Frontiers of Architectural Research 13 (2024) 127–143

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.keaipublishing.com/foar

RESERACH ARTICLE

Evolution of the "ancient Kedah": A study on urban forms at Sungai Batu Archaeological Complex (SBAC), Bujang Valley, Kedah, Malaysia

Mohd Hasfarisham Abd Halim [a,*], Naizatul Akma Mohd Mokhtar [b], Nor Khairunnisa Talib [c], Shyeh Sahibul Karamah Masnan [c], Ahmad Fadly Jusoh [c], Mokhtar Saidin [a]

[a] *Kedah, Malaysia*
[b] *Universiti Utara Malaysia, Kedah, Malaysia*
[c] *Universiti Sains Malaysia, Penang, Malaysia*

Received 19 September 2023; accepted 30 October 2023

KEYWORDS
Chronometric dating;
Urbanization;
Land use;
Monument;
Iron smelting site

Abstract Archaeological research at the Sungai Batu Archaeological Complex (SBAC), which has been carried out until 2023, aims to complete the chronological data and urbanization process of the ancient Kedah. This study will especially prove that the ongoing urbanization process is aimed at developing the iron smelting industry and trade in ancient Kedah, especially in SBAC. This is because archaeological research at SBAC has proven that with the existence of the ancient Kedah iron smelting workshop at SBAC, river jetties, port management, rituals, and Buddhist monuments began to be erected, all of which can be determined by chronometric dating. The results of the chronometric dating have proven that the ancient Kedah Kingdom existed since the 6th century BC and was oriented towards the trade of iron resources, which allowed the use of the area to grow rapidly. The process of urbanization and land use clearly conforms to Lynch's principle, which emphasizes the principles of 1) paths, 2) edges, 3) districts, 4) nodes, and 5) landmarks in the development process of land use and urbanization in the complex.
© 2023 Higher Education Press Limited Company. Publishing services by Elsevier B.V. on behalf of KeAi Communications Co. Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

* Corresponding author.
E-mail addresses: mhasfarisham@gmail.com (M.H. Abd Halim), naizatulm@gmail.com (N.A. Mohd Mokhtar), norkhairunnisa@usm.my (N.K. Talib), shyehsahibul@usm.my (S.S.K. Masnan), ahmad_fadly@usm.my (A.F. Jusoh), mokhtarsaidin@gmail.com (M. Saidin).
Peer review under responsibility of Southeast University.

https://doi.org/10.1016/j.foar.2023.10.006
2095-2635/© 2023 Higher Education Press Limited Company. Publishing services by Elsevier B.V. on behalf of KeAi Communications Co. Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

1. Introduction

The archaeological research conducted at the Sungai Batu Archaeological Complex (SBAC) (Fig. 1) from 2009 until 2023 has the main purpose of completing the chronological data on the existence of the ancient Kedah Kingdom. This is because previous archaeological studies stated that the ancient Kedah Kingdom existed around the 5th century AD (Khaw et al., 2009), while navigation and trade records (I-Tsing, 1896) stated that this kingdom had been involved in the world iron trade since before the 1st century AD. In order to enable primary data to be obtained, a field study was carried out involving excavation methods, taking OSL and radiocarbon dating samples, geophysical mapping (2D resistivity), and core drilling. The field data that had been observed was then analyzed to enable the actual function of the site to be accurately determined, which was as a river jetty, port management, ritual and Buddhist monument, and iron smelting site (Saidin, 2022).

Archaeological research in Southeast Asia to date has also recorded several iron smelting sites involved in iron smelting activities since before the 1st century AD. Prohear, Cambodia (Bayard et al., 1982/1983), Non Chai (Reinecke et al., 2009), Ban Dong Phlong (Nitta, 2015), Khao Sek (Petchey, 2018), Khao Sam Kaeo, Thailand (Biggs, 2013), Dong Son (Nishimura, 2005), and Sa Huynh, Vietnam (Pham, 2005) sites had proven their role in the iron industry since the 8th until the 2nd century BC, which strengthened the fact that the iron smelting industry had been established in Southeast Asia since earlier than the 2nd century AD. The significance of archaeological studies at the SBAC compared to other iron smelting sites in the Southeast Asian region could be seen based on its findings, which consisted of evidence of river jetties, port management, rituals, and Buddhist monuments in an area of about 4 km^2.

The data clearly showed the existence of a planned urbanization process that proved the existence of architects and skilled workers who assisted in the urbanization and land use development in this area. Therefore, this paper discusses the urbanization and land use processes in the SBAC, which are determined based on the chronometric dating of the site. This matter is important to determine completely because it is able to analyze the spatial form of the historic city, and the most important thing is that the data related to the way to understand the local characteristics, development, and evolution of traditional planning (Jiang and Zhou, 2023), especially for the ancient Kedah Kingdom, can be clearly recorded.

Based on the study of the settlement, trade, religious, and industrial centers of the ancient Kedah Kingdom located in the river basin and different periods of existence. This is because archaeological research conducted since the 1940s, whose data was compiled by Khaw (2011), has shown areas such as Sungai Mas, Simpor Tambang, Kampung Sireh, Permatang Pasir, Bukit Batu Pahat, and Pengkalan Bujang have revealed evidence related to the location of the existence of ancient Kedah since 7th century AD but not the urbanization process that took place in the area because most of the sites have been destroyed and cannot be studied.

In order to complete the study of the urbanization process of ancient Kedah, a study of the results of Saidin's

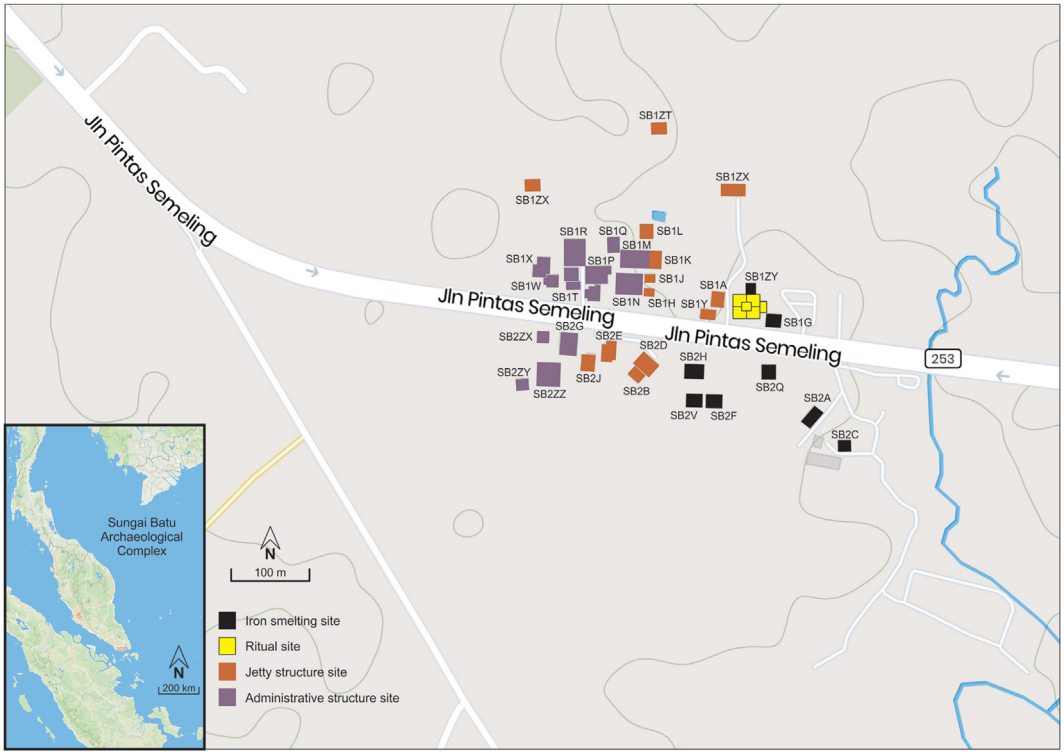


Fig. 1 Archaeological studies at the SBAC revealed evidence of the ancient Kedah Kingdom based on the presence of iron smelting sites, river jetties, port management, ritual and Buddhist monuments. Source: The Authors, based on data from Saidin (2022, 2023).

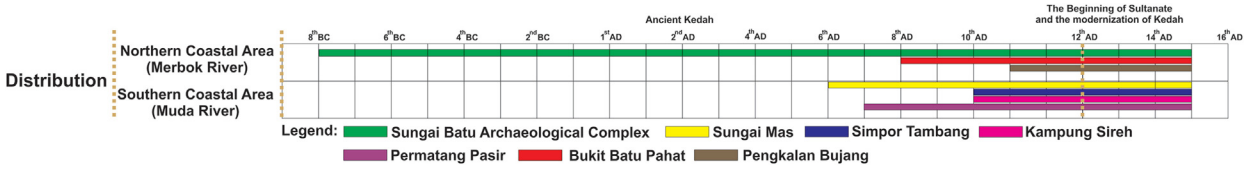


Fig. 2 Regional and period distribution of ancient Kedah Kingdom capitals. Source: The Authors, based on data from Khaw (2011) and Saidin (2022, 2023).

research (Saidin, 2022, 2023) at SBAC was conducted, which tried to reveal evidence of the earliest urbanization process of this ancient kingdom since 8th century BC (Fig. 2), which is still *in situ* and well preserved.

2. Ancient Kedah archaeological background

Results of Low (1848, 1849), Irby (1905), Evans (1931), Wales (1940), Dorothy and Wales (1947), Sullivan (1958), Peacock (1980a, 1980b), Guangwu (1958), Foong (1959), Wheatley (1961), Lamb (1962, 1980), Leong (1973), Yatim (1978), Allen (1988), Rahman (1992), Taha (1983, 1991), Zakaria (1989), Sabtu (1988), Muhamad (2010), and Saidin (2022, 2023) allowed the area of ancient Kedah to be determined over 1000 km^2, covering the border of Choras Hill in the north, Muda River in the south, Straits of Melaka in the west, and Jeniang-Sik in the east (Fig. 3).

Archaeological research since the 1980s has recorded 87 archaeological sites around Bujang Valley and 97 sites in the SBAC. However, in 2009, only about 3 sites in the Pengkalan Bujang Archaeological Complex, 4 sites in the Bukit Batu Pahat Archaeological Complex, and 52 sites in the SBAC revealed evidence that was still in situ. A total of 3 sites in the Pengkalan Bujang Archaeological Complex, 1 site in the Bukit Batu Pahat Archaeological Complex, and 34 sites in the SBAC were built using bricks. This shows that brick is the main building material used as a building material for monument structures, in addition to river stones, laterite, and granite blocks.

Archaeological studies conducted from the 1840s by Low (1848) and towards the 1990s by local researchers had suggested that the ancient Kedah Kingdom existed since the 5th century AD (Allen, 1988), and played a major role in sea trade with China, India, the Middle East, and Europe. Archaeological research conducted at the SBAC proved the existence of the ancient Kedah Kingdom to be recorded much earlier, which was in the 6th century BC at the iron-smelting site (Mokhtar, 2019). The dating was obtained using charcoal samples through the radiocarbon dating method (Mokhtar, 2019). The river jetties structure in this complex was also dated using the OSL method by using *in-situ* brick samples, which showed that the structure was built around the 6th century BC (Halim, 2019) and the administrative site around the 5th century BC (Ahmad, 2016), which proved the continuity of the ancient Kedah Kingdom since the times before the Common Era.

