THE ANCIENT IRON SMELTING IN SG. BATU, BUJANG VALLEY, KEDAH

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This paper discusses the preliminary data of iron smelting site (SB2A) found in protohistorical site of Bujang Valley, Kedah. This site was dated to 3rd - 5th CE. The findings include metal artifacts, remains of furnaces, thousands of iron ores, tuyeres and slags. As the first iron smelting site ever discovered in Bujang Valley, this discovery had given a big impact that may be able to change the old paragdigm about the existence of a possible civilization in Malaysia. The discovery shows that from the 3rd CE, there had been a society that had already acquired the technology of iron smelting in Bujang Valley. The actual form of the structure, in terms of the shape of the furnace, is yet to be identified due to the insufficiency of the intact structure discovered during the excavation. The current research indicates that a large-scale iron-smelting industry existed in Bujang Valley from 3rd - 5th CE. This paper will also attempt to discuss the result of the preliminary analysis on the iron artefact, through the employment of some methods such as polishing section, X-ray fluorescence (XRF) and Scanning electron microscope (SEM).

Keyword: Bujang Valley, Iron Smelting, Iron Slag, Tuyere

INTRODUCTION

The article will discuss the results of archaeological excavations and preliminary analysis of artifacts found at the site SB2A. Site excavation was carried out from February 1, 2009 and ended on April 15, 2009. The site is also the site of no. 71a based on the mapping conducted by Jane Allen in Bujang Valley in 1979 and 1980. Allen also reported that this site serves as a site for religious or secular activity based on the external mound, rectangular in shape with the size of 7x6 m (Allen, 1988) (Photo 1).

HISTORICAL RESEARCH ON BUJANG VALLEY

Studies on Bujang Valley civilization began more than a century ago. During this period, a total of more than 80 sites were found. Most of the sites found were the site of the candi (temple) and entrepot. Preliminary studies began when James Low accidentally discovered the remains of candi and stone inscriptions at Seberang Prai in 1840's. After this discovery, more researchers are conducting research in the Bujang Valley, among them are Evans, Quartrich Wales, Dorothy Wales, Treggoning, Sullivan, Peacock and Lamb. In 1968, the Department of Museums Malaysia has taken the research and maintenance of the candi of the Bujang Valley in collaboration with local universities. Among local researchers involved in research in the Bujang Valley are Adi Taha, Kamarudin Zakaria, Leong Sau Heng, Nik Hassan Shuhaimi, Othman Yatim, Mohd. Supian Sabtu and several other researchers. Until now, study on Bujang Valley found monument function as candi which is related to Hindu-Buddha period and related to trading activities.

Bujang Valley which is also known as Kedah Tua is believed to be the earliest entrepot and religious center in the country. Its role can be proved by the discovery of archaeological evidence such as the discovery site of candi Hindu-Buddhist, statues, broken ceramics, beads, porcelain and many other artifacts connected with the trade (Wales, 1970, 1974, Wheatley, 1964; Lamb, 1960, 1961, 1980; Leong Sau Heng, 1973, Adi, 1991; Supian, 2002; Nik Hassan

Shuhaimi, 1990, 2008). The important of Bujang Valley as an entrepot was proven through the Chinese, Indian and Arab record (Wheatley, 1961). Bujang Valley is located in the middle of two great trade routes, namely China and India (Nik Hassan Shuhaimi & Othman, 1992). Its strategic location has resulted in traders landing at Bujang Valley while waiting for a change of monsoon (Allen, 1988). Three main rivers played an important role as a trade route, namely Muda River, Merbok River and Bujang River.

ISSUES AND PROBLEMS

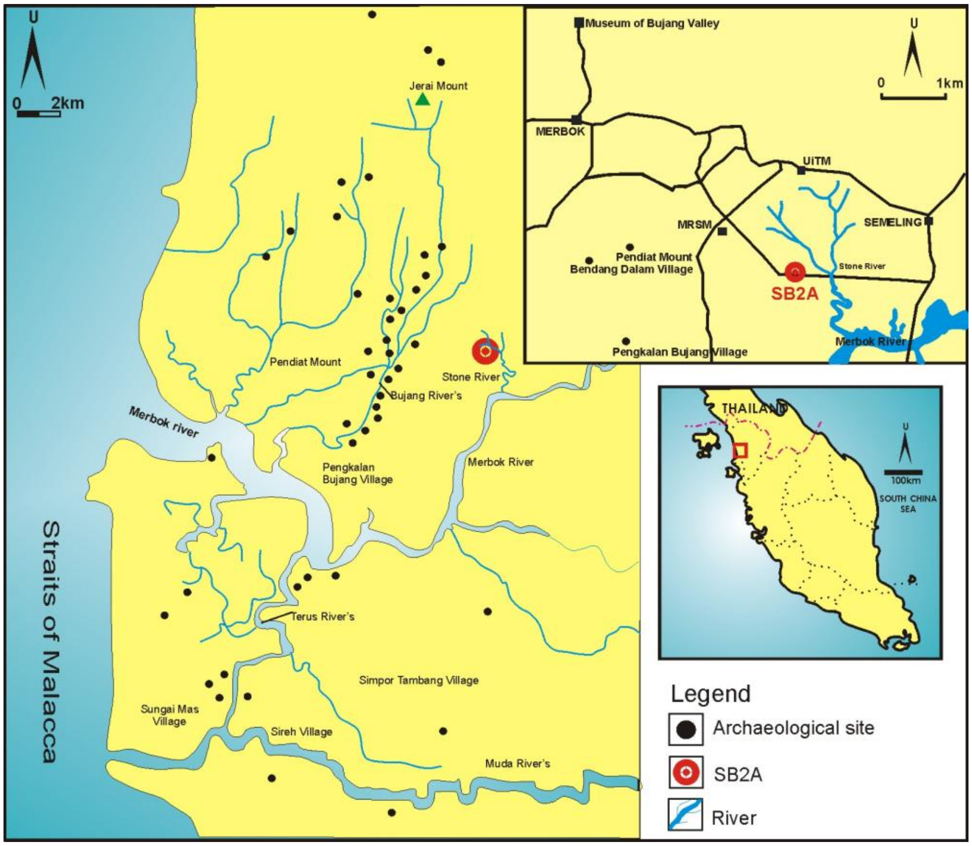
This study aims to determine the function of the base 71a which has been recorded by Jane Allen in 1978. The result of excavations has shown this site was an iron smelting site, the first one ever discovered in the history of archaeological research in the Bujang Valley, which is well-known for its candi and entrepot. This study will discuss SB2A (71a) site function as iron smelting site, utilized from the 3^{rd} - 5^{th} CE.

