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Southern Sumatra late prehistoric and early historical maritime exchange: First elemental analysis data from glass beads

Q1 Laure Dussubieux^a, H. O. Sofian^{b,c}, and B. Bellina^d

^aField Museum, Chicago, IL, USA; ^bNational Research and Innovation Agency (BRIN), Indonesia; ^cEcole Doctorale Espaces, Temps, Cultures (ETC), ED 395, Université Paris Nanterre, Nanterre, France;

^dUMR8068 Technologie et Ethnologie des Mondes Préhistoriques, CNRS, Nanterre, France

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ABSTRACT

Sumatra has long been recognized as a pivotal crossroads for trade in the Indian Ocean, with evidence of this activity dating back to the late first millennium when the Srivijaya regional polity emerged. The predominant hypothesis regarding this trade is that upland areas supplied forest products to lowland centers, which functioned as international trading marketplaces. These marketplaces received imported materials, some of which were exchanged with upland groups. However, evidence of this trade is still poorly supported by archaeological materials. This paper presents the first comprehensive study of glass beads from Sumatra *via* laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) to determine the elemental compositions of the beads. The study encompasses a wide range of sites from upland and lowland areas and various temporal periods, extending from prehistoric to early historic times in Southern Sumatra, Jambi, and South Sumatra Province. The study provides not only improved chronologies, but also data on upland–lowland exchanges that definitively show the upland megalithic sites are not prehistoric, but rather contemporary with Srivijaya. Furthermore, it provides data on the pre-Srivijayan port-settlements and the regional networks in which they were involved, thanks to the presence of certain types of glass, including Mediterranean glass.

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Introduction

Sumatra's strategic importance as a regional center for international trade stems from its advantageous geographical location and abundant natural resources. Positioned at the intersection of the Bay of Bengal and the Strait of Malacca—and serving as a gateway to the Indonesian archipelago—Sumatra became a pivotal crossroads for maritime trade between the seventh and thirteenth century AD (Manguin 2009, 2019, 2021; Miksic 2012; Wolters 1967). During this period, the maritime empire of Srivijaya, centered on Sumatra, emerged as a dominant Malay thalassocracy. Rather than pursuing territorial expansion, Srivijaya's power was rooted in maritime trade and connectivity,

CONTACT Laure Dussubieux  ldussubieux@fieldmuseum.org  Field Museum, 1400 South DuSable Lake Shore Dr, Chicago, IL 60605, USA.

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51 with its capital at Palembang (South Sumatra). The empire controlled much of the
52 Indonesian archipelago and extended its influence across the Strait of Malacca into
53 mainland Southeast Asia, leveraging advanced seafaring capabilities and a political
54 organization focused on dominating maritime routes (Manguin 2019, 2021; Manguin,
55 Griffiths, and Degroot 2015).

56 Srivijaya's economic vitality was underpinned by the region's rich forestry and min-
57 eral resources, including gold and tin. Wolters (1967) emphasized that forest products—
58 such as camphor, sandalwood, aloes, benzoin, rattan, resins, ivory, and hides—were key
59 commodities in Srivijaya's maritime trade. Sourced from Sumatra's and the Malay
60 Peninsula's dense forests, these goods were exported to China, India, and the Middle
61 East, forming a significant part of the empire's revenue. Gold was central to Srivijaya's
62 wealth and power, with the empire dominating its trade in Southeast Asia by control-
63 ling gold-rich regions like Jambi and the Batang Hari River. Chinese records from the
64 Sui and Tang dynasties describe Srivijaya's tribute of gold artifacts which reinforced its
65 political prestige and diplomatic ties (Coedès 1948; Wheatley 1961). Additionally,
66 Q3 Srivijaya monopolized the tin trade, a strategic resource sourced from the Malay
67 Peninsula, Bangka, and Belitung islands. Control over these resources structured
68 Srivijaya's early trade networks and economic system, cementing its role as a regional
69 trade hub.
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72 Srivijaya's prosperity was built on the interdependence between coastal (downstream)
73 and inland (upstream) regions. Palembang, as the maritime trade hub, relied on the
74 hinterland for essential raw materials—forest products, gold, tin, and agricultural
75 goods—which were transported downstream *via* river networks like the Musi. These riv-
76 ers acted as vital trade corridors, linking upstream extraction sites to port cities.
77 Archaeological evidence reveals hierarchical settlements along these rivers, optimized for
78 resource flow, redistribution, and adaptation to economic cycles and defensive needs
79 (Bronson 1978; Manguin 2009, 2017, 2021; Miksic 1985).
80

81 The empire's decentralized political structure depended on alliances between coastal
82 elites and inland chiefs to secure resource access. Inscriptions and artifacts highlight
83 social hierarchies and intermarriage, reinforcing territorial cohesion. Meanwhile, the
84 peneplain's poor soils encouraged communities to develop trade networks and mobility
85 strategies: upstream regions depended on coastal centers for imported goods (e.g., cer-
86 amics, textiles), while downstream areas relied on upstream raw materials (Manguin
87 2009). This dynamic is further illustrated by the movement of finished products such as
88 metal artifacts, glass, and stone beads that were often used upstream as burial deposits
89 in jar burials. However, archaeological reports on upland beads remain scarce, with
90 most findings sourced from the Musi River basin and only negligible numbers from the
91 Batanghari River basin. The significance of these discrepancies, if any, remains uncer-
92 tain, as do the reasons for differences in archaeological investigation and conservation
93 levels.
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95 Upstream sacred sites, such as river sources, held ancestral and political significance,
96 while coastal centers hosted Buddhist monasteries and palaces, legitimizing power and
97 redistribution. The continuous occupation of riverine sites, including sanctuaries and
98 fortified settlements, underscores this integrated system, which adapted to environmen-
99 tal constraints and geopolitical shifts. This upstream–downstream synergy enabled
100

101 Srivijaya to dominate regional trade for centuries, despite disparities in archaeological
 102 investigation across different river basins.

103 Recent archaeological evidence strongly suggests that the southern Palembang region,
 104 particularly at the lowland sites of Karang Agung and Air Sugihan, played a founda-
 105 tional role in the early development of Srivijaya. Located along the Sungai Lalan near
 106 the Banyuasin estuary, Karang Agung has revealed stilt-house settlements dating from
 107 the third to fifth centuries CE, indicating dense and continuous early occupation.
 108 Excavations have uncovered wooden house poles, gold ornaments, glass and stone
 109 beads, iron tools, and tin artifacts, all pointing to active trade connections with India
 110 and the Malay Peninsula (Rangkuti and Fauzi 2019). Alongside nearby sites like Air
 111 Sugihan, these findings demonstrate a clear continuity into Srivijaya's formative period
 112 in the seventh century. The strategic river networks and access to the Bangka Strait in
 113 the Karang Agung region further highlight its importance in early trade and political
 114 consolidation. Southern Palembang and Karang Agung stand as the probable cradles of
 115 Srivijaya, long before its ninth–tenth century peak (Manguin 2009; Wolters 1975).

