

## **Micro-Raman spectroscopy and $\mu$ -XRF in the investigation of ancient glass beads from the archaeological sites, eastern Taiwan**

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Ancient glass beads with different colors, shapes, and stylistics unearthed from the archaeological sites of eastern Taiwan, dating back to approximately 1850-310 BP, have been investigated. It is generally known that glass bead is alien to invade into Taiwan along with metal ware, glass, agate, etc. since the Metal Age of Taiwan. Nevertheless, sourcing provenance and trade routes still remain controversial. Micro-Raman spectroscopy and  $\mu$ -XRF have been applied on fifty-six ancient glass beads to reveal the mineralogical and chemical compositions and to help decipher the raw materials used and sourcing provenance. Micro-Raman measurements indicate the presence of hematite, zincite, siderite, sphalerite, lead tin yellow type II, quartz, feldspar, anatase, rutile, ankerite, graphite, calcite, etc. Among them, hematite, zincite, siderite, sphalerite, lead tin yellow type II, and rutile were found to be colorants/opacifiers. Moreover, crystalline phases such as lead tin yellow type II ( $\text{PbSn}_{1-x}\text{SixO}_3$ ), zincite ( $\text{ZnO}$ ), tricalcium diphosphate ( $\text{Ca}_2(\text{PO}_4)_2$ ), sphalerite ( $(\text{Zn}, \text{Fe})\text{S}$ ) and ankerite ( $\text{Ca}(\text{Fe}, \text{Mg}, \text{Mn})(\text{CO}_3)_2$ ) were detected in ancient glass beads unearthed from Taiwan for the first time. The chemical results obtained by  $\mu$ XRF show  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ ,  $\text{MgO}$ ,  $\text{CaO}$ , and  $\text{PbO}$  as the most abundant oxides.  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{MgO}$ , and  $\text{PbO}$  could be the main/minor fluxes and colorants. In general, results of mineralogical and chemical analyses are compatible. According to chemical results, ancient glass beads can be classified as mineral soda alumina glass (m-Na-Al glass), soda plant ash glass (v-Na-Ca glass), lead silicate glass, and some less well known types. Mineral soda alumina and soda plant ash glass beads, as well as lead silicate glass beads are generally believed to be the distinct phases of production and exchange in Southeast Asia and China, respectively. In terms of chronology of glass bead, beads excavated from sites of 1850-930 BP are mineral soda alumina glass (m-Na-Al glass) and soda plant ash glass (v-Na-Ca glass). On the other hand, beads from sites of <930 BP are belonging to lead silicate glass. It is indicated that the sourcing provenance of ancient beads of eastern Taiwan is probably a multiple sources, i.e. in earlier time, glass beads were brought into Taiwan through the maritime exchange and/or trade activities between Taiwan and Southeast Asia; at the later period, lead silicate glass beads were imported from China. However, some mineral soda alumina and soda plant ash glass beads were found in a later period, it might be attributed to glass beads reuse or trade route between Taiwan and Southeast Asia is successive since ca. 1850 BP.