The port management monument revealed a different architectural appearance from the river jetties. The first difference between the two structures is based on the location where the port management was built at the back of the river jetties structure. Port management structures were built horizontally and did not slope towards the river like the river jetty structure. Another difference is that the port management structure has a space of small rooms separated by a wall structure, which is indicative of the role of various spaces (Ahmad, 2016; Aminuddin, 2015; Yusof, 2016). A ritual and Buddhist monument in the SBAC was classified based on its circular base, a square in the middle, and a small circle on it that faces directly toward Mount Jerai (Fig. 4) (Hassan, 2018). In addition, the discovery of ceremonial pottery around the base circle structure also strengthened its interpretation as a ritual monument before Buddhism was practiced in the area after 7th century AD.

This research allows data related to urbanization and area used to be recorded for archaeological sites in the SBAC. This is because each site was built based on its function, which clearly showed that adequate architectural planning had been implemented in the urbanization process of this area. Referring to Fig. 1, it clearly shows evidence of river jetties being built on both sides of the river, while the port management building is behind the river jetties structure on the west. The iron smelting sites are all located in the east, which is an important center to



Fig. 3 The boundaries of the ancient Kedah civilization. Source: The Authors, based on data from Saidin et al. (2011).

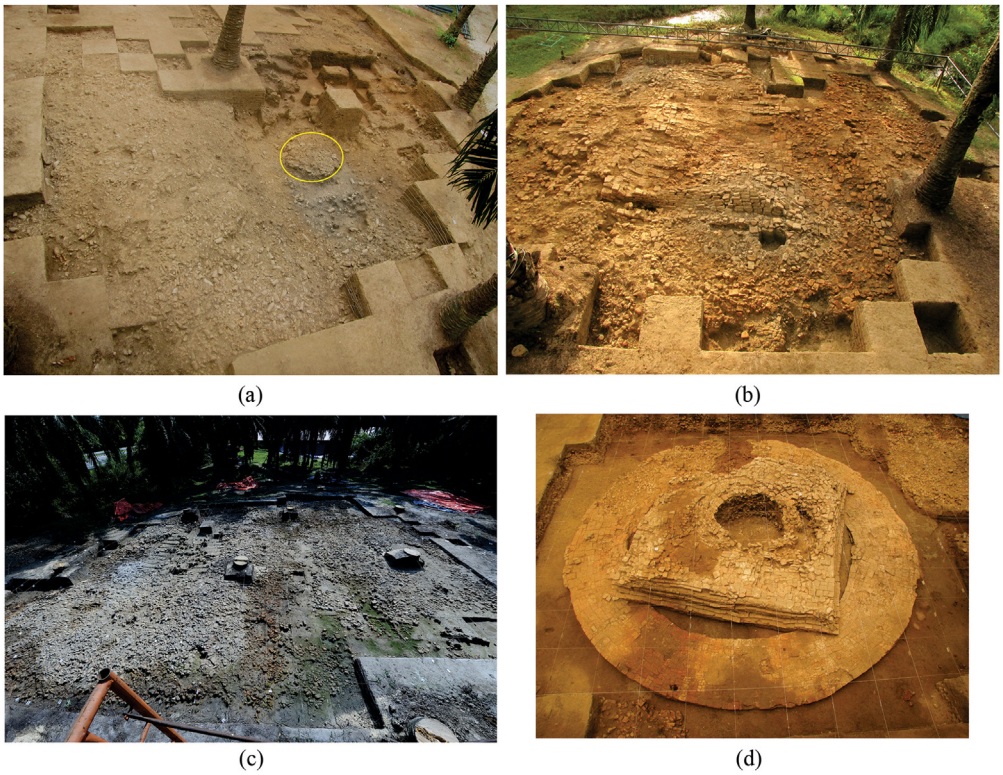


Fig. 4 Archaeological evidence recorded at the SBAC is marked by the presence of an iron smelting site with a furnace area (yellow circle) (a), river jetties (b), port management (c), ritual and Buddhist monument (d). Source: The Authors, based on data from Aminuddin (2015), Ahmad (2016); Yusof (2016), Hassan (2018), Halim (2019) and Mokhtar (2019).

produce iron ingots. The ritual site is located on the promontory, which is close to the ancient lake overlooking Mount Jerai to the north.

3. Research objective

This study was conducted with the main purpose of obtaining data related to the land use and the urbanization process that occurred in the SBAC. The process of using the area involved river jetties, port management, rituals and Buddhist monuments, as well as iron smelting sites in an area that only covered an area of around 4 km^2. In order to strengthen the data, some *in-situ* brick and charcoal samples at the site were taken to obtain their chronometric dating to enable the chronology of the existence of each site to be determined and further clarify the use of space in this complex in meeting the needs of an early urbanization. In addition, geophysical mapping and core drilling were also applied to strengthen the dating data obtained to complete this study.

4. Research methodology

This study involved several methodologies for obtaining primary data to complement the research. Generally, all the sites involved were excavated to determine the exact area for brick and charcoal sampling. The sampling was determined based on the *in-situ* brick sample in the architecture of the monument. For the iron-smelting site, *in-situ* charcoal at the iron-smelting furnace was sampled for dating that could illustrate its functions in iron smelting activities. The sample was then wrapped with aluminum foil and recorded data such as site name, trench, spit and 3D measurements (distance from north, west wall and actual depth). Samples were taken to accredited dating laboratories such as Korea Basic Science Lab, Korea and Hiruzen Lab, Japan for OSL dating while Beta Analytic Lab in Florida-USA was for the AMS/Radiocarbon dating.

For the charcoal sample, clamps were used to collect the sample in order to prevent it from being contaminated (Bird, 2013). A total of 20 g (radiocarbons) and 50 mg (AMS) of charcoal were selected (Waikato Radiocarbon Dating Laboratory, 2017; Rahman and Mohamad, 2012) to enable the AMS/radiocarbon dating technique to be carried out. After that, the charcoals were wrapped in aluminum foil and labeled with the location at which they were taken. While in the dating laboratory, charcoal samples were subjected to chemical treatment to ensure they were not contaminated. Physical treatment through isolation of any external sediment or chemical and thermal treatment was carried out to identify whether the sample was contaminated or otherwise (Pigati et al., 2007). The main purpose of the charcoal treatment carried out was to get rid of specimens that may interfere with the dating of data to the younger or oldest. This allowed direct measurements of the combustion activity of charcoal to be carried out more accurately (Bird, 2013).

The calibration of the radiocarbon age was determined based on the offset to the two errors introduced by T1/2, the conventional half-life (Libby), and the temporal variability of

the atmospheric C14 content. Its measurements used a mathematical procedure that placed the age of the measured radiocarbon (taken with its error) on an experimentally drawn curve. In the probability calibration procedure, the calendar age corresponding to the radiocarbon age obtained for the measured material was given with probability distributions (68% and 95% confidence intervals for 1 sigma and 2 sigma errors, respectively) (Stuiver and Reimer, 1989). The calibrated radiocarbon age was then reported as "cal AD/BC" or "cal BP" (BP calendar year) based on its absolute dating.

In addition, this research also involved the core drilling process (Fig. 5) (Talib, 2009) and 2D electrical resistivity geophysical mapping (Andika et al., 2018; Ramzul et al., 2015) around the SBAC to strengthen the dating data obtained. The core drilling process involved 11 auger holes involving "Gemco" brand drilling machinery with a hydraulically driven rotation method using a flight-mounted solid auger. The collected samples were placed in a PVC pipe container that was split in half according to the drilling depth, wrapped neatly, and analyzed in the laboratory (Talib, 2009).

The 2D resistivity data was processed using Res2Dinv and Surfer8 software. Seismic refraction data was processed using FIRSTPIX v4.21 software to pick the first arrival time, and SeisOpt@2D v3.5 software was used to produce a tomography result. The data were then transferred into Surfer8 software for correlation, validation, and final presentation. The 2D resistivity imaging, seismic refraction tomography results, and borehole record were correlated and validated to identify the relation between resistivity, seismic velocity, and *N*-values. The validated values were applied to other 2D resistivity and seismic refraction survey lines without boreholes for interpretation to achieve the research objective (Andika et al., 2018; Ramzul et al., 2015).

5. Principles of OSL and radiocarbon chronometric dating

There were several types of dating methods used to obtain chronometric dating data in the SBAC. The dating methods were optically stimulated luminescence (OSL) and radiocarbon.

5.1. Optically stimulated luminescence (OSL)

In general, OSL dating involves the concept of the last exposure of light to a mineral or substance (Rhodes, 2011). The OSL method involves the absorption of sunlight on the sample, which is then taken without light exposure and sampled using dark PVC or PE, neatly packed before being sent to the laboratory (Rahman and Mohamad, 2012). The dating is usually carried out on samples of soil, brick, pottery, and roof tiles. The OSL method can be characterized as anti-Stokes emission, which is the excitation of quartz against blue light (440–485 nm) that is generally more effective than green light (500–565 nm) (Huntley et al., 1985), which allows age measurements to be determined.

The OSL dating is proportional to the total dose (D_e [J/kg = Gy]) accumulated in the crystal, which is proportional to the time of exposure of the sample to radiation. Generally, coarse-grain sediments (100 m) are calculated based on the following equation (Huntley et al., 1985).

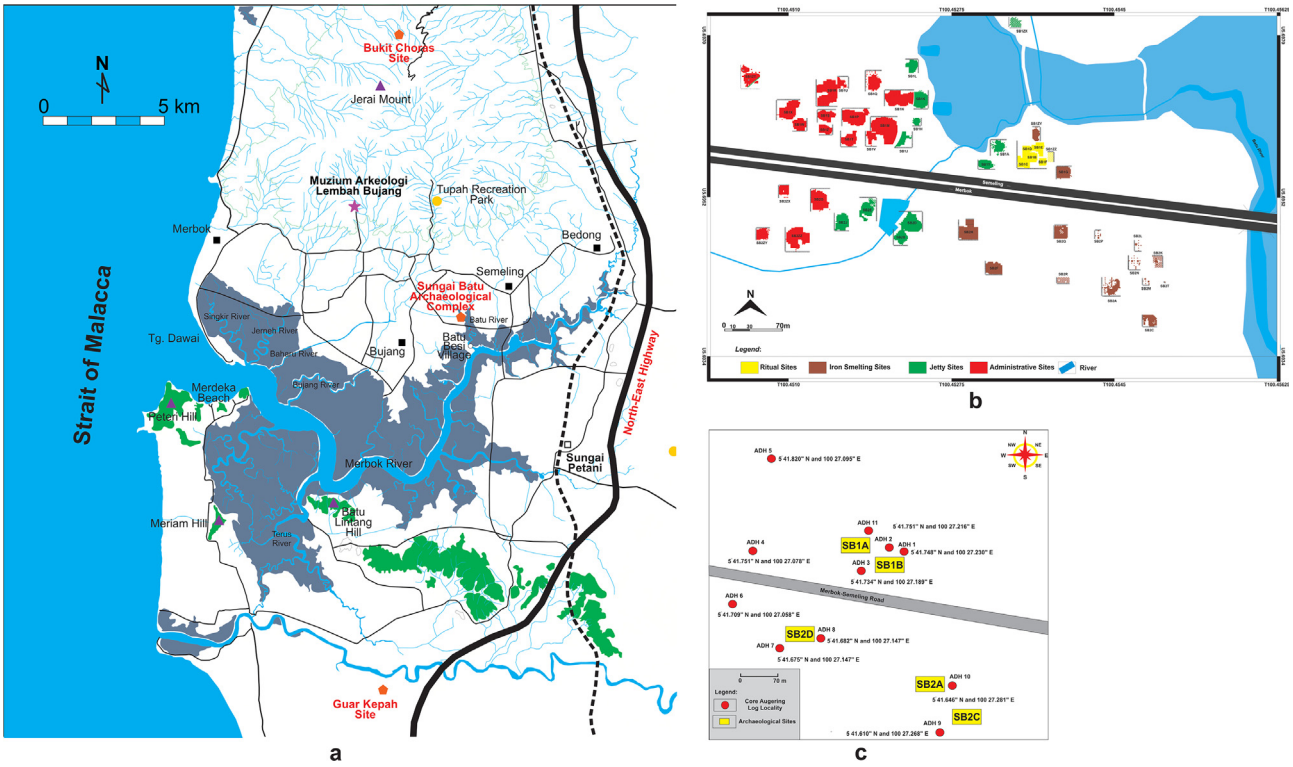


Fig. 5 SBAC (a, b) in Bujang Valley and core drilling locality location (c) also in SBAC to identify its potential as an industrial area. Source: The Authors, based on data from Talib (2009).

