GeoJournal of Tourism and Geosites
ISSN 2065-1198, E-ISSN 2065-0817

Year XVI, vol. 47, no. 2, 2023, p.622-631
DOI 10.30892/gtg.47230-1062

ANCIENT KEDAH IRON SMELTING EXPERIMENT IN PREPARATION FOR OFFERING ARCHAEOLOGICAL TOURISM HERITAGE PACKAGES AT SUNGAI BATU ARCHAEOLOGICAL COMPLEX (SBAC), BUJANG VALLEY, KEDAH, MALAYSIA

Mohd Hasfarisham Abd HALIM*
Independent Researcher, Sungai Petani, Kedah, Malaysia, e-mail: mhasfarisham@gmail.com

Naizatul Akma Mohd MOKHTAR
Independent Researcher, Sungai Petani, Kedah, Malaysia, e-mail: naizatulm@gmail.com,

Iklil Izzati ZAKARIA
Independent Researcher, Sungai Petani, Kedah, Malaysia, e-mail: iklilzakaria@gmail.com

Siti Nurul Siha MOHAMAD
Independent Researcher, Sungai Petani, Kedah, Malaysia, e-mail: nurulsihamohamad@gmail.com

Nur Saerah Abd HAMID
Independent Researcher, Sungai Petani, Kedah, Malaysia, e-mail: nursaerah1811@gmail.com

Shyeh Sahibul Karamah MASNAN
University Sains Malaysia, Penang, Malaysia, e-mail: shyehsahibul@usm.my

Mokhtar SAIDIN
Independent Researcher, Sungai Petani, Kedah, Malaysia, e-mail: mokhtarsaidin@gmail.com

Citation: Halim, M.H.A., Mokhtar, N.A.M., Zakaria, I.I., Mohamad, S.N.S., Hamid, N.S.A., Masnan, S.S.K., & Saidin, M. (2023). ANCIENT KEDAH IRON SMELTING EXPERIMENT IN PREPARATION FOR OFFERING ARCHAEOLOGICAL TOURISM HERITAGE PACKAGES AT SUNGAI BATU ARCHAEOLOGICAL COMPLEX, BUJANG VALLEY, KEDAH, MALAYSIA. GeoJournal of Tourism and Geosites, 47(2), 622–631. https://doi.org/10.30892/gtg.47230-1062

Abstract: In order to obtain primary data related to the iron smelting activities, the experimental process of furnaces, tuyere and air pumps making is carried out. The experiment has conducted since 2013 through the Knowledge Transfer Program (KTP) in Sungai Batu Archaeological Complex (SBAC). Through the experiment, the clay in this complex has been used as a raw material for furnaces and tuyere making while the bellows is made of wood, plywood and fabric. In order to complete the experiment regarding the raw material that use for iron smelting, iron ore was taken through survey activities in the area of Kampung Batu 5, UiTM Merbok and Bukit Tupah while charcoal was used from rubber wood in the rubber plantation near the Sungai Batu Archaeological Complex. After the experiment was conducted, the results recorded were different from the findings of the iron ingot excavation at the iron smelting site which is likely to occur due to the difference in technique and ratio of materials used during smelting activities. Although the results obtained during the experiment are different, the smelting process can be used as the main reference for offering tourism full packages related to the demonstration of iron smelting in this complex to foreign tourists.

Key words: Knowledge Transfer Proggram, experiment, Sungai Batu Archaeological Complex, archaeotourism

* * * * * *

INTRODUCTION

Archaeological research at the Sungai Batu Archaeological Complex (SBAC) (Figure 1) have enabled for the first-time records of the iron smelting industry (Mokhtar, 2019), river jetty (Halim et al., 2022), port management (Ahmad, 2016; Yusof, 2016), rituals and Buddhist monument (Hassan, 2018) sites of ancient Kedah Kingdom to be examined, identified and given chronometric dating used since 788 Century BCE (Beta 516413) in iron smelting activities (Mokhtar, 2019). The determination of the chronometric date uses radiocarbon method on charcoal samples at one of the ancient Kedah iron smelting workshop sites in the SBAC which is still in-situ in the area near the base of the furnace (Mokhtar, 2019). This is because archaeological research from 1840 to 2009 has not been able to record evidence of such industry and jetty-port architecture although there are records from al-Kindi, al-Biruni (Gilmour and Hoyland, 2012), I-Tsing (I-Tsing, 1896), Pattinapalai Poetry (Thilakavathy, 2019), Silappadikaram (Saidin, 2023), Kathasaritsagara, Kaumudimahotsava (Saidin, 2023) and inscriptions (Khaw, 2011) which describe the role of ancient Kedah in the trade and export of early world iron ingots. Previous studies have only recorded findings of Hindu-Buddhist religious structures (Ali et al., 2023) and trade artifacts (Adam, 2020) that most of the sites are given relative dating since the 5th Century AD.

* Corresponding author

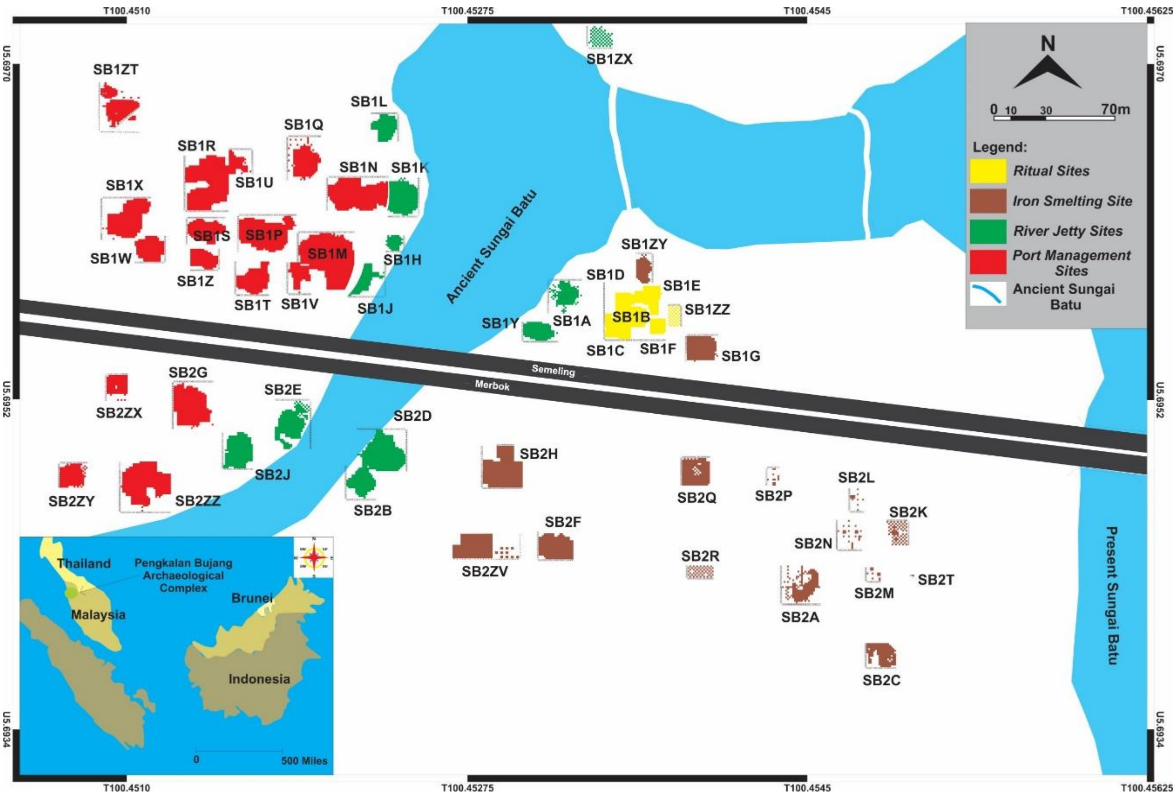


Figure 1. Iron industry, river jetty, port management, ritual and Buddhist sites that
have been conducted systematically research in the SBAC (Source: Research data analysis, 2023)

