Glass ornament production and trade polities in the Upper-Thai Peninsula during the Early Iron Age

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1. Introduction

The Thai-Malay peninsula is at the intersection of the Bay of Bengal (Gupta, 2005; Bellina, in press a) and the South China Sea Interaction Spheres (Solheim, 2006; Hung et al., 2013; Blench, in press; Bellina, in press a). This unique geographical position partly accounts for the peculiar hybrid cultural developments that the upper part of the region witnesses as early as the mid-first millennium as reflected in the urban traits and industries of Khao Sam Kaeo (Bellina, in press a, 2017). As in the case of hard stones (Bellina, 2007, 2014) and possibly of copper-based industries (Pryce et al., 2017), the sudden appearance of complex skills necessary for the production of glass ornaments at Khao Sam Kaeo suggests a transfer of artisans, likely from India. Again, as for siliceous stones which were most likely imported from India (Carter and Dussubieux, 2016), raw glass found at Khao Sam Khao was imported from India through the Bay of Bengal Interaction Sphere to be locally transformed into ornaments with a style shared by communities of the South China Sea Interaction Sphere within which they were then "distributed" as far as the Philippines (Dussubieux and Bellina, 2017).

The excavation of the contemporaneous port-settlement of Khao Sek located 80 km south of Khao Sam Kaeo and at the end of a river system which is part of major ancient trans-peninsular route and the technological reconstruction and comparison of both sites' industries unraveled striking similarities between the two sites. Those are interpreted as the result of related, ranked and complementary ports-of-trade forming part of a confederation controlling the transpeninsular routes. Khao Sek may have acted as an outpost controlling the flux of the Langsuan river system to redistribute the goods to Khao Sam Kaeo acting as the international market place where foreign traders and artisans stayed (Bellina, this issue a,b). The settlement shows many similarities with that of Khao Sam Kaeo in terms of topography, modes of construction, internal organization of craft activities. At the same time, Khao Sek appears smaller and lacking monumental works evidenced at Khao Sam Kaeo such as the encircling walls, the monumental terraces, drainage and hydraulic system. Khao Sek does not appear as socially complex as Khao Sam Kaeo: it did not yield evidence for the presence of foreigners established at the site within socio-professional compounds such as at Khao Sam Kaeo. The smaller port did not provide imports such as Han materials or Indian Fine Ware for instance although Indian Fine ware and Dong Son drums are found in several transshipment and collecting sites along the River Langsuan system/transpeninsular route such as at Pangwan, Ban Na Hyan and wat Pathumtaram (see Map 2 in

Bellina, this issue a). Exogenous traits appear in the shape of Indian-influenced ceramics such as kendi that A. Favereau interprets as produces made at Khao Sam Kaeo and exported to Khao Sek (Favereau, this issue). Khao Sek yielded fragments of one Don Son drum which turned up to be an ancient fake (Pryce and Bellina, this issue) as opposed to Khao Sam Kaeo which yielded several drums of various sizes. Finally, Khao Sam Kaeo furnished more than twenty seals (blanks or inscribed with brahmi inscriptions) whilst only two are reported at Khao Sek, and one of which containing a writing mistake showing the lack of expertise of the artisan. Despite these differences, the fact that the populations in both sites are related is shown by the production of the same domestic ceramics (the two technological groups are found and in similar proportions).

These two sites show evidence for hybrid industries producing similar objects of the "Late Prehistoric South China Sea style" that is found in various sites along the coast of the South China Sea (Bellina, in press a, 2017) and their "chaîne opératoire techniques" is the same (see Bellina, this issue a). This is the case for the glass industry too which is the focus of this study. Like Khao Sam Kaeo, Khao Sek yielded an impressive quantity of comparable glass material including glass wastes suggesting the presence of an active glass workshop at this site. The study of this material presented here includes a general description of the type of artifacts and compositional analysis obtained using laser ablation – inductively coupled plasma – mass spectrometry (LA-ICP-MS) and a comparison with that of Khao Sam Kaeo. This study provides data on the elaboration of a regional craft system and how it contributes to what can be labeled a "South China Sea style" (Bellina, in press a) in the context of emergent maritime silk roads trading polities. More broadly, along other analysis of these port-cities industries, this study of the early glass shed light on aspects of the still poorly known emergent maritime polities in Southeast Asia.

2. Site and glass artifacts

2.1. The glass material at Khao Sek

Khao Sek is an industrial port situated at the mouth of the River Langsuan that emerged during the 4th c. BCE (Fig. 1). It was excavated by the Thai-French Mission in 2013 and 2014; however, most of the glass material was found along a small branch of the river, on the western part of the site which was excavated by the land's owner. Consequently very little contextual information is available for most of the artifacts discussed below and it has not been possible to catalogue all the artifacts individually. Despite these caveats, we are able to provide a general description of the glass corpus found at Khao Sek and to place it in a chronological framework thanks to the small quantity of glass beads and bracelets fragments that were found in-situ by the French-Thai mission and the data obtained through compositional analysis. The material is now kept at the National Museum of Chumphon.

Although we were unable to determine precisely the quantity of glass found at Khao Sek, it is safe to say that several thousand glass artifacts were recovered at the site. A large number of unshaped glass fragments were collected; most of them present evidence of knapping. Unshaped glass fragments with evidence of hot working are available too but in much smaller number. Other glass artifact types recovered at the site includes: refuses of bracelet manufacturing, finished bracelets and beads (Fig. 2).

Pieces of unshaped glass or raw glass are turquoise blue, green, black, red and dark blue. There are two shades of turquoise blue, one being of a more intense color than the other one. The turquoise blue glass is translucent, the green and the dark blue glasses are transparent and the red glass is opaque. In a sample of 162 pieces of unshaped glass artifacts, the proportion of the turquoise blue pieces is 47.5%, transparent green, 44% and black 2.4%. Red glass and dark blue glass represent each 1.8% of the total. The color of a few artifacts could not be identified.

Glass beads were manufactured by the drawn, the wound or the lapidary techniques. Drawn beads are mostly opaque red and transparent dark blue. They are by far the most abundant type of beads at the site. No evidence of drawn bead manufacturing is available as no tubular pieces of glass were visible and red and dark blue waste glass fragments were not very abundant. Based on the lack of local manufacturing evidence, drawn beads might have been imported from elsewhere.

A fairly large number of lapidary glass beads, estimated to more than a hundred, were recovered at Khao Sek. They are transparent green, translucent dark blue, colorless or amber and are available in a variety of shapes. Broken or whole specimens are visible. It is impossible to say whether the broken specimens were production wastes or broken after they were manufactured. A local production is possible as testified by the large quantities of knapped wastes that could have been generated by lapidary glass bead manufacturing. Pelegrin (2000), a specialist in stone-knapping technologies was able to identify flake scars on knapped waste from Khao Sam Khaeo characterizing indirect percussion by the counter-blow technique, a traditional Indian technique also called the "Cambay technique", used since the Harappan period. This technique was used within the same workshop to work siliceous stone ornaments (Bellina and Silapanth, 2006; Dussubieux and Bellina, 2017). At Khao Sek, as at Khao Sam Kaeo, the glass production involves similar Indian techniques for siliceous stones.

Wound beads are fairly rare. A few spherical opaque green beads were manufactured using this technique. Other beads were manufactured using technique that could not be identified.

Some beads were certainly imported as in the case of the orange beads with an annular shape that are present by the hundreds and red disc-shaped beads although found in much smaller number. Both types of beads are abundant at South and Southeast Asian sites although the red disc-shaped beads seem more common in South India and Sri Lanka (Dussubieux, 2001, 103) and the orange annular beads in Thailand (e.g. Higham and Kijngam, 2012; White, 1982) and Vietnam (Dussubieux, 2001, 103). The place of production for these beads is still unknown.

At least, one gold-foiled bead was recovered at Khao Sek and possibly a second one. Both specimens are collar beads. One of the beads is tabular and the other one is cylindrical. They can only have two origins: the Mediterranean area or Pakistan where a number of locally-manufactured gold-foiled beads were found (Dussubieux and Gratuze, 2003).

