Glass Exchange and Changing Networks at Phromthin Tai, Central Thailand

Xu Siwen,[1] **Thanik Lertcharnrit**[2] **& Yang Yimin**[3]

Abstract—This study examines glass beads from Unit S4 at Phromthin Tai (PTT), Lopburi, to investigate changing exchange networks during the transition from the early to later first millennium CE. LA-ICP-MS analysis shows that the assemblage is dominated by m-Na-Al 1 glass associated with southeastern India, while m-K glass, linked to South China Sea exchange networks, occurs only in a few earlier contexts. Comparison with the previously published S3 assemblage reveals a marked shift from m-K glass toward South Asian m-Na-Al glass within the Mekong Interaction Sphere. The identification of v-Na-Ca glass further expands the compositional diversity of the PTT assemblage.

Keywords: Compositional Analysis; Exchange Networks; Glass Beads; LA-ICP-MS; Late Iron Age–Early Historic Transition; Phromthin Tai

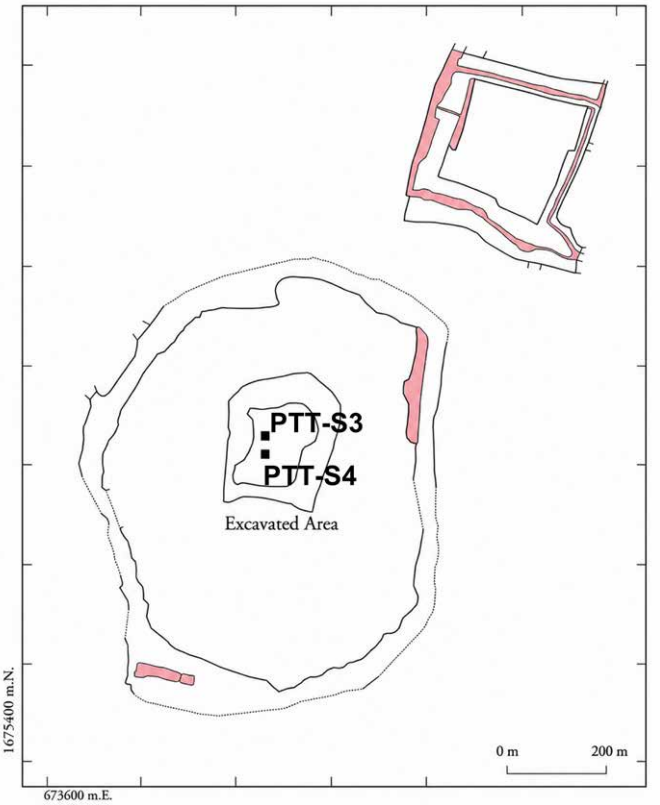
Introduction

Glass beads are important indicators of exchange, craft technology, and social interaction in Iron Age Southeast Asia. From the second half of the first millennium BCE, communities in the region became increasingly connected through networks linking South Asia and East Asia. Compositional studies have shown that different glass types, including mineral potash (m-K) glass, mineral soda-alumina (m-Na-Al) glass, mineral soda-lime-alumina (m-Na-Ca-Al) glass, and others, circulated through distinct exchange systems (e.g., Carter 2015; Dussubieux et al. 2024). The m-K glass is often associated with earlier South China Sea exchange networks, while m-Na-Al glass became more widespread in later regional exchange systems, including inland routes connected with the Mekong Interaction Sphere (e.g., Bellina 2015).

