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ORIGINAL PAPER

Reading the archaeometallurgical findings of *Yodhawewa* site, Sri Lanka: contextualizing with South Asian metal history

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Abstract
This study aimed to provide a chronological interpretation of the *Yodhawewa* settlement and interpret metalworking activities based on artifacts representing metallurgical technology in Sri Lanka and South Asia. The research data was based on a field survey, two vertical excavations, and six profile observations conducted in 2018. The radiocarbon (carbon 14) chronological results of the *Yodhawewa* research represented the first millennium (1^{st}, 4^{th}, and 8^{th} centuries) AD. Archaeological material on iron ore extraction, crucible steel, and copper-related productions was revealed during the study. This *Yodhawewa* research was the first to discover an ancient crucible-shaped (lower half-spherical typed) steel furnace in the northwestern dry zone of Sri Lanka. Besides, this study led to the first archaeological discovery that the "Bellow method" activated an ancient steel furnace in Sri Lanka. In addition to the metalwork, this site reflects significant archaeological materials on the global cultural relations associated with the *Yodhawewa* study area.

Keywords Crucible steel · Furnace · Iron smelting · Metalworking · Sri Lanka · *Yodhawewa*

1 Introduction

The *Yodhawewa* archaeological site can be introduced as a unique historical metal production place in the dry zone of Sri Lanka. The adverse effects of the civil war in the Northern and Eastern parts of Sri Lanka during 1983-2009 brought about significant cultural and geo-environmental changes in the *Yodhawewa* region. Archaeological sites have been accidentally opened to the environment due to rapid irrigation development projects in this region since 2009. The *Yodhawewa* archaeological site was discovered in October 2017 during a reconnaissance survey of ancient settlements around the *Yodhawewa* Reservoir (Giant's Tank), and it was observed that the artifacts were already displaced. However, some areas of the site were still unaffected. With the approval of the Director-General of Archeology Sri Lanka, the research team of the Department of Archeology and Heritage Management of the Rajarata University of Sri Lanka conducted a field investigation in 2018 to uncover more information on metal production and associated settlements. The study mainly provided information on metalworking and ancient foreign cultural relations in ancient Sri Lanka. The guideline for that investigation was the comprehensive narrative field notes obtained during the preliminary investigation about the site's location, physical nature, and scattered artifacts. This study aimed to provide a chronological interpretation of the *Yodhawewa* settlement and interpret that metalworking site based on artifacts representing metal technology in Sri Lanka and South Asia.

Three specific objectives were expected to be achieved in this research: *(a)* Giving a chronological definition to the *Yodhawewa* metalworking settlement, *(b)* Explaining the authentic metal usage, technical parameters, and resource utilization pattern of the *Yodhawewa* site based on artifacts of the field observation in 2018, and *(c)* Rendering the results with time and space by comparing the technical parameters of the *Yodhawewa* artifacts with the material culture of other metal workplaces in the South Asian region. The term "metalwork" was used here to refer to both the

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smelting and refining of metals, based on the results of the artifact found on the *Yodhawewa* premises.

1.1 Production of ancient Iron, Copper, and Steel in the South Asian context

Knowledge of the oldest iron production was used in northern India in the 2nd millennium BC, and with the gradual downward migration, it was used for the oldest ironwork in South India in 1800-1200 BC (Johansen 2014; Tripathi 2015). This primitive iron production was later uncovered in connection with the megalithic burial in Peninsular India and Sri Lanka (Srinivasan and Ranganathan 2004; Seneviratne 1984; Begley, Lukace, and Kennedy 1981). The earliest archaeological records parallel to the evidence discovered from South Indian megalithic burials of iron used in Sri Lanka were confirmed through Iron objects and slags in the Citadel excavation in *Anuradhapura* (dated c. 834-778 BC), *Aligala* (c. 998-848 BC) excavation in *Sigiriya* and *Pomparippu* megalithic burial site in *Vilpattu* wildlife reserve (Begley, Lukace, and Kennedy 1981; Deraniyagala 1992; Karunaratne and Adikari 1994). Juleff (1990, 1996b) and Solangarachchi (2011) provided detailed notes on the research history of Iron and Steel production in ancient Sri Lanka, citing the research and the reports of Knox (1681), Davy (1821), al-Kindi (the 1850s), Ondaatje (1854), Tennant (1859), Baker (1885), Coomaraswamy (1908), Parker (1909), Hadfield (1912), and Cooray (1967). Following this research, Juleff (1996a,b) described the iron extraction of the *Samanalawewa* (Fig. 1b) area of the Ratnapura District, based on the seasonal monsoon wind power through the west-facing technology in the 5th century BC to 12th century AD. The evidence of the magnetite iron ore extraction during the c. 3 rd century BC to c. 10th century AD in the *Sigiriya* area discovered from the Kiri Oya Basin (KOB) archeological research during 2004-2006 was significant in Sri Lanka (Solangaraarachchi 2011).

Iron technology is not closely related to copper and bronze metalworking in the Asian context, but traces of those metals are also not uncommon in many iron extraction sites (Seneviratne 1995). Neogi (1918) states that copper may have occurred between 2000 - 1500 BC and migrated to southern India around 700 BC. However, Seneviratne (1984) points out that copper/bronze technology was also used parallel to Iron in Sri Lanka, based on the metal artifacts related to the Megalithic burials in the 6th/5th cent. BC. In addition, a circular or semi-circular furnace discovered during the Citadel excavations in *Anuradhapura* (1969 and 1984) dates back to 200 BC. Deraniyagala (1972, 1986) points out that it may have been used for copper casting (perhaps alloying). Iron slag has also been used as a flux for smelting copper in South and Southeast Asia (Seneviratne 1995). Therefore, iron slag may be present in the area where the copper was extracted. It is assumed that copper slag found during the Mannar excavations (1980-84) was used to make copper alloys, and expected that copper had been transported to *Mannar* from the *Seruvila* copper deposit in Eastern Sri Lanka (Seneviratne 1995; Juleff 2013). Srinivasan (2016) opines that this Seruwila copper may have been used for *Mannar* and the South Indian copper demand. This assumption is correct because Sri Lanka does not have the tin (Sn) and zinc (Zn) metals required for bronze and brass alloying.

Crucible steel technology reflects a technological translation in iron production in ancient Soth Asia. The earliest evidence of semi-solid crucible steel production dates to 300 BC, mainly the *Kodumanal* megalithic site in Tamil Nadu of South India (Srinivasan 1997, 2013; Srinivasan and Ranganathan 2004; Sasisekaran and Raghunatha Rao 2001). Although no archaeological evidence has yet been obtained about Sri Lankan crucible steel production origin, Arab writers such as al-Kindi have reported the tremendous demand for Sri Lankan *(Sarandibi)* steel from the Islamic world in the 6th – 9th cent. AD (Juleff 1996b). Analyzing the excavation data in *Mannar* (1980-84), Juleff (2013) pointed out that high-quality steel produced in *Sarandibi* may have been exported through the *Mannar* port.

Metal is not the only substance that is handled and used to study metal origins and metallic uses. A clear cross-section of ancient metalwork can be created by focusing on the technical production environment used in the metalworking process, especially furnaces, crucibles, molds, lithic, tools, and fuel sources geological and environmental criteria (Hegde 1973). Workplaces of ancient metalworkers for the production of Bloomery iron, Cast iron, and Crucible Steel (Wootz) are more challenging to identify separately considering refractories, surrounding smelting debris, and other artifacts of metalworking settlements (Gullapalli 2009). However, significant assumptions can be provided regarding the site's use context through the material culture of such a workplace. Considering the morphological characteristics, researchers categorized the furnaces types from time to time. After Banerjee's (1965), and Mahmad's (1988) typologies, Srivastava (1999) presents the general classification for South Asian metal furnaces; Bowl-shaped, Dome-shaped, and Shaft-shaped (Gururaja Rao 1970; Prakash 2001; Saravanan 2017).

Constructed the West-facing bowl or shaft furnaces of central highlands *(Samanalawewa)* of Sri Lanka were made by oval, circular or semi-elliptical type (Juleff 1996b), and the shaft or domed bloomery furnaces of *Sigiriya* (*Dehigaha-ala-Kanda*) were the rectangular and circular shapes (Solangaraarachchi 2011). The front wall of both types of furnaces mentioned above was mainly straight. Moreover, the multiple Tuyeres connected front clay walls of both furnaces were ended with two upright stones at both ends. In such furnaces, it is common practice to break down the front

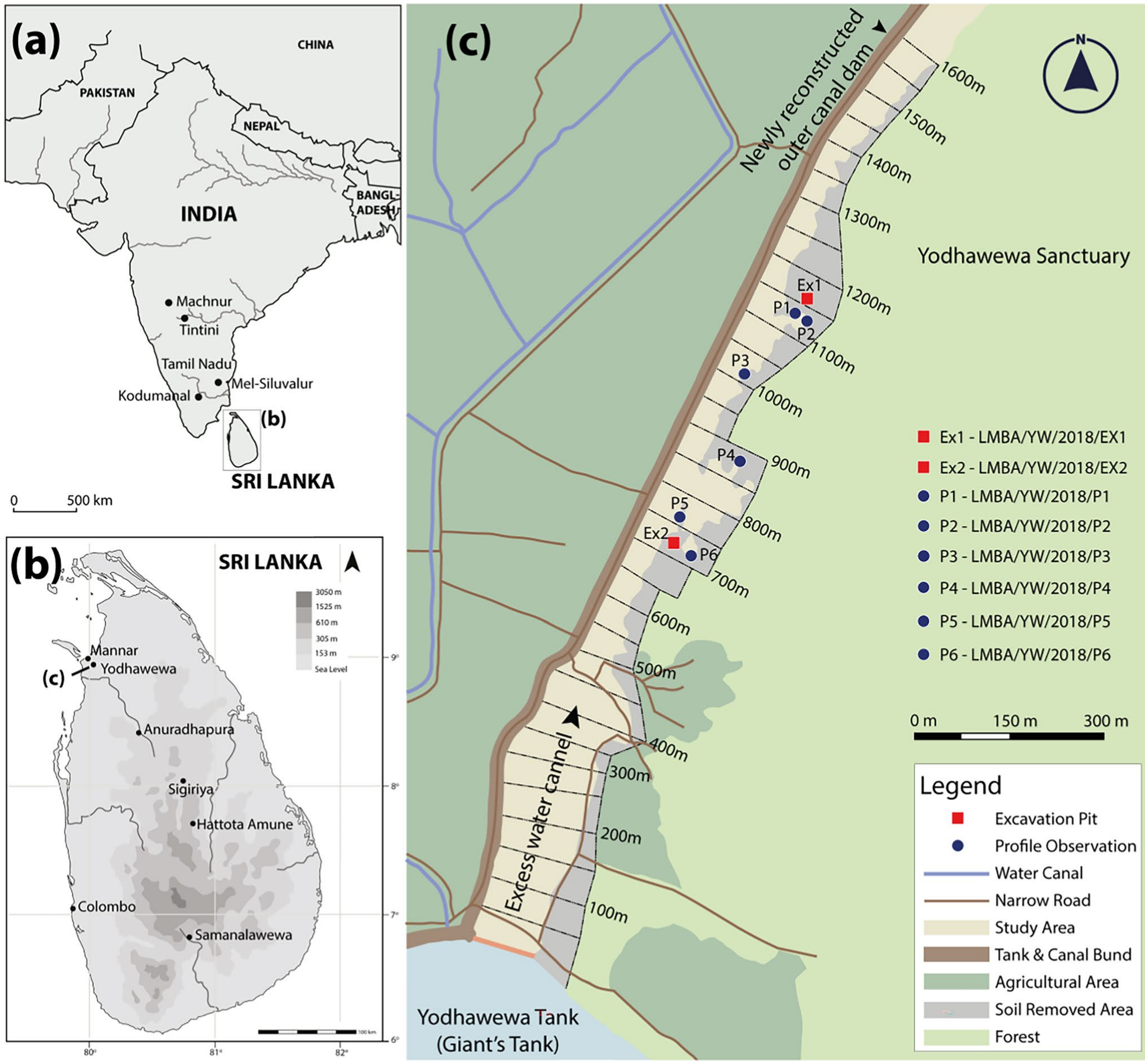

Fig. 1. (a) Sri Lanka is located South-East of India. The figure shows a few South Indian metal production sites described in the text (b) Location of the *Yodhawewa* site close to the Ancient *Mannar* Port including some specific metal production sites of Sri Lanka (c) The study area of the *Yodhawewa* Archaeological Site

