THE COMPOSITION OF AKSUMITE GLASS

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In the summer of 1983 a number of glass specimens excavated at Aksum were analysed non-destructively by X-ray fluorescence spectrometry. The apparatus used, the sample preparation and the conditions of analysis were virtually identical to those employed earlier in a study of Egyptian faience. For relevant information on this matter and on the uncertainties inherent in the reported composition values one should consult the introductory chapter in: ANCIENT EGYPTIAN FAIENCE by A. Kaczmarczyk and R.E.W. Hedges.

The values tabulated below have been rounded off to the nearest 0.1% and detected amounts below that value are simply reported as 'tr' (traces). The figures were rounded off to prevent hasty conclusions on the basis of very low concentrations, where indeterminate errors caused by leaching and other changes produced under various burial conditions may have relatively large impact. However, in computing the mean value for a group of samples all numbers in excess of 0.01% were included in the count. Each analysis reported in Table I represents the arithmetic mean of three measurements at different points on the surface of a specimen. Whenever a glass fragment showed evidence of having been fractured at a time posterior to its burial, the X-ray beam was aimed at the exposed interior, since its analysis would be more representative of the original glass composition than that of the outer weathered surface.

The analytical values listed in Table I represent the contents of the respective oxides. The composition is preceded by numbers identifying the precise provenance of each sample and a description which includes a Munsell colour chart designation. In addition to the elements listed Vanadium-Arsenic, and Chromium were also sought, but no concentrations above 0.01% were detected in any of the glasses. Lighter elements, such as Si, Al, Mg and Na, could not be measured non-destructively with the apparatus available to me at the time.

With regards to the numerical values listed in Table I, one must keep in mind that the concentrations are expressed in terms of the most common valence states of an element. This means that in red opaque glasses, where the pigment is Cu_2O and not CuO, the concentration of the 'true' pigment, i.e., cuprous oxide, would be about 11% lower. Considering all the other sources of error and uncertainties, the matter of whether the given concentration represents the amount of the 'true' valence state is rarely significant enough to alter conclusions based on the data (Kaczmarczyk and Hedges, 1963:10)

The Nature of the Colourants and Opacifiers.

Those who are not familiar with the relationship between glass colour and its chemicaccel composition may consult a very comprehensive book on the subject entitled, COLOURED GLASSES by W. Weyl. A more condensed discussion of the topic may be found in Chapter III of the book on Egyptian faience cited above (Kaczmarczyk and Hedges, 1983:140-144).

At least six of the glasses have been designated as 'colourless', as the intensity of the colouration was judged insignificant and fell outside the range of chromas given in the Munsell charts. Half of them showed a tinge of green which was produced by ca. 1% Fe_2O_3 . To five of the six (from GTII/11A, GTII/11B, GTII/11D, DA13B, shaft TB/B) antimony oxide had been added as the clarifier, and the greenish hue is only observed in glasses which contain only about 0.5% Sb_2O_5 apparently not enough to suppress entirely the colour due to iron. Those (from DA13B, GTII/11D, shaft TB/B) which contained less iron and ca. 0.7% Sb_2O_5 were completely decolourized by the latter. The one glass in which ca. 1.4% of MnO was used as a decolourizing agent, instead of antimony oxide, was obviously made in a different workshop or at a different time. The specimen, from THCVIIC/5, is also distinguished from the other translucent colourless glasses by containing 1% BaO as impurity and showing the highest potassium content of the six.

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This suggests that of the six it is the most likely specimen to have belonged originally to the high-potassium class of ancient glasses.

Two opaque white glasses were included in the examination. The high calcium and antimony contents leave no doubt that calcium antimonate was the opacifying agent. Variations in the manganese and lead contents suggest that the one from DA13A has a different source of origin than the one from GAII/7. The small amount of copper in the latter might have come as impurity with lead.

The four glasses listed as opaque yellow had a colour in the Munsell range 5Y8/10 - 5Y8/12. All four were opacified by and owed their colour to lead antimonate, the classical yellow pigment since the 2nd millennium BC. Three of the four also had a remarkably similar PbO:Sb₂O₅ ratio of ca. 5:1. A somewhat higher ratio of 6:1 and significantly higher iron content were detected in the glass from XXIIIA/6A5. A different origin from the other three is suggested.

Of the 10 glasses designated as green two were greenish-white translucent (7.5BG9/1) and coloured exclusively by under 1% iron oxide, since the CuO content did not exceed 0.01% in either the one from DA13B or XXIIIA/6A5. Had they contained any clarifiers, such as manganese or antimony oxide, they would have been colourless. Both have higher than average concentrations of K₂O as does the one opaque greeen glass from GA111/4. All three were very likely high potassium, high magnesium glasses. This will remain a tentative conclusion until a magnesium analysis of the glasses is available. The opaque one, however, was coloured by CuO and had a different hue, 10BG4/6 on the Munsell chart.