116 This article presents the first extensive study of glass artifacts from Sumatra based on
 117 their elemental compositions determined by laser ablation-inductively coupled plasma-
 118 mass spectrometry (LA-ICP-MS). The study encompasses a diverse array of sites
 119 spanning from upland and lowland regions, ranging from the prehistoric to the early
 120 historical periods. By examining the quantities, distribution, and provenance of glass
 121 beads, the study aims to enhance our understanding of the chronological sequences of
 122 the sites analyzed, and of the network they were part of, with a particular focus on the
 123 upland–lowland connections and inter-regional exchanges. The study provides enhanced
 124 chronologies and data on internal exchanges (upland–lowland) that lend support to the
 125 hypothesis that the megalithic sites in the uplands are not prehistoric but contemporary
 126 with Srivijaya. The study also provides data on the earliest port-settlements in Sumatra
 127 and the regional networks in which they were involved, notably, but not exclusively,
 128 thanks to the presence of certain types of glass, including Mediterranean glass.

133 Samples

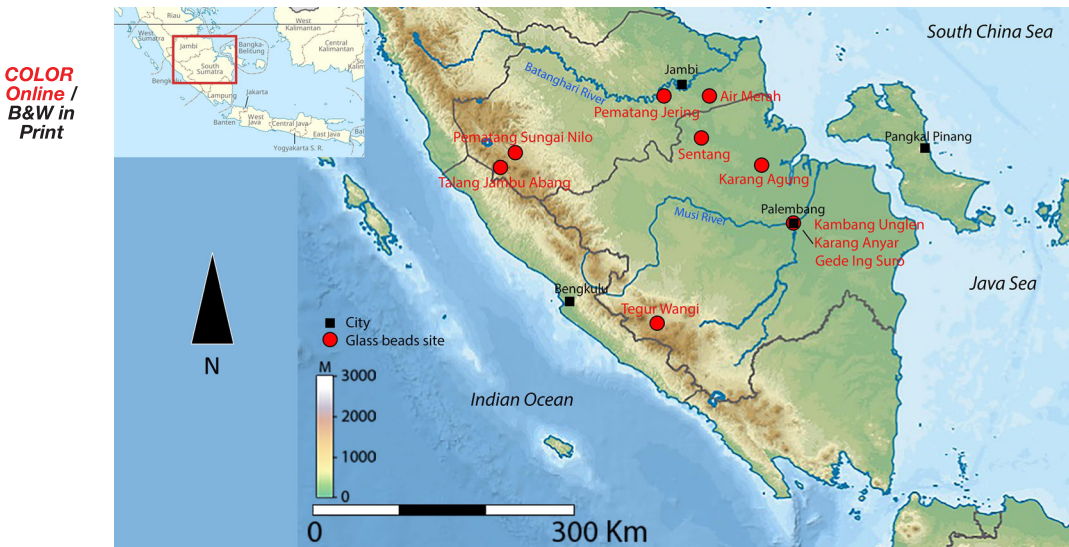
134 The beads in this study come from sites that belong to different environments, cultures,
 135 and periods in South Sumatra (Table 1). Some derive from the lowland port-settlements
 136 such as Karang Agung and Kambang Unglen while others originate from the upland
 137 regions of Kerinci and Pasemah where remains of megalithic cultures are found
 138 (Figure 1). The upland and lowland areas were connected by a 600 km long network of
 139 rivers, the Batanghari and the Musi.

140 In the upland regions of Kerinci and Pasemah, groups are characterized by two dif-
 141 ferent megalithic cultures. In Kerinci, megaliths consist of human-shaped cylindrical
 142 stones (batu silindrik) (Budisantosa 2008), menhir-type stones, and to which are associ-
 143 ated metal artifacts such as bronze drums, including some miniatures, vessels, arm
 144 plates, earrings, and elephant miniatures (Bonatz et al. 2009; van Heekeren 1958).
 145 Meanwhile, in the upland region of Pasemah, the megalithic culture takes the form of
 146 tetralith stones (two standing stones with a third one placed horizontally on top of
 147 them), stone chambers, and stone statues depicting human figures and animals such as
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Table 1. Sites of origin of the glass beads from Jambi and South Sumatra in this study.

No	Sites	Area	Province	Chronology	Amount	Type site	References
1	Tanjung Sri/Talang Jambu Abang	Highland Kerinci	Jambi	Prehistory–historical (?)	2	Megalithic	glass beads; Chinese ceramics; pottery
2	Pematang Sungai Nilo			C14 dating (960 – 1180 AD)	1	Megalithic	iron slag, stone, ceramics, beads, obsidian and charcoal
3	Pematang Jering Temple	Lowland Jambi		Srivijaya	4	Temple	Chinese ceramics; glass beads
4	Air Merah			Ninth–tenth century AD	1	Burial	glass beads; iron knife; pottery
5	Tegur Wangi	Highland Pasemah	South Sumatra	Prehistory–historical (?)	7	Megalithic	metal statue; glass beads
6	Karang Agung Area	Lowland South Sumatra		Pre Srivijaya	177	Port-settlement?	Chinese ceramics; glass and stone beads; intaglio; gold artifacts; iron artifacts; wooden poles; ship; resins
	Gede Ing Suro			Eighth–tenth AD	4	Temple	Chinese ceramics; glass beads; Buddha statue
7	Karang Anyar			Seventh–tenth AD	10	port-settlement?	Chinese ceramics; glass beads; Buddha and Nandi statue
8	Kambang Unglen			Seventh–eighth AD	45	port-settlement?	Chinese ceramics; glass beads
10	Sentang			no date	8	burial	pottery; human skull; glass beads
				Total	259		

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Figure 1. Sites of South Sumatra included in this study.

