Scientific Study of Indian Glass: Past, Present and Future

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Introduction

Glass study in India has a long and distinguished history. Such seminal works as Beck's *The Beads from Taxila* (1941) and Dikshit's *History of Indian Glass* (1969) may be the best known and most comprehensive, but certainly not the only useful early studies that also include excavation reports and reviews of excavated beads from many important sites (reviewed in Kanungo (2004). The scientific study of Indian glass likewise began early, with studies from the 1920s and 1930s by Sanaullah and Hamid (details in Bhardwaj 1987). Analyses of glass from Arikamedu and Ahichhatra by Lal ((1952) and from Kopia by Roy and Varshney (1953), are early studies of sites that remain important today.

However, the watershed year in the scientific study of Indian glass was 1986, with the session on the archaeometry of glass in the XIV International Congress on Glass in New Delhi, subsequently edited by H.C. Bhardwaj and published in 1987 by the Indian Ceramic Society. Contributions from glass scholars of varied backgrounds brought together the then-current thinking on glass found in India, at least in part in order to provide a springboard for further studies. While there has certainly been progress, many of these insights have come from work on glass from areas outside of the subcontinent (e.g. Glover and Henderson 1995), and far too many studies are unpublished or only partially published, with the present author being one of the culprits in this regard. In fact, on re-reading articles by Brill and Bhardwaj in the 1987 volume, my strongest response was how many of the questions remain the same, particularly in terms of production sites and processes. On the other hand, our understanding of glass exchange in the ancient world has changed dramatically with the availability of glass analyses from areas still unstudied in 1987, and the archaeological questions, particularly those related to the uses and meaning of glass in ancient societies- how the glass evidence can help us to understand the lives of people in the past- have expanded in breadth and depth.

Current understanding

We will begin this discussion with a review of the most important chemical compositional groups found at Indian sites, with passing reference to when and where these glasses might have been made.

Glass chemical compositional groups in India

Mineral soda glass with high alumina

By the mid-1980s it was clear the much early glass found in India had certain chemical compositional characteristics unusual outside of Asia. As discussed by Brill (1987), these include levels of alumina (Al_2O_3) greater than 3.5 to 4.0 wt%, and lime (CaO) less than 4.5 to 5.0 wt%. This 'Brill Doctrine' remains true today, certainly for alumina if only slightly less so for lime, and has formed the basis for all subsequent research on Indian glass. Laure Dussubieux (2001, Dussubieux et al 2010) has been particularly active in defining and refining the high-alumina glass chemical compositional groups found in India. Indian high-alumina soda glass is now thought to include at least four different sub-types that may be separated using the values for lime and magnesia, along with trace elements U, Ba, Sr Zr and Cs. These groups also have different archaeological meanings, although it is likely that all four groups represent Indian primary production. Dussubieux abbreviates the groups as m-Na-Al 1-4, where 'm' indicates a mineral source of the alkali, indicated by magnesia less than 1.5 to 2.0 wt%. Al indicates that alumina is high, and significantly higher than lime. These four glass compositional types, along with eleven others, are listed in Table 1, along with their relative prevalence in samples from archaeological sites in seven Indian states. Table 2 lists the same groups by approximate date, artefact type and colour. Both tables are based on data for 569 glass samples, almost all beads, and most of the analyses were by LA-ICP-MS (laser ablaton-inductively coupled plasma-mass spectrometry), and thus include values for about fifty different elements or oxides. The analyses, many unpublished, include work by Dussubieux (2001; Dusubieux et al 2008; unpublished), Lankton and Gratuze (unpublished), Brill (1999) and Sarah (2004).

Although this database represents, to my knowledge, most of the Indian glasses for which major (greater than 1 wt%), minor (0.1 to 1.0 wt%) and trace (below 0.1 wt%) elements are available, the maldistribution within India is readily apparent, with over 90% of the samples from just three states.

