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Tracing the source and origin of earthenware stove in Kelantan State Museum by means of geochemical and mineralogical methods

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Abstract: This study applies geochemical and mineralogical methods to determine the source and origin of the raw materials used to manufacture the earthenware stove in Kelantan State Museum, Kota Bharu. The stove is claimed to be the most unique pottery made in Kelantan but details regarding its place of manufacture and technology are missing due to the poor recording and cataloguing system used by the museum in the past. Three analytical methods employed in this study were X-Ray Diffraction (XRD), X-Ray Fluorescence (XRF) and Thermogravimetric (TGA) analyses. The results of the analyses were compared with the compositional data of raw clay samples obtained from Sungai Galas and Tumpat, two well-known traditional pottery manufacturing localities in Kelantan. In addition, clay samples from Ulu Kelantan were also included in this study to check whether the stove has any similarity with the chemical contents of prehistoric pottery found in the Nenggeri Valley of Kelantan. The results of the analyses showed that the composition of the earthenware stove has closer similarity with the clay samples extracted from Sungai Galas compared to the samples from Tumpat and Ulu Kelantan. Major minerals found between the earthenware stove and clay from Sungai Galas are quartz, albite, muscovite, microcline and cordierite. Furthermore, Thermogravimetric analysis confirmed that the stove was fired below 600 °C, corresponding to the traditional bonfire-firing technique employed by the Mambong potters in Sungai Galas. On the basis of geochemical and mineralogical results, this study concludes that the earthenware stove in the Kelantan State Museum is a product of Kampung Mambong made of clay sourced from Sungai Galas and fired at low temperatures between 400 – 600 °C, probably using the open-firing technique.

Keywords: XRD, XRF, TGA, earthenware stove, Kelantan

INTRODUCTION

The Kelantan State Museum in Kota Bharu, Kelantan preserves a number of important antiquities such as earthenware pots, Chinese ceramics and jars, musical instruments, baskets as well as bronze and iron objects in the form of knives, sickles and swords. One of the significant collections in this museum is the pottery assemblage consisting of traditional Malay pots, e.g. water vessels, rice containers, incense burner, cooking and steaming pots. Also observed in this museum were considerable number of prehistoric potteries particularly from the archaeological site of Gua Cha in the Nenggeri Valley of Kelantan.

Based on previous studies by Suresh (2017, 2019), the museum preserves a unique type of pottery in the form of earthenware stove (Figure 1). Despite its shape and surface design, the stove shares some resemblances to *Lapohan* made by the Bajau Darat potters in Semporna, Sabah (Chia, 2003 & 2016; Suresh, 2009, 2010, 2011, 2014b, 2017, 2019; Suresh & Chia, 2009, 2010; Chia & Suresh, 2017). Even though the stove has been mentioned a while ago, until recently its origin had not yet been ascertained due to the poor recording and cataloguing system used by the museum in the past. Thus, important questions regarding who, when, where and how the pottery stove was made and used are unanswered. According to the museum's old record, two stoves in different sizes (large and small) were bought from a man named Yaacob Haji Osman in 1983. Other details about the stoves and its seller are unavailable. Recent study by Suresh (2019) proposed that the stove might be a product of Kampung Mambong, a Malay pottery-making centre in Kuala Krai, based on the uniformity in surface design. The lack of analytical study, however, caused the origin of the stove to have remained unknown.

Figure 1: Large-sized earthenware stove specimen at Kelantan State Museum, Kota Bharu.

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The present study was, therefore, carried out to determine the possible origin of the earthenware stove by using geochemical and mineralogical analyses. The results of the analyses are compared with the chemical compositions of raw clay samples collected from several areas in Kelantan such as Sungai Galas, Tumpat and Gua Musang (Figure 2). The presence of similar composition between the stove and clay from Sungai Galas in Kuala Krai could indicate the use of the same source while different compositions would suggest different sources, perhaps from Tumpat or Gua Musang in Ulu Kelantan. Based on this information the most probable origin of the earthenware stove can be determined.

In Malaysia, numerous geochemistry studies have been done on prehistoric and traditional pottery since the 1990s. Among these studies are those done by Leong (1989, 1990, 2003), Mohd Kamaruzaman *et al*. (1991), Chia (1997, 2003), Vandiver & Chia (1997), Zuliskandar *et al*. (2001, 2011a, 2014a), Velat (2005, 2010), Gani (2010), Suresh (2011, 2014b, 2017), Zuraidah & Zuliskandar (2018), Mohd Hasfarisham & Mokhtar (2020) and Zuliskandar *et al*. (2021). Elsewhere, recent pottery studies incorporating morphological and geochemistry approaches can be found in the works of Moradi *et al*. (2013), Zuliskandar *et al*. (2014a), Sarhaddi-Dadian *et al*. (2015, 2017), Ferreira *et al*. (2016), Kılıç *et al*. (2017), Pourzarghan *et al.* (2017), Nur Sarahah *et al*. (2018), Eftekhari *et al*. (2021), Gomathy *et al*. (2021), Oudbashi *et al*. (2021) and Sarhaddi-Dadian *et al*. (2021). The geochemistry and mineralogical approach have been adopted in investigating archaeological and cultural remains, especially on clay-based material remains in the Bujang Valley, Kedah. The XRD and XRF methods had been applied in studying the geochemistry of the brick remains found at the temple sites of Sungai Mas (Zuliskandar *et al*., 2012), Pengkalan Bujang (Zuliskandar *et al*., 2011b; Zuliskandar & Nik Hassan Shuhaimi, 2012; Zuliskandar *et al*., 2013a & b; Zuliskandar *et al*., 2014b) and Kampung Baru (Zuliskandar *et al.*, 2018). Among new information gathered from these studies included the origin of raw materials used to make the bricks and the temperature used to burn them. The application of XRD, XRF and TGA analyses in this particular study could give fresh insights into the geochemical composition of the potteries as well as their source and origin.