Ban (village) Phromthin Tai (พรหมทินใต้; PTT), located a short distance north of the city of Lopburi, central Thailand, is a key site for investigating these changing networks **[Map 1]**. Its long occupation from the Late Bronze Age (700–500 BCE) to the late first millennium CE and its position near important metal working areas, suggest that the community was well placed to participate in regional interaction. Previous research by Alison Carter et al. (2022) analyzed glass artifacts mainly from excavation unit PTT-S3 and identified a diverse assemblage dominated in burial contexts by m-K glass, alongside m-Na-Al glass and other less common compositions dating to Early and Late Iron Age periods (500 BCE–500 CE). Lankton & Dussubieux (2013) first identified a chronological shift from m-K glass to m-Na-Al glass

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Map 1: The moated site of Phromthin Tai with excavated units S3 and S4
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during the first millennium CE. Building on this observation, the study on PTT-S3 glass linked Phromthin Tai to both earlier South China Sea exchange routes and later inland networks.

However, glass beads from PTT-S4 remain poorly studied **[Figure 1]**. By conducting a compositional analysis of beads from this excavation area and comparing the results with those previously reported for PTT-S3, this study reassesses whether different sectors of the site reflect changing access to glass, evolving exchange networks, and similar temporal shifts in bead circulation. The aim is to refine our understanding of Phromthin Tai's role in glass exchange networks in central Thailand and mainland Southeast Asia during the transition from the Late Iron Age to the Early Historic period.

Glass Materials

There are two main excavation units at the site of Phromthin Tai, namely PTT-S3 and PTT-S4. Since 2004, systematic excavations directed by Thanik Lertcharnrit (Department of Archeology, Silpakorn University) have demonstrated that the site was occupied from the Late Bronze Age to the mid-late first millennium CE (Thanik 2014). Each unit measures 6x6 meters in size and they are situated near each other: PTT-S3 unit is located one meter north of PTT-S4. PTT-S3, excavated in 2007, contains 35 burials representing 36 individuals (2200–1800 BP), while five subsequent excavation seasons conducted between 2009 and 2019 uncovered a further 34 burials in the adjacent PTT-S4 unit. Although comprehensive ^{14}C dating has not yet been undertaken, the chronology of the cemetery is primarily based on stratigraphic relationships and associated archeological materials, with the S4 burials generally assigned to the Late Prehistoric and Early Historic periods (6th–8th c. CE). Both units yielded similar cultural deposits, including burials, copper-smelting debris (e.g., slag and fragments of clay molds), beads, polished stone tools, ceramic sherds, and metal objects. However, regarding burials, there are some differences in terms of grave goods; PTT-S3 yielded more stone beads, while PTT-S4 burials are associated with more glass beads and ceramic vessels.

Based on their size and color, a total of 30 glass beads from PTT-S4 were selected for analysis in this study **[Fig. 1]**. As presented above, most m-Na-Al glass



Figure 1: Glass beads analyzed from PTT-S4; the scale bar is 2 mm © Xu Siwen

beads were recovered from contexts dating to the 6th to 8th centuries CE. However, a few m-K glass beads were recovered from deeper stratigraphic contexts, suggesting that they may have been deposited during an earlier phase of site occupation. Most beads are monochromatic, whereas PTT-10 and PTT-26 are composite beads consisting of a red glass core surrounded by an outer layer of orange glass.

Methods

The chemical composition of the glass beads from PTT-S4 was analyzed by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) at Beijing Createch Testing Technology Co., Ltd. LA-ICP-MS was composed of an ICP-MS (AnalytikJena PQMS) and a matching RESOlution 193 nm laser ablation system. The laser ablation was set with a spot beam diameter of 38 μm, frequency of 5 Hz, and energy density of 5 J/cm^2. High-purity helium was used as the carrier gas. The analysis process consisted of 3 seconds (s) preablation to remove the corrosion layer, 15 s background, 45 s ablation time, and 25 s purging time. Five standard reference materials were used to calculate the chosen elements: NIST 610, NIST 612, and Corning reference glasses A, B, C and D. We referred to the data from Pearce et al. (1997) to determine the concentrations of minor and trace elements. The relative standard deviation of major elements is mostly lower than 3%, while that of trace elements is mostly lower than 9%. The relative error of major elements is mainly ±5% and that of trace

Table 1: Distribution of glass type in PTT-S3 and S4

Glass type	S3	S4
m-Na-Al	19	20
m-K	27	6
m-Na-Ca	1	2
v-Na-Ca	–	2
m-Na-Ca-Al	9	–

element ranges mainly ±10%. The standard reference materials and accuracy used for calibration are nearly identical to those from the analysis in the Field Museum of Natural History in Chicago, USA (Dussubieux & Bellina 2018; Then-Obłuska & Dussubieux 2023), thereby ensuring the comparability of the compositional data.