Archaeological research at the SBAC until since 2009 to 2023 is the only one to reveal complete evidence of the heavy industry of ancient Kedah up to the architecture of the river jetty and port management monument that managed its trade affairs. To develop this site, especially in the national archaeotourism sector, some initial steps were taken to provide trained and certified tour guides. Therefore, the Knowledge Transfer Program (KTP) at the SBAC was established since 2013 with the main purpose of providing knowledgeable tourist guides to the historical and archaeological evidence at the SBAC in general and Lembah Bujang in particular. In order to strengthen the knowledge of tour guides related to industrial evidence in this complex, archaeological experiments related to iron manufacturing and smelting technology were applied during the KTP programme. These archaeological experiments were conducted with the main purpose of obtaining an initial description of earlier societies through archaeological research as interpreted by Humphris (2010), Humphris et al. (2018) and Chuenpee et al. (2014). Therefore, the experiment archaeological research is able to record primary data related to smelting technology of the ancient Kedah community and it can be processed and applied in offering a full tourism package "iron smelting demonstration" at the SBAC in particular.

In general, the KTP which involved 18 participants from the Kuala Muda district. This program is organized by the Center for Global Archaeological Research (CGAR), University Sains Malaysia, Penang. Through this program, participants will be exposed to archaeological research procedures, in-depth archaeological experiments and also undergo a tour guide course held in collaboration with The Northern Corridor Implementation Authority (NCIA) under the Merbok Area Tourist Guide Program grant. The course is conducted to qualify them to get a green badge and become a certified tourist guide in the Kuala Muda district for the natural heritage category.

AIMS OF THE STUDY

This study aims to provide certified tourist guides related to archaeological heritage sites in the Kuala Muda district. In order to achieve this goal, the iron smelting experimental process is organized under the Knowledge Transfer Program to obtain primary data how the iron smelting process takes place. The information and results observed during the experiment were then used as the main reference for the offer of tour packages based on the demonstration of iron smelting in this complex after they had become certified tour guides in this area.

MATERIALS AND METHODS

This research is based on the iron smelting workshop evidence recorded at the SBAC (Figure 2). Excavations revealed iron ore as the raw material of iron smelting, iron slag and iron ingots, tuyeres and base of furnace. The existence of a combustion furnace clearly strengthened the interpretation it served as an iron smelting workshop. Based on the excavation evidence, several observations and measurements related to the size base of the furnace, tuyere were conducted in detail to obtain primary data related to the measurement of the furnace structure to be used as a guideline during archaeological experiments. Besides, several soil samples at the base of the furnace, iron ore and iron ingots were also sampled, and chemical analysis was carried out to obtain information on the raw materials of the furnace and tuyere. Charcoal found near the furnace area also analyzed to obtain data on the type of trees used for the purpose of iron smelting in this complex. After the information was obtained, survey activities were carried out to obtain the raw material of clay for the purpose of furnaces and tuyere making, iron smelting catalyst and fuel to enable experiments to be carried out more thoroughly. Thus Figure 3 is the working stage of the fieldwork methodology used in the archaeological experiments.

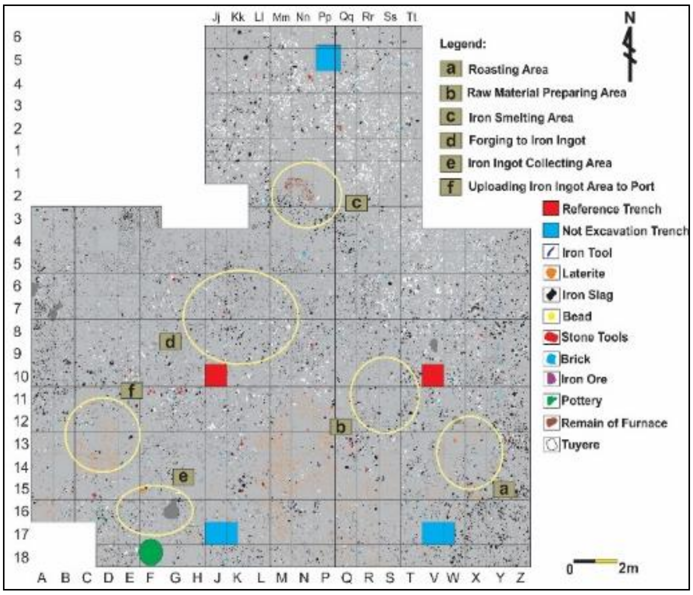


Figure 2. The excavation process revealed the findings of an iron smelting workshop with the presence of iron ore, iron slag, furnace and tuyere at the site

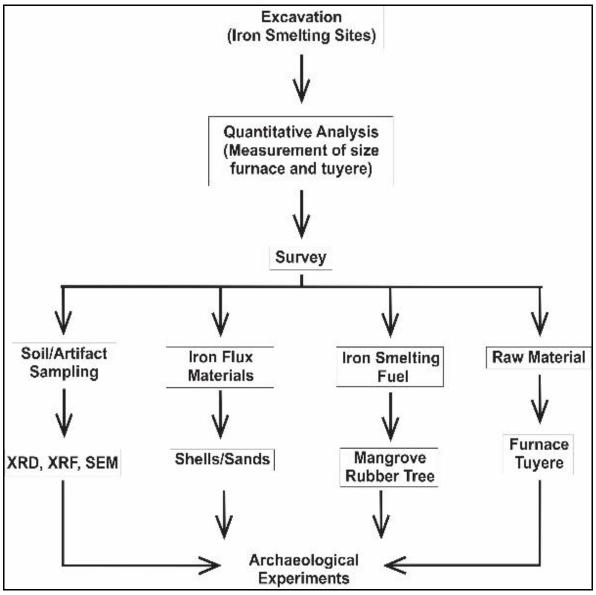


Figure 3. Archaeological experiment flow chart of iron smelting at the SBAC (Source: Research data analysis, 2023)

RESULTS AND DISCUSSION

The KTP at the SBAC has conducted experiments on the production and manufacture of furnaces, tuyere, wind pumps (bellow) to be used in the experimental process of iron smelting. The experiment was conducted with the main purpose of exposing KTP participants to the production technology of iron smelting activities.

