3 From Regional to Global

Early Glass and the Development of the Maritime Silk Road

James W. Lankton

Abstract
Glass exchange was an important part of maritime trade as early as the Late Bronze Age, and glass found in South and Southeast Asia and beyond to Korea and Japan provides some of the best evidence for early long-distance movement of both material goods and skilled craftworkers. By the 1st century CE, pre-existing regional trade networks rapidly incorporated Roman products, including glass. These earlier maritime links provided the infrastructure, not only in terms of maritime technologies but also in the *imagination* of what long-distance trade could be, for what would become the Maritime Silk Roads.

Keywords: Maritime Silk Road, glass trade, Roman glass in Asia, Periplus of the Erythraean Sea, technology transfer, early glass in Korea

Introduction

By studying material culture, particularly the objects and commodities whose transfer from one place to another provided the raison d'être for all the interlocking systems of the Maritime Silk Road (MSR), we gain insight into not only what was traded but also the lives affected by exchange in objects, technologies, and ways of understanding the world. This chapter will follow the glass trail to explore the early development of the MSR, going from regional circuits in the second half of the first millennium BCE to the first phase of exchange along the full expanse of ancient maritime routes from the Roman Empire to India, Southeast Asia, China, and northeast Asia during the first half of the first millennium CE. The glass evidence informs not only the exchange of finished products and raw materials but also the

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movement of people along the same long-distance maritime routes. For the earliest periods, textual evidence, when present, is often vague; points of exchange may be either unknown or short-lived, as we shall see for the evolution of ports along the west coast of the Thai-Malay Peninsula. Few sites have been excavated using modern techniques, and constantly shifting shorelines affected by seasonal flooding may hide architectural indicators for coastal contexts and settlement patterns. However, even where context is incomplete, the careful study of material culture can suggest both origins and destinations and help to identify those who traveled. The detailed evidence hidden in the glass chemical compositions and the technological processes used to produce glass objects can help to draw regional borders as well as show that these borders were challenged by the influx of "foreigners," including craftworkers bringing new technologies and, inevitably, ideas. Glass can be an ideal material in this regard. Glass itself, although fragile as an object, is practically indestructible as a material and remains for thousands of years in most archaeological contexts. Even tiny fragments can help tell the stories of the many societies along the Maritime Silk Road for whom glass was a precious, imported material with an important role in maritime trade from the very beginnings of glass production.

From Lapis to Glass

While we think today of glass as an inexpensive material used in everything from drinking glasses to mobile phones to skyscrapers, early glass was a precious material linked from its inception to luxury and prestige. As early as the seventh millennium BCE, lapis lazuli, a bright to dark blue stone found primarily in Badakhshan in northeast Afghanistan, had been used to make beads found at Mehrgarh in Pakistan and at Tell Sotto in northern Syria (Bader 1993, 69). By the third millennium BCE, lapis had become the most precious bead-making stone, with exchange networks from the lapis sources by land through Iran and by long-distance maritime trade from the Indus Valley. Then, as described by Moorey (1994, 90), "with the eclipse of the Indus trade c. 1750 BCE, the presence of lapis lazuli in the surviving material culture of Iraq declines sharply to the point where it may be suspected that the primary source was recycled stocks, rarely replenished with fresh supplies from the east." This decline in lapis supplies, combined with continued desire by elites for objects made from lapis, created the circumstances for the development or recognition of new materials that might serve as substitutes. While we still debate exactly how glass, the first entirely humanmade

material, emerged—whether from metallurgy, or perhaps more likely from faience technology gone wrong—between the late third and mid-second millennium BCE, the evidence for glass goes from a few scattered pieces to regular production, perhaps initially in Mesopotamia but soon after in Egypt as well. Much of this early glass was colored purplish-blue by adding cobalt to imitate lapis lazuli or greenish-blue by adding copper or bronze to resemble turquoise. Indeed, by the second half of the second millennium BCE, the Akkadian word for glass became "lapis from the kiln" to distinguish it from "lapis from the mountain" (Moorey 1994, 90).

Why Glass?

Glass would become and remain an important component of long-distance exchange, much of it maritime. This importance comes not only because for many centuries glass was a rare and prized commodity but also because glass, as mentioned above, more than almost any ancient material—other than ceramic—tends to persist in the archaeological record, particularly in the acidic soils of much of Asia, where bones and other organics are not well preserved. In some cases, particularly for glass vessels, the typology of the objects may be helpful to determine their origin and date. More recently, using modern methods of scientific analysis such as LA-ICP-MS (Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry) (Gratuze 2016) to identify the chemical components of glass down to the parts per million level, we have learned to decipher the "text" hidden in the chemical compositions of glass recovered from excavations, extending glass study beyond typologies that may be useful for vessels but often not for glass beads and even less for fragments without an obvious parent object. Glass chemical compositions reflect the geographical and geological origin of the raw materials, thus providing evidence for how, and sometimes where, the glass was made, as has been done for Late Bronze Age glass in order to distinguish glass made in Egypt from that made in Mesopotamia (Shortland, Rogers, and Eremin 2007). Glass contains no carbon and cannot be directly dated by conventional techniques. However, as the geographical and geological origins of the raw materials changed over time, the glass compositions changed as well. Thus, we can sometimes match the compositions of glasses with unknown date to those that have been securely dated, providing approximate dates for the contexts or exchange sites where glass was found. As discussed below, this evidence is key to understanding the links and scale of trade from Egypt to Korea in the Late Antique period from the fourth to seventh centuries CE.