Seven glasses were blue-green translucent and were remarkably uniform in colour, 10G3/5 and 2.5B3/5 on the Munsell chart. Most were clarified by antimony oxide, though two (from GAII/7 and shaft TB/A) show the presence of both antimony and manganese. The colour in all of them was produced by 1.3-2.6% CuO with the assistance of variable amounts of iron and lead. Four of the seven (from GAII/2,

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GAII/6, shaft TB/A, shaft TB/B) had enough PbO (0.6-2.0%) to suggest intentional addition, while the remaining three (from DA13A, GAII/7, shaft TB/B) had less than 0.1%, undoubtedly introduced as an impurity. The two sets of greens obviously came from different batches of glass. Whether iron was added intentionally or came with the sand cannot be determined since the concentration range, ca. 1-2%, can easily be achieved with the amounts of iron found in many sands.

Three kinds of blue glass were clearly distinguishable. One royal blue translucent glass (Munsell 5PB4/9) from GAII/7 and three opaque medium-light blue (Munsell 10B6/7 and 5B6/6) from three different sites were coloured by 1-2% CuO. The colour difference was undoubtedly connected with the higher lead, manganese and iron concentrations in the former. Lead oxide in particular has a very marked effect on the colour produced by copper. The opacifying agent in the other three (from DA13A, DA13B, GAII/7) was calcium antimonate, of which there is considerably less in the royal blue glass. Two of the four exhibited slightly elevated potassium concentrations, but not enough to prove that one is dealing with a high potassium glass. Two of the three opaque glasses, No. 2 from DA13A and No.5 from GAII/7, have such a remarkably similar composition that a common source is strongly indicated.

The majority of blue glasses analyzed were dark blue (Munsell 5PB3/8) of varying degrees of translucency and coloured by cobalt oxide. The CoO concentrations ranged from 0.02% to 0.13%, and though all the specimens contained more copper in absolute terms, the colouring power of cobalt is so much greater than that of copper that colour attribution is no problem. Several sources of cobalt and workshops are indicated by the compositions, and at least two distinct subgroups are distinguishable. One group of three (from GAII/4, No.1 from GAII/6, and No. 1 from the Shaft Tomb B) are virtually manganese-free, lead-free, and were clarified by antimony oxide. The absence of manganese and the presence of traces of arsenic suggest that an arsenical cobalt sulfide ore, of the type found in Iran, served as the source of pigment.

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the concentrations of other elements, notably iron, suggest different places of manufacture. The other four cobalt glasses (from DA13A, DA13B, GTII/11B) contain about half as much CuO, on the average, but significant levels of lead as impurity, and have much more uniform iron concentrations of about 1% Fe_2O_3 . There is no way to tell how much of the manganese might have come with cobalt, if another common type of cobalt ore had been used. (Kaczmarczyk and Hedges, 1983:62). The lopsided Mn:Co ratio leaves little doubt that some if not all of the MnO was put in intentionally as clarifier to reduce the interference from iron.

The analyzed specimens included three examples of red opaque glass of a shade known as 'haematikon' (Munsell 7.5R4/11). All of them were coloured and opacified by reduced copper in the form of Cu_2O or metallic copper, the traditional red glass pigments since the 2nd millennium BC. Two contained negligible amounts of lead, but the third (from THC11/2) contained an appreciable quantity of PbO (ca. 8%), albeit at levels somewhat below those favoured by late Ptolemaic and early Imperial Roman glass in Alexandria (ca. 30%). The introduction of lead facilitates the formation of red colour and stabilizes it so that less rigorous control of the reducing furnace conditions can be tolerated. A different atelier is indicated for this glass.

Another traditional recipe was used to make purple translucent glass (Munsell 5RP5/10) with the aid of manganese alone. The two examples (one from DA13A, the other from GAI/5) are so remarkably similar in composition that, even if they did not come from the same batch of glass, the same atelier or a very similar technical tradition is strongly indicated.

The only glass whose composition does not seem to fit within the established glassmaking tradition of the Ancient Near East is the type designated as "pink translucent" (Munsell 10RP7/8). All five thus labelled appear to be low potassium glasses with antimony oxide serving as the clarifier. None of them have more than 0.01% Cu_2O , or 0.04% MnO, and the CoO content in no case exceeds 0.01%. This leaves only

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iron as a possible pigment, with or without the assistance of titanium, which being a common impurity in iron and in many sands is no more elevated in these glasses than in others. Though for centuries red faience had been coloured by iron oxide (Kaczmarczyk and Hedges, 1983:167), there is no precedence for the use of iron to make red glass, even if iron is the source of colour in many natural red stones. Making such a glass requires great skill or good fortune in the choice of raw materials and furnace conditions. In composition this glass is as no other seen by me or unlike any other described in the archaeological literature. The question of possible affinities of this and all the other glasses described above to glasses of known composition from the Hellenistic Near East, or the Byzantine and Persian world will be dealt with in the next section.