Glass Types and their Origins

The complete composition data of all the samples from PTT-S3 and PTT-S4 are presented in **Online Appendix Table S1**.[4] Based on their flux types, four glass groups were identified and compared in the following summary **Table 1**.

The m-Na-Al Glass

The dominant group from PTT-S4 is m-Na-Al, accounting for 67% of the analyzed assemblage. The m-Na-Al beads are characterized by high Na2O (10.79%–19.58%) and Al_2O_3 (4.30%–12.60%) contents and low MgO (0.21%–1.02%) contents. Based on the characteristics of Ca, Ba, U, Sr, Zr elements, m-Na-Al glass can be divided into multiple subtypes, which correspond to different regions and chronological periods (Dussubieux & Wood 2021). All these beads have low U (4.09–19.99 ppm) and high Ba (264.50–1341.00 ppm), Sr (156.79–556.85 ppm), and Zr (282.43–1094.90 ppm) contents, broadly comparable to m-Na-Al 1 subtype classified by Dussubieux et al. (2010), which is characterized by U (1–21 ppm), Ba (499–1363 ppm), Sr (228–518 ppm), and Zr (141–981 ppm). The production of this subtype of glass is generally considered to have been concentrated in South Asia. Based on isotopic and trace element analyses, Dussubieux et al. (2025) further demonstrated compositional differences between glass manufactured in southeastern India and that produced in Sri Lanka. Most of the m-Na-Al 1 glass unearthed at PTT-S4 falls within the characteristics typical of production in southeastern India. The m-Na-Al 1 glass from PTT-S3 (Carter et al. 2022) exhibits a similar compositional distribution, suggesting that the two adjacent sectors may have participated in the same trading network **[Figure 2]**.

Notably, one orange bead (PTT-26), consisting of a red glass core surrounded by an outer orange layer, shows higher P_2O_5 (1.56% and 1.61%) and MgO (2.43% and 2.44%) contents. The elevated MgO

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and P_2O_5 contents are unlikely to reflect the use of plant ash as a primary flux, but probably resulted from components introduced during secondary glass working associated with the addition of copper colorants (Dussubieux et al. 2013). Similar orange glass beads have also been reported from Non Ban Chak (โนนบ้านจาก), Udon Thani province, northeast Thailand (Dussubieux et al. 2024).

The color range of PTT-S4 m-Na-Al 1 glass is very wide, including blue, black, yellow, green, orange, red, and amber. Blue samples generally contain elevated Cu, while black samples contain iron in the range of 1.46%–2.84%. Their characteristic black color, despite this relatively low iron concentration, is likely attributable to Fe-S chromophores rather than iron oxides. This coloring mechanism has been documented in black glasses from Thai and Burmese archeological sites (Dussubieux et al. 2020, 2024; Xu et al. 2025). The amber-colored glass contains a high concentration of Fe_2O_3, suggesting that its coloration is primarily attributable to Fe ions. Both the yellow and green glasses contain elevated concentrations of PbO and SnO_2, consistent with the intentional addition of lead tin yellow type II as an opacifier (Xu et al. 2022a). The green glass further exhibits a significantly higher Cu content; the combined effect of Cu and lead tin yellow type II particles is responsible for the observed green hue. The red and orange samples are enriched in Cu, Fe, and Pb. In particular, the orange sample exhibits markedly elevated Cu and Pb contents, creating favorable conditions for the precipitation of cuprite (Cu_2O) (Bandiera et al. 2020), which is likely responsible for its distinctive coloration.