Our samples of m-Na-Al 1 glass are mostly from South India, where 29% of the samples from Tamil Nadu are m-Na-Al 1 glass, with no m-Na-Al 1 glasses from Haryana, Maharashtra or Uttar Pradesh. On the other hand, m-Na-Al 1 glass is the most common type of Indian high-alumina soda glass outside of India, with many examples

from areas stretching from West Africa to Korea. There is evidence for the primary production of m-Na-Al 1 glass in Sri Lanka (Giribawa, Dusubieux 2001), and similar glass was most likely made in South India as well. In Thailand, millions of small drawn 'Indo-Pacific' beads have been found at Khuan Lukpat, and many of these may have been made there, possibly from ingots of Indian-made m-Na-Al 1 glass.

The other pre-9th century mineral-soda-alumina glass found in India is m-Na-Al 3, slightly lower in alumina and higher in lime than m-Na-Al 1, and with considerably higher uranium levels. Based on chemical analyses by Brill (Kanungo and Brill 2009) and Dussubieux (unpublished), the glass made at Kopia was m-Na-Al 3. Very similar results for glass from Kausambi (Lankton and Gratuze, unpublished) substantiate this identification.

Table 1. Distribution of glass chemical compositional groups as percent of total samples from each state. Note that 92% of the analysed samples come from just three states: Maharashtra, Uttar Pradesh and Tamil Nadu.

group	total samples	Haryana	Jharkhand	Maharashtra	Orissa	Punjab	Tamil Nadu	Uttar Pradesh
m-K-Ca-Al	93		22%	4%			23%	9%
m-Na-Ca natron	12			1%			3%	2%
m-Na-Al 1	90				14%		29%	
m-Na-Al 2	28			34%	14%			
m-Na-Al 3	111	40%	39%				2%	67%
m-Na-Al 4	41	20%		49%				
m-Na-Ca-Al	50				43%		13%	6%
m-mix-Ca-Al	13						4%	
v-mix-Ca-Al	65		30%		14%		18%	1%
mixed alkali high Cu	17		9%		14%		2%	4%
v-Na-Ca-Al	19			9%		100%	1%	4%
v-K-Ca-Al	5			1%			1%	
v-Na-Ca	10	40%		1%			1%	1%
total samples	569	10	23	79	7	3	310	137
percent of total samples by state		2%	4%	14%	1%	1%	54%	24%

Table 2. Glass chemical compositional group distribution by date, artefact type and colour

group	number of samples	% of total	date	form	colour													
					aqua	cobalt blue	greenish blue	black	brown/ amber	colourless	gold-glass	green	green opaque	red opaque	orange opaque	white opaque	yellow opaque	violet
m-K-Ca-Al	93	16%	1-3c CE (?)	drawn beads, beadmaking waste	5%	69%	1%	5%	1%		1%	3%	1%				6%	3%
m-Na-Ca natron	12	2%	1-3c CE (?)	fragments, bracelets, beads wound and drawn		50%				8%	17%	8%		8%				8%
m-Na-Al 1	90	16%	1c BCE-5c CE (?)	drawn beads			19%	19%		3%		2%	19%	20%	7%	1%	7%	1%
m-Na-Al 2	28	5%	9-19c (?)	beads		21%	14%	11%				11%		18%		7%	18%	
m-Na-Al 3	111	19%	4c BCE-4c CE (?)	wound, zone, tabular, mosaic beads	3%		14%	15%	10%		1%	23%	8%	6%	1%	14%	5%	
m-Na-Al 4	41	7%	15-16c CE	bangles														
m-Na-Ca-Al	50	9%	1-3c (?)	bead drawn, vessel, frags	18%	34%	2%	6%	6%			4%	20%	18%	2%	2%	2%	2%
m-mix-Ca-Al	13	2%	1-3c CE (?)	drawn beads		8%		8%					85%					
v-mix-Ca-Al	65	11%	1-3c CE (?)	beads drawn, fragments				25%	2%					71%	2%			
mixed alkali high Cu	17	3%	3c BCE-3c CE (?)	disk beads										35%	65%			
v-Na-Ca-Al	19	3%	2c BCE-3c CE (?)	bead wound, bead zone, bangle	5%	16%		21%				5%	16%	16%				5%
v-K-Ca-Al	5	1%	3c BCE-3c CE (?)	bead, ear spool				40%						60%				
v-Na-Ca	10	2%	2c BCE-2c CE (?)	beads, bangles		10%	60%						10%	20%				
total samples	571				18	98	45	68	16	4	4	38	52	100	20	19	23	7
percent of total					3%	17%	8%	12%	3%	1%	1%	7%	9%	18%	4%	3%	4%	1%