Colorants, particularly cobalt, can also be very useful for dating because cobalt sources changed quite often, with each source linked to a trace element signature in the composition of the finished glass.

In addition to documenting ancient exchange, glass can provide evidence for the movement of craftworkers along the MSR. Glass technologies, whether for smelting glass from its raw materials or turning already fused glass into vessels, glassware containers, such as bottles, bowls and goblets, or ornaments, such as beads, earrings, and bracelets, were closely held secrets often passed down through families. Even today in traditional societies, the recipes and techniques may be reserved for close relatives; and in ancient societies, there was no way to learn glass technologies without a lengthy apprenticeship. The appearance of glass technologies in new places almost certainly meant that workers had moved, whether by choice or force, from an area where the technology was already established to the new area where the technology appears. For these reasons, glass, when present, is arguably the perfect material for the study of both long-distance trade and the movement of people beyond the sailors, ship captains, and merchants directly involved in maritime trade. The production of glass beads and bangles using North Indian glass and technology in late first millennium BCE Thailand and the production of blown-glass vessels using Roman techniques in second century CE Sri Lanka, as discussed below, provide excellent evidence for just such exchange.

Glass and the Development of Long-Distance Maritime Exchange

Mediterranean Regional Exchange in the Late Bronze Age

The long-distance MSR discussed in this volume was the extension and adaptation of preexisting exchange systems, and glass was an important part of these as well. During the Mediterranean Late Bronze Age, from ca. 1500 to 1200 BCE, there was an extensive and well-organized maritime exchange among Egypt, the Levant, and Mycenaean Greece. Throughout this period, glass remained a precious material, often combined with gold and seemingly as valuable as the lapis lazuli that it was designed to imitate. There are many examples for the use of glass to produce or enhance prestige objects, but perhaps the best known is the combination of gold and cobalt-blue glass in the headdress and beard of the funerary mask of Egyptian pharaoh Tutankhamun (Brill, R.H. 1976, unpublished notebook, Corning Museum of Glass). Just a few years after Tutankhamun's death in

1323 BCE, a fifteen-meter ship with a rudimentary keel sunk off the Uluburun cape on the southern coast of Turkey. It is one of the earliest shipwrecks yet found. Discovered in 1982 and excavated between 1984 and 1994, the Uluburun shipwreck provides some of the best evidence for the scale and scope of early Mediterranean exchange (Pulak 2008). Over seventeen tons of artifacts have been recovered, including ten tons of Cypriot copper; one ton of tin; one-half ton of terebinth resin, ebony logs, and many other precious materials, including at least four hundred kilograms of glass in the form of glass ingots—raw glass produced in one place specifically to be made into objects in another. Together, the Uluburun ingots are by far the largest deposit of Late Bronze Age glass, many times the total from all other Late Bronze Age sites combined. They bring to life the textual evidence for Late Bronze Age glass trade in the Amarna Letters (see Moran 1992), a group of cuneiform tablets found at the Egyptian capital Amarna that recorded correspondence by and to Amenhotep III and Akhenaten (Amenhotep IV), the father of Tutankhamun. Five of the letters, all from civil servants governing Levantine towns under Egyptian control, refer to shipments of glass being sent as requested by the pharaoh (Shortland 2012, 147–152). While the details for these shipments to Egypt, whether by land or by sea, are not known, published analyses of samples from three Uluburun ingots suggest that at least some of these were Egyptian (Jackson and Nicholson 2010). They were probably first transferred to a port on the Levantine coast before being loaded for the long voyage west, with a destination most likely one or more of the Mycenaean palatial centers where the production of objects from unworked glass was highly developed (Nikita, Henderson, and Nightingale 2009), but the manufacture of the glass itself is so far unknown. Recent evidence for Late Bronze Age glass trade comes from the identification of beads made from Egyptian and Mesopotamian glass at sites in western Europe and Scandinavia (Varberg, Gratuze, and Kaul 2015; Varberg et al. 2016), as well as from samples of Mesopotamian glass in Egypt, primarily Amarna, and from small amounts of Egyptian glass in Mesopotamia (Lankton, Pulak, and Gratuze 2022). However, by the end of the Late Bronze Age in the twelfth century BCE, this first great period of long-distance maritime glass exchange had come to an end.

Hellenistic to Roman Maritime Glass Trade

Although glass production may have continued, at least in small amounts in Egypt (Schlick-Nolte and Werthmann 2003) and Iran (Stapleton 2011), long-distance trade would begin again only with the rise of Iron Age mercantile

societies, such as the Phoenicians on the Levantine coast. Distinctive glass beads depicting bearded faces have been found at many sites around the Mediterranean and were probably made both in the Levant and in North Africa at the Phoenician city of Carthage. At about the same time, early Greeks established outposts or colonies connected by sea. Large-scale exchange of glass, particularly raw glass, returned only with increased demand for glass at La Tène Iron Age sites in western Europe. The massive quantities of glass beads and bracelets, many of them cobalt-blue, made by La Tène artisans from the end of the fifth through the second century BCE (Rolland 2017), coupled with a lack of local technology for making glass from its raw materials, produced the perfect conditions for maritime exchange between glass-producing centers in the Levant and possibly Egypt and glass-using La Tène workshops. Shipwrecks again tell the story, with glass evidence essential for understanding maritime links between production and consumption.