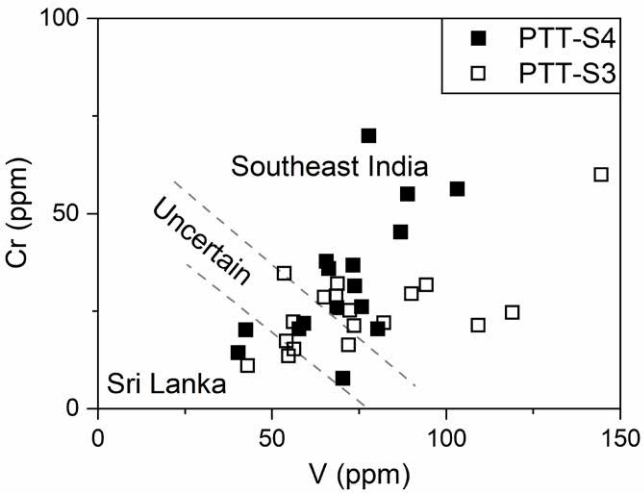


Figure 2 The potential origin of m-Na-Al glass from PTT-S3 and PTT-S4. Data of PTT-S3 from Carter et al. 2022 © Xu Siwen

However, LA-ICP-MS analysis detected no significant compositional differences between the red and orange areas of sample PTT-26. The color contrast is therefore likely related to variations in the size of internally precipitated crystalline particles rather than differences in bulk chemical composition (Theja et al. 2014).

The m-K Glass

The m-K glass is characterized by elevated K_2O and low MgO concentrations, reflecting the use of mineral-derived potash as the alkali source. Although its exact production centers remain uncertain, geochemical and archeological evidence indicate that this glass tradition was widely distributed across mainland Southeast Asia and southern China during the late first millennium BCE and early first millennium CE (Dussubieux 2016). It formed an important component of the South China Sea exchange networks.