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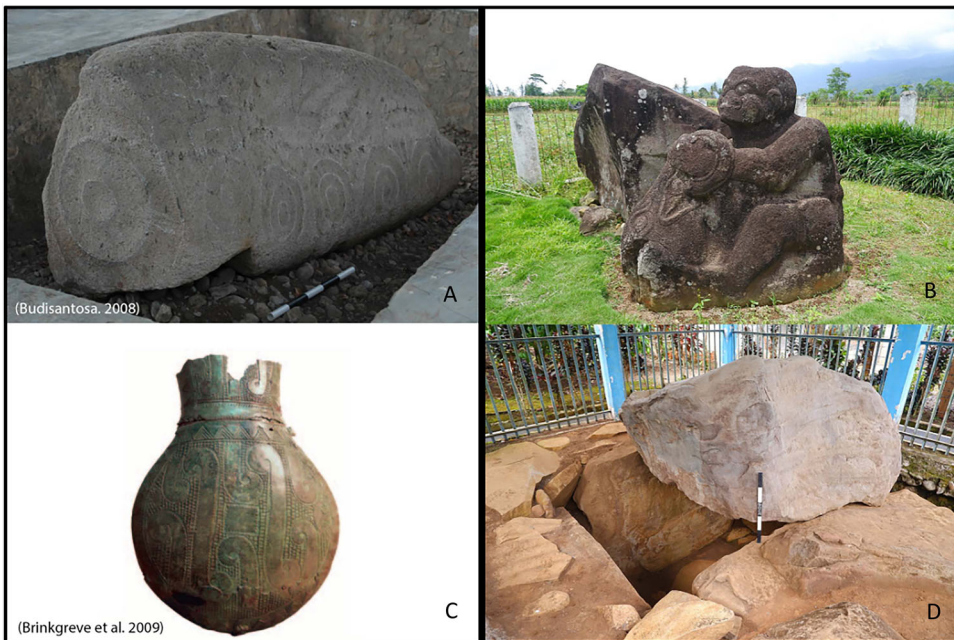
Q4 elephants, tigers, and snakes (Indriastuti et al. 2017; van der Hoop 1932; Wurjani 2015) (Figure 2). These different megalithic cultures share a number of similar imported artifacts such as glass beads, stone beads, and metals. Sumatra's highland megaliths, once broadly assigned to the Early Metal Age, have seen significant chronological revisions. Bellwood (1978) initially dated the Pasemah megaliths to the late first millennium BC but later revised this to the early to mid-first millennium AD (2017), explicitly allowing for overlap with the Srivijaya Period (seventh–thirteenth century AD). This shift reflects growing recognition of Srivijaya's potential cultural and political influence beyond coastal centers. The Kerinci megaliths further challenge earlier assumptions. Bonatz et al. (2006) dated these sites to the eleventh–thirteenth century AD, aligning them with Srivijaya's peak.

In the lowlands, the Karang Agung area comprises a group of closely spaced sites discovered in the 1980s. Wolters and Manguin suggested that this region represented the heart of the Srivijaya kingdom (Manguin 1982, 1984; Wolters 1975). Habitations in the Karang Agung area are in a tidal swamp along the Lalan River (Rangkuti 2007). Two wooden poles made from nibung tree (*Oncosperma* sp.) were radiocarbon dated to the third–fourth century AD (Manguin, 2004, 2009; Manguin, Soeroso, and Charras 2006). In Mulya Agung (part of the Karang Agung area), wooden poles were radiocarbon dated to the fourth century AD (Budisantosa 2002, 2005). Gold and tin artifacts found there, such as amulets, pendants, or necklaces, are similar to those found at the early historic site of Oc Eo, Vietnam, providing further chronological indication and connections (Hardiati et al. 2007). The site also yielded glass, semi-precious stones, and clay beads (Budisantosa 2002). Apart from these artifacts, Purwo Agung also yielded a wealth of human and animal remains, such as pig, monkey, wild boar, fish, turtle, salt-water crocodile, and birds (Rangkuti and Fauzi 2019; Wiyana 2015).

The lowland sites of Karang Agung, Karang Anyar, and Kambang Unglen (Figure 1) correspond to port-settlements where craft activities took place, including possible glass

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Figure 2. A. Cylindrical stones (*batu silindrik*) from Lolo Gedang, Jambi (Budisantosa 2008). B. Stone statues of human figures holding an elephant trunk. C. A Kerinci bronze vessel was found in 1922 (Brinkgreve and Sulistianingsih 2009). D. Stone chambers Belumai Site in Pasemah upland.

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bead making in Kambang Unglen based on the presence of raw glass fragments and unfinished tubes found in this study (Manguin 1987). Karang Agung is located in Tanahabang, Sungsang IV Village, Banyuasin II Subdistrict, Musi Banyuasin Regency, South Sumatra Province. For this study, 16 sites from the Karang Agung area were included: Karangmukti 4, Mulyaagung 2, Mulyaagung 1, Mulyaagung 4, Karyamukti 3, Karangmukti 1, Mulyajaya 1, Karyamukti 9, Mulyajaya 4, Mulyajaya 3, Mulyaagung 3, Karyamukti 4, Sukajadi 1, Karyamukti 8, Bumiagung 1, and Purwoagung. Each site has an average distance of 3 km from one another, with only Bumiagung 1 and Sukajadi 1 being quite far from each other and located 11 km away. Due to a lack of radiometric dating, the chronology of all these sites remains vague and ranges from the Prehistoric Period to the tenth century AD.

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Results

The elemental composition of 256 glass samples was measured with laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS). Most of these samples are glass beads from the lowland area of Jambi ($n=5$), the lowland area of South Sumatra ($n=245$), and a few from the upland area of Kerinci ($n=3$) and Pasemah ($n=7$) (Table 1; Figure 3). The glass beads are from the collection of the Museum Taman Wisata Kerajaan Sriwijaya (TWKS) and the Research and Innovation Agency (BRIN). All but four of the glass beads from Air Merah and Kambang Unglen were analyzed at the Institut de Recherche sur les ArchéoMATériaux (IRAMAT)—Center Ernest Babelon

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Figure 3. Glass beads from Kambang Unglen (KU), Tegur Wangi (TGW), Karang Agung (SKJ1, KYM8, KYM9, BMG1), Karang Anyar (TPK5), Geding Suro (GDS), and Sentang (SNT).

(CEB) by Nadine Schibille in 2023, while the other objects were analyzed by the Elemental Analysis Facility (EAF) at the Field Museum by Laure Dussubieux in 2024. The details about the analytical protocols in each lab are available in [Supplementary Materials A—Analytical methods](#).