The two earliest wrecks from this period are Sanguinaires A, dating to the second half of the third century BCE, found off the eastern coast of Corsica, and Lequin 2, from the late third century to early second century BCE, found off the French coast just east of Marseille (Fontaine and Foy 2007, 241). Five hundred kilograms of cobalt-blue glass blocks have been recovered from the Sanguinaires A wreck, with approximately the same amount remaining on the sea floor. This is by far the largest amount of unworked glass from the Hellenistic period, and it would have provided enough raw material for hundreds of thousands of Celtic beads and bracelets. The cargo of Lequin 2 was also largely raw glass, also cobalt-blue, although the total quantity is difficult to estimate because of extensive treasure hunting at the wreck site. While the precise locations of the major Hellenistic primary glass production centers have not been identified, chemical analysis of the glass itself reveals a likely Levantine fingerprint. Many other Late Hellenistic to Early Roman wrecks contained glass objects, often luxury glassware as on the Antikythera wreck from the first century BCE, with similar vessels found at ports around the Mediterranean and further inland along river systems. The Embiez shipwreck, off the coast of southern France (Fontaine and Foy 2007), dating to the second half of the second century CE, contained glass and little else. Although the ship held eighteen hundred glass vessels and two types of window glass, the estimated sixteen to eighteen tons of colorless raw glass was certainly the most important cargo. In this case, the glass most likely originated from Egypt, the other great center for glass production during the Roman period. The overwhelming conclusion from shipwreck evidence from the Hellenistic to early Roman period is that glass

objects and—at least in some cases—raw or unworked glass in the form of blocks broken from the large tank furnaces, used for glass manufacture at the time, were often part of a merchant ship's cargo. Long-distance shipping linked specialized production, such as cobalt-blue glass, with consumers who knew what they wanted, such as the La Tène Celtic craftsmen who transformed raw glass into finished products tailored to the needs of local consumers. This is exactly what we see in the references to glass in the mid-first-century CE *Periplus Maris Erythraei* (see Casson 1989; de Saxcé, Chapter 5, this volume; Seland, Chapter 1, this volume).

Glass in the Periplus Maris Erythraei

If the *Periplus* merchants' guide to trade from the Red Sea to Africa and India is an exception for its detailed descriptions of which materials may be best sold where, at least for glass, with just a few changes it could serve as instructions for any contemporaneous Roman maritime expedition headed for ports around the Mediterranean. Thus, what is striking is not the uniqueness but the banality of the trading instructions. The four types of glass—glass "stones" (probably beads), "myrrhine" (mosaic glass), glassware, and unworked or raw glass—were the same glass cargo sent to Mediterranean ports as revealed by the shipwrecks described above and the excavation of port sites. On the other hand, the venture itself—to send Roman ships across the Indian Ocean—was new, at least for the Roman merchants if not for the sailors, many of whom may have had experience on other ships, perhaps Arabian or Indian, that forged the trading links and mapped the routes. The Romans ramped up shipping, but it is likely that the enterprise was successful more for its reliance on tested routes and contacts than for its originality of concept. Long-distance trade was not a novelty either for the Romans or for their trading partners in Africa, along the Arabian coast; or in India, whether at Barbaricon near the mouth of the Indus River, at Barygaza on the Indian central west coast, or at Muziris—probably near Pattanam—on the southwest Indian coast. Nor was it probably a novelty at any of the other smaller sites mentioned in the *Periplus*. And, of course, the success of trade in India via the Red Sea depended not only on Roman appetites for silk, gems, and spices but also on Indian appetites for what the Roman merchants had to offer. Although some Roman luxury products found in India may have been for the use of local or expatriate communities at ports of trade on the Indian west coast, it is likely that the majority of goods off-loaded from arriving Roman ships would have been traded onward, both by land and by sea, over long-established exchange

networks. There is no suggestion that Roman ships or merchants were involved in this further trade, although the *Periplus* does mention some details describing how western goods would be off-loaded to smaller vessels for the voyage around the southern tip of India to ports, such as Poduke (Arikamedu), located along the Indian east coast up to the mouth of the Ganges River (see Casson 1989, 229). According to the *Periplus*, western goods, no doubt combined with local products, were loaded from these ports onto "the very big *kolandiphonta*," translated as "large ocean-going ships of Southeast Asia" (see Casson 1989, 230). According to the *Periplus*, these goods were transported even farther east to Chrysê and Chrysê Island, the "golden land" and "golden island" that in Sanskrit sources are almost certainly Suvarnabhumi and Suvarnadvipa, included in *Jātaka* tales dating as early as the third century BCE (Winternitz 1993). The location for the golden land and golden island was likely somewhere in Southeast Asia, with glass evidence pointing toward the Thai-Malay Peninsula (Lankton and Gratuze. 2019). For the Southeast Asian *kolandiphonta*, neither the home ports nor who controlled the trade beyond India is known. However, there is evidence that these maritime exchange routes across the Bay of Bengal were established well before the first century CE peak of Indo-Roman trade (Gupta 2018; Jahan 2012).