wall to move out the result of the metal extraction process, but these upright stones are very useful in protecting the remaining parts when the same furnace was used repeatedly (Juleff, 1996b; Solangaraarachchi, 2011). Considering the other extracting debris from the Iron extraction site (400-300 BC) at *Banahalli* in *Karnataka*, a metallic iron slag cake was at the bottom of the bowl-shaped furnace. Besides, stone slabs near such a furnace indicate both smeltings and forging occurring at this site. One of the oldest Iron extraction circular furnaces (c. 700 BC) found at *Naikund* in the *Vidarbha* region were constructed using curved bricks made of refractory clay (kaolin), and the furnace chamber base was also made of bricks (Gullapalli 2009; Prakash 2001). Dave (1821) and Coomaraswamy (1908) points out that iron extracted furnaces for regional or personal use in Sri Lanka in the pre-modern time (19th - 20th centuries) were built on ore above the ground level (using clay) in rectangular or box-shaped (Juleff, 1990b; Solangaraarachchi, 2011).

There are clear examples from India of circular furnaces in terms of structural design. More than twelve (12) small circular furnaces associated with a sizeable oval furnace found (by 1985-1996 excavations) in the *Kodumanal* ancient metal workplace were used to make crucible steel/wootz (Gullapalli 2009; Sasisekaran and Raghunatha Rao 2001;

Sasisekaran 2002). An unearthed steelmaking crucible found in one of the furnaces has been cited as evidence of this fact. Thus, evidence of the crucible adjacent to the furnace in an ancient metalworking site is critical in identifying the crucible steel product furnaces. However, no information was revealed from Sri Lanka regarding the bottom circular crucible type furnaces until the *Yodhawewa* was discovered.

An adequate supply of air is an essential requirement for a metalworking furnace, and there is evidence that both natural and artificial methods have been used. Banerjee (1965) has found evidence from *Ujjain* excavations that blacksmiths used the Bellow method since c. 500-200 BC (Sasisekaran and Raghunatha Rao 2001), and it is reported to have been used in India until the 19th century (Sasisekaran 2002). That bellows method has been used in ancient metal furnaces in Sri Lanka, and Knox (1681), Davy (1821), Coomaraswamy (1908), and Parker (1909) have provided more detailed reports on such furnaces (Juleff, 1990; Solangaraarachchi, 2011). Apart from this, "Tuyers" and "Blowpipes" which supply air to the furnaces, are considered an essential factor in identifying metal furnaces in ancient times (Juleff 1996a, 1996b, 2015; Gullapalli 2009; Srinivasan and Ranganathan 2004; Johansen 2014; Solangaraarachchi 2011; Rehder 1994).

Steel-related crucible technology is the fundamental concept of the ancient carburization process in South Asia. The solid-state carburization of wrought iron was known as "steel or wootz." After the carburization process, the metal absorbs a high percentage of carbon in a crucible, enhancing the tools to achieve the required rigidity and sharp cutting edges when quenching and tempering (Srinivasan 1994; Prakash 2001; Feuerbach 2002; Woźniak 2011). Ondaatje (1854) and Coomaraswamy (1908) have provided eyewitness accounts of Sri Lanka's crucible-steel production in recent history (Juleff 1996b; Solangaraarachchi 2011), and most recently, a significant study has been carried out in the *Samanalawewa* area by Juleff (1996b).

Slag is the initial reaction to remove undesirable constituents (gangs) from metal ore and reactants (fluxes) as a liquid product at high temperatures (Davenport et al. 2002; Cooke and Aschenbrenner 1975). Slag is a solution of molten oxides and is usually present in the area where it is formed. Although slags have been identified primarily due to the smelting process, they can be formed by smelting ores, melting metal, remelting slag or metal, refining, casting, or forging metal in a metalworking site (Hauptmann 2014; Johansen 2014).

1.2 Unique antiquities that confirms Time and Space

Researchers have focused on strengthening chronological interpretations using comparative data from other material cultures, in addition to the absolute chronology, as the stratification of significant ancient metalworking sites in the South Asian region may vary significantly due to long-term utilization (Solangaraarachchi 2011; Juleff 1996; 2015; Srinivasan and Ranganathan 2004). Accordingly, the fragments of foreign ceramics and porcelain, and numismatics evidence, are also discussed here.

Black and Red Ware (BRW) is a unique type of pottery that was technologically developed from the Early Iron Age (related to the megalithic burial practices) to the historical period of India (Mohanty 2013). Despite some differences in typography and fabrics, the BRW tradition related to early Iron Age megalithic burial sites, regional and urban settlements, and port cities, with a total of more than 150 archaeological sites with BRW pottery found in Sri Lanka (Seneviratne 1984; Begley, Lukace, and Kennedy 1981; Dharmawardene 2015). However, as an extension of the Black and Red Ware pottery type, a "Fine Gray Pottery" tradition, including the Rouletted Ware (RW) type, develops in the South Asian region from 200 BC to 200 AD (Schenk 2006). These two types of ware fragments were homogeneous in shape and texture and were found in more than 150 places, mainly in the early settlements of South Asia, including *Mantai*, *Anuradhapura* citadel, and *Tissamaharama* in Sri Lanka (Deraniyagala 1972; Begley 1988; Schenk 2001, 2006, 2015; Magee 2010; Mohanty 2013). Besides, China and Sri Lanka have maintained a close cultural relationship based on trade and travel in ancient times, and it was confirmed by Chinese porcelain found from archaeological sites in Sri Lanka (Prematilake 2003). Many types of Chinese porcelain, such as the Stoneware, Yueh ware, Dusun type Storage Jars, Changsha Stoneware, Black glazed ware of the Tang Dynasty (610-907 AD), and the Yue celadon ware of the Middle Tang period (756-827 AD), have been unearthed in archaeological sites inland and along the sea coast (Carswell 2013).

In the seventh and eighth centuries, the Pallava kingdom was established based on the South Indian *Kanchipuram* area, and the Pallava kings implemented a regime that brought significant political stability to the South Indian region (Dirks 1976; Avari 2016). Although short-lived, they maintained various political relations with Sri Lanka during their tenure, confirming that *Mannar* was an important port in those relations (Bohingamuwa, 2017). Codrington (1994) points out that the ancient *Mannar* port city area (Tirukketisvaram place of Hindu pilgrimage) and various archaeological sites in *Anuradhapura* have acquired Pallava coins.

2 Study Area, Physiographic and geologic setting of the region

Sri Lanka is an island in the South Asian Peninsula below India and slightly to the southeast (Fig. 1a). Mannar is the geographical region of Sri Lanka closest to Peninsular

India, and the *Yodhawewa* reservoir is located 12 km southeast of the old port city of Mannar (Fig. 1b). According to the territorial boundaries, this archaeological site is located in the *"Yodhawewa"* village of the *Mannar* District in the Northern Province of Sri Lanka. It was bounded by the *Yodhawewa* Sanctuary from the east, the *Yodhawewa* (Giant's tank) from the South, and the canal and agricultural lands from the north and west. Archaeological investigations of the whole area were carried out beginning from the outer spill of the *Yodhawewa* reservoir to a length of 1600m area, especially on the right bank of the canal in the GPS location 08°89'14.0' N - 080°04'82.2' E (Fig. 1c).

The study area belongs to the Northwestern plains of Sri Lanka, and the subsurface geology comprises Miocene limestone beds (Cooray and Katupotha 1991). Climatically it belongs to the Northwestern Dry-semi-arid zone, and three different soil types are distributing in the area (Pemadasa 1984). The undulating terrain spreads eastward from the *Yodhawewa* comprising Reddish Brown Earth developed on the Red Yellow Latosol horizon. The flat coastal terrain mainly comprises alluvial soils (with a high amount of Solodized Solonetz and Solonchaks) and eroded surfaces and grumusols. Deposition of alluvial soil is reporting from the river and flood basins (Alwis and Panabokke 1972). Despite the prolonged drought, the region receives < 1,200 mm of rainfall annually, from June to August. Droughts after August create a significant impact on the soil and the vegetation. The temperature remains high throughout the year causing higher evaporation and relatively low humidity. The dehydrating Southwest monsoon winds prevail from April to August. Dry climates are typical in the region, and the temperature range was from 30-35°C during the research period. Heavy rainfall in the north-central part of the country causes occasional flooding in the study region. Grasslands and shrubs with thorny bushes are prominent as vegetation (Pemadasa 1984).

3 Methods and Materials

3.1 Surface Sampling

Recent irrigational reconstruction works, frequent flooding, and the release of excess water from the *Yodhawewa* Reservoir have resulted in the exposure and displacement of archaeological remains on the site's surface from time to time. During the reconnaissance survey, slag scattered on the surface of the archaeological area have identified the site as a metallurgical site. Therefore, we focused on conducting a formal surface exploration to precisely define the premise through further information on ancient metalworking settlements. The surface sampling was done along the right bank of the water canal length of the area 1600m and was divided into 32 sampling units in an interval of 50m length (Fig. 1c). In order to present a detailed and unbiased image of the premise's cultural and natural phenomena, artifacts scattered on the surface were collected to represent each sample unit following the Exploration Procedures (2015) declared by the Department of Archaeology Sri Lanka. Among these artifacts collection, only furnaces evidence, slag, crucible fragments, metal ore, Roulette Ware (RW), Black and Red ware (BRW), and coins are using in this discussion. Collected artifacts were classified, recorded, and stored in the zip lock bags at the archeology laboratory of the Rajarata University of Sri Lanka.

Archaeological objects such as refractory clay fragments, slags, and crucible fragments, were collected without focusing on classification in the field. Other objects such as porcelain and coins were collected along with detailed field records. A considerable amount of samples were obtained for further studies of metal ores, but not all specimens were collected. During the initial observation, several irregular vertical soil profile units were observed in the center of the *Yodhawewa* archaeological site. In order to identify the soil layer pattern and the scattering of artifacts in the study area, the formal profile (100cm / 150cm x 15cm) of such places was observed in parallel with the field survey and named 1 - 6 (P1 - P6). Profiles detail were also included in this research under exploration.

3.2 Excavations

The first excavation pit (LMBA/YW/2018/Ex1) (Fig. 1C) was selected by considering the surface artifacts scattering of the 1150-1200m sampling unit. The objective was to excavate the selected location to record and sample the debris deposit from a maximum to a minimum of 0.50m to 0.80m of surface level. The grid system was used for excavation site preparation for proper recording by dividing the 9m^2 square excavation pit into nine (9) sub squares of 1 x 1m grids. This excavation was carried out in 15 days in March 2018 using the vertical method and were identified and reported contexts (including layers) stratigraphically. All excavated materials were weighed, sorted, and stored in separate polythene bags.