Another type of glass artifacts present at the site is bracelets. They come in a variety of shapes and colors. They are mostly transparent green (~80%), black (~14%) and turquoise blue (~5%). Other colors are orange, opaque green, opaque red and transparent dark blue but they are extremely rare and only a specimen or two is available in each of those colors. A large proportion of the bracelets has a semi-circular section (A or B type as defined at Khao Sam Kaeo, see Fig. 3) and are transparent green. Other sections include triangular, house-shaped, D or C sections. Different artifacts are distorted pieces of bracelets (Fig. 2). They would indicate that glass bracelets were manufactured at Khao Sek.

2.2. Comparison with Khao Sam Kaeo

Khao Sam Kaeo is a unique site in Southeast Asia as it yielded evidence of ornament production dating as early as the 4th c. BCE. This discovery changed the long and well-established view that glass ornaments in Southeast Asia at that time were exclusively imported from South Asia (Dussubieux and Bellina, 2017). The presence of a second glass working site 80 km away from Khao Sam Kaeo raises a range of new questions related to the chronology of the two sites, their roles and relationships.

Both sites have in common the presence of an important quantity of glass wastes and more especially of knapped glass fragments. Transparent green glass objects dominated the Khao Sam Kaeo glass

Fig. 1. Map indicating the location of Khao Sek.

Fig. 2. Glass material found at Khao Sek. Please, note that it was impossible to insert a scale in the pictures and they all have very different magnifications. Starting with the top left picture and going clockwise: beads and knapped glass waste, broken lapidary bead, bracelet fragments and hot worked waste, tabular lapidary bead.

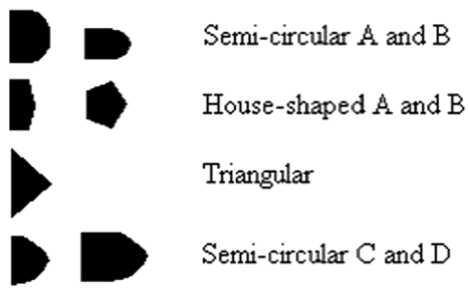

Fig. 3. Different shapes of bracelet section found at Khao Sam Kaeo and Khao Sek.

assemblage. It represented 87% of the bracelet, 87% of the knapped wastes and 90% of the hot worked wastes. All lapidary beads found at Khao Sam Kaeo were transparent green but very few were found there (16 in the excavations) compared to Kao Sek (> 100). Lapidary rectangular tabular beads are totally absent at Khao Sam Kaeo but fairly common at Khao Sek. At Khao Sek, more turquoise blue (47.5%) and less transparent green (44%) glass fragments were found among the waste. Color distributions for the bracelets are similar at both sites with approximately 80% of transparent green glass and approximately 5% of turquoise blue glass at Khao Sek; however, shape distributions for the bracelets are different for the two sites: at Khao Sam Kaeo, house shaped bracelets are the most common, followed by the semi-circular one. Other shapes were identified with 6 to 16 specimens in each category. At Khao Sek, even in the absence of an exact count, it was apparent, that the bracelets with a semi-circular section (B type) were the most common and the presence of distorted fragments of glass bracelets with a semi-circular and house shaped section indicate that both types of bracelets were made at the site. At both sites there is an important presence of drawn beads but no convincing evidence of their manufacture could be found.

It seems, according to the observations on the material from Khao Sam Kaeo and Khao Sek, that glass workers were using very similar technologies for the production of glass bracelets and possibly the production of lapidary glass beads. However, we noticed, very subtle differences in the productions from the two sites. As an illustration, at Khao Sam Kaeo there are many more house-shaped glass bracelets but no tabular beads.

3. Compositions

3.1. Analytical technique

The analyses were carried out at the Field Museum of Natural History in Chicago, USA, with a Analytik Jena Inductively Coupled Plasma - Mass Spectrometer (ICP-MS) connected to a New Wave UP213 laser for direct introduction of solid samples.

The parameters of the ICP-MS are optimized to ensure a stable signal with a maximum intensity over the full range of masses of the elements and to minimize oxides and double ionized species formation (XO^+/X^+ and $X^{++}/X^+ < 1$ to 2%). For that purpose the argon flows, the RF power, the torch position, the lenses, the mirror and the detector voltages are adjusted using an auto-optimization procedure.

For better sensitivity, helium is used as a gas carrier in the laser. The choice of the parameters of the laser ablation not only will have an effect on the sensitivity of the method and the reproducibility of the measurements but also on the damage to the sample. To be able to determine elements with concentrations in the range of ppm and below while leaving a trace on the surface of the sample invisible to the naked eye, we use the single point analysis mode with a laser beam diameter of 80 μm, operating at 70% of the laser energy (0.2 mJ) and at a pulse frequency of 15 Hz. A pre-ablation time of 20 s is set in order, first, to eliminate the transient part of the signal and, second, to be sure that a possible surface contamination or corrosion does not affect the results of the analysis. For each glass sample, the average of four measurements corrected from the blank is considered for the calculation of concentrations.

The isotope Si29 was used for internal standardization. Concentrations for major elements, including silica, are calculated assuming that the sum of their concentrations in weight percent in glass is equal to 100% (Gratuze, 1999). Two different series of external standards are used to measure major, minor and trace elements. The first series of external standards are standard reference materials (SRM) manufactured by NIST: SRM 610 and SRM 612. Both of these standards are soda-lime-silica glass doped with trace elements in the range of 500 ppm (SRM 610) and 50 ppm (SRM 612). Certified values are available for a very limited number of elements. Concentrations from Pearce et al. (1997) will be used for the other elements. The second series of standards were manufactured by Corning. Glass B and D are glasses that match compositions of ancient glass (Brill, 1999, vol. 2, p. 544).

The detection limits range from 10 ppb to 1 ppm for most of the elements. Accuracy ranges from 5 to 10% depending on the elements and their concentrations. A more detailed account of the performances of this technique can be found in Dussubieux et al. (2009).

3.2. Samples

Forty five samples were analyzed (Table 1).

3.3. Results

The 45 compositions obtained using LA-ICP-MS are available in Table 2. For a few samples with $SiO_2 > 80\%$, it is quite likely that some corroded material was analyzed but based on their whole composition, it was possible to assign them to a glass type.

The samples belong to three main glass groups:

- Potash glasses (22 specimens),
- M-Na-Al 3 glass (19 specimens),
- Soda plant ash glass (4 specimens).

3.3.1. Potash glass

A little more than half of the analyzed glass samples from Khao Sek are made of potash glass. In potash glasses, potash (K_2O) is the most abundant constituent after silica and its concentration is around 15%. Soda concentrations are generally low as are magnesia concentrations (< 1.5%). A relatively pure source of potash such as saltpetre was likely used. Different qualities of sand were added to the potash flux. Indeed, lime and alumina concentrations are very variable and based on compositions identified in South and Southeast Asia, three groups have been distinguished (Dussubieux and Gratuze, 2010; Lankton and Dussubieux, 2006, 2013):

- a high Ca − low Al − K glass
- a low Ca − high Al − K glass
- a moderate Ca and Al − K glass.

Most of the high Ca − low Al − K glass samples were identified at Ban Don Ta Phet, Thailand (4th − 3rd c. BCE). Potash glass found in India generally fits within the moderate Al and Ca − K glass compositional range. From a general point of view, potash glasses from Southeast Asia have either moderate alumina and lime composition or low Ca − high Al composition. The origin of the potash glasses is still uncertain at this point even if a Chinese (Li, 1999) or a Southeast Asian origin (Dussubieux and Pryce, 2016; Lankton et al., 2008) have been hypothesized. Potash glass is associated with sites that are usually dated no later than the 5th c. CE.

At Khao Sek, the compositions of the potash glass samples vary, with alumina and lime ranging respectively from 0.5 to 7% and 0.2 to

Table 1
List of samples from Khao Sek analyzed with LA-ICP-MS. "Not available" means the information was not available to the author, "?" the author could not determine this information (e.g. due to broken artifact), "n/a" this info is not relevant to the type of artifact.