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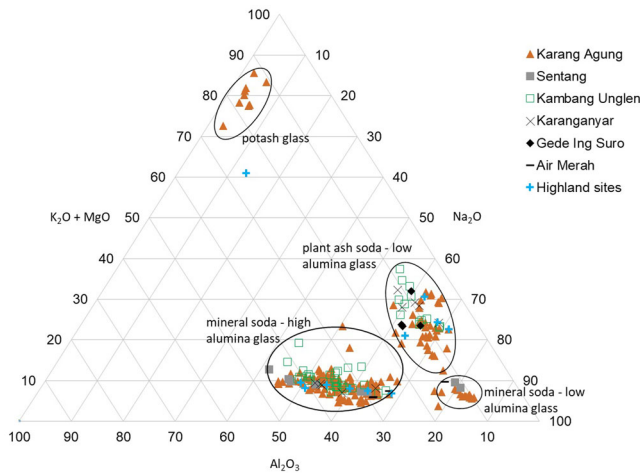


Figure 4. Triangular graph showing the proportions of alumina, soda, and potash + magnesia in the glass samples from Sumatra with the major glass groups that were identified.

Two hundred and fifty-six glass compositions are reported in [Supplementary Materials B](#)—Compositions with the major and minor elements in weight percent of oxide and the trace elements in parts per million (ppm). For each composition a description is provided of the object and the site it comes from. The compositions have high concentrations in either soda (Na_2O) or potash (K_2O) and form four major groups ([Figure 4](#)):

- the largest group includes 172 soda-rich samples with low magnesia ($<1.5\%$) and high alumina ($>5\%$) concentrations, suggesting the presence of a mineral soda–high alumina glass;
- the second largest group, with 57 samples, is also soda-rich, but has higher magnesia concentrations ($> 1.5\%$) and lower alumina concentrations ($< 4\%$). This composition is typical of the soda plant ash–low alumina glass;
- 17 soda-rich samples show low magnesia and low alumina concentrations, as found in the mineral soda–low alumina glass; and
- nine samples have a potash-rich composition and form the potash glass group.

The single bead found at Pematang Jereng is likely a European bead manufactured in Bohemia during the seventeenth or eighteenth century CE and will not be discussed any further as it is outside our chronological focus.

Mineral soda–high alumina (m-Na–Al) glass

The largest group comprises 172 soda-rich samples characterized by low magnesia concentrations ($<1.5\%$), indicating the use of mineral soda and high alumina levels ($>4\text{--}5\%$), suggesting a mineral soda–high alumina (m-Na–Al) glass composition. This type of glass is quite abundant in South Asia ([Dussubieux 2021](#)) where it was manufactured ([Brill 1987](#)) using a recipe comprising a single ingredient called reh, naturally combining a sand with a sodic efflorescence. Sub-groups were identified for the m-Na–Al glass

(Dussubieux, Gratuze, and Blet-Lemarquand 2010; Dussubieux and Wood 2021; Trivedi and Dussubieux 2022) and can be visualized with principal component analysis (PCA), including the concentrations of the following elements: magnesium (Mg), calcium (Ca), strontium (Sr), zirconium (Zr), cesium (Cs), barium (Ba), and uranium (U) to compare the compositions of the beads from Indonesia with the compositions of the five most common m-Na–Al glass sub-groups: m-Na–Al 1, 2, 3, 4, and 6 (Figure 5). To define the different m-Na–Al sub-groups, unpublished glass compositions from samples found in Sri Lanka and India (m-Na–Al 1), Chaul in Maharashtra (m-Na–Al 2; Dussubieux et al. 2008), Kopia in Uttar Pradesh (m-Na–Al 3; Dussubieux and Kanungo 2013), Sumatra, Indonesia (m-Na–Al 4; Dussubieux 2009), and Tanzania (m-Na–Al 6; Dussubieux and Wood, 2021) were used.

The majority of the m-Na–Al compositions fall within the m-Na–Al 1 group. Despite similar compositions for all the samples, the compositions in ellipse A are characterized by lower Cs concentrations, while the compositions in ellipse B have generally higher U concentrations.

Recently, subgroups were identified in the m-Na–Al 1 glass group based on the concentrations of vanadium (V) and chromium (Cr). As demonstrated in the study by Dussubieux et al. (2025), the Cr and V concentrations were found to be elevated in samples originating from eastern South India, while samples from Sri Lanka exhibited reduced concentrations. With the exception of Karang Agung, all sites have m-Na–Al 1 glass samples with higher concentrations of V and Cr indicative of a South Indian provenance. For Karang Agung, results are difficult to interpret: indeed, the concentrations of V and Cr vary in a wide range, encompassing both the areas assigned a Sri Lankan and an eastern South Indian origin. No discrete groups appear, suggesting possible mixing of the glasses from both locations (Figure 6). Those two new sub-groups (m-Na–Al 1 SL and m-Na–Al 1 ESI) are still poorly defined and additional research would be necessary to fully understand their distribution and chronology.

In the m-Na–Al 1 glass group, South Asian imitations of Roman or Islamic segmented gold-foil beads that were themselves imitations of gold beads were identified. They appear as gold-foil beads, although they do not contain any metal foil (Figure 7).

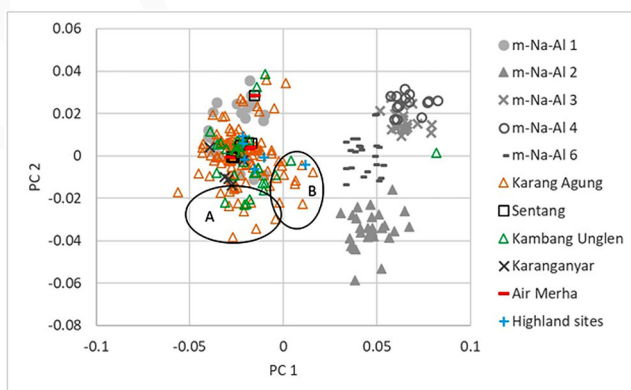
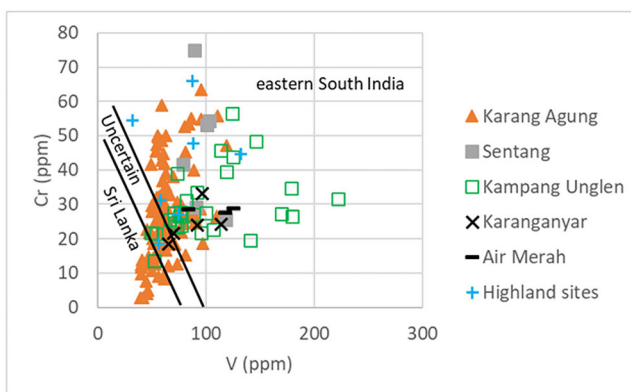


Figure 5. Scatterplot for PC1 vs. PC2 calculated for the m-Na–Al glass samples from glass groups m-Na–Al 1 (unpublished data), 2 (Dussubieux et al. 2008), 3 (Dussubieux and Kanungo, 2013), 4 (Dussubieux, 2009) and 6 (Dussubieux and Wood, 2021). PC1 accounts for 61.6% of the variability of the dataset and PC2 for 14.7%.