$$\text{Age} = \frac{D_e}{0.90D_\beta + D_\gamma + D_c}. \quad (1)$$

Based on Eq. (1), D_e refers to the accumulated dose in the crystal, while D_β is the annual dose rate absorbed by beta particles. D_γ refers to the rate of γ radiation, and D_c refers to the rate of cosmic rays (Tatumi et al., 2020). Generally, the beta and gamma particles contained in the samples are obtained from uranium (U), thorium (Th), and potassium (K40), which are common compounds contained in the soil. The numerical factor of 0.90 is more due to the reduction of β particles in the sample. In order to correct the data, the water content calculation is done to obtain the wet dose content based on the formula described in Eq. (2). Based on Eq. (2), W is the saturated water content (water weight/dry sediment weight), while F refers to the average water content contained in the sample while it is embedded in the soil.

$$D_\beta = \frac{D_{\beta\text{dry}}}{1 + 1.25W \cdot F},$$

$$D_\gamma = \frac{D_{\gamma\text{dry}}}{1 + 1.14W \cdot F}. \quad (2)$$

Thus, the principle of OSL is more to measure electrons trapped in mineral crystals such as quartz and feldspar that can liberate and enter the conduction band when a light stimulus is applied. Photons are detected through the photomultiplier tube when light emission occurs, and the signal detected through the inflatable can be used in the calculation of the dose absorbed by the sample (Rhodes, 2011).

The OSL measurements were carried out using an automated Risø OSL/TL measuring system that was performed at the Korea Basic Science Lab Institute. The stimulation light source was a blue-LED (470—30 nm) array, which delivered $\sim$80 nW•cm^{-2} to the sample position. The reader was also equipped with a 90Sr/90Y beta source delivering $\sim 0.162 \pm 0.003$ Gy•s^{-1}. Photon detection was through a 7 mm of Hoya U-340 filter. Equivalent doses (De) were estimated using the SAR protocol (Single-Aliquot Regenerative Dose Protocol) according to Murray and Wintle (2000), Rhodes (2011) (Table 1). For De estimation, prepared samples were used in 8 mm aluminum aliquots. All samples were tested using 1 Gy, 5 Gy, 10 Gy, and 30 Gy regeneration doses to create a regeneration curve to estimate the equivalent doses (De). The SAR protocol parameters are: preheating at 240°C for 10 s, 1 Gy for the test dose, cut-heating at 220°C, and optical stimulation at 125°C for 40 s. The recuperation values are all less than 1%, and there is no systematic change in this fraction with preheat temperature (Murray and Wintle, 2000). The radionuclide concentration of the samples was measured using low-level, high-resolution gamma spectrometry. All dose rates were modified using both present and satiated water contents, and the attenuation beta attenuation factor of 0.93 ± 0.03 was used for the dose rate calculation of all the samples. The cosmic ray contribution was assumed to be 0.13 ± 0.03 Gy/ka.

Table 1 The Single-Aliquot Regenerative-Dose protocol. Source: The Authors, based on data from Jorge and Manuela (2013).

Step	Treatment	Observed
1	Give dose, D_i	—
2	Preheat (240°C for 10 s)	—
3	IR stimulation for 100 s at 50°C	
4	Blue Stimulation for 40 s at 125°C	L_i
5	Give test dose, D_t	—
6	Cut-heat to 220°C for 0 s	—
7	IR stimulation for 100 s at 50°C	
8	Blue Stimulation for 40 s at 125°C	T_i
9	Return to step 1	—

5.1.1. Sample collection

Each brick and charcoal that will be used as a dating sample was ensured to be *in-situ* with architectural structures or evidence of iron smelting. The brick was then wrapped using aluminum foil and written with complete information related to the name of the site, location, and association. Charcoal samples were collected using tweezers to avoid contamination. For brick and charcoal samples, a 2 mm layer from each surface was removed by sawing with a diamond wheel. Samples were gently crushed in a vice, and particles in the diameter range of 90—180 μm were extracted by sieving.

The same chemical procedure used for the sediment was used for the grain. Quartz extracts were used to assess dose equivalents to TL using a multiple-aliquot additive dose protocol (Jasper, 2013). All luminescence measurements were made based on an automated Risø TL/OSL/DA-12 equipped with a blue LED (470 ± 30 nm) and an IR laser diode (830 nm), and the signal was detected through a 7.5 mm thick Hoya U-340 UV filter. Dose rate determination is based on low-level, high-resolution gamma-ray spectrometry. The sediment was dried at 110 °C until it reached a constant weight, crushed, and homogenized (Gupta et al., 1985; Kima et al., 2013).

5.2. Radiocarbon

In addition, the radiocarbon method using the isotope Carbon-14 (^{14}C) covering a time range of up to 40,000 years accurately on materials containing the element carbon (Olive and Hubert, 1984), was also applied to obtain the absolute dating of iron smelting sites. The atmosphere contains three main isotopes consisting of carbon-12, carbon-13, and carbon-14 whose concentrations are not the same: carbon-12 (^{12}C) (99%), carbon-13 (^{13}C) (1%), and carbon-14 (^{14}C) (Reimer et al., 2013). One of the radioactive isotopes is C14.

Atom 14 (^{14}C) is unstable because it contains 8 neutrons and 6 protons. Thus, the unstable C14 atom will shrink at a uniform rate that takes 5730 years to reach its half-life. Based on that, the determination of its age can be made based on the amount of radiocarbon left in the charcoal sample. The radiocarbon dating ages were then reported conventionally along with the standard deviation for laboratory measurements and multiplied to obtain a 95% confidence interval for dating accuracy (Halim, 2014).

The composition of CO_2 in the air is naturally identified in organic compositions such as plants, animals, and so on. When it dies, the carbon-14 content contained in

plants and animals decreases. Through this method, the measurement of the carbon reduction of carbon-14 that is still contained in the plant or animal can be done, which allows the absolute age to be known. In order to find out the absolute age, the results of the analysis will be calculated based on the calendar before, after AD, or before the present time (before the present), which is before 1950.

6. Analysis and results

This section focuses on the discussion of OSL and radiocarbon chronometric dating results that have been obtained. The results of this dating are strengthened with core drilling and geophysical mapping data that had been carried out in this complex area.

6.1. Chronometric dating result

Table 2 and Table 3 are classifications of OSL and radiocarbon dating data obtained at the monument and iron smelting sites in the SBAC. The data allows information on land use and urbanization in the SBAC to be scientifically proposed. The chronometric dating data sets using the radiocarbon technique reveal the oldest age of the iron industry at the SBAC (Beta-401263). Charcoal samples were taken at the SB2H site near the ruin of the furnace, which is still *in situ*. The dating data have provided evidence that the iron industry has started since 545 BC (Appendix A) with a probability percentage of 95.4% (Halim, 2019; Mokhtar, 2019), clearly showing the charcoal samples used meet the absolute dating standards carried out.

This dating is also confirmed by the analysis of the High Probability Density Range Method (HPD), which allows a convincing dating result to be obtained. Sample Beta-401263 (SB2H/W14/6) has given two probability percentage categories, which are 95.4% and 68.2% (Mokhtar, 2019). For the 95.4%, there are three possible probabilities: 87.9% (545–387 BC [2494–2336 BP]), 6.2% (732–690 BC [2681–2639 BP]), and 1.3% (661–650 BC [2610–2599 BP]). The probability of 64.8% revealed 64.8% (491–398 BC [2440–2347 century BP]) and 3.4% (507–501 BC [2456–2450 BP]). Since the best percentage for this charcoal sample is

Table 2 Result of OSL dating for monument sites at SBAC. Source: The Authors, based on data from Zakaria (2014), Aminuddin (2015), Ahmad (2016) and Yusof (2016).

Sites	Trench	Spit	Sample classification	Dating OSL (years ago)	Age AD: Anno Domini BC: Before Christ	Function
SB1A	P16	5	Floor	1740 ± 260	3rd Century AD	Jetty
SB1B	S9	9	Circle ground floor	1900 ± 100	2nd Century AD	Ritual
SB1C	D5	7	Floor	1800 ± 200	3rd Century AD	Ritual
SB1D	H23	7	Floor	2100 ± 100	1st Century BC	Ritual
SB1E	C20	3	Floor	1820 ± 150	2nd Century AD	Ritual
SB1F	F6	3	Floor	830 ± 260	12th Century AD	Ritual
SB1H	R12	7	Floor	2100 ± 200	1st Century BC	Jetty
SB1J	h8	5	Ship mast anchors	2100 ± 200	1st Century BC	Jetty
SB1K	K9	3	Corridor	2000 ± 200	1st Century AD	Jetty
SB1L	b24	4	Corridor	1700 ± 100	4th Century AD	Jetty
SB1M	F21	3	Floor	2100 ± 200	1st Century BC	Port management
SB1N	C7	5	Floor	2100 ± 200	1st Century BC	Port management
SB1P	R13	6	Floor	2200 ± 200	2nd Century BC	Port management
SB1Q	K14	6	Floor	2100 ± 200	1st Century BC	Port management
SB1R	R21	5	Pillar base	2500 ± 200	5th Century BC	Port management
SB1S	K22	9	Wall	2500 ± 200	5th Century BC	Port management
SB1T	E11	7	Wall	2200 ± 200	2nd Century BC	Port management
SB1U	C10	2	Floor	1900 ± 200	2nd Century AD	Port management
SB1V	E16	4	Floor	1800 ± 200	3rd Century AD	Port management
SB1W	K10	5	Floor	2500 ± 200	5th Century BC	Port management
SB1X	B5	5	Corridor	1900 ± 200	2nd Century AD	Port management
SB1Y	D23	8	Floor	1900 ± 200	2nd Century AD	Jetty
SB1Z	c19	6	Floor	2300 ± 200	3rd Century BC	Port management
SB1ZZ	c19	6	Floor	830 ± 260	12th Century AD	Ritual
SB2B	L15	4	Stair	1600 ± 100	5th Century AD	Jetty
SB2D	f19	5	Floor	2700 ± 300	6th Century BC	Jetty
SB2E	K16	4	Floor	1500 ± 100	3rd Century BC	Jetty
SB2G	d38	3	Floor	2500 ± 300	5th Century BC	Port management
SB2J	P18	8	Floor	1700 ± 100	4th Century AD	Jetty
SB2ZZ	J17	6	Stage	1900 ± 200	2nd Century AD	Port management
SB2ZY	K10	5	Floor	2500 ± 300	5th Century BC	Port management

Note: ∗Oldest dating data for each site is processed and used in this table.

Table 3 Results of radiocarbon dating at iron smelting sites (Source: authors based on data from Mokhtar, 2019).