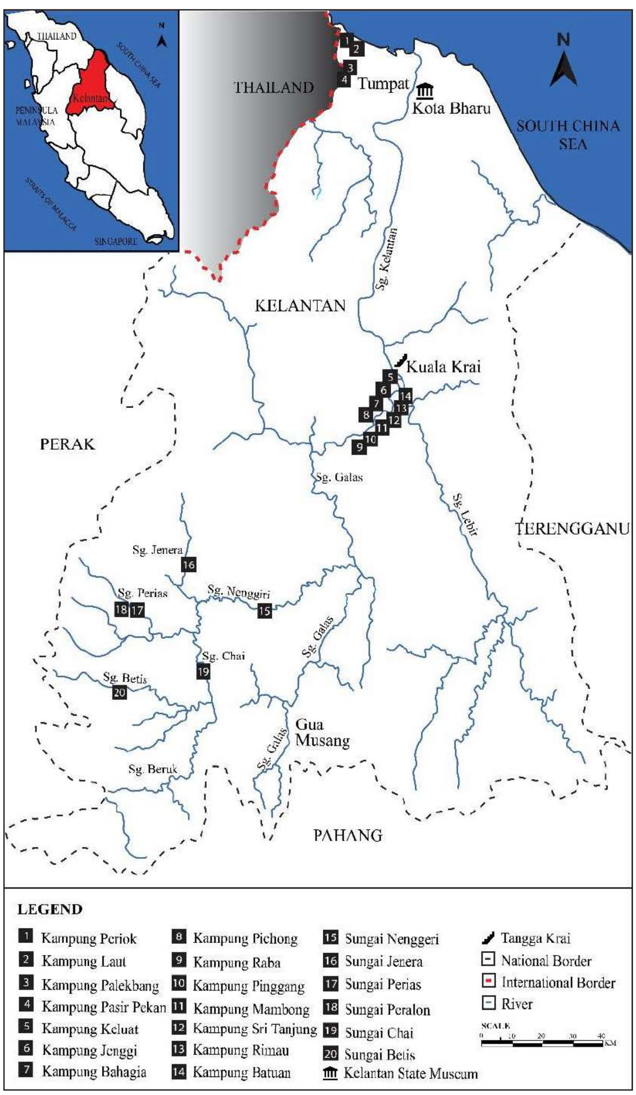

Figure 2: Location of clay samples collected in Tumpat, Kuala Krai and Gua Musang (Ulu Kelantan).

GEOLOGICAL BACKGROUND

Geologically, Kelantan is bounded by Main Range Granite and Stong Igneous Complex on the west, Kemahang Granite in the north and Boundary Range Granite in the east (Goh *et al.*, 2006). The regional geology of the state is also known for its various types of sedimentary and metasedimentary rocks, and shares some similar geological setting with Thailand. Three areas in Kelantan namely Tumpat, Kuala Krai and Gua Musang were selected for this study. As shown in the geological map (Figure 3), Tumpat and its other neighbouring areas such as Kota Bharu and Bachok are embedded on recent alluvium sediments. Previous geological studies have shown that these areas were formed during the quaternary age and consisted mainly of continental deposits such as clay, silt, sand and peat (Department of Mineral and Geoscience Malaysia, 2014). The Kuala Krai district lies on Permian basin which contain metasediment rocks such as phyllite, slate, shale, limestone and volcanic. Almost a similar lithological texture is identified in the lower part of Kelantan where Gua Musang and the Nenggeri Valley are located with additional presence of sandstones, schist and intrusive rocks in the form of granites, andesites and diorites. To be specific, the Gua Musang district covers a few geological formations of different age such as Gua Musang Formation, Telong Formation and Aring Formation. The Gua Musang and Telong formations were formed during the Permian period and comprise primarily limestone or marble

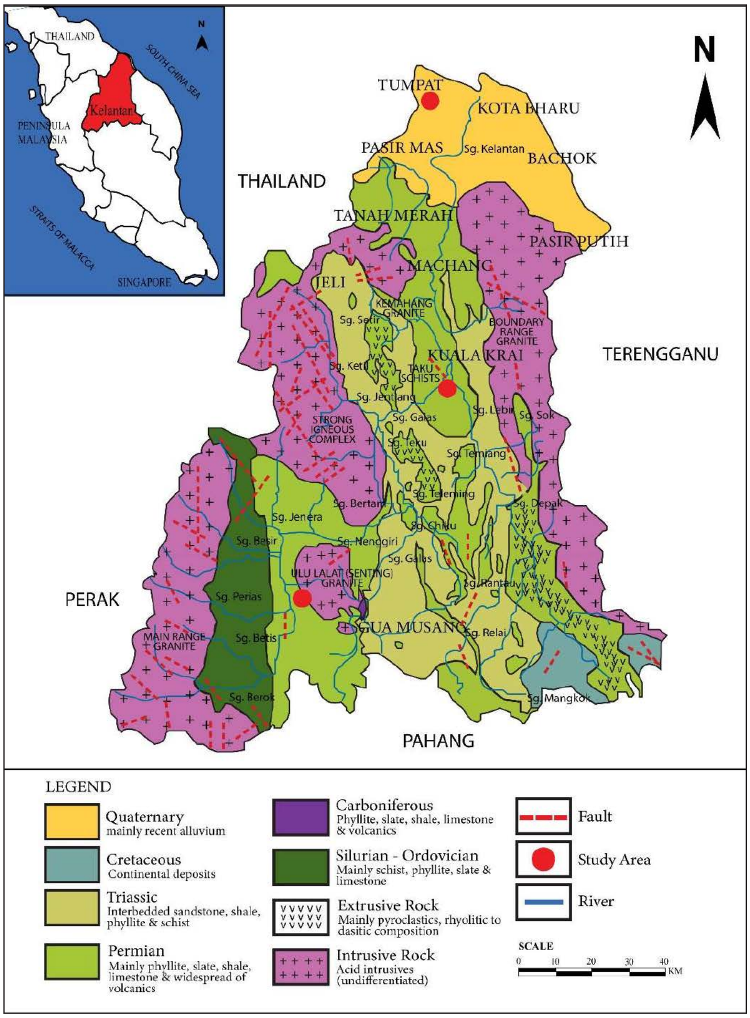

Figure 3: Geological map of Kelantan and the study area (modified after Mohd Hariri Arifin *et al*., 2019).

while the Aring Formation was formed during Carboniferous to Triassic period (Lee *et al*., 2004).