Table 1. Evidence of the discovery of furnace base at iron smelting sites of ancient Kedah at SBAC (Source: Molingka, 2013; Mokhtar, 2019)

No	Sites	Classification
1	SB1G	The base of furnace I is about 48 cm high and a width of 95 cm. Based on the remnants of the furnace, it is suggested that this furnace I is shaft shaped.The base of the furnace II has a length of about 146 cm and a width of 96 cm. It is likely that this furnace is dome shaped with a height of about one meter.
2	SB1ZY	The base structure of the furnace III at this site is about 83 cm wide and 15 cm thick, which suggests that the furnace is a dome type with a height of about 100 cm. through the air pump (tuyere).
3	SB2A	The base of the furnace IV consists of soil and bricks measuring about 110 cm long and about 90 cm wide. Therefore the shape of the furnace structure at this site is dome shaped.
4	SB2C	The base of the furnace V at this site is produced using soil measuring about 100 cm with a width of about 90 cm. The wall thickness of the furnace is estimated at about 18-20 cm.
5	SB2F	The base of furnace VI consists of soil and burnt bricks. The length of the base of the furnace is 114 cm with a width of 110 cm. Based on the width of the furnace base, it is suggested that the architecture of furnace VI is dome shaped. The base of the furnace VII has a length of about 100 cm with a width of about 90 cm. The thickness of the soil layer for the base of this furnace is about 20-26 cm.The base of furnace VIII was also built using clay. The length of the base of the furnace is 190 cm with a width of 130 cm. The thickness of the soil layer of the base of the furnace is around 10-16 cm which suggests the architecture of furnace VIII is dome-shaped with a height of between 100-150 cm.
6	SB2H	The structure of the furnace IX at this site is characterized by the shape of a crater surface with a diameter of up to five meters. The base structure of the furnace is in the middle of the crater surface with respect to the length of the furnace reaching 153 cm and a width of about 53 cm. It is made of soil.

Finance and tuyere experiments making

In order to maximize the knowledge related to the information on the architectural design of the furnace that is likely to be used in the ancient Kedah iron smelting activity at the SBAC, the furnace making experiment was conducted. Mokhtar (2019) study at the iron smelting site at the SBAC and Muztaza (2015) in Jeniang was used as the main reference regarding the architectural appearance of the furnace to be erected by KTP participants.

The furnace structure is an enclosed architecture and has only openings at the top and a small portion at the base in addition being able to withstand high combustion temperatures (Rostoker and Bronson, 1990). It is also constructed in the presence of a hollow cylinder shaped tuyere to conduct air (oxygen) during the smelting process (Tylecote, 1962). Archaeological studies have so far been able to record the findings of furnace base with a diameter of between 90 to 100 cm which suggest the domed furnace type (Table 1). Furnace base with less wide is required for a domed furnace structure as it is only built at a height of about one meter only (Marks et al., 2020).

This is in contrast to the shaft-type furnace structure which requires a wider furnace base to accommodate the height of the constructed furnace to exceed a height of two meters (Domergue and Fabre, 2017). Until 2022, there is only one find of a furnace base at the SB1G site that has a remnant of a wall structure as high as 48 cm with a base diameter of 158 cm and a width of 95 cm which suggests the furnace represents a shaft type (Mokhtar, 2019).

Table 2. Results of X-Ray Diffraction Diffractometer (XRD) analysis of clay samples in the riverbank of the ancient Sungai Batu

Sample	Locatin	Mineral Content
S1a	Riverbanks of ancient Sungai Batu	Quartz (SiO_2), kaolonite-1A ($Al_2Si_2O_5(OH)_4$) & microline ($KAlSi_3O_8$)
S2a		Quartz (SiO_2), montmorilonite ($Na_{0.3}(AlMg)_2Si_4O_{10}OH_{2.6}H_2O$)& kaolonite-1A ($Al_2Si_2O_5(OH)_4$)
S3a		Quartz (SiO_2), montmorilonite ($Na_{0.3}(AlMg)_2Si_4O_{10}OH_{2.6}H_2O$)& kaolonite-1A ($Al_2Si_2O_5(OH)_4$)
S4a		Quartz (SiO_2), montmorilonite ($Na_{0.3}(AlMg)_2Si_4O_{10}OH_{2.6}H_2O$)& kaolonite-1A ($Al_2Si_2O_5(OH)_4$)
S5a		Quartz (SiO_2) & kaolonite-1A ($Al_2Si_2O_5(OH)_4$)
S6a		Quartz (SiO_2), kaolonite-1A ($Al_2Si_2O_5(OH)_4$) & diaspora (AIO(OH)
S7a		Quartz (SiO_2), kaolonite-1A ($Al_2Si_2O_5(OH)_4$) & orthoclase $K(AlSi_3O_8)$
S8a		Quartz (SiO_2), kaolonite-1A ($Al_2Si_2O_5(OH)_4$) & orthoclase $K(AlSi_3O_8)$
S9a		Quartz (SiO_2), kaolonite-1A ($Al_2Si_2O_5(OH)_4$), orthoclase $K(AlSi_3O_8)$ & dolomite ($CaMg(CO_3)_2$
S10a		Quartz (SiO_2), montmorilonite ($Na_{0.3}(AlMg)_2Si_4O_{10}OH_{2.6}H_2O$) & kaolonite-1A ($Al_2Si_2O_5(OH)_4$)
S11a		Quartz (SiO_2), montmorilonite ($Na_{0.3}(AlMg)_2Si_4O_{10}OH_{2.6}H_2O$) & kaolonite-1A ($Al_2Si_2O_5(OH)_4$)
S12a		Quartz (SiO_2), montmorilonite ($Na_{0.3}(AlMg)_2Si_4O_{10}OH_{2.6}H_2O$) & kaolonite-1A ($Al_2Si_2O_5(OH)_4$)
S13a		Quartz (SiO_2), montmorilonite ($Na_{0.3}(AlMg)_2Si_4O_{10}OH_{2.6}H_2O$) & kaolonite-1A ($Al_2Si_2O_5(OH)_4$)
S14a		Quartz (SiO_2), montmorilonite ($Na_{0.3}(AlMg)_2Si_4O_{10}OH_{2.6}H_2O$) & kaolonite-1A ($Al_2Si_2O_5(OH)_4$)

Table 3. XRF analysis of the major elements of clay samples taken from the vicinity of the ancient riverbank at SBAC

No. Sample	Dry Weight (%)									
	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K2O	P_2O_5
S1a	75.77	0.78	16.00	1.80	0.01	0.48	0.03	0.06	0.77	0.02
S2a	75.85	0.74	15.52	1.73	0.01	0.44	0.02	0.07	0.72	0.02
S3a	71.97	0.79	17.04	1.89	0.01	0.46	0.03	0.06	0.76	0.03
S4a	69.57	0.83	18.05	1.88	0.01	0.54	0.02	0.06	0.83	0.01
S5a	69.76	0.83	18.05	1.88	0.01	0.54	0.02	0.06	0.83	0.01
S6a	74.31	0.76	16.03	1.90	0.01	0.48	0.03	0.08	0.74	0.02
S7a	73.05	0.77	14.80	1.64	0.01	0.42	0.04	0.06	0.66	0.06
S8a	79.78	0.60	11.61	1.30	0.01	0.35	0.03	0.08	0.52	0.04
S9a	69.17	0.90	17.93	2.07	0.01	0.51	0.02	0.06	0.82	0.02
S10a	74.38	0.80	15.50	1.82	0.01	0.47	0.06	0.06	0.75	0.02
S11a	76.17	0.70	14.16	1.81	0.01	0.39	0.04	0.08	0.63	0.03
S12a	76.73	0.74	14.78	1.72	0.01	0.42	0.03	0.06	0.65	0.01
S13a	72.10	0.80	16.94	1.83	0.01	0.49	0.03	0.07	0.76	0.02
S14a	75.73	0.78	15.15	1.93	0.01	0.46	0.02	0.06	0.68	0.01