Mixed alkali high Cu

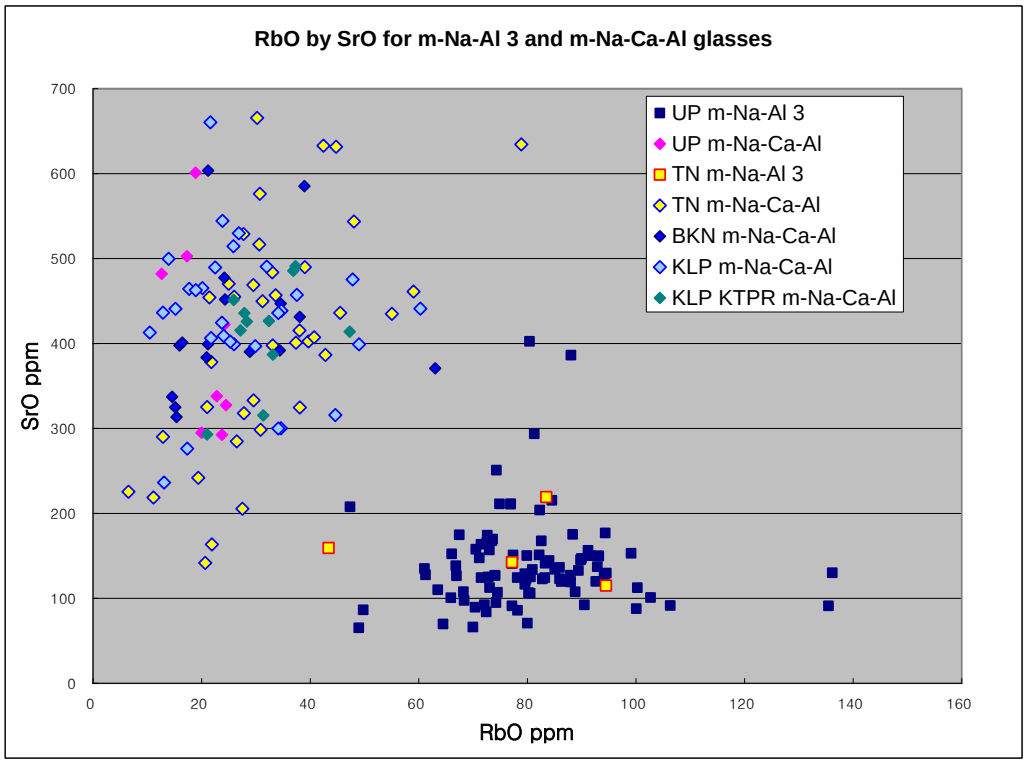
Another important group also possibly made in India is mixed alkali high Cu glass, characterized by very high copper, usually greater than or equal to 6 wt%, and an average ratio of potash to total alkali (K_2O/ (K_2O+Na_2O)) of about 50%. Almost all of the beads made from this glass are very different from the Indo-Pacific m-Na-Al 1 beads, being cut as thin slices from solid tubes, then drilled to perforate. The opaque orange and red colours are from Cu_2O, cuprous oxide, present as small crystals for the orange glass and large crystals for the red. Disc beads made from mixed alkali high Cu glass have been found both in India, and, more abundantly, in Southeast Asia. We have analysed one chunk of mixed alkali high Cu glass for strontium isotopes, and the very high isotope ratio is consistent with a possible northern Indian origin, although the glass in other ways seems to be South Indian or even Southeast Asian.

m-Na-Ca-Al

This mineral soda glass differs from m-Na-Al glass in having higher lime and lower alumina, although the values for both oxides are quite variable, depending in some cases on colour, and, in other cases, not. One-third of the m-Na-Ca-Al glasses in our database are cobalt-blue, a colour otherwise found only in potash glass and in later high-alumina mineral soda glass (m-Na-Al 2 and 4). Trace elements are variable in m-Na-Ca-Al glass, and, for many trace elements, seem to depend as much on the cobalt colourant as on the base glass. By major elements alone it may be difficult to distinguish m-Na-Ca-Al glass from other mineral soda glasses, particularly m-Na-Al 3, the probable North Indian glass with high uranium levels. However, using LA-ICP-MS data, the values for Rb and Sr are instructive in most cases (Figure 1).