The distinguishing features of each colour are summarized in Table 2, where the arithmetic mean compositions of glasses of specified Munsell shades are listed. Left out of the Table were those oxides whose mean did not exceed 0.01% in any of the colour, or as in the case of ZnO where only among the greens did the average reach an unimpressive 0.03%.

Comparisons with Glasses of the Ancient Near East

The Near Eastern glasses of greatest relevance for such a comparison are those made between the 3c. BC and 7c. AD, since they would have served as most likely models for whatever glassmaking industry existed at Aksum during the time period spanned by the excavated sites. While the published literature on Roman glasses has grown by leaps and bounds during the last half century, the bulk of the published analyses deal with European areas of the Empire. Much less numerous are the analyses of glass from the Hellenistic and Roman East and even less numerous those from Parthian and Sassanian sites. For a virtually complete compilation of the analyses published prior to 1957 the best reference is the admirable book of Earle Caley's entitled: <u>Analyses of Ancient</u>

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<u>Glasses, 1790-1957</u>. Since that date several important papers by Brill, Turner, and Sayre have added considerably to our knowledge of Near Eastern glasses of all time periods. Opaque glasses.

For over 15 centuries from the time glassmaking began antimony was the mainstay of the production of opaque glasses other than red, which have traditionally been opacified by reduced copper. In white glasses the opacifying agent was calcium antimonate $(Ca_2 Sb_2 O_7)$, in yellow lead antimonate $(Pb_2 Sb_2 O_7)$. For reasons that are not understood, between the 1st and 5th c.AD tin oxide replaced antimony oxide in glasses manufactured within the confines of the Roman Empire. While the change seems to have began in the West, by the 3rd c. AD glasses from Roman Syria and Palestine are more often opacified with tin than with antimony oxide, and it is very difficult to find any antimony-opacified glasses in the Byzantine world after the 5th c. AD (Brill, 1968:59; Turner and Rooksby, 1963:306). It appears that antimony might have remained in use somewhat longer in the Sassanian world, but not enough work has been done to tell by how many centuries.

Examination of the tabulated data shows that in <u>not a single</u> one of the analysed opaque glasses from Aksum can the opacity be attributed to tin oxide. Except in red glasses, which were opacified by Cu₂O here, as everywhere else from Europe to India, antimony oxide remained the opacifier of choice. This can mean one of two things, either the local industry was relatively insulated from changes taking place in the Roman-Byzantine world, or it had closer links with the Mesopotamian and Persian technical traditions. Of course, if all the glasses are of a date earlier than, let us say, the 4th c. AD, depending on the frequency of commercial exchanges a lag of a century or more between innovations in the Levant and their imitation in Ethiopia might not be unreasonable. Diplomatic and ecclesiastical missions between the capitals are not an effective way to propagate technical changes. However, if the glasses were to be of a date later than the 3rd c. AD, for instance, one would expect to see at least some imported specimens opacified by tin oxide.

The matter of tin and a comparison of the pigment concentrations in the opaque glasses with a few reported analyses of specimens dated between the 3rd c. BC and 5th c. AD, would favour local production or importation from somewhere else than the Roman world. This, however, will have to remain conjectural until more analyses had been performed on opaque glasses of the first half of the 1st millennium. The paucity of information can best be illustrated by looking at the data on red opaque glasses. Search of the literature yields only ten full analyses of such glasses spanning a time period from the 15th c. BC to the 3rd AD. Of these, nine are from Egypt and only <u>one</u> from Hellenistic Mesopotamia, and only four have a terminal date <u>AD</u>, none later than the 3rd century. To the count given above one might add five more analyses of red Egyptian glass that I have done and five 5th c. AD Byzantine glasses analysed at the Louvre (Kaczmarczyk and Lahanier, in preparation).

Comparisons with the analyses of Alexandrian glass and glass from other parts of the Greco-Roman Egypt show more differences than similarities, particularly in the levels and ratios of key elements such as lead, antimony and copper (Brill and Moll, 1963:147; Caley, 1967). Interestingly enough, the one opaque red glass from THCI1/2 that stands out by its lead content, resembles most closely not the glasses of the Roman period but 2nd c. BC Ptolemaic glasses from Elephantine (Caley, 1962:16) and some later Ptolemaic glasses, probably from Memphis, analysed by me. There is little if any resemblance to the few analysed opaque red glasses from Hellenistic Mesoptamia or from India (Caley, 1962:50-53).