Sites	Trench	Spit	Conventional age (BP: Before Present)	Age of calibration AD: Anno Domini; BC: Before Christ
SB1G	E9	8	1620 ± 30 BP	4th Century AD
SB1ZY	G6	5	2210 ± 30 BP	4th Century BC
SB2A	M7	16	1680 ± 40 BP	1st Century AD
SB2C	H19	5	1570 ± 40 BP	5th Century AD
SB2F	M19	6	1990 ± 30 BP	1st Century BC
SB2H	D4	7	2500 ± 30 BP	8th Century BC
	W14	6	2420 ± 30 BP	6th Century BC
SB2K[a]	G8	8	1270 ± 30 BP	7th Century AD
SB2L[a]	B10	5	990 ± 30 BP	11th Century AD
SB2M[a]	F2	6	1560 ± 30 BP	5th Century AD
SB2N[a]	Q9	4	1570 ± 30 BP	5th Century AD
SB2P[a]	F7	11	1570 ± 40 BP	5th Century AD
SB2Q[a]	P7	4	1050 ± 30 BP	6th Century AD
SB2R[a]	K4	4	1460 ± 30 BP	6th Century AD
SB2T[a]	P.P.1	3	1570 ± 40 BP	5th Century AD

Note: ⁎Oldest dating data for each site is processed and used in this table.
[a] Rescue Excavation Sites.

95.4%, it has been suggested that the exact age for the start of iron smelting at this SB2H site is from 545—387 BC (2420—2430 BP) until AD 1400 (620—630 BP).

The data is also strengthened by the results of OSL dating of the jetty site at SBAC, which also reveal that it was built since 582 BC (Appendix B). This shows that the urbanization process that takes place in SBAC is to meet the needs of the iron industry, which is rapidly progressing.

In addition to the 545 BC date, the iron industry in SBAC also revealed the earliest date, dating back to 788 BC. This is due to the fact that chronometric dating from Beta-516413 (SB2H/D4/7) (Appendix C) generally has two probability percentage categories, which are 95.4% and 66.2% for its dating results. For a probability of 95.4%, it continues to give a dating range of 788—537 BC (2737—2468 BP), while for a probability of 66.2%, it gives three possible probabilities, which are 46.4% (644-552 BC [2593—2501 BP]), 11.1% (767—744 BC [2716—2693 BP]), and 10.8% (687—665 BC [2636—2614 BP]). Since the best percentage for this charcoal sample is 95.4%, the most likely acceptable date is 788—537 BC (2737—2486 BP).

Because until now, in the Southeast Asian region, the beginning of the development of iron smelting technology is accepted to be around the 5th century BC as interpreted by Bronson (1985). The dating sample Beta-516413, which gives an age of 8th century BC, although HPD shows accurate confidence, needs more samples to strengthen the chronometric dating data.

6.2. Analysis of urbanization and land use proccess at SBAC

Urbanization and land use in the SBAC are expected to begin in the 6th century BC due to the area's ability to supply raw materials for the iron smelting process (Fig. 6). The results of the survey conducted proved that the raw material for iron smelting is only located within a distance of 1—11 km from this complex (Dunn, 1975).

Based on the paleoenvironment, this area has been used as an iron smelting site in ancient Kedah since 545 BC. During the 6th century BC, the SB2D site also began to be erected as a port in the area of the SBAC. The presence of early monuments in the western part of the SB2D and SB2H sites is also a clear indication that the ancient Kedah iron industry process received high demand, which required a port management structure to be established to facilitate trade at the river jetty area.

Archaeological studies in the western part of the Sungai Batu until 2023 did not record any findings of iron smelting sites, which suggested that the port management in that area served as an administrative structure for the export of iron ingots and forest products for ancient Kedah in this complex. The interpretation had been strengthened based on the records of the ancient Kedah Kingdom, which also conducted trade activities on forest products such as cardamom, agarwood, laka wood, aleo wood, honey, sandalwood, ivory, tortoise shell, betel nut, and amber, which

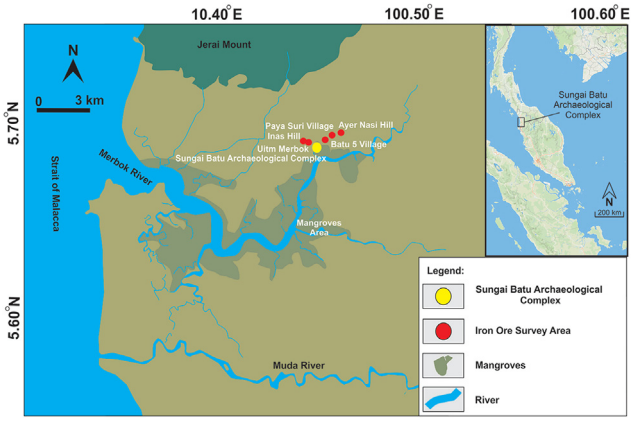


Fig. 6 The raw material of iron smelting located within 1—11 km of this complex. Source: The Authors, based on data from Saidin (2022).

had become parts of ancient Kedah export products before the 1st century BC (Dunn, 1975; Tibbets, 1979).

By the 5th century BC, several port managements, which at the same time also served as river jetties, were built in SB1R, SB1S, SB1W, SB2G, and SB2ZY sites. The sites were built on the western side of the SB2D jetty. The site is expected to have such a function because, during the 4th century BC, it was located on the west bank of Sungai Batu. In the 4th century BC, the SB1ZY iron smelting site was used for the ancient Kedah iron smelting industry in this complex. The SB2E jetty structure and the SB1Z port management monument were also built in the 3rd century BC to balance the rapidity of trade in this complex. The urbanization process in the SBAC was further intensified with the construction of SB1P and SB1T port management sites in the 2nd century BC, while SB1H, SB1J, SB1M, SB1N river jetties, SB1Q port management, SB1D ritual monuments, and iron smelting sites SB2F were constructed around the 1st century BC.

In the 1st century AD, the SB1K river jetty structure and SB2A iron smelting workshop began to be built and used in this complex, while the SB1Y jetty, SB1B, SB1E ritual sites, SB1U, SB1X, and SB2ZZ port management also began to be built in the 2nd century AD. This marked the era of rapid development of the iron smelting industry and trade in ancient Kedah. The river jetty SB1A, ritual monuments SB1C and SB1D, and port management SB1V began to be built in the 3rd century AD, while the river jetties SB1L and SB2J, as well as the iron smelting site SB1G, have been built and used since the 4th century AD.

In the 5th century AD, the river jetty SB2B and iron smelting sites SB2C, SB2M, SB2N, SB2P, and SB2T were also established for the iron trade and industry activities in this complex. In the 6th century AD, the iron smelting sites SB2Q and SB2R began to play a role in iron smelting activities at the SBAC. After the 6th century AD, the urbanization process in the SBAC continued to grow with the construction of

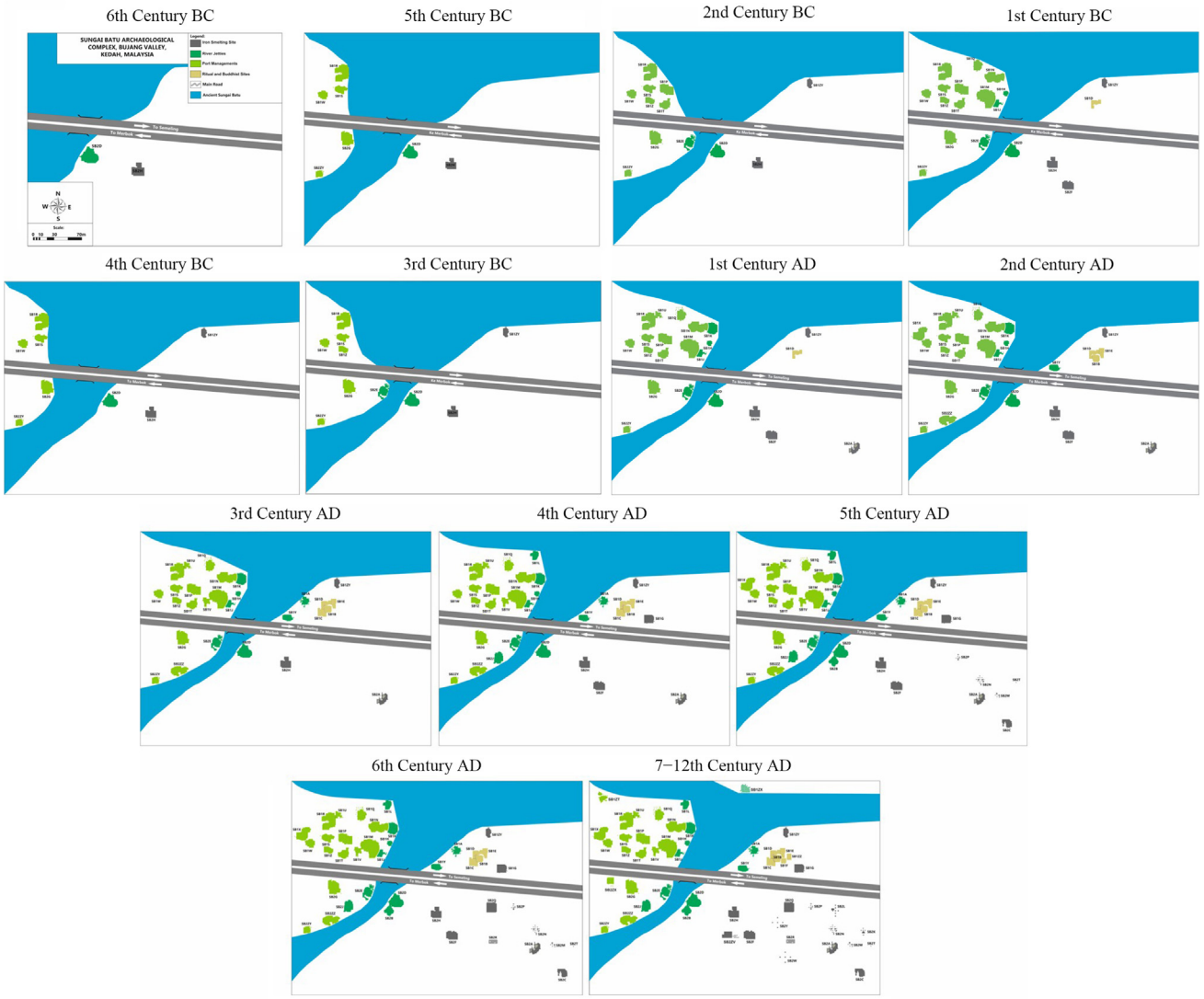


Fig. 7 The urbanization process that took place from the 6th century BC until the 12th century AD in SBAC, which aims to develop the iron smelting industry in the area. Source: The Authors, based on data from Zakaria (2014); Aminuddin (2015); Ahmad (2016); Yusof (2016); Hassan et al. (2018); Halim (2019) and Mokhtar (2019).