Table 4. XRF analysis of trace elements for clay samples around SBAC area

Code Sample	Element (ppm)																				
	Bi	Br	Ce	Cl	Cr	Cu	Ga	Nb	Ni	Pb	Rb	S	Sr	Th	Y	Zn	Zr	Au	F	Pr	Hf
S1a	bdl	bdl	bdl	130	70	-	20	30	40	30	50	260	20	30	20	40	330	-	-	-	-
S2a	-	10	-	370	60	20	20	20	40	30	40	550	20	-	20	40	300	-	570	-	-
S3a	-	10	bdl	140	70	bdl	20	20	bdl	30	40	310	20	20	20	30	300	-	bdl	-	-
S4a	-	10	-	170	90	bdl	220	20	bdl	30	40	300	10	-	20	30	330	-	-	-	-
S5a	-	10	-	120	80	bdl	20	20	-	30	30	340	20	-	20	30	330	-	-	-	-
S6a	-	10	-	130	90	-	10	20	bdl	40	50	170	20	-	20	30	310	-	-	-	-
S7a	-	bdl	-	100	70	20	230	20	-	30	40	130	20	bdl	30	20	280	-	-	-	-
S8a	-	bdl	-	100	40	bdl	280	20	-	20	40	280	20	20	20	20	330	-	-	-	-
S9a	-	bdl	140	120	120	bdl	280	20	40	40	40	170	20	bdl	20	40	320	-	-	-	-
S10a	-	bdl	-	120	40	bdl	20	10	bdl	20	30	230	10	-	20	30	300	-	bdl	-	-
S11a	20	10	-	140	70	-	10	30	-	30	30	230	10	-	20	40	400	-	-	-	-
S12a	-	10	-	150	60	-	10	20	50	30	50	370	20	-	20	30	340	-	-	-	-
S13a	-	bdl	bdl	100	40	bdl	140	20	40	30	40	310	10	bdl	30	30	320	-	bdl	100	-
S14a	-	bdl	-	130	70	bdl	180	20	bdl	30	40	350	20	-	30	50	330	760	bdl	-	-

*bdl: Below Detection Limit; Bismuth (Bi); Bromine (Br); Cerium (Ce); Chlorine (Cl); Chromium (Cr); Copper (Cu); Gallium (Ga); Niobium (Nb); Nickel (Ni); Lead (Pb); Rubidium (Rb); Sulfur (S); Strontium (Sr); Thorium (Th); Yttrium (Y); Zinc (Zn); Zirconium (Zr); Gold (Au); Iron (F); Praseodymium (Pr); Hafnium (Hf)

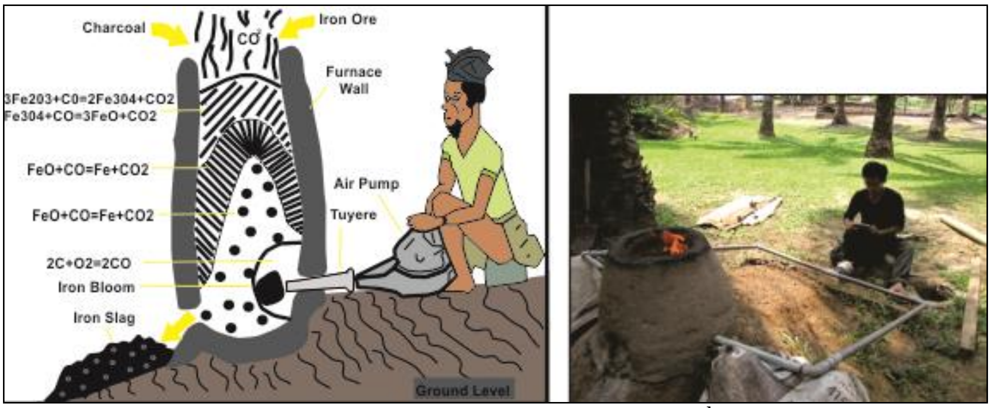
Raw materials from the riverbanks of ancient Sungai Batu was proposed based on XRD (Table 2) and XRF major (Table 3), trace element (Table 4) and SEM analysis of the samples which revealed the similarity of the elements and mineral content of both the furnace and soil samples. XRD analysis has revealed the presence of quartz, phyllites and soil minerals (muscovite, montmorillonite and illite) which are also reinforced by SEM analysis which clearly shows the presence of subsidual and subcircular quartz which explains the raw material taken in river environment (Mokhtar, 2019). XRF analysis also showed that the silica and alumina content dominated the sample between 62.94% and 10.33-15.54% which explains the use of raw materials in the area around Sungai Batu as the raw materials for furnace manufacturing. Therefore, archaeological experiments of furnace making were carried out using alluvial raw material (soil) taken from the ancient riverbanks of Sungai Batu and mixed with sand and hay as temper.

After that, the process of kneading the soil is done by mixing a little water. The mixture was arranged into a spiral structure on the ground to form a circle for the furnace. Tuyere is also produced using soil that is shaped to form a circle and has a length of about 22 cm with a hole in the middle between 1-2 cm. This tuyere is formed using PVC pipe as a mold which is cut according to the size of the tuyere (Figure 8). The clay joint will be formed in a circle by sticking to the PVC pipe which eventually allows a circular opening space in the tuyere to be formed. During the process of forming the base of the furnace is carried out with a diameter of one meter, the structure of the mouth of the furnace is also built which serves as a place to drain the slag after smelting. When the base part of the furnace structure is dry and strong then the top of the furnace was built up until it reached a height of 93 cm. Once the construction of the furnace reached a height of 25-30 cm, four tuyeres were placed on the furnace wall to facilitate the process of channeling oxygen into the furnace.

After the furnace reaches a height of about 93 cm, an opening space with a diameter of 40 cm is produced with the main purpose as a place to insert iron ore, charcoal, sand and shells for smelting purposes. Once the furnace structure is completed, the furnace will be left to dry for five to seven days (depending on weather conditions) before being burned to harden the furnace wall structure (Figure 4). The purpose is the furnace wall does not crack and collapse as a result of the sudden evaporation of water content when the furnace is used in high temperature of smelting activities.

a b

Figure 4. The process of attaching the tuyere to the furnace wall to complete the shape of the built furnace (a) and when the furnace is dry, it is burned to strengthen of the furnace structure (b) (Source: Research data analysis, 2023)



a b

Figure 5. Illustration of iron smelting using a hand pump (a) (Bendama, 2010) and experimental process of iron smelting using an bellow as a air pump (Source: Research data analysis, 2023)

Bellow experiments making

The study of Mokhtar (2019; 2012) and Muztaza (2015) at the Sungai Batu and Jeniang archeological sites did not record any findings of bellow used in iron smelting activities. For the bellow making experiment, the reference from the study of Bandama (2010) has been used as a yardstick related to the shape of the bellow used in iron smelting activities in Africa. Bandama (2010) has provided information that the shape of bellow used in iron smelting activities is circular in shape, fastened with animal skin and pumped by hand. Such a shape is also described by Gilboa et al. (2018) at the Levant site which is used as a guideline for the bellow making for this archaeological experiment.