Reference	Artifact	Technology	Diaphanity	Color	Shape
KSEK001	Not available	Not available	Translucent	Dark blue	Not available
KSEK002	Not available	Not available	Translucent	Dark blue	Not available
KSEK004	Not available	Not available	Opaque	Red	Not available
KSEK005	Not available	Not available	Opaque	Yellow	Not available
KSEK006	Not available	Not available	Translucent	Dark blue	Not available
KSEK007	Not available	Not available	Translucent	Turquoise blue	Not available
KSEK008	Not available	Not available	Translucent	Turquoise blue	Not available
KSEK009	Not available	Not available	Transparent	green	Not available
KSEK010	Not available	Not available	Opaque	Red	Not available
KSEK011	Not available	Not available	Opaque	Red	Not available
KSEK012	Not available	Not available	Translucent	Dark blue	Not available
KSEK013	Not available	Not available	Opaque	Red	Not available
KSEK015	Not available	Not available	Transparent	Green	Not available
KSEK016	Not available	Not available	Transparent	Green	Not available
KSEK018	Waste	Knapped	Translucent	Turquoise blue	n/a
KSEK019	Bead	n/a	Translucent	Turquoise blue	n/a
KSEK020	Bead	Drawn	Translucent	Turquoise blue	n/a
KSEK021	Bead	Drawn	Translucent	Dark purple	Oblate
KSEK022	Bead	Drawn	Translucent	Dark purple	Oblate
KSEK023	Bead	Drawn	Translucent	Dark purple	Oblate
KSEK024	Bead	Drawn	Translucent	Dark purple	Oblate
KSEK025	Bead	Wound	Opaque	Green	Oblate
KSEK026	Bead	Drawn	Translucent	Turquoise blue	Oblate
KSEK027	Bead	Drawn	Translucent	Dark blue	Oblate
KSEK028	Bead	Drawn	Opaque	Red	Oblate
KSEK029	Bead	Drawn	Opaque	Red	Oblate
KSEK030	Bead	Drawn	Opaque	Green	Oblate
KSEK031	Bead	Drawn	Translucent	Turquoise blue	Oblate
KSEK032	Bead	Drawn	Translucent	Turquoise blue	Oblate
KSEK033	Bracelet (fragment)	?	Opaque	Red	Not available
KSEK034	Bracelet (fragment)	?	Opaque	Red	Not available
15KSek04	Bead	Lapidary	Translucent	Green	Tabular rectangular
15Ksek06	Waste	Knapped ?	Translucent	Green with blue	n/a
15Ksek07	Waste	Knapped ?	Translucent	Green	n/a
15Ksek08	Waste	Hot worked	Translucent	Green	n/a
15Ksek09	Pendant	?	Translucent	Green	Double headed
15Ksek10	Waste	Knapped ?	Opaque	Red	n/a
15KSek11	Bead	Lapidary	Transparent	Colorless	Tabular rectangular
15Ksek12	Bracelet	?	Translucent	Green	Semi-circular B
15Ksek16	Bracelet	?	Opaque	Black	Semi-circular B
15KSek17	Bead	Lapidary ?	Translucent	Amber	Broken
15KSek18	Bead	?	Opaque	Green	Broken
15KSek19	Bead	Drawn	Opaque	Orange	Square section, broken
15KSek20	Waste	Knapped ?	Translucent	Green	n/a
15KSek21	Waste	Knapped ?	Opaque	Black	n/a

7.2%. Fig. 4 shows that samples fall in different groups: 4 samples with Al_2O_3 concentrations higher than 3% and CaO concentrations lower than 2% are part of the m-K-Al glass group. Eight samples have moderate alumina (< 4%) and lime (< 4%) concentrations and are part of the m-K-Ca-Al group. A significant number of samples have compositions that do not match any of the groups listed above. Four samples have very low alumina and lime concentrations (respectively ~0.5% and 1−1.3%). Other samples have relatively high lime concentrations (> 4%) but do not fit very well in the m-K-Ca glass group due to alumina concentrations that are much higher than the usual for this glass type. At this point, it is uncertain whether those potash glass samples form sub-groups of their own or whether they are variations of one of the three sub-groups described above.

The four samples with very low alumina and lime are very similar small dark blue drawn beads. All the other groups contain samples that vary in nature and color. In the m-K-Al group, beads and a fragment of bracelet are either translucent/transparent turquoise and dark blue, transparent green and opaque yellow. The m-K-Ca-Al group contains translucent or transparent turquoise and dark blue beads or wastes. The samples with higher lime and aluminum are translucent green and amber or opaque red. They are drawn or lapidary beads, pendant and waste.

We identified three different types of coloring recipes for the potash dark blue glass samples. The four beads (KSEK21 to 24) with low lime and alumina are colored by a combination of manganese and copper (~2% for both constituent as oxides). Those beads contain > 5000 ppm of barium which is much higher than in all the other potash dark blue beads. Two other samples (KSEK01 and 27) contain no significant amount of copper but ~1% of MnO. Their barium levels are ~1000 and 1400 ppm. These values are also much higher than in the glass without any significant amounts of manganese. This suggests that manganese and barium were added together to the glass. Sample KSEK01 belongs to the m-K-Al group and KSEK027 to the m-K-Ca-Al group suggesting some connections between the craftsmen producing the two different potash glasses. Two beads (KSEK02 and 06) in the m-K-Ca-Al group are colored by cobalt (Co > 1000 ppm). They contain very little manganese (0.04%) but significant concentrations of copper (0.8−1.4%). Arsenic is significantly more elevated in these two samples compared to the other potash dark blue ones.

Turquoise blue samples contain between 1.2 and 2.6% of CuO. Other glass samples colored with copper are the red glass samples (KSEK13 and 28). Their CuO concentrations are slightly higher (~3%). They also have higher MgO, P_2O_5 and CaO concentrations compared to the other potash glasses. Higher concentrations of these constituents

Table 2
Composition of the glass samples from Khao Sek in %w of oxide and ppm of element. < dl stands for below the detection limit.

