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ORIGINAL PAPER

GEOPHYSICAL APPROACH TO IDENTIFYING ANCIENT IRON AT SUNGAI BATU, BUJANG VALLEY, KEDAH, MALAYSIA

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ABSTRACT

Archaeological evidence has demonstrated that the Bujang Valley is Malaysia's richest archaeological site and served as the primary coastal centre. A study in the Bujang Valley found monuments related to trading activities and others that functioned as a temple related to the Hindu-Buddhist period. The main purpose of this study was to resolve issues and problems arising from previous studies related to the Bujang Valley civilisation, particularly in terms of iron studies. Geophysics plays a vital role in assisting archaeologists to obtain excellent preliminary results before they proceed with excavation and digging works. Therefore, the 2-D resistivity and ground-penetrating radar (GPR) methods were conducted to locate and map the potential iron smelting site at Site B2 (SB2). Three main characteristics that can be observed on the surface are a mound area, exposed clay bricks and surface finds. Two-D resistivity showed the resistivity values of a possible buried structure, with values > 800 Ωm. Radargram profiles showed the highest amplitude, indicating the reflections uncovered in the location in certain survey lines. This paper presents the first summary of research on the metallurgical sites in the Bujang Valley, the most important site in Malaysia. Geophysical methods, which rely on a physical contrast between buried archaeological features and the properties of the surrounding subsoil, can assist archaeological investigations.

1. INTRODUCTION

Bujang Valley, also known as Kedah Tua, is believed to be the earliest entrepot and religious centre in Malaysia. It is located near Merbok, Kedah, between Gunung Jerai in the north and Muda River in the south. Sungai Batu is located in the Bujang Valley civilisation. Archaeological findings on the site, such as the discovery of Hindu-Buddhist temples, shattered ceramics and many other artefacts associated with trade, demonstrate its importance (Backus et al., 1969). Furthermore, Sungai Batu provides the earliest evidence of a monument (with chronometric dates) in South-East Asia, based on the influential discovery of a monument dating from 110 CE. This study aimed to locate a buried structure in an area of Sungai Batu with significant archaeological potential (SB2A) using 2-D resistivity and Ground-Penetrating Radar (GPR).

Studies on the Bujang Valley civilisation began more than a century ago. Since then, over 80 sites have been found. Most of these are associated with the site of a candi (temple) and an entrepot. Preliminary studies began when James Low accidentally discovered the remains of a candi and stone inscriptions at Seberang Prai in the 1840s. After this discovery, more researchers began conducting studies in the Bujang Valley, among them Evans, Quartrich Wales, Dorothy Wales, Treggoning, Sullivan, Peacock and Lamb. Studies in the Bujang Valley have found monuments related to trading activities and those which functioned as candi related to the Hindu-Buddhist period. The site's role is demonstrated by the archaeological evidence, such as the discovery of a site of a Hindu-Buddhist candi, statues, broken ceramics, beads, porcelain and many other artefacts connected with trade (Wales, 1970, 1976; Wheatley, 1961; Lamb, 1980; Leong, 1973; Adi, 1991; Supian, 2002; Nik Hassan Shuhaimi, 1990, 2008). The importance of the Bujang Valley as an entrepot was proven through Chinese, Indian and Arab records (Wheatley, 1961). The Bujang Valley is located in the middle of the route between two great trading cultures, namely China and India (Nik Hassan Shuhaimi and Othman, 1992). Its strategic location resulted in traders landing at the Bujang Valley while waiting for a change of monsoon (Allen, 1988). Three main rivers formed important trade routes, namely the Muda, Merbok and Bujang Rivers.

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Geophysical methods have been proven to assist in archaeological investigations. Geophysics is a type of underground mapping that is commonly employed for archaeological purposes. These studies began in the mid-nineteenth century, when archaeologists discovered that underground remains could be detected using geophysical methods on the surface. The fundamental interest in archaeogeophysics is diverse geophysical approaches, which are now playing an increasingly essential role. Compared to other regions, Malaysia has few integrated studies of the archaeological application of geophysical methods. Thus, more efforts and initiatives are needed to expand the contribution of geophysical studies.

Along the Nile valley in Egypt, valuable human heritage items can be found that extend thousands of years back into history. Unfortunately, due to natural and man-made circumstances, several of these monuments suffer from bad conditions. Khalil et al. (2016) focused on applying the stochastic method of simulating ground motion in historical time during the Cairo 1992 earthquake at Zoser pyramid. This method is used for its effectiveness, low computational efforts and the faster production of reliable simulation results when applied to engineering applications. The research determined the response characterisation of the site using the HVSR technique, with the results of this work being highly important in the future understanding of the area's behaviour during earthquakes, especially taking into consideration the importance of this heritage area for national income. Ground motion parameters obtained from the current study showed that the ground motion from the focus area of the Cairo earthquake was expected to be high. Besides that, other work by Khalil et al. (2015) was motivated by similar efforts, with a focus on the potentiality of using the spectral ratio method (HVSR) to define subsurface monuments. Microtremor measurements were performed at 15 sites distributed in front of the southern side of the Zoser pyramid region to calculate the HVSR. The array shape and dimensions were chosen based on prior information about the location and extension of the tunnel underneath. The amplification spectra were evaluated for the soil columns at each site location, while the fundamental frequency and peak amplitudes obtained were contoured, showing some low value trends at the area adjacent to the southern gate. This indicates that the HVSR method could be employed to explore subsurface monuments.

Geophysical methods were used to identify an interesting archaeological site that includes various artefacts, at Kampung Sungai Mas in Kuala Muda, District of Kedah. Since the early 1980s, this site has yielded several significant and intriguing archaeological finds related to the history of the Bujang Valley. Archaeological teams from USM, UKM and the Malaysian Museum Department discovered several remains in the village, including low mounds of laterite block and brick foundations for structures. A 2-D resistivity method using a dipole-dipole array was used to study the artefacts and locate archaeologically significant anomalies in the area. The findings suggest that 2-D resistivity can be utilised to successfully reveal archaeological anomalies like shallowly buried artefacts in the area (Samsudin and Hamzah, 1999).

Shyeh et al. (2014) explained how archaeological evidence was detected utilising the GPR method at the SB2K site, Sungai Batu, Lembah Bujang, Kedah, Malaysia. The main objective was to locate possible buried archaeological evidence. The research site was SB2K, which covered approximately 12 m × 11 m. A GPR cross-section of south-north survey lines was produced, which was presented through 3-D GPR data processing. Three lines were discovered to have potential anomalies at depths of 0.5 m to 0.9 m. The anomalies were caused by the presence of a small archaeological artefact entombed beneath the observed location. GPR successfully identified a potentially historical archaeological sample buried beneath the earth but was unable to differentiate each anomaly by specific types such as iron slags, pottery, freshwater shells, beads and ceramics. Further examples of successful non-invasive geophysical, seismic refraction and magnetic applications were conducted by Alashloo et al. (2011) at Sungai Batu Archaeological Site, Bujang Valley, Kedah, to detect buried artefacts and specify subsurface geological properties. The seismic refraction method was undertaken for two profiles, S_1 and S_2, using a 24-channel seismograph. The profile S_1 was comprised of two layers, the first of which had a velocity of 250 to 400 ms^{-1}, while the second had a velocity of 1650 to 2000 ms^{-1}. The profile S_2 had the same range of wave velocity as that of the profile S_1 in two layers, with the depth of the first layer ranging from 1.2 m to 3.3 m. The results suggested that no anomaly had been caused by archaeological structures over the seismic profiles. Magnetic measurements were taken in 15 profiles using a G-856AX proton precession magnetometer with a 5 m sampling interval along parallel survey lines spaced 10 m apart. Two anomalies with high magnetic values could be related to ruins of historical mud brick structures. Mud brick construction ruins have been discovered during archaeological excavations in some parts of the anomaly and the nearby site, thus supporting this analysis. Archaeologists performed an excavation test, which indicated the ruins of an old building in correspondence with these anomalies. The use of seismic refraction and magnetic methods in archaeological research has produced further information to which archaeologists can refer during future site investigations.