Based on that information, bellow made from a combination of plywood, PVC pipe and fabric began to be produced. The air pump is of the pressure type using hands to pump oxygen into the furnace through the tuyere. It is circular shape with a height of about 50 cm, has an air chamber and a handle that acts as a device to pump oxygen into the furnace. For the purpose of this archaeological experiment this bellow is then connected into a tuyere in the furnace wall using PVC pipe (Figure 5) during the iron smelting process.

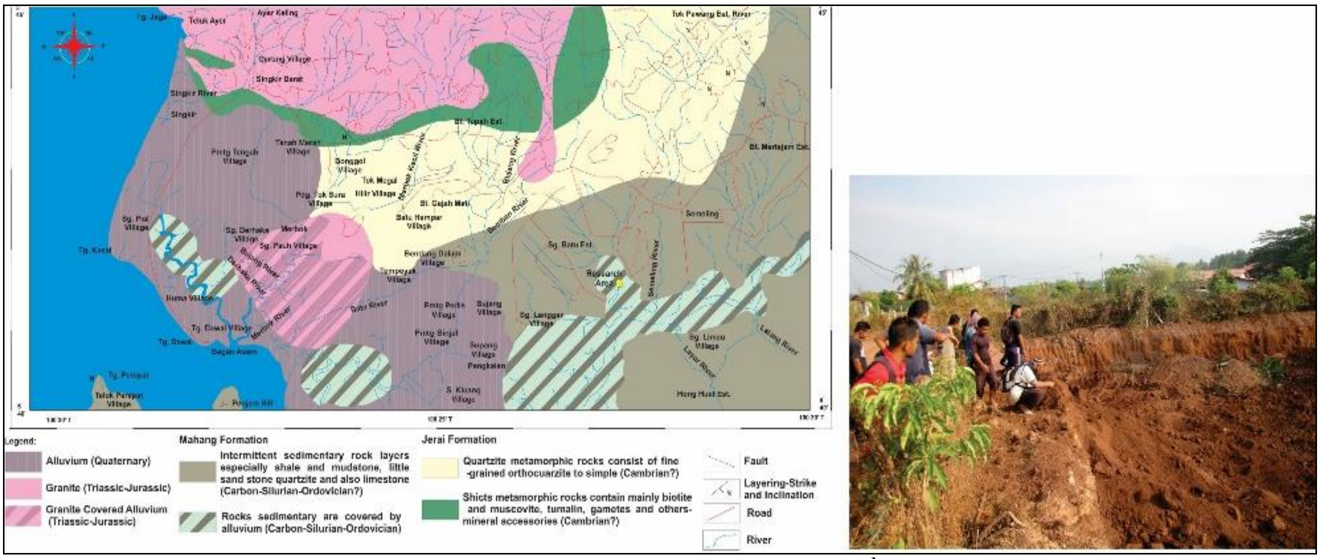
Survey raw materials of iron smelting

Survey activities were also carried out at the areas of Kampung Batu 5, UiTM Merbok and Bukit Tupah to obtain the raw material for smelting iron, namely iron ore (Figure 6). This area was selected as a survey area based on the survey and mapping of raw materials for smelting activities by Mokhtar (2019; 2012) which provides information related to the potential of the area in supplying iron smelting for the SBAC.

The research of the raw material of iron smelting used the iron ore mineral distribution map by Bradford (1972) and the Sungai Petani Map produced in 1943 because the map still clearly shows the route and flow of the old river compared to the map produced in 1970. According to Mokhtar (2019), distance sampling method based on the area near the SBAC and river flow is a priority in the survey to btain data related to the location of the raw material of iron smelting. The tools used during the sampling were GPS, notebooks and magnets for the purpose of testing the magnetic properties in the iron ore whose findings were recorded during the survey.

The iron ores that were sampled during the survey activities were of the types of magnetite ($Fe^{2+}Fe^{3+}{}_2O_4$), hematite (Fe_2O_3) and goethite (α-Fe3+O(OH)). This is because the three types of iron ore are dominantly found in the iron smelting workshop at the SBAC (Mokhtar, 2019). The XRF analysis carried out on the iron ore clearly revealed that the mean Fe content of the iron smelting site in this area ranged from 57.86% to 66.40% with the largest standard deviation of 4.53 (Mokhtar, 2019). The mean percentage of silica (SiO^2) is around 2.02% to 5.79% with a standard deviation of 1.74. The percentage of alumina (Al_2O_3) is between 1.12% to 5.33% (Mokhtar, 2019).

Based on the XRF analysis, it is clear that the chemical composition of SBAC iron ore reveals a range that is almost the same as the iron ore in the vicinity of Mount Jerai in the area involved in the survey activities. In addition, XRF analysis of iron ore also recorded the presence of potassium oxide (K_2O), manganese oxide (MnO_2), phosphorus oxide (P_2O_5) and low carbonate oxide ($C(=O)(O-)_2$) elements that matched the iron ore content in the samples in the Gunung Jerai area. This analysis also proves that the iron ore used in iron smelting activities is of high quality based on the high percentage of iron compared to other mineral content (Mokhtar, 2019).



a b

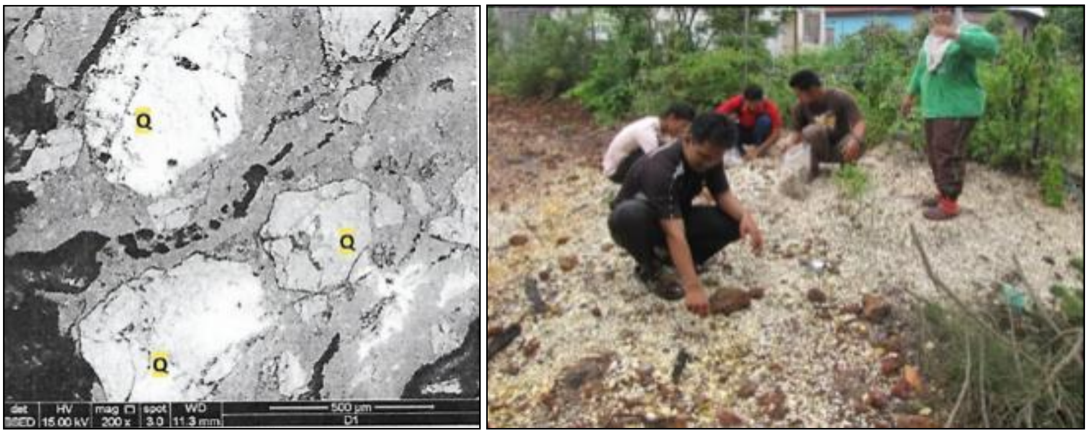
Figure 6. Areas involved in survey activities to obtain the raw material of iron smelting, namely iron ore to meet the needs of iron smelting experiments at the SBAC (a) (Geological Map, Sheets 2-1/2 & 2-1/6, Years 1972) and successful survey activities record the findings of iron ore that used as a raw material for iron smelting experiments at SBAC (b)

