THE CHEMICAL INTERPRETATION OF THE TEXTS

ROBERT H. BRILL
One of the main objectives of this volume was to bring together specialists from three different disciplines in an attempt to combine their separate kinds of knowledge and points of view in order to gain as full an insight as possible into the meaning of these texts. In this chapter and its Appendix are presented some of the findings which result from a consideration of the translations in light of the chemical knowledge now available concerning Mesopotamian glasses. But before presenting the findings it will be helpful to discuss some of the complications that arise in making these considerations.

The most important contribution to this effort is, of course, Professor Oppenheim’s translations. For those who are interested primarily in the texts themselves, the archaeologist’s evidence and the chemist’s reasoning are only ancillary, for the tablets and what they say do, after all, have an existence of their own, regardless of whether or not they are consistent with knowledge from these other disciplines. But even so, if these, or indeed any translations, are to be made a meaningful part of the history of man, and to become something more than just suspended information, they cannot be left in philological isolation. At some point, one must venture beyond to another level, that of interpretation, and it is in this process that several risks are run and many difficulties encountered.

First, Professor Oppenheim’s warning must be kept in mind, that the texts should not be treated as explicit recipes and instructions for glassmakers. They are a part of a literary tradition. But even though the texts may be literary in character, it is doubtful that they are merely literary caprice. The particular substances and processes recorded must have referred in some way to the real world. What we can hope for then—and the best we can hope for—is to reconstruct just what it was that someone saw or what it was that someone was told that led him to write down what he did.

Secondly, it must be realized that the chemical and archaeological information available at present has been gathered from a relatively small number of glass objects that have been recovered from Antiquity and it cannot be said with certainty that they represent an accurate sampling of what was made in different times and places in the ancient world. Moreover, even though the archaeological and chemical information is every bit as valid as the philological knowledge, we have no right to expect that the particular objects from which we have happened to gain this information have any necessary connection with the materials (or objects, if one prefers) to which the texts alluded. But if we are to proceed at all we can only proceed on the basis of things we know, and obviously not on the basis of things we do not yet know. It is conceded, therefore, that in the years to come, as more evidence becomes available, the chemist or archaeologist might tend to view Professor Oppenheim’s translations in an entirely different light than we do here.


2. While carrying out his studies the author has deliberately not consulted any previous publications dealing with these texts. By working only with Professor Oppenheim’s new trans-
There are other difficulties, too, of a different type, which arise in this kind of project, and although we hope we have been able to overcome these it might be helpful to others to note their existence. These are the difficulties inherent in all interdisciplinary efforts, difficulties which stem from differences in the modes of thinking which prevail in different disciplines.

The physical scientist, even accustomed as he is to dealing with the abstract, and with entities like electrons and atoms which he knows he can never expect to see, feels a genuine sense of wonderment at the accomplishments of philologists who have been able to unravel such things as cuneiform texts. To a chemist, the verbalized terms remain little more than nonsense syllables, and it is only with either some help or luck that he even manages to examine the tablets themselves right side up. But he finds in the philologist's approach an unfamiliar type of logic and must take special care to understand its subtleties. Even more importantly it requires a conscious effort on the part of workers in both fields to appreciate fully the nature of the goals for which the other is reaching.

lation, it has been possible to draw interpretations which, whether they be valid or not, are at least free of any bias imposed by familiarity with earlier interpretations. After having brought these studies to their present state, however, some of the earlier interpretations of R. Campbell Thompson were reviewed. It is clear that this earlier work was imaginative, carefully thought out, and that it deserves high praise. But it is also true that the chemical information now available on ancient glasses, just as the philological information, is much advanced beyond that which was available some 30-40 years ago. From such an advantaged position, it obviously would not be fair to criticize an earlier work, but it might be noted in passing that if he had had at his disposal as much chemical data as is now available, Campbell Thompson possibly would not have been led to some of the conclusions he stated. For example, the existence of gold-containing ruby glasses in Mesopotamia seems doubtful, or at least unsupported by current philological, archaeological or chemical evidence.

To the philologist, for example, the ultimate value of a translation may not perhaps be much affected by whether a particular term might mean tin or lead or antimony, or whether it might even mean one or another in different contexts. But to the historian of technology or to the archaeological chemist such a point is crucial. So if it takes a while for the chemist to adapt himself to the manner of reasoning by which the philologist accomplishes his translations, so also the historian or literary scholar may grow impatient with the chemist's preoccupation with exactitude when considering the minutaie of translations, for he, the literary scholar, deals instead with the over-all meaning and feeling of a text as a whole, and the place it takes in relationship to the rest of our heritage of the written word.

It will already be evident to the reader that Professor Oppenheim has done his part of this task (the major part, to be sure) with excellence and care, and that the archaeological evidence which follows has been compiled with great thoroughness. The chemical interpretation has trailed somewhat behind due to the fact that we are still in the process of gathering pertinent information. Progress is slow in chemical analyses and other scientific investigations of Mesopotamian glasses because of the very limited availability of samples from well-authenticated objects. One cannot proceed by simply selecting samples representative of the dates and places which he would like to study. Instead, he can study only the materials which happen to be available.

The complexity of the chemical interpretation also enters the picture. It is immediately obvious that the texts are of interest to anyone studying early glass technology, but the casual observer is not likely to realize just how interesting they are. There is scarcely a line in these tablets that does not connect in some way with something we already know, or suggest a connection with something that we do not know but would like to know. In addition, the interpretation of any one small section of the texts cannot be
fixed conclusively until its interrelationships with all the other parts are understood and tested for consistency. Consequently, the interpretation of the translations is far more complicated than it appears at first glance.

Although much experimental and theoretical work still lies ahead before a full chemical picture of the texts can emerge, we do have already a considerable body of chemical information from which to draw. It is worth noting, too, that while future investigations will undoubtedly add to what is known about Mesopotamian glasses, they are not likely to undo the knowledge we have at present. Much of this chemical information has been discussed with Professor Oppenheim and he has incorporated some of it into his own comments at suitable places throughout the major part of this book. Part of this information, that believed to have a direct bearing on questions which might have already occurred to those familiar with early glass technology, is summarized in the Appendix at the end of this chapter. Since Professor Oppenheim has established the most immediate connections required, a more comprehensive chemical interpretation, should it seem to be warranted, can be deferred until additional experimental evidence and information are available on the types of glasses and related materials involved. The sort of chemical information now being sought includes chemical analyses of as many Mesopotamian glasses as possible, covering as wide a range of date and origin as is obtainable, various types of isotope experiments, experimental laboratory melts, determinations of physical properties, and microscopic examinations, as well as similar studies on raw materials and on the whole family of faience, Egyptian blue, and other chemical relatives of glass.

Another line of reasoning being pursued, a line which parallels one used by the philologist, also appears promising. Just as the philologist can find vestiges of ancient languages in modern languages, so also is it possible to find some vestiges of early technologies in the everyday work of village craftsmen at work today in remote regions. This anthropological approach has been successfully applied to other crafts and materials, but its first applications for learning something about early glassmaking have just been started.

* * *

The first question which occurs to everyone interested in these texts is, “What are the materials being prepared by these procedures?”—or to be more specific, “Are they glasses?” My own answer, for reasons that are detailed below, is that they almost certainly are glasses. But as long as the translations remain incomplete it cannot be said without some reservation that the materials referred to must be glasses. There is just enough ambiguity in the identifications and chemical details as gleaned from the translations, that the possibility cannot be entirely ruled out that the final products might instead have been some form of faience, Egyptian blue, or similar materials, instead of true glasses.

Having mentioned these terms we must distinguish between them, for even though these materials resemble one another in many ways they are indeed distinctly different, as is explained in the Appendix (p. 114). All of these materials found widespread use in the ancient world, have similar general appearances and often similar colors, and are made from similar ingredients. Therefore, they are often confused for one another. This confusion has been compounded by loose usage of the terms describing them. For example, frit is used often for faience in English and Fritte for Egyptian blue in German, whereas frit has a different and very specific, traditional meaning to the glassmaker and ceramicist. There is a group of other terms such as paste and composition which are used sometimes to describe Egyptian blue and faience as well as more or

less indefinite finds. In most cases simple visual examination of an object will serve to differentiate between these materials, if one knows what to look for. However, there are cases where microscopic examination or even laboratory tests might be required to distinguish between, for example, a dense, compact, Egyptian blue bead and one made of blue glass.

Reiterating the main point of this discussion, there is sufficient ambiguity in the translations of the texts to leave room for the possibility that the materials being prepared were glassy faience, Egyptian blue, or some related but not yet clearly-defined material. The ambiguity causing most of the difficulty for the chemist is that resting in the identifications of certain pivotal terms, for it is obviously perplexing to attempt to understand "recipes" in which some of the ingredients are unknown. The key terms whose exact meanings are missing (through no fault of the philologist) are set off in the Appendix (p. 115). Without more complete identifications of these terms, the chemist cannot be absolutely certain of any conclusion he draws. Even in the face of this uncertainty, however, there is very strong evidence in favor of the opinion that the materials being prepared actually were true glasses.