The observed furnace structural remains and other metalworking debris in area 700-750m sampling unit were decided to be suitable for an exploratory excavation to determine the nature and possible date of the metalworking activity. The second excavation (LMBA/YW/2018/Ex2) (Fig. 1c) aimed to detect the nature and physical parameters of the furnace and systematically sample and record all remaining factors. It was completed at the end of 0.60m to 0.75m depth from the surface level. That was 17 days of excavation in March-April 2018, and all other functional parameters were the same as the first excavation. A new series of context numbers were given to the soil layers and assemblages of the second excavation. No cultural evidence was found anywhere in the lower natural deposits of the six profiles, and as a result, no further attempt was made to dig below the second cultural layer. At the end of the excavations, the discovered furnace and several artifacts assemblages were covered with Paris plaster and transported to the Archaeological Laboratory of the Rajarata University of Sri Lanka, where they were further observed in May 2020. The excavation process followed the established procedure (Standing Order No. 488) of the Department of Archeology Sri Lanka and included detailed statements, illustrations, measurements, and photographs in contextual reporting.

3.3 Materials

The material culture acquired during the above field observations was utilized to achieve the main objectives of the research. Five charcoal samples were collected from the second excavation pit and dated using Accelerator Mass Spectrometry (AMS) from the USA's Beta Analytic laboratory. All radiocarbon dates were conventional Radiocarbon Ages, and sigmas are rounded to the nearest ten years for the 1977 International Radiocarbon Conference's conventions. The Beta analytic released the result, including ± 30 years in the date determination, and the reported results were accredited to ISO/IEC 17025:2005 testing accreditation PJLA #59423 standards. Besides, the Roulette Ware (RW), Black and Red Ware (BRW), and some Indian coins were found from *Yodhawewa* field observations were used for comparative chronological discussions.

The artifacts collection was the main factor for discussing the actual metalwork, technical parameters, and resource utilization pattern related to the *Yodhawewa* site. In order to identify the authentic utility of the *Yodhawewa* furnace, structural nature, quantitative factors, and associated smelting debris were also considered. In addition, the data were compared with contemporary metallurgical research in Sri Lanka and South India to explain the *Yodhawewa* ancient metalworks by comparing the macro-morphological features of the acquired artifact pool. Accordingly, the crucible fragments and slags collection of the *Yodhawewa* site were compared with ancient iron smelting, copper-related metalworks, and crucible steel production research. The waste metal droplets (less than 1 cm in size) were not included as artifacts. In explaining the raw material used for metal extraction, well-known ore samples and notes from previous research on regional ores were examined. Other artifacts were also briefly explained here to overview the overall findings at the *Yodhawewa* archaeological site.

4 Results

4.1 Stratification and Chronology

During the pre-excavation observations, an idea of the general topography and the underground layering of the premises was given through six profiles, which revealed that the entire region consisted of five main soil layers. The topography of the study area was always varied, and similarities were found only in Ex-1, P1, and P2 areas (Fig. 2; Table 1). The maximum recorded depth of exposed faces was 240cm. The Reddish Brown Earth was developed on the surface level or at the 1-40 cm of depth, and the lower horizons comprise reddish-brown soil (Dull Reddish Brown Layer). The anthropogenic provenances were noticed from two layers deposited between the upper two layers and characterized only in the Reddish Brown Earth. The Dull Reddish Brown soils in the lower horizon were devoid of any trace of archaeological content.

The first excavation reported five main layers and seven contexts. The stratigraphy is similar to the profiles registered during the exploration, where two anthropogenic layers (3^{rd} and 4^{th} layers) were sandwiched between the top and bottom, natural layers (Fig. 2).

The second excavation reported 24 contexts in four layers, and the layers were assigned the numbers, which are the context numbers of 1, 2, 4, and 21 (Fig. 2 and 3b). The top layer (con. 1) is heavily disturbed through the recent canal expansion constructions and secondly by the monsoonal runoff. The second context was the first cultural layer of the premises, and it was divided into two units as 2A and 2B, for smooth recordings. The 4^{th} context was the second cultural layer of the premises, and it also was divided into five units in a sequence (4A, 4B, 4C, 4D, and 4E), providing an incremental column of small samples. Two circular features were exposed during the excavation and were numbered as context 5 and 9 identified as remnants of furnaces. Layer 2 and 4 were the main cultural layers, including the remains of the furnace preparation, operational debris accumulation, post-production abandonment, and human-induced debris from later settlement phases (Table 2). As the profiles did not produce any cultural relations with the lowest layer (context 21), the excavation was stopped at the end of the second cultural layer without further probing (Fig. 2, 3a, 3b). All the reported profiles and excavations revealed that the region's stratigraphic distribution is almost evenly deposited and has similar attributes, except that the layers' thickness varies to some extent (Table 1).

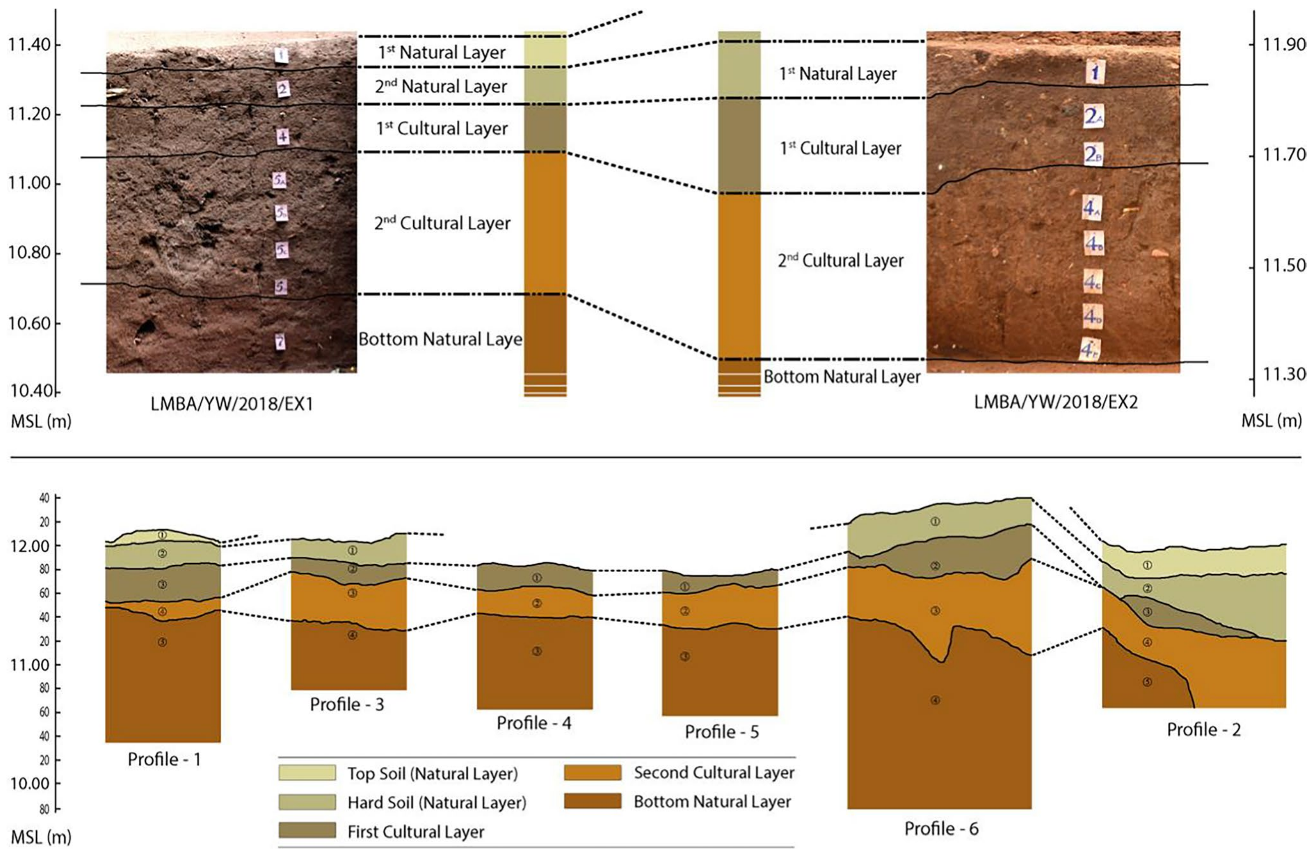

Fig. 2. Significant layer distribution pattern of *Yodhawewa* site; First excavation *(top left)* and second excavation *(top right)* comparing the layer configuration and six profiles' layer arrangement pattern *(bottom)*

Table 1. Equivalence of soil distribution in the surveyed region (mentioned the soil colors of each excavation and profile layers according to the Munsell Soil Colour Chart 2009), ND=Not Detected.

Soil colours	Layers or contexts of each excavation and profile							
	Excavations Context No's		Profiles Layer No's					
	Ex-01	Ex-02	P.01	P.02	P.03	P.04	P.05	P.06
7.5 YR 3/4 Dark Brown	1	ND	1	1	ND	ND	ND	ND
7.5 YR 3/3 Dark Brown	2	1	2	2	1	ND	ND	1
5 YR 3/3 Dark Reddish Brown	4	2	3	3	2	1	1	2
5 YR 3/4 Dark Reddish Brown	5	4	4	4	3	2	2	3
5 YR 4/4 Dull Reddish Brown	7	21	5	5	4	3	3	4

Five charcoal samples collected from three different contexts in the Ex-2 were dated. In preparing a contextual note chronologically, it is essential to inquire about the context in which the samples were acquired. The S-159 sample was obtained from (MSL=11.45) an accumulation (context 12), and it was dated back to the c. 1st century AD. The S-27 sample was collected from (MSL=11.61) context 4A (significantly closer to the furnace structure), and results have been confirmed to belongs to the c. 5th century AD. The subsequent three samples were collected from layers unrelated to other contexts: the S-48 (MSL=11.41) sample was collected from the 4C context, while the S-64 (MSL=11.36) and S-78 (MSL=11.32) samples were collected from the 4D context. Thus, the datings were confirmed that the three samples from the 4C and 4D contexts belong to the c. 8th century AD.