EXPERIMENTAL

Sampling

In this study, clay samples from Sungai Galas in Kuala Krai and Sungai Kelantan in Tumpat were used for comparison to earthenware stove because these are two main areas involved in traditional pottery manufacturing for many years in Kelantan. In Kuala Krai, pottery is still being produced and used by the locals in Sungai Galas particularly for cooking and steaming while pottery production in Tumpat had ceased many years ago (Syed Ahmad, 1992; Yeoh, 1994; Ibrahim & Sahaimi, 2005; Tajul Shuhaizam, 2007; Suresh, 2014a, 2017, 2019, 2020; Suresh & Nasha, 2021). In addition, clay samples from Gua Musang, Ulu Kelantan have been included in this study for comparison. This was done to check whether the stove has any similarity with the mineral types and chemical contents of prehistoric pottery found in the Nenggeri Valley of Kelantan.

At Kelantan State Museum, no permission was granted to cut off sample of the stove because destructive sampling measurements can cause physical damage such as chipping and cracking to the vessel. However, during the investigation some minor defects were noted especially at the lower part of the stove. The defect seems to have happened recently (could be due to the shifting and transportation works of artifact from the museum's main building to the storehouse) and some freshly broken fragments were seen scattered inside the specimen. These fragments were collected for scientific analysis and it was done after obtaining permission from the museum's higher authority. It was observed that the core of the stove was black in colour while the surface colour ranged from dark grey to black. The sample of the stove is labelled as P3 and the macroscopic view is shown in Figure 4. The clay samples, on the other hand, are labelled and presented in Table 1 according to their source.

Methodology

The X-ray diffraction (XRD) and X-ray fluorescence (XRF) methods were employed in this study to characterise and compare the mineral phases and elemental contents of the earthenware stove and clay samples. Both the XRD and XRF analyses of pottery and clay samples were done at the

Earth Material Characterization Laboratory of Centre for Global Archaeological Research, USM. In a nutshell, XRD provides information on the actual minerals present in the sample while XRF renders information on the major and trace elements of any materials studied (Papachristodoulou *et al*., 2006; Sarhaddi-Dadian *et al*., 2015; Zeinab, 2018). All the samples used in this study were digitally photographed before being crushed and pulverised to a homogenised grain size 20-30 µm using Retch PM100 milling machine.

For XRD, the Bruker D8 Advance was used to analyse the samples with parameter; 40kV, 40mA, 2theta range from 10°-70°, with Copper (Cu) X-Ray tube in 0.04/s scan rate. All diffractogram from the analysis were further analysed using the DIFFRAC.EVA version 3.0 software. Peaks and pattern were matched with qualitative Crystallography Open Database (COD).

For XRF, the Panalytical Axios Max was employed to analyse all the prepared samples. The samples were powdered and heated up for one hour at a temperature of 105 °C and then weighed and pressed into pallet with boric acid lining base. For major element analysis, samples were refined and mixed until homogenous with the Lithium Tetraborate flux powder. These mixtures were baked for an hour in Fluxana Vulcan at a temperature of 1,300 °C. The molten homogenous mixture was then moulded using a platinum container and cooled gradually into pieces of fused glass with a thickness of approximately 2 mm and a diameter of 32 mm (Ratnah *et al*., 2020). The laboratory uses up to 30 certified reference materials (CRMs) to build a calibration graph for 8 major elements. To verify the accuracy of analysis and the calibration, both the observed and certified values (from the CRM certificate) were compared to determine the percentage of relative error (Table 2). For trace element analysis, the Omnian analysis software was used to acquire observable elements of the clay and pottery samples.

In addition to studying dry weight percentage of major elements, the XRF results were also used to produce ternary

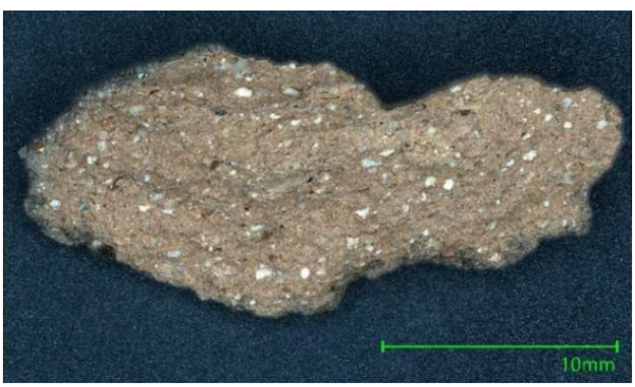

Figure 4: Image of earthenware stove sample (P3) captured with high resolution using VHX 7000 Keyence Digital Microscope (magnification x 12.4 using serial recording mode).

Table 1: Clay samples selected for compositional and elemental studies.

Sample	Source
KM1	Kampung Mambong, Kuala Krai
KB	Kampung Bahagia, Kuala Krai
KR	Kampung Raba, Kuala Krai
KPC	Kampung Pichong, Kuala Krai
KSP	Kampung Sungai Pinggang, Kuala Krai
KLT	Kampung Keluat, Kuala Krai
KJG	Kampung Jenggi, Kuala Krai
KBT	Kampung Batuan, Kuala Krai
KSR	Kampung Sungai Rimau, Kuala Krai
KST	Kampung Sri Tanjung, Kuala Krai
KP1	Kampung Periok, Tumpat
KPT	Kampung Laut, Tumpat
KPB	Kampung Palekbang, Tumpat
KPP	Kampung Pasir Pekan, Tumpat
SN	Sungai Nenggeri, Ulu Kelantan
SB	Sungai Betis, Ulu Kelantan
SS	Sungai Perias, Ulu Kelantan
SC	Sungai Chai, Ulu Kelantan
SJ	Sungai Jenera, Ulu Kelantan
SP	Sungai Peralon, Ulu Kelantan

Table 2: The measure of accuracy of XRF major element analysis as shown by the analysis of certified reference material GBW 07773 (rhyolite), using fused glass beads.