ARCHAEOLOGICAL RESEARCH IN SUNGAI BATU

The main purpose of research at the site of Sungai Batu is to answer the issues and problems arising from previous studies related to the Bujang Valley civilization, particularly from the aspect of iron studies. This study was also conducted to prove the early hypothesis that assumes Sungai Batu area was formerly served as an important complex in the community. This hypothesis is based on the survey results of 97 potential archaeological sites in the area of Sungai Batu. This survey was carried out from 2007 until Mac 2009 by a research team from Centre for Global Archaeological Research, Universiti Sains Malaysia. SB2A site is one of 97 mounds in the area of Sungai Batu. It is bounded by the coordinate of longitude 100° 27,277' east and latitude 5° 41,651' north, with altitude of 11 m above sea level, based on the reading of the GPS (Global Positioning System) at the datum point of the study site. This site is located inside the oil palm estate in Sungai Batu around 10 km from Sg. Petani and 80 km from Alor Star, capital city of Kedah state. It is also situated within the vicinity of nine other sites in the study area of Sungai Batu, namely SB2B, SB2C, SB2D, SB1A, SB1B, SB1C, SB1D, SB1E dan SB1F (Map 1).

ARCHAEOLOGICAL EXCAVATION IN SB2A

Excavation of SB2A involved digging a mound approximately measuring $575m^2$. Each trench is by 1x1 meter grid, which is labeled in alphabetical order and numbered systematically. Alphabet labeling is laid out from north to south, while the number sequence extends from east to west of the site. Excavation works were carried out after the grid mapping of the site is complete. Trenches were dig on checker-board like pattern before opening up the whole area, after the function of sites is known. Excavation carried out in accordance with the spit system, in which each spit has 10 cm depth. In addition, data collection such as photos, sketches of artifacts, stratigraphic data, dating sample and scientic analyses were also carried out during the excavations. During three months of excavation, a total of 200 trenches have been uncovered (Figure 1, Photo 1 & Photo 2). Trench O9 (painted yellow) was used as a reference for spit depth (Figure 1).



Map 1: Location of SB2A in Bujang Valley.