The strongest evidence, perhaps, is in the proportions of major ingredients called for, but in addition, the presence of certain other elements in the recipes, such as copper, lead, and possibly antimony, ties in well with the known chemistry of the minor ingredients of Mesopotamian glasses. Neither should one overlook the fact that there are no obviously inappropriate materials included among the major ingredients. Several other pieces of evidence indicate that procedural details, as well as the purely chemical factors, also make very sound glassmaking sense, and reinforce independently the opinion that the materials being made are indeed glasses. (See Appendix, pp. 118, 120, 122 and passim.)

Before continuing we should dispose of a minor point. In a few places the texts appear to call for the addition of more ingredients than are really necessary, or for the addition of ingredients already introduced in an earlier stage. Some present-day glass technologists have been disturbed by this. They recognize that glasses of any of the colors mentioned could have been prepared with the use of between three and six ingredients, and question why, in the extreme case, one of the complex processes (section 7) should call for the introduction of as many as nine ingredients in one stage. But this can hardly be raised as a serious argument against the contention that the texts deal with true glasses. In the first place, the same argument could be raised against contentions that they deal with any other materials, and in the second place, any apparent superfluity of ingredients can be readily accounted for. Glassmakers in ancient times were not able to control melting conditions as effectively as we can today and consequently they may not have been able to determine exactly which ingredients were essential for some processes, and which were not. Therefore, particularly in the cases of those glasses which were the most difficult for them to make, they may have introduced extra ingredients simply because they did not realize they could have done without them, or because they wanted added assurance of obtaining the products desired. Moreover, the use of substitutes or adulterant ingredients to partially take the place of scarce or expensive ingredients would have been just as economical then as it is now. In any event, the fact is that glassmakers have historically been inclined to behave in the manner the texts suggest anyway. A perusal of formula books as recent as those of late 19th- and early 20th-century glassmakers shows that they often incorporated up to a dozen or even more ingredients in their favorite batches. While most of these ingredients served useful and perhaps subtly-defined purposes, the benefits of some of the others must certainly have been more imagined than real.

The inference that the texts allude to true glassy materials is considerably strengthened
by the calculation and experimental findings to which we next turn. Although the chemical arguments may appear tedious to some readers, these two topics must be discussed in detail because they are so important for the understanding of these texts. The first discussion centers around a calculation of the composition to be expected of the products of one of the processes described in the texts, and the second around laboratory experiments conducted by following the instructions they give.

A Calculation of the Chemical Composition of zuku

The first process described for the manufacture of one variety of “artificial lapis lazuli” (sections 1 and 4, pp. 35-38) is the preparation of zuku, which appears to be a chemical intermediate, that is, a manufactured substance to be used as a starting material for other manufacturing processes. Because the instructions given are straightforward and because the ingredients can be identified with some confidence, it is possible to calculate a reasonable approximate chemical composition of zuku.

The two major ingredients specified are immanakku, a mineral, and aljussu, a plant ash. A third ingredient, mentioned in only one of the texts, is namrutu, or “white plant” which comprises about 6 per cent by weight of the starting batch. Because the chemical identity of namrutu is unknown, we have no choice in our calculations except to neglect its presence. (But it might be noted in passing that if namrutu is essentially a limey ingredient, its introduction in this portion would not have much effect on the material being prepared.)

Professor Oppenheim has been able to show that immanakku is a mineral, but has not been able to specify what mineral it is. He tells us that it is not a precious stone, it is whitish in color, hard enough to be used for making cylinder seals, and that, at least in one connection, it looks like “river silt dotted with pebbles.” A connection of some sort also may exist with tin ore. From this evidence one could construct arguments for identifying immanakku as limestone, a conglomerate rock (like sandstone), quartzite pebbles, or conceivably other rocks or minerals.

The first possibility, limestone, does not seem too likely, for it would lead to a chemical composition for zuku which would be essentially an alkali-lime mixture. The subsequent processes then would not seem to lead either to a recognizable archaeological material, or to a meaningful chemical composition. In fact, to make archaeological sense, that is, to produce any of the synthetic ancient materials such as glass, glassy faience, Egyptian blue, or even a glazing material, silica would have had to have been introduced at some stage. The most difficult chemical step in opening up the manufacture of any of these materials is essentially a pyrotechnological one, the reaction of a flux with the silica-bearing mineral. It therefore seems reasonable to assume that the immanakku is the source of silica and that zuku is the chemical intermediate in which the silica has been transformed into a workable, more reactive form by reaction with plant ash.

We, therefore, prefer the identification of immanakku as quartzite pebbles, probably collected with some care from river beds. Such pebbles can be white or whitish, unless stained with iron, and would not have been considered precious stones. Quartzite pebbles are very hard, too hard and brittle, in fact, to be carved conveniently into cylinder seals, but they do provide the basic stuff of which faience cylinder seals—or virtually all faience—are made. While quartzite pebbles do not look like “river silt dotted with pebbles” they are, in fact, one of the types of pebbles with which river silt itself is dotted. One might also argue that the connection with tin-ore referred to in footnote 85, (p. 74), may be through a common source where both minerals were collected, for tin ore also could have been collected in river beds or gravels rather than having been mined. It is also of interest to note that in a present-day primitive glass factory near Herat, Afghanistan,
the glassmaker uses crushed pebbles as his source of silica.

While any one of the above points taken singly may amount only to weak evidence, their cumulative effect is sufficient, we feel, to assume for the purpose of our calculations that immanakku refers to quartzite pebbles collected from river beds. If indeed, immanakku were instead a conglomerate like sandstone the net chemical effect would be a dilution of the silica content by the substitution of a cementing phase relatively rich in some combination of alumina, silica, iron, and lime, along with some alkali.

Professor Oppenheim has translated *ahusu*, the other major ingredient of *zuku*, as ashes of the *naga* plant. It would, of course, be very helpful if the plant itself could be identified, but unfortunately, this is not yet possible.

In any event, various species of the genera *salicornia* and *salsola* (among others) which dot the desert or line marshy regions in Iraq, Iran, Syria, and elsewhere within the area of our interest, are still gathered today in some places and burned in pits to obtain hard chunks of strongly alkaline ashes. These ashes find use as detergents and occasionally as alkali for glaze and glass manufacture. It seems very likely that these chunks of alkali resemble the kind of material called for in the ancient texts. The problem is that the chemical composition of such plant ashes is quite variable depending upon the particular plants which are chosen, the environments in which they grew, and the ways in which they were burned. Therefore, without an exact identification of the *naga* plant and lacking even a knowledge of its supposed region of occurrence, the best that can be done for the purposes of our calculations is to guess at the composition of its ashes.

We now have at our disposal quantitative and qualitative chemical analyses of about twenty plants collected from various arid or saline coastal environments throughout the Middle East and the Mediterranean World. Although such a small sampling is admittedly inadequate for obtaining a reliable picture of what plant ash compositions are like, they indicate the extent of variability to be expected among larger groups of samples, and for our purposes here, they provide a useful guideline. It would be a worthwhile undertaking to collect in the future a comprehensive and systematic suite of plant samples for an analytical survey. In order to accomplish this, an expedition would have to be assembled comprising botanists, anthropologists, archaeologists, and historians of technology.

In Table 2 (p. 124) are shown the analyses of several plant ashes each of which, for one reason or another, can be of help in making a guess as to the composition of *ahusu*. The first is a composition reported by the late Professor W. E. S. Turner. This is a composite of 50 analyses of *keli*, the ashes of the *chinān* plant, collected near Damascus. The other analyses include those of five specimens of plant ashes as prepared today in Iran, Syria, and Afghanistan for use by local technologists. These all come from chunks of hard, gray, porous materials (Nos. 1304, 1305, 1330, 1331 and 1381). The remaining analyses are of the residues of various plant specimens which were dried and ashed under laboratory conditions. The final column gives a composite composition estimated from selected data appearing throughout the table. It was not considered valid to use simple mean values of all of the analyses, for certain of the samples were clearly not good approximations of those used for glassmaking in ancient times. For example, those having low Na₂O:K₂O ratios could not lead to glasses having Na₂O:K₂O ratios of the order of 10:1, as required to fit the known analytical data for Mesopotamian glasses. (See Table 1, p. 122.)

In order to calculate an approximate composition for *zukū*, we made use of the “recipes” prescribed in sections 1 and 4 (pp. 35–38). It was assumed that the composition of immanakku could be represented by that of quartzite pebbles used today in Qom for faience manufacture, and that of *ahusu*, by a plant ash having the composite composition in Table 2. While we know that these choices are purely arbitrary, and cannot pretend that the com-
posite ash composition used in the calculation necessarily corresponds closely to that of *ahussu*, the calculated composition of *zuiku*, as shown in Table 1, is in astonishingly close agreement with that of early Mesopotamian glasses. (One must overlook, as is correct, those elements present in the glasses as colorants or colorant-opacifiers.) The agreement is not as close if one uses the 10:15 ratio of *immanakku* to *ahussu*, given in section 1 (p. 35), instead of the 10:12 ratio prescribed in section 4, but it is still close enough to suggest strongly that *zuiku* could very well have served as a base glass or cullet or chemical intermediate, as implied by Professor Oppenheim’s translation of the texts. To state this result somewhat more rigorously, this calculation does not prove that *zuiku* was such a material, but it does show that a plant ash which had only a slightly different composition from that used in the calculation (or any of those given in the table) could have been used along with quartzite pebbles in these recipes to produce a glass which would have had a composition very closely resembling that of analyzed archaeological specimens of glass.