The findings from those studies demonstrate that Kedah Tua was a maritime trade centre or entrepot. The remapping of the Bujang Valley in 1987-1988 recorded eighty-seven archaeological sites identified to have served various functions (Allen, 1988). As many as eighteen of these are estimated to be trade markets, based on evidence such as ceramics and

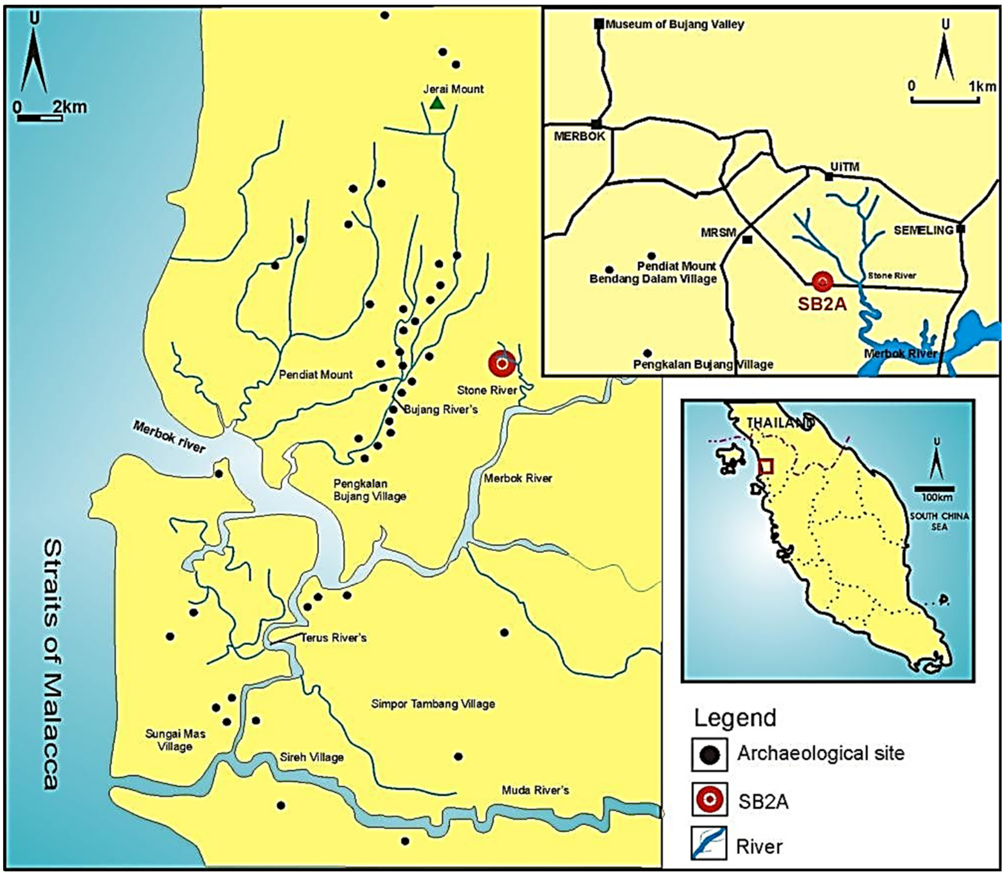


Fig. 1 Location of SB2A in Sungai Batu, Bujang Valley (Mokhtar, 2012).

beads. However, no findings or studies in the Bujang Valley have unearthed evidence of iron smelting activities, although historic documents mentioned ancient sword-making locations, in addition to those in Yemen and India (*Hindi*) (Mokhtar, 2011; Singaravelu, 2011; Hoyland and Gilmour, 2006). The locale has been referred to by various names: *Kataha* is Sanskrit and three names are Tamil. Of these, *Kadaram* and *Kidaram* are variants of the same word, which has the same meaning as *Kataha*. *Kalagam*, meaning 'black', is synonymous with *Kadara*, also Sanskrit, meaning 'tawny' or 'dark brown'. This is represented as 'black iron' and it has been claimed that this is related to high-quality ores (Braddell, 1989).

Therefore, the main purpose of this research at the Sungai Batu site was to address issues and problems raised by previous studies related to the Bujang Valley civilisation, particularly in terms of iron studies. This study was also conducted to prove an early hypothesis that the Sungai Batu area formerly served as an essential complex for the community (Mokhtar, 2012). This hypothesis was based on the findings from a survey of 97 potential archaeological sites in the Sungai Batu area.

Due to the critical historical importance of remains in the Bujang Valley, extensive work must be undertaken to provide a proper record and procedures for preserving this aspect of Malaysian history. The results were interpreted using geophysical data (2-D resistivity and ground-penetrating radar) as a preliminary study; archaeology observations of features such as a mound area and exposed clay bricks on the surface; and previous information on the site. Using these methods, features with contrasting electrical properties to those of the surrounding material could be located and characterised in terms of their resistivity, geometry and depth of burial. In particular, the application of the 2-D resistivity and GPR approaches allowed the researchers to obtain subsurface images of the cross-sections of the bearing soil, whose complex layers and structures clearly show the presence of eventual anomalies. Hence, fully implementing these geophysical techniques will aid in locating, mapping and characterising ancient artefacts.

2. STUDY AREA

The earliest archaeological sites discovered in Malaysia are those near the north-west coast of south Kedah (Fig. 1) (Sapiai, 2011). These have been extensively investigated, first by Quaritch Wales before the Second World War and more recently by Lamb (1980) and Jacq-Hergoualc'h (2002). Wales, writing about the most substantial temple remaining, Candi Bukit Batu Pahat, remarked that the most notable feature '*as indeed of all Kedah temples, is the extreme lack of ornament, beyond a few plain mouldings'* and pointed to a Kedah-Pattani land route for the transport of goods between the two sides of the