It is also noteworthy that the red opaque and the only opaque green glass (from GAIII/4) have potassium concentrations far in excess of what was customary in the contemporary Roman glass. In this they resemble glasses from east of the Euphrates, where high-potassium high magnesium glasses remained fashionable until Islamic times. More on this subject will be presented in the next section.

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Translucent Glasses

On the basis of several hundred analyses of colourless or faintly coloured glasses Sayre has documented (Sayre, 1963: 269-276) some very interesting changes in the composition of Near Eastern glasses between the 15th c. BC and 12th c. AD. The implications of these changes are fully discussed by the author and by Smith in a companion article (Smith, 1963). What makes the two studies particularly interesting is that they represent the first statistically significant attempt to compare glasses of the Eastern Mediterranean Area (the Levant) with those from Mesopotamia and areas further East.

For the period of interest to us, two changes are particularly noteworthy: 1. the replacement of high mangesium, high potassium glasses by those with substantially lower concentrations of the two elements, and 2. the phasing out of antimony as clarifier in favour of manganese or no clarifier at all (Sayre, 1963:270,271). The switch to low potassium glass was so thorough within the Roman Empire that glasses of the type are often referred to as "Roman glasses". What is noteworthy, however, and could only have been demonstrated by statistically large sample of analyses is the fact that glasses of the older type persisted east of the Euphrates into Islamic times. Thus, while glasses of both types may be found in any one East Mediterranean or Persian site of the 1st-5th c. AD, a considerably higher proportion of glasses from Mesopotamian sites, for example, will contain K₂O in excess of 1% and have antimony oxide as clarifier.

The importance of the statistical aspects of this study cannot be overemphasized and the hazards of looking at only a few glasses from too few sites will be illustrated below. In 1969 Brill published the analyses of some Mesopotamian glasses of the Sassanian period (Brill, 1969). Of the 13 green samples from Choche (near Ctesiphon) 12 were high-potassium high-magnesium types, very uniform in composition, and contained neither antimony nor manganese as clarifiers. However, the 13th resembled Roman glasses; it was decolourized with manganese and had one fifth as much potassium as

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most of the others (0.69% vs. 3.5% average for the other 12). It is obvious that if the 13th had been the only glass recovered, or if it had been one out of two or three, one would have come to a very different conclusion regarding the nature of Mesopotamian glasses of the period.

The case for the persistence of high-potassium glasses east of the Roman world is strengthened by the analyses of glasses from a Sassanian glassmaking site at Tel umm Kirin, not too far from Choche. The average K₂O content of four green to colourless glasses was 2.2%, but these glasses were also decolourised with 0.8% MnO, so here the old and the new technical traditions are not clearly delineated. Of course, just as some Mesopotamian glassmakers remained faithful to old traditional recipes, while others changed partially or completely to the "Roman" formulations, one can see in the analyses of Byzantine glasses from Aphrodisias (Brill, 1969:52) the persistence of highpotassium and high-magnesium compositions in the absence of either manganese or antimony, at a time when most glasses of the Levant are clarified with manganese and contain very little potassium.

Returning to the tabulated analyses of Aksumite glasses, it must be said at the outset that the concentrations of the colourants cannot be used to distinguish translucent glasses locally made from those that might have been imported. The concentration ranges observed in these glasses fall within the wide spectrum observed in glasses from all areas of the Near East. The same is true of the concentrations of the principal impurities, such as titanium and strontium. They resemble as much the Byzantine glasses from Aphrodisias (in Anatolia) or Roman from Egypt as they do those from the Sassanian sites discussed above. The one exception, of course, are the pink translucent glasses mentioned at the end of the preceding section.

In the case of tin, there is clear correlation between its concentration and that of copper, indicating that at Aksum, as in other parts of the Ancient World, bronze scrap was frequently used as a source of copper in glass. The average SnO_2 :CuO ratios in

green blue and red glasses were 0.075, 0.091, and 0.058, respectively. The ratios are very similar to those found in Ptolemaic and Roman faience from Egypt (Kaczmarczyk and Hedges, 1983:88-90), and show that here too 5-10% tin bronzes must have been the most common aloys.