	KSEK001	KSE-K002	KSE-K004	KSE-K005	KSEK006	KSE-K007	KSEK008	KSE-K009	KSEK010	KSE-K011	KSE-K013	KSE-K015	KSE-K016	KSE-K018	KSE-K019	KSEK020	KSE-K021	KSE-K022	KSE-K023	KSEK024	KSE-K025
	Potash	Potash	m-Na-Al3	Potash	Potash	Potash	Potash	m-Na-Al3	m-Na-Al3	m-Na-Al3	Potash	m-Na-Al3	m-Na-Al3	Potash	Potash	Potash	Potash	Potash	Potash	Potash	v-Na-Ca
SiO2	79.7%	82.6%	65.1%	49.5%	73.9%	85.2%	77.4%	76.0%	68.8%	68.4%	63.6%	67.0%	66.7%	82.6%	75.2%	75.9%	78.0%	79.4%	78.7%	76.4%	63.4%
Na2O	0.57%	0.17%	12.8%	0.34%	0.12%	1.32%	1.44%	6.91%	8.42%	8.49%	0.5%	15.6%	15.3%	0.51%	1.05%	1.39%	0.64%	0.59%	0.61%	0.72%	13.9%
MgO	0.22%	0.25%	1.62%	0.13%	0.54%	0.50%	0.38%	1.31%	1.83%	1.86%	2.8%	1.2%	1.1%	0.33%	0.55%	0.44%	0.15%	0.14%	0.14%	0.18%	3.51%
Al2O3	3.10%	2.52%	6.72%	3.09%	1.91%	1.31%	1.12%	8.03%	7.94%	8.11%	1.9%	7.9%	7.5%	1.79%	1.77%	3.94%	0.55%	0.53%	0.54%	0.51%	3.69%
P2O5	0.13%	0.13%	1.02%	0.09%	0.33%	0.24%	0.20%	0.51%	1.37%	1.27%	1.1%	0.4%	0.3%	0.29%	0.47%	0.28%	0.16%	0.16%	0.14%	0.15%	0.22%
K2O	13.9%	10.8%	4.67%	9.30%	17.8%	6.66%	14.8%	3.69%	4.24%	4.23%	18.8%	2.8%	4.4%	10.1%	15.3%	13.7%	12.5%	11.5%	11.8%	13.7%	4.29%
CaO	0.33%	1.33%	4.27%	0.22%	3.85%	2.41%	2.53%	2.08%	3.52%	3.52%	6.16%	2.63%	2.13%	2.57%	3.21%	2.25%	1.16%	1.04%	1.05%	1.39%	6.20%
MnO	0.96%	0.04%	0.15%	0.02%	0.04%	0.02%	0.03%	0.09%	0.17%	0.17%	0.1%	0.1%	0.1%	0.02%	0.03%	0.04%	1.85%	1.78%	1.82%	1.78%	0.07%
Fe2O3	0.45%	0.52%	0.99%	0.43%	0.46%	0.23%	0.28%	1.04%	1.47%	1.51%	1.0%	2.1%	2.1%	0.46%	0.43%	0.62%	0.19%	0.23%	0.26%	0.28%	0.33%
CuO	0.10%	1.44%	2.20%	0.10%	0.84%	1.25%	1.27%	0.03%	1.95%	2.09%	3.6%	0.0%	0.0%	1.29%	1.80%	1.23%	2.16%	2.05%	2.10%	2.09%	0.46%
SnO2	0.04%	0.01%	0.009%	3.48%	0.01%	0.007%	0.02%	0.02%	0.02%	0.01%	0.02%	0.002%	0.005%	0.002%	0.01%	0.003%	0.03%	0.03%	0.03%	0.03%	0.60%
PbO	0.27%	0.004%	0.009%	33.3%	0.002%	0.02%	0.003%	0.006%	0.006%	0.007%	0.005%	0.005%	0.004%	0.008%	0.004%	0.006%	0.02%	0.02%	0.02%	0.02%	3.02%
Li	14	7.1	16	3.1	12	3.1	10	20	30	29	11	23	21	2.7	6.9	7.1	3.3	2.3	2.5	3.2	17
Be	1.9	2.3	2.4	1.2	1.2	1.6	1.3	3.0	2.2	2.1	1.6	2.9	2.1	0.4	0.4	0.9	0.7	1.0	0.9	0.9	0.6
B	83	67	107	30	83	82	71	115	184	112	263	139	124	92	89	89	78	74	75	69	142
Sc	4.1	1.2	5.8	1.9	1.0	0.8	0.9	5.3	6.8	7.0	3.7	8.0	7.3	3.6	3.3	4.8	1.5	1.6	1.9	2.1	2.9
Ti	757	435	1906	660	547	384	332	2089	2260	2323	775	1963	1883	436	565	859	138	125	129	134	914
V	42	13	60	16	12	12	12	69	56	56	19	64	60	11	9.2	18	13	12	13	13	13
Cr	17	14	39	23	11	10	11	45	53	54	19	47	44	18	15	19	4.5	6.4	5.5	7.5	10
Ni	29	290	38	15	264	40	28	18	51	48	66	19	20	21	58	33	21	21	21	21	9.4
Co	171	1232	24	4.0	1108	58	28	6.5	16	16	81	7.8	6.2	13	54	17	104	99	102	99	3.6
Zn	34	27	112	27	27	29	22	83	136	134	118	90	78	19	28	29	37	39	37	36	19
As	24	453	21	3.4	747	52	25	2.3	14	10	13	< dl	< dl	32	148	52	102	86	98	85	1.7
Rb	430	111	87	170	182	116	153	142	128	123	87	94	256	86	147	124	93	86	93	97	89
Sr	38	67	172	14	84	102	103	157	183	187	200	122	111	74	63	87	38	36	37	47	302
Zr	130	69	204	112	94	88	74	222	222	236	38	198	181	71	84	103	35	19	16	17	153
Nb	4.4	2.3	9.5	5.1	2.7	2.0	1.7	11	12	12	3.0	10	10	1.6	2.5	3.9	1.0	0.8	0.8	0.9	4.4
Ag	0.9	5.0	2.5	40	0.5	0.7	1.2	1.6	2.9	1.4	5.0	1.0	0.6	2.2	1.5	1.3	9.0	10	10	8.1	3.3
Sb	1.4	4.6	4.7	2.0	9.0	2.8	2.1	0.9	3.5	1.5	3.3	0.8	2.2	0.7	2.7	0.8	8.2	7.6	7.5	7.3	27
Cs	2.7	2.0	3.5	2.1	1.3	0.5	1.0	4.6	6.4	5.9	1.6	4.3	4.8	0.5	0.8	1.2	0.4	0.4	0.3	0.6	1.4
Ba	994	122	371	51	216	84	105	398	469	486	250	333	314	96	191	239	5217	5180	5542	5548	654
La	13	11	32	10	13	13	11	38	35	36	7.0	30	27	8.4	10	15	3.7	3.5	3.8	3.7	13
Ce	62	23	63	21	24	24	22	75	69	71	14	64	57	16	20	28	17	16	18	18	24
Pr	3.6	2.7	7.5	2.3	2.8	2.9	2.4	8.9	8.4	8.5	1.7	7.2	6.5	1.9	2.4	3.4	0.9	0.8	0.9	1.0	3.2
Ta	0.8	1.5	0.8	0.4	0.2	0.2	0.2	1.1	1.2	1.2	0.4	1.0	0.8	0.1	0.2	0.4	0.2	0.3	0.2	0.2	0.5
Y	8.6	8.3	23	8.4	8.6	7.6	7.9	25	24	25	5.7	24	21	6.6	7.4	11	3.1	3.2	3.1	3.0	8.3
Bi	0.4	2.8	3.5	0.7	1.7	3.9	1.6	0.9	1.5	1.5	4.0	0.4	0.4	4.1	1.6	2.5	11	10	10	10	2.7
U	1.1	1.0	68	2.6	1.1	1.0	1.2	163	29	26	2.5	61	55	0.6	0.8	4.7	0.5	0.5	0.5	0.5	1.4
W	0.7	2.6	2.0	0.4	1.2	1.2	0.6	3.5	3.0	3.2	2.6	2.2	1.9	1.7	0.8	1.5	0.8	0.7	0.8	0.7	0.3
Mo	20	101	12	1.1	36	27	23	8.2	14	14	13	10	8.1	56	25	43	27	24	28	25	0.9
Nd	12	9.1	26	7.8	10	9.3	8.8	31	29	30	5.9	26	23	6.7	8.7	12	3.2	3.0	3.2	3.3	11
Sm	2.7	1.8	5.4	1.6	2.0	2.0	1.8	6.3	6.1	6.1	1.3	5.4	4.4	1.5	1.8	2.5	0.9	1.1	0.8	1.0	2.5
Eu	0.7	0.3	0.9	0.3	0.4	0.3	0.3	1.2	1.3	1.1	0.4	0.9	0.9	0.2	0.3	0.5	0.3	0.3	0.3	0.3	0.6
Gd	2.2	1.7	4.6	1.5	1.8	1.5	1.5	5.5	5.0	5.4	1.1	4.5	3.9	1.2	1.5	2.1	0.8	0.8	0.8	0.9	2.0
Tb	0.4	0.2	0.7	0.3	0.3	0.3	0.3	0.9	0.8	0.8	0.4	0.7	0.6	0.2	0.2	0.3	0.1	0.1	0.1	0.1	0.3
Dy	2.1	1.6	4.2	1.4	1.6	1.5	1.5	4.8	4.8	5.0	1.8	4.3	3.5	1.1	1.5	2.2	0.7	0.9	0.7	0.8	2.0
Ho	0.5	0.3	0.9	0.4	0.3	0.3	0.3	1.0	1.0	1.0	0.5	0.8	0.7	0.2	0.3	0.5	0.2	0.2	0.2	0.2	0.4
Er	1.1	1.0	2.3	1.0	0.9	0.9	0.8	3.0	2.8	2.7	0.9	2.6	2.1	0.6	0.8	1.2	0.4	0.4	0.4	0.4	1.2
Tm	0.3	0.4	0.3	0.2	0.2	0.1	0.1	0.4	0.4	0.4	0.1	0.4	0.4	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.2
Yb	1.3	1.0	2.5	1.2	0.9	0.8	1.0	2.9	2.6	3.1	1.0	2.4	2.3	0.6	0.8	1.6	0.5	0.7	0.5	0.5	1.3