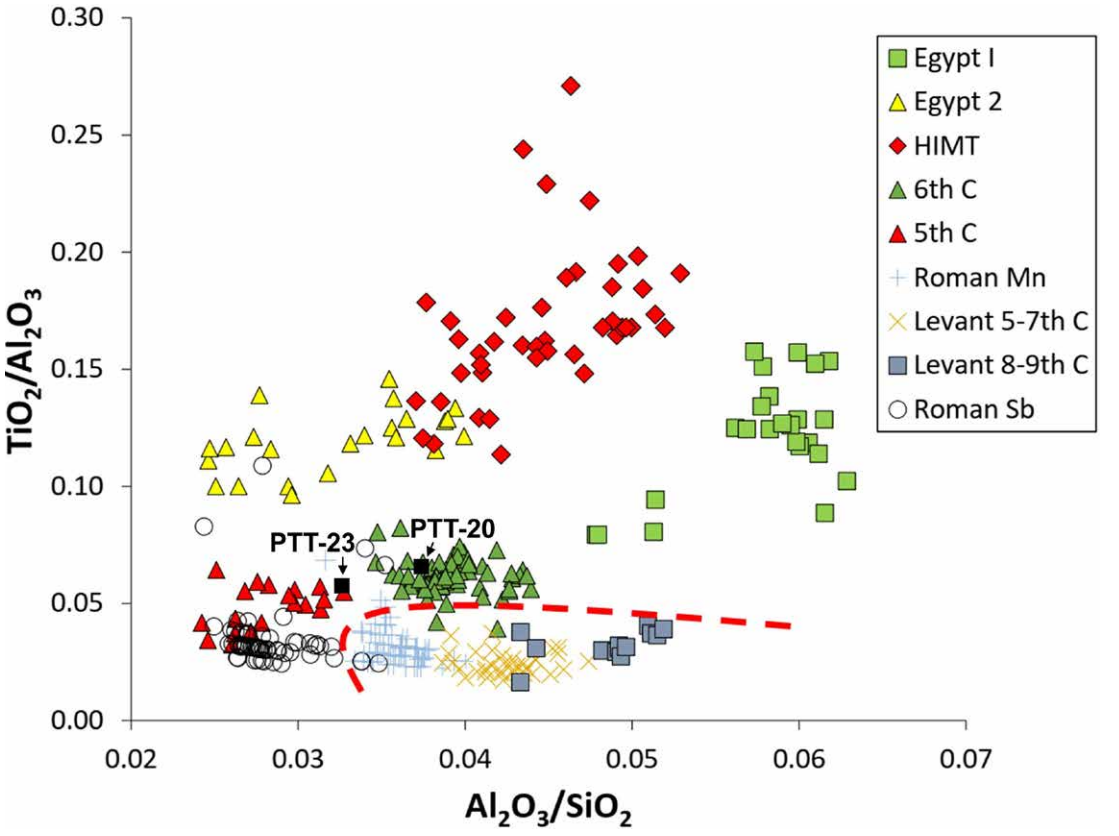


Figure 3: Classification of m-Na-Ca glass. The dashed line marks the approximate compositional boundary between Egyptian glasses (upper left and right) and Levantine glasses (lower right). HIMT = High Iron Manganese Titanium © Xu Siwen, adapted from Freestone 2021

Potash glass is present but less common in the samples analyzed. Four dark blue samples belong to the m-K-Al subtype, with high K_2O contents ranging from 10.40% to 13.50%, Al_2O_3 between 3.24% and 4.23 % and low CaO between 0.61% and 1.05%. Two additional blue samples belong to the m-K-Ca-Al subtypes, with higher CaO (1.24%–2.94%) and lower Al_2O_3 (0.94%–2.27%). In contrast to the more abundant m-K glass identified in PTT- S3 (Carter et al. 2022), m-K glass from PTT-S4 occurs only in small quantities. Most of these beads (except for PTT-13) were uncovered from the deeper stratigraphic contexts **[Online Appendix Table S1]**, indicating that they belong to earlier phases. This chronological distribution suggests a decline in the use of m-K glass and its eventual disappearance during the Late Iron Age.

The four dark blue glass samples are colored with cobalt and exhibit markedly elevated concentrations of manganese and barium. The cobalt source is identified as a Co-Mn-Ba type, which was the dominant cobalt pigment employed in Iron Age cobalt blue glass production across Southeast Asia (Dussubieux 2016).

The m-Na-Ca glass

The m-Na-Ca glass originated in the Mediterranean region and was widely distributed from the 8th century BCE to the 8th century CE. It has been identified