The absolute chronological results of Ex-2 are expected to be compared with the relative chronology from the morphological characteristics of selected artifacts found at the *Yodhawewa* site. Several ceramic pieces and coins found on the premises were considered for this purpose. The *Yodhawewa* survey collected 12 RW (Fig. 4a) fragments,

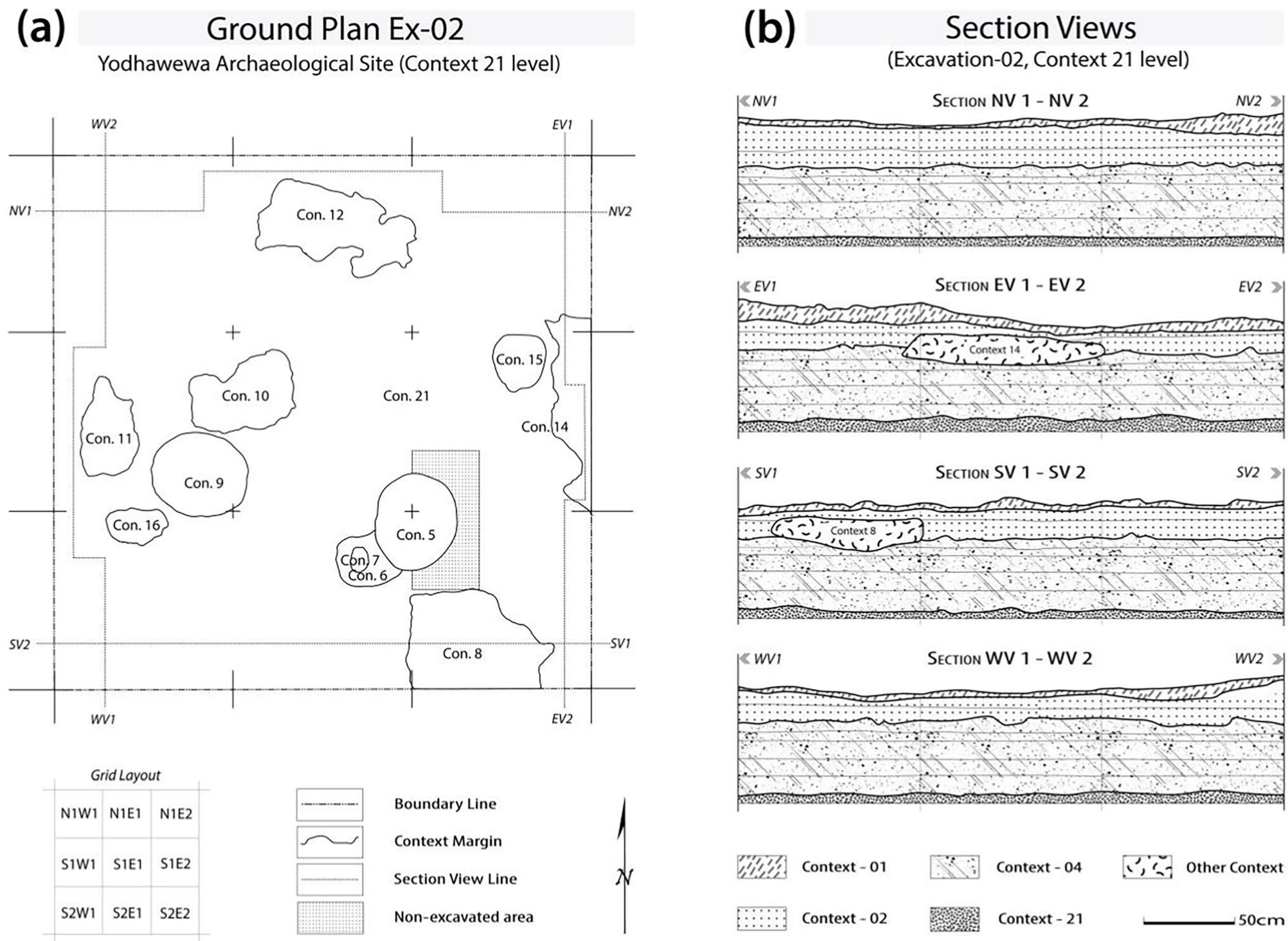

Fig. 3. second excavation pit at *Yodhawewa* (LMBA/YW/2018/02); (a) Ground Plan: end of the excavation (b) Four section views related to the ground plan [scale: 50cm represented to (a) and (b)]

Table 2. Conventional radiocarbon dating results of selected contexts of the Ex-2

Sample Reference in the article	Sample No. (at the study - beginning, at the Beta analytic laboratory - end)	Locality		AMS dating results (Conventional radiocarbon age)		Accuracy
		Context No.	Location type	Calibrated date (cal AD)	Radiocarbon determination (cal BP)	
S-27	Y/18/Ex2/Sample/27 -- Beta - 517342	4A	Layer	**430 ± 30**	**1520 ± 30**	**95.40%**
S-159	Y/18/Ex2/Sample/159 -- Beta - 517842	12	Accumlation	**70 ± 30**	**1880 ± 30**	**95.40%**
S-48	Y/18/Ex2/Sample/48 -- Beta - 517843	4C	Layer	**760 ± 30**	**1190 ± 30**	**95.40%**
S-64	Y/18/Ex2/Sample/64 -- Beta - 517844	4D	Layer	**730 ± 30**	**1220 ± 30**	**95.40%**
S-78	Y/18/Ex2/Sample/78 -- Beta - 517343	4D	Layer	**730 ± 30**	**1220 ± 30**	**95.40%**

23 BRW (Fig. 4b) fragments, and six Porcelainware fragments; however, they have not been identified from two excavation pits. One of the identified Changsha porcelain bowl fragments belongs to the Tang Dynasty period of China (Fig. 4c). Furthermore, five coins were also collected during the *Yodhawewa* survey, and four of them were severely oxidized, but one coin was preserved in excellent detail. The coin's obverse depicts a lion standing in the middle of a beads circle and a large flower pot

Fig. 4. (a) Rouletted ceramics (b) Black and Red Ware (c) Porcelainware (d) A copper coin obverse and reverse, were discovered from the *Yodhawewa* site [scale: 1cm]

on the reverse (Fig. 4d), this type of coin belongs to the Pallava dynasty of South India.

4.2 *Yodhawewa* Metalworking settlement

The archaeological research discovered 14017 artifacts of the *Yodhawewa* site. The 57.20% (n=8018) of the majority of them were obtained from the second excavation pit. Other 16.25% (n=2278), 16.14% (n=2263), and 10.40% (n=1458) were collected by exploration, first excavation pit, and six profiles, respectively (Fig. 5a). Furnace fragments, crucible fragments, and slags were represented 53.83% of the real artifacts in the collection, which are discussed in detail below. In addition, other ceramics, beads, metal objects, pieces of glass, lithics, flora, and faunal remains (46.17 percent of the total artifact collection) also reflected the past socio-cultural environment of the *Yodhawewa* settlement (other objects of table 3 and Fig. 5e).

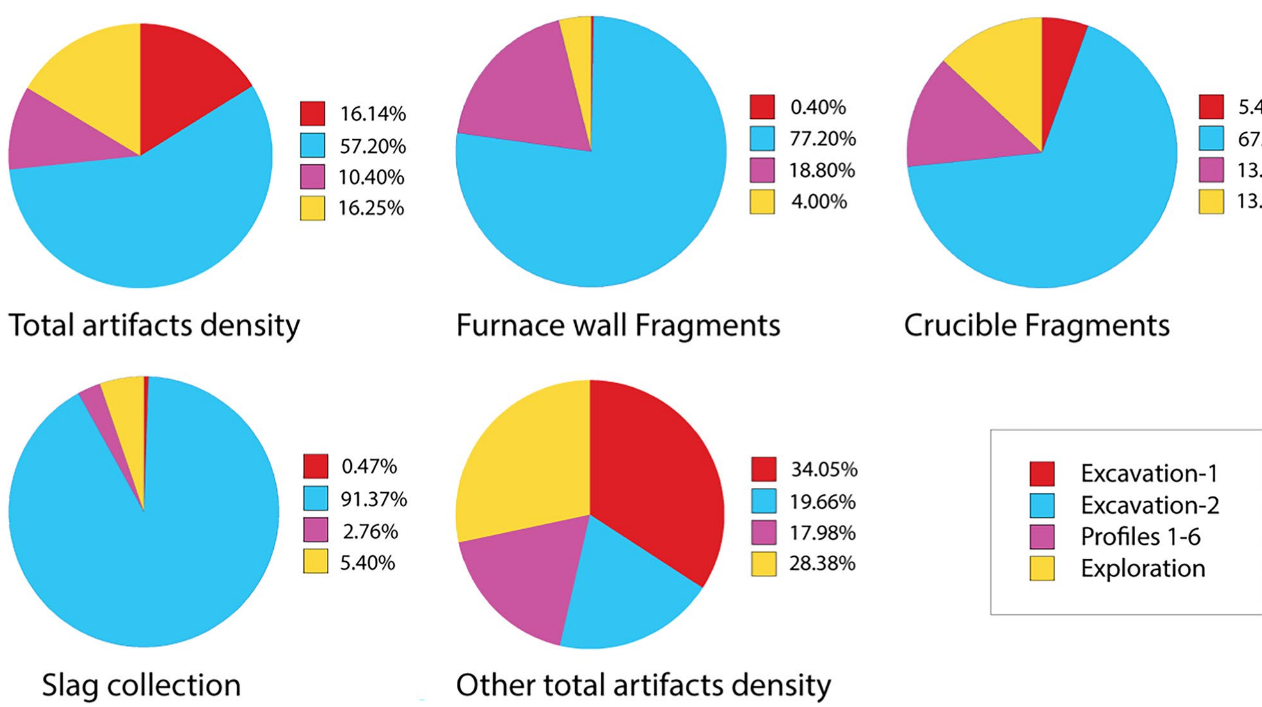

Fig. 5. The percentages of the *Yodhawewa* artifacts density: (a) Total artifacts density (b) Furnace wall fragments (c) Crucible fragments (d) Slag collection (e) Other total artifacts density

4.2.1 Furnace and other Refractories

The furnaces are one of the most informative points in ancient metalworking sites. The total number of 251 refractories (77.2%) of the *Yodhawewa* research were found in Ex-2 (Fig. 5b), and contexts 5 and 9 presented significant structural evidence for the furnaces. A well-preserved lower half of a crucible-type furnace (context 5) was exposed at the surface, while the upper parts were not preserved (Fig. 6). The remaining half of the furnace had an internal depth of 29 cm, and in the level between 16–22 cm inside the furnace chamber, 18 pieces of crucible fragments and lids were detected. The total abandoned furnace chamber was filled with the debris of the crucible fragments (n=32), slags (n=8), metal fragments (n=1), and potsherds (n=3), and refractory clay fragments (n=21). There was no tuyere evidence found related to the furnace; however, a closed air tube's features could be seen about 15 cm from the furnace chamber base (Fig. 6d). The next furnace remains (context 9) was identified at the 2B context level, and it was an assemblage of furnace wall fragments.

In terms of the structural preparation of the furnace, the wall has been prepared by bonding with clay using pre-prepared and fired clay pieces of various sizes. Inside the remaining furnace, a burnt and impressed clay (daub) coat could be seen around the entire radius to a depth about 22 cm deep from the furnace surface. Although it looks like a single plaster, when the same furnace was used for an extended period, the daub plaster thickness could be seen about 1.5-2.5cm by repeated applying that coat. The clay tuyers were not used to the *Yodhawewa* crucible furnace, and the air was supplied into the furnace using the bellow method. Figure 6 shows the "Tube hole" of the air conduit connected to the bellow and the furnace. This idea was further confirmed after a fragment of clay tube was found among the artifacts in the furnace chamber.

In addition, iron slags and other smelting debris (including a few tuyere fragments) scattered throughout the premises provided the primary evidence for assuming that there should be furnaces for the iron extraction to produce the raw iron. Although Slags and crucibles, including copper prills (spots of powdery green corrosion) found in the vicinity of the *Yodhawewa* Ex-1 area.

4.2.2 Crucible fragments

These crucible fragments (crucibles and lids) were represented 3.42% (n = 480) of the entire artifacts of *Yodhawewa* research. However, when considering only crucible fragments, the second excavation pit revealed 67.92 percentage. The other 32.08 percentage were collected from the archaeological survey (13.13%), Profiles (13.53%), and Ex-1 (5.42%) were collected (Table 3, Fig. 5c). Despite observing all the crucible fragments collected from the *Yodhawewa* entire site, a non-damaged (complete) crucible could not be found, and they have been uncovered as parts of the rim, body, base, and lids (Fig. 7). The crucibles' shape, size, and thickness in the Ex-1 area displayed variations compared to the crucibles found in the Ex-2 area. *Yodhawewa* crucibles in the Ex-1 area were shaped round bowls with a flat base, and copper fragments were also deposited inside some crucibles fragments. Besides, the crucibles of the Ex-2 area represented an elongated tube-shaped and rounded base.