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Table 2 (continued)

	KSEK001	KSE-K002	KSE-K004	KSE-K005	KSEK006	KSE-K007	KSEK008	KSE-K009	KSEK010	KSE-K011	KSE-K013	KSE-K015	KSE-K016	KSE-K018	KSE-K019	KSEK020	KSE-K021	KSE-K022	KSE-K023	KSEK024	KSE-K025
Lu	0.2	0.2	0.3	0.1	0.1	0.1	0.1	0.6	0.5	0.4	0.3	0.4	0.3	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.2
Hf	3.8	2.4	6.4	3.1	2.8	2.9	2.6	7.5	7.4	7.3	1.3	6.0	5.3	1.8	2.5	3.3	1.2	1.0	0.7	0.8	6.6
Th	4.0	5.0	13	4.4	5.8	4.3	3.7	16	16	16	3.2	14	12	2.7	4.5	6.6	1.5	1.5	1.6	2.0	6.6

	KSE-K026	KSE-K027	KSE-K028	KSE-K029	KSE-K030	KSE-K031	KSE-K032	KSE-K033	KSE-K034	15KSe-k04	15Kse-k06	15Kse-k07	15Kse-k08	15Kse-k09	15Kse-k10	15KSe-k11	15Kse-k12	15Kse-k16	15KSek17	15KSe-k18	15KSe-k19	15KSe-k20	15KSe-k21
	Potash	Potash	Potash	m-Na-Al 3	v-Na-Ca	Potash	Potash	m-Na-Al 3	m-Na-Al 3	m-Na-Al 3	m-Na-Al 3	m-Na-Al 3	Potash	Potash	m-Na-Al 3	m-Na-Al 3	m-Na-Al 3	m-Na-Al 3	Potash	v-Na-Ca	m-Na-Al 3	m-Na-Al 3	m-Na-Al 3
SiO2	73.2%	78.3%	60.2%	63.1%	60.3%	73.5%	75.3%	64.0%	64.0%	71.5%	70.9%	77.0%	61.7%	69.0%	61.0%	61.2%	67.9%	61.3%	83.5%	57.8%	57.2%	67.2%	59.5%
Na2O	2.56%	0.19%	0.21%	11.11%	15.19%	2.57%	0.22%	13.2%	13.4%	11.0%	11.4%	9.36%	8.86%	0.18%	14.0%	13.9%	14.3%	19.4%	< dl	16.2%	12.8%	15.7%	20.4%
MgO	0.53%	0.15%	2.94%	1.90%	3.87%	0.53%	0.16%	1.66%	1.65%	1.30%	0.92%	0.95%	1.04%	0.64%	1.61%	1.62%	1.27%	1.37%	0.31%	3.72%	1.28%	1.45%	1.18%
Al2O3	2.60%	2.57%	2.39%	8.12%	3.21%	2.39%	4.70%	6.88%	6.79%	4.97%	4.15%	4.57%	6.92%	1.53%	8.41%	8.37%	5.94%	7.58%	2.59%	3.10%	6.72%	6.26%	8.30%
P2O5	0.30%	0.15%	1.58%	1.11%	0.26%	0.31%	0.11%	0.95%	0.97%	0.33%	0.33%	0.41%	0.53%	0.96%	0.75%	0.72%	0.38%	0.29%	0.19%	0.27%	0.30%	0.46%	0.30%
K2O	15.1%	15.4%	21.2%	5.62%	3.35%	15.0%	16.2%	5.22%	5.06%	3.43%	3.88%	2.58%	11.4%	17.1%	3.73%	3.78%	4.41%	2.59%	8.11%	3.44%	3.15%	2.29%	3.04%
CaO	2.42%	0.40%	7.26%	5.52%	6.37%	2.39%	0.24%	4.52%	4.54%	5.10%	6.48%	2.54%	5.76%	5.27%	5.48%	5.48%	3.85%	2.57%	4.99%	6.81%	4.60%	4.37%	3.02%
MnO	0.12%	0.95%	0.12%	0.12%	0.09%	0.12%	0.02%	0.17%	0.17%	0.12%	0.09%	0.10%	0.21%	2.83%	0.12%	0.13%	0.13%	0.14%	0.01%	0.12%	0.12%	0.13%	0.11%
Fe2O3	0.43%	0.99%	0.88%	1.30%	0.73%	0.67%	0.67%	1.10%	1.07%	2.04%	1.50%	1.99%	3.22%	0.91%	2.63%	2.63%	1.70%	4.69%	0.33%	0.74%	4.18%	2.04%	4.01%
CuO	2.58%	0.04%	3.05%	1.91%	0.65%	2.40%	1.74%	2.08%	2.10%	0.08%	0.17%	0.01%	0.01%	0.89%	2.17%	2.11%	0.05%	0.00%	0.00%	0.62%	9.38%	0.09%	0.01%
SnO2	0.02%	0.04%	0.001%	0.005%	0.74%	0.01%	0.18%	0.009%	0.009%	0.001%	0.002%	0.002%	0.006%	0.001%	0.02%	0.02%	0.01%	0.003%	0.0004%	0.53%	0.04%	0.001%	0.003%
PbO	0.03%	0.16%	0.004%	0.003%	4.99%	0.02%	0.43%	0.007%	0.007%	0.006%	0.005%	0.005%	0.006%	0.01%	0.01%	0.01%	0.005%	0.003%	0.002%	6.57%	0.17%	0.007%	0.009%
Li	15	22	9.5	23	18	12	8.4	16	15	21	17	13	205	8.2	21	21	16	17	5.2	19	17	16	20
Be	145	0.6	0.6	1.6	0.5	142	0.6	1.3	1.4	2.0	1.4	1.3	5.2	0.7	1.5	1.5	1.2	1.5	0.5	0.3	1.4	1.2	1.8
B	81	110	68	147	152	84	68	101	105	77	112	144	27	63	122	124	86	98	59	153	70	141	100
Sc	3.2	6.2	5.8	9.6	5.2	4.3	6.5	8.6	8.7	6.8	4.7	6.7	9.5	3.5	8.3	8.2	5.8	7.0	3.3	2.7	6.2	6.4	8.1
Ti	736	626	1384	2631	981	678	1012	2267	2245	1656	986	1533	2220	524	2004	2020	1447	1875	657	763	1657	1559	2102
V	19	30	34	62	15	18	19	61	60	64	43	77	52	26	72	72	48	74	12	14	44	69	82
Cr	13	23	30	54	22	21	25	46	52	41	21	37	3.8	11	44	39	28	44	5.6	9.3	32	33	49
Ni	83	38	33	34	13	82	15	38	36	20	62	17	19	27	46	46	13	12	3.1	25	256	14	15
Co	86	206	11	11	7.3	81	3.2	24	23	21	202	20	10	190	12	12	27	4.9	1.3	19	119	5.5	5.8
Zn	34	30	153	110	153	32	35	120	116	63	71	74	1939	88	100	101	57	86	14	251	53	65	83
As	153	3.5	24	8.0	5.5	142	353	12	11	6.6	207	17	< dl	0.2	13	10	13	< dl	< dl	31	516	< dl	< dl
Rb	128	343	88	95	51	110	364	78	76	93	82	125	237	100	96	95	79	81	97	48	83	70	94
Sr	92	28	282	209	274	79	8.4	155	155	180	199	125	365	115	149	149	119	110	72	279	113	133	124
Zr	96	103	54	227	169	80	143	191	175	241	137	199	280	62	153	145	166	186	89	172	207	179	211
Nb	3.3	3.4	4.4	11	4.1	2.7	5.5	8.7	8.4	10	5.8	9.4	21	2.7	10	11	7.7	10	3.6	3.8	10	8.4	11
Ag	5.3	0.3	6.4	3.1	8.7	4.6	11	2.5	2.4	0.2	0.1	0.3	0.1	1.0	3.1	3.0	0.1	0.1	0.1	7.8	8.3	0.1	0.1
Sb	8.9	0.3	3.8	4.6	177	7.3	22	4.5	3.6	0.4	3.0	1.1	0.5	0.4	4.8	4.9	3.5	0.7	0.5	43	26	1.7	1.0
Cs	4.1	1.2	1.4	4.1	0.9	3.3	3.3	2.8	2.8	3.5	2.7	3.5	2.1	0.5	4.4	4.4	3.0	3.9	1.1	0.8	3.7	2.8	4.6
Ba	238	1404	332	446	350	183	48	367	358	430	424	357	780	3968	402	395	315	370	97	307	328	322	428
La	15	12	9.1	33	8.2	11	9.5	26	26	36	22	33	54	9.0	30	30	26	30	13	8.2	32	30	35
Ce	31	53	19	69	16	24	22	53	51	68	43	67	106	29	60	60	51	58	26	15	62	63	69
Pr	3.5	3.0	2.1	7.9	1.8	2.5	2.1	6.3	6.0	8.6	5.4	8.0	13	2.4	7.3	7.4	6.4	7.3	3.2	1.9	7.9	7.5	8.7
Ta	0.4	0.3	0.6	0.9	0.3	0.2	0.4	0.7	0.7	1.0	0.5	0.9	2.5	0.2	0.9	0.9	0.8	1.1	0.3	0.3	0.9	0.8	1.0
Y	10	10	6.9	25	5.9	9	10	20	20	26	15	23	36	6.9	24	23	20	22	11	6.3	21	22	25
Bi	4.0	0.2	467	0.8	22	2.7	58	4.6	2.9	0.4	0.9	0.3	0.6	1.3	3.2	3.3	0.2	0.1	0.1	14	8.3	0.2	0.1
U	7.6	0.9	0.7	37	2.4	5.0	1.3	54	50	59	131	204	9.2	0.8	111	115	50	185	1.4	1.4	36	139	206
W	1.2	0.2	1.5	2.1	0.4	0.9	0.4	1.7	1.7	1.7	2.0	2.6	1.1	0.6	2.3	1.9	1.9	2.1	2.6	0.6	1.7	1.8	2.3
Mo	25	1.3	17	10	1.0	28	0.5	11	11	10	27	21	0.3	14	18	13	12	5.0	95	1.2	9.4	16	5.7
Nd	12	11	8.0	28	6.6	9.1	7.6	22	22	29	18	27	43	9.0	24	24	20	24	10	6.2	26	24	28
Sm	2.6	2.6	1.7	5.7	1.4	1.9	1.6	4.5	4.4	5.9	3.9	5.5	8.3	1.9	4.8	4.8	4.0	4.6	2.0	1.3	5.0	4.9	5.7
Eu	0.4	0.6	0.4	1.0	0.3	0.3	0.3	0.8	0.7	0.9	0.6	0.9	1.3	0.5	0.8	0.8	0.7	0.8	0.4	0.3	0.8	0.8	1.0
Gd	2.3	2.1	1.6	4.9	1.3	1.6	1.4	3.7	3.5	5.1	3.0	4.6	6.8	1.9	4.1	4.1	3.5	4.0	1.9	1.2	4.1	4.0	4.7