Like a Circle in a Spiral: From Regional Networks to a Linked System of Long-Distance Exchange

The Godawaya (Godavaya) Shipwreck and Glass from South India

The oldest shipwreck from South Asia, dating between the second century BCE and the second century CE, found off the southern coast of Sri Lanka near Godawaya, has been partially excavated by the Sri Lankan government and the Institute for Nautical Archaeology (Bopearachchi, Disanayaka, and Perera 2016). Materials found onboard included several glass ingots with a high-alumina soda-glass composition, as suggested by initial qualitative analysis (Chandraratne et al. 2012) and confirmed by quantitative analysis by LA-ICP-MS of two complete ingots and one half-ingot (Lankton and Gratuze 2016); for further details on the wreck itself see Kimura, Chapter 4, this volume). Based on trace elements, the Godavaya ingots show greater similarity to glass made in South India at such sites as Appur (Abraham 2016; Sarah 2004) than to any known glass from Sri Lanka. The three ingots studied so far have similar chemical compositions, plus the same diameter and

bowl-like form, so it is possible that they were made in the same workshop. These are not only the earliest glass ingots in Asia but also the only ones with a South Asian composition. In addition, their form has nothing in common with western or Roman glass, since after the Late Bronze Age, Levantine and Egyptian raw glass was traded as large chunks and not as ingots. The glass ingots, and by extension the Godawaya shipwreck, would have come from a port on the southeastern coast of India, perhaps one of those mentioned in the *Periplus*. It is probably not from Arikamedu, in southern India, since the high-alumina soda glass in the ingots is quite different from the types of soda glass found there. The destination of the ship could have been a port linked to a southern Sri Lankan center such as Tissamaharama. Similar glass found in Southeast Asia dates only to the first or even second century CE, so if the Godawaya shipwreck dates to the earlier part of its radiocarbon range, as suggested by some of the other materials onboard, the voyage may represent a South Asian regional network predating open water crossings from South India to Southeast Asia. The glass evidence is helpful here: the earliest Roman glass artifact in Southeast Asia is a Late Hellenistic mosaic vessel fragment from Phu Khao Thong (Thailand) that probably dates to the first century BCE (Lankton and Gratuze 2019, Figure 3). At the same site (see below for discussion), there is ample evidence for the types of glass found at Arikamedu, but no South Asian high-alumina glass of the type found on the Godawaya shipwreck until perhaps one hundred or so years later. It is likely that the Godawaya ship was traveling, and perhaps forging, the same maritime exchange routes along which Roman glass would follow.

Northern Bay of Bengal to the South China Sea: Khao Sam Kaeo and the Big Bang of the Maritime Silk Road

The actual circumstances of maritime exchange—the trading spaces and the agents involved—are often not clear, particularly for the prehistoric period of Indian Ocean exchange. However, there is one exception for which quite a bit is known, and those are the two sites of Khao Sam Kaeo and Khao Sek. Both are on the east coast of the Isthmus of Kra, the narrowest part of the Thai-Malay Peninsula. Khao Sam Kaeo was excavated between 2005 and 2009, and the findings were published in full in 2017 (Bellina 2017a). Results of the Khao Sek excavation, by much the same team in 2013 and 2014, were published in 2018 (Bellina and Sinopoli 2018). Together, the two sites reveal the most complete picture of any prehistoric archaeological complex from the mouth of the Red Sea to southern China, the broad swath of what would become the Maritime Silk Road. The excavators interpret Khao Sam Kaeo

as a port-city that "prefigured some of the pre-modern trading societies and their entrepots" (Bellina 2017b, 19), and that its cosmopolitan character and multiethnic residents spread over thirty-five hectares might even be classified as an incipient city-state (Bellina 2017a, 623). With many radiocarbon dates calibrated to the late fifth to second century BCE, Khao Sam Kaeo is one of the most thoroughly dated sites in Asia and one of the earliest found between South Asia and China. Khao Sek, eighty kilometers to the south, was smaller at ten hectares, but it had a similar riverfront location that provided easy access to the Gulf of Thailand. With similar material culture and ornament production technologies, the two sites are interpreted as the western extension of a "South China Sea Sphere of Interaction" (Bellina and Sinopoli 2018, 10). This regional South China Sea network may have begun as early as twenty thousand years ago and was manifested through shared concepts of material culture, including desired goods such as nephrite, carnelian, and glass ornaments as well as characteristic bronze drums and vessels (Bellina and Sinopoli 2018, 1).

In addition to placing Khao Sam Kaeo within the South China Sea Interaction Sphere, the site report emphasizes exchange across the Bay of Bengal, with local production of stone beads using Indian raw materials and technology and the import of luxury ceramics from the Indian world. Some of the strongest evidence for Bay of Bengal interaction is the use of North Indian glass to produce locally valued objects (Dussubieux and Bellina 2017). From the beginning of occupation at Khao Sam Kaeo, unworked glass was imported in bulk from North India, where the primary production of glass from raw materials probably began sometime around the mid-first millennium BCE. The high-alumina, high-uranium soda glass from Khao Sam Kaeo is identical to that produced at specialized primary glass production sites such as Kopia (Dussubieux and Kanungo 2013; Kanungo and Brill 2009), and probably at early urban sites such as Kausambi (Gratuze et al. 2015), both in northern India. Because of the unique trace element pattern, there is no other possible source for the Khao Sam Kaeo high-alumina glass that makes up half of the samples analyzed from the site and probably a much greater fraction of the actual glass found during excavation and on the surface. Because Khao Sam Kaeo is so early in the history of glass in India and Southeast Asia, this North Indian glass in peninsular Thailand is arguably the first well-documented link between South China Sea networks and those further west across the Bay of Bengal. No other site captures this moment as well as Khao Sam Kaeo, although within one or two hundred years there would be several areas on both the east and west coasts of the Thai-Malay Peninsula with evidence for Indian exchange, followed shortly

by evidence for the exchange of goods produced in the Roman Empire. If this period from 400–200 BCE was the "Big Bang" of the start of MSR, then Khao Sam Kaeo was at the "B of the Bang."[1]