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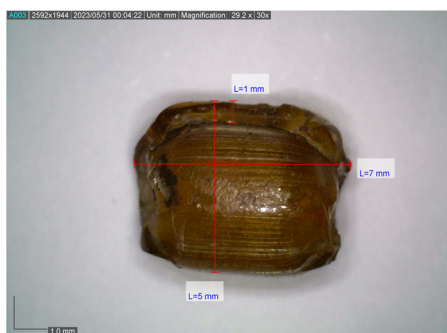
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464 **Figure 6.** V and Cr biplot for the m-Na-Al 1 samples from the different sites under study.

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477 **Figure 7.** A gold-foil-looking glass bead from Kambang Unglen (photo H. Sofian).

479 They are manufactured with two layers of amber glass, producing a golden color, and individual beads were obtained by pinching a tube of hot softened glass at regular intervals. Beads with similar features were found at the site of Pengkalan Bujang, Malaysia, dating from the eleventh to the fourteenth century AD (Dussubieux, Larson, and Landau 2025).

486 **Soda plant ash–low alumina or v-Na–Ca glass**

487 The second largest group consists of 57 soda-rich samples with relatively high magnesia concentrations (>1.5%) and lower alumina levels (<4%), typical of a soda plant ash–low alumina glass composition. The soda plant ash glass was prevalent in the Middle Eastern region from the Late Bronze Age (see Shortland et al. 2018) throughout the Sasanian Period (Mirti et al. 2008, 2009) and the Islamic Period (Phelps, 2018; Schibille et al. 2019). Around the eighth century AD, the diffusion of soda plant ash glass occurred concomitantly with the expansion of Arab trade, particularly around the Indian Ocean.

495 PCA was undertaken with the following elements: Mg, phosphorus (P), Ca, rubidium (Rb), Cr, and lanthanum (La) (Dussubieux, Larson, and Landau 2025), including comparative data from Sasanian and post-Sasanian samples found at Kish, of assumed Mesopotamian origin (Dussubieux 2023) and some samples from Quseir Al-Qadim in Egypt from the fourteenth century AD (Dussubieux 2017). The results of the PCA are illustrated in Figure 8.

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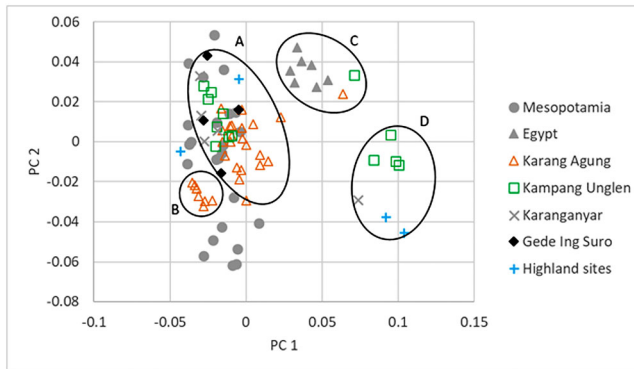


Figure 8. PC 1 and 2 calculated using Mg, P, Ca, Cr, Rb and La for two groups of reference glass compositions thought to be typical of Mesopotamia (Dussubieux 2023) and Egypt (Dussubieux 2017) and for the glass beads from Indonesia.

Groups A and B fall into the area of the Mesopotamian glass, two samples are close to the Egyptian glass group (C), and a number of samples form a separate group with an unknown provenance (D). Group B differs from group A by lower concentrations of a number of elements, including aluminum oxide (Al_2O_3), titanium (Ti), V, Rb, Zr, neodymium (Nd), etc., suggesting that a purer sand was used for this group compared to group A. Most of the beads in group B are dark blue and contain cobalt (Co) as a coloring agent. One bead is opaque and red. Those beads have different shapes and sizes and do not form a homogeneous group of objects. The two beads in the Egyptian group are KU008 (from Kumpang Unglen; Figure 3), a dark, drawn, and segmented bead, and KYM3-4 (from Karang Agung), a colorless, drawn, and segmented bead. Group D includes KU05IN, KU05OUT (from the same bead), and KU06, which are both segmented gold-foil beads. TPKS02, KU32, and TNS1 are quite large turquoise blue beads that were drawn and segmented. TNS1 might have some longitudinal grooves, although the fragmented aspect of this bead makes this uncertain. The last sample in this group is PSN. It is a turquoise blue bead that seems to have been wrapped and was shaped like a long bi-pyramid with a square section.

From a general point of view, the v-Na-Ca glass objects include a rather important quantity of dark blue glass objects containing cobalt. However, it is interesting to note that dark blue glass containing cobalt beads are neither found in Kambang Unglen nor the upland sites. In contrast, they form two-thirds of the v-Na-Ca glass objects from Karang Agung. Two out of the five v-Na-Ca glass samples from Karanganyar are dark blue. Dark blue glass beads with cobalt are absent from the m-Na-Al 1 glass group.

Mineral soda-low alumina glass

Eighteen soda-rich samples exhibit low magnesia (MgO) and alumina (Al_2O_3) concentrations—typically lower than lime (CaO)—a composition characteristic of mineral soda-low alumina glass. These samples also show low potassium oxide (K_2O) levels.

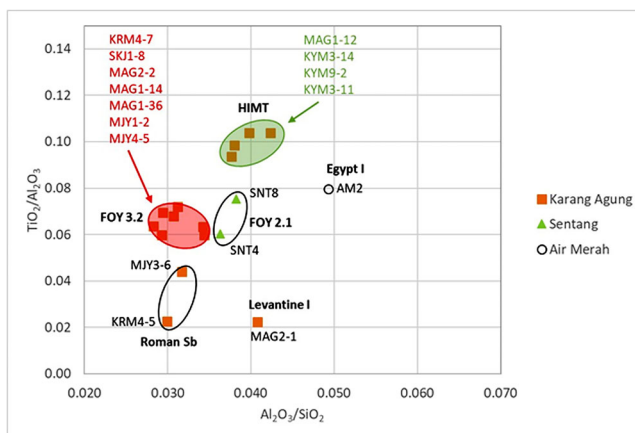


Figure 9. $\text{Al}_2\text{O}_3/\text{SiO}_2$ vs $\text{TiO}_2/\text{Al}_2\text{O}_3$ for the glass samples thought to have been manufactured from mineral soda and low alumina sand.

Table 2. Mineral soda–low alumina natron glass from Sumatra.

