

The composition of Egyptian glass as a function of melting temperature

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The remarkable homogeneity of two of the major groups of ancient glasses over vast geographical regions and across chronological periods was recognized from the beginning of systematic chemical studies, but has remained relatively unexplained (1,2). Chemical analyses have mainly been used as a descriptive tool to characterize different groups of glasses. Successful attempts have been made to provenance Medieval and later pot-ash-based glasses based on chemical composition. The more ancient soda-lime silica based glasses have proven more difficult to provenance, probably due to the fact that their base glass compositions (3) are so tightly grouped. Based on this tight compositional grouping, it has been suggested that very few glass making centres existed in ancient times and a strict formula for glass production was adhered to. It follows that across the entire eastern Mediterranean and into Mesopotamia, a conservative technology was used to produce glass, with raw materials and methods unchanged for over 500 years in two separate periods to produce 'Egyptian' (high-MgO) and 'Roman' (low-MgO) type glass respectively. More recently, it has been observed that the composition of the vast majority of Late Bronze Age Egyptian and Mesopotamian glass is closely related to the cotectic trough leading from the eutectic region of the soda-lime-silica system towards more calcium rich compositions (4). Similarly, Roman glass typically falls into the more silica rich cotectic trough of the system (5,6).

Although the traditional model of a conservative and closely guarded technology does provide a plausible explanation for the witnessed compositional pattern seen in ancient glasses, the compositional variance in the raw materials, mineral natron, plant ash natron, and sand, particularly the contents of calcium oxide and reactive soda compounds, could not possibly have been within the control of the ancient glass makers. Modern analyses show this raw material variance to be at least one order of magnitude greater than the variance in the final glass compositions for the major components of silica, soda and lime, indicating that some other mechanism significantly contributed to this homogeneity.

It is argued here that the correlation witnessed between glass compositions and the liquidus surface morphology of the relevant phase diagrams is too close to be coincidence, and the observed scatter or variance in chemical composition is too narrow to result primarily from raw material control. Instead, we propose a

smelting model for glass making that includes the formation of a cotectic glass melt in the presence of a considerable amount of crystalline material that acts as a buffer or reservoir material from which the melt forms. The model proposed here is rooted in the petrological model for the formation of well defined, compositionally selective liquid phases during incomplete melting of a range of parental petrologies (e.g. magma generation in subduction zones or during anatexis) at given temperatures (and pressures). It is the first model to offer a genetic explanation for the tight compositional clustering of ancient glasses. Such a partial melting model can explain very closely controlled melt compositions deriving from far more variable batch compositions.

A series of experimental melts is presently being carried out, testing this hypothesis of system-controlled glass forming behaviour. In addition, the relationship of glass melting temperature and chlorine content in the forming glass is investigated.

Results

Initial findings have shown that time is a decisive factor in glass formation when melting different batch compositions of the same theoretical liquidus temperature but moving along the contour line from the soda rich equilibrium trough to the silica rich equilibrium trough. The formation of glass occurs much more rapidly near the soda rich trough than near the silica rich trough. The general relationship between melting time and temperature is by no means new (7). The strong relationship of this to the overall composition, however, and the connotation implied by this for early glassmakers is highly relevant to the compositions witnessed, and the preference for 'Egyptian' compositions during the Late Bronze Age.

As the typical Late Bronze Age Egyptian glass tend to form around the soda rich cotectic trough as apposed to Roman glass which forms around the silica rich cotectic trough this observed phenomenon may be clear evidence for the preference of earlier glass makers to choose batch compositions closer to the soda rich cotectic trough for glass production. With the glass melt taking less time or less overheat (7) to achieve a good quality glass, the fuel requirement would be reduced and the design of the furnace would not need to be as good or efficient as that of later, Hellenistic and Roman period, furnaces.



Fig 1: Cross section through crucible Nr 3, fired about 20 degrees below liquidus temperature. Note the formation of some glass only, indicating incomplete or partial melting.

Different batch compositions covering the range of 'Egyptian' and 'Roman' glasses were melted in crucibles at temperatures from 900°C to 1200°C at intervals of 50°C for 16 hours. Mullite crucibles were used to reduce the interaction between the vessel and the formed glass. The cooled vessels were cut open to study the degree of separation of the glass phase and any residue, and the volume proportion of glass to crystalline phases (Fig. 1). Samples were initially investigated optically to inspect the level of crystallization. Microprobe analysis was then used to determine the composition and homogeneity of the formed glass, and to identify crystalline phases (Fig. 2). Measuring the alumina content of the resulting glass allowed to monitor any interaction between the glass and the mullite crucible.

As part of the experimental study we are exploring the dependency of chlorine content in the forming glass from melting temperature and melt composition. A rough inverse correlation of calcium oxide and chlorine content has been found for ancient Egyptian glasses; it is to be tested whether this represents a possible archaeo-thermometre or just a compositional prefer-

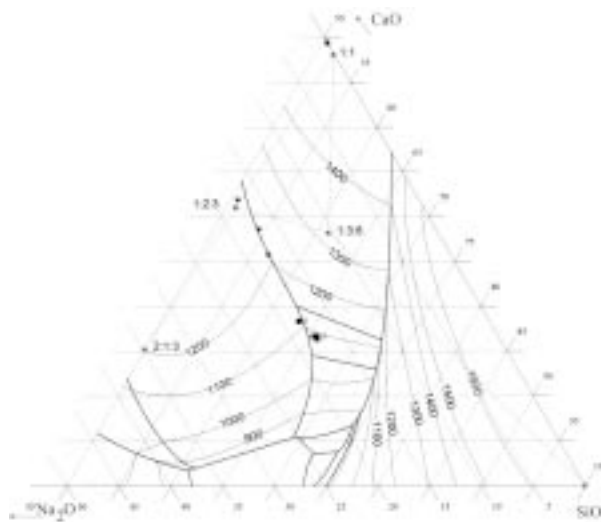


Fig 2: Plot of compositional data for experiment Nr 3 in the soda-lime-silica diagram, fired at 20 degrees below liquidus temperature. Black circle indicates batch composition, six-pointed stars to the upper left are analyses of individual crystals within the glass (contaminated with some glass), and open crossed circles are actual glass analyses. Note the offset of the glass composition from the batch composition.

ence of chlorine for low-CaO glasses within the compositional region of glass under study here.

References

1. Caley, E., *Analyses of Ancient Glasses 1790-1957*. Corning Museum of Glass, Corning, 1962.
2. Sayre, E., In: *Application of Science in Examination of Works of Art*, Boston, 1965, 145-154.
3. Lilyquist, C. & Brill, R., *Studies in Early Egyptian Glass*, The Metropolitan Museum of Art, New York, 1993.
4. Rehren, Th., Pusch, E. & Herold, A., In: *Prehistory and History of Glassmaking Technology*, American Ceramic Society, Westerville, 227-250.
5. Wedepohl, K.H., *Die Herstellung mittelalterlicher und antiker Gläser*. Mainz, Stuttgart, 1993.
6. Rehren, Th., *Journal of Archaeological Science* 27, 2000, 1225-1234.
7. Cable, M., In: *Prehistory and History of Glassmaking Technology*, American Ceramic Society, Westerville, 315-329.