Sample	Dry Weight (%)							
	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	Fe_2O_3
Recommended Value	2.57	0.16	12.96	72.78	1.22	0.59	0.30	3.22
Observed Value	2.54	0.18	13.00	73.09	0.39	0.58	0.28	3.28
Absolute Deviations (σ)	0.03	0.02	0.04	0.31	1.45	0.01	0.02	0.06
Relative Error (%)	1.17	12.5	0.31	0.43	0.23	1.69	6.67	1.86

and 3-dimension scatter plot diagrams. The ternary diagram (adapted from the commonly known ternary phase diagram) was used to visualized three major elements (oxides) which represent the data grouping pattern in the most accurate way. For this study the three major elements chosen to produce ternary diagram were iron oxide (Fe_2O_3), silicon oxide (SiO_2) and aluminium oxide (Al_2O_3) (Figure 5). The software used was XLSTAT 2019 edition which was integrated into the existing Microsoft Excel. All the data were tabulated in the similar manner of creating a normal Excel graph. However, one of the parameters for the ternary plot was that the total value of data set must be tied to a single fixed constant, in this case a 100 (hundred) which can be referred to as a hundred percent (West, 2013; Stover, 2021).

The 3-dimension scatter plot was created using the IBM SPSS Statistic 26 software. The software helps to fit the graph according to the maximum and minimum data value, autofitting the axis scale for best representation (Emerson *et al*., 2013). Generally, the use of three variables (x-axis, y-axis and z-axis) on a single graph can give a clearer data correlation and pattern for comparison analysis.

Thermogravimetric Analysis (TGA) was performed on the stove (P3) sample to determine its firing temperature. 8.25 milligram of crushed sample was subjected to TGA and it was tested using model Mettler Toledo in Nitrogen (N_2) gas with an increment of 20 °C/min (Cayme *et al.,* 2016). The sample was heated from room temperature up to 800 °C and the continuous weight loss and temperature were recorded. Result produced by the TGA analysis is not only useful in identifying the range of firing temperature used but also the firing methods and atmosphere to which the stove was submitted.

RESULTS AND DISCUSSION

Previous studies have suggested that the clays used in the production of prehistoric and traditional pottery in Peninsular Malaysia are naturally rich in silica, alumina and potassium (Suresh, 2017; Asyaari, 2002). From the XRD analysis, it was found that the earthenware stove

Calculation for normalised Fe_2O_3, SiO_2 and Al_2O_3 concentration percent

let the normalised Fe_2O_3 concentration percent $= Fe_2O_{3_{Normalised}}$

$$Fe_2O_{3_{Normalised}} = \frac{Fe_2O_3 \text{ concentration percent}}{\text{Sum of } Fe_2O_3, SiO_2 \text{ and } Al_2O_3 \text{ concetration percent}} \times 100$$

Calculation for normalised Fe_2O_3 concentration percent

let the normalised SiO_2concentration percent $= SiO_{2_{Normalised}}$

$$SiO_{2_{Normalised}} = \frac{SiO_2 \text{ concentration percent}}{\text{Sum of } Fe_2O_3, SiO_2 \text{ and } Al_2O_3 \text{concetration percent}} \times 100$$

Calculation for normalised Fe_2O_3 concentration percent

let the normalised Al_2O_3 concentration percent $= Al_2O_{3_{Normalised}}$

$$Al_2O_{3_{Normalised}} = \frac{Al_2O_3 \text{ concentration percent}}{\text{Sum of } Fe_2O_3, SiO_2 \text{ and } Al_2O_3 \text{ concetration percent}} \times 100$$

Figure 5: The calculation for normalised concentration in percentage for three chosen elements (Fe_2O_3, SiO_2 and Al_2O_3) to produce ternary diagram (West, 2013; Stover, 2021).

contains several minerals such as quartz, albite, muscovite, microcline and cordierite. Similar minerals were found in clay samples extracted from Sungai Galas in Kuala Krai. From geological point of view, these minerals are commonly found in the soil profile and river deposits of Sungai Galas and Kuala Krai (Suresh, 2014a). Furthermore, similar minerals particularly quartz, muscovite, biotite, feldspar, garnet and minor metamorphic minerals (kyanite, sillimanite, andalusite and cordierite) have been reported to be found in the rock samples from Taku Schist formation in Kelantan (Muhammad Afiq, 2018; Muhammad Irman Khalif *et al*., 2020). Kaolin is an additional mineral found in Sungai Galas clay but absent in earthenware stove.

Mineral composition in clay from Tumpat and Gua Musang (Ulu Kelantan) were, on the other hand, significantly different from those found in Sungai Galas. For instance, cordierite is a distinct mineral found in Sungai Galas clay and the earthenware stove. Conversely, montmorillonite was found in clay from Tumpat and Ulu Kelantan but absent in earthenware stove and Sungai Galas clay. The present study also disclosed that cordierite mineral found in clay from Sungai Galas is only present at selected localities particularly in those located on the western bank of Sungai Galas at a depth between 1.8 and 2.5 meters. This mineral was not found in clay collected from the eastern bank of Sungai Galas. However, it was observed that clay samples extracted from the eastern bank of Sungai Galas contain montmorillonite mineral. The physical and geochemical differences in soil minerals between the western and eastern parts of Sungai Galas could be due to natural phenomenon such as erosion and weathering of the surrounding rock formations and river deposits which can alter the type and amount of mineral content of the soil. Frequent floods in Kelantan might have also caused contamination and changes in the soil composition over time.