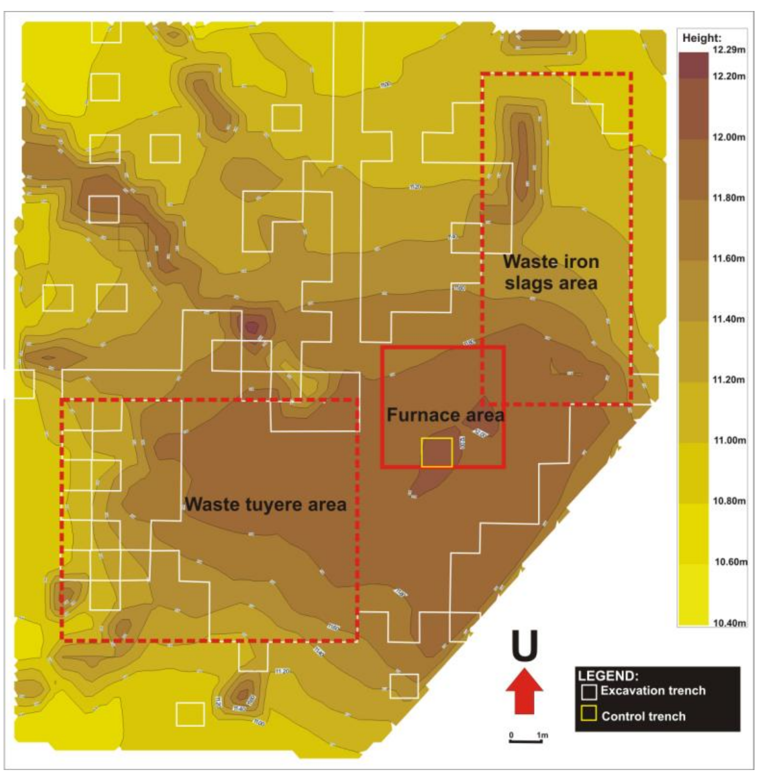


Figure 1: Contour Map SB2A

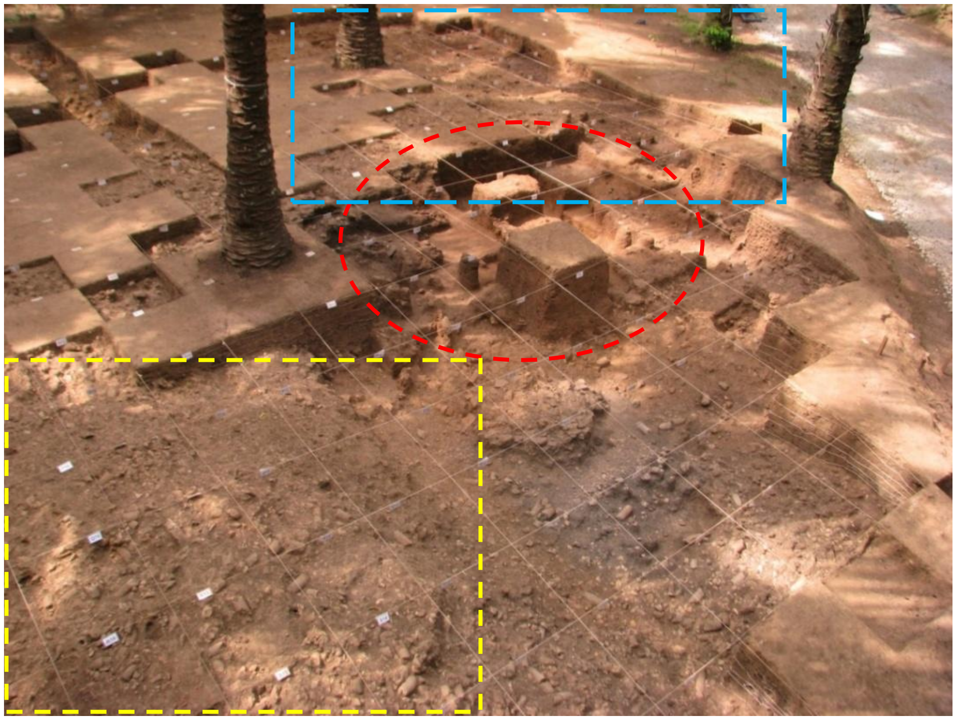


Photo 1: SB2A from an upper view. (Yellow line indicates waste tuyere area, red line shows the furnace area and blue line represents waste iron slags area)

Photo 2: Iron slags area from an upper view. (Yellow line shows the distibution of iron slags and blue line shows the tuyere area)

PRELIMINARY ARTEFACT ANALYSIS

Based on the artifacts found and the scientific analysis conducted to date, it is accepted that the site functioned as an iron smelting area, from the 3rd until 5th CE. This is based on the discovery of furnaces, burnt clay, iron slags, iron ore, tuyere, iron artifact, stone tools, pottery, beads, ash, charcoal and others. Preliminary analysis includes classification and 3-dimension recording of the artifact (Table 1). Iron slags and tuyere are the dominant artifacts found. The analysis of artifacts found 1,742.5 kg (69.1%) of iron slags, 867.4 kg (25.41%) of tuyere and 157.9 kg (4.7%) of iron ore (Table 1). These number represent artifacts that has been excavated, however, there are more which are buried *in situ*. The iron slags found in this site has no particular form. Among the physical characteristics of the remaining iron is dark color, dense, spongy, metallic or rusty figure. The iron ores found here consist of hematite and magnetite. A total of 1.4kg (0.02%) of laterite were also found on site. The presence of laterite is associated with iron ore (hematite and magnetite) brought to the site, and it has no significant role as raw material to produce iron.

Tuyere are used to allow air to enter the furnace with the forced of bellows (Suchitta, 1983). The hole in the center allows air in for oxygen (O_2) supply and increase the pressure in the furnace temperature. Most of the tuyere was found with remnants of liquid metal at one end (Photo 12). The longest tuyere found here is 27.1cm length and 11.2cm wide. The diameter of the center hole is approximately 2.1 cm to 3.6 cm. Tuyere will be infixed in the furnace wall by certain angles (Lee & Williams, 2002). The differences of angle will have an impact on increasing the pressure and temperature in the furnace (Lee & Williams, 2002).

Piles of bricks were also found in this site. The analysis to determine the features of this brick is still in progress. It is possible that these clay bricks were used for the construction of the furnace. Location of the brick suggested it was used as the lining of the furnace base. It is estimated that more than 100 pieces of brick were found here. The maximum and minimum thicknesses of the brick are 5.2cm and 1.3cm. In addition, there are 8 metal artifacts found, consist of 3 blades, 2 iron fitted into the hole of the tuyere, a circle-shaped piece of metal and an metal ring (?) and a bronze ring (Photo 5, 9, 10 & 11). 18 stone tools were also discovered, and analysis revealed that they were 1 handaxe, 6 broken anvil, 6 hammer stone or mortar (?) and 5 unkown stone tools (Photo 3 & 4). This five unknown stones were likely used as a polishing stone. A total of 676 pieces of pottery found consist of 610 body parts, 51 parts of the rim and 15 others. Also, a total of 6 beads and shell remains were found here. The shells were found in 4 different locaton which is in a spit 13 of Q9, spit 12 of Q11, spit 13 of Q10 and spit 13 of R10.

Stratigraphy has revealed 7 to 10 layers of soil and cultural layers, beginning at layer 5 (Figure 2 & 3). It also shows the presence of different layers at the same time. These differences occurred because of the different work activities and can be seen clearly on the stratigraphy of trench P15-P9 and Q7-N7. Stratigraphy of the trench P15-P9 shows the changes of the work area (iron smelting activities) to waste area of tuyere (Figure 2), while stratigraphy at trench Q7-N7 signifies the main area of iron smelting (Figure 3, with dating results).

Radiocarbon, AMS dan OSL (Optically Stimulated Luminescence) dating precisely proved that the site was actively used during 3rd - 5th CE (Figure 2 & 3). Radiocarbon dating using charcoal and organic material found inside the trench were sent to the Beta Analytic Inc., Florida, while a sample of brick and tuyere for dating were sent to Korea Basic Science Institute, South Korea. Dating results show that the site had been used since the first CE (Beta-268001) and the 17th CE (Beta-267996), indicate that SB2A is an important site in Bujang Valley archaeology.