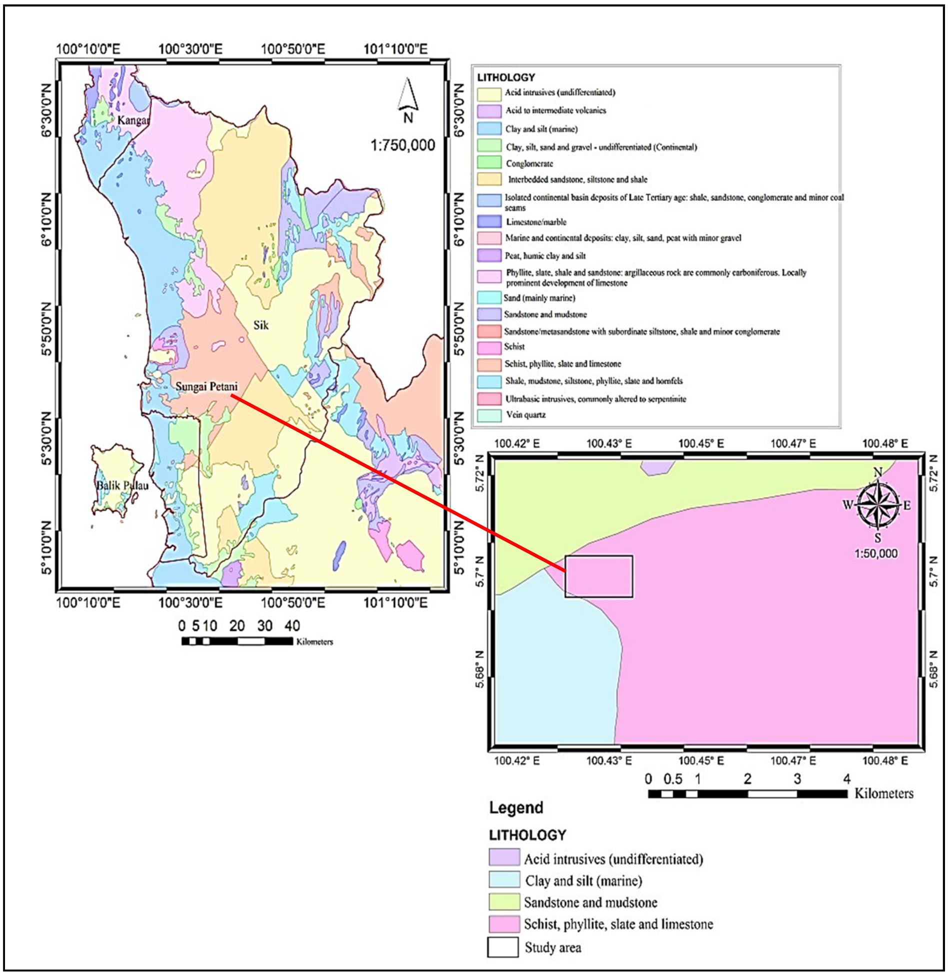


Fig. 2 The geological map of Kedah and study area at Sungai Batu, Lembah Bujang (Minerals and Geoscience Department Malaysia, 1985).

peninsula (Dumarçay and Smithies, 1998). This place is known as the Bujang Valley.

The Bujang Valley is a highly significant archaeological site in Malaysia. Since the middle of the first millennium CE, the influence of Indian Hindu-Buddhist civilisation in South-East Asia has been undeniable, and it can be found almost anywhere except in the remote and forested interior of the mainland or in the eastern islands of Indonesia and the Philippines. From this time onwards, there was a growing acceptance of Hindu and Buddhist cults, as evidenced by archaeological finds of numerous religious monuments and icons, the latter imported from India or modelled after Indian prototypes (Glover, 2000).

The geophysical study was conducted near the SB2A site, within an area measuring 575 m^2. The site was proposed as part of a plan to select the smelting location, which was based on the location being close to the river and the richness of raw material resources (iron ore, clay and fuel). Rivers were the main ways to transport iron ore and transfer fluffy iron, in addition to meeting the basic needs of smelting activities. The sedimentation process of the river environment also influenced the selection of iron smelting locations.

3. GEOLOGY OF THE STUDY AREA

This study was undertaken in various study areas in Sungai Batu, Bujang Valley (Kedah). The Bujang Valley descends from Kedah Peak (Gunung Jerai), stretches southwards towards Sungai Muda and Cherok Tokun in Seberang Prai, and rolls gently to meet the Straits of Melaka in a westerly direction. It is drained by two principal rivers, the Merbok and Muda. Gunung Jerai, peaking at 1,300 metres, is the highest landform in the area. To the north of Lembah Bujang is Bukit Choras. This is Malaysia's richest archaeological area, covering approximately 224 km^2 (Bradford, 1972). The western region of Gunung Jerai is made up of granite, while the rest of the mountain is composed of sedimentary materials.

The Sungai Batu area is mostly comprised of sandy clay covered in fine sand. The geomorphology of the Sungai Batu area is mainly flat, with rubber trees and oil palm fields. It is covered with rivers and small streams, with swampy areas in the eastern part of the study area. The geological map of Sungai Batu is shown in Figure 2.

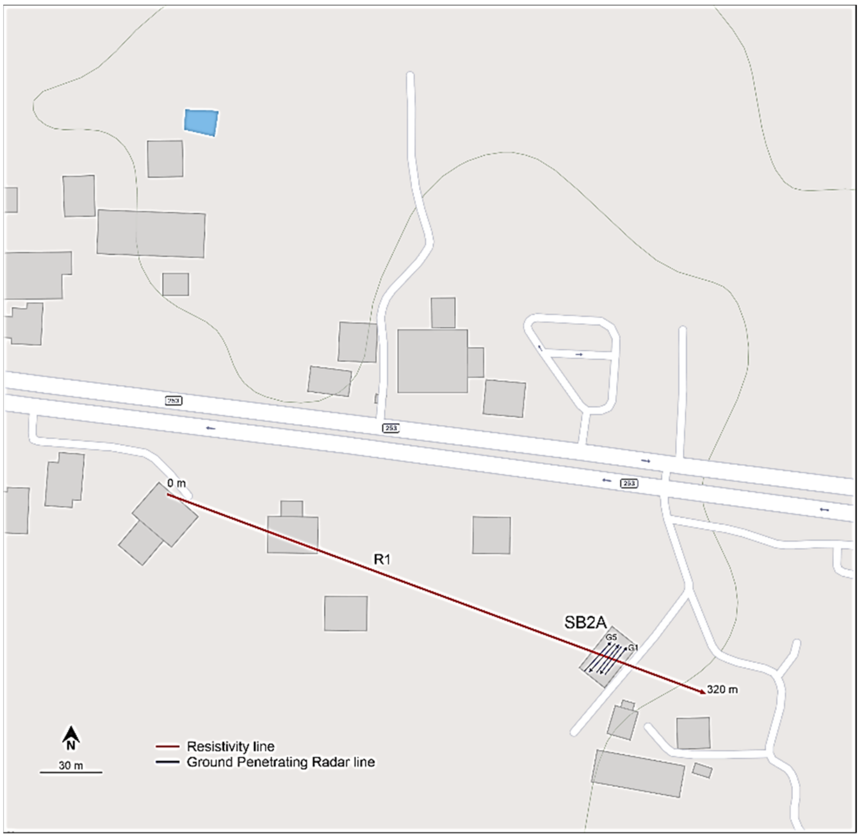


Fig. 3 2-D resistivity and GPR survey lines in the study area of SB2A.

4. IRON

The presence of iron deposits in the Gunung Jerai area has long been known. Scrivenor (1919) mentioned veins of magnetite on Gunung Jerai, and Willbourn (1926) referred to haematite deposits on a small hill close to milestone 26 on the Alor Star – Sungai Petani road. The hill, known locally as Bukit Ahan, is located some three miles northwest of Smiling at the back of Bukit Tupah Estate. It was prospected for iron by a Japanese company between 1932 and 1934. Apart from some haphazard production during the Japanese occupation, no mining of iron ore was undertaken in Kedah until 1955. From then until 1963, the production of the few companies in the Gunung Jerai area amounted to a total of 1.75 million tons and continued until 1972 (Bradford, 1972).

5. METHODOLOGY

Two geophysical methods were used in this survey area (SB2A): 2-D resistivity and GPR (Fig. 3). The former was conducted as a preliminary study, while the latter focused on the mound area. The selection of the mound area was made due to the exposed surface finds. Ground resistivity is a function of various geological factors, such as porosity, mineral content and the degree of water saturation in the rock. Therefore, variations in resistivity values may indicate changes in layering, composition or contaminant levels (Loke, 1994). Ground-Penetrating Radar (GPR) is a geophysical method that employs radar pulses to determine points in the subsurface. A typical GPR setup includes a transmitting antenna and a receiver antenna. The former transmits electromagnetic waves with a fixed frequency into the subsurface. The receiver antenna accepts a portion of the energy reflected by variations in the material properties of the subsurface; the amplitude of this response is recorded for mapping purposes.