There is one impurity which does not seem to be correlated with any other element and is seen most frequently in glass from the shaft tomb B. The impurity is BaO, a substance rarely seen at comparable concentrations in ancient glass or faience (Kaczmarczyk and Hedges, 1983:106-110), except in Chinese glasses, where it is found at concentrations an order of magnitude higher. The only glasses that I know of which consistently have similar levels of BaO are Bronze Age glasses from Failaka (Kuwait) at the northern end of the Persian Gulf (M. Pollard, unpublished analyses). While the similarity would simply reinforce other hints at a close relationship with the Gulf area, caution is advisable in view of the big time gap between the Aksumite and Failaka glasses. It is unfortunate that no Hellenistic glasses from Failaka were available for analysis. However, at the levels detected in the Aksumite glasses barium must have been introduced with the sand or the lime, so the five barium-containing glasses were most probably manufactured somewhere else than all the other glasses. Consequently, the time gap would not preclude the possibility that these exceptional glasses were imported from the same area as were the ones found at Failaka, since sand of good quality can serve as a source of raw material for many generations of glassmakers.

I have been unable to find any mention or ancient red or pink glasses which even remotely resemble in composition the pink ones from Aksum. As a rule glasses of this composition are pale green or colourless. Search of the published literature revealed that even the mention of <u>rose</u> or <u>pink</u> glasses is rare. Analyses of two glasses described respectively as "deep rose" and "pale rose" from late 3rd c. BC Nippur (Iraq) have been reproted (Caley, 1962:35). The former contains iron at a concentration very similar to the concentrations in Aksumite pink glasses, the latter twice as much. Unfortunately,

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they also had substantial amounts of manganese (1.04 and 0.41% Mn_2O_3 , respectively) and copper (0.55 and 0.36% CuO, respectively.) Consequently, it is more likely that either the copper or the manganese were responsible for the rose colour instead of iron.

Until new data come to light one is forced to conclude that the pink glass was made locally, and that by some good fortune and lucky choice of raw materials the Aksumite glassmakers succeeded in making a material that faintly imitates natural gems, such as garnet, in which iron is responsible for the colour. Of course, such glass can now be made, but it still requires very careful control of ingredients and furnace conditions (Weyl, 1978:94,100). A key ingredient in the synthesis of such glasses is phosphate, therefore, it would be interesting to see if these ancient pink glasses have elevated phosphate levels. A number of ancient glasses contain additive amounts of phosphorus, suggesting that bone ash, or a mineral source of phosphate was for some reason mixed with the more standard ingredients. No phosphorus determination was performed on any of the glasses, since such analysis could not have been done without destroying a part of the glass.

The question arises at this point whether anything more positive can be deduced about the possible affinities of Aksumite glass with contemporary Near Eastern glasses from the potassium content and the nature of the clarifiers, if any. The interpretation of the potassium data is complicated by the fact that alkali are most easily leached out of glasses during burial in humid soils. However, one can still say that a certain K_2O concentration indicates a similar or <u>higher</u> concentration in the original glass. With that in mind, one can look at the fraction of translucent glasses which probably originally contained over 0.7% K_2O , for example. The dividing line was selected on the basis of the statistical studies comparing high magnesia with low magnesia glasses of the Greco-Roman world and of Mesopotamia. In the majority of the Near Eastern high magnesia glasses the K_2O concentrations cluster around 2%, while in the low magnesia glasses the majority cluster between 0.2 and 0.6% (Smith, 1963:285-288). The data in Table 1 show that almost 50% of the translucent glasses were probably of the high-potassium type, and even if the dividing line is set higher at 1% K₂O, the proportion is still an impressive 40%. The proportions are similar if only colourless glasses are counted, or if both opaque and translucent glasses are included in the count. It would seem that the "Roman" glass was less common at Aksum than the older variety. This can be interpreted to mean that Persian influences were more significant than Roman-Byzantine, at least in the 'industrial' sphere. One is still left with 50% of glasses that contain less than 0.7% K₂O. It is very unlikely that all or even most of them contained as little potassium in their pristine state. Glasses with truly low potassium content are few in number, so one must conjecture that if such glasses represent imported Levantine objects, glass could not have been a major commodity brought in from the Roman-Byzantine world.

The argument in favour of local industry or one subject to Persian influences is reinforced by examination of the antimony and manganese contents of Aksumite glasses. Of the 30 translucent glasses only <u>three</u> dark-blue cobalt-coloured specimens were free of antimony and were probably clarified by manganese, while an overwhelming 66% (20 specimens) used antimony oxide in preference to manganese oxide. The tradition that antimony should be introduced to improve the clarity of the glass must have been very well entrenched, since a substantial amount of antimony was introduced into manganese-coloured purple glasses, which in view of their Mn:Fe ratio certainly did not need any assistance from antimony or any other clarifier. If one looks solely at the colourless glasses, the type of glasses most extensively investigated by Sayre (Sayre, 1963:269-276), the preference for antimony shows up in <u>five out of the six</u> Aksumite specimens. Only one colourless glass from THCVIII/5 was free of antimony and rich in manganese, but even it does not conform to the standard "Roman" type, since it also contained almost 4% potassium oxide.