BIL.	ARTIFACT	PERCENTAGE (%)
1.	Metal artifact	0.004
2.	Handaxe	0.001
3.	Anvil	0.003
4.	Hammer stone/ mortar (?)	0.003
5.	Polishing stone (?)	0.002
6.	Fragment of pottery	0.25
7.	Ceramic	0.008
8.	Beads	0.003
9.	Brick (?)	0.055
10.	Laterite	0.02
11.	Iron ore	4.7
12.	Iron slags	69.1
13.	Fragment of tuyere	25.41
	TOTAL	100.002

Table 1: Artifact finding at SB2A

Photo 3: Handaxe

Photo 4: The broken of anvil

Photo 5: Bronze ring

Photo 6: Beads

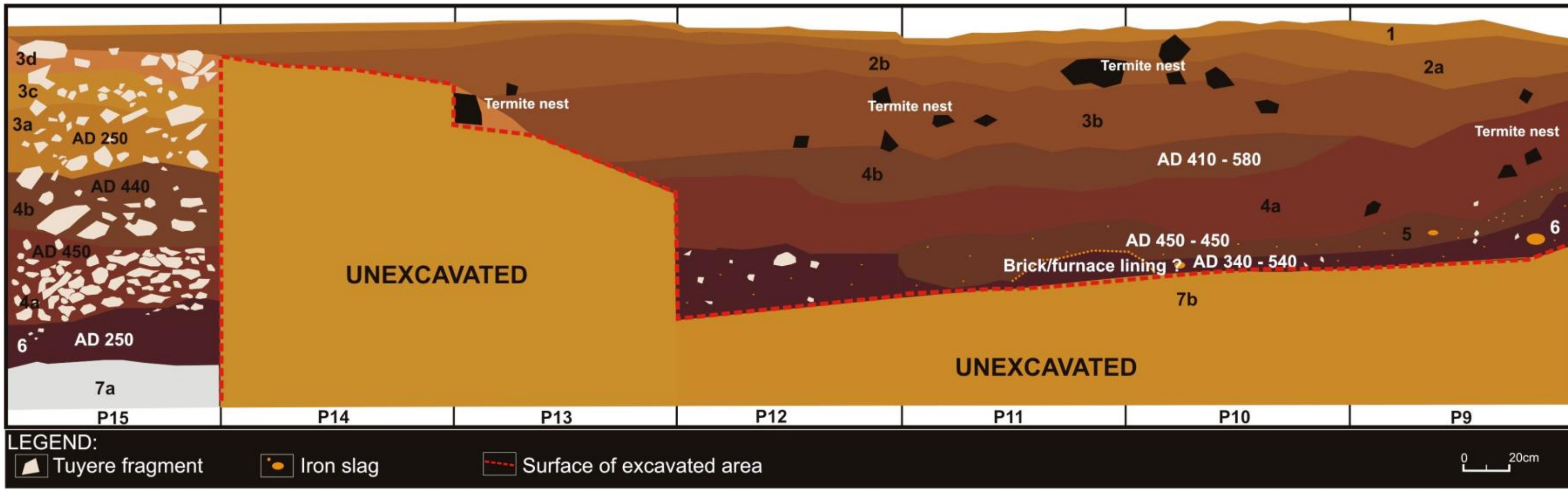


Figure 2: Stratigraphy of P15 - P9

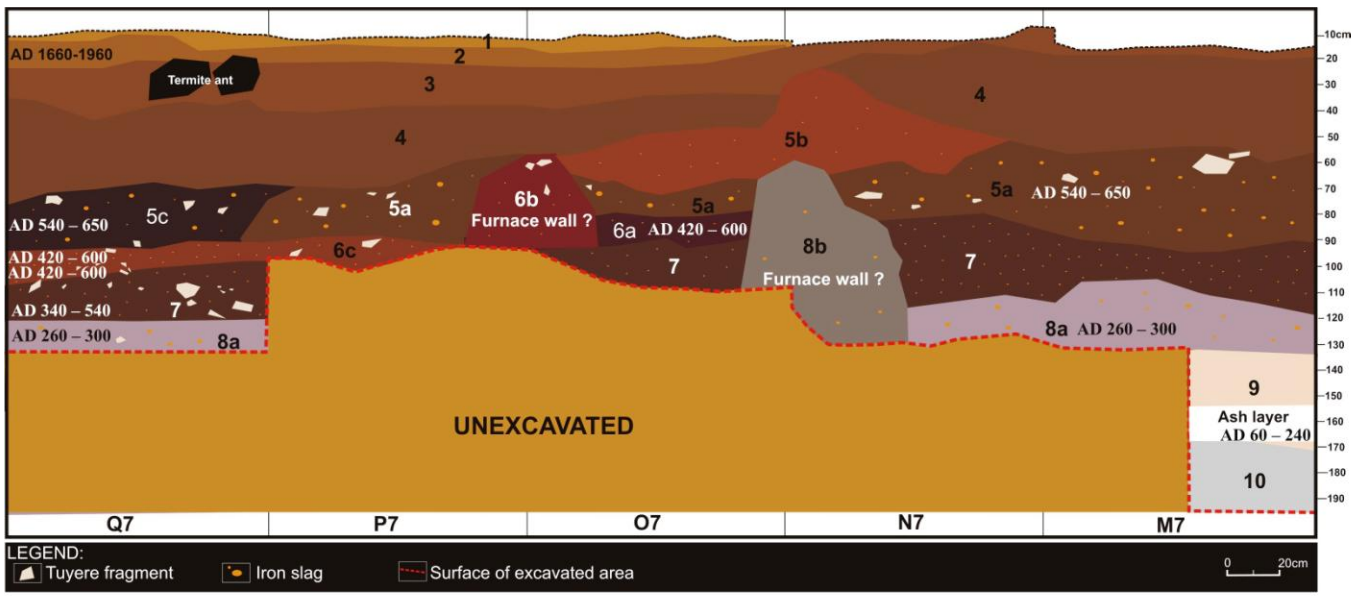


Figure 3: Stratigraphy of Q7 – M7

PRELIMINARY SCIENTIFIC ANALYSIS

Hypotheses generated during field study could be tested by scientific analysis. Scientific analysis used for this study include the application of scanning electron microscopy (SEM), energy dispersion X-ray (EDX), X-ray fluorescence (XRF) and X-ray Diffraction (XRD), mainly used to analyze the mineralogy, microstructure and microfabric of artifacts such as soil samples, burnt clay, iron ore, iron slags and tuyere. Table 3 shows SEM-EDX result of three sample of iron slags; B1, B2 and B3. There are three different percentages of each mineral and the highest content of iron was found in samples B2. While, Table 4 shows the results of XRF analysis of four samples of iron ore found on site. Composition of Al_2O_3 and MgO in iron ores revealed that it was sourced from