The greatest discrepancy in the calculated composition (and it is hardly a serious one) is the relatively low proportion of silica to the rest of the components. If the ratio of ash to silica were reduced from 15:10 or 12:10 to something more like 10:10, this would diminish the discrepancy. Alternatively, if something were present in the plant ash to dilute the “active ingredients” to about 75% of their analyzed concentrations, something which would not appear in the final glass, then that also would bring the silica vs. non-silica ingredients closer into line. The calculation above is so tentative that it may not be warranted to do so, but there are in fact two rather obvious ways to rationalize these findings. Either a higher content of unburned carbon in the ash (due to lower combustion temperatures or inadequate oxygen supplies) or the absorption of moisture by the hygroscopic salts in the ashes (possibly even through some lixiviation process of purification) could account for such a hypothetical dilution of the active ingredients, if one wanted to extend the argument that far.

These calculations, and particularly the plant-ash analyses, also serve another important purpose in the understanding of the compositions of ancient glasses. Numerous analyses by Dr. E. V. Sayre have enabled him to establish two different compositional categories of ancient glasses. Both types are essentially soda-lime-silica glasses, but they differ from one another in their concentrations of potassium oxide ($K_2O$) and magnesium oxide ($MgO$). In the first category both oxides are relatively low (0.1–1.0% and 0.5–2.5% respectively) while in the second both are somewhat higher (1–4% and 3–7%). These findings have been borne out by many dozens of analyses carried out elsewhere. The levels of $K_2O$ and $MgO$ in glasses of the high $K_2O$-high $MgO$ composition are consistent with the use of plant ashes as a source of alkali, that is, plant ashes of some of the types we have analyzed so far. These include plants from approximately twenty different sites, although only a few are given in the accompanying table. Glasses with the low $K_2O$-low $MgO$ compositions may have been made with natron as their alkali ingredient, or else some plant having lower $K_2O$ and $MgO$ contents (relative to the soda) than we have yet encountered in our analyses. This inference has been anticipated by those interested in the problem, at least in an informal way, but it requires much further experimental evidence before it can be stated with certainly.

A Laboratory Synthesis of *zuiku*

Another means for investigating the texts is the direct experimental approach of following out some of the instructions to see
what kind of products result. Since sections 1 and 4 (pp. 35 and 38) dealing with the preparation of zukū are probably the most straightforward of the procedures given, and the least ambiguous as far as their ingredients are concerned, they were selected for our first trial experiments. But two important choices had to be made beforehand. Suitable materials had to be found to approximate the ingredients, and the times and temperatures to be used in firing them had to be chosen.

Quartzite pebbles were selected to represent immanakku. These particular pebbles came from a group of materials on loan to The Corning Museum of Glass from the Smithsonian Institution. They had been collected by Hans Wulff at a present-day potter’s shop in Isfahan, where they are used, after having been ground to a powder, for the manufacture of a “stone paste pottery.” Similar quartzite pebbles have been described by Wulff as having been used in other factories in Iran for the manufacture of pottery, faience, and glazes. After having been collected from river beds, the pebbles were sorted and used for these various purposes.

The alkali material selected to represent ahussu, is called tezāb, and was purchased by the author at a soap shop in Kandahar, Afghanistan. Chemically it resembles similar samples of plant ash originating elsewhere in this part of the world. (See sample No. 1330 in Table 2.) The principal chemical difference from the other plant ashes we have analyzed is in its K₂O:Na₂O ratio, but this is thought to be unimportant in these experiments. This particular material was used because more of it was available at the time than our other materials having more favorable K₂O:Na₂O ratios, as compared to early glasses. The tezāb consists of hard, gray chunks of ash containing a substantial residue of incompletely burned plant matter, which shows up as the charred remains of stems and twigs. Throughout these chunks the shapes of the original twigs often remain in the contours of the ash itself.


In preparing this batch a 6:5 ratio of ash to quartz was used. This is the ratio specified in section 4. (Because of the scarcity of our ingredients we reduced the quantities used to about 5% of those actually called for in the recipes.)

For immanakku: 192.0 grams quartzite pebbles (No. 1314).
For ahussu: 230.5 grams tezāb (No. 1330).

After each of the batch materials had been crushed and pulverized separately to finer than 100 mesh, they were weighed, and then thoroughly mixed. A small quantity of this mix was placed in a platinum boat and heated in a gradient furnace. The heating was continued for 24 hours, with the boat placed in the furnace so that at one end the temperature reached 1128°C, whereas at the other end, the cool end, it was only 483°C. It was concluded from this experiment that for the actual synthesis of zukū the first heating called for by the instructions should probably be carried out at about 900°C., in order to prepare a partially reacted frit from which most of the gaseous products would have been evolved. It was also apparent that the second heating, as described in the recipes, would have to be at a temperature of a least 1050–1100°C. in order for the frit to be melted in any reasonable amount of time to a glass free of unreacted batch. This conclusion concurs with the results of many similar gradient furnace experiments conducted over the years in our laboratory.

Aided by this information we then heated 400 grams of the mixture at a temperature of 920°C. for 10 hours, in a platinum crucible. The ingredients reacted, but not uniformly, to form a frothy frit which varied from a

6. We are grateful to Mr. John F. Wosinski and Mr. William Edmister of Corning Glass Works for their assistance in carrying out the gradient furnace experiments.
7. These experiments were carried out by Dr. August A. Erickson of Corning Glass Works, whose assistance was, as it has been many times in the past, indispensable to the author’s research.

ROBERT H. BRILL
pale purplish color to brown, with the color apparently depending upon the access of different zones to the surrounding air. The frit was then crushed and heated a second time, but to a higher temperature, again following the instructions of the recipes. This time the glass was heated to a temperature of 1100°C where it was held for sixteen hours in a neutral atmosphere. The resulting glassy product was allowed to cool in the crucible and was annealed at 450°C.

The product that resulted was not only a glass, but a glass of unexpectedly high quality, with few traces, if any, of unreacted material and only a moderate number of bubbles. It was entirely transparent, but had an amber color. A colorless layer of glass, perhaps 2 to 3 millimeters thick, had been formed at the surface, where the molten glass had been exposed to air during the firing.

The amber color was undoubtedly caused by the high sulfate content and the high proportion of unburned carbonaceous material in the particular plant ash used. The glass experienced a strongly reducing internal atmosphere during the heating, and the sulfate was reduced to sulfide which formed a "carbon amber" color. This carbon amber is due to the presence of a complex formed between traces of iron and sulfur in the glass. The same coloring species accounts for the common amber color of many modern bottle glasses. (The experiments in the gradient boat, in which a much greater relative surface of the batch was exposed to air during the firing did not produce this amber color. It occurred only in the more confining conditions of the platinum crucible.) Additional firings carried out on a piece of glass from this experiment showed that the amber color could be removed by reheating the glass in a strongly oxidizing atmosphere or by reheating it with a small amount of ammonium nitrate, which serves as an oxidizing agent. The final glass was entirely transparent but had a faint pale blue color.

8. It is uncertain if this blue color is due to reduced iron impurities or possibly to traces of colloidal elemental sulfur.

The net result of these experiments is an important one for the interpretation of the texts. Although the conditions selected for our experiment were obviously arbitrary, the experiment nevertheless did verify the inference drawn from the calculation described in the preceding section. The main point is that if the directions given in section 4 are followed out, employing only moderate temperatures, and using two materials which can reasonably be argued to approximate immanakku and aḫusan, a glassy material is indeed obtained. Of course, one should resist being led too quickly to favorable conclusions on the basis of only one such experiment, even though it seems to have turned out so surprisingly well. But even after realizing that the choice of these two materials was arbitrary, it is apparent that other plant ashes, though varying in composition from our tezāb, do not vary so drastically that they would be expected to yield very different results. Neither would the substitution of different silicate rocks, such as a sandstone, for the quartzite pebbles be likely to alter the results of the experiment to any great extent. The compositions of the resultant products would vary somewhat and the colors might differ, but the products almost certainly would still be glasses.

An important question, however, still remains to be settled. The amber color in the glass seems inevitable if the ashes used have a high sulfate content and also contain unburned carbon, providing that the first heat treatment or fritting operation is carried out under more or less confined conditions. Perhaps the container (unspecified in the texts) which was used for the first heating was a flat, open tray which would have exposed the materials more fully to the surrounding atmosphere and allowed the ready escape of sulfur dioxide; or perhaps the ash used had been calcined previously to burn off the carbon more completely. Another (less likely) alternative is that the unidentified ingredient namrātu, introduced in small proportions in section 1 (p. 35), could have been an oxidizing agent of some sort which would have pre-
vented the formation of the carbon amber coloring species.

Although the results of this experiment and the preceding calculation have been discussed in detail here they should be considered preliminary findings pending the completion of other melting experiments. But the importance of this approach to the interpretation of the texts is so great that we feel these findings had to be included in this publication.

* * *

In concluding this chapter it is also appropriate to evaluate our efforts in terms of the objective stated at the outset, that of bringing together specialists from three different disciplines to combine their separate kinds of knowledge and points of view in order to gain as full an insight as possible into the meaning of these texts. To a certain extent, this attempt has been successful, but until now we have really done more in the way of assembling our knowledge rather than in integrating it. This is not due to any fallacy in the concept behind the work but rather only to geography. Except for a few brief days, the principals involved were but rarely within a thousand miles of one another. Consequently, we have missed the lengthy conversations we needed, ranging deep into one another's fields, and the mutual exploration of those ideas which can arise spontaneously only from close personal associations. As a corollary, neither do we necessarily always concur with one another on the various opinions expressed throughout the book, and the reader may find some inconsistencies. But even so, although many possibilities remain unexplored, and much more will be said about these texts in the future as research continues in all three fields, we have nevertheless made much progress towards our objectives.