The question of identifying m-Na-Ca-Al glass is particularly important, since it may be an example of non-Indian primary glass that is relatively common at Indian sites. Large blocks of partially fused m-Na-Ca-Al glass have been found at Khuan Lukpat (KLP KTPR m-Na-Ca-Al in Figure 1) in southern Thailand, as well as artefacts made from glass of this composition, much of it coloured dark blue by cobalt. In addition, the Sr isotope signature of this raw glass is consistent with a coastal origin that could be South Indian or Southeast Asian, but certainly not North Indian, in spite of the high uranium values. Glass with a very similar composition is common at Ban Kluay (BKN), just north of Khuan Lukpat on the west coast of the Thai-Malay Peninsula. Compositionally, this cobalt-blue 'Southeast Asian' glass is virtually indistinguishable from the cobalt-blue m-Na-Ca-Al glass found in both Uttar Pradesh and Tamil Nadu. Despite the 'coals to Newcastle' implications of this line of reasoning, we wonder if for some reason early Indian craftsmen relied, at least in part, on imported cobalt-blue glass.

Figure 1. RbO by SrO for m-Na-Al 3 glass from Uttar Pradesh (UP) and Tamil Nadu (TN) vs m-Na-Ca-Al glass from UP, TN, Ban Kluay Nok (BKN) and Khuan Lukpat (KLP). KLP KTPR m-Na-Ca-Al glass is most likely primary glass made at KLP



m-K-Ca-Al

The only other Asian glass compositional type found in cobalt-blue is a potash glass with moderate lime and alumina (usually between 2 and 4 wr%). While most of our m-K-Ca-Al samples are from one site, Arikamedu in Tamil Nadu, there were also a significant number of samples at Kausambi and Kopia. Based on his studies of the Arikamedu material at the Pondicherry Museum, Francis (1987) estimated that as much as 40% of the glass found at Arikamedu was cobalt-blue, and much of this was probably potash glass, although we have identified cobalt-blue m-Na-Ca-Al there as well. The origin of the m-K-Ca-Al glass found in India is also a mystery, although we believe that an Indian origin is more likely for m-K-Ca-Al glass than for the m-Na-Ca-Al glass, at least the cobalt-blue variety. In fact, there were probably several m-K-Na-Ca glasses produced in different areas at different times. The earliest seems to be from Southeast Asia or possibly southern China, with dates from the 4th to 2nd c. BCE from Khao Sam Kaeo. Similar m-K-Ca-Al glass has been found at a number of other very early (pre 1st c. BCE) Southeast Asian sites, including Ban Don Ta Phet in west-central Thailand.