Khao Sam Kaeo was built on four hills, with the early settlement and craftworking areas concentrated on the three southern hills and later craftworking on the northernmost hill, Hill 4. Notable for Hill 4 is the accumulation of Han ceramic jars sherds, the earliest known west of Vietnam, with most dated from the first century BCE and produced in southern China or northern Vietnam (Peronnet and Srikanlaya 2017). All of the glassworking, and much of the early phase of hardstone ornament production, was done at the foot of Hill 2 along the river (Dussubieux and Bellina 2017). Many of the earliest dates were from test pits with evidence for bead and bracelet manufacture, leading investigators to conclude that glassworking was important at the site from the beginning of occupation (Lankton and Dussubieux 2013; Lankton, Dussubieux, and Gratuze 2008). There are also three other glass types at Khao Sam Kaeo. Based on chemical analysis, glassmakers had used potassium oxide (potash) rather than soda as the flux necessary to lower the melting temperature of silica. One of these types is low in lime and strontium and relatively high in alumina. It is found only at very early sites in Southeast Asia (and by extension in pre-Han or early Han southern China), but not in India, so this first type was likely produced somewhere in the South China Sea area. The second and third types are both moderate in lime and alumina but can be distinguished from each other by trace elements, including zirconium and yttrium. The second type is higher in zirconium and, in Southeast Asia, seems to be about one hundred years earlier than the third type. This second type has not been found in India, suggesting production within Southeast Asia or southern China. The third glass type, low in zirconium, is common at many Indian sites, ranging from Arikamedu in Tamil Nadu to Ter and to Junnar in Maharasthra. Because this low-zirconium potash glass forms a coherent group in India, it seems likely to have been made there, although the precise production center, or possibly centers, remains unknown. At Arikamedu, 32 percent of the over three hundred samples analyzed to date (Dussubieux 2001; authors' own data, unpublished) are low-zirconium potash glass. Most of these are purplish-blue from coloring with cobalt. The distinction between the second and third types made of moderate lime and alumina potash glass is important because Indian *potash* glass appears to precede typical South Indian high-alumina *soda* glass. This is true at Khao Sam Kaeo and at other

1 From British sprinter Linford Christie, who said that he started his races not at the "bang" of the starting pistol but at "the B of the Bang."

early sites in Southeast Asia, such as Giong Ca Vo in Vietnam and the three sites of Bit Meas, Village 10.8, and Prohear in Cambodia, all dating from the late centuries BCE (Carter 2015). The Indian glass at Khao Sam Kaeo—first from North India and perhaps one hundred years later from South India—is arguably the earliest positively identified Indian material found on the Thai-Malay Peninsula, the dividing line between South Asia and China. With the settlement of Khao Sam Kaeo, the peninsula became the bridge between the South China Sea and the Bay of Bengal. As noted previously, early hardstone ornament production was in the same area as glassworking at the foot of Hill 2, and both the raw material and the technological *chaîne opératoire* are interpreted as being Indian (Bellina 2017b), with the suggestion that the actual workers may have been imported as well.

Imported Glass, Imported Technologies: North Indian and Vietnamese Glassworkers at Khao Sam Kaeo

Who were the glassworkers at Khao Sam Kaeo? While the strongest evidence for an Indian presence may be the chemical fingerprint of the raw glass, hotworking—the manipulation of glass reheated in a furnace—for bangle production, and coldworking or lapidary techniques—similar to the shaping, grinding, drilling, and polishing steps in stone bead manufacture—for large faceted glass beads were common in North India, with large lapidary beads found at sites such as Kausambi (Gratuze et al. 2015, 366). The use of these techniques at Khao Sam Kaeo suggests that North Indian glassworkers were important in establishing the glass workshops. The beads produced at Khao Sam Kaeo or at the related site Khao Sek were traded through the South China Sea Interaction Sphere and have been found at Giong Ca Vo—a site on the south coast of Vietnam linked to the southern Sa Huynh or Dong Nai cultures. At the same time, glassworkers trained in Sa Huynh technologies were likely present at Khao Sam Kaeo, based on evidence for locally made glass ornaments with distinctive Sa Huynh morphologies. At least two ear ornaments in the form of a double-headed animal, made with Sa Huynh technology combining hotworking and coldworking but using typical North Indian soda glass, have been recovered at Khao Sam Kaeo (authors' own data, unpublished). Making these pendants was difficult and very different from making the Khao Sam Kaeo beads and bangles, and only Sa Huynh glassworkers would have had this knowledge. Similar Sa Huynh ornaments made from North Indian glass have not yet been found in Vietnam, and it is possible that the ear ornaments at Khao Sam Kaeo were made for the use of the workers themselves or for other culturally Sa Huynh people, possibly merchants or sailors who were based there.