APPENDIX

For the convenience of the reader there are set out here in separate notes brief discussions of a few of the most important chemical questions which arise in connection with the texts.

1. Faience, Egyptian Blue and Glass
2. Some Crucial Terms
3. Antimony in Mesopotamian Glasses
4. The General Scheme of Sections 1–3 and 4–6
5. Ancient Red Opaque Glasses
6. The Red Opaque Glasses Described in Sections i–iv
7. Slow Copper and Fast Bronze
8. The Quantities of Glasses Melted
9. Chemical Analyses of Mesopotamian Glasses
10. An Apparent Excess of Alkali

1. FAIENCE, EGYPTIAN BLUE AND GLASS

Faience consists of a porous body of very finely ground crystalline quartz grains, each of which still retains its individual identity in the final object. These grains are held together by a glassy "connective issue." The surfaces of the objects themselves are covered with a vitreous (glassy) coating. The bodies may be either dense and hard, or friable; some are weathered, some are not; most are white in color, and consist almost entirely of silica in the form of quartz. The glaze is often of a blue or green transparent color, but purple transparent, and white, yellow, and red opaque glazes are not at all uncommon. Faience occurs in both monochrome and polychrome varieties.

Glassy faience is a more compact and less porous form of faience in which the glassy connective tissue is about as abundant as the crystalline grains. The color is not confined to the surface as on ordinary faience, but it extends uniformly (or nearly so) throughout the entire body of the object.

Egyptian blue is a definite chemical compound, a copper-calcium-tetrasilicate (CuO. CaO.4SiO₂). It occurs in a dense form so hard that it can be polished to look like glass or it can occur in a friable, porous form so soft and chalky that it can be scratched with the fingernail. Egyptian blue
is always at least partially crystalline, and usually contains sizeable portions of unreacted quartz grains.

Glasses differ from faience and Egyptian blue in many ways, and there are as many different ways of describing what the differences are. To the chemist, glasses are homogeneous throughout, and have a random, liquid-like (non-crystalline) structure. To the non-scientist, perhaps the best technological distinction is that the manufacturing process for glasses requires that at some point the ingredients become completely fused into a liquid melt, which is then cooled and sets up as a glass. Faience and Egyptian blue and most other synthetic materials from the ancient world (other than metals or alloys) were never taken through a completely melted state. They have only been sintered, that is, the ingredients were heated sufficiently so that some of them melted or reacted to form a very small proportion of liquid, which upon cooling served to cement together the unfused grains. True glasses occur in a wide variety of colors. Among the most common glasses of the ancient world are colorless, blue, purple and green transparent glasses, and red, yellow, white, blue, and, occasionally, orange opaque glasses. The transparent glasses owe their color to metallic compounds dissolved in the glasses, just as salts can be dissolved in water. The opaque glasses owe their color and opacity to tiny flakes of a separate colorant-opacifier dispersed throughout the glassy matrix. Their structure is analogous to that of a paint, which consists of a transparent dried vehicle, such as an oil or egg white, in which is suspended a colored and often opaque pigment.

Glazes are vitreous (glassy) coatings applied to pottery or faience bodies, or to minerals or stones such as quartzite pebbles and steatite. Glaze compositions on highly siliceous bodies such as faience or clays containing a large proportion of quartz may have compositions closely resembling alkali-silicate glasses. These glazes do not in general adhere well to the more common clay fabrics, however, and consequently, the true glazes found on ancient pottery usually contain a high proportion of lead oxide, which improves adhesion. The origin and occurrences of lead glazes on bricks and tiles (from Mesopotamia, for example) and on pottery is in the opinion of this author a topic which requires much further investigation. Special care should be taken to avoid confusing true vitreous glazes with slips, paints and burnished finishes on pottery.

Other unusual synthetic materials, which appear to be composites of glasses and faience and perhaps other materials are occasionally encountered. We are referring particularly to some finds from Nuzi and Tell al-Rimah whose physical nature has not yet been established.

2. SOME CRUCIAL TERMS

Many of the words used in the texts remain untranslated, and the chemist at this stage would be grateful for more specific identifications of almost any of these terms. But for the most part there are only a few words—particularly those used for certain ingredients—which, as far as we know, have a crucial bearing on the interpretation of the texts. Among those which we feel are most important are anzalj, lj, u, and bu§u, because they play an important part in characterizing the nature of the materials described in sections 1-3 and 4-6 (pp. 35-38); gulj, lu, and related words, because of their possible connections with antimony; URUDU.1}I.A and siparru arlj,u, the enigmatic “slow copper” and “fast bronze”; and tuzku and dusu, because of their connections with the very important red and yellow glasses.

There is hope that some of these terms will become known in the future and if a chemist might be permitted one speculation outside his own field, it would be that connections with the technological vocabularies of other apparently unrelated languages may provide useful clues.
3. ANTIMONY IN MESOPOTAMIAN GLASSES

The use of antimony compounds in ancient glasses, for two distinctly different purposes, has been firmly established by chemical analyses of dozens of specimens of excavated glasses. The earliest use was in the form of the yellow lead-antimony pigment, $\text{Pb}_2\text{Sb}_2\text{O}_7$, as a colorant-opacifier. It is certain that most, if not all, of the yellow opaque glasses (and glazes) ranging from both the earliest Egyptian and Mesopotamian cored vessels up through the mosaic tesserae of about the 1st-3rd century A.D.—and all of the yellow decorative glasses in between—were colored with this pigment.\textsuperscript{10} Chemical analysis and x-ray diffraction have also shown antimony to be present in intentionally additive amounts in green opaque glasses, which contain the same yellow pigment, and in red opaque glasses. It has not yet been resolved whether the antimony in the red opaque glasses was there to help develop the red color by acting as an oxidizing and/or reducing agent, or whether it was there just because the glassmaker thought it had some beneficial effect. It is possible too, that antimony found its way into some of the colored glasses through the use of cullet or frits that happened to be in the workshop.

The other use of antimony in early glasses was as a decolorizer or possibly as a fining agent, or both. Antimony oxide in a glass can decolorize (at least partially) the common greenish color of most glasses which is due to the presence of iron impurities in the raw materials. Acting as a fining agent it removes small seeds or bubbles from the glass. Either

10. W. E. S. Turner and H. P. Rooksby, "A Study of the Opalising Agents in Ancient Opal Glasses Throughout 3400 Years," Part I, Glastechnische Berichte, 32K, VIII, 1959, pp. 17–28; H. P. Rooksby "Opacifiers in Opal Glasses Through the Ages," General Electric Company Journal, 29, No. 1, 1962, pp. 20–26. At some time, probably varying from place to place, during the 1st to 4th century A.D., this pigment was replaced by an analogous lead-tin pigment, $\text{PbSnO}_3$. A few examples of Ptolemaic yellow glasses are known to the author which are colored by cuprous oxide.

use would call for the presence of about 1–2% of antimony oxide in the glass. This is the amount of antimony found in many glasses of the first millennium B.C. throughout the Mediterranean World and the Near East.\textsuperscript{11} Starting late in the 1st century B.C. manganese gradually replaced the antimony, a replacement that was completed by about the end of the 3rd century. Antimony-containing glasses are known from "western" sites in about the same frequency as manganese-containing glasses, but in Mesopotamia they predominate over the manganese-containing glasses.

Because the use of antimony is so firmly established in ancient yellow opaque glasses, it would be extremely helpful to be able to confirm unequivocally that it is mentioned in the texts. This would provide independent—and very convincing—evidence that the products described were true glasses. But one must be very careful here not to fall into a path of circular reasoning. If it is assumed that the materials are glasses, then it is possible to demonstrate that they must contain antimony; but in that case, the presence of antimony obviously cannot in turn be proposed as an argument to prove that the materials are glasses. On the other hand, if one attempts to establish independently that antimony-containing substances are present among the ingredients, and argue that the materials must therefore be glasses, then it is necessary to rely upon evidence which is, unfortunately, still open to question.

In sections 1–3 and 4–6, (pp. 35 and 38) what seems to be a blue transparent glass (tersitu) is transformed by the addition of $\text{anzahhu}$ and $\text{bu\textsuperscript{u}}$ into a greenish-colored artificial lapis lazuli. Professor Oppenheim feels that the identification of the greenish opaque color is unquestionable, and because such a color change could only be brought about by the addition of a yellow pigment, it seems reasonable to conclude that one of the two ingredients added is indeed the $\text{Pb}_2\text{Sb}_2\text{O}_7$ colorant-opacifier.

11. See note 4, p. 111.
Taking the other line of reasoning, since the uses of antimony, as far as we know now, were so restricted during the 2nd and 1st millennia, if the mention of antimony can be established in the texts it would be difficult to think that they could be dealing with any other material than glass. However, a serious question then comes up.

Several terms appearing in the texts have been identified as referring to antimony or antimony-containing substances. Each of these terms owes its individual identification as such through some connection with the word $gul\textsuperscript{1}$, which had been translated earlier as "antimony." The validity of these several identifications hinges solely on the validity of the translation of $gul\textsuperscript{1}$, as explained to the author by Professor Oppenheim. This brings one face to face with the problem of deciding just what constitutes a proof and what does not.