5.1. ARCHAEOLOGICAL OBSERVATION

Based on archaeology observations, two significant features of the Sungai Batu area can be identified as potential archaeological sites: a mound area and exposed samples on the surface. Figure 4 shows the view of the mound at the SB2A site before digging began. The highest topography values were found between 1.0 and 2.0 m. Surface finds, as illustrated in Figure 5, were scattered extensively across the mound area, contributing to the evidence suggesting that this place would be an interesting site. Similar discoveries made in Sriksetra and Ban Don Phlong dated from before Sungai Batu. An excavation of the Tabet-Ywa iron smelting site located in Sriksetra revealed a two-metre deep mound of iron slag covering an area of fourteen thousand square metres, which dated from the first to the third century CE (Hudson, 2012). The iron blooms were produced

Fig. 4 View before excavation work at site SB2A mound, while the geophysical study was still ongoing.

Fig. 5 Surface finds in SB2A that can be seen all over the mound. This sample was later identified as tuyère, a nozzle through which air is forced into a smelter, furnace, or forge.

by burning a mixture of charcoal and haematite in furnaces, and they were probably forged into nails and other hardware (Hudson, 2012). The remains of iron smelting activities in Ban Don Phlong, north-eastern Thailand, included ellipsoidal and oval furnaces, a large amount of iron slag, tuyères and potsherds (Nitta, 1997).

5.2. 2-D RESISTIVITY

2-D resistivity is a non-destructive method that is highly useful to archaeologists who wish to preserve cultural heritage. It allows researchers to obtain detailed images of the lateral as well as vertical distributions of the electrical resistivity within the relevant portion of the subsurface. It employs advanced, efficient and reliable inversion 2D algorithms. The data acquisition was conducted using a Terrameter ABEM SAS4000 system and performed using Pole-dipole array configuration. This array configuration is moderately sensitive to both horizontal and vertical structures. Pole-dipole (short) and Pole-dipole (long) arrays were combined with a minimum electrode separation of 2.5 m. The lines were extended using the roll-up technique. The resistivity survey was conducted as a preliminary study before the excavation work started. The Pole-dipole array has relatively good horizontal coverage and is more sensitive to vertical structures, while the signal strength of this array is higher than the other array. The raw data was converted and processed using RES2DINV software (Loke, 2004).

The computer program automatically subdivided the subsurface before applying a least-square inversion scheme to convert the apparent resistivity values into true resistivity values and determine the appropriate resistivity values to use for geological interpretation (Loke, 1999). Later, the inversion results were output into Surfer 8 software for gridding, contouring and mapping. Finally, the inversion model of the 2-D resistivity obtained from this survey was correlated with the buried subsurface structures.

5.3. GPR

GPR can be applied to obtain a detailed interpretation, and this approach can assist considerably with surveying sensitive archaeological sites remotely and non-destructively. Targeting what to excavate saves time and money and it protects fragile artefacts. GPR can also aid investigations comparing a site's natural soils with its archaeological components. GPR can pinpoint the optimal places to excavate and indicate which areas should be avoided. In Sungai Batu, GPR could be used to produce a more localised survey across discrete features to better understand their sizes and depths, as well as determine if the anomalies are intact and if a cellar hole is filled with rubble or clean material.

The dielectric permittivity parameter is used in the GPR method. Since this method employs electromagnetic waves, the signal is reflected on the surface when it encounters different subsurface materials with varying dielectric permittivity (Reynolds, 1997). The conductivity of the geological media also influences the GPR method. The depth of penetration is limited, especially for subsurfaces with conductive unconsolidated sediments like clay (Loke, 1999).

For the GPR method used during this survey, the antenna was the 250 MHz shielded antenna with 360 mm antenna separation. Five survey lines were created in a gridding manner and in perpendicular directions, with various line lengths from 50 m to 110 m in the vicinity of a mound at the SB2A site (Fig. 3). The sampling interval was 2.5 cm between successive traces. The data processed using the Ramac GroundVision V.1.3.1 software took the form of a radargram. This software functions by generating more perceived images utilising common filters such as the Band Pass filter, DC Removal and Time-Varying Gain.

The background removal filter was applied by running average background subtraction to the data to remove the horizontal banding in profiles like the system noise, electromagnetic interference and surface reflections. Time-Varying Gain was chosen, which is designed to provide a frequency response in the passband that is as flat as possible. It is used to shape a signal's frequency spectrum. Band Pass Filters are used to isolate or filter out specific frequencies within a given band or range of frequencies. The filtering application helps improve the signal-to-noise ratio and visual quality (Cassidy, 2009). The changes in amplitude of reflection will be interpreted as the geological signature.

5.4. EXCAVATION

The results of two geophysical methods showed potentially buried structures, leading to an excavation of the SB2A area. The whole excavation area covered 19 × 19 m2. The excavation of SB2A involved digging a mound approximately measuring 575 m^2. Each trench was defined by 1x1 m grids that were alphabetically named and sequentially numbered. The alphabet was used to label grids from north to south, whereas the number sequence was written from east to west. After the grid mapping of the site had been completed, excavation work began. Trenches were dug on a checker-board pattern, with the whole area opened up after the functions of particular sites had been identified. The excavation was undertaken in accordance with the spit system, in which each spit has a depth of 10 cm. In addition, other data was collected during the excavation, such as photos, stratigraphic data, sketches of artefacts and dating samples.

6. RESULTS

The resistivity survey, R1, and the GPR surveys, G1 to G5, were carried out on the M71 mound. The results from both geophysics methods were analysed by referring to the subsurface profile, with the inversion model of the resistivity interpreted from the contouring image. In contrast, the radargram image of the GPR method was viewed based on the level of the reflective wave contrast between the hyperbolic curve patterns for the materials at the subsurface (Muztaza et al., 2019).

6.1. 2-D RESISTIVITY

R1 was the most significant 2-D resistivity line in Sungai Batu, as it was carried out exactly on mound M71 at the SB2A site. Figure 6 shows a very shallow part from the surface to a depth of 4 m, where the values were 500 – 800 Ωm. This range is in the middle of the range of resistivity values identified in this study. The region has a middle resistivity value (relatively green colour) within 0 – 15 m, which could be associated with alluvium, sandy clay and boulders. Interesting anomalies were discovered in areas with high resistivity values ranging from 800 to 5,000 Ωm, predominantly at the top surface at a depth of 3 m, which were interpreted as possible buried structures. High resistivity values indicated the presence of a buried structure due to the incredibly powerful ceramic bonds formed by the effect of heat at a high temperature. According to Ismail (2020), the high resistivity values correspond to a building that remains, mainly located at a depth of up to 2.5 m. Taha et al. (2010) implied that high resistivity anomalies could be interpreted as shattered walls or limestone walls. Although the results show the great potential of proposing this area for excavation, the main aim of this paper was to focus on mound M17/ the SB2A area.

6.2. GROUND PENETRATING RADAR (GPR)

A total of five GPR survey lines were found in the SB2A study area. The GPR radargram images from G1 to G5 reveal several zones showing interesting anomalies, most probably iron (Fig. 7).