Roman Glassworkers in Sri Lanka

While transferred glass technologies at Khao Sam Kaeo provide evidence for the movement of glassworkers within Bay of Bengal and South China Sea regional networks in the late centuries BCE, there is strong evidence that people were moving over longer distances as well. For example, there were Egyptian or Levantine glassworkers present in Sri Lanka by the second to third century CE, who were making small blown-glass stupa models in Sri Lankan styles. Following the introduction of Buddhism in Sri Lanka, traditionally attributed to the third century BCE, Sri Lankan Buddhist architecture developed with an emphasis on large, even enormous, stupas made from fired bricks, sometimes over a natural rock core. Excavated cavities within these stupas contained precious relics enclosed in small miniature stupas made from rock crystal, gold—and as early as the second century BCE—glass. Glass stupa models are so far unique to Sri Lanka; the earliest is a remarkable colorless glass stupa model found in the Deliwala stupa (Borell 2017), dated to the second century BCE. While this early miniature stupa was made using Asian molding techniques and Asian potash glass, the miniature stupas found within the Nawagala stupa (Bailiff et al. 2013), thirty kilometers south of the early capital of Sri Lanka, Anuradhapura, differ in both forming technology and glass chemical composition (authors' own data, unpublished). Recovered from deposit cavities thought to date to the second phase of construction of the large Nawagala stupa (from the second to third century CE), these bubble-shaped models are some of the only blown-glass objects known to have been produced in South or Southeast Asia. Glassblowing was discovered in the mid-first century BCE, with the earliest evidence found in an abandoned well in Jerusalem. The technique requires long periods of training and is best achieved using malleable glass with a relatively broad working temperature to allow the various steps necessary for vessel production. Glassblowing is almost unknown in ancient Asia. This is perhaps due to lack of technological expertise but also possibly because typical Asian glasses were high in alumina and would have been much "stiffer" and difficult to blow than the natron-based glass from Egypt and the Levant. What is remarkable about the Nawagala miniature stupas is that not only were they made using Mediterranean techniques but also the glass itself is almost identical to Egyptian glass from the same period, differing only in trace elements such as uranium. This shows that the glass could not have been made in the West but was more likely a local or regional product made using Roman recipes and local ingredients. Both the workers who made the glass itself

and those who made the objects were intimately knowledgeable about Roman technologies, something possible only if Levantine or Egyptian glassworkers were present on site.

Flood from the South

By the first century BCE, the end of Khao Sam Kaeo's most active period, there is much less North Indian glass found in Southeast Asia. The focus for North Indian trade had turned west and north, with North Indian glass found at exchange centers such as Niya (Lin, Yixian, unpublished LA-IC-MS data, pers. comm. 2010) on the overland Silk Road around the Taklamakan Desert in China. In Southeast Asia, sites such as Phu Khao Thong and Wat Pathumthatam (both in Thailand) pop up in Ranong Province on the west coast of the Isthmus of Kra, along with Tha Chana and other yet-to-be-excavated sites on the east coast. At most of these sites, dated from about the first century BCE, there is still some North Indian glass, but it accounts for less than 10 percent of the total found. Thirty percent of the glass is Southeast Asian and has the same compositions as those found at Khao Sam Kaeo, but up to 50 percent of the samples now have a South Indian composition—similar, although not identical, in distribution and color to the glass found at Arikamedu (that is, low-zirconium potash glass and soda glass with approximately equal parts lime and alumina)—along with some mixed-alkali samples that seem to be a mixture of North Indian and Southeast Asian glass (Dussubieux et al. 2012). While there were several fragments of possibly first-century BCE Roman glass at Phu Khao Thong, as mentioned above, no Roman glass was found at Wat Pathumtharam (author's own data, with Boonyarit Chaisuwan, unpublished). This could suggest that activity at Wat Pathumtharam was slightly earlier and may represent glass exchange between southeastern India and Southeast Asia before the advent of Indo-Roman trade.

For these very early sites on the west coast of the Isthmus of Kra, as at Arikamedu, beads made from "typical" high-alumina South Asian soda glass, Dussubieux's m-Na-Al type 1, made with soda from a mineral source combined with sand containing high levels of alumina (Dussubieux et al. 2010) are rare, with none at Wat Pathumtharam and only one out of 217 total samples analyzed from Phu Khao Thong (Dussubieux et al. 2012).[2] However, within a relatively short period, this high-alumina glass became common; it comprises 12 percent of the samples (91 samples analyzed) from

2 This is also based on author's data, unpublished.

Bang Kluay, a site next to Phu Khao Thong.[3] While in many ways similar to glass from Phu Khao Thong, the glass from the Bang Kluay site has two aspects consistent with an overlapping but slightly later period: a lower proportion of Southeast Asian potash glass and a greater proportion of South Indian high-alumina soda glass. Meanwhile, the amount of Roman glass is similar at roughly 10 percent of the total samples.