The presence of kaolinite in Sungai Galas clay showed that it is very suitable for making pottery while the feldspar and mica minerals such as muscovite and microcline found in the earthenware stove sample probably came from the sand temper used by the potters. This could be the reason why P3 sample contain a lot of fine sand grains, as seen in Figure 4. Previous ethnography study by Suresh (2017) showed that a small amount of sand collected from the riverbank of Sungai Galas is added to the clay so that the pottery has sparkling effects on its surface after the firing. The same study also confirmed that the composition Sungai Galas sand is extremely rich in minerals like quartz, microcline, muscovite, kaolinite, albite and magnetite (Suresh, 2017). The presence of feldspar and mica minerals suggested that the stove was fired at low temperature presumably around 600 °C or less. This is because mica minerals such as muscovite in clay decomposes at temperature of 600 – 700 °C (Zuliskandar *et al*., 2011a). This indicates the earthenware stove was very likely fired using the open-firing method. The absence of kaolinite in the stove further supports the use of primitive firing technology with heating temperature ranging between 400 – 600 °C. New mineralogical study explains that kaolinite in the clay can degrade at temperature as low as 400 – 450 °C (Yanti & Pratiwi, 2018). The list of minerals found in earthenware stove and clay samples is presented in Table 3.

The XRF analysis result of major elements is presented in Table 4. The dry weight percentage of silica (Si) in earthenware stove is about 42.8%. Clay samples that contain almost similar dry weight percentage of silica (Si) to the stove are those from Sungai Galas (Table 4). However, the dry weight percentage of silica in earthenware stove appeared to be slightly higher compared to clay from Sungai Galas because clay samples analysed in this study have not been mixed with tempering material yet. As mentioned earlier, a small portion of sand (quartz mineral) is often added to the clay by the potters and this act will eventually increase the amount of silica in the final product. Aluminium (Al), titanium (Ti), iron (Fe) and magnesium (Mg) are other minerals that shared almost similar dry weight percentage between the stove and clay from Sungai Galas. Comparatively, the dry weight percentage of silica in clay

Table 3: The list of minerals in earthenware stove and clay samples based on XRD analysis.

Location	Sample name/ Material	Mineral/ Chemical configuration
Kelantan State Museum, Kota Bharu	P3/ pottery	Quartz (SiO_2), Albite ($NaAlSi_3O_8$), Muscovite ($KAl_2Si_3AlO_{10}(OH)_2$), Microcline ($KAlSi_3O_8$), Cordierite ($Mg_2Al_3(Si_5AlO_{18})$)
Kampung Mambong, Kuala Krai	KM1/clay	Quartz (SiO_2), Microcline ($KAlSi_3O_8$), Kaolinite ($Al_2Si_2O_5(OH)_4$), Albite ($NaAlSi_3O_8$), Montmorillonite ($AlSi_2O_6(OH)_2$)
Kampung Bahagia, Kuala Krai	KB/clay	Quartz (SiO_2), Kaolinite ($Al_2Si_2O_5(OH)_4$), Albite ($NaAlSi_3O_8$), Cordierite ($Mg_2Al_3(Si_5AlO_{18})$)
Kampung Raba, Kuala Krai	KR/clay	Quartz (SiO_2), Microcline ($KAlSi_3O_8$), Kaolinite ($Al_2Si_2O_5(OH)_4$), Albite ($NaAlSi_3O_8$), Montmorillonite ($AlSi_2O_6(OH)_2$)
Kampung Pichong, Kuala Krai	KPC/clay	Quartz (SiO_2), Kaolinite ($Al_2Si_2O_5(OH)_4$), Albite ($NaAlSi_3O_8$), Cordierite ($Mg_2Al_3(Si_5AlO_{18})$)
Kampung Sungai Pinggang, Kuala Krai	KSP/clay	Quartz (SiO_2), Microcline ($KAlSi_3O_8$), Kaolinite ($Al_2Si_2O_5(OH)_4$), Albite ($NaAlSi_3O_8$), Montmorillonite ($AlSi_2O_6(OH)_2$)
Kampung Keluat, Kuala Krai	KLT/clay	Quartz (SiO_2), Kaolinite ($Al_2Si_2O_5(OH)_4$), Albite ($NaAlSi_3O_8$)
Kampung Jenggi, Kuala Krai	KJG/clay	Quartz (SiO_2), Kaolinite ($Al_2Si_2O_5(OH)_4$), Albite ($NaAlSi_3O_8$)
Kampung Batuan, Kuala Krai	KBT/clay	Quartz (SiO_2), Microcline ($KAlSi_3O_8$), Kaolinite ($Al_2Si_2O_5(OH)_4$), Albite ($NaAlSi_3O_8$), Montmorillonite ($AlSi_2O_6(OH)_2$)
Kampung Sungai Rimau, Kuala Krai	KSR/clay	Quartz (SiO_2), Microcline ($KAlSi_3O_8$), Kaolinite ($Al_2Si_2O_5(OH)_4$), Albite ($NaAlSi_3O_8$), Montmorillonite ($AlSi_2O_6(OH)_2$)
Kampung Sri Tanjung, Kuala Krai	KST/clay	Quartz (SiO_2), Microcline ($KAlSi_3O_8$), Kaolinite ($Al_2Si_2O_5(OH)_4$), Albite ($NaAlSi_3O_8$), Montmorillonite ($AlSi_2O_6(OH)_2$)
Kampung Periok, Tumpat	KP1/clay	Quartz (SiO_2), Kaolinite ($Al_2Si_2O_5(OH)_4$), Microcline ($KAlSi_3O_8$), Montmorillonite ($AlSi_2O_6(OH)_2$)
Kampung Laut, Tumpat	KPT/clay	Quartz (SiO_2), Kaolinite ($Al_2Si_2O_5(OH)_4$), Microcline ($KAlSi_3O_8$), Montmorillonite ($AlSi_2O_6(OH)_2$)
Kampung Palekbang, Tumpat	KPB/clay	Quartz (SiO_2), Kaolinite ($Al_2Si_2O_5(OH)_4$), Microcline ($KAlSi_3O_8$), Montmorillonite ($AlSi_2O_6(OH)_2$)
Kampung Pasir Pekan, Tumpat	KPP/clay	Quartz (SiO_2), Kaolinite ($Al_2Si_2O_5(OH)_4$), Microcline ($KAlSi_3O_8$), Montmorillonite ($AlSi_2O_6(OH)_2$)
Sungai Nenggeri, Ulu Kelantan	SN/clay*	Quartz (SiO_2), Muscovite ($KAl_2Si_3AlO_{10}(OH)_2$)
Sungai Betis, Ulu Kelantan	SB/clay*	Quartz (SiO_2), Muscovite ($KAl_2Si_3AlO_{10}(OH)_2$)
Kampung Perias, Ulu Kelantan	SS/clay*	Quartz (SiO_2), Muscovite ($KAl_2Si_3AlO_{10}(OH)_2$), Orthoclase ($KAlSi_3O_8$)
Sungai Chai, Ulu Kelantan	SC/clay*	Quartz (SiO_2), Muscovite ($KAl_2Si_3AlO_{10}(OH)_2$)
Sungai Jenera, Ulu Kelantan	SJ/clay*	Quartz (SiO_2), Muscovite ($KAl_2Si_3AlO_{10}(OH)_2$)
Sungai Peralon, Ulu Kelantan	SP/clay*	Quartz (SiO_2), Muscovite ($KAl_2Si_3AlO_{10}(OH)_2$)