three different locations, yet sample A4 and A2 are from the same source. However, this four iron ore are low grade ore based on the amount of iron, which is less than 50%. The results of XRD analysis of this iron ore show a present of hematite and goethite (Graph 1 & 2). Tables 5, 6 and 7 show the results of SEM-EDX analysis on samples of metal artifacts, which are blade 1, blade 2 and metal ring (?). XRF analysis of tuyere clearly showed that it was made of clay and sand (Table 5). This tuyere has been use during the process of iron smelting based on high content of Fe_2O_3 element in the tuyere.

SAMPLE NO.	BLACK REGION	Al_2O_3	SiO_2	K_2O	TiO_2	MnO	Fe_2O_3	T.Fe	FeO
B1	Wt%	7.64	50.36	-	0.69	0.29	40.93	28.651	36.837
B2	Wt%	3.29	3.41	-	-	-	93.29	65.303	83.961
B3	Wt%	13.55	59.51	0.21	0.33	0.31	26.07	18.249	23.463

T.Fe: Total ferum

Table 3: Result of SEM-EDX analysis of iron slags sample

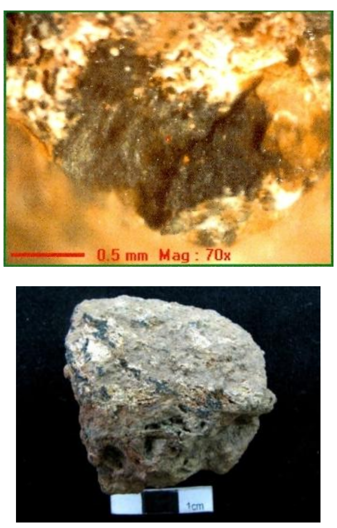


Photo 7(a) B1

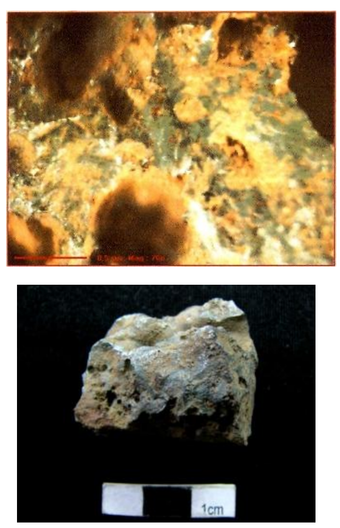


Photo 7(b) B2

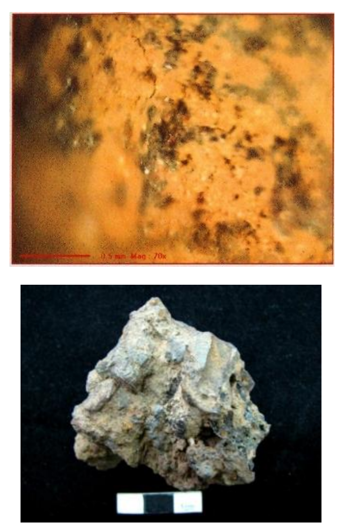


Photo 7(c) B3

SAMPLE NO.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	Na_2O	K_2O	CaO	MgO	T. Fe
A5	17.294	0.236	-0.053	70.947	-1.726	0.439	0.083	12.779	49.663
A1	20.086	0.360	12.203	64.898	-2.731	0.333	0.046	4.805	45.429
A4	15.388	0.237	6.961	69.131	0.044	0.324	0.057	7.857	48.392
A2	17.874	0.243	9.030	65.051	-1.038	0.291	0.114	8.435	45.536