What is significant about this glass evidence is not only what types of glass were found where and when but also the patterns of trade. The evidence shows there were shifting sources and destinations in the very early years of the MSR. According to the *Periplus*, first-century Roman products, including several types of glass, were transferred to ports on the Malabar Coast in India. These were combined with local or regional goods that were then shipped to Chrysê or Chrysê Island (Lankton and Gratuze 2019). We can now identify more precisely some of the Southeast Asian destinations for this trade, and the glass evidence shows that although such southeast Indian ports as Poduke (Arikamedu) were important, these were superseded by other ports. For example, the high-alumina soda glass found at Bang Kluay could not have come from Arikamedu, where such glass was rare. The Southeast Asian destinations for this trade changed as well, and the glass evidence offers an opportunity to build an approximate chronology of these changes.

Early Global Exchange

The View from Korea

As discussed above, the rapid expansion of maritime links to include western products like Roman glass was built on preexisting networks across the Bay of Bengal and around the South China Sea, with evidence in each case that involves the movement of pre-Roman Asian glasses. There is less evidence for how far these early networks extended into northeast Asia, but Korean graves dated to the first century BCE contain imported glass beads.[4] Some of these are typical Chinese lead-barium glass from the Han Dynasty (206 BCE–220 CE), but most have early Southeast Asian compositions found also at very early sites in Vietnam and Thailand,[5] indicating a wide-ranging regional

3 Analysis conducted by author and Boonyarit Chaisuwan, unpublished data.

4 This is based on author's data, unpublished.

5 Author's data for Sa Huynh and Dong Son sites in Vietnam and Ban Don Ta Phet in Thailand, unpublished.

network for which the glass evidence provides the strongest support. By the first century CE, the glass found in Korean graves had changed compositional types to Southeast Asian and Indian potash glass with moderate lime and alumina, such as found in India at Arikamedu and in peninsular Thailand at Khao Sam Kaeo and Phu Khao Thong; there was also a small amount of South Indian soda glass of the Arikamedu type. In addition, there is one gold-glass bead of a first-century CE Roman composition that may have been imported with the South Indian glass.

The glass assemblage in Korean graves dated to the second century CE includes much less Southeast Asian glass and more Arikamedu-type South Indian glass. It includes also up to 10 percent South Indian high-alumina soda glass, which is rare in first-century graves. In addition, there is a small amount (5 percent of samples) of glass likely produced in northern Pakistan or Central Asia. These types of Central Asian glass have not been found in Southeast Asia, indicating that the MSR was probably not the only mechanism for glass imports into the Korean peninsula. Overall, the pattern of glass compositions in Korea in second century CE matches that at Phu Khao Thong in Thailand. The third-century Korean glass is likewise similar to that from Thailand, although in this case more like glass found at Bang Kluay, the site near Phu Khao Thong that, based on the glass evidence, may chronologically overlap and then extend the Phu Khao Thong settlement. Graves dated to the third century contain much more Roman glass than graves from the second century (12.8 percent and 2.8 percent of total samples, respectively). Most Roman glass from these third century graves has chemical compositions identifiable to the first to third centuries CE (Freestone et al. 2018), corroborating the Korean dating. There are still many gaps in the knowledge of the actual routes taken; for example, large amounts of glass have been found at possible exchange sites in Cambodia and Vietnam, particularly at Oc Eo, but the glass types found there are different enough in their distribution to make these sites unlikely direct links to northeast Asia (Carter 2010).[6] Several typologically Roman vessels have been found in China (Borell 2016); but in terms of detailed glass chemical analyses, China remains problematic. There are few quantitative analyses that include trace elements; those available from southern China and Han Dynasty-period northern Vietnam (Zhao and Li 2016) show Southeast Asian and some Indian glass, but little Roman glass.[7]

There is ample evidence of imported glass in fourth-century CE Korea, mostly beads, that suggests changing sources, if not changing patterns of

6 Also based on author's data, unpublished.

7 Also based on author's data, unpublished.

trade. The glass in Korea is no longer like that from Phu Khao Thong and other early sites but is similar to glass recovered in Thailand from survey and excavation at Bang Ro and sites further south along the estuary of the Nang Yon River in Kuraburi district, Phang-nga Province. The Kuraburi glass samples date to the fourth and fifth centuries CE, based on finds of clay votive tablets from the Dvaravati period (sixth through eleventh centuries CE) (Pongpanich 2009, 177).[8] At both the Bang Ro site and in fourth-century CE Korean graves, the amount of Southeast Asian glass is less than 2 percent, but up to 50 percent of the glass beads are South Indian m-Na-Al type 1 glass. Also striking is the large amount of Late Roman or Late Antique glass with chemical compositions that indicate fourth-century Egyptian production, with 28 percent at Bang Ro and 14 percent in Korea. Much of the glass is cobalt-blue (25 percent at Bang Ro and 40 percent in Korea), and the higher-nickel cobalt colorant for the Egyptian samples confirms a fourth-century CE date (Schibille et al. 2016). This increase in the amount of Egyptian glass in the fourth century parallels evidence for increased activity at Egyptian Red Sea ports like Berenike, in decline in the third century CE because of widespread economic troubles in the Roman Empire but rebounding in the fourth century (Sidebotham 2019). By the fifth and sixth centuries CE in Korea, the proportion of glass beads made with Egyptian glass continued to increase, reaching a high of 50 percent of all glass types in the fifth century but then tapering to 25 percent in the sixth century—still a striking percentage for glass that had traveled the length of the MSR. In addition, glass vessels have been found in fifth- and sixth-centuries CE Korean graves, all from royal or high-status burials (Lankton et al. 2010). While most of these vessels appear to be copies of contemporaneous Roman glassware, probably made in Central Asia based on the chemical compositions, some small vessels, almost all cobalt-blue, do have an Egyptian Late Antique composition,[9] although the actual place of manufacture is not known. The fragments were poorly blown, with many bubbles, and do not match fine Roman production standards. The few vessel fragments at Bang Ro do not match Korean glass, and it is possible that even the Korean vessels with an Egyptian composition were made in Central Asia using imported raw glass. These vessels underscore the complex nature of glass trade, with multiple possible sources and routes for exchange. What may be most surprising about the Korean samples is that such an overwhelming percentage of the glass trade was almost certainly by sea.