As far as Professor Oppenheim has been able to ascertain, the only evidence behind the translation of $gul\textsuperscript{1}$ as "antimony"\textsuperscript{12} (or more properly an antimony-containing substance) is that $gul\textsuperscript{1}$ was used as kohl, the well-known eye cosmetic. This is where the difficulty arises. If that identification was made purely on the basis that, "everyone knows that kohl was stibnite or antimony sulfide," then the whole argument appears to fall apart, for it has been pointed out that this generalization is not really true. More specifically, it is not true for Egypt and may not be true for Mesopotamia. We might repeat here the origin of this persistent misunderstanding which has led to the belief that all kohl was stibnite (Sb\textsubscript{2}S\textsubscript{3}), even though its fallacy has been amply pointed out by several authors. The chemical symbol for antimony, Sb, is derived from the Latin stibium which apparently did refer correctly to stibnite which was used for kohl in Roman times—but possibly not until Roman times. This might be only a minor defect in the logic discussed above, were it not for the fact that among analyses of some 74 specimens of ancient Egyptian kohl discussed by Lucas\textsuperscript{13} only one was found which appears to be antimony sulfide. The analyses showed instead that the specimens consisted mainly of galena, pyrolusite, brown ochre or malachite.

Although chemical analyses of ancient kohl or pigments from Mesopotamia may have been carried out, none are known to this author or to several archaeologists consulted.\textsuperscript{14}

\textsuperscript{12} See p. 21.

\textsuperscript{13} A. Lucas, Ancient Egyptian Materials and Industries, (Revised by J. R. Harris), London, Edward Arnold, 1962, pp. 80–83. The actually reported by Lucas is as follows:

- Galena (lead sulfide) 45
- Manganese oxide (probably pyrolusite) 10
- Brown ochre 7
- Malachite (a basic copper carbonate) 5
- Black iron oxide and lead carbonate 2 each
- Black copper oxide, chrysocolla, stibnite 1 each

The indicated predominance of galena is probably valid, but with such a small number of samples it should be kept in mind that the over-all distribution could very well reflect a strong bias favoring the substances predominating in those particular sites or periods from which the greatest number of samples were drawn.

\textsuperscript{14} While this text was being prepared we completed spectrographic and x-ray emission analyses of traces of the original contents of four ancient cosmetic containers in the collection of the Oriental Institute, Chicago.

Two of these samples were removed from stone vessels excavated at Khafaje (in the Diyala region). The vessels date from ca. 2700 B.C. (Oriental Institute Nos. A9238 and A7563.) Both samples, which consisted of fine black powders, were found to contain manganese as their only major metallic component. That from A7563 also contained a substantial proportion of sulfur. Antimony, lead and copper were not detected in either sample. X-ray diffraction indicated the presence of MnO\textsubscript{2} in both specimens, probably in the form of the mineral pyrolusite.

The other two samples are of ancient greenish cosmetics. The first was removed from a shell excavated in a house at Khafaje (No. A17715, field No. Kh VI.54 from locus F-29/3). This sample dates from 2000 B.C. or earlier. Its only major metallic component is copper. The second
If we take into consideration the fact that antimony compounds apparently were not used to any great extent for kohl in ancient Egypt, then the assumption that they were so used in ancient Mesopotamia becomes a weak one and is really unwarranted until it can be verified by chemical analyses of actual excavated specimens. For the present, the term gühlu could just as logically, or perhaps even more so, be equated to galena, pyrolusite, malachite, or any of the other substances known to have been used as kohl in pre-Roman times. It is also possible that the word might have been a generic one referring collectively to several different substances used as kohl.

It may, of course, turn out that future analyses will prove that stibnite really was used for kohl, and if so, this would help us greatly in the understanding of these texts, but until then the identification of gühlu as antimony should be held in abeyance. We are left then without any real proof that the texts call for antimony-containing ingredients, except through the inference drawn above based upon the color changes. The evaluation of all the arguments involved is so much a matter of personal viewpoint

sample, containing both copper and zinc as major constituents, was removed from a stone cosmetic jar excavated at Choga Mish in southwestern Iran (No. A33213). It dates from the Protoliterate Period, ca. 3400-3200 B.C. Also present in both greenish samples are minor amounts of manganese.

We thank Mr. Gustavus F. Swift, Jr., and Miss Judith Franke for providing the samples, Mr. Donald Stephenson, of Corning Glass Works, who carried out the x-ray emission analysis, and Dr. Hans Holland who carried out the x-ray diffraction experiments.

We have also been informed by Mr. P. R. S. Moorey of the Ashmolean Museum of the results of an analysis of a sample of kohl carried out at the request of Prof. Oppenheim. The sample was removed from a cockle shell found in the "Plano-Convex Building" at Kish (Ashmolean Museum No. 1924.316; excavation No. U.G. 488). Mr. Moorey dates it as Early Dynastic III B. The analysis, reported by Dr. E. T. Hall of Oxford, showed that the kohl consisted of lead sulphide and that no antimony was detected.

that we leave it to each reader to make his own evaluation.

We have delved deeply into this particular question not only because of the importance of learning more about the role of antimony in early technologies, but also because it illustrates the dilemma which one encounters at every turn throughout these texts. If one is to be absolutely rigorous, there is really very little that can be said about these texts at all; but if one wants badly enough to learn something from them, then he has to make some reasoned and reasonable assumptions along the way. Unfortunately, the assumption that looks reasonable one afternoon may look like speculation the next morning.

4. THE GENERAL SCHEME OF SECTIONS 1–3 AND 4–6

It appears from the translations that these sections describe a three-step process by which a green opaque glass is prepared. The first step consists of the manufacture of a base glass, zuku, from plant ash and quartzite pebbles. The material is sintered at a moderate temperature, evolving gaseous products, is then cooled and ground to a fine texture, and finally fired, apparently at a higher temperature, to fuse the mixture to a glass. The product is essentially without color. This is a sound glassmaking procedure which would accomplish first the pyrotechnological step of starting the quartz-alkali reaction and would clear the system of most of the gaseous reaction products. The grinding of the frit thus produced is essential in order to hasten the second part of the process, which is to complete the melting and reaction and to reduce the system to a glass. Thus the most difficult chemical step has been accomplished

15. Antimony has been reported as a constituent of many early bronzes, but opinions vary as to whether it was introduced knowingly by the early metallurgists or accidentally or mistakenly. The author has personally had analyzed a piece of very pure metallic antimony from Hasanlu (ca. 850 B.C.) and a few other examples are mentioned in the literature.
ROBERT H. BRILL

and the glassmaker can next turn to the process of adding colorants or opacifiers to this zukū.

The next step appears to be the process of producing a blue transparent glass by the introduction of copper into the zukū. This is done by an unusual means, that is, by spreading the ground glass over an equal weight of the heated copper-containing material, uruduji, or "slow copper." It is also hinted that the reaction does not go to completion. The puzzling parts of this section are the identification of "slow copper" and the explanation of why the reaction is carried out in the way described. (See also the note on "Fast Bronze" and "Slow Copper" p. 121).

The third step seems to describe the introduction of a yellow colorant-opacifier, which, in a transparent blue matrix of tersitu, would yield the green opaque color mentioned in the text. The yellow colorant-opacifier is also implied by the connections Professor Oppenheim has established with antimony, although the identification of the antimony-containing ingredient is open to question (see supra, p. 117). It is well known that the yellow pigment used in Mesopotamian glass (as well as throughout the rest of the ancient world for the first 15 centuries of glass history) was lead antimonate, Pb₂Sb₂O₇.¹⁶

Sections 3 and 6 deserve especially careful study because they touch on some broader aspects of ancient glass. For example, Professor Oppenheim's suggestion that anzahu was a material prepared by craftsmen other than the glassmakers, is consistent with our suspicion that the Pb₂Sb₂O₇ yellow pigment was a commodity traded over considerable distances. This has important implications in the interpretation of several other lines of research on ancient glass, such as the lead isotope relationships which have been found between red and yellow glasses from Egypt and Mesopotamia.¹⁷

In summary, from the glassmaker's point of view both the over-all scheme of these sections, and most of the procedural details, are all quite reasonable. In fact, this is the same way one might go about preparing a green opaque glass today; first make the colorless base glass, then introduce copper to form a transparent blue glass, and finally, add a yellow pigment.

5. ANCIENT RED OPAQUE GLASSES

Red opaques were among the most difficult glasses for early glassmakers to prepare. Despite this, however, red glasses occur early in the history of glassmaking, probably contemporaneously with early cored vessels. Scattered examples are known from the centuries which followed, and by Hellenistic times red opaque glasses had become quite common. The red color, which sometimes can be rather brownish, is always due to the presence of cuprous oxide, Cu₂O, although small amounts of metallic copper are also sometimes present. The bright orange opaque glasses of the ancient world are very similar chemically to the red opaques, and can be treated as a variant of them.

When copper is introduced into a glass under neutral or oxidizing conditions (as is normally the case) it goes into solution in the glass, much as a dye goes into solution in water. The copper exists as individual copper ions, and (again like a dye) it confers

¹⁶. See Note 10, p. 116.
a transparent blue color to the glass. However, if the glass is held under chemically reducing conditions, the copper may be precipitated out of the glass as separate small crystals of cuprous oxide. These tiny crystals have a bright red color, which the glass itself takes on. Since the crystals block the transmission of light, when many are present, the glass also becomes opaque.