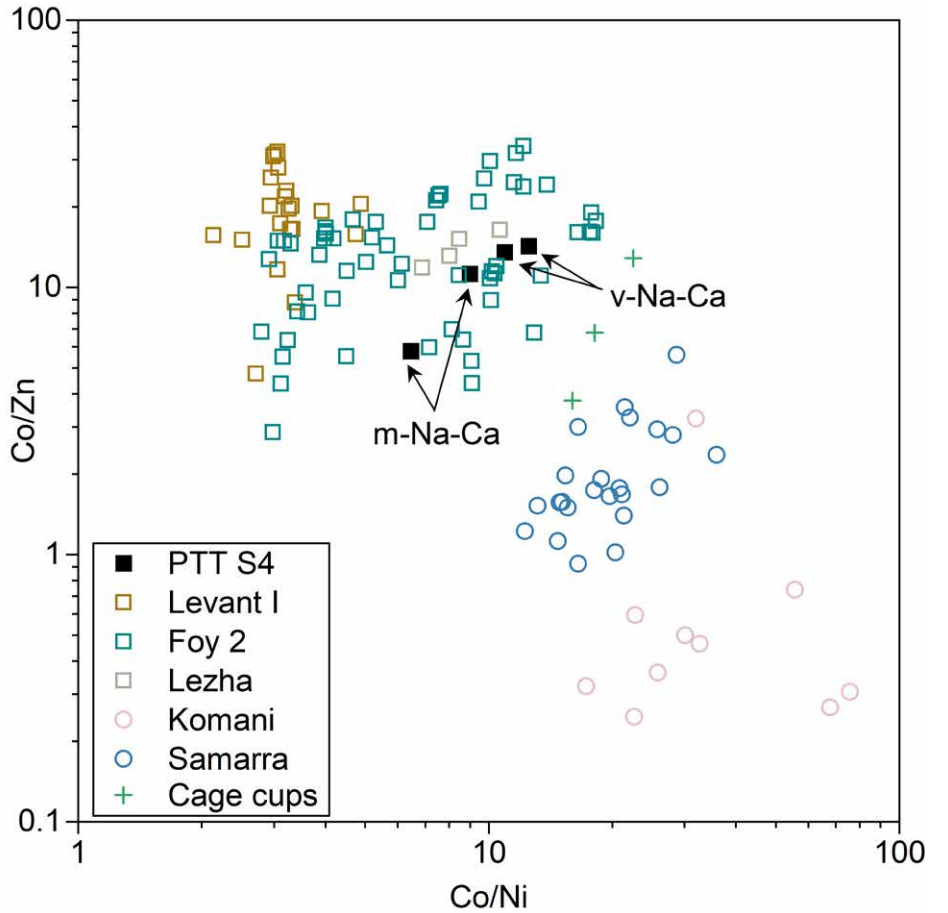


Figure 4: The characteristics of cobalt blue glass from PTT-S4 and Middle East. Cross-shaped: Roman period; Hollow block: late antique period; Hollow circle: early Islamic period. Data from Schibille et al. 2016, 2018, Cholakova et al. 2017, Neri et al. 2019 © Xu Siwen

at archeological sites including Ridiyagama in Sri Lanka, Arikamedu, and Karaikadu in India; Phu Khao Thong (ภูเขาทอง) and Khuan Lukpat (ควนลูกปัด) in southern Thailand; Lach Truong in Vietnam; and Angkor Borei in Cambodia (Dussubieux et al. 2012; Dussubieux & Gratuze 2013).

Two dark blue beads (PTT-20 and PTT-23) from PTT-S4 are made of m-Na-Ca glass. They are characterized by high Na_2O (4.88% and 16.47%) and CaO (9.24% and 8.37%) contents, together with low MgO contents (0.95% and 0.93%). The Na_2O content in the PTT-23 sample is relatively lower, likely attributable to preferential leaching of sodium during surface weathering, as laser ablation did not completely remove the weathered layer.

Based on the Al_2O_3/SiO_2 and TiO_2/Al_2O_3 ratios (Freestone 2021), both glass samples are consistent with Egyptian primary glass production **[Figure 3]**. Sample PTT-20 shows the closest affinity to 6th-century Egyptian glass, whereas PTT-23 corresponds to 5th-century Egyptian glass. Their compositional characteristics therefore suggest a production date in the 5th to 6th centuries CE,

in good agreement with the age of the archeological layer at Phromthin Tai.

Both beads were colored using a cobalt-based colorant. However, the cobalt source differs from that identified in the m-K glass samples. Gratuze et al. (2018) have demonstrated that temporal changes in cobalt colorants used for glass production in Europe, West Asia, and North Africa during the first millennium CE can be distinguished by their Ni and Zn signatures. As shown in **Figure 4**, the high Co/Zn and low Co/Ni ratios of the PTT-S4 samples closely match those of Late Antique glass, when compared with published compositional data for cobalt-blue glass from the Late Antique and Early Islamic periods. This observation indicates that the cobalt colorant is consistent with the cobalt source used during the Late Antique period and provides independent support for the 5th- to 6th-century CE chronology inferred from the Egyptian primary natron glass.