T.Fe: Total ferum

Table 4: Result s of X-ray fluorescence (XRF) analysis of iron ore sample

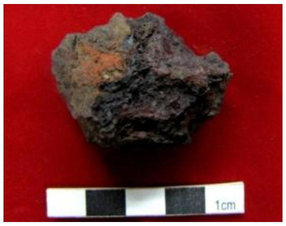
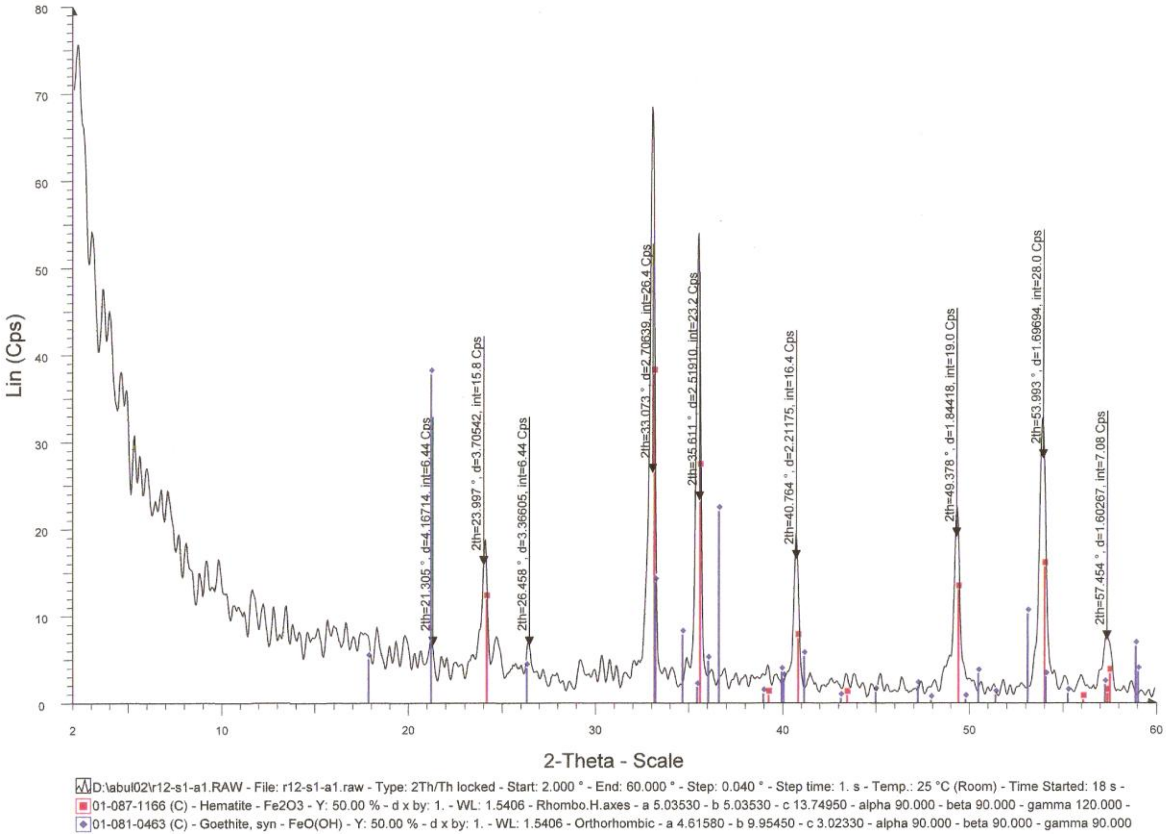


Photo 8(a) A5

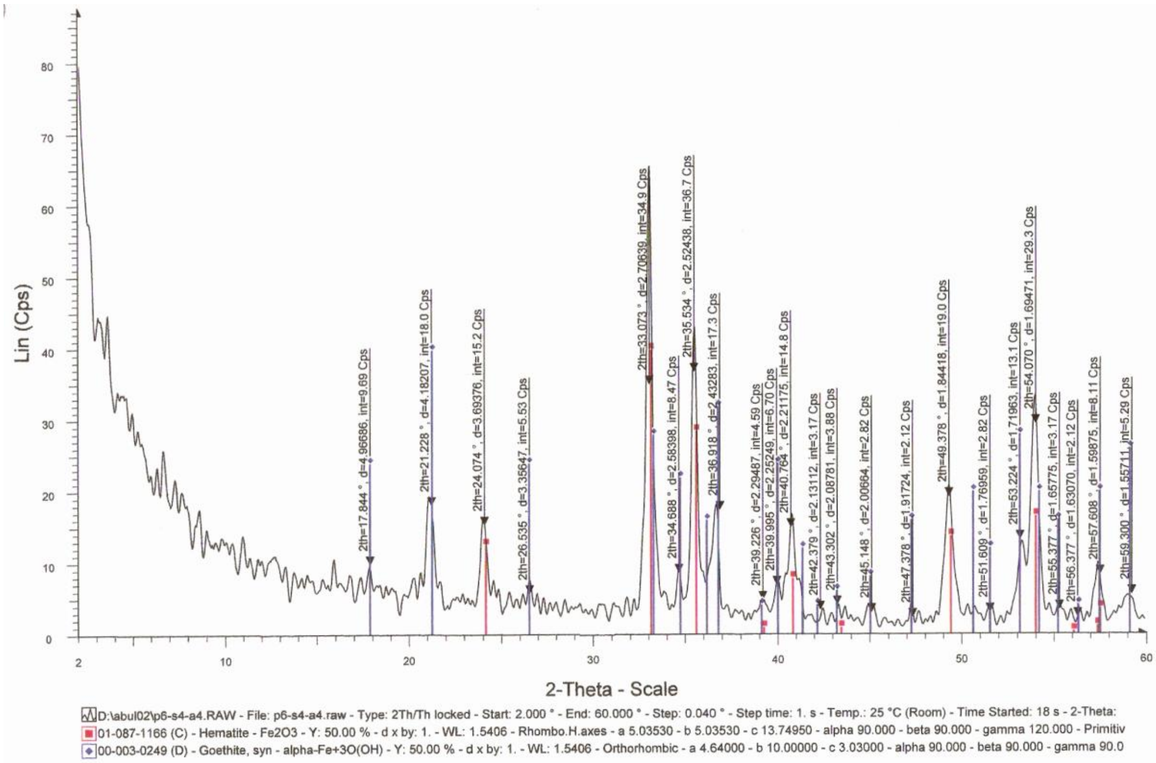
Photo 8(b) A1

Photo 8(c) A4

Photo 8(d) A2



Graph 1: Result of X-ray diffraction (XRD) analysis of iron ore sample, A1

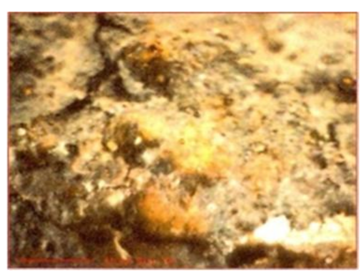


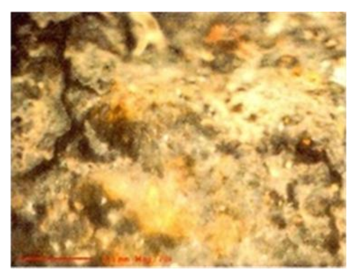
Graph 2: Result of X-ray diffraction *(*XRD) analysis of iron ore sample, A4

