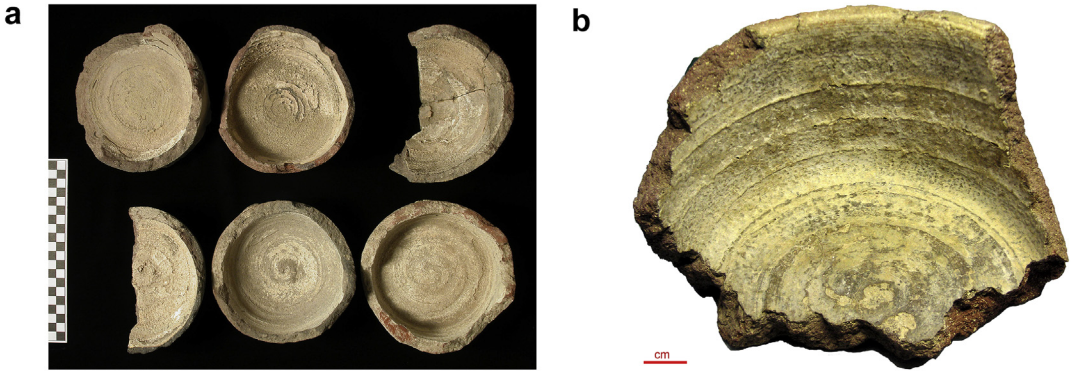

Fig. 1. a: Collection of crucibles from Qantir – Pi-Ramesse. b: Crucible fragment from the site of Amarna.

2005; Pusch and Rehren, 2007a; Schoer and Rehren, 2007). Industrial waste associated with glassmaking excavated by Nicholson in the 1990s at the site of Amarna, and a well-contextualized find of one semi-finished glass fragment (TA22) from the site O45.1 are pointing to primary glass production at Amarna (Nicholson, 2007: 109). A recent study of finds from Amarna also identified semi-finished glass among the finds from Petrie's excavations, representing direct evidence that glass was being made at Amarna from its raw materials (Smirniou and Rehren, 2011).

This paper now examines crucible fragments from Amarna and Lisht, comparing them with fragments from Qantir as well as with crucibles from experimental studies replicating LBA glass-making (Merkel, 2006; Merkel and Rehren, 2007). The aims of this paper are (a) to document the various distinctive layers and zones of discolouration found on the archaeological and experimental crucible fragments, (b) to show that the causal explanations already proposed for the formation of these layers and discolourations for Qantir (Schoer and Rehren, 2007; Merkel and Rehren, 2007) and for Merkel's experiments (Merkel, 2006; Merkel and Rehren, 2007) can be applied also to the material from Amarna and Lisht, and finally (c) to demonstrate how the diagnostic features for glass-making that have been identified by detailed microscopic, macroscopic and geochemical analysis can be used to identify archaeological remains of possible LBA glass-making sites elsewhere.

1.1. Crucibles for glass-making

Coloured glass can be made in a one-step process fusing together the necessary raw materials (Turner, 1954, 443T; Jackson et al., 1998). However, practical considerations such as the volume of unreacted batch material or crushed semi-finished glass relative to the volume of the crucibles and the thickness of the finished glass ingots (Pusch and Rehren, 2007a,b, 153; Merkel and Rehren, 2007, 217, Fig. 26), textual indications from Mesopotamian cuneiform tablets from the 1st millennium BC (Brill, 1970), even though they should be interpreted with some caution (Nicholson, 2007: 117), and the archaeological evidence from Qantir (Rehren and Pusch, 2007) and Amarna (Nicholson, 2007: 129; Smirniou and Rehren, 2011) all point to a process where there were at least two stages in LBA primary glass production.

According to the evidence from Qantir, the raw materials were first mixed in ceramic reaction vessels (in Pi-Ramesse, re-used ovoid beer jars were used for this step) and fired at relatively low temperatures to make semi-finished glass rich in residual quartz, intermediate newly-formed crystals, and porosity (first stage); that frothy semi-finished glass was then crushed and mixed with a colourant and possibly minor amounts of additional flux in purpose-built ceramic crucibles that were fired at somewhat higher temperatures to produce well-fused coloured glass ingots virtually free of residual quartz, intermediate crystals and bubbles (second stage). Prior to their use, the reaction vessels and the cylindrical crucibles from Qantir were coated on their inside with a mm-thick layer of mostly lime ('parting layer'; Fig. 2) to separate the glass from the ceramic, thus facilitating the removal of the glass from the crucible and preventing contamination of the glass batch by ceramic material (Turner, 1954; Rehren, 1997; Rehren and Pusch, 2005; Pusch and Rehren, 2007a; Schoer and Rehren, 2007; Merkel and Rehren, 2007). The crucible fragments from Amarna (Nicholson, 2007: 123) and Lisht also demonstrate this lime-rich parting layer, first identified and analysed by Turner (1954) on finds from Amarna, on the inner surfaces of the vessels. In addition, some of the ceramic fragments showed a unique pink discolouration of the inner half of the wall fragments (Fig. 3).

1.2. Glass-making in ceramic vessels

Experiments testing the glass-making model developed by Rehren and Pusch (2005) provided a better understanding of the parting layer and its role, examined how the raw materials and the glass melt react with the ceramic vessels, and replicated the pink discolouration that can be found on glass-making crucibles, but not on those used for re-melting existing glass (Merkel and Rehren, 2007). The main points that came out from these experiments are:

- The parting layer does not act completely as a barrier between the batch and the ceramic. Compounds such as soda, chlorides and lime do transfer between the ceramic and glass.
- The presence of significant amounts of salt (NaCl, above 10 to 20 wt%) in the glass batch affects the appearance of the ceramic, leading to its discolouration near the parting layer interface.
- The absence or presence of salt in the batch is responsible for the development of a layered structure on the crucibles during use, including the **parting layer (PL), buff ceramic (Buff), pink discolouration (Pink), and unaltered ceramic (Ceramic).** In some cases all layers appear, while in other cases some of the layers might not be present.

In some archaeological finds from Qantir and Amarna, a layer of bottle-green glass has been identified between the pink discolouration and the buff ceramic (Rehren, 1997). The experimental work showed that the buff ceramic layer and the pink discoloured ceramic zone only formed in the presence of significant amounts of chlorides in the batch. Thus, the presence of a discolouration zone in archaeological ceramics should indicate the presence of large amounts (equal to about 10–20 wt %) of chlorides in the crucible charge. The presence of such amounts of chlorides is thought to be