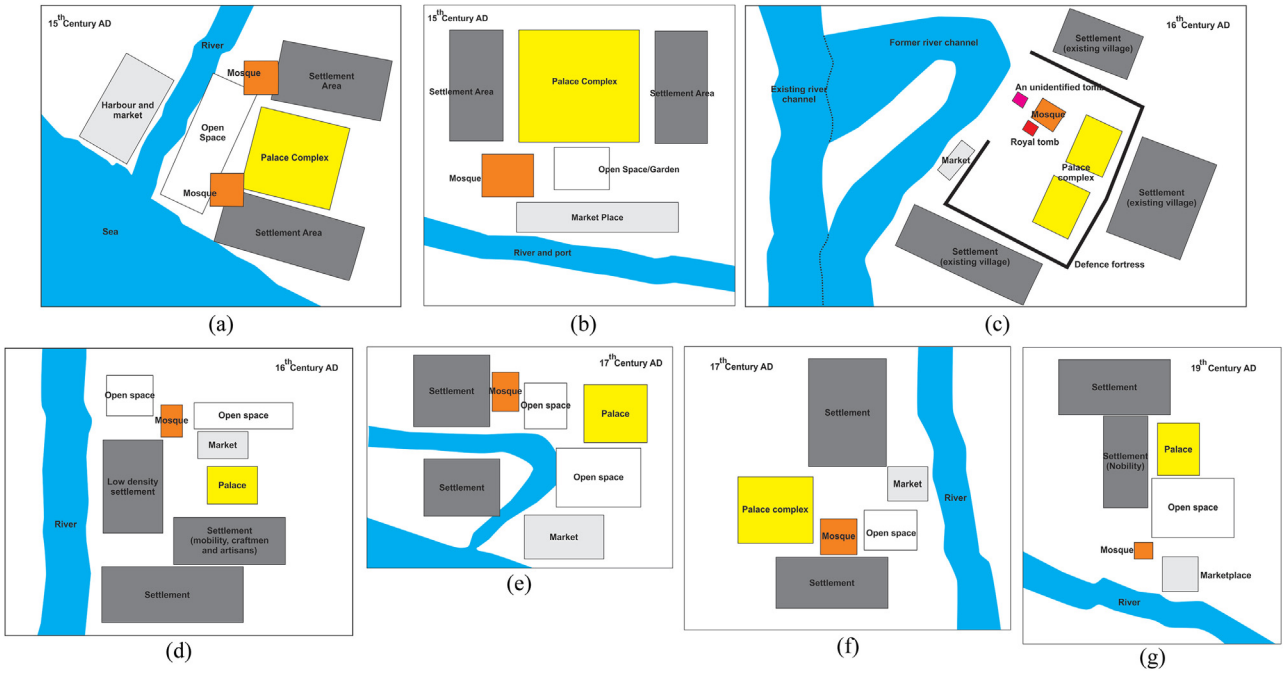


Fig. 8 The urbanization process for the Malay Kingdom after the 15th century AD shows that safety aspects are important in the framework of the development of its urbanization system. Source: The Authors, based on data from Shukri et al. (2018); Ibrahim et al. (2018) and Mamat et al. (2022).

the SB1F and SB1ZZ ritual monuments until the 12th century AD. After the 12th century AD, there is no record of any construction of ritual religious monuments relating to Hinduism and Buddhism because, after the 12th century AD, the Kedah sultanate had embraced Islam (Abdullah, 2006).

In addition, in the period after the 6th century to the 11th century AD, evidence of the viability of Kedah's ancient iron smelting industry also continues with the involvement of SB2L and SB2K sites in iron smelting activities in this complex. SBAC also has several sites that have yet to reveal their chronometric dates. The sites are SB1ZX jetty, SB1ZT port management, iron smelting sites SB2W, SB2Y, and SB2ZV. The presence of the SB1ZX jetty site in the northern part of the complex clearly indicates that the sea level had begun to recede, allowing land to form. This allowed the area of the river, which was previously as wide as 100 m (Saidin, 2002) in the northern part of the complex, to start shrinking into a lake, which allowed the jetty structure to be built in the area.

Thus, the process of urbanization in the SBAC area that continued from the 6th century BC until the 12th century AD (Fig. 7) clearly revealed the importance of this area in supplying iron-based products to foreign civilizations (Hoyland and Gilmour, 2006; I-Tsing, 1896; Tibbets, 1979; Thilakavathy, 2019; Mokhtar, 2012), in addition to the forest produce around Mount Jerai (Dunn, 1975; Suzuki, 2019). After the 12th century AD, Kedah started its sultanate system, and this made the center of Kedah's government change

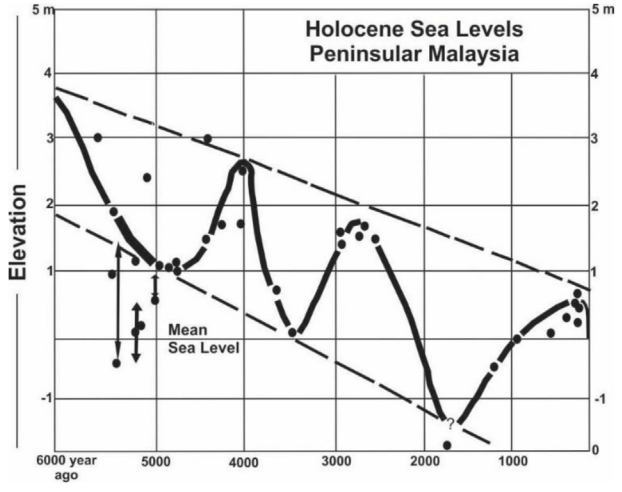


Fig. 9 A graph of sea level change around 6000 BC in Southeast Asia that charts the process of urbanization in the SBAC. Source: The Authors, based on data from Tjia (1995, 2009).

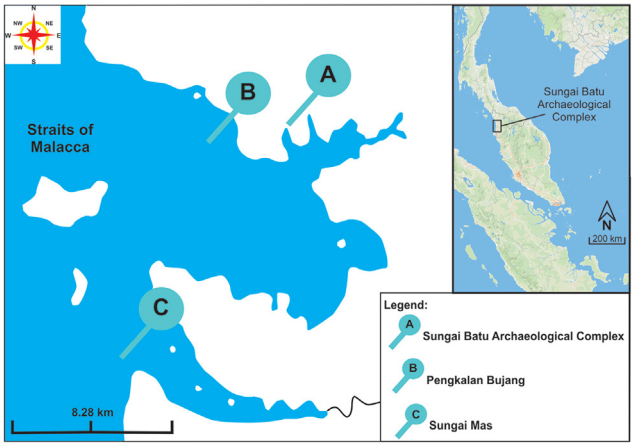


Fig. 10 SBAC area close to the sea in the 1st century AD. Source: The Authors, based on data from Saidin et al. (2019).

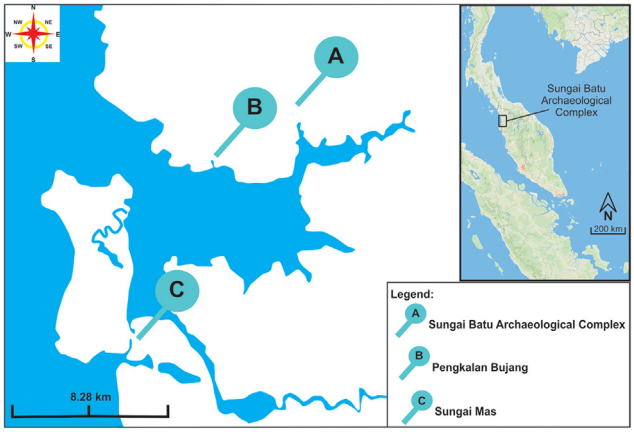


Fig. 11 In the 4th century AD, land areas began to appear in the ancient Kedah port at Sungai Mas, Simpor Tambang, Kampung Sireh, and Pengkalan Bujang, which caused the river flow at the SBAC to decrease. Source: The Authors, based on data from Saidin et al. (2019).

to a fort, namely Kota Kuala Kedah Fort in the 15th century AD (Dziyauddin, 2018) and Kota Kuala Muda Fort (Ali et al., 2021) in the 18th century AD. This is because during that period, the development of the urbanization process followed the same pattern as recorded based on studies in Tanah Abang Royal Complex, Melaka Fort, Siputeh Fort, Malawati Fort, and Sultan Mansur Shah Palace Complex 1 (Fig. 8) (Mamat et al., 2022). All the patterns of urbanization that occur in the area show an urbanization process that is concerned with the security aspect of government.

For the case study at SBAC, the urbanization process taking place in the area clearly shows the decline of the average sea level as well as playing a major role in the urbanization process. Before 6000 BC, the sea level in Peninsular Malaysia was found to be the same as the rest of the world, which is between 100 and 130 m, compared to up to 130 m around 18000 BC (Tjia, 1995, 2009; Hassan, 2003). Around 5000 BC, the sea level continued to rise until it reached a height of 5 m above the current average sea level. After entering 5000 BC, the sea level is expected to fluctuate until it falls above the current sea level.

Figure 9 shows the pattern of sea-level change around 6000 BC, which shows the sea level change decreasing to reach less than 1 m from the current average sea level in the 1st century AD. Then, the area that was previously still under the sea began to appear on land. Based on the current pattern of sea level decline, new settlements can be opened in inland areas close to the drainage system. Based on the data, it shows that the archaeological sites built and used since the 6th century BC at the SBAC were found to be getting further away from the river flow by the 1st century AD. Therefore, the process of building new sites that were closer to the river flow was needed so that the trade activities that took place were not affected.

In order to study the potential of the SBAC as an area for trade activities, data on sea-level fluctuations in the Merbok area were collected. Data observations showed that after 5000 years BC, the sea level began to decline by 2000 years ago (Figs. 10 and 11). This allowed the complex to be an early activity and economic area due to its paleo-environmental suitability, which is close to drainage systems such as the Merbok and Batu Rivers.

6.3. Core drilling data

Core augering around the SBAC area had successfully penetrated the soil layer from a depth of 1.0 m (auger hole ADH2) up to a depth of 20 m (auger hole ADH11) (Fig. 12). It was found that three auger holes, namely ADH1, ADH2, and ADH8, only penetrated the soil layer for less than 2 m following the discovery of a hard layer. The identified

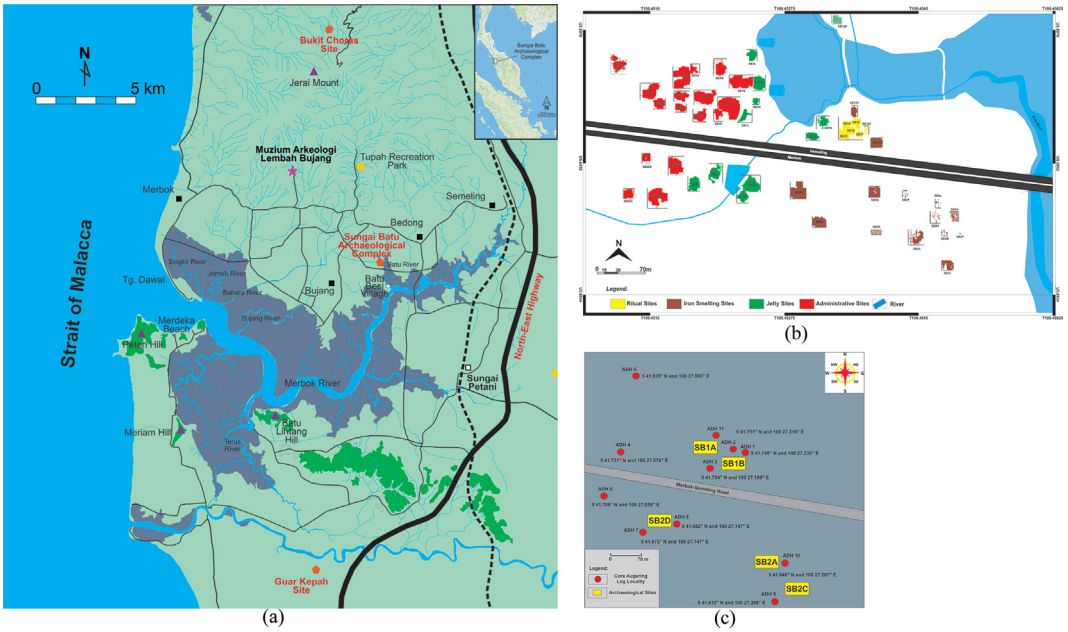


Fig. 12 SBAC (a, b) in Bujang Valley and core drilling locality location (c) to identify its potential as an industrial area. Source: The Authors, based on data from Talib (2009), Halim et al. (2021).