The inner diameter of all crucible fragments found in the Ex-2 area was approximately 4cm - 6.5cm. Macro-morphologically, the outer surface was completely dark green or blue (mixed) with glazy vitrification or a waxy solution, including tiny white splots (Fig. 7f, i, k). The inner middle or lower area shows glassy fins as a smelting line (Fig. 7g, h) and visible some honey-comb pattern in the bottom part of the inner crucibles (Fig. 7i). Crucible lids appear in the *Yodhawewa* assemblages with a unique shape (Fig. 7a, b, c); all the lids examined show evidence of being pierced with one or more small holes (Fig. 7d), and an unbroken lid also was not found to identify their form precisely. In some cases, traces of small metal particles were visible inside the crucible upper parts (Fig. 7e) or lids.

4.2.3 Archaeometallurgical Slags

Slag occupies a significant role among all the archaeological finds at the *Yodhawewa* site (Fig. 5d). Accordingly, a total weight of 48.5kg (N=6814) slag fragments were collected from the whole study area (Table 3 and 4). Two thousand fifteen fragments of them (38.3 kg) were higher than 1cm in size, and 4799 (10.2 kg) were less than 1cm. Slags were detected throughout the 200-1600m study area, and a significant increase in the 700–750m and 1100–1200m sample units was observed. However, no slag was found up to 150m in the exploration region closest to the *Yodhawewa* reservoir and was rarely found until the 700m region (Table 3). The 700-750m sampling unit represented the highest slag density, with total slag fragments of 6447, including Ex-2, profile-6, and the exploration (Table 3 and 4). The removal of more soil from the 750-900 zone due to development activities may also reason for a reduced slag amount in that area (Fig. 1).

In terms of physical characteristics, we can divide *Yodhawewa* slags into two types: Heavy slags (Type-A) and Light slags (Type-B). Type-A, the dominant slag type of *Yodhawewa* are high-to-medium density, from a few centimeters to decimetres in size (maximum length of 14.2cm), and uneven surface with or without tapping structures (Fig. 8a, c, e, g). This type of slags may less or may not have vesicles (small holes). Another prominent feature is the strongly oxidized surfaces

Table 3. Artifacts density of two excavations, six profiles, and survey area of the *Yodhawewa* archaeological site in 2018

Study Area	Context / *Area*	Furnace wall parts	Crucible Fragments	Slag pieces	Other artifacts	Total
Excavation-1	Context 4	0	4	1	338	343
	Context 5 all	1	22	11	1852	1886
	Other all contexts	0	0	20	14	34
	Total (EX-1)	**1**	**26**	**32**	**2204**	**2263**
Excavation-2	Context 1	0	48	382	244	674
	Context 2 all	69	46	4221	144	4480
	Context 4 all	3	99	975	670	1747
	Other all contexts	121	133	648	215	1117
	Total (EX-2)	**193**	**326**	**6226**	**1273**	**8018**
Profiles 1-6	Profile 01 all	0	6	77	5	88
	Profile 02 all	31	59	51	630	771
	Profile 03 all	2	0	2	34	38
	Profile 04 all	0	0	0	2	2
	Profile 05 all	0	0	17	0	17
	Profile 06 all	14	0	41	487	542
	Total (All Profiles)	**47**	**65**	**188**	**1158**	**1458**
Exploration/ Survey	0 – 50	0	0	0	0	0
	50 – 100	0	0	0	0	0
	100 – 150	0	0	0	0	0
	150 – 200	0	0	**1**	3	4
	200 – 250	0	**1**	**2**	**18**	21
	250 – 300	0	0	**2**	9	11
	300 – 350	0	0	**10**	28	38
	350 – 400	0	0	**7**	5	12
	400 – 450	0	0	**5**	9	14
	450 – 500	0	0	**5**	44	49
	500 – 550	0	0	**2**	43	45
	550 – 600	0	0	**15**	238	253
	600 – 650	0	**2**	**7**	**212**	221
	650 – 700	0	**1**	**2**	**54**	57
	700 – 750	**4**	**14**	**180**	**174**	372
	750 – 800	0	0	**9**	64	73
	800 – 850	0	0	**4**	62	66
	850 – 900	0	1	**2**	74	77
	900 – 950	0	0	**1**	40	41
	950 – 1000	0	0	**2**	21	23
	1000 – 1050	0	0	**3**	10	13
	1050 – 1100	0	**1**	**8**	**22**	31
	1100 – 1150	**5**	**28**	**33**	**238**	304
	1150 – 1200	**1**	**1**	**29**	**146**	177
	1200 – 1250	0	0	**6**	1	7
	1250 – 1300	0	9	**15**	152	176
	1300 - 1350	0	5	**5**	53	63
	1350 – 1400	0	0	**3**	3	6
	1400 – 1450	0	0	**2**	29	31
	1450 – 1500	0	0	**2**	40	42
	1500 – 1550	0	0	**4**	37	41
	1550 – 1600	0	0	**2**	8	10
	Total (Exploration)	**10**	**63**	**368**	**1837**	**2278**
Total Artifacts content of the *Yodhawewa* site		**251**	**480**	**6814**	**6472**	**14017**

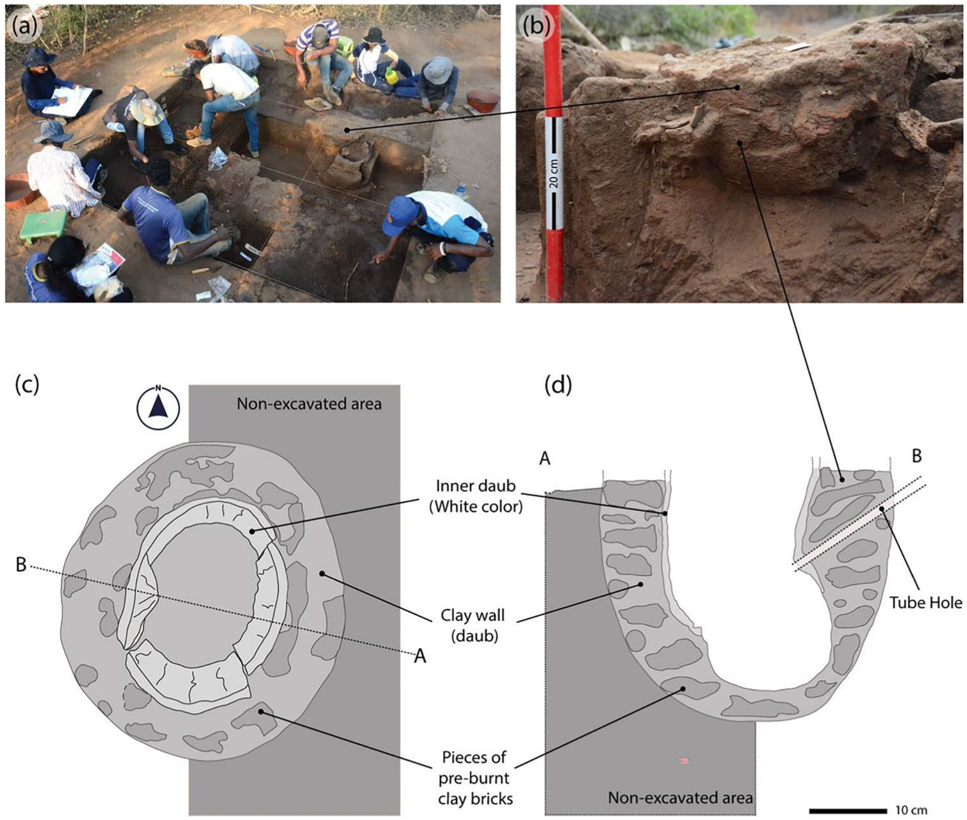

Fig. 6. (a) Fieldwork at the *Yodhawewa* second excavation pit (b) Remaining lower part of the Crucible-type furnace (Context 5) (c) Detailed drawing of the Furnace Plan (d) Details of Section A – B [scale: 10cm represented to (c) and (d)]

(Fig. 8a, c), and the oxidation was clearly due to the exposure to the atmosphere after smelting and from the long-term connection with underground water and oxygen. Surface and interior colors range from red, gray, brown, and black, and some have a shiny interior surface. Type-B is the Light, glassy or vitreous, vesiculate slags from a single decimeter drop to a few centimeters in size (Fig. 8b, d, f, h). These types of slags were mainly found in the vicinity of the second excavation pit. Blue and green were the predominant colors and were also available in black and white (Fig. 8b, d, f). Some glassy-type slags with tiny air holes can be seen here (Fig. 8f). Commonly both types of slags exhibit heavily rusted, irregular plano-convex cake shapes. The slags are characterized by extreme porosity and heterogeneity on the external surface, and quartz and charcoal are sometimes visible. In general, these metal slags can be identified as having high viscosity, and there is also evidence that they reach the melted level.

4.2.4 Raw Materials for Iron Smelting

In addition to the *Yodhawewa* slag file and furnace factors, observing the iron ore samples found at the premises confirmed that iron extraction had also occurred. The *Yodhawewa* surface survey revealed 23 iron ore specimens (4.83 kg) >2cm in size and, from the Ex-1 pit, have uncovered 2130 (6.82 kg) iron ore nodules <2cm in size. However, no sources were available in the study area or periphery regarding individual copper ore deposits.

5 Discussion

5.1 Dating for the Yodhawewa metalworking site

There are three main stages in the chronology of the *Yodhawewa* second excavation pit (Table 2). S-159 Sample demonstrated 70 ± 30 and is the oldest date the *Yodhawewa* site has received. Context 12 was an assemblage contained slags, pottery pieces, and crucible fragments that stretched from the beginning to end of the second (bottom) cultural layer (context 4). The bottom level of context-12 represents the excavation's ending level (context-4E); then, the S-159 sample can be interpreted as an accurate dating determination of the context. However, the S-27 sample was inverted in terms of the stratigraphic sequence. We have considered the possible causes of the inversion, such as land preparation for furnace construction, post-production activities, incorrect labeling of the samples, or misidentifying the sample (The exact dates can be compared through Table 2). However, all three samples from the 4C and 4D contexts represented the 8th century