Survey of iron smelting flux materials

The study of Zakaria et al. (2018) has been able to record the use of flux materials in the iron smelting process at the SBAC. The flux materials are sand and shells. The use of shells as a flux material was also reinforced by the discovery of shell piles at the iron smelting site at the SBAC itself (Yusof, 2016). Based on the morphology of the shell, which has no burning effect and is peeled for cooking, it is suggested that it be used as a flux in iron smelting activities to allow temperatures as high as 1,200ºC to be obtained. This is because by applying bloomery smelting technology along with the use of sand and shell flux enables temperatures as high as 1,200ºC to be achieved (Mokhtar, 2019).

In addition, the results of XRF analysis on bases furnace samples also revealed a content of magnesium oxide (MgO) between 0.17-01.06% and calcium oxide (CaO) between 0.25-0.66% also strengthen the possibility of sand and shells after being used as flux in iron smelting activities (Mokhtar, 2019).

In addition, SEM analysis on furnace base samples also revealed the effects of cracking and recrystallization on quartz minerals suggesting the use of flux agents in iron smelting (Mokhtar, 2019). Therefore, survey activities to obtain sand and shells are carried out to complete the materials required in iron smelting activities. The survey activity was conducted in the river area near Sungai Batu Besi village, which is approximately one kilometer from the SBAC (Figure 7). In the area, the shells and sand were sampled for the purpose of iron smelting experiments that will be conducted.



a b

Figure 7. SEM analysis on bases furnace samples showing the presence of quartz recrystallization (Q) which suggests the presence of flux use in iron smelting activities (a) and survey activities were carried out to obtain samples of shells and sand for iron smelting experiments (b) (Source: Research data analysis, 2023)

Iron smelting fuel survey

Mokhtar (2019) has reported the possibility of mangrove wood having been used in iron smelting activities at the SBAC based on SEM-EDX analysis of the moisture of charcoal samples. In addition, the presence of elemental calcium (CaO) in the analyzed charcoal samples is also an indication that the fuel used is from a plant type most likely from the mangrove wood type. The results of the analysis revealed a carbon content of around 50.51-68.81% which is close to good charcoal quality. Photomicrographic analysis of charcoal also clearly shows that it is derived from hardwood based on dense and hollow texture (porosity). This is because good quality charcoal should have at least 70% fixed carbon and less than 15% volatile matter. According to Mokhtar (2019) the low percentage of carbon is because it has been used in iron smelting activities that cause chemical reactions between fuel and iron ore. Apart from using SEM-EDX analysis, the charcoal was also sent to the genetic laboratory of the Forest Research Institute of Malaysia (FRIM) to identify plant species through deoxyriboneucleic acid DNA analysis was also conducted to identify the type of charcoal used in smelting activities at the SBAC. Based on the results of SEM-EDX and DNA analysis, the study on the topographic map of shift 16 in 1970 was used to survey the remaining mangrove trees around Sungai Merbok which is expected to be the main fuel for iron smelting in this complex. Although the results of the analysis show that Merbok mangroves are most clearly used as iron smelting fuel in this complex, this survey activity only involved the use of rubber wood as fuel for ethnoarchaeological experiments conducted and did not involve cutting mangrove trees.

a b c

Figure 8. Charcoal photomicrograph of an iron smelting workshop site showing iron smelting fuel taken from hardwood (a). Based on the fact survey activities was carried out to obtain fuel for iron smelting experiments (b) and after that a rubber wood is burned in a furnace to produce charcoal (c) for iron smelting experiment (Source: Research data analysis, 2023)

This is done for the purpose of conservation and sustainability of the mangrove trees which at present its area has been reduced to 3,000 ha from its original area of more than 6,000 ha due to development (Ong et al., 2015). After that the rubber tree wood obtained will be cut to a size of about 20-30 cm using a saw and burned in a furnace (Figure 8) to produce charcoal for iron smelting experiments. The rubber wood is burned between 4-5 hours until it turns into charcoal which allows archaeological experimental activities of iron smelting to be carried out.

Archaeological experiments of iron smelting

Once the furnace structure, tuyere, wind pump (bellow), iron smelting material (iron ore), catalyst (shell) and fuel (charcoal) were obtained through survey and reconstruction, then iron smelting experiments were carried out. Mokhtar et al. (2018) stated that iron smelting at SBAC generally involves five main processes such as (1) iron ore mining, (2) ore cleaning and preparation, (3) smelting process, (4) iron ingot forming and (5) production of iron tools by forging. The smelting is carried out directly (bloomery) which involves the extraction of iron directly from iron ore (Rostoker and Bronson, 1990). This iron smelting experiment started with the cleaning and preparation of iron ore because the first stage in the smelting process was carried out through survey activities.

This stage involves the process of cleaning iron ore from soil residues and knocking it into chunks of smaller size before roasting (Figure 9). The purpose of the iron ore being roasted is to get rid of silica and carbon in order to accelerate the chemical reactions occurring during smelting (Rostoker and Bronson, 1990). After that the roasted iron ore will be melted together with catalyst materials such as sand and shells using rubber tree charcoal. These experiments involved charcoal and iron ore mixing volume ratios of 1:3, 1:5 and 1:10 (Figure 10) as suggested by Mokhtar et al. (2018). The smelting process lasts for seven to eight hours and requires a melting temperature around 1,200. After the smelting process takes about seven to eight hours, it is found that the molten iron slag has not yet flowed out.

Therefore, the structure of the furnace was broken to see and examine the condition of the iron ore that has been melted. Research on the results of iron smelting experiments shows that it is still brittle and easily broken if compared to iron blooms at the Sungai Batu Archaeological Complex. This is because the iron blooms are more solid, precise and have good smelting quality and high quality (Figure 11) with over 60% iron oxide (Fe) content (Mokhtar, 2019).

a b

Figure 9. The process of breaking iron ore into small lumps (a) and the roasting process (b) (Source: Research data analysis, 2023)

a b

Figure 10. The process of weighing charcoal (a) and iron ore (b) before an experiment is carried out at SBAC

This indicates that iron smelting experiments carried out with the prescribed ratio of iron ore and coal need to be re-examined and modified as well as the optimal combustion temperature needs to be adjusted to obtain better smelting results using a bimetal thermometer temperature measuring device. Non-uniform smelting temperatures are believed to be the cause of molten iron ore not to flow out.

Although the archaeological experiments of iron smelting did not give the same results as the evidence of iron blooms at iron smelting sites, the information obtained is primary data that can be improved in further experiments. The most important thing from the archaeological experiments is that the iron smelting demonstration archeology package is offered to tourists at the SBAC itself which can give tourists an initial understanding of how the iron ore smelting stage was done by the early people in this area who generally represent the iron industry community ancient Kedah.