8 Also based on the author's data, unpublished.

9 Also based on author's data, unpublished.

New Sources, New Routes in the Seventh Century CE

By the seventh century, long-distance maritime glass trade to the Korean peninsula had all but stopped. A few beads with late Roman compositions have been found at seventh-century Korean sites, but these may have been heirlooms from prior centuries. Changes in social and burial customs, combined with new local glass sources to fill what need there was, were at least partly responsible. However, as discussed in several contributions to this volume (Park, Chapter 2; Kimura, Chapter 4; Miksic, Chapter 7; Heng, Chapter 8, all in this volume), even if the long-distance maritime exchange routes no longer continued to Korea, there was new emphasis on direct trade with China and possibly Japan, particularly during the nineth and tenth centuries CE. The development of an all-water passage through the Straits of Malacca was certainly a factor in the ability of the same boats to sail the entire expanse of the MSR, since goods no longer had to be off-loaded for portage across the Thai-Malay Peninsula. The large number of Early Islamic glass vessel fragments recovered in both northern Sumatra and at Malaysian peninsular sites in Kedah (Perret and Jaafar 2014) attest to the growing importance of this all-water route. However, there are still large quantities of eighth–tenth-century Early Islamic period glass beads and vessels in Thailand at peninsular ports, such as Thung Tuk on Koh Kho Khao Island in the Takua Pa River estuary (Chaisuwan and Naiyawat 2009), with matching material evidence from Chaiya, which is directly across on the east coast of the peninsula. This evidence suggests that the transpeninsular and all-water routes were used simultaneously for at least two hundred years. Some Islamic period glass vessels have been found in China (An 1991), physical evidence for the numerous textual references to western glassware given as tribute there (Heng 2009; Wong 1979) and in Japan (Nakai and Shindo 2013), but so far no evidence has been found in Korea. Part of this long-distance maritime trade may have been mediated through such ports as Mantai in Sri Lanka, where large amounts of Islamic period glass have been found (Carboni 2013). The tenth-century CE Cirebon shipwreck, off the northern coast of Java, provides ample evidence for some of the products, including glass, being transported across Asian waters (Swan Needel 2018). There are more written sources available from this period. The study of maritime exchange entered a new phase that combined materials analyses with textual interpretations and the archaeological knowledge of more permanent remains.

Conclusions

The careful study of material culture can provide surprising insights into patterns of exchange and of the lives of people living along long-distance trade routes such as the Maritime Silk Road. Glass is particularly useful to study because it was a prized commodity both during life and as grave offerings and has been found—at least in small quantities—at most archaeological sites. In addition, glass objects and production debris may provide evidence for the presence of glassworkers who traveled far from their original homes, whether voluntarily or by force. These workers include the North Indian glassworkers at Khao Sam Kaeo and probable Egyptian glassworkers in Sri Lanka. While the form of a glass ornament may not necessarily indicate the identity of the owner, it can identify the glassmaker. For example, the double-headed ear ornaments made at Khao Sam Kaeo certainly identify that the glassworkers had a strong Sa Huynh identity. With our constantly increasing understanding of glass compositional types, made possible by the incorporation of trace element analyses using such techniques as LA-ICP-MS, we are in a better position to" read" the glass evidence to reconstruct these stories of long-distance maritime trade. Based primarily on glass evidence, for instance, we now know that trade ran from the Mediterranean basin to northeast Asia in the early first millennium CE.

Glass also shows us that regional networks across the Bay of Bengal and the South China Sea became linked as early as the fourth century BCE. It is through these networks that Mediterranean and South Indian glass beads from the first century CE made their way to Southeast Asia and to Korea. In the seventh century CE, this glass trade was changing. There were fewer exports of any kind coming through the Red Sea, with ports such as Berenike in decline or deserted. Changing demand in northeast Asia played a part as well, with Egyptian and Indian glass beads no longer used as grave goods in Korea. Sea routes were changing as well. The all-water route through the Straits of Malacca allowed individual ships to make the full journey from western Asia to China, as suggested by Arab and Chinese accounts of Islamic tribute missions to China (see Park, Chapter 2, this volume). Glass evidence is useful here as well, with many fragments of Abbasid glass vessels found not only at Malaysian and Sumatran sites but also at Koh Kho Khao and Chaiya on opposite sides of the Thai-Malay Peninsula. A more focused look at this later stage of the MSR will continue elsewhere in this volume, with an emphasis on regional nodes in overall long-distance exchange as seen through cultural and trade networks in the western Indian Ocean, port-cities along the Malacca Straits, and the relationships between ports and hinterlands as told through Chinese ceramics.

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