OXIDE	**Al_2O_3**	**SiO_2**	**K_2O**	**CaO**	**TiO_2**	**Fe_2O_3**
ORANGE REGION (Wt%)	15.82	33.91	0.20	0.87	0.35	48.86
BLACK REGION (Wt%)	18.94	47.09	0.30	0.80	0.31	32.56

Table 5: Result of SEM-EDX analysis on blade 1


Photo 9: Blade 1

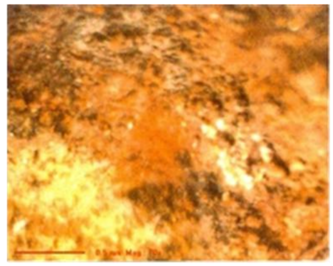

Orange region


Black region

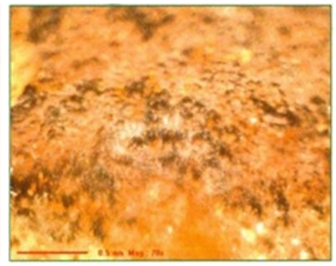
OXIDE	**Al_2O_3**	**SiO_2**	**SO_3**	**CaO**	**Fe_2O_3**
ORANGE REGION (Wt%)	11.63	29.17	0.30	0.18	58.71
BLACK REGION (Wt%)	9.78	12.69	-	-	77.53

Table 6: Result of SEM-EDX analysis on blade 2

Photo 10: Blade 2



Orange region



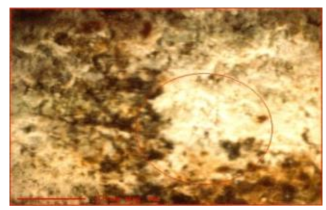
Black region

OXIDE	SiO_2	Fe_2O_3	PbO_2
Wt%	11.19	1.66	87.15

Table 7: Results of SEM-EDX analysis on metal ring (?)

Photo 11: Metal ring (?)

Area of observation



Closer View

LOCATION SAMPLE	SiO_2	Al_2O_3	Fe_2O_3	K_2O	CaO	TiO_2	MgO
O6/S7	24.707	7.856	2.874	0.204	0.083	0.269	0.585
Q21/S8	22.581	10.214	2.068	0.283	0.323	0.321	0.693

Table 8: Result of XRF analysis of tuyere

Photo 12: Tuyere

EARLY INTERPRETATION

The discovery of the furnace, tuyere, iron ores, iron slags, charcoal and ash showed this site was an iron smelting site. Based on radiocarbon dating, AMS and OSL, this site was actively used from the 3rd - 5th CE (Figure 2 & 3). The site was assumed to be used for 300 years because of its strategic location and within close vicinity to the source of fuel and iron ore. Based on the production of iron slags (more than 100,000 pieces), this site was assumed to produce iron on a large scale. It is most likely that ancient people who live here know how to choose a location for smelting iron, since it is close to the sources of iron ore, fuel and water (transport).

Area of the furnace revealed iron, coal and ash (area marked with red circle in Photo 1). The presence of burnt clays, as well as very dark and fine texture of soil clearly shows the effects of the combustion. These clays assumed to be used as the raw material for furnace wall. When the melting process starts, reduction reactions occur and lead to the changes of important elements between the elements of smelting and element in the furnace wall (David et.al., 1989). Scientific analysis on soil samples of this area is under progress, in order to prove significant changes in the composition of the soil. In normal condition of clay, oxygen should have same amount with silica and carbon (Bradford, 1972). Furthermore, burnt clays were found associated with the tuyere, brick and iron slags. The actual form of the furnace is yet to be identified. However, based on the discovery and distribution of burned clay and tuyere, it is assumed that the furnace was circular in shape, with a diameter of approximately 50 – 60 cm width and a height of about 50 - 70 cm.

Iron ore at site SB2A underwent a process of cleaning, preparation and smelting based on the discovery of artifacts and remains of furnaces. The process of cleaning and preparation demonstrated by the discovery of iron ore in the small size and the discovery of several stone tools such as a mortar and anvil that were used to prepare an iron ore (Natapintu, 1988; Bennet, 1988). Based on ethnographic research records, big chunks of iron ore from the mining process were pounded to a smaller size during preparation process, in order to accelerate chemical reaction occurs in smelting process (Rostoker & Bronson, 1990). Small iron ore has a large surface area for reduction process. Then, the iron ore will be sintered to remove impurities (minerals such as silica and carbon) to help increase chemical reaction during the smelting process (Rostoker & Bronson, 1990; Suchitta, 1983).