The 'Indian' variety of m-K-Ca-Al glass seems to appear not before the 1st c. CE

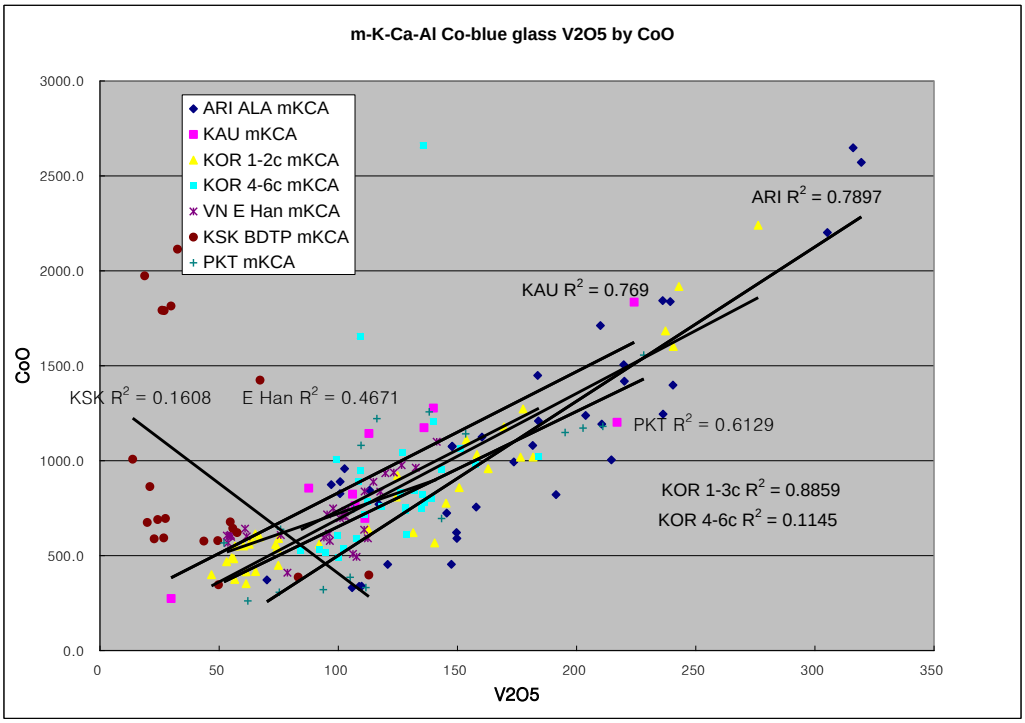
(Bhardwaj 1987), and then possibly in both North and South India. At about this same time, the earlier, 'Southeast Asian,' m-K-Ca-Al glass all but disappears. Most Southeast Asian sites, with one exception to be discussed below, dating after the 2nd century CE have almost no potash glass of any kind. But, virtually simultaneously, large amounts of m-K-Ca-Al glass, most of it cobalt-blue, appear not only in Eastern Han (ca 1st to 3rd c. CE) tombs in northern Vietnam, probably in southern China, and at sites dated from the 1st to 6th c. CE in Korea and Japan. The samples from Korea are virtually indistinguishable from the Arikamedu samples based on major and minor elements. In this case, the trace elements, especially those associated with cobalt, such as Mn, Ba, V, Ce and Ni, are helpful. Figure 2 is a plot of V_2O_5 by CoO, showing the striking correlation for these oxides in the North and South Indian examples (ARI, Arikamedu, and KAU, Kausambi), as well as in samples found in Han tombs in Thanh Hoa Province in northern Vietnam (Lankton and Gratuze unpublished) and in Korea (Lankton and Gratuze, in preparation). Samples from the one Southeast Asian site for which we have evidence for potash glass extending past the 1st c. CE, Phu Khao Thong (PKT), show the same correlation patterns as the Indian samples. Although only V_2O_5 by CoO is illustrated here, the results are identical for Ni and Ce, and similar for BaO and MnO, although both the Arikamedu samples and the later samples from Korea show a weaker correlation with MnO, possibly because cobalt was not the only source of MnO in some of these glasses. Of course, the fact that the cobalt colourant was identical does not mean that the base m-K-Ca-Al glass was identical, since it is possible that cobalt itself was an object of exchange. This is certainly true for later periods in terms of Iranian cobalt to decorate Chinese ceramics, but, as far as we know, the evidence for pre-10th c. CE long-distance exchange of cobalt as a glass colourant is nonexistent.

In contrast, as seen in Figure 2, the cobalt colorant used for the early Southeast Asian samples (KSK) was completely different, with no correlation with V_2O_5, CeO, BaO or MnO, but a strong correlation with NiO and, for some samples, As_2O_3.

m-mix-Na-Ca-Al and *v-mix-Na-Ca-Al*

In addition to the mineral-soda m-Na-Ca-Al glasses, there are two groups in Table 1 in many ways similar, but differing in potash, and, for v-mix-Na-Ca-Al glass, magnesia. m-mix-Na-Ca-Al glass is perhaps the most straightforward. Almost all of the Indian samples were found at Arikamedu, and almost all are green opaque beads coloured with copper, tin and lead. We have called these glasses 'mix' because the soda and potassia are similar, with a potassia to total alkali (Na_2O plus K_2O) ratio of about 60%. The overall compositions are very similar in major elements to those of a group of 2nd to 4th c. CE powder glass beads found in Korea that were most likely produced by grinding