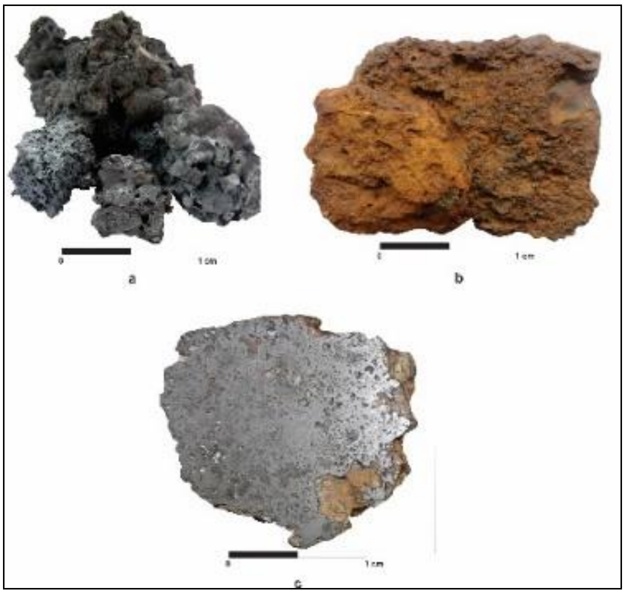


Figure 11. Iron smelting experiments which revealed brittle and hollow results (a) which showed differences with iron ingots found at iron smelting sites (b,c) which showed that they were more solid and high quality (Source: Research data analysis, 2023)

Development of the archaeotourism sector in Kuala Muda District

Archaeological experiments of iron smelting have been able to provide primary data related to raw materials and smelting procedures which eventually led to the offering of archaeotourism packages at the SBAC. The result is a guided tour package and a full package (Figure 12) which involves activities such as site visits, iron smelting demostration, brick making and excavation. All these activities involve the cooperation of KTP who has been certified as a nationally recognized tourist guide. Through the tour package offer, KTP participants who have obtained a green badge and are recognized as professional tour guides in the Kuala Muda district can participate directly in all activities offered in the tour package, especially in the SBAC area.

a b c d

Figure 12. Full tour package offered at SBAC such as guided tour, (a) iron smelting demostration, (b), excavation, (c) and brick making (d) involving by KTP participants directly (Source: Research data analysis, 2023)

This means that for the first time in the Kuala Muda district, there is a group of local people who are trained and able to be the front line to the empowerment of tourism products that have been mapped in the Kuala Muda district specifically. Apart from being involved in the tourism package activities offered, KTP is also directly involved in assisting in exhibition and festival programs organized by the state government and non-governmental organizations (NGOs). KTP also assists in the process of preparation and work of royal, ministers, chief ministers members of parliament, foreign delegations and media filming visits, that can promote this archeological site to foreign tourists.

Based on KTP's consistent involvement in tourism activities and promotion of district tourism products, it can be considered that the KTP really has a positive impact in providing qualified and knowledgeable tour guides from locals in Kuala Muda district in general and Kedah in particular.

CONCLUSION

The KTP based on archaeological research and tourist guide courses established from 2013 has successfully achieved its objectives and is able to produce many certified tourist guides in the Kuala Muda district. KTP's intellectuality in archeology, history and culture in the Kuala Muda district is the best added value that a natural heritage tour guide should have. Therefore, it is not an exaggeration to suggest that the existence of such a program allows ancient Kedah smelting and manufacturing technology to be identified and classified through archaeological experiments and the results disseminated to the community through tourism packages created.

As a result, successful district tourism ambassadors have been able to be formed through this KTP which will definitely help the state and the country in the development of the archaeotourism sector.

Author Contributions: Conceptualization and writing-original draft preparation: M.H.A.H.; formal analysis: N.A.M.M.; investigation and data curation: I.I.Z., S.N.S.M., N.S.A.H.; Methodology: S.S.K.M.; supervision, project administration and writing-review and editing: M.S. All authors have read and agreed to the published version of the manuscript.

Funding: This study was conducted under the grant of "KTP Berasaskan Penyelidikan Arkeologi Di Tapak Sungai Batu, Kedah 203/PARKEO/6750032".

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study may be obtained on request from the corresponding author.

Acknowledgments: Authors are thankful to Dato Dr. Mokhtar Saidin, former Chairman, Geopark Implimentation Committee, Ministry of Energy and Natural Resources, for providing all necessary facilities to successfully conducting this research.

Conflicts of Interest: The authors confirm that there is no conflict of interest involve with any parties in this research.

REFERENCES

Adam, A. (2020). *Research at Pengkalan Bujang Archaeological Complex, Bujang Valley, Kedah*. Unpublish Master Disertation, University Sains Malaysia, Pulau Pinang, 176p.

Ahmad, N. (2016). *Kajian Arkeologi di Tapak SB1R, SB1S, SB1T, SB1U, SB1V dan SB1Z di Kompleks Sungai Batu Lembah Bujang, Kedah [Archaeological Research at SB1R, SB1S, SB1T, SB1U, SB1V and SB1Z in Sungai Batu Complex, Bujang Valley, Kedah]*. Master Dissertation, University Sains Malaysia, Pulau Pinang, Malaysia, 340p.

Ali, M.A., Halim, M.H., Masnan, S.S.K., Saidin, M. & Narayanen, S. (2023).Geoarchaeosites for Heritage Tourism Product of Kuala Muda District, Kedah, Malaysia. *GeoJournal of Tourism and Geosite*, 1(46), 63-70. https://doi.org/10.30892/gtg.46107-1001

Bandama, F. (2010). *Indigenous Iron Production in South Africa: An Archaeometallurgical Investigation of Metal Working at Rhenosterkloof 1, Limpopo Province*. Paper Presenter at 13th Joint PNAF-SAFA Conference, Dakar, Senegal 2p. https://doi.org/10.13140/RG.2.2.30576.00005

Bradford, E.F. (1972). *Geology and Mineral Resource of the Gunung Jerai Area, Kedah*. Geological Survey Headquarters, 242p.

Chuenpee, T., Won-In, K., Natapintu, S. & Takashima, I. (2014). Archaeometallurgical Studies of Ancient Iron Smelting Slags from Ban Khao Din Tai Archaeological Site, Northeastern Thailand. *Journal of Applied Sciences*, 14(9), 938-943. https://doi.org/10.3923/jas.2014.938.943

Domergue, C. & Fabre, J.M. (2017). *Once Upon a Time, a Shaft Furnace.* The Standard Bloomery Furnace (1st Century BC) at Les Martys (Southern France). Paper Presenter at Iron in Archaeology: Bloomery Smelters and Blacksmiths in Europe and Beyond, 1-2.

Geological Map (1972). *Sheets* 2-1/2 & 2-1/6, Years.

Gilboa, A., Sharon, I., Zorn, J.R. & Matskevich, S. (2018). Excavations at Dor, Final Report: Volume IIB Area G, the Late Bronze and Iron Ages: Pottery, Artifacts, Ecofacts and Other Studies, Hebrew University of Jurusalem, 1-340. https://www.jstor.org/stable/26493568

Gilmour, B. & Hoyland, R.G. (2012*): Medieval Islamic Swords and Swordmaking*. Medieval Islamic Swords and Swordmaking, 1-200. ISBN-13: 978-0906094570.