The site of SB2A produced iron ingots from the smelting process. However, this form of iron bars cannot be identified since there was a lack of evidence found in the study site, since it was assumed to be marketed and traded. This is based from earlier reports that the port also has a trade of old iron (Wheatley, 1961). There is also a possibility that iron ingots were sent to other iron formation site around Sungai Batu complex, however this site has yet to be found. The site of SB2A does not undergo the iron formation process. The blade found here possibly used as a tool during iron smelting process, and not produced on site. EDX result substantiated this by showing different elements of the blade in contrast with the remaining elements in the iron slag at the site SB2A (Table 6 & 7). Blade 1 shows the presence of the TiO_2 element, while blade 2 shows the elements of SO_3. On the other hand, metal ring-shaped artifact shows the presence of PbO_2 elements. Based on the amount of PbO_2, this metal element is possibly made by lead. Lead is one of the most stable metals and therefore naturally resistant to corrosion. Once exposed to oxygen, it produces a very thin patina of lead oxides (PbO and PbO2), lead carbonates (2PbCO3 or Pb[OH]2), lead chloride (PbCl2), lead sulfide (PbS) or lead sulfate (PbSO4), thus forming a protective layer preventing the material from further decay (Lockman, 2006). The element of TiO_2, SO_3 and PbO_2 are not presence in the content of iron ore and iron slags found at this site (Table 3 & 4).

Early hypothesis suggests that this site underwent a “Direct Process”, or the 'bloomery process”. The difference of composition shows that the smelting process undergoes several stages (Table 3). The changes in the percentage of mineral content may be caused by several factors, including the uses of different sources of iron ore, difference in the amount of air combusted into the furnace, different temperature and different work stages (Rostoker.W. & Bronson. B., 1990; Tylecote, 1992). In iron slags, differences in mineral percentage are probably caused by different work stages, for example initial smelting. To reach a high temperature, the ratio of iron ore to fuel must be set to 1:3. When the appropriate temperature is reached, the second stage of the fuel consumption is reduced by the ratio of 1:1 (Rostoker & Bronson, 1990). In addition, other reduction of an important factor such as air pressure, iron ore, fuel and combustion temperature could generate these differences during the smelting process. Based on the XRD analysis of an iron ore, hematite and goethite were used as raw material to produce iron (Graph 1 & 2). Further XRF analysis of iron slags and soil should be conducted to determine the process and work space.

Based on the XRF analysis, SiO_2, TiO_2, Al_2O_3, Fe_2O_3, K_2O and CaO are the elements contained in the tuyere (Table 8). The results of XRF analysis indicate the presence of iron oxide (FeO) at the one end of the tuyere. Its presence was the result of overheating, in which vitrification (glass like) can be clearly seen at one end of the tuyere (Photo 12). This indicates that one end of the tuyere was connected to the furnace, thus proving its function.

The presence of flux is also an indicator to the technology of iron smelting process. Flux was used as a catalyst in the iron smelting process and helps to extract Fe ion out from iron ore to produce pure iron (Rostoker & Bronson, 1990; Suchitta, 1983). Among material that can be used as flux are limestone, sand, shells and materials in the iron ore. Based on the finding of shells near the furnace, there is possibility that it was used as a flux in the smelting process. XRF analysis of iron slags should be carried out to detect the presence of the calcium oxide (CaO) to substantiate this hypothesis (Young, 2006). The discovery of pieces and bits of charcoal suggest its use as fuel for smelting iron. Chunks and bits of charcoal can be found in the smelting area and in the remaining pieces of iron slags.

Ancient society of Sungai Batu has the knowledge to use iron ore sourced from nearby areas. The location of iron ore sources could not be ascertained because the scientific analysis was not performed yet. Ancient society did not choose iron ore based on the high iron content, such as magnetite, but it is based on the convenience factor to obtain iron ore (Rostoker & Bronson, 1990). This is probably due to the mining technique which utilized stone or metal tool to acquire iron, preferably laterite or hematite. As a result, the ancient miners choose iron ore source which is easily obtained and processed, found on the ground surface or near the foothills. Based on geological studies in Kedah, the Sungai Batu area is comprised of alluvial soil and the distribution of iron ore can be detected to the south of Kampung Merbok (Bean, 1969 & Bradford, 1970). Iron ores are found in this area consists of hematite and magnetite, which is very fine in texture because it is adjacent to the layer of granite and metaquartzite (Bean, 1969; Syed Sheikh Almashoo, 1974). Cessation of iron mining and iron products on this site is expected to result from a decline of iron ore.

Ancient society produced stone stools as equipment for the iron ore supply (ore dressing). They used anvils, mortar and hammer stone for ore dressing process (Natapintu, 1988; Bennet, 1988; Craddock & Craddock 1996). Excavation of site SB2A revealed 18 stone tools consist of a handaxe, 6 broken anvil, 6 hammer stone or mortar (?) and 5 unkown stone tools (Table 1). This main function of this handaxe is not clear, but it is not used in the smelting process. Yet, the anvil and hammer stone were used mainly in the preparation of iron ore.

The research of SB2A is still undergoing. Scientific studies such as scanning electron microscopy (SEM), energy dispersion X-ray (EDX), X-ray Diffraction (XRD), X-ray fluorescence (XRF) and petrographic and polishing section are being carried out on samples of soil, burnt clay, iron ore, iron slags, iron ore, tuyere and samples from the iron ore resources. This analysis is important to understand the mineralogy, microstructure and microfabric among artifact.

CONCLUSION

SB2A clearly shows the evidence of large iron industry in Sungai Batu based on the discovery of thousands of slags, iron ores and tuyeres. Based on radiocarbon, AMS and OSL dating, SB2A actively used from 3rd-5th CE. However, the dating also shows the site has been used since the first CE (Beta-268001) and during the 17th CE (Beta-267996). An evidence of iron artefacts and remaining of furnaces were found as well here. Based on iron slags, this site undergoes bloomery process using tuyere and charcoal. However, no iron product was found in SB2A because the product may have been traded to other places.

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