Figure 2. Correlation between CoO and V_2O_5 for m-K-Ca-Al glass samples from various sources. All samples similar to Arikamedu and Kausambi m-K-Ca-Al with exception of those from Khao Sam Kaeo and Ban Don Ta Phet



together m-K-Ca-Al cobalt-blue glass and blue-green m-Na-Al 3 glass imported from northern India. We believe that the m-mix-Ca-Al Arikamedu beads, while not powder glass, were also made from two glass types melted together, one of them a potash glass, although not cobalt-blue, and the other a glass similar to the opaque green m-Na-Ca-Al glass also found at Arikamedu. Further evidence for this mechanism is the one cobalt-blue m-mix-Ca-Al sample. Some sort of cobalt-blue glass was most likely used to produce this glass, and the only choices would be m-K-Ca-Al or m-Na-Ca-Al, both of which are found at Arikamedu. Further, the composition of the m-mix-Ca-Al glass is well approximated by a 1:1 compositional mixture of the m-Na-Ca-Al and m-K-Ca-Al Arikamedu glass. Why the Arikamedu beadmakers would want to do this is unknown, but it is not the only example of apparently deliberate mixing of glass types, the other being in 5th to 6th c. CE East Java (Lankton, Dussubieux and Rehren 2008).

v-mix-Ca-Al glass seems to be more common, with samples from Arikamedu but also from 'Bihar-Dhalbhum,' the origin of bead given by Dikshit to van der Sleen that we have not been able to positively locate, although Jharkhand state is a good possibility, and Karur Amaravati in Tamil Nadu. Almost all of the v-mix-Ca-Al beads are opaque red or black The ratio of K_2O to total alkali is an average of 26%, so lower than for the m-mix-Na-Ca glasses, and it is not clear that the same explanation applies for the v-

mix-Ca-Al samples. Dussubieux (in press) has suggested that the addition of an ingredient containing MgO, K_2O, CaO and P_2O_5, in different amounts depending on the desired colour, to a base m-Na-Ca-Al glass could produce the observed compositions. Although this explanation may hold for the red and black glasses high in all of these ingredients, it seems less clear for the opaque green m-mix-Ca-Al glasses, where K_2O is markedly elevated, while the other oxides are not. For the red and black glasses with a v-mix-Ca-Al compositions, plant ash would satisfy most of the compositional requirements for the added substance. A somewhat similar situation may apply for mid- to late-Roman red and green opaque glasses used for mosaic glasswork (Nenna and Gratuze 2009); these colours are often plant ash glass, otherwise very unusual at Mediterranean sites before the late 8th to early 9th c. CE.

v-Na-Ca and *v-Na-Ca-Al*

Plant ash soda lime was the predominant glass compositional group from the Mesopotamian and Egyptian Late Bronze Age until the mid-1st millennium BCE. If it had ever decreased, production of v-Na-Ca glass had resumed at Sasanian-controlled sites in central Iraq by the late 3rd c. CE (Mirti et al 2008, 2009). There are few v-Na-Ca samples in our database, but, based on compositional grounds, we suspect a Mesopotamian origin for these samples. The v-Na-Ca-Al glass in our Indian samples is similar to v-Na-Ca but with lower CaO and higher Al2O3, often greater than 4.0 wt%. Most of our samples were from Kausambi, Rupar in the Punjab, and Nevasa, with relatively early suggested dates. A very similar glass was reported from Bara, an area near modern Pesharwar in Northwest Pakiston (Dussubieux and Gratuze 2003). The Bara material, most likely some type of refuse dump from what was probably a nearby worksite, has been dated to the 2nd c. BCE to the 2nd c. CE, in line with the dates for our samples. We suspect that this v-Na-Ca-Al glass represents a kind of 'Kushan' glass, with samples relatively rare in Central and Southern India and Southeast Asia, but not uncommon in Xinjiang, Mongolia and Korea (Liu et al 2011, Lankton and Gratuze, unpublished), indicating a northern focus for exchange not unexpected for the Kushan Empire.

m-Na-Ca 'natron'