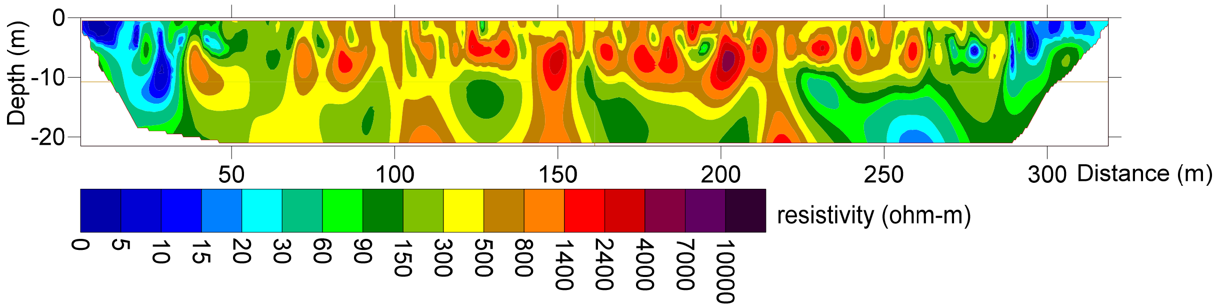


Fig. 6 The inversion model of R1 at Sungai Batu.

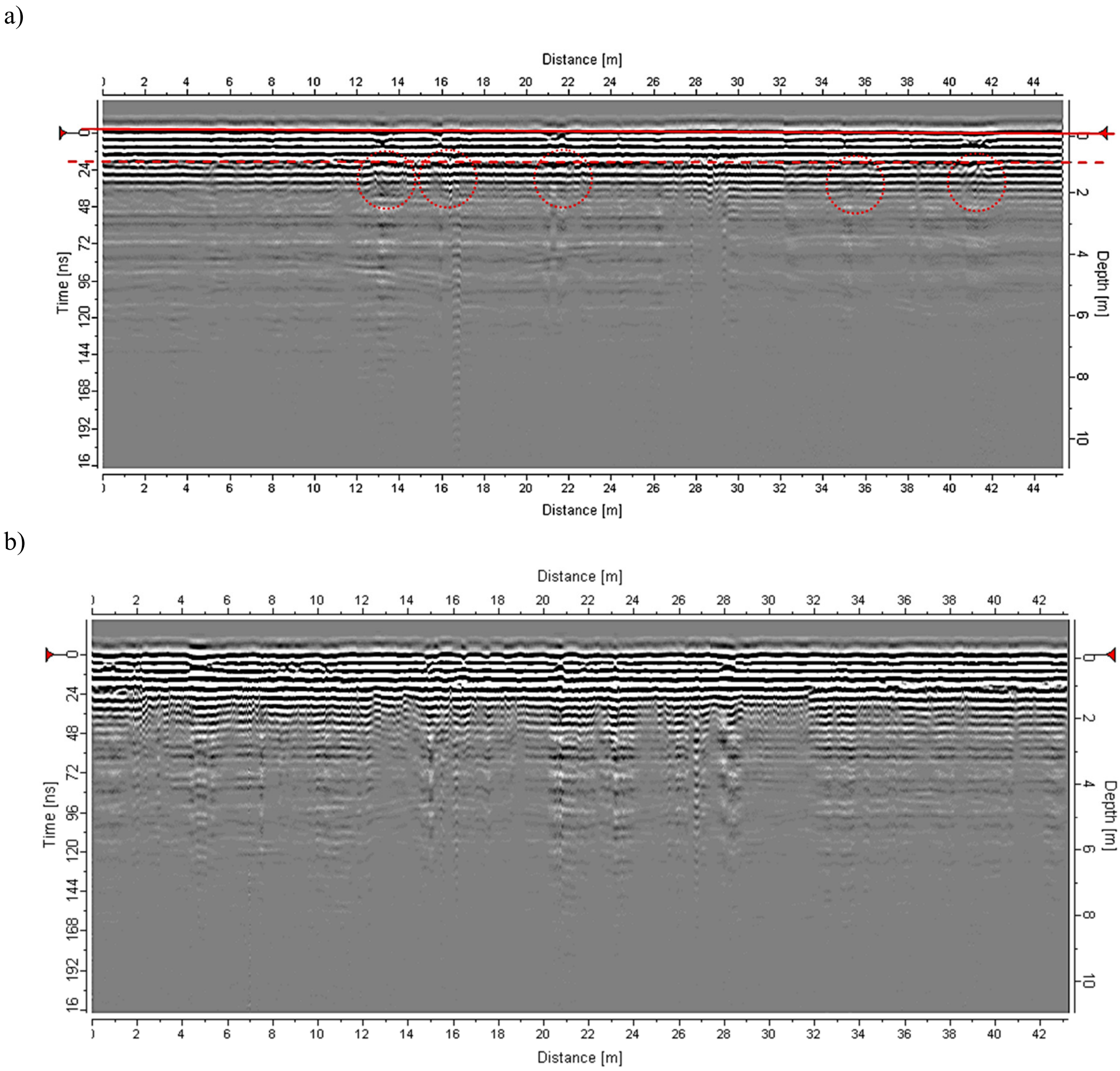
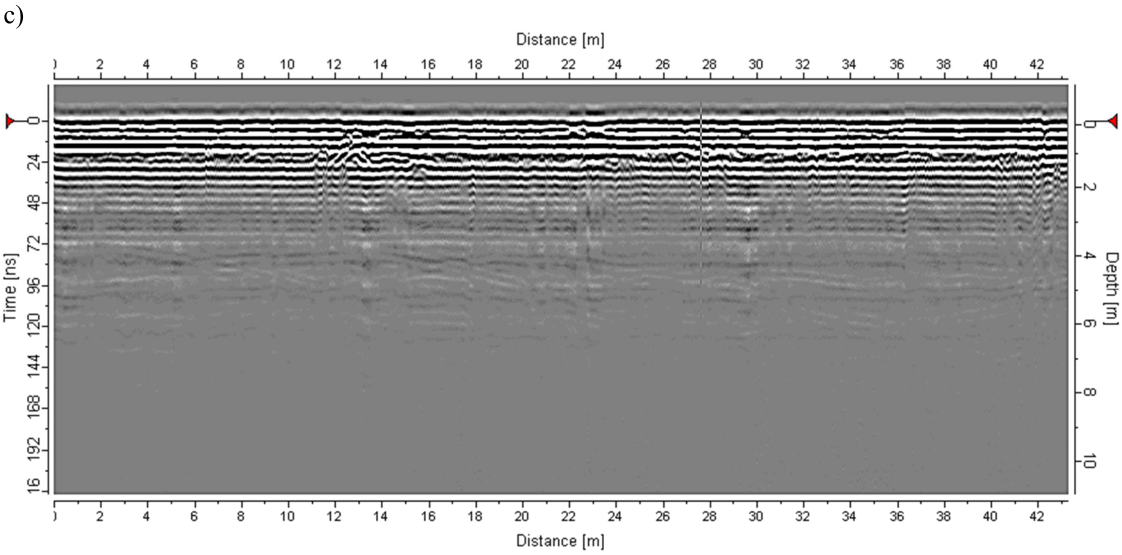


Fig. 7 GPR radargram images for the SB2A area from a) G1, b) G2, c) G3, d) G4, and e) G5. The distribution of the possible archaeological buried structure was marked with a red color.

c)