*Data extracted from earlier study on clay from Ulu Kelantan by Zuliskandar *et al*. (2011a).

Table 4: The list of major elements with quantitative value for earthenware stove and clay from Sungai Galas, Tumpat and Ulu Kelantan.

Sample	Dry Weight (%)							
	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	Fe_2O_3
P3	1.08	1.90	16.20	42.78	1.22	1.81	1.28	9.22
KM1	0.41	1.22	19.72	35.92	0.39	1.27	2.06	15.14
KB	0.44	1.75	17.37	39.66	1.45	1.73	2.04	12.11
KR	0.40	1.22	24.87	33.80	0.23	1.20	2.05	14.78
KPC	0.48	1.67	21.48	39.50	1.64	1.56	1.06	11.24
KSP	0.40	1.43	24.96	34.90	0.49	1.25	1.18	14.90
KLT	0.40	1.57	24.23	35.10	0.24	1.34	2.23	14.01
KJG	0.45	1.23	21.45	40.23	1.23	1.88	1.36	7.32
KBT	0.44	1.78	23.24	36.20	0.21	1.12	2.33	13.19
KSR	0.42	1.56	20.22	35.10	0.32	1.50	1.89	14.21
KST	0.41	1.54	20.10	33.90	0.25	1.89	2.98	15.03
KP1	0.08	0.15	13.97	53.47	0.58	0.08	0.49	1.65
KPT	0.13	0.17	14.11	54.65	0.47	0.05	0.50	1.04
KPB	0.07	0.14	13.78	49.80	0.78	0.08	0.46	2.11
KPP	0.05	0.11	13.51	54.50	0.69	0.09	0.39	1.78
SN	0.24	1.29	22.35	69.20	3.52	0.37	0.95	3.41
SB	0.24	0.89	23.27	61.59	2.33	0.18	0.81	1.99
SS	0.27	4.13	25.29	60.35	3.16	0.32	0.27	4.13
SC	0.22	1.58	21.52	65.53	3.31	0.22	0.87	3.13
SJ	0.31	1.31	22.13	65.24	2.45	1.19	0.98	3.96
SP	0.34	1.56	28.87	66.35	3.42	0.09	1.01	4.35

from Tumpat and Ulu Kelantan are much higher (in a range of 50% - 69%) compared to those from Sungai Galas (Table 4). Sodium (Na), potassium (K) and calcium (Ca) contents were very small in all samples. Previous study conducted by Gani *et al.* (2015) also suggested that the elemental content for Ulu Kelantan clay ranged between 60-69.2% for silica, 21.5-28.8% for aluminium and 0.81-4.35% for iron, titanium and potassium. The silica (Si) content in clay from this area is found to be slightly higher compared to other places in Peninsular Malaysia.

To further verify the origin, a comparison of dry weight percentage between silicate, aluminium and iron of the stove and clay samples was made (Table 5). The close relativity between these sample was plotted and is shown in the ternary diagram below (Figure 6). The dry weight of silica between the stove and clay samples from Sungai Galas is between 46% - 63% compared to other clay samples which have silicate concentration in range of 67% - 78%. The dry weight of aluminium between the stove and clay samples from Sungai Galas is between 24% - 34% while iron is about 11% - 22%. Such range of concentration confirms

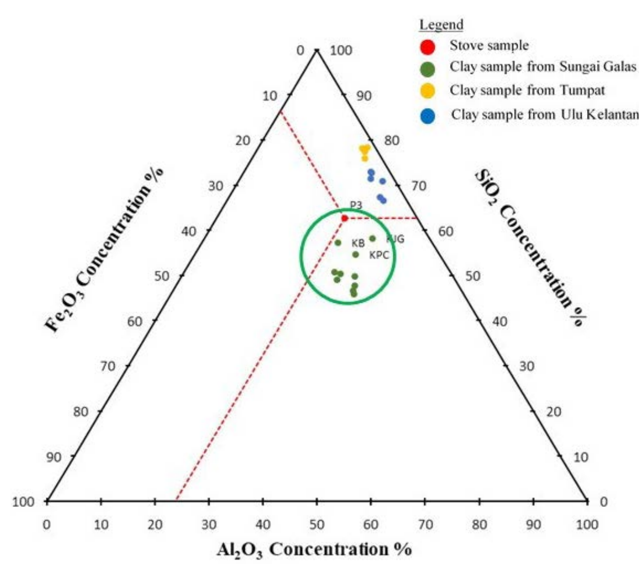

Figure 6: The ternary diagram of SiO_2, Al_2O_3 and Fe_2O_3 in earthenware stove and clay samples (dry weight normalised to 100%) (West, 2013; Stover, 2021).

Table 5: Three major elements; silica, alumina and iron oxide selected for dry weight comparison study.