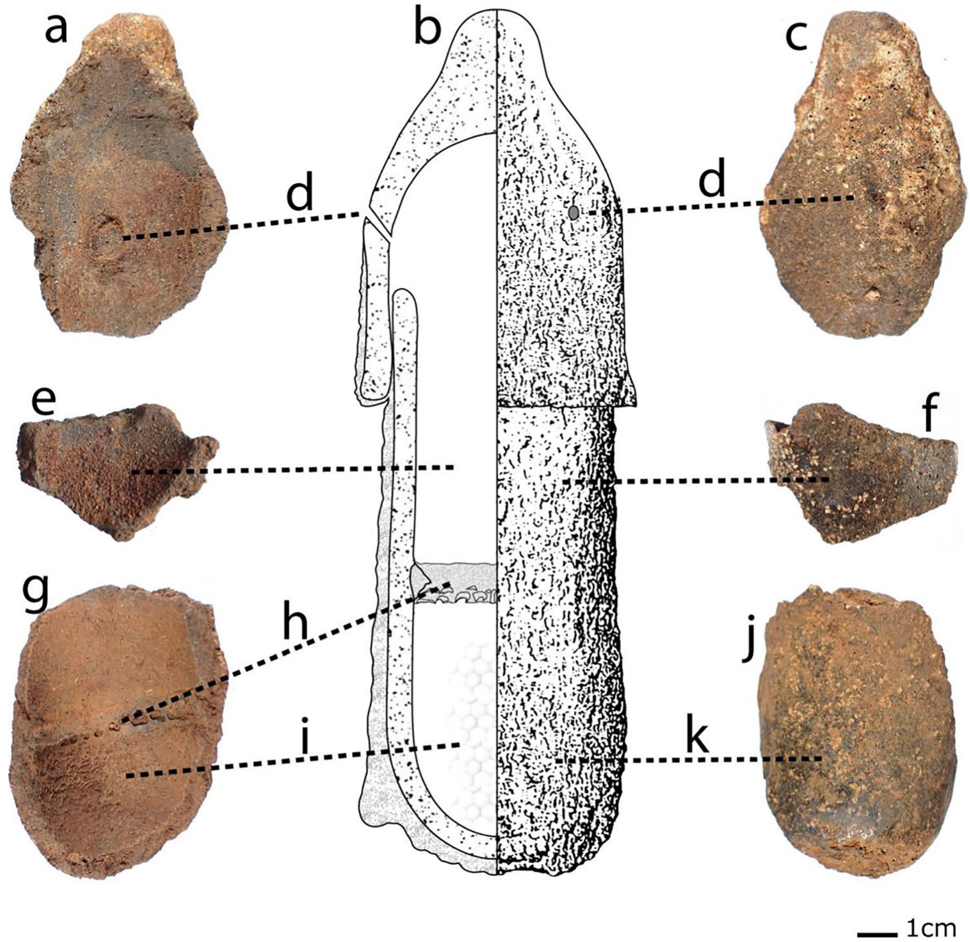

Fig. 7. The crucible-related steel production; inner details *(left)*, the outer surface *(right)*, detailed drawing (nonscale) of the crucible, and a lid *(center)*. (a, b, c) Crucible lid (d) with a small hole (c) Almost all crucible lid's outer top surface mostly in white color and non-vitrified (e) Tiny metal splots in the top part of the crucible (h) Inner middle or lower part shown glass fins (i) Appear the bottom of that line and the bottom of the crucible a honeycomb pattern (f, j, k) Dark blue or green color glaze vitrification shown outside the crucible. [scale: 1cm related to a, c, e, f, g, j]

AD, and the relevant contexts in which the samples were collected were unaffected by other contexts.

Solangaraarachchi (2011) and Juleff (1996b, 2015) have confirmed contextual verification problems in the chronological results of metal furnace-related research. Accordingly, attention was drawn to a comparative chronological interpretation approach parallel to the absolute chronology, based on the identities of selected artifacts found on the *Yodhawewa* premises. The BRW and RW pottery found in *Yodhawewa* research is a testament to the international significance of this site. Preliminary research has revealed that these pottery types were extensively used in the Asian region, including historical settlements of Sri Lanka, between the 2nd century BC and 2nd century AD (Schenk 2006). Thus, the absolute chronological evidence provided by the *Yodhawewa* S-159 sample and the discovery of these exotic clay pots confirms that the site became internationally important even in the first century AD.

Archaeological pieces of evidence have revealed that the Changsha Porcelain of the Tang Dynasty of China (617-908 AD) spread to Central Asia, South Asia, and the rest of the world (Flecker 2001). Various types of Chinese porcelain have been unearthed from time to time during excavations at the Ancient *Mannar* port near the *Yodhawewa*, and the excavations 1980-84, have been given special attention to Changsha porcelain ware (Carswell 2013; Linrothe 2013). In addition, the discovery of the South Indian Pallava coin from the *Yodhawewa* premises is also noteworthy. When presenting the absolute chronological results of three samples of *Yodhawewa* research as 8th century AD, contemporary international relations have also been confirmed by Chinese Changsha porcelain evidence and South Indian Pallava coins discovered in the premises.

5.2 Crucible typed furnace and other furnaces

The specialty of the *Yodhawewa* premises was the discovery of a spherical metal furnace in the lower half for the first time. Inspecting the furnace chamber revealed that the artifacts file was a natural or cultural filler formed after being discarded of the furnace. However, artifact collection contained many crucible fragments and lid fragments used to make crucible steel. A significant collection of crucibles fragments and lids used to make steel from the Ex-2 and the surrounding area have been found concerning the entire

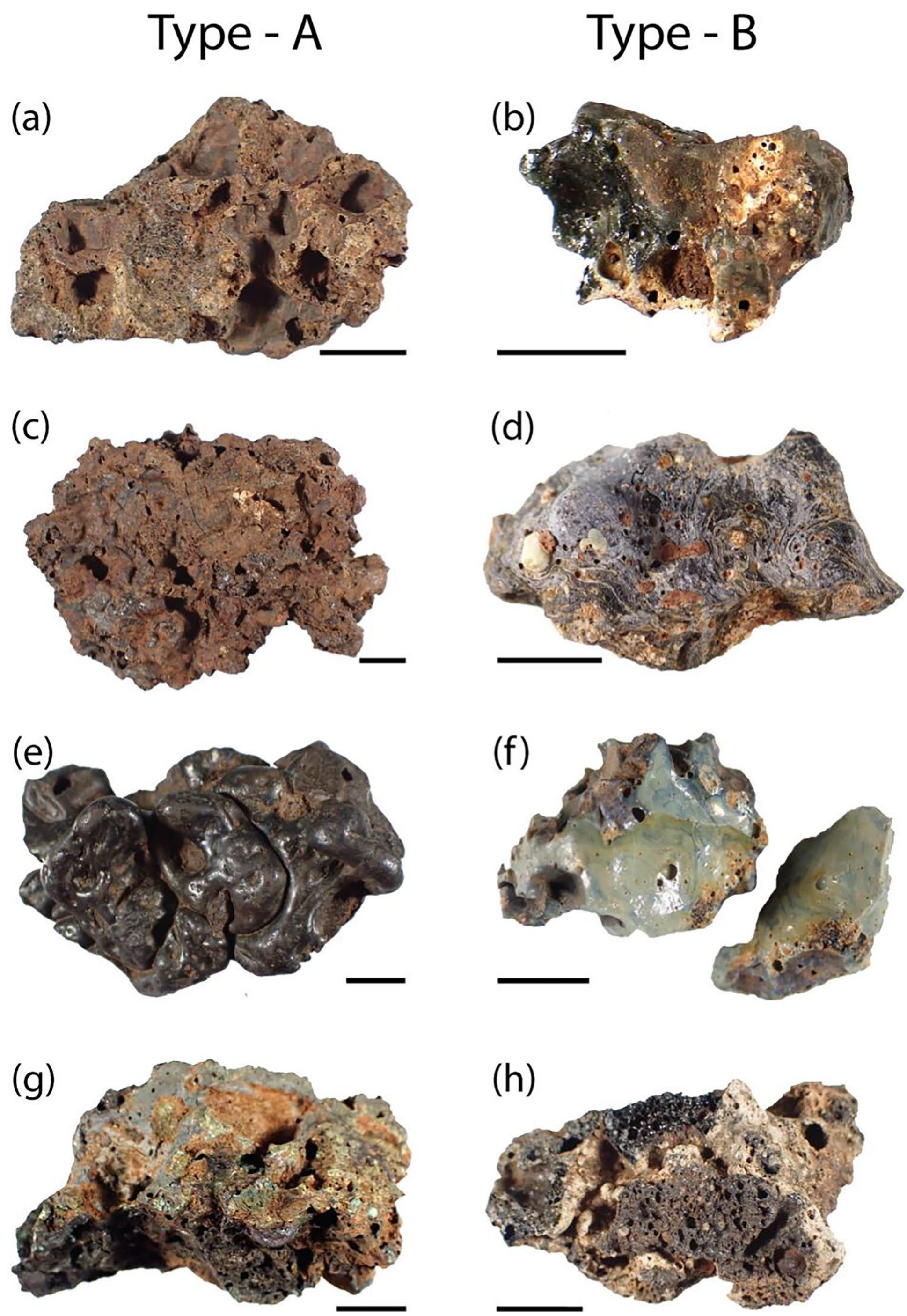

Fig. 8. Heavy slags (Type-A) and Light slags (Type-B) collected from *Yodhawewa* site (a, c) Irregular plano-convex slag cake with corrosion (e) Tap slag (g) Slag occurs copper alloy splots, (b, f) green glass slag (d) Light blue slag with white lines (h) lightweight more vesicular slag [scale: 1cm]

research area. Although no such lower spherical metal furnaces have been found in Sri Lanka until 2018; however, crucible steel furnaces have been found during excavations at the *Kodumanal* Megalithic site in Southern India (Gullapalli 2009; Sasisekaran and Raghunatha Rao 2001). In addition to being similar to the *Yodhawewa* furnace in physical and structural factors to that *Kodumanal* furnaces, the surrounded crucible fragments, lids, and other debris prove that it was a furnace used to produce crucible steel.

Other research has shown that the interior plaster of the furnace chamber usually acts as a thermal insulation layer (Weisshaar, Schenk, and Wijeyapala 2001; Parr and Boyd 2002). When considering the structural form of the *Yodhawewa* crucible steel furnace, it was also found that the thermal insulation plaster (daub), which was weakened during prolonged use of the same furnace, was maintained by re-coating.

Air supply tuyeres, refractory clay fragments of the furnaces, and slag pool were discovered at the *Yodhawewa* premises was confirmed that metal extraction work had also taken place. However, the field revealed no other evidence of the nature or functionality of such a furnace. In addition, although archaeological evidence confirms that copper-based metalwork (extraction, refining, alloying, or manufacturing) took place in the Ex-1 area; No clear evidence of such furnaces also was found in this research.

5.3 Crucibles for Steelmaking and Copper working

Yodhawewa (Ex-2 area) crucible fragments show similar characteristics with the *Mawalgaha* crucibles (Juleff 1996b) and the *Hattota-Amune* crucibles (Juleff 2015) of Sri Lanka. When comparing crucibles in both places of *Yodhawewa* and *Mawalgaha*, *(a)* dark blue/green glass verifications entire outer surface, *(b)* elongated tube shape rounded base, *(c)* quite rough texture and, *(d)* very dark brown/black fabric are the similar characteristics. When the crucible is elongated, the contents are more comfortable to smelt and easier to handle (Erb-Satullo, Gilmour, and Khakhutaishvili 2015; Juleff 2015). The lining of glass slags and the honey-comb pattern of the inner crucibles bottom part would have been occupied by molten charge and solid ingot (cake) of some steel crucibles in South and Central Asia (Srinivasan 1997; Feuerbach 2002; Srinivasan and Ranganathan 2004; Srinivasan et al. 2009). These particular characteristics have also can be seen in the *Yodhawewa, Mawalgaha, and the Hattota-Amune* crucibles. Small iron particles were deposited on the upper inner wall of the crucibles and lids due to explosive droplets (splashes) with bubbles in the melting metal solution (Srinivasan 1997), and this feature can also be seen in the *Yodhawewa* and other specific place's crucibles in Sri Lanka. One or more perforations can be seen in the crucible lids used to make steel in *Yodhawewa* and elsewhere in Asia (Juleff, 1996b, 2015; Prakash, 2001; Feuerbach, 2002). The function of the perforations of lids was to balance the heating pressure when melting charge inside the crucible (Coomaraswamy 1962). Srinivasan's account of the steel-producing crucibles found at *Mel-Siruvalur* near the *Tiruvannamalai* city of Tamil Nadu and *Machnur* and *Tintini* near the banks of the Krishna river in the *Raichur* in Karnataka District fits well with the physical forms of the steel crucible in Sri Lanka (Juleff 1996b, 2015; Srinivasan 1997, 2013; Srinivasan et al. 2009). Thus, the macro-morphological features of the crucibles acquired from *Mawalgaha, Hattota-Amune*, and some South Indian archeological studies reflected the similar characteristics of the *Yodhawewa* (Ex-2 area) crucibles.