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Table 2 (continued)

	KSE-K026	KSE-K027	KSE-K028	KSE-K029	KSE-K030	KSE-K031	KSE-K032	KSE-K033	KSE-K034	15KSe-k04	15Kse-k06	15Kse-k07
Tb	0.4	0.4	0.2	0.8	0.2	0.2	0.2	0.5	0.5	0.8	0.5	0.7
Dy	2.1	2.3	1.4	4.8	1.1	1.5	1.6	3.3	3.2	4.7	2.8	4.2
Ho	0.4	0.5	0.3	0.9	0.3	0.3	0.3	0.7	0.6	1.0	0.6	0.9
Er	1.2	1.4	0.8	2.5	0.7	0.9	1.0	1.9	1.8	2.7	1.5	2.4
Tm	0.2	0.2	0.1	0.4	0.1	0.1	0.2	0.3	0.3	0.4	0.3	0.4
Yb	1.3	1.5	0.8	2.5	0.7	0.9	1.1	1.9	1.9	2.7	1.5	2.5
Lu	0.2	0.2	0.1	0.4	0.1	0.1	0.2	0.3	0.3	0.4	0.3	0.4
Hf	3.2	2.9	1.7	6.5	5.2	2.3	3.9	5.2	4.6	7.6	4.2	6.2
Th	6.4	3.7	3.7	15	3.6	4.2	5.1	10	9.7	15	8.4	15

	15Kse-k08	15Kse-k09	15Kse-k10	15KSe-k11	15Kse-k12	15Kse-k16	15KSek17	15KSe-k18	15KSe-k19	15KSe-k20	15KSe-k21
Tb	1.1	0.3	0.6	0.6	0.5	0.6	0.3	0.2	0.6	0.6	0.7
Dy	6.3	1.7	3.9	3.9	3.2	3.7	1.8	1.0	3.8	3.8	4.4
Ho	1.2	0.3	0.8	0.8	0.7	0.8	0.4	0.2	0.8	0.8	0.9
Er	3.5	0.8	2.2	2.2	1.8	2.1	1.0	0.6	2.2	2.2	2.5
Tm	0.5	0.1	0.3	0.3	0.3	0.3	0.1	0.1	0.3	0.3	0.4
Yb	3.5	0.9	2.1	2.1	1.8	2.0	1.1	0.7	2.0	2.1	2.4
Lu	0.5	0.1	0.3	0.3	0.3	0.3	0.2	0.1	0.3	0.3	0.3
Hf	8.7	1.9	4.6	4.2	4.7	5.7	2.7	5.2	6.7	5.4	6.5
Th	25	3.6	13	13	10	12	4.7	3.2	13	14	14

have been observed in other red glass with different compositions such as the m-Na-Al glasses (Dussubieux et al., 2011, 2010). It was suggested that an ingredient containing calcium, magnesium, phosphorus and maybe other elements were added in order to facilitate the reduction of the copper and to facilitate the red color.

Three other glass samples are either translucent green or amber. One of the green samples (15KSEK09) contains copper (0.9%) and manganese (2.8%). The other green sample (15KSEK08) contains 3.2% of Fe_2O_3. For the amber sample (15KSEK17) no specific element seems to be present in higher quantities.

3.3.2. m-Na-Al 3 glass

In South and Southeast Asia, one of the most abundant glasses is called mineral soda-alumina or m-Na-Al glass and results from the mix of a soda-rich efflorescence called reh and a high alumina sand (Brill, 1987). Alumina that has concentrations varying from 5 to 15% in this glass is introduced by poorly refined sand. The sand composition is similar to that of granite and contains a small amount of potash and lime, and relatively high concentrations of iron, titanium and other trace elements, such as rare earth elements (Dussubieux, 2001; Dussubieux and Gratuze, 2004). Trace elements allow for the separation of the m-Na-Al glass type into sub-groups (Dussubieux et al., 2010). To determine what type of m-Na-Al glass was found in Khao Sek, Principal Component Analysis (PCA) was conducted using MgO, Zr, Sr, Ba, U and Cs concentrations measured in m-Na-Al 1 glass samples (southern India/Sri Lanka), m-Na-Al 2 glass samples (western India) and in m-Na-Al 3 glass samples (northern India) (Fig. 5). The 19 samples from Khao Sek with a m-Na-Al composition are more similar to glass m-Na-Al 3. This glass was identified at Kopia, in the region of Uttar Pradesh (Kanungo, 2006; Kanungo and Misra, 2004; Kanungo and Shinde, 2005). The finding of hundreds of glass chunks and ceramic fragments coated with glass suggested that glass was manufactured at this site; however, most of the glass manufacturing evidence was found in disturbed deposits that could not be dated. Charcoal found in a furnace pit yielded a date of 120 cal CE (± 120) (Kanungo et al., 2010). Kanungo (2010:473) suggests that "glass might have been produced here (in Kopia) from the NBP period onwards". The NBP period or the Northern Black Polished Ware culture corresponds to 700−200 BCE.

