The sustainability of the iron industry based on local wisdom in the Barito watershed

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Abstract. Iron has been important in human civilization since the abandonment of stone tools. The traditional technology of iron ore smelting in Indonesia has been known for hundreds of years, but research on the local traditional iron industry is still very minimal. This study aims to explain the iron industry in the southeast Kalimantan before modern times until the present using ethnography and experimental archaeological approaches. The research conducted in 2017-2019 at the upstream of Barito watershed, North Barito Regency, Central Kalimantan, has found 19 sites with the findings were furnaces, air pipes, iron ore fragments, charcoal, and slag. The traditional iron-making began with the process of mining, followed by iron ore smelting and forging. The archaeological experiments by smelting furnace produced the raw iron by a percentage of 40-60% from ore. The experiments produced the ingots with Fe content of about 80% (XRF analysis) and showed good ore quality. However, since the early 20th century the iron-making industry has been abandoned because of the arrivals of cheaper iron from China. Recently, the remaining iron industry consists of only the blacksmiths who produce agricultural equipment from scrap iron, some only gild to sharpen machetes and 'mandau'.

1. Introduction
After the stone age period, iron was the most dominant type of metal as a material for human equipment. Iron ore is abundant on the surface of the earth to the earth's core and celestial bodies that fall to the earth (meteors). Iron has been processed and used by humans for thousands of years ago, but the massive use of iron has occurred since the discovery of blast furnace technology in the United States from the early 17th century, but in this 21st century, China is leading the iron and steel production [1]. Iron is obtained from the stones containing the iron element (Fe), then it is melted and forged. Iron ore smelting expertise had been owned by people who live near iron ore sources, such as the Angkor iron and Cambodia which were mined by the Kui people on the border with Laos. Burmese and Siamese iron is mined from the mountains near the border of Burma and Siam, then processed in blacksmith villages [2]. In Malaysia, the smelting furnaces and tuyere fragments were found at the Lembah Bujang and Kampung Gading sites dating from 535 BCE-1500 CE [3,4]. The furnaces with associations of laterite ore deposits were also found at the Ban Kao Din Tai site, (Bangkok), Thailand with the site dating from the 4th-15th century [5]. The iron smelting technique in Xinjiang, China is much older at 1000 BCE [6], while in Khasi Hill, India at 353 BCE – 128 CE [7]. In Sumatra, iron ore mines were located in Gunung Besi, West Sumatra, which then moved to Salimpaung in the late 18th century, Beliton and Bangka [2]. The iron ore from Lake Matano, Luwu (South Sulawesi) is the best because of the nickel content that makes solid and corrosion-resistant iron [8,9]. Based on the OXIS (Origins of Complex Society in South
Sulawesi) research, it is known that the oldest iron foundries in Matano Lake were from the years of 1000-1250 CE [10].

People in Kalimantan are familiar with iron weapons such as mandau, blowguns, machetes, jamiya, and the spearhead. The narrative story states that the ancestors have the expertise to choose rocks that contain iron. The oral story of the greatness of iron in Kalimantan is well known, but until early 2017, the sites for making iron and iron ore sources have never been researched and scientifically informed. Archaeological research on traces of ironwork began with information that people in the Montalat watershed are still salvaging ironstones. The research has found some evidence of iron ore smelting sites such as iron slag mounds, iron ore fragments, air pipes made of clay (tuyere), charcoal, and dust furnaces [11,12].

There are four technique stages of iron metals making, mining of iron ore, breaking iron ore into small pieces, smelting ore to separate iron minerals from their impurities, and the final stage is forming the desired object [13]. The result of geological and mineral research found that the reserves of laterite iron ore in the southeastern part of Kalimantan is the highest compared to other places in Indonesia [14]. Laterite types are formed due to weathering, decomposition, and accumulation of residues in environments with a humid tropical climate that is very commonly found in Africa and Southeast Asia in the form of eluvial and alluvial deposits. The dominant mineral types in laterite are limonite and hematite [8,15].

Indonesia has an iron-making history, ore, and fuel sources, but until now we still import almost all raw iron as a material for the national steel industry. Blacksmith craftsmen in Indonesia still use traditional techniques that last for generations. On the other hand, nature in the southeast of Kalimantan provides a source of iron ore that can be processed not only for the local iron industry but also for the national iron industry. Therefore, this study aims to explain the traditional iron industry that once existed in southeastern Kalimantan, especially in the Barito watershed in the past and its sustainability until the present.

2. Materials and Methods
This research is qualitative and quantitative descriptive with deductive inductive reasoning. Primary data were obtained from archeological research in 2017-2019 using survey, excavation, and experimental methods. Tools used in surveys and excavations were data recording equipment (cameras and voice recorders), notebooks, GPS, compass, scraper to extract findings in the soil, buckets to dispose of soil, meter as a measuring instrument, scales, threads, and pegs to layout dig box, water-pass to measure the height of the ground surface, and Munsell soil color charts to determine the type and color of the soils. Medical kits were also prepared, especially basic medicines and first aid such as bandages, red drugs, alcohol, and disinfectants.

The Archaeological experiment and mineral analysis used the square-shaped furnace from the Buren Benangin as a basis for preparing the equipment. Iron ore smelting experiments required a place in open land, an electric blower with a capacity of 2 inches and 3000 RPM (rotation per minutes) as a substitute for double piston gray, air pipes from the iron pipe with a size of 2 inches, large pliers to lift iron, wooden square to solidify the walls of the furnace, water and water barrel for emulsifying the soil and safety if fire spread, thermometer with the ability to measure up to 1763 °C, metal detectors, charcoal from halaban or ulin wood, limestone as flux, iron ore in the form of laterite rocks, clay for making furnaces, and magnets to find out the iron content (figure 1).