Considering the physical characteristics and inclusions of the *Yodhawewa* crucibles (Ex-1 area), it can be determined that they were used for copper metalwork such as extraction, refining, alloying, or production. Archaeological excavations at *Mannar* in 1980-84 have uncovered crucible fragments larger (in diameter) than the *Yodhawewa* crucibles; however, the wall thickness of the crucibles found in the Ex-1 area and the reddish color fabric on the outer wall, physically similar to crucibles found in *Mannar* (Juleff 2013). Accordingly, we would like to point out that the same method has been followed for the *Yodhawewa* copper needs, without challenging the pre-hypothesizes that the *Seruvila* copper deposit in the eastern part of Sri Lanka has been utilized for the copper needs of *Mannar* and South India (Seneviratne 1995; Juleff 2013; Srinivasan 2016).

5.4 Slag as a by-product of metal extraction

In examining the physical properties of the *Yodhawewa* slag collection, an attempt was made to compare it with several previous studies on the physical properties of iron, copper, and steel slags. Juleff (1996b) points out that the presence of circular slag "cakes" of various sizes are generally considered an indicator of bowl or shaft furnace designs. Johansen (2014) confirms that approach, quoting Craddock (1995), Schmidt (1997), Sim (1998), and declaring separated slag gangue from the iron smelting furnaces. Otherwise, tap slag could also be found at some iron extraction sites. Slag cakes abounded in the *Yodhawewa* slag collection, and tap slag was predominantly red and black (Fig. 8e). Juleff (1990, 1996b, 2013, 2015) pointed out that a certain amount of glassy slag originates on the steel ingot in the crucible in crucible steel production. This slag strip can be seen as glassy fins (Fig. 7h) inside the crucibles. Therefore, some of the slags found in the *Yodhawewa* premises can be called glassy slag, originating in crucible steel production (Fig. 8b).

Considering the copper extraction process: red, gray, brown, or black colored metal slag, blue, white, and green vitreous or "glassy" type slag can be identified as copper extraction proof (Hegde 1981; Gorai, Jana, and Premchand 2003; Rehren, Boscher, and Pernicka 2012). Accordingly, it has been scientifically proven that glassy slag is released during copper production and crucible steel. According to Yang *et al.* (2013), residual slag is transformed into light-color glass-ceramics when separating the iron from the copper batch. The presence of oxidized copper particles in some of the slags found during the *Yodhawewa* exploration confirms a certain percentage of copper in the metal ores used for the extraction (Fig. 8g). Examining the physical and macro-morphological characteristics of the *Yodhawewa* slag with the above research findings can confirm that it is associated with the Iron, copper, and crucible steelwork of these premises representing types of A and B together.

5.5 Raw Materials for Iron Smelting

Archaeological findings on iron ores used in metal production by the *Yodhawewa* metalworkers are discussed here. Although there are no records of large metal ore deposits in the area, several geological and archaeological records have focused on possible traces of metal ore in the region. Ferruginous gravels were found beneath the distinctive reddish-brown soil structure of the North-Western, North-Central, and Jaffna Peninsulas of Sri Lanka, and the amount of iron content in that nodules could have contributed significantly to the region's metal demand (Seneviratne 1985). The red color of brown Earth means that there are oxidative conditions required to make red hematite. Soil testing in these regions has also revealed that reddish-brown earth hematite predominates (Cooray and Katupotha 1991). In addition, a dark brown iron ore layer could be seen below the surface of the Early-historic urn burial site of *Pomparippu* (Begley, Lukace, and Kennedy 1981), located 62km south of the *Yodhawewa* site. Based on the above statements and the collection of iron ore specimens, it can be ascertained that the raw material used for the *Yodhawewa* iron extraction was sourced from the surrounding or Imported from outside ore deposits. Furthermore, the raw material for the copper-based metalworks at the *Yodhawewa* area may have been obtained from the *Seruwila* copper deposit, as mentioned above.

5.5.1 Crucible steel production of ancient *Yodhawewa* metalworkers

Crucible steel production was one of the significant metal activities that were identified from *Yodhawewa* research. As the site reveals many significant facts about iron extraction, it can be concluded that steelmaking was also done here in parallel with iron extraction. Three main iron production processes can be identified as; wrought iron, cast iron, and steel—moreover, the most qualitative variant of these was the steel products (Srinivasan and Ranganathan 2004). The raw iron (wrought iron) produced nearly after the extraction process is a soft and spongy substance that must be mixed with carbon in the right proportions to obtain sufficient quality and hardness (Solangaraarachchi 2011; Juleff 1996b; Saravanan 2017). Due to the acceptable carbon content of the steelmaking process, the metal hardens sufficiently without instability (Gururaja Rao 1970).

As mentioned above, based on the relative and absolute chronology, it has been established that the *Yodhawewa* metalworking site was in operation in the first and eighth centuries AD. Al-Kindi and other Islamic reporters state that high-quality steel was produced in *Sarandibi* (Sri Lanka) in the 9th century AD (Juleff, 1996b). Furthermore, she points out that for the high carbon steel trade to remain at its peak between Sri Lanka and the Islamic world in the 9th century, Sri Lanka must have produced high-quality steel in the 6th and 7th centuries. Accordingly, the activation of the technologically advanced west-facing steel furnaces in the *Samanalawewa* area and the contemporary steel production at *Hattota-Amune* further intensify the idea (Juleff 2013, 2015). However, considering the *Yodhawewa* Ex-2 chronological results, research into the contemporary Sri Lankan crucible steel production, and statements of Islamic writers such as al-Kindi, it can be pointed out that the ancient metalworkers of *Yodhawewa* in the 8th century AD produced the most dynamic crucible steel.

Mantai was the main commercial port during the early *Anuradhapura* Kingdom period, and there is a high probability of South Indian technological migration to Sri Lanka in parallel. If an indigenous technological source did not influence crucible-Steel production, the Indian influence must inevitably be addressed. The *Yodhawewa* can be pointed out as a primary production site established near the significant harbor of *Mantai* at the beginning of the metal ore search journey in the central highlands of Sri Lanka. Apart from this, the above information confirms that crucible steel production technology has developed simultaneously in the central highlands and coastal areas of Sri Lanka parallel to South India.

6 Conclusion

Extensive archeological field studies at the *Yodhawewa* site in 2018 examined evidence of metal extraction, crucible steel production, and some other international relations during the early and middle historical period in Sri Lanka. According to the *Yodhawewa* premises' findings, it is manifest that its iron ore extraction, crucible steel production, and copper-related work using crucible were carried out. The focus of the thematic discussion was on chronological revelations and the use and technology of crucible steel production of the premises. The metalworkers at *Yodhawewa* refined the cast Iron in a crucible-shaped furnace with the carburization method to produce quality crucible steel. The chronology of the second excavation of the *Yodhawewa* dates back to the 1st, 4th, and 8th centuries AD, with 60% confirmation of the 8th century dates. The relative chronology of Chinese Changsha porcelain and coins related to the Pallava dynasty found in the *Yodhawewa* research confirms that the site maintained international relations by the 8th century AD. Al-Kindi's Islamic report states that high-quality steel was produced in Sarandibi (Sri Lanka) in the 6th and 7th centuries AD. The radiocarbon dating of this research confirms that the metalwork in the *Yodhawewa* settlement dates back to the 1st century AD and also that the most active period in metal-producing was around the 8th century AD.

The *Yodhawewa* research has uncovered the earliest evidence of a steel furnace in the northwestern dry zone of Sri Lanka, and it was extraordinary evidence of a crucible-shaped (lower half-spherical typed) steel furnace activated using the Bellow method found in Sri Lanka. For the first time, the excavations during 1985-1996 at the *Kodumanal* site in South India have been reported using crucible-shaped furnaces for steel production. The crucible fragments collection is the primary evidence that the *Yodhawewa* and *Kodumanal* furnaces were used for steel production. Furthermore, the *Yodhawewa* crucible fragments show morphological similarities in crucible fragments found in the *Samanalawewa* and *Hattota-Amune* sites in Sri Lanka.

The high slags density and several fragments of tuyeres found in this research area showed that iron had been extracted long-lasting. Furthermore, the oxidized copper particles in the crucibles and the copper components in the slags confirm that copper-based extracts, products, or reproductions occurred at the site. However, although there is evidence that the iron ore material for the iron extraction was discovered on-site, we hypothesize that the copper ore may have been transported from the initial ore deposit at *Seruvila* on the east coast of Sri Lanka. In observing the collection of artifacts found in the entire *Yodhawewa* research, it is more appropriate to define this premises not as an isolated manufacturing center with domestic supplies but as a sub-commercial center open to the world.

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Authors' contributions **WMTB Wijepala**: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Software, Visualization, Roles/Writing - original draft

Sansfica M Young: Conceptualization, Formal analysis, Methodology, Software, Supervision, Writing - review & editing

H Ishiga: Conceptualization, Formal analysis, Funding acquisition, Methodology, Resources, Software, Supervision, Writing - review & editing

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References

Alwis, K.A.D., and C.R. Panabokke. 1972. Handbook of the Soils of Sri Lanka (Ceylon). *Journal of the Soil Science Society of Ceylon* II: 1–97.

Avari, Burjor. 2016. *India: The Ancient Past: A History of the Indian Subcontinent from c. 7000 BCE to CE 1200*. New York: Routledge.

Begley, V. 1988. Rouletted Ware at Arikamedu: A New Approach. *American Journal of Archaeology* 92 (3): 427–440. https://doi.org/10.2307/505557.

Begley, V., J.R. Lukace, and K.A.R. Kennedy. 1981. Excavations of Iron Age Burials at Pomparippu, 1970. *Ancient Ceylon* 4: 49–141.

Bohingamuwa, W. 2017. Ancient " Mahatittha " (Mantai) in Sri Lanka : A Historical Biography. *Journal of the Royal Asiatic Society of Sri Lanka* 62 (2): 23–50 https://www.jstor.org/stable/45219028.

Carswell, J. 2013. Chinese Ceramics. In *Matai City by the Sea*, ed. J. Carswell, S. Deraniyagala, and A. Graham, 231–238. Aichwald: Linden Soft Verlage e.K.

Codrington, H.W. 1994. *Ceylon Coins and Currency*. New Delhi: Asian Educational Services.

Cooke, S.R.B., and S. Aschenbrenner. 1975. The Occurrence of Metallic Iron in Ancient Copper. *Journal of Field Archaeology* 2 (3): 251–266. https://doi.org/10.1179/009346975791491015.

Coomaraswamy, A.K. 1962. *Medieval Sinhalese Art*. 2nd ed. New York: Pantheon Books.

Cooray, P. G., and J. Katupotha. 1991. "Geological Evolution of the Coastal Zone of Sri Lanka." In *Symposium on" Causes of Coastal Erosion in Sri Lanka"*, 5–26. Colombo: CCD/GTZ.

Davenport, W.G., M. King, M. Schlesinger, and A.K. Biswas. 2002. *Extractive Metallurgy of Copper*. Fourth. Oxford: Elsevier Science Ltd.

Deraniyagala, S.U. 1972. The Citadel of Anuradhapura 1969: Excavations in the Gedige Area. *Ancient Ceylon* 2: 48–169.

Deraniyagala, S.U. 1986. Excavations in the Citadel of Anuradhapura: Gedige 1984, a Preliminary Report. *Ancient Ceylon* 6: 39–48.