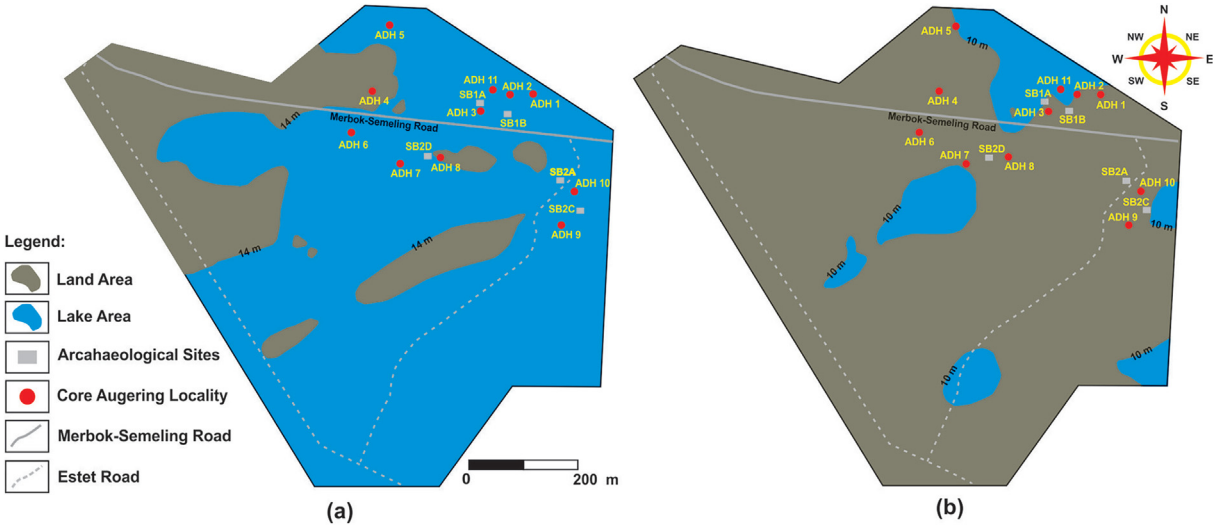


Fig. 13 A part of the ancient marine bay environment in SBAC is based on core drilling data (a) and the environment of SBAC, which shows the sea level began to fall and land began to appear, which allowed this area to be inhabited as an industrial area (b). Source: The Authors, based on data from Halim et al. (2021).

alluvial sediments were dominantly up to 3 m thick, except for the ADH9 auger hole, which reached a thickness of 4.5 m. Alluvial deposits could be divided into two layers, namely the top soil layer and the sediment layer. The cover soil layer had the characteristics of sandy clay and silty clay. In addition, there were also secondary minerals that existed in this layer, which were muscovite minerals (ADH5 and ADH9). The muscovite was likely derived from weathered and transported shale rocks of the Jerai Formation (Ramzul et al., 2015).

Based on the core drilling log and sample identification in the auger hole in Sungai Batu, it is possible that there was a lake environment in some of the holes that existed at a depth of 0.5—4.5 m. Meanwhile, the presence of an ancient river may only exist after the presence of the lake due to the drop in sea level. Even in the clay, a small presence of muscovite was found in the auger holes ADH5 and ADH9, which may be the result of ancient river flow from the Jerai Formation that deposited the mineral in the lake (Talib, 2009).

Based on core drilling data, it is clear that there is evidence of the flow of lakes and rivers in this complex, which makes this area unsuitable for use as a settlement and industrial location. After the drying of the lake, a land area emerged, which allowed several monumental architectural structures to be built that acted as river jetty and port management in this area (Fig. 13). This allowed the processes of area use and urbanization to grow rapidly in this complex until the 12th century AD.

6.4. 2D resistivity data

Based on the analysis of 2D resistivity imaging and seismic refraction data, the thickness of the ancient Sungai Batu sedimentation could be determined, which corroborated the core drilling data. Based on Fig. 14, the contour map of shale topography generated from 2D resistivity imaging and seismic refraction results clearly revealed that the thickness of the ancient Sungai Batu sediment is increasing from the northeast to the southwest. The sediment deposits were characterized by low resistivity and velocity values ($<$314 Ω·m and $<$1822 m/s), while shale was characterized by high resistivity and velocity values ($>$314 Ω·m and $>$1822 m/s). The contrast values indicated that the Sungai Batu ancient river flowed from the north-west and east (Andika et al., 2018). This clearly proved that the environment played a major role in the development of the land use process in this complex. This is because the structure of the river jetty had been built on the riverbank of Sungai Batu; port management was at the back of the jetty; rituals were on the northernmost cape of this complex; and the iron smelting workshop was located on the west side.

7. Urban concept of SBAC

The process of urbanization and land use in the SBAC was able to grow due to its position in the middle of the early world trade routes (Coedes, 1967), which connected between east and west (Wales, 1976). This is based on the factors of urbanization development in early civilization, which were all centered on the ability of an area to help the economic development of a kingdom by being selected as an industrial area and settlement. The process of urbanization and land use were closely related to geographical features such as the river, mountain, and inland environment that allowed architects to be able to build an industrial and port city based on the suitability of the local climate and geography.

Based on the archaeological evidence that had been studied in this complex, it was clear that the principle of urbanization that occurred was closely related to Lynch's concept. Based on the concept of the development of urbanization, it should be based on 1) paths, 2) edges, 3) districts, 4) nodes, and 5) landmarks. For paths, it is the most legible element in the city's image. The observer walks along the linear form, such as streets, walkways, canals, or railroads. Observers experience the city while moving through

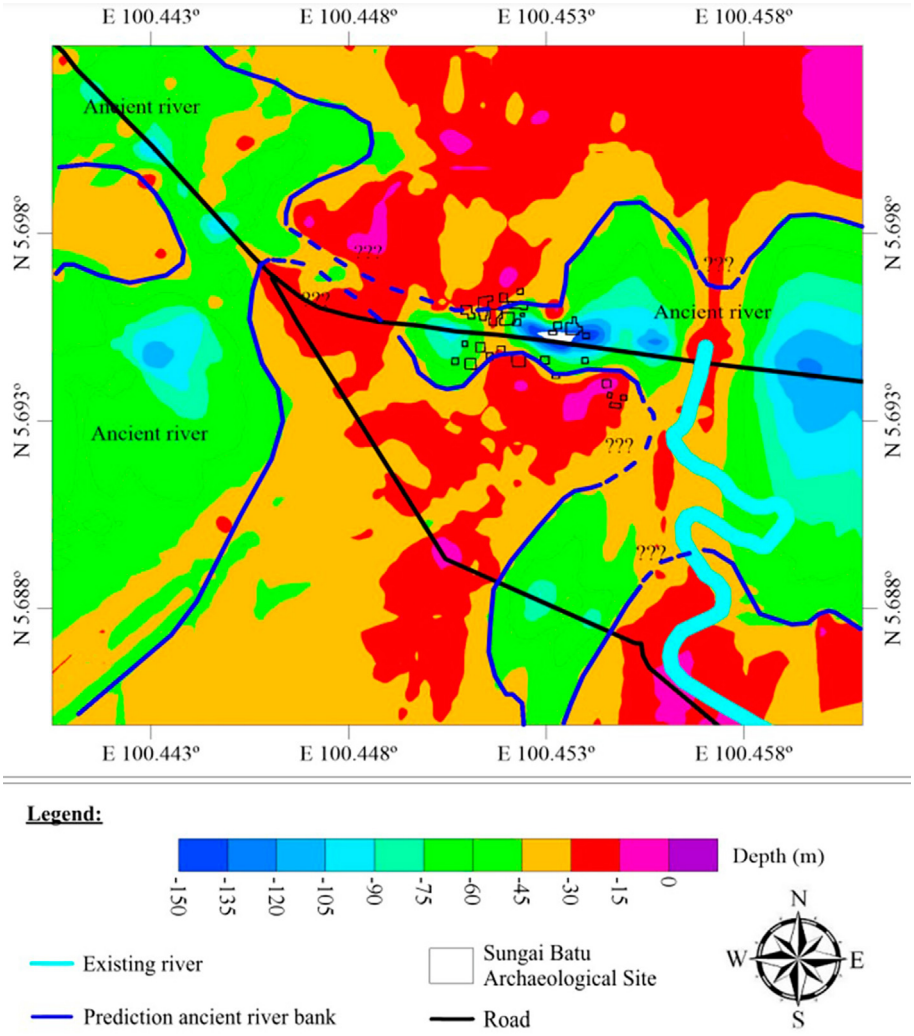


Fig. 14 Sungai Batu sediment topography and the identified ancient river. Source: Andika et al. (2018).

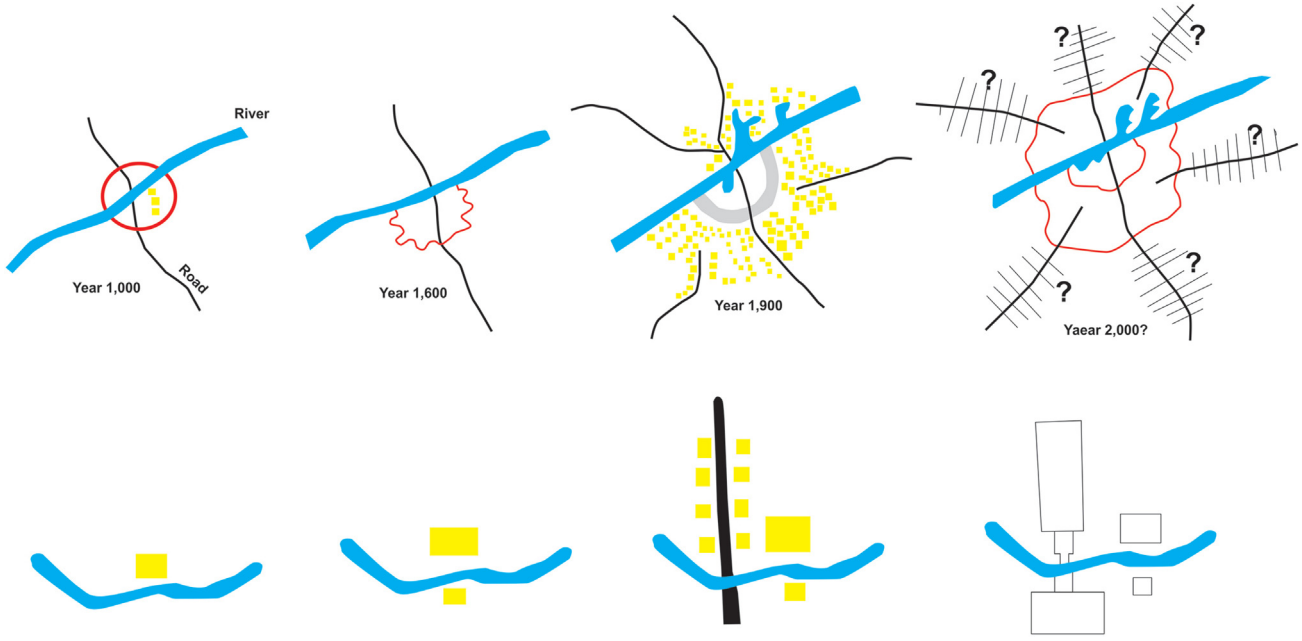


Fig. 15 Generic illustration of city development in close relationship with a river. Source: The Authors, based on data from Lynch (1981).