Sample	Normalization by 100 % Dry weight Concentration		
	Al_2O_3	SiO_2	Fe_2O_3
P3	23.75	62.73	13.52
KM1	27.86	50.75	21.39
KB	25.12	57.36	17.52
KR	33.86	46.02	20.12
KPC	29.74	54.69	15.56
KSP	33.39	46.68	19.93
KLT	33.04	47.86	19.10
KJG	31.09	58.30	10.61
KBT	32.00	49.84	18.16
KSR	29.08	50.48	20.44
KST	29.12	49.11	21.77
KP1	20.22	77.39	2.39
KPT	20.21	78.30	1.49
KPB	20.98	75.81	3.21
KPP	19.36	78.09	2.55
SN	23.54	72.87	3.59
SB	26.79	70.92	2.29
SS	28.17	67.23	4.60
SC	23.86	72.67	3.47
SJ	24.23	71.43	4.34
SP	28.99	66.64	4.37

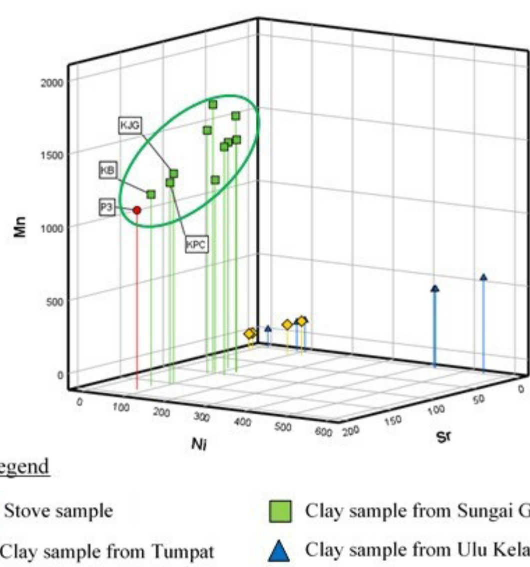

Figure 7: Three-dimensional scatter plot graph for Mn, Ni and Sr.

that the earthenware stove was made using raw materials sourced from Sungai Galas.

It is believed that the stove was made by the ancestors of Mambong potters in Kuala Krai because they are the only potting community in Sungai Galas to engage in traditional pottery-making and the tradition is traceable as early as 1850s (Suresh & Nasha, 2021). Recent ethnographic study and comparative analysis using morphological approach proves that the earthenware stove at Kelantan State Museum shares close similarity with potteries made at Kampung Mambong in terms of design (Suresh, 2019). Function-wise, the stove was apparently used for cooking and grilling meat or fish, similar to the *Lapohan* Bajau in Sabah. This ethnographical information is important and can be used to support the provenance of the earthenware stove which represents close cultural links to Mambong pottery tradition in Sungai Galas.

The earthenware stove and clay from Sungai Galas, particularly Kampung Bahagia, Kampung Pichong and Kampung Jenggi have the same range of concentration of manganese (Mn), strontium (Sr) and nickel (Ni). This was confirmed by the analysis of trace element using XRF Omnian software. Table 6-7 show the content of trace element in part per million (ppm) in the stove and clays from Sungai Galas, Tumpat and Ulu Kelantan. A comparison based on the dry weight percentage of manganese (Mn), strontium (Sr) and nickel (Ni) was made using 3D scatter plot and is shown in Figure 7. This data is viable and can be used to support the similarity of the major elements highlighted above.

The TGA analysis shows that the degradation of mineral in the earthenware stove occurred around 400 – 600 °C. The moisture in the sample was removed between temperature 62.08 – 150.0 °C. As the temperature increases, the organic material and water in the sample undergoes combustion (Worral, 1968) and it was clearly noted between temperature 410.88 °C – 574.29 °C. A drop of sample weight was detected at 410 °C and this is likely due to the decomposition of kaolinite mineral in the sample. A distinct endothermic peak was also observed in the TGA curve at temperature of 410 °C and it is circled in green (Figure 8). It is unsure if the kaolinite converts into metakaolin at this temperature because the dehydroxylation of kaolin to metakaolin usually occurs at temperature ranging from 500 – 800 °C, depending on the purity and crystallinity of the precursor clay (Shoval, 2003; Badogiannis *et al*., 2005; Granizo *et al*., 2007; Chakchouk *et al*., 2009). Metakaolin has a highly amorphous and disordered structure and therefore it will not be visible in X-Ray diffractograms. From morphological point of view, the dark grey or black colours of inner and outer surfaces of the stove were most likely caused by smudging while the black cores were due to incomplete oxidation of carbonaceous materials in the clay (Shepard, 1956; Rye, 1981). All this information signifies that the earthenware stove was fired in an open flame at low temperature between 400 – 600 °C.

Table 6: The list of trace element with quantitative value for earthenware stove and clay samples.

Elements	Dry Weight (ppm)										
	P3	**KM1**	**KB**	**KR**	**KPC**	**KSP**	**KLT**	**KJG**	**KBT**	**KSR**	**KST**
F	bdl	bdl	bdl	bdl	402	bdl	bdl	bdl	bdl	bdl	120
P	811	297	289	297	281	279	286	293	291	277	284
S	199	241	240	213	221	222	227	232	237	214	220
Cl	164	126	126	132	112	103	128	125	113	135	124
Sc	bdl	bdl	bdl	bdl	bdl	bdl	bdl	25	bdl	bdl	bdl
Cr	51	185	190	172	182	188	180	169	184	188	171
Mn	1116	1452	1201	1478	1267	1553	1434	1321	1712	1643	1201
Co	bdl	2232	bdl	bdl	bdl	2620	bdl	3024	bdl	2101	bdl
Ni	79	128	80	127	97	88	87	96	81	127	89
Cu	71	121	127	146	125	129	124	136	127	131	122
Zn	112	94	100	108	99	96	98	111	97	93	91
Ga	24	35	30	113	31	40	32	101	124	32	21
Br	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
As	0	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
Rb	72	29	20	23	24	23	14	19	12	10	29
Sr	184	105	168	90	154	106	81	149	96	91	97
Y	35	41	45	43	21	30	42	41	38	39	44
Zr	185	260	263	261	273	270	242	266	bdl	bdl	271
Ba	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
Nb	14	29	33	32	10	23	21	25	31	33	25
Ce	343	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	167	bdl
Ag	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
Au	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
W	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
Pr	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
Nd	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
Hg	bdl	bdl	bdl	bdl	43	bdl	bdl	bdl	bdl	30	bdl
Pb	bdl	40	bdl	bdl	45	bdl	23	bdl	42	bdl	47