The m-Na-Al 3 glass samples found at Khao Sek include knapped wastes, lapidary beads and bracelets fragments. Four colors were identified: orange, opaque red, black and transparent green. These colors were obtained using two main constituents (Fig. 6): iron and copper. In samples with very little copper, iron (Fe_2O_3) ranges from either 1 to 2% in the transparent green glass or higher than 4% in the black glass samples. In both cases, the quantities of copper are very low. In the red glass samples, copper is ~2% with variable iron concentrations (1−2.6%). The orange glass sample has more copper (9.4%) and more iron (4.2%).

3.3.3. Soda plant ash

The third type of glass (also called v-Na-Ca glass) found at Khao Sek is manufactured using soda plant ashes. This type of glass presents many similarities with glass made in the Middle-East from the Sasanian period through the Islamic period. Samples with a v-Na-Ca composition are separated in two groups. Some of them are either vessel fragments with a clear Middle-Eastern influence regarding their typology or glass beads. Both types of artifacts appear at later sites dated mostly around the 7th to the 10th c. CE. Direct importation from the Middle-East seems quite likely for that type of material. Earlier material, only available in the forms of beads, was found at Sri Lankan sites (dated from the 4th c. BCE to the 2nd c. CE) but also in Southeast Asia at sites such as Angkor Borei (200 BCE−200AD) or Oc Eo (50−250 CE and 400−550 CE). Because of the early dating of this material, a Middle-Eastern provenance is more questionable and the source of this glass material remains uncertain at this point (Dussubieux, 2001; Lankton

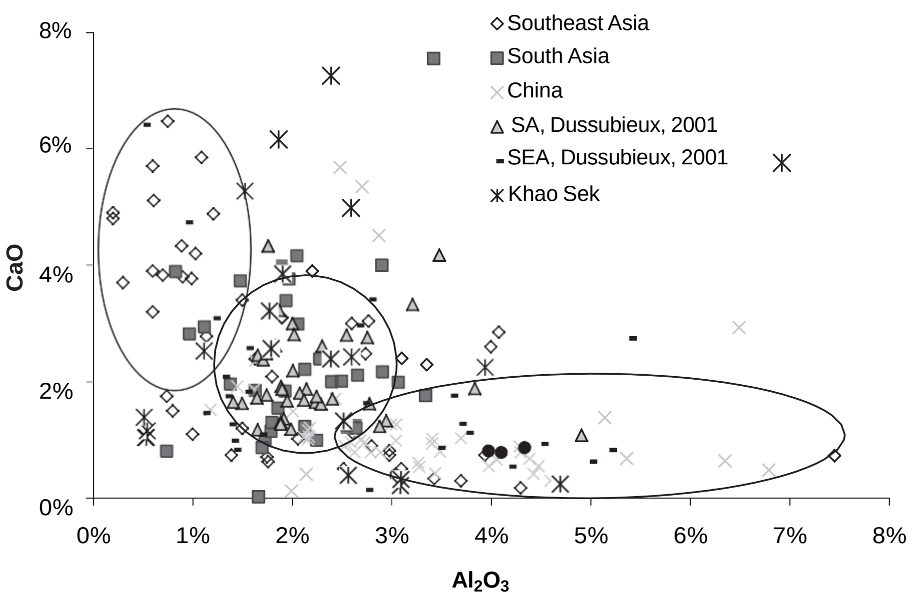

Fig. 4. Alumina and lime concentrations in potash glass artifacts found in South Asia (Brill, 1987, 1999; Glover and Henderson, 1995; Francis, 1998; Lal, 1952; Lamb, 1965; Singh, 1989; Subramanian, 1950; Varshney, 1950, Varshneya et al., 1988, Dussubieux, 2001), Southeast Asia (Brill, 1999; Basa, 1991; Salisbury and Glover, 1997, Dussubieux, 2001), China (Qishan, 1996; Li, 1999; Fukang, 1991; Zhang et al., 2005, 2004) and Khao Sek. The ellipses are for an easy visualisation of the three main potash glass groups.

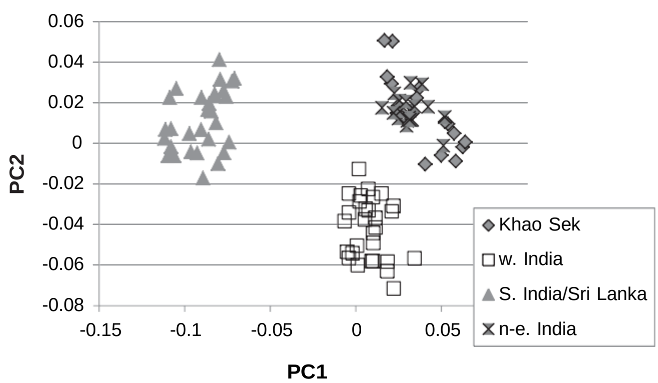

Fig. 5. Principal components 1 and 2 obtained with PCA including MgO, Sr, Ba, U and Cs concentrations measured in glass samples found in Southern India/Sri Lanka (Dussubieux, unpublished), in Western India (Dussubieux et al., 2008) and North-eastern India (Dussubieux and Kanungo, 2013). PC 1 and 2 account for 83% of the variability of the dataset.

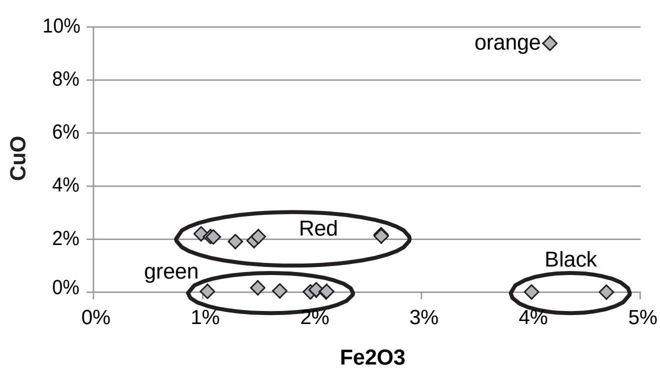

Fig. 6. Bi-plot showing the Fe_2O_3 and CuO concentrations in the Khao Sek m-Na-Al 3 glass samples.

Table 3
Proportions of the different glass types present at Khao Sam Kaeo and Khao Sek.

	Khao Sam Kaeo	Khao Sek
Potash	50%	49%
m-Na-Al 3	28%	42%
v-Na-Ca	0%	9%
Other	22%	0%

and Dussubieux, 2006).

Samples made from soda plant ash are either dark blue (KSEK12) or opaque green (KSEK25 and 30, 15KSKEK18). The dark blue sample contains significant quantities of cobalt (300 ppm), copper (0.4%) and arsenic (300 ppm). The opaque green glass beads have higher concentrations of tin (0.5–0.7% of SnO_2) and lead (3.0 to 6.6% of PbO) that might have been used as lead stannate that is a yellow opacifier. The presence of copper (0.5–0.7% of CuO) and lead stannate in the glass are certainly causing the green opaque aspect of the glass.

4. Glass type distribution in Southeast Asia

4.1. Comparison with Khao Sam Kaeo

Typological similarities were noted earlier between the type of material found at Khao Sam Kaeo and at Khao Sek. It is therefore essential to compare the compositions found at both sites (Table 3). It is first important to note that a larger quantity of glass was analyzed at Khao Sam Kaeo (162 specimens) compared to Khao Sek (45). At Khao Sam Kaeo, 50% of the analyzed glass samples had a potash composition. The m-Na-Al 3 glass samples were then the second most abundant with 28%. At Khao Sek, the proportion of the m-Na-Al 3 and potash glass are fairly similar (respectively 42 and 49%). Other glass types identified at Khao Sam Kaeo include m-Na-Al 1, m-Na-Ca-Al, mixed-alkali for those with the highest proportions (Dussubieux and Bellina, 2017).