Halim, M.H.A. (2019). *Sumbangan Kajian di Tapak SB1Y, SB2G, SB2J dan SB2ZZ kepada Bukti Seni Bina Pelabuhan di Kompleks Sungai Batu, Lembah Bujang, Kedah [Contribution of Studies on SB1Y, SB2G, SB2J and SB2ZZ on Architectural Proof of Port in Sungai Batu Complex, Bujang Valley, Kedah]*. Unpublish Doctoral. Disertation, University Sains Malaysia, Pulau Pinang, Malaysia, 551p.

Halim, M.H.A., Zakaria, I.I., Masnan, S.S.K, Talib, N.K., & Saidin, M. (2022). Kedah Tua Kingdom Ancient River Jetty Architecture as an Iconic Tourism Products of Kuala Muda District, Kedah, Malaysia. *GeoJournal of Tourism and Geosites*, 43(3), 850–860. https://doi.org/10.30892/gtg.43301-8xx

Hassan, Z. (2018). *Tapak SB1B Sungai Batu, Kedah Malaysia: Pertaliannya kepada Sejarah Senibina dan Sosio-Budaya Tanah Besar Asia Tenggara [SB1B Sungai Batu Site, Kedah Malaysia: Its Relationship to the Architectural and Socio-Cultural History of the Mainland of Southeast Asia]*. *Malaysia Museum Journal (PURBA)*, 37, 20-43, ISSN 2600-7673.

Humphris, J.E. (2010*). An Archaeometallurgical Investigation of Iron Smelting Traditions in Southern Rwanda*. University College London, 1-355. https://doi.org/10.1080/0067270X.2011.647955

Humphris, J., Charlton, M.F., Keen, J., Sauder, L. & Alshishani, F. (2018). Iron Smelting in Sudan: Experimental Archaeology at the Royal City of Meroe. *Journal of Field Archaeology*, 43(5): 399-416. https://doi.org/10.1080/00934690.2018.1479085

I-Tsing (1896). *A Record of the Buddhist Religion as Practised in India and the Malay Archipelago (A.D. 671-695).* The Clarendon Press, Oxford, 240p. ISBN-13: 978-1330056646

Khaw, N.R. (2011). *Pensejarahan Kedah Tua: Satu Analisis Sosioekonomi [History of Kedah Tua: A Socioeconomic Analysis]*. Unpublish Master Disertation, University Sains Malaysia, Pulau Pinang, Malaysia, 460p.

Marks, Y., Groat, N., Lortie, L., Hughes, M., Thompson, H., Woodland, C., Adams, T., Thorpe, T., Tang, B., Kenyon, R. & Langhorne, B. (2020). Smelting Conditions and Smelting Products: Experimental Insights into the Development of Iron Bloomery Furnaces. *EXARC*, 1-11. https://exarc.net/ark:/88735/10504

Mokhtar, N.A.M. (2019). K*ajian Industri Peleburan Besi di Kompleks Sungai Batu, Lembah Bujang daripada Perspektif Arkeometalurgi [A Study of the Iron Smelting Industry in the Sungai Batu Complex, Bujang Valley from an Archaeometallurgical Perspective]*. Unpublish Doctoral Disertation, University Sains Malaysia, Pulau Pinang, Malaysia, 326p.

Mokhtar, N.A.M. (2012). *Ekskavasi Tapak Peleburan Besi SB2A, Sungai Batu, Lembah Bujang* [*The Excavation of Iron Smelting Site SB2A, Sungai Batu, Bujang Valley]*. Unpublish Master Dissertation, University Sains Malaysia, Pulau Pinang, Malaysia, 352p.

Mokhtar, N.A.M., Zakaria, I.I., & Saidin, M. (2018). Peleburan Besi di Tapak Sungai Batu: Satu Kajian Etnoarkeology [Iron Smelting at Sungai Batu Sites: Ethnoarchaeological Studies]. IN: Isa, H.M., Khaw, N.R. & Zainun, N. (eds). *Etnoarkeologi di Malaysia: Cerminan Budaya Material Masyarakat Peribumi [Ethnoarchaeology in Malaysia: Development of Individuals Culture Materials*, UTHM, 25-37. ISBN: 978-967-2183-25-9.

Molingka, N. (2013). *Teknologi Peleburan Besi di Tapak SB2C, Sungai Batu, Lembah Bujang, Kedah: Abad ke-8 Hingga Ke-11 Masihi [Iron Smelting Technology at Site SB2C, Sungai Batu, Bujang Valley, Kedah: 8th to 11th Century AD]*. Unpublish Master Disertation, University Sains Malaysia, Pulau Pinang, 251p.

Muztaza, N.M. (2015). *Kajian Arkeologi di Tapak Kampung Chemara dan Kampung Sungai Perahu, Jeniang, Kedah [Archaeological studies at Chemara Village and Kampung Sungai Perahu, Jeniang, Kedah]*. Unpublish Master Dissertation, University Sains Malaysia, Pulau Pinang, Malaysia, 281p.

Ong, J.E., Ahmad, W.J.W., Yong, J.W.H. & Mohamed, M. (2015). The Merbok Mangroves: Present and the Way Forwad. IN: Rahim, A.R.A., Aman, K.A.K., Bokti, H.M., Hassan, M.N.A. & Abdullah, M. (eds). *Hutan Paya Bakau Merbok: Persekitaran Fizikan dan Kepelbagaian Flora [Merbok Mangroves Forest, Kedah: Forest Management, Physical Environment and Flora Diversity]*. Peninsular Malaysia Forestry Department, Kuala Lumpur, 23: 21-33. ISBN: 9670539226.

Rostoker, W. & Bronson, B. (1990). *Pre-industrial Iron: Its Technology and Ethnology*. Archaeomaterials Monographs, 1-232. ISBN-13: 978-0924171031.

Saidin, M. (2016). *Kedah Tua Kingdom: New Evidence from Sungai Batu Complex.* Paper Presenter at Kedah Tua International Conference, Sungai Petani, Kedah, Mei 20-23, 2016.

Thilakavathy, M. (2019). *Sangam Tamils: With Special Reference to Pattinapalai*. MJP Publishers, 1-122. ISBN 13: 978-8180941894.

Tylecote, R.F. (1962). Metallurgy in Archaeology. *Edward Arnold Publishers,* 1-368. https://doi.org/10.2307/1505260

Yusof, S. (2016). *Ekskavasi Tapak Monumen SB1P, SB1Q, SB1W dan SB1X di Kompleks Sungai Batu, Lembah Bujang, Kedah [Excavation of Monument Sites SBIP, SB1Q, SB1W and SB1X at the Sungai Batu Complex, Bujang Valley, Kedah].* Unpublish Master Dissertation, University Sains Malaysia, Pulau Pinang, Malaysia, 243p.

Article history: Received: 03.03.2023 Revised: 20.04.2023 Accepted: 24.05.2023 Available online: 21.06.2023