*bdl - below detection limit

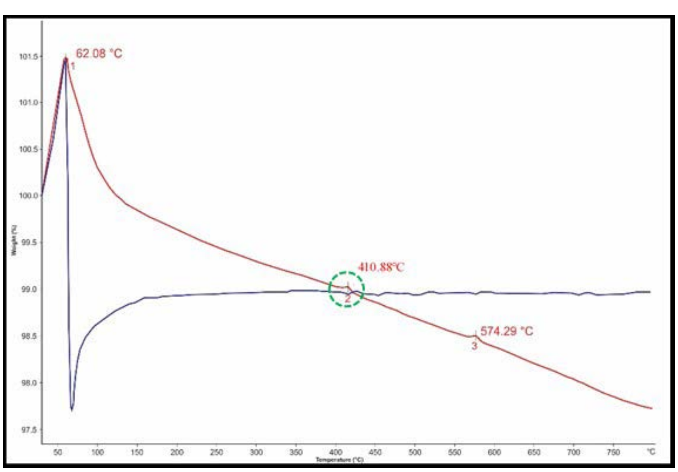

Figure 8: Thermographical graph of the earthenware stove.

Table 7: The list of trace element with quantitative value.

Elements	Dry Weight (ppm)									
	KP1	KPT	KPB	KPP	SN	SB	SS	SC	SJ	SP
F	bdl	bdl	bdl	bdl	-	-	-	-	-	-
P	284	223	290	320	-	-	-	-	-	-
S	284	290	272	190	-	-	-	-	-	-
Cl	115	103	121	132	-	-	-	-	-	-
Sc	bdl	bdl	bdl	bdl	-	-	-	-	-	-
Cr	45	50	41	39	-	-	-	-	-	-
Mn	bdl	bdl	121	92	15	86	546	106	428	424
Co	bdl	bdl	bdl	40	-	-	-	-	-	-
Ni	bdl	bdl	bdl	bdl	-	-	-	-	-	-
Cu	bdl	110	bdl	40	15	4	53	27	18	46
Zn	37	bdl	50	26	34	67	99	19	84	106
Ga	31	35	29	47	-	-	-	-	-	-
Br	bdl	bdl	bdl	bdl	-	-	-	-	-	-
As	bdl	bdl	bdl	bdl	-	-	-	-	-	-
Rb	26	31	19	26	-	-	-	-	-	-
Sr	11	15	11	14	-	-	-	-	-	-
Y	14	11	23	15	-	-	-	-	-	-
Zr	335	290	134	300	-	-	-	-	-	-
Ba	bdl	bdl	bdl	bdl	3	6	11	6	5	3
Nb	bdl	12	bdl	bdl	-	-	-	-	-	-
Ce	bdl	bdl	bdl	bdl	-	-	-	-	-	-
Ag	bdl	bdl	bdl	bdl	11	11	6	4	11	4
Au	bdl	bdl	bdl	bdl	0.5	0.5	1	0.5	1	0.5
W	116	bdl	90	100	-	-	-	-	-	-
Pr	bdl	bdl	bdl	bdl	-	-	-	-	-	-
Nd	bdl	bdl	bdl	bdl	-	-	-	-	-	-
Hg	17	bdl	10	bdl	-	-	-	-	-	-
Pb	25	bdl	21	30	5	7	21	24	11	7

*bdl - below detection limit
*- unknown

CONCLUSION

In this study, the XRD and XRF techniques have been very useful in determining the possible source of origin of the earthenware stove at Kelantan State Museum. Comparative study based on XRD and XRF results showed that the mineral content of the stove is similar to the clay samples extracted from Sungai Galas, Kuala Krai. However, the mineral composition of the stove is found to be different from the clay composition of Tumpat. The study also had not establish clear links in terms of chemical composition with the clay from Ulu Kelantan and Nenggeri Valley. Traditionally, the Mambong potters of Sungai Galas use highly kaolinitic clay to make pottery. Such source is available at Kampung Bahagia, located on the western bank of Sungai Galas, and its surrounding areas like Kampung Pichong and Kampung Jenggi. Tempering material such as sand is procured from the banks of Sungai Galas and the well-dried pottery is baked using the open-firing method. The range of firing temperature lies between 400 °C and 600 °C. All these point out that the earthenware stove at Kelantan State Museum is one of the many clay products produced by the Malay potters at Kampung Mambong. This pottery has probably been made in the late 1940s or perhaps earlier because the production of Tuku (a local term for pottery stove) is believed to have ceased right after the Japanese invasion period which took place in Kelantan and Malaya between 1942 and 1945 (Suresh & Nasha, 2021). The techniques and tools used in making the stove are believed to be similar to that of other traditional potteries made at Kampung Mambong. It is suggested that the small-sized earthenware stove which is now displayed in the museum's gallery was also made at Kampung Mambong since both the large and small-sized stove specimens are similar in shape and design. More advanced and non-destructive analytical approaches such as handheld XRF, Raman spectroscopy and ultrasonic applications should be considered for future study so that more substantial results can be obtained for regional pottery comparative study. In addition, old potteries from Kampung Mambong should also be included in future study and tested using similar applications to check if the results of chemical compositions are similar to the earthenware stove at Kelantan State Museum. Although information on the history and production of earthenware stove in Sungai Galas is limited, the outcome of this study had significantly shed some light into the source and origin of the earthenware stove at Kelantan State Museum which shares similar technological and cultural affinities with Mambong pottery in Sungai Galas. Further intensive research on pottery in Sungai Galas and Kuala Krai is believed to provide more information on the historical perspective of earthenware stove making at Kampung Mambong, Kelantan.

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AUTHOR CONTRIBUTIONS

All the fours authors have contributed their expertise during the ethnography fieldwork in Kelantan as well as in conducting the scientific analysis and writing of this article. To be specific, FJ and SZ were involved in the collection and preparation of clay samples for compositional analyses while SN and NRK worked on literature review, analyses, data interpretation and drafting the article.

CONFLICT OF INTEREST

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare absence of conflicting interests with the funders.

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