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Therefore, the scarcity of manganese clarified glass and the retention of antimony as a key ingredient in translucent glasses, also point in the direction of the Persian world as being more important than the Greco-Roman when it comes to the art of glassmaking. None of the factors discussed above, can by themselves prove or rule out local production for most if not all of the analysed specimens. What the absence of tin opacified glasses, the high incidence of high potassium glasses, and the clear preference for antimony as clarifier suggest is that one is either dealing with an old wellestablished, conservative, tradition-bound glass industry or an industry more in tune with Mesopotamian than with Levantine practices. Moreover, if there should have been imports among the analysed glasses these were more likely to have come from Mesopotamia or Persia than from Egypt or Syria.

<u>Acknowledgment</u>. I want to take this opportunity to thank the Research Laboratory for Archaeology at Oxford and Dr. Mark Pollard, in particular, for making it possible for me to carry out the analyses on their spectrometer.

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K₂O CaO TiO₂ MnO Fe₂O₃ CoO NiO CuO ZnO PbO SrO SnO₂ Sb₂O₅ BaO from D13A(901-74)Red opaque mosaic glass, Munsell:7.5R4/11 2.1 7.0 0.1 0.2 1.2 0.0 0.0 2.2 0.0 0.2 tr. 0.0 0.0 0.0 No.1 from DA13A Small dark blue glass, Munsell:5PB3/8 0.4 3.9 0.1 0.4 1.3 0.1 0.0 0.2 0.0 0.3 tr. tr. tr. 0.0 No.2 from DA13A Medium-light blue opaque glass, Munsell: 10B6/7 and 5B6/6 0.4 7.3 0.1 0.1 0.4 tr. 0.0 0.8 tr. 0.1 tr. 0.1 0.8 0.0 No.3 from DA13A White opaque glass 0.4 7.1 0.0 tr. 0.5 0.0 0.0 0.0 0.0 0.0 tr. 0.0 2.3 0.0 No.4 from DA13A Dark blue-green translucent glass, Munsell: 10G3/5 and 2.5BG3/5 0.7 0.0 0.0 1.8 tr. tr. 0.1 0.2 0.6 1.2 9.8 0.1 0.1 0.0 No.5 from DA13A Dark blue cased translucent glass with colourless interior, Munsell:5PB3/8 0.7 1.4 0.1 tr. 0.3 0.0 0.4 tr. 0.0 0.0 0.0 0.4 5.7 0.2 No.6 from DA13A Purple translucent glass, Munsell:5RP5/10 1.9 0.7 0.0 0.0 tr. tr. 0.0 tr. 0.0 0.6 1.0 7.8 0.2 0.0 No.1 from DA13B Half of colourless glass bead 0.5 7.2 0.1 tr. 0.7 0.0 0.0 0.0 tr. 0.0 tr. 0.0 0.8 0.0 No.2 from DA13B Medium-light blue opaque glass bead, Munsell: 10B6/7 and 5B6/6 1.0 8.2 0.0 0.1 0.7 0.0 0.0 2.1 0.0 0.2 tr. tr. 3.0 0.0 No.3 from DA13B Half of red opaque glass bead, Munsell: 7.5R4/11 3.0 6.2 0.2 0.4 1.7 0.0 0.0 1.7 tr. 0.3 tr. 0.1 0.0 0.0 No.4 from DA13B Half of dark blue glass bead, Munsell: 5PB3/8 0.0 0.3 5.7 0.1 0.5 1.4 0.1 0.0 0.1 0.0 0.2 tr. 0.0 0.2

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Table 1. Concentrations (\$) of Listed Oxides in Glasses from Various Sites