The v-Na-Ca Glass

Two additional beads (PTT-14 and PTT-24) from PTT-S4 are distinguished by their elevated MgO contents (3.71% and 4.41%), which are substantially higher than those of the m-Na-Ca glass beads. Accordingly, they are assigned to the v-Na-Ca type. Similarly, the cobalt colorant responsible for the dark blue coloration exhibits low Zn and high Ni concentrations, a compositional signature consistent with that of the cobalt source used in the m-Na-Ca glass described above **[Fig. 3]**.

The production of the v-Na-Ca glass type was likely related to the Sassanian Empire (Mirti et al. 2008). Small beads of identical composition, manufactured using the drawing technique, have been identified at numerous sites across Southeast Asia, including Maliwan in lower Myanmar (Dussubieux et al. 2020), Ban Non Wat (บ้านโนนวัด) in northeast Thailand, and Angkor Borei in southern Cambodia (Carter 2013), as well as in East Asia, including Xinjiang (Xu et al. 2022b) and Taiwan (Wang et al. 2025), suggesting their distribution through exchange networks connected to the Sassanian Empire **[Map 2]**.

Exchange Networks

The transition from the Late Iron Age to the Early Historic period is clearly marked at Phromthin Tai by a shift in the composition of the glass bead assemblages: the earlier PTT-S3 assemblage (mainly 100–500 CE) is dominated by m-K glass, whereas the later PTT-S4 assemblage (600–800 CE) is dominated by m-Na-Al glass. The compositional differences between the PTT-S3 and PTT-S4 glass beads mainly reflect changes in glass supply over time. The identification of v-Na-Ca glass in PTT-S4, a glass type not previously reported from PTT-S3, further expands the known compositional diversity of the site's glass assemblage.

The predominance of m-Na-Al glass is particularly noteworthy because this type has been widely linked to production centers in southeastern India and Sri Lanka. Recent studies have shown that the m-Na-Al 1 subtype became increasingly important in mainland Southeast Asia during this transition period, connecting Southeast Asian sites to South Asian exchange networks (Carter et al. 2021; Dussubieux et al. 2024).



Map 2: Distribution of archeological sites mentioned in this study in relation to glass bead exchange networks © Xu Siwen

The PTT-S4 m-Na-Al 1 beads fit well within this broader technological tradition, suggesting that PTT-S4 was strongly connected to the Mekong Interaction Sphere through the circulation of South Asian glass (Carter et al. 2023).

In contrast, m-K glass represents only a minor component of the PTT-S4 assemblage and is largely restricted to earlier archeological contexts. Compared with the earlier PTT-S3 assemblage, which contains a substantially higher proportion of m-K glass, the PTT-S4 assemblage indicates a gradual shift in glass supply over time. This transition, however, was not abrupt. Two m-K glass beads (PTT-17 and PTT-18) and one m-Na-Al glass bead (PTT-19) were recovered from the same context, demonstrating that the two glass traditions overlapped for a period before m-Na-Al glass became dominant. A similar coexistence of these glass types was also observed in Burial 20 of PTT-S3 (Carter et al. 2022).

The changing composition of the glass assemblages may be related to the development of trade associated with the emergence of Funan as a major political and commercial center in mainland Southeast Asia during the early centuries CE (Carter et al. 2021). The presence of small quantities of m-Na-Ca and v-Na-Ca glass further demonstrates that PTT-S4 was not supplied through a single exchange network or from a single source. Some m-Na-Ca glass beads were also found in PTT-S3 and Non Ban Chak (Carter et al. 2022; Dussubieux et al. 2024). Although these compositions are relatively rare, their presence indicates continued access to diverse glass exchange networks beyond the dominant South Asian-linked network.

Overall, the PTT-S4 assemblage reaffirms previous interpretations that multiple glass exchange systems coexisted in central Thailand during the Late Iron Age and continued into the Early

Historic period. The new compositional data from PTT-S4 further strengthen the evidence for the growing importance of South India- and Sri Lanka-linked networks within this broader system of exchange, while also demonstrating that these connections existed alongside other, less prominent sources and exchange networks.

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