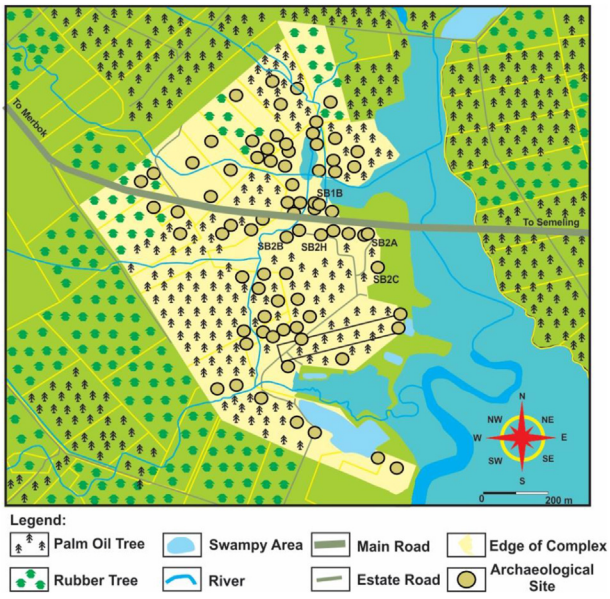


Fig. 16 The edges of the complex based on survey and mapping since 2009. Source: The Authors, based on data from Saidin (2022).

it. For edges, these create a boundary between two or more close regions or districts, creating linear breaks in continuity. Districts are groups of urban landscapes that have a similar or common character that observers could mentally experience "inside of". Nodes are points; they can be intersections or junctions between paths where observers can enter the points, and landmarks are points of reference that simply define a physical object such as signs, buildings, mountains, or monuments (Lynch, 1960).

Due to the location of the SBAC, which had a wide and deep estuary, it allowed this location to grow rapidly as a major settlement and industrial area, such as Yanshi Xian (Shang Dynasty, 16th century BC) and Babylon (23rd century BC) (Benevolo, 1980). This is because almost all the concepts of urbanization in early world civilizations developed due to their location on the river route (Fig. 15), which allowed the communication system to develop well (Benevolo, 1980). This is evident when the survey and mapping conducted were able to estimate the area of this complex to be around 4 km^2 based on the distribution of artifacts that had been mapped since 2009 (Fig. 16). In fact, based on the research, the site has served as an iron-smelting workshop located in the east, a river jetty on the riverbank of Sungai Batu, port management at the back of the jetty, and a ritual monument in the north (Saidin, 2022, 2023). This clearly shows that each site was built based on its function, and this shows the application of the concept of district in the urbanization process in this complex.

The complex also had an area that was the focus of the population, which conforms to the concept of nodes in the Lynch principle. This is because the population concentration area in this complex is concentrated in the area of religious monuments and iron smelting workshops. This is because in that area, the residents need to gather to enable ritual and religious ceremonies to be performed. Iron smelting workshops, on the other hand, require a large work force to enable smelting activities and the production of stale ingots for export purposes to be carried out in an orderly manner. In addition, the landmark of this complex area is Mount Jerai, which can be seen as far as 15 km from the ocean (Maznah et al., 2010) and is at the same time used as a landmark for traders to trade to the ancient Kedah port area, especially in the SBAC. Based on this, the urbanization process that took place in this complex area was planned, systematic, and in accordance with the principles of urbanization outlined by Lynch (1981).

8. Conclusion

This research, which was conducted at the monument sites and iron smelting sites at the SBAC, enabled primary data related to dating and urbanization processes to be recorded. Based on the usage data of the area, it is clear that the urbanization process that took place in the SBAC was based on the iron industry. The data had been reinforced by geophysical mapping and core-drilling methods that clearly showed the presence of ancient river flow effects based on muscovite and aluvium (clay) sediments and saturated area research, especially at the rear of the river jetty structure. This showed that when the sea level was falling, it caused new land to be formed, which led to the need to rebuild a jetty and move port management closer to the river.

Even the applied urbanization technology had been modified from the principles of Lynch and adapted according to the climate, geography, and iron industry in the area. This showed that there had been a development of local wisdom for the iron smelting community in Sungai Batu, which had its own standards in the urbanization process. This made the SBAC the world's largest iron ingot export center since 545 BC.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This study was conducted under the grant of Malaysian (1001/PARKEO/870015) and Global Archaeological Research (304/PARKEO/650953/L127). Authors are thankful to Center for Global Archaeological Research (CGAR), University Sains Malaysia, Pulau Pinang, Malaysia, for providing all necessary facilities to successfully conducting this research.

Appendix. Supplementary data

Appendix A, B and C in this article can be found at https://doi.org/10.1016/j.foar.2023.10.006.

References

Abdullah, A.R., 2006. Islam Dalam Sejarah Asia Tenggara Tradisional [Islam in Traditional Southeast Asian History]. Pustaka Haji Abdul Majid, Selangor.

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]. Unpublish Master Dissertation, Universiti Sains Malaysia, Penang, Malaysia.

Ali, M.A., Halim, M.H.A., Masnan, S.S.K., Saidin, M., 2021. Kuala Muda historical site in fullfill requirement of tourism industry in Kedah. Quantum Journal of Social Science and Humanities 2 (5), 10—28. https://doi.org/10.55197/qjssh.v.2i5.92.

Allen, J.S., 1988. Trade and site distribution in early history-period Kedah: geoarcheology, historic and locational evidence. In: Unpublish Doctoral Dissertation. Universitiy of Hawaii, Honolulu.

Aminuddin, S.A., 2015. Kajian Arkeologi di Tapak SB1M dan SB1N, Kmpleks Sungai Batu, Lembah Bujang, Kedah [Archaeological Study at SB1M and SB1N Sites, Sungai Batu Complex, Bujang Valley, Kedah]. Unpublish Master Dissertation, Universiti Sains Malaysia, Penang, Malaysia.

Andika, F., Saad, R., Saidin, M., Muztaza, N.M., Asmir, 2018. Identification of Sungai Batu sediment using 2-D resistivity imaging and seismic refraction methods for ancient river mapping at Kedah, Malaysia. IOP Conf. Series: J. Phys. Conf. 995, 1—7.

Bayard, D., Charoenwongsa, P., Rutnin, S., 1982/1983. Excavations at Non Chai, northeastern Thailand, 1977-1978. Asean Perspectives 25 (1), 13—61.

Benevolo, L., 1980. The History of the City. The MIT Press, Cambridge, USA.

Biggs, L., Bellina, B., Martinon, M., Pryce, T.O., 2013. Prehistoric iron production tech-nologies in the upper Thai-Malay peninsula: metallography and slag inclusion analysis of iron artifacts from Khao Sam Kaeo and phu Khao thong. Archaeological and Anthroological Sciences 5, 311—329.

Bird, M.I., 2013. Charcoal. In: Elias, S.A. (Ed.), The Encyclopedia of Quaternary Science, 4. Elsevier, pp. 353—360.

Bronson, B., 1985. Notes on the history of iron in Thailand. J. Siam Soc. 72, 205—225.

Coedes, G., 1967. The Making of Southeast Asia. Routledge and Regan Paul Limited, London.

Dorothy, W., Wales, Q., 1947. Further work on Indian sites in malaya. In: Journal of the Malayan Branch of the Royal Asiatic Society, 20. Malaya Publishing House, Limited, Singapore, pp. 1—11.

Dunn, F.L., 1975. Rain-forest collectors and traders: a study of resource utilization in modern and ancient malaya. Malaysian Branch of Royal Asiatic Society Monograph 5, 1—151.

Dziyauddin, N.,N., 2018. *Yesterday-Today-Tomorrow: Magnifying the Historic Space of Kuala Kedah Fort*. Unpublish B.A. Thesis. Universiti Teknologi Mara, Shah Alam, Selangor.

Evans, I.H.N., 1931. A search for antiquities in Kedah and perlis. Journal of the Federal Malay States Museums 15 (1), 43—50.

Guangyu, W., 1958. The nanhai trade: a study of the early history of Chinese trade in the south China sea. Journal of the Royal Branch of the Royal Asiatic Society 31 (2), 3—135.

Gupta, Sushil, K., Polach, H., 1985. Radiocarbon Dating Practice at Australian National University, Handbook, Radiocarbon Laboratory. Research School of Pacific Studies, ANU, Canberra.

Halim, M.H.A., 2014. Ekskavasi Tapak Seni Bina Jeti SB2E, SB1H, SB1J, SB1K Dan SB1L, Kompleks Sungai Batu, Lembah Bujang, Kedah [Excavation of Jetty Architecture SB2E, SB1H, SB1J, SB1K and SB1L, Sungai Batu Complex, Bujang Valley, Kedah]. Unpublish Master Dissertation, Universiti Sains Malaysia, Penang, Malaysia.

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 Dissertation, Universiti Sains Malaysia, Penang, Malaysia.

Halim, M.H.A., Masnan, S.S.K., Talib, N.K., Saidin, M., 2021. Sungai Batu archaeological complex as a major industrial area for the Kedah tua kingdom based on core drilling data. Kapata Arkeologi 17 (2), 71—84.

Hassan, K., 2003. Mid-holocene to recent sea level changes in peninsular Malaysia: a tectonic implication. Geol. Soc. Malays. Bull. 46, 313—318.

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.

Hoyland, R.G., Gilmour, B., 2006. Medieval Islamic Sword and Swordmaking. Gibb, Memorial Truss.

Huntley, D.J., Smith, D.I.G., Thewalt, M.L.W., 1985. Optical dating of sediments. Nature 313, 105—107.

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.

Ibrahim, I., Abdullah, A., Ibrahim, M., Murtaz, F.F., 2018. Historical urban form: a case study of Melaka. Planning Malaysia: Journal of the Malaysian Institute of Planners 16 (2), 153—163. https://doi.org/10.21837/pmjournal.v16.i6.470.

Irby, F.W., 1905. The ruins on gunong Jerai, Kedah. Journal of the Federal Malay State Museum 1, 79—81.

Jasper, V.N., Vandenberghe, D., Gelaude, F., Peter, V.D.H., 2013. Absolute dating of aeolian sediments in relationship to the development of the city of ghent: first results. Mediterranean Archaeology and Archaeometry 13 (3), 25—35.

Jiang, H., Zhou, Y., 2023. Evolution of the "golden royal city": analytical study on urban forms of ancient capital cities in Myanmar. Frontiers of Architectural Research 12, 714—731. https://doi.org/10.1016/j.foar.2023.03.002.

Jorge, S.S., Manuela, P.M., 2013. Delimiting the urban growth of santiag de compostela (NW Spain) by OSL dating of medieval anthropogenic sediment. Mediterranean Archaeology and Archaeometry 13 (3), 163—173.

Khaw, N.R., Shahidan, S., Zainun, N., Saidin, M., 2009. The post-14th century ancient Kedah: a port in decline?. In: Mat Akhir, N.S., Sulong, J., Wan Harun, M.A., Muhammad, S., Wei Lin, A.L., Low Abdullah, N.F., Pourya Asl, M. (Eds.), Role(s) and Relevance of Humanities for Sustainable Development. European Proceedings of Social and Behavioural Sciences, 68. Future Academy, pp. 25—34. https://doi.org/10.15405/epsbs.2019.09.3.

Kima, M.J., Jung, B.J., Kimc, S.Y., Hong, D.G., 2013. Comparison of osl and 14c dates estimated from paleolithic paleosol of the suheolri site in cheonan, Korea. Mediterranean Archaeology and Archaeometry 13 (3), 117—126.

Lamb, A., 1962. A note on a small inscribed stone tablet from dr. Wales Kedah site No. 1. Federated Museums Journal, New Series 7, 67—68.