The glasses are difficult to prepare because the ease with which the color can be developed is quite sensitive to chemical composition, and because a carefully-controlled firing is required under reducing conditions. Also the glasses are very quickly reoxidized to a transparent green color if they are exposed even momentarily to air while hot. This is caused by the rapid dissolving of the red crystals by the hot glass.

One chemical factor having an important effect upon the development of the red color is the presence or absence of lead. While the red color can be formed in glasses not containing lead, its presence greatly facilitates the precipitation of the cuprous oxide phase. In this connection it is interesting to consider the lead contents of ancient red opaques from various sources, but, unfortunately, analytical data on this subject are scarce. From the few analyses that have been made it appears that the earliest red opaque glasses, those of the 18th dynasty from Egypt, do not seem to have contained more than about 1% PbO. Red and orange glasses dating from roughly the 6th–3rd centuries B.C. and onward into Roman times may be very heavily leaded, and contain as much as 15–30% PbO. Our knowledge of what happened in the intervening centuries is still obscure, for among the few examples analyzed some show lead in additive quantities and some do not. But when it is present in these glasses the lead seems to be at a moderate level of about 1–5%.

Where percentages in the range of about 5% or greater occur, the lead undoubtedly was a separate intentional ingredient added to facilitate the development of the red (or orange) color. Where the lead content falls below this level it may either have been introduced deliberately, for some real or imagined benefit, or perhaps it merely came along as a companion of the copper in the ingredient used to introduce that element. It should not, incidentally, be assumed automatically that any of the ingredients used, including the copper-containing ingredients, were necessarily of high purity in the element whose effect was to be utilized. There is a great deal of evidence, for example, that blue glasses from Roman and post-Roman times were colored by copper introduced in the form of bronze, or, more likely, some material derived from bronze, because the copper:tin ratios in the glasses correspond to those of ancient bronze alloys. The same applies to other glasses, both red and blue, dating back well into the first millennium.

The tradition of using bronze or a bronze-derived material as a copper ingredient may have been an all-pervasive one throughout the early history of glassmaking (see p. 123).

The descriptions given in the texts which specify the use of copper, closed containers, long firing times, cooling while still within the kiln, and the awareness of the difficulty of the process (which is implicit in the ritual connections), all favor the interpretation that these texts describe the manufacture of a red opaque glass, or red glass objects.

As was mentioned above, the inclusion of lead-containing ingredients in these formulas, as is indicated in the translations, would definitely have been beneficial for the developing of the red color. This raises other important questions too, however, for the little analytical evidence we have at present suggests that the use of major proportions of lead as an aid in developing the color may not have begun until as late as about the 9th century B.C., or possibly even later. The earliest occurrence known to the author of lead at a level which might be considered as intentionally additive is in one of the red opaque sections of the mosaic beaker from Hasanlu, dated to about 850 B.C. (see p. 216). This glass contains 3.2% PbO. If it can ever be established accurately just when lead, as a
separate major ingredient, was first employed in making red opaque glasses, that would offer important evidence to be considered when making attributions of dates for those texts which prescribe the use of lead as an ingredient for red glasses. From all of the above it is clear that there is a need for chemical analyses of further specimens of ancient red opaque glasses.

6. THE RED OPAQUE GLASSES DESCRIBED IN SECTIONS i-iv

The directions given in sections i-iv (pp.63-64) for the preparation of a red opaque glass are quite detailed and complete compared to some of the other sections. This is not to say that they are without perplexing problems and inconsistencies of their own, but they do allow one to follow the ingredients through the processes and make some chemical sense of them. Without becoming absorbed in all of the details it will suffice to say here that the ingredients include both those which are essential for making a red opaque glass and those which are beneficial in making them; and the chemical treatments such as the heating procedures are appropriate for making red glasses. Moreover, the chemical composition of the product prepared is consistent, in a semi-quantitative sense, with analyses of some excavated specimens of red opaque glasses.

In Table 1 (p. 122) are presented the results of a calculation carried out on the assumption that the zuku called for in sections i and ii can be approximated by the composition calculated earlier, and that the “lead,” “copper,” and “antimony” called for can be approximated by PbO, a copper-containing ingredient which contains about 65% copper, and Sb₂O₅. The resulting composition for the material yielded by sections i-iv is a rather good approximation of ancient red opaque glasses, at least of those having lead-rich compositions, as discussed in the previous section.

Among the chemical inconsistencies and puzzles which arise throughout these texts, each investigator will pick out a few which become especially vexing to him, even though they may not be of overriding importance. In these particular sections, the use of paritu to describe the appearance of the outer surface of the red glass being prepared seems contradictory. Why should a word well attested as meaning alabaster be used in this connection? Alabaster has a very characteristic creamy color and translucency which is just the opposite of the black or dark gray, coarse-textured, slaggy materials that would be expected to coat these red glasses when they were prepared. (This is not to be confused with the white, buff or greenish weathering products usually found on excavated fragments of red opaque glasses.)

7. SLOW COPPER AND FAST BRONZE

The use of ingredients best translated as “slow copper” and “fast bronze” in sections 2, 5, 13, and 15 (pp.35, 39, 44, 45) for introducing copper into a previously formed intermediate glass, poses a tantalizing puzzle. One can by conjecture arrive at a whole array of possible identifications for these materials, ranging from minerals like malachite or azurite to synthetic materials like faience, blue glass cullet or Egyptian blue, to waste materials like smelting slags and copper scale, suggesting along the way various rationalizations as to why the one should be termed slow and the other fast. None of these conjectures, however, is probably sound enough to allow it to be singled out in preference to others at present, but the peculiar way of combining these ingredients with zuku glass perhaps serves to illustrate another point.

Powdered zuku glass, it will be recalled, is thrown upon a previously heated mass of “fast bronze” (section 13, p. 45) and allowed to react, with a certain amount of stirring. The resulting intermediate is later used for preparing a red artificial lapis lazuli. Intuitively to us today, this seems an awkward way of mixing in an ingredient. Why not add the ingredient to the molten glass, or mix it into the dry batch before melting? The texts also suggest that the mixing of the softened glass and the heated “fast bronze” will be incomplete and that the latter will settle.
TABLE I

COMPOSITIONS OF MESOPOTAMIAN GLASSES

<table>
<thead>
<tr>
<th>Typical Values (and Ranges)</th>
<th>Hypothetical “Base Glasses”</th>
<th>Calculated Composition</th>
<th>Calculated Semi-Quantitative Composition of A Red Opaque Glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Found Upon Analysis¹</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Comp.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>55</td>
<td>64%</td>
<td>68</td>
<td>56</td>
<td>66%</td>
<td>70</td>
<td>56.0%</td>
<td>SiO₂</td>
<td>40%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na₂O</td>
<td>13</td>
<td>16</td>
<td>19</td>
<td>14</td>
<td>17</td>
<td>20</td>
<td>23.8</td>
<td>Na₂O</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CaO</td>
<td>4</td>
<td>6.5</td>
<td>8</td>
<td>4</td>
<td>7</td>
<td>10</td>
<td>6.6</td>
<td>CaO</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K₂O</td>
<td>1</td>
<td>1.5</td>
<td>3</td>
<td>1</td>
<td>1.5</td>
<td>3</td>
<td>3.8</td>
<td>K₂O</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MgO</td>
<td>3</td>
<td>4.5</td>
<td>6</td>
<td>3</td>
<td>4.5</td>
<td>6</td>
<td>5.6</td>
<td>MgO</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>1.5</td>
<td>2</td>
<td>3</td>
<td>1.5</td>
<td>2</td>
<td>3</td>
<td>2.2</td>
<td>Al₂O₃</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.5</td>
<td>1</td>
<td>1.5</td>
<td>0.5</td>
<td>1</td>
<td>1.5</td>
<td>0.7</td>
<td>Fe₂O₃</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.1</td>
<td></td>
<td></td>
<td>0.1</td>
<td></td>
<td></td>
<td>0.05</td>
<td>TiO₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MnO</td>
<td>var.</td>
<td></td>
<td></td>
<td>0.02</td>
<td></td>
<td></td>
<td>0.05</td>
<td>MnO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sb₂O₅</td>
<td>var.</td>
<td></td>
<td></td>
<td>0.00X(?)</td>
<td></td>
<td></td>
<td>nil</td>
<td>Sb₂O₅</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PbO</td>
<td>var.</td>
<td></td>
<td></td>
<td>0.000X(?)</td>
<td></td>
<td></td>
<td>nil</td>
<td>PbO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BaO</td>
<td>~0.1</td>
<td></td>
<td></td>
<td>~0.1</td>
<td></td>
<td></td>
<td>~0.1</td>
<td>BaO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SrO</td>
<td>~0.1</td>
<td></td>
<td></td>
<td>~0.1</td>
<td></td>
<td></td>
<td>~0.1</td>
<td>SrO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P₂O₅</td>
<td>~0.3</td>
<td></td>
<td></td>
<td>~0.3</td>
<td></td>
<td></td>
<td>1.0</td>
<td>P₂O₅</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SO₃</td>
<td>~0.3</td>
<td></td>
<td></td>
<td>~0.3</td>
<td></td>
<td></td>
<td>~0.5(?)</td>
<td>SO₃</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cl</td>
<td>~0.3</td>
<td></td>
<td></td>
<td>~0.3</td>
<td></td>
<td></td>
<td>~0.5(?)</td>
<td>Cl</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Other elements sometimes found in the range of 0.000X–0.2 in ancient glasses from various sources: B₂O₃, Li₂O, Rb₂O, V₂O₅, Cr₂O₃, ZrO₂, NiO, ZnO, Ag₂O, SnO₂, Bi₂O₃.