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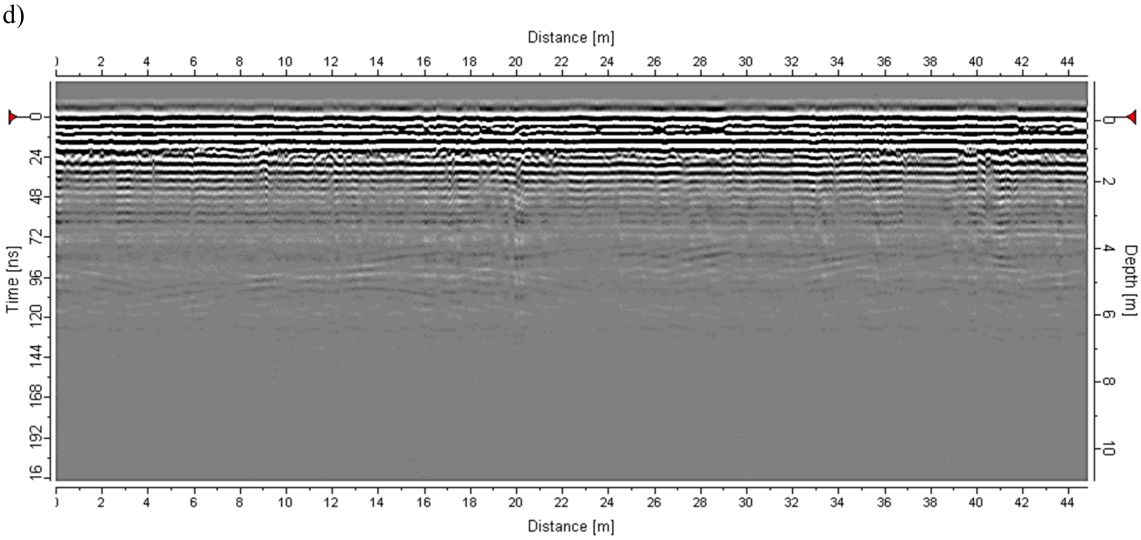

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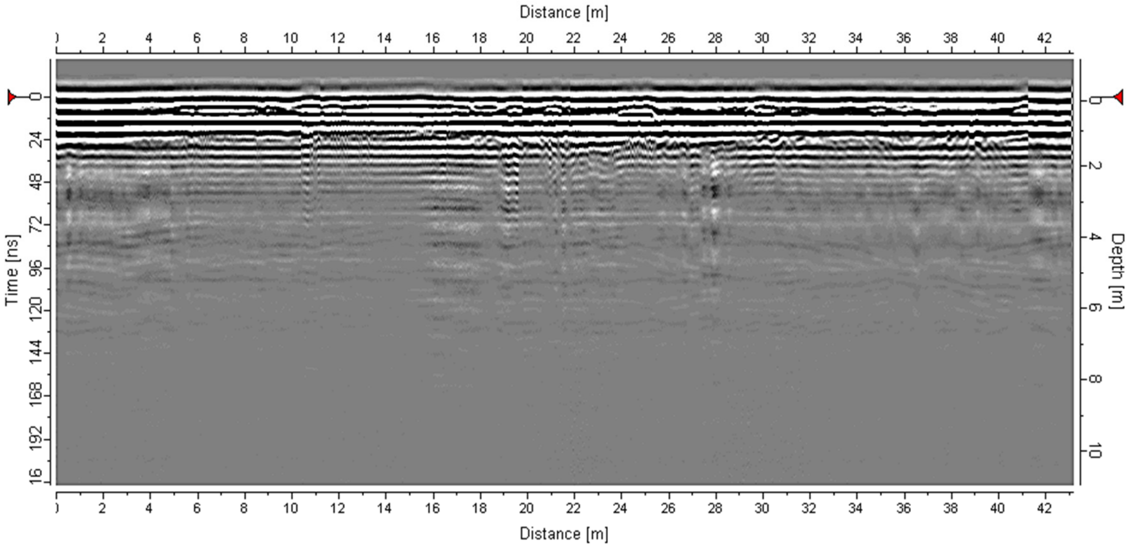

Fig. 7 Continued
(GPR radargram images for the SB2A area from a) G1, b) G2, c) G3, d) G4, and e) G5. The distribution of the possible archaeological buried structure was marked with a red color).

Potential anomalies were spotted, with red marks indicating the distribution locations of the possible archaeological buried structure, based on the reflective signals (Ismail, 2020). The triangular shape was interpreted as pipes, while the round shape could be iron. The radargram could only show the depth of penetration up to 2 m. The signals eventually faded due to radar wave attenuation (Teoh et al., 2018).

6.3. ARCHAEOLOGICAL EXCAVATION

The excavation at SB2A was implemented with the aid of 2-D resistivity and GPR interpretation. During the three months of excavation, 200 trenches were dug (Figs. 8, 9 and 10). In addition, trench O9 (marked in yellow) was used as a spit depth reference (Fig. 8).

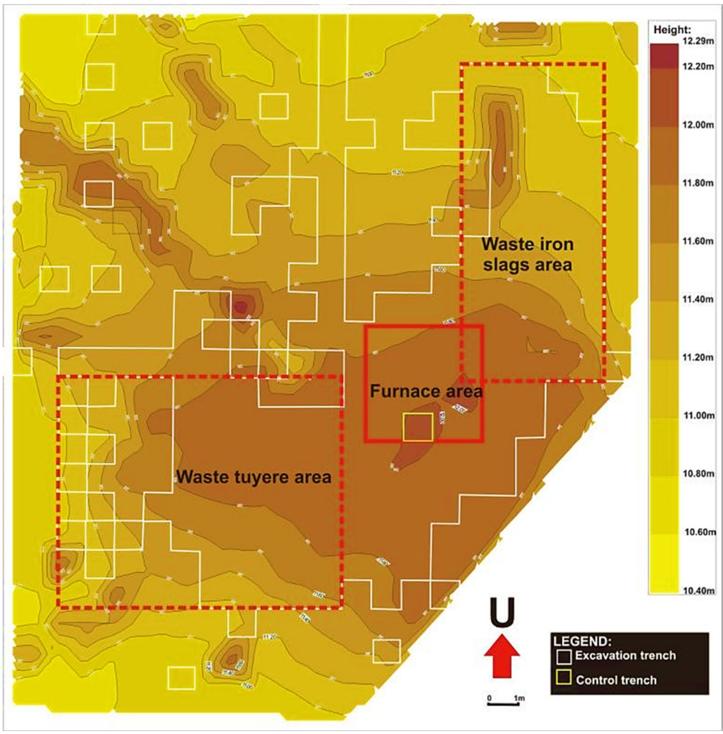

Fig. 8 Contour Map of SB2A

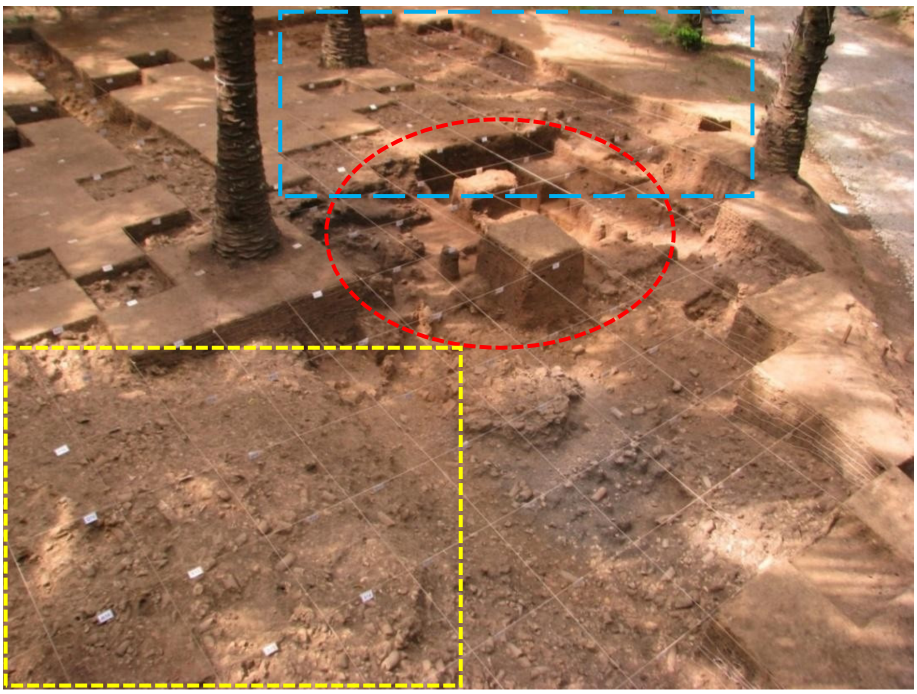

Fig. 9 SB2A from an upper view. (Yellow line indicates waste tuyère area, the red line shows the furnace area, and the blue line represents waste iron slags area).