Lamb, A., 1980. The temple on the river of cut stone. In: Persatuan Sejarah Malaysia. Lembah Bujang the Bujang Valley. Department Federation of Malaya, Kuala Lumpur, pp. 61—66.

Leong Sau Heng, 1973. *A Study of Ceramics Deposit from Pengkalan Bujang, Kedah*. Unpublish Master Dissertation. University Malaya, Kuala Lumpur.

Low, J., 1848. An account of several inscriptions found in province wellesley on the peninsula of malacca. Journal of the Asiatic Society of Bengal 18 (2), 62—66.

Low, J., 1849. On an inscription from keddah. Journal of Asiatic Society of Bengal 18 (1), 247—249.

Lynch, K., 1960. The Image of the City. Harvad-MIT Press, United State of America.

Lynch, K., 1981. A Theory of Good City Form. The MIT Press, Cambridge, USA.

Mamat, M.J., Khaw, N.R., Narayanen, S., Edinur, H.A., Wahid, N., Masnan, S.S.K., Talib, N.K., Zainun, N., Abdullah, M.F., 2022. Tanah Abang, perak: the layout and planning of a 16th century fortified Malay royal town. Planning Malaysia 20 (3), 76—86. https://doi.org/10.21837/pm.v20i22.1128.

Maznah, W.O., Syakirah, M., Nordin, R., Alauyah, J., 2010. Hidden tales of the Bujang Valley. Asian Cult. Hist. 2 (2), 221—227.

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, Universiti Sains Malaysia, Penang, Malaysia.

Mokhtar, N.A.M., 2019. Kajian 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 Dissertation, Universiti Sains Malaysia, Penang, Malaysia.

Muhamad, A., 2010. Ekskavasi arkeologi di Kota lukut, port dickson, negeri sembilan [archaeological excavatin in Kota lukut, port dickson, negeri sembilan]. In: Chia, S., Isa, H.M. (Eds.), *Archaeological Heritage of Malaysia*. Center for Global Archaeological Research. University Sains Malaysia, 3. Pulau Pinang, pp. 1—27.

Murray, A.S., Wintle, A.G., 2000. Luminescence dating of quartz using an improved single-aliquot regenerative-dose protocol. Radiation Measurements 32 (1), 57—73.

Nishimura, M., 2005. Settlement pattern on the red river plain from the late prehistoric period to the 10th century AD. Bulletin of the Indo-Pasific Prehistoric Association 25 (3), 99—107.

Nitta, E., 2015. Iron smelting site and activities in prehistoric Southeast Asia. The present day research on the ancient iron production in the world. In: International Conference of Research Center of Ancient East Asean Iron Culture. Ehime University, Japan, pp. 75—84.

Olive, P., Hubert, 1984. P. *Interpretation des Ages 14C des Bois et Ossements*. Report CRG. October 1984.

Peacock, B.A.V., 1980a. New light on the ancient settlement of Kedah and province wellesley. In: Persatuan Sejarah Malaysia. *Lembah Bujang the Bujang Valley*. Persatuan Sejarah Malaysia, Kuala Lumpur, pp. 82—88.

Peacock, B.A.V., 1980b. Two celedon plates from the sungei Muda, Kedah. In: Persatuan Sejarah Malaysia. *Lembah Bujang the Bujang Valley*. Persatuan Sejarah Malaysia, Kuala Lumpur, pp. 67—69.

Petchey, P., Bellina, B., Pryce, O.T., Innanchaic, J., 2018. A late prehistoric iron smithing workshop and associated iron industry in the port settlement of Khao Sek, Thai-Malay peninsula. Archaeological Prehistoric Association Bulletin 19 (3), 61—64.

Pham, T.N., 2005. A report on recent excavations on ly Son island (central Vietnam). Indo-Pasific Prehistoric Association Bulletin 25 (3), 133—137.

Pigati, J.S., Quade, J., Wilson, J., Jull, A.J.T., Lifton, N.A., 2007. Development of low-background vacuum extraction and graphitization systems for 14C dating of old (40—60 ka) samples. Quat. Int. 16, 4—14.

Rahman, N.H.S.N.A., 1992. Zaman protosejarah Malaysia [protohistoric period in Malaysia]. In: Wahid, Z.A.A., Khoo, K.K., Ibrahim, M.Y., Rahman, N.H.S.N.A., Hassan, M.A. (Eds.), Malaysia Warisan dan Perkembangan [Malaysia Heritage and Development]. Dewan Bahasa dan Pustaka, Ministry of Education Malaysia, Kuala Lumpur, pp. 1—5.

Rahman, N.H.S.N.A., Mohamad, A., 2012. Kaedah pentarikhan relatif dan mutlak dalam penyelidikan arkeologi [relative and absolute dating methods in archae-ological research]. In: Rahman, N.H.S.N.A., Mohamad, A., Ramli, Z. (Eds.), Isu-Isu Pentarikah Tapak Warisan & Artifak Budaya Alam Melayu [Dating Issues of Heritage Sites & Malay Culture Artifacts]. Institute of Malay World and Civilization (ATMA), National University of Malaysia, Bangi, pp. 9—23.

Ramzul, I.S., Nordiana, M.M., Saad, R., Saidin, M., Maslinda, U., Hisham, H., Sulaiman, N., 2015. Inverstigations of ancient river at lembah Bujang, Kedah, Malaysia. Electron. J. Geotech. Eng. 20 (11), 4385—4392.

Reimer, P.J., Bard, E., Bayliss, A., Beck, J.W., 2013. IntCal13 and Marine13 radiocarbon age calibration curves. Radiocarbon 55 (4), 1869—1887.

Reinecke, A., Laychour, V., Sonetra, S., 2009. The First Golden Age of Cambodia: Excavation at Prohear. Thomas Muntzer, Jerman, pp. 1—225.

Rhodes, E.J., 2011. Optically stimulated luminescence dating of sediment over the past 200,000 years. Annu. Rev. Earth Planet Sci. 39, 461—488.

Sabtu, M.S., 1988. Zaman hindu buddha di Lembah Bujang: satu penilaian berdasarkan data arkeologi [the hindu -buddhist period in the Bujang Valley: an assessment based on archaeological data]. In: Unpublish Master Dissertation. Malaya University, Kuala Lumpur.

Saidin, M., 2022. Merungkai Rahsia Sejarah Alam Melayu Dan Nusantara, Siri 2: Tamadun Kedah Tua, Peradaban Manusia & Besi [Unraveling the Secrets History of the Malay World and the Archipelago, Series 2: Kedah Tua Civilization, Human & Iron Civilization]. Paper Presenter at *Kedah Tua Webinar*. Sunday, 20 Mac 2022.

Saidin, M., 2023. The secrets of 2,800 Years of Sungai Batu archaeology since 788 BCE. In: Paper Presenter at *Ancient Kedah Early Civilization Seminar Series*. Memorial Tunku Abdul Rahman, Kuala Lumpur. Febuary 25, 2023.

Saidin, M., Abdullah, J., Osman, A.J., Abdullah, A., 2011. Issues and problems of previous study in Bujang Valley and the discovery of Sungai Batu. In: Chia, S., Andaya, B.W. (Eds.), Bujang Valley and Early Civilizations in Southeast Asia. Universiti Sains Malaysia Publisher, Penang, pp. 15—26.

Saidin, M., Saad, N.S., Abdullah, N., 2019. Warisan geoarkeologi [geoarchaeological heritage]. In: Mokhtar Saidin & Ibrahim Komoo. Jerai Geopark Warisan Geologi, Geoarkeologi dan Biologi [Jerai Geopark Geological Heritage, Geoarchaeological and Biological]. Universiti Sains Malaysia Publisher, Penang, pp. 71—118.

See Tonn, Foong, 1959. The university of malaya archaeology society survey of the Kuala Muda area (south Kedah) in July 1956. Journal of the Malayan Branch of the Royal Asiatic Society 33 (1), 209—213.

Shukri, S.M., Wahab, M.H., Amat, R.C., Taib, I., Rozaly, M.Z.M., 2018. Definition and physical attributes that characterise settings of Malay royal towns in Malaysia. Int. J. Eng. Technol. 7 (3.9), 55—58. https://doi.org/10.14419/ijet.v7i3.9.15274.

Stuiver, M., Reimer, P., 1989. Histograms obtained from computerized radiocarbon age calibration. Radiocarbon 31, 817—823.

Sullivan, M., 1958. Excavation in Kedah and province wellesley, 1957. J. Malays. Branch R. Asiatic Soc. 51, 188—219.

Suzuki, T., 2019. The History of Srivijaya, Angkor and Champa. Mekong Publishing Co., Ltd.

Taha, A., 1983. Recent archaeological discoveries in peninsular Malaysia 1972-1982. Journal of the Malayan Branch of the Royal Asiatic Society 56 (1), 47—63.

Taha, A., 1991. Perkembangan sejarah awal negeri Kedah berdasarkan penemuan bahan-bahan arkeologi [development of the early history of the state of Kedah based on the finding of archaeological materials]. In: Documentation of the Kedah Darul Aman State Historical Convention. Kedah. Kedah State Museum Board, pp. 20—28.

Talib, N.K., 2009. Laporan Awal Penggerudian Sungai Batu, Lembah Bujang, Kedah [Preliminary Report Core Drilling of Sungai Batu, Bujang Valley, Kedah]. Universiti Sains Malaysia, Penang.

Tatumi, S.H., Rossetti, D. de F., Soares, E.A.A., 2020. Optically Stimulated Luminescence (OSL) Dating in the Amazonian Wetlands, first ed. Cambridge Scholars Publishing.

Thilakavathy, M., 2019. SANGAM TAMILS: with Special Reference to Pattinapalai. MJP Publishers.

Tibbets, G.R., 1979. A Study of the Arabic Text Containing Materials on South East Asia, 44. E.J. Brill, Leiden, pp. 1—305.

Tjia, H.D., 1995. Sea Level Changes in the Tectonically Stable Malay-Thai Peninsular. Petronas Research and Scientific Services, Selangor.

Tjia, H.D., 2009. Aspek Geologi Kuaternari Asia Tenggara [Aspects of Quaternary Geology of Southeast Asia]. Malaysia Nasional University Publisher, Bangi.

Waikato Radiocarbon Dating Laboratory, 2017. AMS Processing Technical Report. The University of Waikato, New Zealand, pp. 1—13.

Wales, Q.H.G., 1940. Archaeological research on ancient Indian colonization in malaya. Journal of the Malayan Branch of the Royal Asiatic Society 19, 1—87.

Wales, Q.H.G., 1976. The Malay Peninsular in Hindu Times. Bernard Quaritch Ltd., London.

Wheatley, P., 1961. The Golden Khersonese. Malaya University, Kuala Lumpur.

Yatim, O.M., 1978. Oriantal ceramic find in west Malaysia: a study of their distribution and typology. In: Unpublish Master Dissertation. University of Durham, England.

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, Universiti Sains Malaysia, Penang, Malaysia.

Zakaria, K., 1989. Lembah Bujang: kompleks percandian Bukit Choras, Kedah darul aman: laporan awal [Bujang Valley: Choras Hill archaeological complex, Kedah darul aman: a preliminary report]. Malaysia Journal Arkeology 2, 25—46.

Zakaria, I.I., 2014. Kajian Arkeologi di Tapak Jeti SB2B dan SB2D, Kompleks Sungai Batu, Lembah Bujang [Archaeological Study at SB2B and SB2D Jetty Sites, Sungai Batu Complex, Bujang Valley]. Unpublish Master Dissertation, Universiti Sains Malaysia, Penang, Malaysia.