Site	Nb	Composition	Estimated date
Karang Agung	2	Roman Sb	First–fourth century CE
	5	High Iron–Manganese–Titanium or HIMT	Fourth–fifth century CE
	1	Levantine I	Sixth–seventh century CE
	7	Foy 3.2	Fourth–fifth century CE
Sentang	2	Foy 2.1	Fifth–seventh century CE
Air Merah	1	Egypt I type C	Eighth century CE

Recent research has distinguished several sub-groups for mineral soda–lime glass manufactured from natron during the first millennium CE. They were correlated with an Egyptian or Levantine origin and belong to different periods (Freestone et al. 2020; Schibille 2022). Among the beads from Indonesia, six different sub-groups were identified (Figure 9; Table 2; Supplementary Materials—Comparison Roman Glasses). The overwhelming majority of them were from Egypt, with the exception of the Levantine I sub-group.

A significant number of glass objects in this group are dark blue and colored with cobalt with some exceptions. Sample MJY3-6 is a segmented gold-foil bead and KRM4-5 is a turquoise blue drawn bead that looks similar to what is made in India. In the Foy 3.2 group, all but one of the beads (MAG2-2) are dark blue with different shapes and sizes. MAG2-2 is a segmented gold-foil bead.

The two Foy 2.1 beads from Sentang are small drawn and dark blue, and also look like the beads made in India. In the HIMT glass group, MAG1-12 and KYM9-2 are large dark blue beads while KYM3-11, 12, and 14 are small drawn beads also looking like Indian beads.

Potash glass

Nine samples from Karang Agung have a potash-rich composition. Typically, this glass type contains around 15% of potash while soda and magnesia concentrations are below 1%. The concentrations of lime and alumina vary widely, and were used to identify three distinct sub-groups (Dussubieux and Gratuze, 2010; Lankton et al. 2008):

- low lime–high alumina potash glass (m-K–Al),

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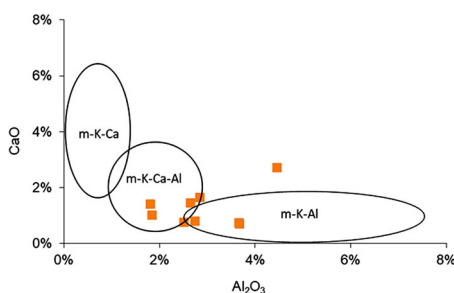


Figure 10. Al₂O₃ and CaO concentrations for the four potash glass samples found at Karang Agung. The ellipses were traced based on Dussubieux and Gratuze (2010, Table 2, p. 251).

- low alumina–high lime potash glass (m-K–Ca),
- moderate lime and alumina potash glass (m-K–Ca–Al).

The distribution of the potash glass encompasses South Asia, Southeast Asia, and China with most of the moderate lime and alumina sub-type found in South Asia, while the low lime–high alumina variety is more common in China. Both sub-types are present in Southeast Asia where the low alumina–high lime glass is also available, generally associated with fairly early contexts. The samples from Karang Agung fit in either the m-K–Al or the m-K–Ca–Al, as expected for potash glass from Southeast Asia (Figure 10). With one exception, they are all some shades of blue and contain significant concentrations of manganese (MnO = 1.2–2.1%), and cobalt (185–518 ppm). The existence of multiple sub-groups lends support to the hypothesis that potash glass was produced in multiple locations, with Northern Vietnam and China as possible place of manufacture (Brill and Fullagar, 2009; Dussubieux and Pryce, 2016; Li 1999).

m-Na–Ca–Al glass

A single bead from Karang Agung, sample PWA-1, possibly belongs to the mineral soda glass with moderate amounts of lime and alumina. More details about this glass type can be found in Dussubieux et al. (2012) and Dussubieux and Gratuze (2003). The m-Na–Ca–Al glass has been identified at South Indian and Southeast Asian sites, with a general dating range from 300 BC to 400 AD (Dussubieux et al. 2012).

As for the m-Na–Al 1 glass, subgroups were identified based on the concentrations of V and Cr in the m-Na–Ca–Al glass. The concentrations of these elements are notably higher in samples originating from India, while samples from Sri Lanka exhibit lower concentrations (Dussubieux et al. 2025). Sample PWA-1, with a vanadium concentration of 73 ppm and a chromium concentration of 12 ppm, fits into the Sri Lankan group.

Discussion

Dating implications

A large proportion of the glass compositions in this study belong to m-Na–Al 1, which can be found in Southeast Asia from around the beginning of the Common Era to the beginning of the second millennium AD. Due to the wide age range of this glass type,

651 it is not very useful in terms of chronology. The second most abundant glass type is the
652 v-Na-Ca glass, which is also quite early (turn of the millennium), but also later, starting
653 from about the eighth or ninth century AD. The natron, potash, and m-Na-Ca-Al
654 glasses are more closely dated. The potash and m-Na-Ca-Al glasses have generally dis-
655 appeared by the middle of the first millennium AD, and quite possibly earlier. For
656 Karang Agung, chronological information can be gleaned from the two Roman antim-
657 ony (Sb) glass beads, dated to the first–fourth century AD, and other natron glass beads
658 dated to the fourth–fifth century AD. The identification of these two types of Roman
659 glass supports the idea that the occupation of this site may have begun during the first
660 half of the first millennium AD.
661

662 Sentang yielded some natron glass samples dated from the fifth to the seventh cen-
663 tury AD, supporting the hypothesis of a pre-Srivijaya dating, but appears to lack the
664 earliest component (pre-mid-first millennium AD) identified at Karang Agung.
665 The large difference in the number of samples tested between the two sites may explain
666 the narrower range of compositions found at Sentang. Karanganyar and Kambang
667 Unglen do not feature any of the unambiguous early glasses (potassium (K), Roman,
668 m-Na-Ca-Al), supporting a later dating compared to the two previously discussed sites.
669

670 As far as the upland sites are concerned (except for Pematang Jering), they all yielded
671 either m-Na-Al 1 and/or v-Na-Ca glasses. The absence of natron, potash, and m-Na-
672 Ca-Al glass in this part of the island makes it unlikely that these glass beads are earlier
673 than the Srivijaya Period. Pematang Jering will be excluded from the discussion as the
674 only bead analyzed from this site is more recent, seventeenth–eighteenth century AD, a
675 period outside the focus of this report.
676