1. Excluding red opaques with high PbO contents. Values in italics show approximate maxima and minima.
2. To be modified substitutionally by colorants and colorant-opacifiers.
3. SO₃ and Cl uncertain due to unknown extent of retention.
4. Includes K₂O, MgO, Al₂O₃, Fe₂O₃, etc.

Var. = variable, depending upon color of glass.

COLORANTS AND COLORANT-OPACIFIERS

<table>
<thead>
<tr>
<th>Comp.</th>
<th>Amount</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>CuO</td>
<td>1-2%</td>
<td>blue transparent</td>
</tr>
<tr>
<td>CoO</td>
<td>0.05-0.2%</td>
<td>blue transparent</td>
</tr>
<tr>
<td>MnO</td>
<td>1.5%</td>
<td>purple transparent</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>2-3%</td>
<td>green transparent</td>
</tr>
<tr>
<td>Fe(S)x</td>
<td>2-3%</td>
<td>amber transparent</td>
</tr>
<tr>
<td>Mixture of above</td>
<td>5%</td>
<td>black &quot;transparent&quot;</td>
</tr>
<tr>
<td>Cu₂O</td>
<td>~5, ~10, ~15%</td>
<td>red opaque</td>
</tr>
<tr>
<td>PbO</td>
<td>0.0X, ~3, ~10, ~20%</td>
<td>white opaque</td>
</tr>
<tr>
<td>SnO</td>
<td>nil, X%</td>
<td>yellow opaque</td>
</tr>
<tr>
<td>Sb₂O₅</td>
<td>.X, 2%</td>
<td>light blue opaque (turquoise)</td>
</tr>
<tr>
<td>Ca₃Sb₂O₇</td>
<td>(2-5% Sb₂O₅)</td>
<td>green opaque</td>
</tr>
<tr>
<td>Pb₃Sb₂O₇</td>
<td>(2-5% Sb₂O₅)</td>
<td>green opaque</td>
</tr>
<tr>
<td>Ca₃Sb₂O₇ + CuO/CoO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pb₃Sb₂O₇ + CuO/CoO</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

to the bottom, and the glass, after having apparently extracted something from the "fast bronze," is to be poured off. The more one thinks about this the more it appears that the term "fast bronze" should perhaps be taken literally, for this unusual way of mixing the zuku and "fast bronze" would seem to make sense only for an ingredient that would melt to a very fluid liquid, which would remain immiscible with the softened glass, and would be of much greater density—for example, a metal. Any solid material, if it did not react completely would just make an unmanageable and inseparable mess with the softened glass; any other glass would be essentially miscible, and could not be handled this way.

Whatever "fast bronze" was, it obviously was connected with copper, but contained in addition something other than just copper, otherwise it would have been called copper and not bronze. A very logical material would have been a bronze, or similar alloy, which would have introduced not only copper but also lead and possibly tin, both of which are notably beneficial in helping copper to develop the red cuprous oxide which is responsible for the color of the red glasses. Supporting this is the observation that lead is found in many early red opaque glasses, and tin is found in some. Furthermore, many copper-containing ancient glasses from all periods have copper : tin ratios which are consistent with the use of bronze, or some material derived from bronze, as the ingredient used to introduce the copper into the glasses (see p. 120).

In order to see if this literal interpretation of the term for "fast bronze" would make practical glassmaking sense, several experiments were carried out in which a 70:20:10 copper:lead:tin bronze alloy was melted and a glass having a composition resembling an ancient glass was then melted in contact with it.19 The experiments showed that the molten glass extracted copper, lead and tin from the molten alloy in a matter of minutes. Reheating of this glass, upon breaking it away from the cooled metal, did form bright red opaque cuprous oxide crystals in some regions of the glass.

The point of this discussion is that even though this interpretation is not the only possible one, and although this process may not seem to us today to be the easiest way of adding copper and lead or tin to the glass, it nevertheless does seem to work if one takes the term literally and follows out the directions.

8. THE QUANTITIES OF GLASSES MELTED

The quantities of ingredients called for by the various sections also offer clues to the operations with which the texts were associated. For example, assuming that one mina is equal to 450 grams, or approximately one pound, it can be estimated that the bulk volume of the batch mixed according to sections 1 and 4 (pp. 35 and 38), would have been approximately 7.5 liters. After reducing the batch to a frit it could have been loaded into a container about the size of a large salad bowl, an analogy chosen because we believe that this might have been the shape of the pots used by most early glassmakers. The volume of zuku glass resulting from the melting of this batch in its entirety would have been approximately 3.5 liters. These are reasonable quantities of materials to have been handled in single operations by the Mesopotamian glassmakers. The volume of glass produced is large enough to have yielded usable quantities of glass, and yet small enough to have permitted the batch to have been brought to a temperature sufficient to melt it and small enough to have been heated uniformly throughout its mass. Furnaces capable of maintaining this quantity of glass at temperatures of the order of 1050–1100°C. for several hours were within the reach of technologists of the times, but the author believes (though it is purely a matter of opinion at present) that their capabilities would not have reached much beyond this.

19. We are grateful to Dr. W. Thomas Brydges and Mr. Dennis Smith, both of Corning Glass Works, for their assistance in carrying out these experiments.
<table>
<thead>
<tr>
<th></th>
<th>keli²</th>
<th>1304</th>
<th>1305</th>
<th>1330</th>
<th>1331</th>
<th>1381</th>
<th>1381</th>
<th>1301</th>
<th>1326</th>
<th>1324</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na₂O</td>
<td>28.0%</td>
<td>41.2%</td>
<td>37.5%</td>
<td>21.3%</td>
<td>35.5%</td>
<td>25.4%</td>
<td>39.2%</td>
<td>42.5%</td>
<td>25.5%</td>
<td></td>
</tr>
<tr>
<td>K₂O</td>
<td>5.5</td>
<td>4.47</td>
<td>10.6</td>
<td>17.2</td>
<td>4.59</td>
<td>5.83</td>
<td>8.12</td>
<td>7.01</td>
<td>4.96</td>
<td></td>
</tr>
<tr>
<td>CaO</td>
<td>21.1</td>
<td>3.50</td>
<td>6.70</td>
<td>10.8</td>
<td>7.30</td>
<td>17.7</td>
<td>5.56</td>
<td>4.67</td>
<td>13.8</td>
<td></td>
</tr>
<tr>
<td>MgO</td>
<td>0.5</td>
<td>10.0</td>
<td>4.01</td>
<td>13.3</td>
<td>8.75</td>
<td>11.2</td>
<td>7.50</td>
<td>12.2</td>
<td>8.00</td>
<td></td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>—</td>
<td>1.18</td>
<td>0.42</td>
<td>0.56</td>
<td>1.14</td>
<td>1.82</td>
<td>0.62</td>
<td>0.45</td>
<td>4.89</td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>34.0</td>
<td>22.0</td>
<td>24.8</td>
<td>19.8</td>
<td>23.0</td>
<td>28.7</td>
<td>—</td>
<td>26.4</td>
<td>8.6</td>
<td></td>
</tr>
<tr>
<td>SO₃</td>
<td>2.2</td>
<td>0.77</td>
<td>1.81</td>
<td>1.07</td>
<td>4.74</td>
<td>21.6</td>
<td>2.27</td>
<td>2.16</td>
<td>1.73</td>
<td></td>
</tr>
<tr>
<td>Cl</td>
<td>2.1</td>
<td>8.98</td>
<td>11.4</td>
<td>3.81</td>
<td>9.46</td>
<td>3.41</td>
<td>52.08</td>
<td>6.10</td>
<td>1.98</td>
<td></td>
</tr>
<tr>
<td>P₂O₅</td>
<td>1.8</td>
<td>~1</td>
<td>~1</td>
<td>~1</td>
<td>~1</td>
<td>~1</td>
<td>~1</td>
<td>~1</td>
<td>~1</td>
<td></td>
</tr>
</tbody>
</table>

**FeO₃**  0.48 | 0.46 | 0.33 | 0.39 | ~1   | 0.43 | 0.33 | 3.52 |
**MnO**  0.0X | 0.0X | 0.0X | 0.0X | 0.0X | 0.0X | 0.0X | 0.0X | 0.0X |
**TiO₂**  0.0X | 0.00X| 0.00X| 0.00X| 0.00X| 0.00X| 0.00X| 0.00X| 0.00X|
**SiO₂**  ~2   | 0.0X | 0.0X | 0.0X | ~2   | ~1   | 0.0X | major |
**Li₂O**  0.0X | 0.00X| 0.00X| 0.00X| 0.00X| 0.00X| 0.00X| 0.00X| 0.00X|
**BaO**  0.0X | 0.00X| 0.00X| 0.00X| 0.00X| 0.00X| 0.00X| 0.00X| 0.00X|
**SrO**  0.0X | 0.00X| 0.00X| 0.00X| 0.00X| 0.00X| 0.00X| 0.00X| 0.00X|
**B₂O₅** 0.00X| 0.00X| 0.00X| 0.00X| 0.00X| 0.00X| 0.00X| 0.00X| 0.00X|
**ZrO₂** 0.0X | 0.0X | n.f. | 0.00X| 0.00X| 0.00X| 0.00X| 0.00X| 0.00X|
**PbO**  n.f. | 0.00X| 0.00X| 0.00X| 0.00X| 0.00X| 0.00X| 0.00X| 0.00X|

"Other"²° ~5   | ~5.5 | ~3   | ~11  | ~5.5 | ~0   | ~8   | ~8   | ~12  | ~6°  | 3.1  |
Na₂O/K₂O  3.57 | 4.19 | 5.89 | 0.43 | 0.23 | 0.092| 0.78 | 6.64 |
Ash residue 42  | ~14  | ~32  | ~3   | ~9   | —    | —    | —    | —    | —    | —    |
Description of Samples

Keli — Composition derived from analyses of 50 specimens of keli, the ash of the chinäm plant which grows in the Syrian desert. The analyses, carried out by Imperial Chemical Industries Ltd., were published by W. E. S. Turner in *Journal of the Society of Glass Technology*, XL, June, 1956, pp. 277T-300T. (*Keli* is synonymous with *qili* used below.)