The last glass compositional group we'll consider is a mineral soda glass with lime considerably higher than alumina (alumina to lime weight ratios around 0.4). This composition for major elements is typical for Mediterranean 'Roman' glass, but there may be some overlap with lower-alumina samples of m-Na-Ca-Al glass found in India and Southeast Asia. Here, the key element for making the distinction is uranium. Roman glass, made with trona, an efflorescent sodium carbonate/bicarbonate mixture

from the lakes at Wadi Natrun in Egypt, is always low in uranium, with values seldom above 2.0 ppm (parts per million), while m-Na-Ca-Al glass is usually at least an order of magnitude higher. The study of Indo-Roman trade is of course a big business, and it is surprising that there is so little (12 sample, 2% of total) Roman glass among the analysed samples. From Table 2, half of these are cobalt-blue, and almost 20% are gold-glass beads, made by encasing a thin layer of gold or silver foil between two layers of glass. Most of the Roman samples are from Arkamedu and Alagankulam in Tamil Nadu, but beads made from Roman glass are also included in the Kopia and Nevasa samples. We suspect that there will be a significant percentage of beads made from Roman glass in those currently being excavated at Pattanam in Kerala, but, to our knowledge, none of these have been studied using scientific techniques. If we were to rank our Indian samples by ink spilled vs actual evidence, those made from m-Na-Ca natron glass would certainly top the list.

Emerging themes in Indian glass study

The brief nature of this report precludes adequate discussion and interpretation of the chemical compositional evidence, but I would like to at least mention several important underlying themes in current glass research. All of these have important historical, cultural and political implications in many ways more interesting than our background review of the compositional types.

Glass exporters and glass importers

The current picture of early glass in India is very different from that in Southeast and Northeast Asia, where most of the glass was imported from one area or another. In contrast, the early Indian societies seem to have been net exporters of both glass and glass technology, with evidence from 4th to 3rd c. BCE Khao Sam Kaeo for North Indian m-Na-Al 3 glass, and, most likely, North Indian glass craftworkers (Lankton, Dussubieux and Gratuze 2008). In contrast, by the beginning of the 1st millennium CE, glassworkers at sites in both North and South India seen to have been making beads from cobalt-blue m-Na-Ca-Al glass cullet imported from Southeast Asia, perhaps from such maritime sites as Khuan Lukpat and Ban Kluay. The mechanisms and reasons for this remain a mystery. It is possible that the two most common types of cobalt-blue glass in India, and at Arikamedu in particular, m-Na-Ca-Al and m-K-Ca-Al, represent different chronological periods. However, while not precisely dated, m-Na-Ca-Al glass production at Khuan Lukpat was almost certainly somewhere between the 2nd and 6th centuries, the time period during which large numbers of m-K-Ca-Al cobalt-blue glass beads similar to those found at Arikamedu were being shipped to Northeast Asia. A

possible alternate explanation would be two different production systems and groups of craftworkers operating simultaneously at Arikamedu. Such an arrangement is not out of the question, and has been suggested by Francis (2002) for stone bead production.

Regionalization

At the same time that early Indians were sending glass, and possibly glassworkers, to distant areas, there seems to be relatively little exchange, at least for glass artefacts, between North and South India. The 'southern' m-Na-Al 1 glass is very rare in the north, and northern m-Na-Al 3 glass rare in the south, with only 2% of the Tamil Nadu samples made from this composition. In fact, based on our work in both places, the amount of m-Na-Al 3 glass is proportionally higher in Korea than in South India, a rather remarkable observation.

Targeted exchange

Three examples of 'targeted' exchange have emerged from our compositional studies of early glass in India and other areas in the ancient world. The first of these would be from northern India to Khao Sam Kaeo, as mentioned above. While it was definitely worked into beads and bracelets on site, all of the raw soda glass at Khao Sam Kaeo was made in northern India, based not only on chemical compositions, but also on newer Sr isotope data (Lankton, Dussubieux and Gratuze 2008, Lankton and Degryse, unpublished). In addition, this high-uranium soda glass is virtually absent at other, contemporaneous sites, the only exceptions being beads and bracelets most likely imported from Khao Sam Kaeo. The second example is the close similarity of both soda and potash glass found at Arikamedu with that found at Phu Khao Thong on the Thai/Malay Peninsula, and, so far, only there, at least for the soda glass. Both of these examples imply a special, specific, commercial, and possibly political and cultural, relationship between early Indian polities to probable production sites in Thailand, beginning in the Mauryan period.