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Table 1. Continued

 K_20 Ca0 Ti0₂ MnO Fe₂0₃ CoO NiO CuO ZnO PbO SrO SnO₂ Sb₂0₅ BaO No.5 from DA13B Greenish-white translucent glass bead, Munsell:7.5BG9/1 3.1 8.1 0.0 0.0 0.6 tr. 0.0 0.0 0.0 0.0 tr. tr. 0.0 0.0 from GAI/5 Purple translucent glass, Munsell: 5RP5/10 0.7 9.1 tr. 2.7 0.7 0.0 0.0 tr. 0.0 0.1 0.0 0.5 0.0 from GAII/2 Dark-blue-green translucent glass bead, Munsell: 10G3/5 and 2.5BG3/5 0.6 5.0 0.3 0.2 2.1 0.0 0.0 2.6 tr. 1.8 tr. 0.3 0.3 0.0 from GAII/4 Small dark-blue translucent glass bead, Munsell: 5PB3/8 0.2 7.1 tr. tr. 1.0 tr. 0.0 0.3 0.0 0.0 tr. tr. 0.4 0.0 No.1 from GAII/6 Large fragment of dark blue-green glass, Munsell: 10G3/5 and 2.5BG3/5 1.3 7.1 0.1 0.1 1.2 0.0 0.0 2.0 tr. 2.0 tr. 0.2 0.6 0.0 No.2 from GAII/6 Half of dark blue bead, Munsell:5PB3/8 0.5 7.6 0.2 tr. 2.2 0.1 0.0 0.6 tr. tr. tr. 0.0 0.6 0.0 No.1 from GAII/7 Royal blue translucent glass, Munsell:5PB4/9 1.3 9.0 0.1 0.6 1.1 0.0 0.0 1.5 tr. 0.9 tr. 0.2 0.5 0.0 No.2 from GAII/7 White opaque glass 0.7 8.2 tr. 0.5 0.9 0.0 0.0 0.2 0.0 1.0 tr. 0.0 2.5 0.0 No.3 from GAII/7 Dark blue-green translucent glass, Munsell: 10G3/5 and 2.5BG3/5 1.2 10.4 0.1 0.6 1.4 0.0 0.0 1.7 tr. 0.1 0.1 tr. 0.6 0.0 No.4 from GAII/7 Pink translucent glass bead, Munsell:10RP7/8 0.5 7.2 0.1 tr. 0.9 0.0 0.0 tr. 0.0 tr. tr. 0.0 0.7 0.0 No.5 from GAII/7 Medium-light blue opaque glass, Munsell: 10B6/7 and 5B6/6 0.5 7.2 0.0 0.0 0.6 0.0 0.0 0.9 0.0 0.0 tr. 0.0 1.0 0.0

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Table 1. Continued

 K_20 Ca0 Ti0₂ Mn0 Fe₂0₃ Co0 Ni0 Cu0 Zn0 Pb0 Sr0 Sn0₂ Sb₂0₅ Ba0 from GAIII/4 Thick moderate-blue-green opaque glass, Munsell: 10BG4/6 5.9 3.4 0.3 tr. 1.7 0.0 0.0 1.3 tr. tr. tr. 0.0 0.3 0.0 from GTTT/11A Very thin colourless glass with a greenish tinge 0.9 6.5 0.1 0.1 1.0 0.0 0.0 0.0 0.0 0.0 0.1 0.0 0.5 0.0 No.1 from GTII/11B Half of a dark-blue translucent glass bead, Munsell: 5PB3/8 tr. 4.8 tr. 0.6 0.8 tr. 0.0 0.1 tr. 0.1 tr. 0.0 0.0 0.0 No.2 from GTII/11B Colourless translucent glass with a greenish tinge 1.6 6.6 tr. 0.2 0.9 0.0 0.0 0.0 0.0 0.0 tr. 0.0 0.5 0.0 from GTII/11D Colourless translucent glass 0.1 5.8 0.1 0.0 0.4 0.0 0.0 0.0 0.0 0.0 tr. 0.0 0.7 0.0 No.1 from Shaft TB/A Dark blue-green translucent glass, Munsell: 10G3/8 and 2.5BG3/5 1.3 9.0 0.1 0.6 1.1 0.0 0.0 1.5 tr. 0.9 tr. 0.2 0.4 0.0 No.2 from Shaft TB/A Pink translucent glass, Munsell:10RP7/8 0.4 7.1 0.2 0.0 0.7 0.0 0.0 tr. 0.0 0.0 tr. 0.0 0.7 0.0 No.3 from Shaft TB/A Pink translucent glass, Munsell:10RP7/8 0.4 6.0 0.1 0.0 0.6 0.0 0.0 tr. 0.0 0.0 tr. 0.0 1.4 0.0 No.1 from Shaft TB/B Dark blue translucent glass, Munsell:5PB3/8 0.4 6.2 0.0 0.0 1.7 tr. 0.0 0.4 0.0 0.0 tr. tr. 0.7 0.3 No.2 from Shaft TB/B Dark blue-green translucent glass, Munsell: 10G3/5 and 2.5BG3/5 0.2 0.0 2.4 8.0 0.1 0.2 1.3 0.0 0.0 1.6 0.0 tr. tr. tr. No.3 from Shaft TB/B Yellow opaque glass, Munsell: 5Y8/12 0.7 4.9 0.0 tr. 1.3 0.0 0.0 0.0 tr. 11.5 tr. tr. 2.5 0.0