Fig. 10 Iron slags area from an upper view. (Yellow line shows the distribution of iron slags, and the blue line indicates the tuyère area).

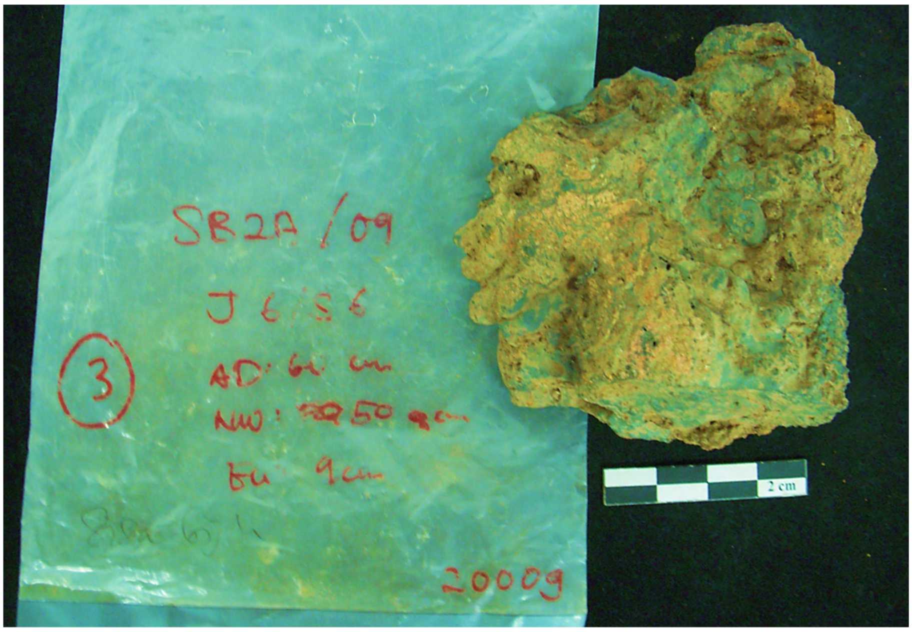

Fig. 11 One of the samples from SB2A site trench J6, identified as iron slag found at a depth of 60 cm from the ground.

Figures 11-13 show the artefacts found from the excavation at site SB2A, which support the high resistivity values from the 2-D inversion results and the reflective amplitude contrast from the GPR profiles. The archaeological findings - the ruins and artefacts found in the SB2A area - suggest that it served as a multi-functional building (port-industry) within the Sungai Batu complex. The location is believed to be an important building in the southern part of the Sungai Batu complex due to the huge scale of the building structures on this site and their proximity to the ancient river.

7. DISCUSSION

The materials identified within the subsurface features were determined by resistivity values (ρ) and

Fig. 12 At the SB2A site in trench J6, a fraction of tuyère associated with an iron remnant was discovered at a depth of 60 cm.

Fig. 13 Tuyère remains in site SB2A (Trench P15).

reflectivity amplitudes from the GPR profile. The depths of the anomalies were based on resistivity data and supported by the GPR sections. The clayey sand layer caused a severe attenuation of the electromagnetic signals used in the GPR surveys. Therefore, GPR may have a limited application in the study area. For the Sungai Batu area, the low resistivity range is < 100 Ω-m, the middle range is between 500 – 800 Ω-m, while the high resistivity range is > 800 Ω-m. The radargram images were observed to aim for various reflections that could be caused by archaeological buried structures.

The inversion model for R1 shows that the middle resistivity value (500-800 Ωm) lies within a depth of 0 – 15 m, which could be associated with alluvium, sandy clay and a mixture of boulders. This may be related to the monument's base, which is made of laterite or granite bricks. Laterite can be soft and brittle, or it can be firm and physically resistant. Indurate varieties are sometimes cut into blocks and used as brickstones for house construction. The term comes from a Latin word that later meant 'brick' or 'tile' (Sapiai, 2011).

Site SB2A revealed a complex smelting site, due to the finding of artefacts such as slags, iron ores and tuyères (Mokhtar, 2012). The average tuyère at this site is 13 to 16 cm in length, with a diameter of 8.1 to 11.5 cm. These small objects frequently appear on GPR radargram profiles.

Based on the artefacts discovered and the scientific analysis completed to date, it is accepted that the site served as an iron smelting area from the third to the fifth century CE. This is based on the discovery of furnaces, iron slags, iron ore, burnt clay, stone tools, tuyère, iron artefacts, beads, pottery, ash, charcoal and other similar items.

Table 1 Artifact finding at SB2A.

NO.	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	0.250
7.	Ceramic	0.008
8.	Beads	0.003
9.	Brick (?)	0.055
10.	Laterite	0.020
11.	Iron ore	4.700
12.	Iron slags	69.100
13.	Fragment of tuyère	25.410
	TOTAL	100.002

The preliminary analysis includes a classification of the artefacts (Table 1). The most common artefacts discovered are iron slags and tuyères. The artefact analysis found 1,742.5 kg (69.1 %) of iron slags, 867.4 kg (25.4 1%) of tuyères and 157.9 kg (4.7 %) of iron ore. These numbers represent artefacts that have been excavated; however, more are buried *in situ*. The iron slags found on this site have no particular form. The remaining iron has a dark colour and a dense, spongy texture. It has a metallic or rusty appearance. The iron ores found here consist of haematite and magnetite. The presence of laterite is associated with the iron ore (haematite and magnetite) brought to the site, and it had no significant role as a raw material for iron production.

A tuyère is used to allow air to enter a furnace with the force of bellows (Suchitta, 1983). A hole in the centre allows air to enter as the oxygen (O_2) supply and raises the temperature of the furnace. Most of the tuyères were found with remnants of liquid metal at one end (Fig. 14). The longest tuyère found here is 27.1 cm long and 11.2 cm wide. The central holes range in diameter from 2.1 cm to 3.6 cm. A tuyère would be affixed to the furnace wall at specific angles (Lee and Williams, 2002). The differences in angle affected the increases in pressure and temperature within the furnace (Lee and Williams, 2002).

Piles of bricks were also found on this site. The analysis to determine their features remains in progress. These clay bricks may have been used for the construction of the furnace. The brick locations indicated that they were used to line the furnace base. It is estimated that more than 100 pieces of brick have been found here. The maximum and minimum thicknesses of the bricks are 5.2 cm and 1.3 cm, respectively. Eighteen stone tools were also discovered, with analysis revealing one handaxe, six broken anvils, six hammer stones or mortars, and five unknown stone tools (Figs. 15 and 16). In addition, eight metal artefacts were found, consisting of a bronze ring, beads, blades, a circular piece of metal and a metal ring (Figs. 17, 18, 19, 20 and 21). Five unknown stones were likely used as polishing stones. A total of 676 pieces of pottery were found to consist of 610 body parts, 51 parts of rims and 15 others. Six beads and some shell remain were also found here.