The third example of targeted exchange is somewhat different, although no less interesting. The exchange of what was possibly 'Indian' cobalt-blue potash glass, perhaps from Arikamedu, to Han Chinese-controlled northern Vietnam and on to Korea and Japan is one of the great, early, Silk Road stories. Why there is so little m-K-Ca-Al glass at contemporaneous sites in Thailand (with the exception of Phu Khao Thong), Cambodia and Vietnam is not known, but is certainly an important topic for future exploration.

The future for the past?

I hope this paper has given some feeling for how both chemical compositional analysis

and isotope ratio analysis can be useful in identifying possible chemical compositional groups, along with their provenances and routes of exchange, in a group of ancient glasses. With this data we can start to think about the meaning of glass in early societies, and how not just the exchange of glass artefacts, but the control of that exchange and the ultimate use of the artefacts themselves, hold keys to important cultural, political and ideological questions. The quantitative measurement of glass compositions provides the building blocks for any further interpretation, and most of the work presented in this paper would not have been possible without knowing both the major element content of the glass samples and the trace element compositions.

We pointed out also the very patchy nature of our knowledge of early glass in India, with samples responding more to availability than to what might actually be important for a more complete picture of early Indian societies. As stated, most of our samples were from just three states- important areas, no doubt, but there is equally no doubt that other areas were important as well, and we know next to nothing about these.

With these ideas in mind, I see as vital for the progress of glass research in India the following developments:

1. Analytical facilities for chemical analysis, including at a minimum LA-ICP-MS and some type of electron image-based spectrometry, whether SEM-EDS (scanning electron microscopy with energy dispersive spectrometry) or EPMA (electron probe microanalysis).
2. Dedicated, well-trained personnel to oversee, calibrate and repair the above equipment.
3. Archaeologists familiar with both the important archaeological questions involved and the characteristics of ancient glass who are willing and able to spend the time necessary to learn the principles and pitfalls of new analytical techniques. From my experience, giving the glass samples to a technician, no matter how well trained, does not lead to good results.
4. Less immediate, although probably no less important, is the need for the analysis of isotope ratios for such elements as strontium, neodymium and lead. The most commonly used equipment for this today is a multi-collector ICP-MS, considerably more expensive than an ICP-MS used for conventional compositional analysis. There are questions that compositional analysis alone will not answer, and the ability to do isotope ratio analysis can be critical.
5. Access to glass samples from well-controlled excavations with special attention to dating. With such virtually non-destructive techniques as LA-ICP-MS now available,

there seems little reason why even glasses destined for eventual display should not be analysed. One of the biggest obstacles we face is permission for the export, even temporary, of archaeological samples for analysis elsewhere. Such decisions are not easy, and respond as much to current political and cultural conditions as to the needs of archaeology. The availability of similar analytical capability within India is the logical next step.

None of these developments is easy. Even after at least ten years of international awareness of and experience with LA-ICP-MS, there are only a handful of laboratories set up to perform adequate work on ancient glass samples; by the same token, the occasional use of the LA-ICP-MS unit in the geology lab next door is an almost certain recipe for failure. In establishing a new laboratory, it is relatively easy to buy the equipment, but seems to be much more difficult to keep it running well, with the compulsive attention to detail required to achieve excellent results. Human resource issues are perhaps the most difficult. Not only must the laboratory personnel be well trained and experienced, but the investigative archaeologist should be present during the analysis to make the important decisions of where on the sample to analyse and how to know if the analytical result will be a good one. Getting the training to do this well is not easy for most archaeologists, whether burdened by teaching or writing obligations, or simply not comfortable with quantitative tools. This is certainly the situation in Korea, and I would guess that it applies to a certain degree to India as well. How many Indian archaeologists are trained in analytical techniques? From my experience during the last ten years at the UCL Institute of Archaeology, I've seen many international students pass through the programs there, but no one from India, although there had been Indian students before I arrived at UCL. The archaeometry training programs at the Institute of Archaeology are hardly the only ones available, but they are the largest in Europe. At the same time, while the number of articles on early glass submitted to the most prominent English language archaeometry journals from such countries as China is rapidly increasing, those from India are still very few. While these comments are not intended as a criticism of Indian archaeology in general, they do point out the gap between traditional approaches to archaeological inquiry and the understanding that scientific analysis, when combined with solid archaeology, glass study and text analysis, can unlock the language of glass to tell so much about life in ancient times.

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