Deraniyagala, S.U. 1992. *The Prehistory of Sri Lanka: An Ecological Perspective*. Colombo: Department of Archaeological Survey, Govt. of Sri Lanka.

Dharmawardene, R. 2015. A Classification of Black and Red Ware in Sri Lanka. *Ancient Ceylon* 24: 15–38.

Dirks, N.B. 1976. Political Authority and Structural Change in Early South Indian History. *Indian Economic & Social History Review* 13 (2): 125–157. https://doi.org/10.1177/001946468101300201.

Erb-Satullo, Nathaniel L., Brian J.J. Gilmour, and Nana Khakhutaishvili. 2015. Crucible Technologies in the Late Bronze-Early Iron Age South Caucasus: Copper Processing, Tin Bronze Production,

and the Possibility of Local Tin Ores. *Journal of Archaeological Science* 61: 260–276. https://doi.org/10.1016/j.jas.2015.05.010.
Feuerbach, A. M. 2002. "Crucible Steel in Central Asia: Production, Use, and Origins." http://discovery.ucl.ac.uk/1317704/1/272398.pdf.
Flecker, M. 2001. A Ninth-Century AD Arab or Indian Shipweck in Indonesia: First Evidence for Direct Trade with China. *World Archaeology* 32 (3): 335–354. https://doi.org/10.1080/00438240120048662.
Gorai, B., R.K. Jana, and Premchand. 2003. Characteristics and Utilisation of Copper Slag - a Review. *Resources, Conservation and Recycling* 39 (4): 299–313. https://doi.org/10.1016/S0921-3449(02)00171-4.
Gullapalli, P. 2009. Early Metal in South India: Copper and Iron in Megalithic Contexts. *Journal of World Prehistory* 22 (4): 439–459. https://doi.org/10.1007/s10963-009-9028-0.
Gururaja Rao, B.K. 1970. Development of Technology During the Iron Age in South India. *Indian Journal of History of Science* 5 (2): 253–271.
Hauptmann, A. 2014. The Investigation of Archaeometallurgical Slag. In *Archaeometallurgy in Global Perspective: Methods and Syntheses*, ed. B.W. Roberts and C.P. Thornton, 91–105. New York: Springer. https://doi.org/10.1007/978-1-4614-9017-3.
Hegde, K.T.M. 1973. A Model for Understanding Ancient Indian Iron Metallurgy. *Man* 8 (3): 416–421. https://doi.org/10.2307/2800318.
Hegde, K. T. M. 1981. "Scientific Basis and Technology of Ancient Indian Copper and Iron Metallurgy." *Indian Journal of History of Science*.
Johansen, P.G. 2014. Early Ironworking in Iron Age South India: New Evidence for the Social Organization of Production from Northern Karnataka. *Journal of Field Archaeology* 39 (3): 256–275. https://doi.org/10.1179/0093469014Z.00000000086.
Juleff, G. 1990. Crucible Steel in Sri Lanka and India: New Evidence. *Ancient Ceylon* 6 (12): 33–59.
Juleff, G. 1996a. An Ancient Wind-Powered Iron Smelting Technology in Sri Lanka. *Nature* 379 (4): 60–63. https://doi.org/10.1038/379060a0.
Juleff, G. 1996b. "Early Iron and Steel in Sri Lanka." Ph.D. Thes., University of London.
Juleff, G. 2013. Metal-Working at Mantai. In *Matai: City by the Sea*, ed. J. Carswell, S.U. Deraniyagala, and A. Graham, 277–312. Aichwald: Linden Soft Verlage e.K.
Juleff, G. 2015. "Crucible Steel at Hattota Amune, Sri Lanka, in the First Millennium AD: Archaeology and Contextualisation." In *Metals and Civilizations: Proceedings of the Seventh International Conference on the Beginnings of the Use of Metals and Alloys (BUMA VII)*, edited by S. Srinivasan, S. Ranganathan, and A. Giumlia-Mair, 78–86. Bangalore: National Institute of Advanced Studies.
Karunaratne, P., and G. Adikari. 1994. Excavations at Aligala Prehistoric Site. In *Further Studies in the Settlement Archaeology of Sigiriya Dambulla Region*, ed. S. Bandaranayake and M. Mogren, 55–62. Colombo: PGIAR.
Linrothe, R. 2013. A Changsha Sherd. In *Mantai: City by the Sea*, ed. J. Carswell, S. Deraniyagala, and A. Graham, 267–269. Aichwald: Linden Soft Verlag e.K.
Magee, P. 2010. Revisiting Indian Rouletted Ware and the Impact of Indian Ocean Trade in Early Historic South Asia. *Antiquity* 84 (326): 1043–1054. https://doi.org/10.1017/S0003598X00067065.
Mohanty, R. 2013. Indian Imported Pottery. In *Mantai: City by the Sea*, ed. J. Carswell, S. Deraniyagala, and A. Graham, 213–227. (Germany) Aichwald: Linden Soft Verlag e.K.
Neogi, P. 1918. *Copper in Ancient India*. Calcutta: The Indian Association for the Cultivation of Science. http://arxiv.iacs.res.in:8080/jspui/bitstream/10821/917/1/ The Indian association for the cultivation of science copper in ancient INDIA_P NEOGI_IACS_1.pdf.
Parr, J.F., and W.E. Boyd. 2002. The Probable Industrial Origin of Archaeological Daub at an Iron Age Site in Northeast Thailand. *Geoarchaeology - An International Journal* 17 (3): 285–303. https://doi.org/10.1002/gea.10013.
Pemadasa, M.A. 1984. Grasslands. In *Ecology and Biogeography in Sri Lanka*, ed. H. Dumont, 99–131. Lancaster: Dr. W. Junk Publishers.
Prakash, B. 2001. "Ferrous Metallurgy in Ancient India." In *Metallurgy in India: A Retrospective*, edited by P. Ramachandra Rao and N. G. Goswami, 52–91. Varanasi. http://eprints.nmlindia.org/5804.
Prematilake, P.L. 2003. Chinese Ceramics Discovered in Sri Lanka - An Overview. In *Sri Lanka and the Silk Road of the Sea*, ed. S. Bandaranayake, L. Dewaraja, R. Silva, and K.D.G. Wimalaratne, 225–236. Colombo: Sri Lanka Institute of International Relations.
Rehder, J.E. 1994. Blowpipes versus Bellows in Ancient Metallurgy. *Journal of Field Archaeology* 21 (3): 345–350. https://doi.org/10.1179/009346994791547562.
Rehren, T., L. Boscher, and E. Pernicka. 2012. Large Scale Smelting of Speiss and Arsenical Copper at Early Bronze Age Arisman, Iran. *Journal of Archaeological Science* 39 (6): 1717–1727. https://doi.org/10.1016/j.jas.2012.01.009.
Saravanan, R. 2017. "Iron : From Metal to Metallurgy." *Heritage: Journal of Multidisciplinary Studies. Archaeology* 5: 514–518.
Sasisekaran, B. 2002. Metallurgy and Metal Industry in Ancient Tamilandu- an Archaeological Study. *Indian Journal of History of Science* 37 (1): 17–29.
Sasisekaran, B., and B. Raghunatha Rao. 2001. "Iron in Ancient Tamilnadu." In *Metallurgy in India: A Retrospective*, 92–103. New Delhi: India International Publisher.
Schenk, H. 2001. "The Development of Pottery at Thissamaharama." In *Ancient Ruhuna: Sri Lankan–German Archaeological Project in the Southern Province*, edited by H. J. Weisshaar, H. Roth, and W. Wijeyapala, 59–138. (Germany) Mainz: Verlag Philipp Von Zabern.
Schenk, H. 2006. "The Dating and Historical Value of Rouletted Ware." *Zeitschrift Für Archäologie Aussereuropäischer Kulturen 1 (German)* 1: 123–52.
Schenk, H. 2015. Role of Ceramics in the Indian Ocean Maritime Trade during the Early Historical Period. In *Maritime Contacts of the Past: Deciphering Connections Amongst Communities*, ed. Sila Tripati, 143–181. New Delhi: Delta Book World.
Seneviratne, S. 1985. Iron Technology in Sri Lanka: A Preliminary Study of Resource Use and Production Techniques during the Early Iron Age. *Sri Lanka Journal of the Humanities XI* (1 & 2): 129–166.
Seneviratne, S. 1995. "The Ecology and Archaeology of the Seruwila Copper-Magnetite Deposit, North East Sri Lanka." *The Sri Lanka Journal of the Humanities* xxi (1 and 2): 114–45. http://hdl.handle.net/123456789/2449.
Seneviratne, S. 1984. The Archaeology of the Megalithic - Black and Red Ware Complex in Sri Lanka. *Ancient Ceylon* 5: 237–307.
Solangaraarachchi, R. 2011. "Ancient Iron Smelting Technology and the Settlement Pattern in the Kiri Oya Basin in the Dry Zone of Sri Lanka." Ph.D. Thes., University of Florida. 10.16194/j.cnki.31-1059/g4.2011.07.016.
Srinivasan, S. 1994. Wootz Crucible Steel: A Newly Discovered Production Site in South India. *Institute of Archaeology* 5: 49–59.
Srinivasan, S. 1997. Crucible Steel in South India-Preliminary Investigations on Crucibles from Some Newly Identified Sites. *In Materials Research Society Symposium* 462: 111–125.
Srinivasan, S. 2013. "Indian Iron and Steel, with Reference to Southern India." *The World of Iron*, 83–90.
Srinivasan, S. 2016. Tamil Chola Bronzes and Swamimalai Legacy: Metal Sources and Archaeotechnology. *JOM* 68 (8): 2207–2221. https://doi.org/10.1007/s11837-016-1959-1.

Srinivasan, S., and S. Ranganathan. 2004. *India's Legendary Wootz Steel*. Bangalore: National Institute of Advanced Studies and Indian Institute of Science.

Srinivasan, S., C.M. Sinopoli, K.D. Morrison, R. Gopal, and S. Ranganathan. 2009. South Indian Iron Age Iron and Higher Carbon Steel: With Reference to Kadebakele and Comparative Insights from Mel-Siruvalur. In *Metallurgy and Civilisation: Eurasia and Beyond, Proceedings of the 6th International Conference on the Beginnings of the Use of Metals and Alloys (BUMA VI)*, ed. J. Mei and Th. Rehren, 116–121. London: Archetype.

Tripathi, V. 2015. Metallurgical Innovations and Pattern of Adaptation of Iron in Early Cultures of India. In *Metals and Civilizations: Proceedings of the Seventh International Conference on the Beginnings of the Use of Metals and Alloys (BUMA VII)*, ed. S. Srinivasan, S. Ranganathan, and A. Giumlia-Mair, 95–102. Bangalore: National Institute of Advanced Studies.

Weisshaar, H. J., H. Schenk, and W. Wijeyapala. 2001. "Excavations in the Citadel at Akurugoda: The Workmen's Quarter (Tissa 1) and the Court's Garden (Tissa 2)." In *Ancient Ruhuna Sri Lankan–German Archaeological Project in the Southern Province*, edited by W. Weisshaar, H. J., Schenk, H., Wijeyapala, 5–39. (Germany) Mainz: Verlag Philipp von Zabern.

Woźniak, M. 2011. Indian Steel a Forgotten Commodity of the Great Trade Routes. *PAM* 24 (1): 709–726.

Yang, Z., Q. Lin, J. Xia, Y. He, G. Liao, and Y. Ke. 2013. Preparation and Crystallization of Glass-Ceramics Derived from Iron-Rich Copper Slag. *Journal of Alloys and Compounds* 574: 354–360. https://doi.org/10.1016/j.jallcom.2013.05.091.