Fig. 14 Tuyère.

Fig. 15 Handaxe.

Fig. 16 The broken of anvil.

Fig. 17 Bronze ring.

Fig. 18 Beads.

Fig. 19 Blade 1.

Fig. 20 Blade 2.

Fig. 21 Metal ring.

Stratigraphy revealed seven to ten layers of soil and cultural layers, beginning at layer 1, and demonstrated the presence of multiple layers at once. These differences occurred because of the various work activities and can be seen clearly on the stratigraphy of trenches P15-P9 and Q7-N7. The stratigraphy of trench P15-P9 shows how the work area (iron smelting activities) changes to a waste area for tuyères (Fig. 22). In contrast, the stratigraphy at trench Q7-N7 signifies the main area of iron smelting with datable results (Fig. 23).

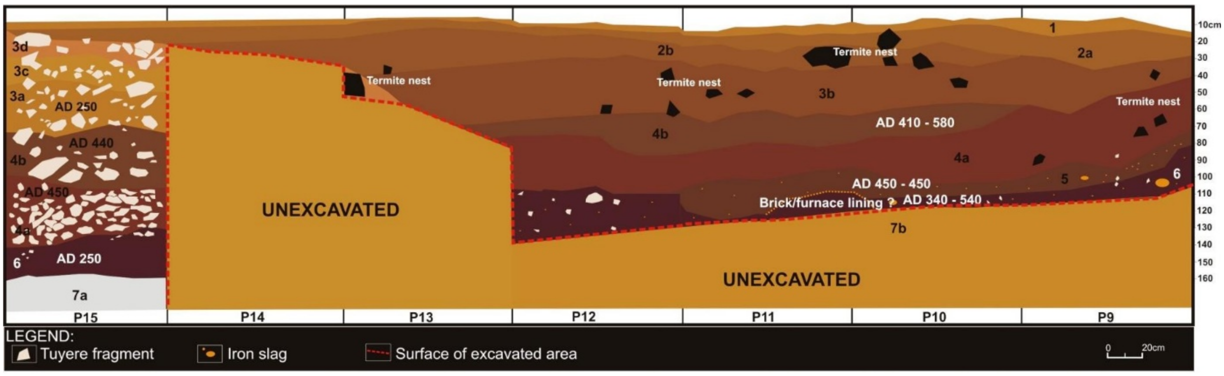

Fig. 22 Stratigraphy of P15 - P9.

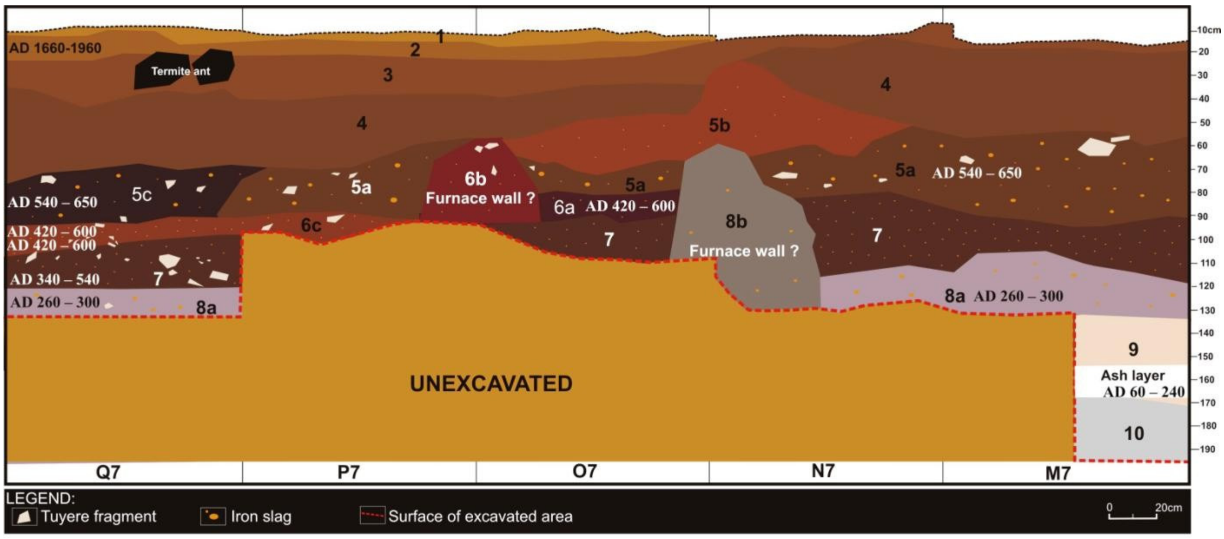

Fig. 23 Stratigraphy of Q7 – M7.

Radiocarbon, AMS and OSL (Optically Stimulated Luminescence) dating proved precisely that the site was actively used during the third to the fifth century CE (Figs. 22 and 23). Radiocarbon dating was conducted by sending charcoal and organic material found inside the trench to Beta Analytic Inc., Florida, while a sample of brick and tuyères was sent for dating to Korea Basic Science Institute, South Korea. The dating results show that the site was used from the first century CE (Beta-268001) until the 17th century CE (Beta-267996), indicating that SB2A is an important site in the Bujang Valley archaeology.

8. CONCLUSION

Based on the interpretation of the geophysical methods (2-D inversion resistivity and GPR results), SB2A clearly reveals evidence of major iron industrial works in Sungai Batu and the discovery of thousands of slags, iron ores and tuyères. The middle resistivity values (500-800 Ωm) could be associated with alluvium, sandy clay and a mixture of boulders. This could be related to the monument's base, which is made of laterite or granite bricks. Meanwhile, the higher resistivity values (> 800 Ωm) were interpreted as potential archaeological anomalies formed from high temperatures. The GPR data showed anomalies at depths of less than 3 m, based on the high reflective signals, probably from iron and pipes (tuyères), supported by surface and excavation findings.

Based on radiocarbon, AMS and OSL dating, SB2A was actively used from the third to the fifth century CE. However, the dating indicates that the site was in use since the first century CE (Beta-268001) until the 17th century CE (Beta-267996). Evidence was also found of iron artefacts and the remaining furnaces. Based on iron slags, this site underwent a bloomery process using tuyères and charcoal. However, no iron products were discovered at SB2A because these may have been traded elsewhere.

In the future, the integration of geophysical techniques can provide valuable data for archaeological mapping applications to validate the results. Furthermore, this approach is important for eliminating the uncertainty of subsurface interpretations; hence, more reliable subsurface models could be introduced. The SB2A site study has strengthened the archaeological data from Lembah Bujang in terms of the periodisation, economics and technology of iron smelting. However, a study of iron smelting experiments should be conducted in future to understand the iron smelting process in detail and subsequently complete our knowledge of ancient iron smelting techniques. These experiments should be undertaken using the same furnace and tuyere construction materials as those used in the past. In addition, when conducting a comparative study, the iron ore and fuel must utilise the same materials as those used by the historical society.

The iron source survey in this paper was conducted only in a small area of the study site. Thus, a survey study of the largest location of iron resources should be performed by expanding the study area. Besides, the mining operations of the early Sungai Batu communities need to be understood and proven to determine the process of smelting iron overall, starting from the mining process. Studies on fuel should also be carried out to identify the types of tree timbers used as timber charcoal. Ethnoarchaeological studies should also be conducted to complement the ethnographic data concerning the iron smelting activities.

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