Among the m-Na-Al 3 glass found at Khao Sam Kaeo, only three colors were represented: translucent green (the most preeminent), opaque red and more rarely black. At Khao Sek, those three colors are present but opaque orange is also available. The range of colors in the potash glass group at Khao Sam Kaeo is wider, including colorless and orange glasses that are absent at Khao Sek. However, the number of potash samples is much lower at Khao Sek and a larger sample might have revealed more colors in the Khao Sek potash glass. At Khao Sek, 3 lapidary beads were analyzed and two of them have a m-Na-Al 3 composition and one is manufactured from potash glass. The four analyzed lapidary beads from Khao Sam Kaeo were all manufactured with m-Na-Al 3 glass.

At Khao Sek, the presence of dark blue potash glass containing cobalt and arsenic is worth noticing as this combination is rare and was only identified at the site of Khao Sam Kaeo and Ban Don Ta Phet (4th c. BCE). It seems that this cobalt was used early on (4th – 2nd c. BCE) and then replaced by another type of cobalt (Co-Mn-Ba) that is usually present in most of the dark blue glass with a potash composition found in South and Southeast Asia (Dussubieux, 2016).

Overall the two groups of glass samples have a lot in common with identical major glass types in addition of similar ornament typology. This suggests connection between the two places.

4.2. Comparison with other South and Southeast Asian sites

At Khao Sam Kaeo, as at Khao Sek, the dominant glass types are potash and m-Na-Al 3. This is usually associated with the very early glass network that operated around the 4th to the 2nd c. BCE (Dussubieux and Gratuze, 2010) and that includes also Ban Don Ta Phet (Thailand) and Giong Ca Vo (Vietnam). More recently, research undertaken on glass beads found in the Samon Valley in Myanmar, showed that this network extended into this region although beads types and color palette were very different there compared to what was found in Thailand and in Vietnam, suggesting the existence of two exchange networks: a larger network encompassing Northeastern India, modern Myanmar and Thailand used to trade raw glass and a series of more regional networks used to trade finished glass products (Dussubieux and Pryce, 2016).

Among the different sites (Ban Don Ta Phet and Giong Ca Vo) and areas (Samon Valley) mentioned above, Khao Sek and Khao Sam Kaeo are the only sites presenting evidence of glass bead and bracelet manufacturing, setting these two sites apart.

The most distinctive ornaments found at Khao Sek and Khao Sam Kaeo are the lapidary beads and bracelets. Lapidary beads have been identified in South and Southeast Asia. The sites of Ahichchhatra and Kausambi in North India yielded translucent green beads with a prismatic shape whereas hexagonal bi-conical beads were more common in South India (Basa, 1992). A possible production site could be Arikamedu (Basa, 1992); however no solid evidence for a glass lapidary bead-production centre in South Asia has been found so far. Chakraborty (1995–96) mentions the similarity between some hexagonal green beads found at Harinarayanpur, Chandraketugarh, and Deulpota (West Bengal) and at Arikamedu. In Southeast Asia, lapidary beads were found in Thailand at Ban Chiang (Labbé, 1985), and Peter Francis (2001) mentions the use of lapidary techniques at Ban Don Luang. Ban Don Ta Phet yielded a variety of beads that were certainly manufactured using the lapidary techniques (Glover, 1990). LA-ICP-MS analysis showed that they have a potash composition (Dussubieux, unpublished analysis).

As far as bracelets are concerned, their presence is attested at Ban Don Ta Phet (Glover, 1990) and at a Mimotien site in Cambodia (Haidle, 2001). Similar material was recovered during excavation at certain Sa Huynh-related sites in Vietnam, sites such as Giong Ca Vo, Phu Hoa, and Go Ma Voi (Van Thang and Hien, 1997:32; Fontaine, 1972:437–8; Nguyen Kim Dung et al., 1995; Reinecke et al., 2002:77, Fig. 59, n°9). Possibly similar specimens were recovered in the Oc Eo area in Vietnam (Malleret, 1962:257, n°1189) and from Chamber B in Manunggul Cave, Tabon Caves, Palawan Island, Philippines (Fox, 1970:118).

5. Discussion

As expressed earlier, the presence of two very early glass workshops displaying similar industrial models at Khao Sam Khaeo and Khao Sek located 80 km apart and whose productions are comparable raises a range of questions related to their respective role and relationships. At Khao Sam Kaeo, it was established that possible glass workers from Northeastern India settled there to manufacture glass ornaments. The difference in the object styles and colors found at both sites is so subtle that it clearly indicates that the people that worked at both locations were the members of a same group of artisans, trained within the same tradition. However the presence of two glass workshops producing ornaments in a same region whereas workshops in Southeast Asia are so rare was at first puzzling. This glass industry standardization is also observable for other industries in both sites, strengthening the idea of close links between them and raising the question of how similar hybrid industrial models were implemented. The hypothesis of the circulation between polities of the same confederation of trading polities controlling different networks and trans-peninsular routes is suggested to account for this standardization (Bellina, in press a, 2017; Bellina, this issue c,d). As in the case of the hard stone industry, the standardized production between the two sites is hypothesized to result from the transfer of artisans in the context of a hierarchically and complementary-organized confederation of trade polities (see Bellina on stone industry organization and general discussion, Bellina, this issue a,b). Khao Sam Kaeo, larger but also whose settlement configuration is more complex (rampart, compounds, cosmopolitan population) and craft productions bigger, is interpreted as the leading polity acting as the central market at an « international » level where foreign merchants settled and craftsmen concentrated (Bellina, this issue a,b). The two contemporaneous workshops operated with artisans circulating between the two sites. What made this transfer possible? Either the original group split into two groups (or more) to start distinct glass workshops within this confederation, or they trained apprentices who moved to Khao Sek. Under which conditions this move took place can only be speculated. If one agrees to postulate that in the context of trading polities ornaments and their industry could have played the role of political currency, then the transfer of attached artisans could have taken the form of an honorific "gift" made by the central place polity's leader to weave his network of clients to secure the loyalty of the attached polity. This transfer could have been a means for the central place polity's leader to weave a network of clients as well as to secure his marketplace supply, thus ensuring the wealth of his polity and its charisma. Artisans, either those who initially settled at Khao Sam Kaeo or who were trained by them, could have moved to Khao Sek in the frame of these strategic political and economic bonds.

6. Conclusion

The analysis of the glass from Khao Sek and its comparison with Khao Sam Kaeo provides unprecedented evidence for a regional craft standardization involving hybrid industrial models. In both workshops, bracelets and lapidary beads were made using similar Indian techniques and glass. The high alumina glass type relates more specifically to the northeastern part of the Indian subcontinent. Meanwhile, the diffusion of both workshops manufactured artifacts were directed in the hinterland and in the South China Sea towards other communities involved in trade at different levels (Bellina, in press a). The confederation of trading polities controlled the local resources exploitation (tin in particular see Pryce et al., 2017; Pryce and Bellina, this issue) and trans-peninsular routes (Bellina, this issue a), possibly through the exchange of glass and other locally-manufactured products. As suggested in the case of the hard stone industry, it is possible that the diffusion of these hybrid products but also of industrial models were transferred between associated trade polities. This could thus correspond to what Manguin called "Umland", a wider « hinterland » connected by its riverine and maritime network (2002). The transfer through this broader hinterland provides a tentative framework to explain the diffusion of similar pan-regional culture with the South China Sea Sphere of Interaction (Bellina, in press a).

To sum up, along other industries, the analysis and comparison of the glass industry at Khao Sek with Khao Sam Kaeo brings unprecedented data on the economic and political organization of the early trading polities of the South China Sea and a possible explanation for the diffusion of a pan-regional culture.

Conflict of interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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