677 **Exchange systems**

678 ***Between upland and lowland***

679 The results of glass bead analysis provide data that lend support to the model of
680 exchange between upland and lowland groups during the Srivijaya Period. However, it
681 is important to emphasize that the conclusions are limited and possibly biased due to
682 the difference in the number of beads between the upland and lowland sites and among
683 the upland sites, for which only a small number of specimens were available for ana-
684 lysis. The upland groups at Tegur Wangi yielded a greater number of beads ($n=7$)
685 than the upland groups at Pematang Sungai Nilo and Tanjung Sri, where only one and
686 two beads, respectively, were analyzed. Nevertheless, the similarity in the bead composi-
687 tions between the upland sites and the lowland coastal sites of the Srivijaya Period is
688 consistent with links between lowland and upland sites during the Srivijaya Period. This
689 result does not imply that lowland and upland areas were not connected in the earlier
690 period, but the data we have do not provide evidence of this.
691

692 ***South Sumatra inter-regional maritime networks***

693 To understand the inter-regional connections between the Sumatran coastal sites
694 included in this study and other sites in Southeast Asia, we consider a number of con-
695 temporary sites with glass beads analyzed for their elemental composition. Karang
696 Agung and Sentang are specifically compared with Kuala Selinsing, Malaysia, second-
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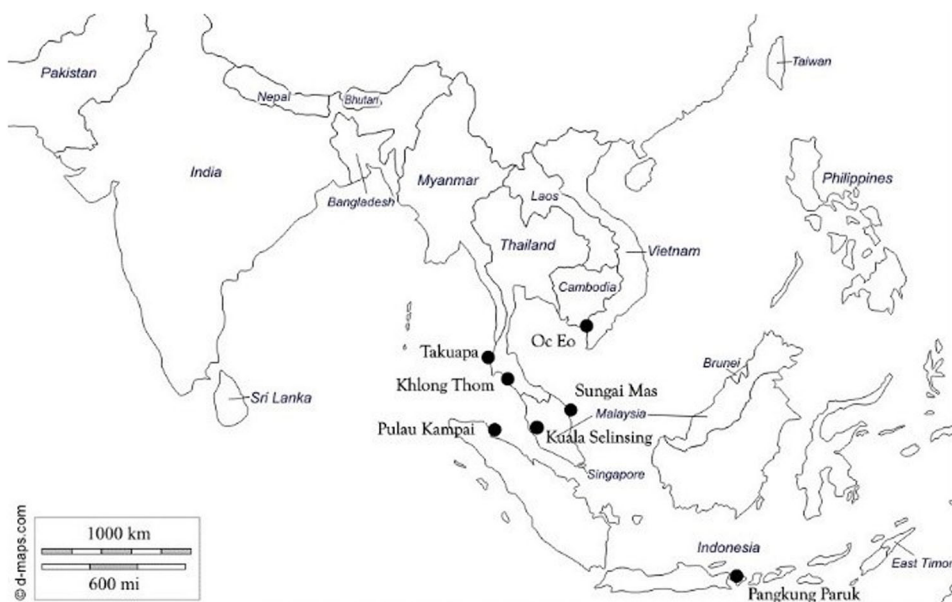


Figure 11. Map including sites mentioned in the discussion.

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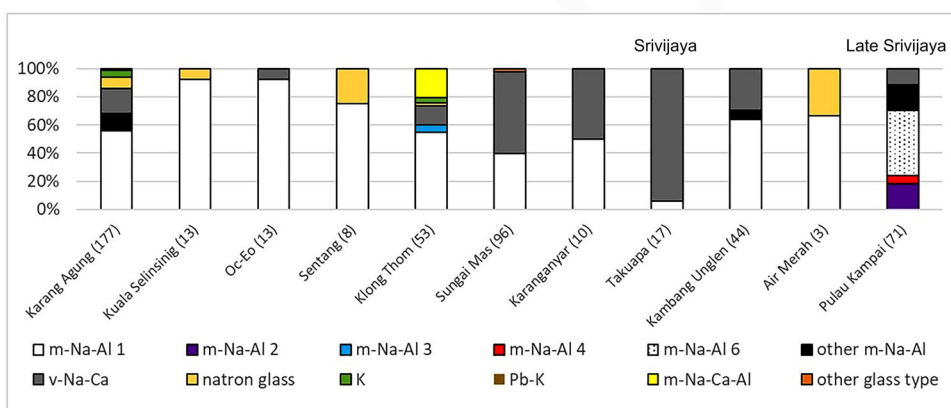


Figure 12. Proportions of the different glass types for a number of sites in Southeast Asia including the ones in this study.

Q32

eighth century AD (Dussubieux, Larson, and Landau 2025; Ramli, Rahman, and Hasan 2017), Oc Eo, Vietnam, second–seventh century AD (Carter et al. 2020; Manguin and Stark 2022; Minh Tri Bui 2023), and Klong Thom, first millennium AD (unpublished data). Karanganyar, Kambang Unglen, and Air Merah are compared with Sungai Mas, Malaysia (ninth–eleventh century AD) (Dussubieux and Allen 2014) and Takuapa (Chaisuwan, 2011; Dussubieux, Larson, and Landau 2025). We also added the site of Pulau Kampai, which is slightly later than the sites in this study, eleventh–fourteenth century AD, but is located also on the island of Sumatra (Dussubieux and Soedewo 2018; see Figure 11 for site locations). Additional sites have yielded beads that were studied using their elemental compositions, but the proportions of each glass type were

751 not published so the sites could not be added to [Figure 12](#). This is the case for the late
752 prehistoric site of Pangkung Paruk (Calo et al. 2020), which yielded beads in burial con-
753 text that included a number of gold-foil beads made from a natron glass manufactured
754 in Egypt between the first and the fourth century CE. Although only two gold-foil beads
755 were analyzed, a total of 43 similar beads were found. No composition is available in
756 the article, but based on the description, it seems that m-Na-Ca-Al and possibly m-
757 Na-Al 1 glass beads were found at that site.
758

759 ***Inter-regional maritime networks during the pre-Srivijaya Period***

760 In the pre-Srivijaya lowland site of Karang Agung, the glass compositions are consistent
761 with those observed at other Southeast Asian sites, including Kuala Selinsing, Khlong
762 Thom, and Oc Eo. At these sites, a significant proportion of the glass falls within the
763 m-Na-Al 1 category, accompanied by the presence of v-Na-Ca and/or natron glass. At
764 Oc Eo, no Roman glass beads were analyzed (only m-Na-Al 1 and v-Na-Ca glasses
765 were identified there), but it is likely that they were present, as Malleret (1962) reports
766 on gold-foil beads that are usually from the Mediterranean area. Khlong Thom exhibits
767 a more intricate glass profile, characterized by a higher proportion of m-Na-Ca-Al glass
768 compared to the specimens from Sumatra, Vietnam, and Malaysia. However, this dis-
769 crepancy is attributable to the geographical location of Khlong Thom along the Bay of
770 Bengal, where this particular glass is prevalent (Dussubieux et al. 2012, 2020).
771