Table 1. Continued

K₂O CaO TiO₂ MnO Fe₂O₃ CoO NiO CuO ZnO PbO SrO SnO₂ Sb₂O₅ BaO No.4 from Shaft TB/B Pink translucent glass, Munsell:10RP7/8 0.1 6.9 0.0 0.0 0.7 0.0 0.0 0.0 0.0 0.0 tr. 0.0 1.1 0.4 No.5 from Shaft TB/B Colourless translucent glass 0.3 7.7 tr. 0.0 0.4 tr. 0.0 0.0 tr. 0.0 tr. 0.0 0.7 0.0 No.6 from Shaft TB/B Dark blue green translucent glass, Munsell:10G3/5 and 2.5BG3/5 0.6 8.6 tr. 0.2 0.9 0.0 0.0 2.0 tr. 0.6 tr. 0.1 1.1 0.2 from THCII/2 Red opaque glass, Munsell: 7.5R4/11 (low chroma) 4.5 8.3 0.2 0.2 1.6 0.0 0.0 2.8 0.0 8.2 tr. 0.1 0.2 0.0 from THCVIIC/5 Colourless translucent glass with a greenish yellow tinge 3.6 3.4 0.0 1.4 1.3 0.0 0.0 0.0 tr. 0.0 tr. 0.0 0.0 1.1 No.1 from XXIIG/4G Small thick rim of yellow opaque glass rim, Munsell:5Y8/12 0.8 5.2 0.0 tr. 1.1 0.0 0.0 tr. tr. 9.0 0.0 tr. 1.8 0.0 No.2 from XXIIG/4G Large fragment of thin pink translucent glass, Munsell: 10RP7/8(low chroma) 0.1 6.8 0.2 tr. 0.7 0.0 0.0 0.0 0.0 0.0 tr. tr. 0.9 0.0 No.3 from XXIIG/4G Large fragment of thin yellow opaque glass. Munsell: 5Y8/10 0.9 6.0 0.0 0.0 1.4 0.0 0.0 0.0 0.0 11.7 0.0 0.2 2.2 0.0 No.1 from XXIIIA/6A5 Greenish-white translucent glass bead, Munsell: 7.5BG9/1 3.4 7.1 0.0 0.0 0.9 0.0 0.0 tr. 0.0 0.0 0.1 0.0 0.0 0.1 No.2 from XXIIIA/6A5 Yellow opaque glass, Munsell: 5Y8/12 0.6 5.3 0.2 0.0 2.5 0.0 0.0 tr. 0.0 7.4 tr. 0.0 1.2 0.0

Colourless		White	Yellow	Blue	Light	Dark	Purple	Red	Pink	
	- 		5Y8/12 and 5Y8/10	10G3/5 and 2.5BG3/5	10B6/7 and 5B6/6	5PB3/8	5RP5/10	7.5R4/11	10RP7/8	
к ₂ 0	1.17	0.55	0.75	1.81	0.63	0.31	0.85	3.20	0.30	
Ca0	6.20	7.65	5.35	7.66	7.57	5.86	8.45	7.17	6.80	
Ti0 ₂	0.07	0.05	0.05	0.14	0.03	0.11	0.15	0.17	0.12	
MnO	0.29	0.27	0.02	0.24	0.08	0.32	2.28	0.27	<0.01	
Fe 203	3 0.76	0.72	1.55	1.28	0.58	1.39	0.72	1.50	0.71	
000	<0.01	<0.01	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	<0.01	
Cu0	<0.01	0.10	<0.01	1.82	1.27	0.29	0.02	2.23	<0.01	
РЪО	<0.01	0.49	9.89	0.71	0.11	0.13	<0.01	2.89	<0.01	
Sr0	0.07	0.05	<0.01	0.06	0.05	0.04	0.08	0.04	0.05	
Sn02	<0.01	<0.01	0.08	0.13	0.06	<0.01	<0.01	0.08	<0.01	
^{Sb} 2 ⁰ 5	0.54	2.41	1.91	0.50	1.58	0.28	0.56	0.05	0.98	
BaO	0.18	<0.01	<0.01	0.02	<0.01	0.04	<0.01	<0.01	0.08	

Table	2.	Mean	%	Concentrations	of	Selected	Oxides	in	Aksumite	Glasses
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		No. of	specime	ns inclu	uded in ea	ach Muns	sell colo	ur range:	
	6	2	4	8	3	7	2	3	5
Note	1.	The white	,yellow	,blue,an	nd red wer	re opaqu	ue, the ot	hers trans	lucent
Note	2.	The green shade, 7.5 was not a	column BG9/1. veraged	exclude The one in with	es two gla transluce the othe	asses of ent roya	distinc al blue g	tly differ lass,5PB4/	ent '9,