No. 650 — Spongy pods and thin stems from shrubs near the shoreline of Dazkiri Lake (Aci Göli) in southwestern Turkey. The same plant is found at other lakes near Konya. Collected by Myles A. Walsh (2/16/64). The specimen was examined by A. J. Cronquist of the New York Botanical Gardens who believes it is of the genus *Salicornia*. Appearance of ash: light ash which collapsed to a fine brown powder.

No. 653 — Twigs from a bush growing in the desert near the Cairo-Alexandria highway (74 km. south of Alexandria). Collected by the author with Zaky Hanna (9/30/62). Appearance of ash: gray ash which collapsed to a coarse powder.

No. 654 — Seaweed from Acre Bay. Collected by the author (7/9/64). We thank Moshe Ish-Shalom for partiallyashing this sample. Appearance of ash: friable spongy gray mass.

No. 1301 — Small twigs and stems of the "soda plant" (*osnan*), from Shareza. (Probably *Salsola* species.) Collected by Hans Wulff. (Wulff Nos. 126 and 137; Smithsonian Institution, Department of Ethnology. Catalogue No. 409392.) Appearance of ash: fused to grayish, hard mass, with some bubbles.

No. 1304 — A chunk of hard, gray, porous material described as "potash" by Hans Wulff, who collected the specimen in Qom, where it is used today for making faience beads. (Wulff No. 28; Smithsonian Insti-
No. 1305 — A similar chunk of hard, gray, compact material described by Wulff as “calcined potash,” from Shareza. (Wulff Nos. 129 and 140; Smithsonian Institution, Department of Ethnology, Catalogue No. 409395.)

No. 1320 — Twigs and fine debris from a large tamarisk bush growing on the bank of the Naaman River (Belus River) near its outlet into Acre Bay. (Possibly *Tamarix meyeri* or *Tamarix tetrandra.*) Collected by the author (7/11/66). Appearance of ash: friable brown ash preserving original shapes of plant.

No. 1323 — Thin stems from a bush growing in the sand dunes behind Caesarea. Collected by the author (8/4/65). Appearance of ash: fused to hard bluish gray mass.


No. 1325 — Bracken leaves from the edge of the woods near the site of a Wealden glass factory (16th cent.) at Knightons, Alford, Surrey. Collected by the author with G. H. Kenyon (6/26/68). We thank Gerald Shaw for ashing this sample. Appearance of ash: fine white powder with slightly purplish tinge.

No. 1326 — Small thin stems of the *chinān* plant from Qasr el Hayr Sharqi, Syria. Collected by Hayat Salam and Oleg Grabar in the first week of June, 1969. They describe the plant as being very abundant in the desert for many miles around. It is collected and burned for the preparation of *qili* by the inhabitants of the area. Appearance of ash: light-colored, friable ash preserving original shapes of stems. (This plant was ashed at a lower temperature, 600°C, than the others because it fused completely at the higher temperature.)

No. 1380 — Small thin stems of the *chinān* plant from Qasr el Hayr Sharqi, Syria. Collected by Hayat Salam and Oleg Grabar in June, 1969. This material was prepared by local workers from the plants described under No. 1380.

Note: Those samples designated as plant material were ashed before analysis, according to the procedure given below, by Dr. August A. Erickson, of Corning Glass Works.

The plant material was dried for 2 hours at 120°C, then placed on a platinum tray in a small kiln. The material was ignited and held at 250°C for one hour, then raised to 750°C, and held for one hour. After cooling and reweighing, the ashes were “calcined” at 750°C for three hours with oxygen being slowly passed through the kiln. After the final cooling, the residues were weighed again.
Applying the same logic to the instructions for the preparation of the red glass (section 12, p. 41), the estimated maximum volume of glass would be approximately 800 cc. This corresponds to a convenient size of mold or closed crucible for preparing this glass. Since the red glass required especially careful control, the manageable volume would have been smaller than that possible for some of the other glasses. A volume much greater than one or two liters might have posed difficulties of control. The volume is great enough, however, that if one regards the container as being a mold for a single object, and one in which all of the batch was used, then it must be concluded that either the object being made was rather large, or, alternatively, that this section actually describes the manufacture of a material rather than an object.

Most of the other batches seem to be about the size of one or the other of those mentioned above. This probably divides the sections in either of two ways, that is, the preparation of simple vs. more difficult materials, or the preparation of materials vs. objects. Notable exceptions are sections 19 (p. 48) and P (p. 53) which call for about three times the weight of ingredients, some 80 minas. The texts do not indicate how these are treated, and do not, in fact, imply that all of the batch was necessarily to be dealt with in one operation. (See p. 128).

9. CHEMICAL ANALYSES OF MESOPOTAMIAN GLASSES

In all, probably no more than about twenty reliable chemical analyses have been made of glasses of the dates and geographical sources of direct concern here. While this number may seem large the glasses are of such diverse origins and colors that their analyses are not easily compared to one another. Therefore, we shall not undertake here a compilation of all published analyses of ancient Mesopotamian glasses, for even though such a compilation might be useful to have for other purposes, it would not add materially to the interpretation of Professor Oppenheim's translations or to that of the finds listed in the catalogue sections of this book. Instead, there are given in Table I ranges of some typical analyses and compositions of hypothetical base glasses. Although these could hardly be said to be representative of glasses from any particular site or period, they do nevertheless illustrate the compositional variability occurring in Mesopotamian glasses dating from about the middle of the second to the middle of the first millennium B.C. It should be noted, however, that these compositional ranges are not unique to Mesopotamian glasses but apply as well to all glasses of the period. Also there is a considerable diversity of color and type among glasses dating from this period, and perhaps it is somewhat misleading to lump them all together. The composition, for example, of one of the colorless hemispherical bowls from Nimrud is obviously very different from that of the yellow opaque threading on an early cored vessel, but looked at properly, both fit into the table as constructed.

The composition in the table is to be thought of as that of a hypothetical base glass to which additional colorants and colorant-opacifiers, as listed separately in the table, would have been added. This composition and the ranges of analytical values have been arrived at rather subjectively after considering analyses published by W. E. S. Turner,20 E. V. Sayre,21 and by E. R. Caley,22 who has reviewed the early analytical work on ancient glasses. In addition, we have drawn upon our own unpublished analyses.

The calculated composition of zukkē is discussed on page 109 and that of the red opaque glass is discussed on page 121.

21. See note 4, p. 111.
10. AN APPARENT EXCESS OF ALKALI

Two sections of the texts appear to call for a large excess of alkali over what would ordinarily be required for glassmaking operations. Whereas section 1 (p. 35), as well as others, requires approximately the same quantities of immanakku and abussu, as has been shown to be consistent with glass compositions, sections 19 and P (pp. 48 and 53) call for about three times the weight of naga ash as immanakku. There are several plausible explanations. The first which comes to mind is the general inexactitude which Professor Oppenheim says characterizes such texts. To the scribe it did not matter particularly whether he wrote down 60 minas of naga ash or 20. Or perhaps the recipes describe the making of some other form of zukū in which the objective was to get the silica reacted quickly with a later step to be carried out to bring the alkali: silica ratio back into line.

Noticing, however, that the recipe does not actually specify naga ashes, but rather naga, with the ashes presumed to have been the intended meaning, it does seem possible that the “author” of the texts really meant the naga plant and not naga ashes. Since the plants we have examined so far yield about 30–35% of residue after ashing, the texts once again, if taken literally, would make sense.

In order to test this hypothesis, some dried stems of the chinān plant were mixed with one-third their weight of sand and the mixture was ignited inside a kiln at 750°C. The plant ashed nicely, forming a frit with the sand where they were in contact. Upon re-firing at 1100°C for 8 hours, a colorless, and very well melted glass was obtained.23

The interpretation that the texts in these sections really intended plants and not plant ashes is weakened by the fact that the term for ash was omitted by the scribe in other sections of the texts, where the alkali: silica ratios are consistent with the use of ashes.

23. See Note 7, p. 112.