772 It is noteworthy that this study has revealed a substantial number of early Roman
773 glass beads ($n=18$). The dating of these beads spans a considerable time period, rang-
774 ing from the first to the fourth century AD, to the eighth century AD. The presence of
775 Roman glass beads at the Pangkung Paruk site has also been reported by Calo et al.
776 (2020), with a total of 43 glass beads identified. Roman glass is found in two prominent
777 forms: either gold-foil beads or dark blue colored beads. The soda plant ash glass (from
778 the Middle East) is also overwhelmingly dark blue, and v-Na-Ca gold-foil beads were
779 also identified. It is important to keep in mind that the m-Na-Al 1 glass is not available
780 in dark blue, and cobalt, a key component in the production of this blue glass, is not
781 among the coloring agents employed with the m-Na-Al 1 glass. This observation sug-
782 gests that the importation of these beads from western regions may have been a stra-
783 tegic effort to address a specific market demand in Southeast Asia. A noteworthy
784 observation is the imitation of gold-foil beads by some of the m-Na-Al 1 glass beads.
785 This imitation can be interpreted as a response to the prevailing appeal of Roman and
786 Middle Eastern gold-foil beads, offering a more accessible and economical alternative.
787
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791 ***South Sumatra inter-regional maritime networks during the pre-Srivijaya Period***

792 For the later sites, dating from the Srivijaya Period comparative data are scarce. The
793 sites of Takua Pa in Thailand (eighth–ninth century AD) and Sungai Mas in Malaysia
794 (ninth–eleventh century AD) are roughly contemporary with the Srivijaya sites of this
795 study (Karanganyar, Kambang Unglen, and Air Merah). The glass material at these two
796 sites consists of more than half v-Na-Ca glass, which is indicative of the significant
797 influence of Islamic trade on Southeast Asia, particularly from the seventh to the eighth
798 century AD. The influx of glass beads from the Middle East is more significant than
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800

that of beads from Egypt and the Levant observed in earlier periods. However, the same type of material, dark blue (Co-colored) beads, were imported. The other glass beads, predominantly manufactured from m-Na-Al 1 glass, are not yet available in this color, which appears to have been as popular at the end of the first millennium AD as it was earlier. In contrast, the later site of Pulau Kampai (eleventh–fourteenth century AD) exhibits a markedly divergent glass composition, featuring significant proportions of m-Na-Al 2 and six glass groups, accompanied by a smaller proportion of soda plant ash glass. It appears that a shift occurred, with Indian production becoming more prominent in comparison to soda plant ash glass. This finding lends further support to the hypothesis that the Srivijaya sites were active during earlier periods than Pulau Kampai and did not overlap chronologically with this later Indonesian site.

Kambang Unglen: A production site of glass beads

Kambang Unglen is distinctive among the sites examined in this study (Manguin 1987). Indeed, it yielded evidence for glass working involving raw glass chunks and unfinished tubes with a m-Na-Al 1 and a v-Na-Ca composition. This finding suggests that the site may have functioned as a center for the production of glass beads. This finding is of significance as it represents the first identification of a glass bead manufacturing site in Sumatra. However, it remains uncertain whether the beadmakers in Kambang Unglen procured raw glass from South Asia and the Middle East to make the beads, or whether they recycled glass objects. Notably, despite the substantial number of glass samples analyzed for Kambang Unglen ($n = 49$), there is a striking absence of v-Na-Ca glass colored with cobalt (although gold-foil beads were present), contrasting significantly with the observations at the other sites included in this study.

Conclusion

This extensive preliminary study of glass beads from South Sumatra, despite its limitations, provides some important new insights. First, it has enabled the dating of a number of prehistoric and historic sites to be clarified. Distinctive glass patterns were identified at pre-Srivijaya and Srivijaya sites with the presence of Roman, potash, and m-Na-Ca-Al glass at the earliest sites, and usually a combination of m-Na-Al 1 and v-Na-Ca glass at the later ones.

The analysis of the available data also indicates that the upland–lowland network was operational during the Srivijaya Period. It is possible that the network was active prior to this, however, the data from upland sites do not provide information on this period. During the pre-Srivijaya era, South Sumatra was part of a global exchange network that also encompassed Bali, the Mekong Delta, and the Thai–Malay Peninsula. There is a possibility that Java was also involved though this study does not include glass from that region.

Prior to this, there had been isolated evidence for links between Sumatra and Vietnam, northern Vietnam, and the Dong Son drums, and the Mekong delta with intaglio and face masks at Gion Lon (Lâm Thị Mỹ Dung 2023; Trương Đắc Chiến 2017). Evidence has also been found between the Thai–Malay peninsula and the

851 Mekong delta. Chinese sources provide a historical account of the supposed conquest of
852 Thai–Malay city-states by the Funan ruler, which is believed to have occurred by the
853 third century AD (Pellicot 1903). Subsequent accounts refer to the influence Srivijaya
854 exerted on the Thai–Malay peninsula by Srivijaya (Cœdes 1918). The links and competi-
855 tion between the three exchange nodes must be more significant than the still scarce
856 data as comparative studies suggest. These early connections merit further investigation.
857 Research into connections within Southeast Asian port-settlements has received com-
858 paratively less attention than research focusing on links with South Asia and the
859 Mediterranean world.
860

861 A further research avenue could be to understand the organization of these early
862 first-century port sites in South Sumatra, and to what extent they share elements with
863 other similar sites in the Thai–Malay Peninsula and in the Mekong Delta. A further line
864 of enquiry would be to determine whether these sites also functioned as centers for a
865 wide range of craft activities, such as bead-making and metalworking workshops. The
866 production of goods for exchange with surrounding and upstream groups would have
867 been facilitated by these activities. The relationship between these early port-settlements
868 and the question of whether they constituted a single political entity is another potential
869 avenue for exploration, with bead production systems offering a valuable source of data
870 for this analysis.
871

872 As far as the Srivijaya Period is concerned, glass beads were made in Kambang
873 Unglen in the Palembang area using imported glass from the southern Indian subcon-
874 tinent and the Middle East. The distribution area of the beads produced in the
875 Kambang Unglen workshop will perhaps be determined by future research.
876 Concomitant study of the bead industry with other industries may also engender
877 enhanced comprehension of the economic and political organization of the Srivijaya.
878
879

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887

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890
891

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895
896

897 **Data availability statement**

898 All data relevant to this manuscript were placed in [supplementary materials](#).
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