2.1. Archaeological survey and excavation
A survey was conducted to gain a physical description of data in the field by directly observing objects and interviewing informants who knew about the object. The excavation was a way to obtain archeological data that was buried in the ground through systematic soil excavation [16]. The excavation was based on surface findings and alleged archeological data placed in the ground obtained from the survey. The excavation consisted of the stages of preparation, excavation, recording data, and findings analysis.
The preparation phase included licensing with agencies, customs, and landowners, checking equipment, laying out the digging box according to the direction of the wind, determining the highest point (datum point) for the reference depth of findings, and determining the type of excavation (system grid, lot, spit, or layer). The excavation process consisted of extracting soil per layer or certain depths (spit) depending on the condition of the finding (for these Buren sites with spit depth per 10 cm and the soil layer), recording the findings, and ending with returning the soil into the dug box. The handling of basic level findings in the form of cleaning of attached soil, basic classification, and labeling was done in the field. The taxonomy and typology phases were carried out in the base camp or the artifact workspace at the office, while mineral and radiocarbon analyzes were carried out in the laboratories. The mineral analysis using X-RF (X-ray fluorescence) technique was conducted at the Mineral and Materials Laboratory of the Faculty of Mathematics and Natural Sciences (MIPA), University of Negeri Malang, while for dating analysis radiocarbon (AMS) was used at Waikato University, New Zealand.

2.2. Archaeological experiment and mineral analysis
The stages in archeological experiments include:
1. Preparing tools and materials
2. Constructing smelting furnaces and installation of air pipes
3. Drying ore and breaking into small pieces
4. Inserting charcoal into the furnace, ore fragments, and flux through the top of the furnace
5. Lightening the furnace, turn on the electric blower to supply air into the furnace through the air pipe (PVC)
6. Smelting iron ore until it reaches the melting point of iron (1530 °C)
7. Taking the raw material through the bottom of the furnace

The experiment began with two questions about the iron content in laterite ore and smelting furnaces which had square shape interior. Several variables were the objects of this experiment, independent variables and dependent variables. The independent variable was the actor or research subject who determined the shape of the melting furnace: round or square, the amount and type of iron ore, fuel (charcoal), air intake, and the time needed to melt. The dependent variable in the form of physical data was the amount and quality of raw material (ingot) and iron slag produced.

The experimental furnace was made based on data from Buren Benangin, whose top was a round cone and the inside was square. The furnaces were built by yellow and black clay taken from the outcrop of the Montalat River at RT 01, Pelari Village, Kecamatan Gunung Timang District, Kabupaten Barito Utara. One of the aims of this experiment was to prove the difference in the melting point between the two different shapes of furnaces. Therefore, four furnaces have been made in two different types, square
and spherical inside shape. The question would be answered by the first stage of smelting, from furnace A (square) and B (spherical).

The two hypotheses formulated to be tested in the iron smelting experiments were:
1. Laterite ore from the Buren sites has a low iron (Fe) content so to obtain raw iron (ingot) requires a lot of ore.
2. The interior furnace with a square shape requires more time to reach the melting point than the furnace which has a spherical shape because the air circulation in the square is not smooth.

The first hypothesis about red laterite (hematite) was tested in furnaces A and C, while brown laterite in furnaces B and D. Experimental materials in the form of laterite were taken from Buren Benangin and Semayap River, while red laterite (hematite) was taken from Buren Benangin and Temelalo. The four-furnace experiment required about 250 kg of halaban wood charcoal.

There were two methods used to measure temperature quantitatively, thermocouple measuring instrument and steel-stirr-up. Thermocouple measuring devices functioned as temperature sensors. The K thermocouple sensitivity type starts at 0°C-1767°C, so temperatures above 1767°C cannot be measured. Steel stirrups were inserted into the smelting furnace to help the limitations of thermocouple devices. The iron would melt at a temperature of 1538°C and boil at 2800°C so that the comparison between the two tools would be obtained by cross-checking the obtained temperature.

3. Results and discussion

3.1. The results of archaeological survey and excavation

Archaeological research of ancient metals was started based on the ironstones (the Dayak Taboyan community term for iron ore) information in Montalat River. The Montalat is a branch of the upper Barito River located in Kecamatan Gunung Timang and Montalat, Kabupaten Barito Utara, Central Kalimantan. The upstream is situated on the Muller Mountains (Kabupaten Murung Raya, Central Kalimantan) and empties into the Java Sea.

The Dayak Taboyan community called the location of the former iron ore smelting as ‘Buren’, which was marked by a mound of iron slag. Archeological research in 2017 s.d. 2019 found the Buren sites along the Teweh River and Montalat River, both of them were tributaries of the Barito. The survey found 19 sites that were identified by the remaining findings of iron ore smelting activities such as iron slag, the raw material (ingot), iron ore fragments, and burning clay. The fragments of burning clay indicated forms of smelting furnaces and air pipes (tuyere) beside it in almost intact forms.

Figure 2. The Buren Benangin with findings of furnaces, ore, tuyere, and slag. (Source: Balai Arkeologi Kalsel)
The excavation of test pits was carried out at four sites, Buren Benangin, Buren Mejahing, Buren Temelalo, and Buren Jaga. The excavations at those sites found six smelting furnaces, thousands of iron slags, the fragments of air pipes from clay (tuyeres), and iron ores. The other furnaces were found during the survey. Through the excavations in Buren Benangin (figure 2), Buren Temelalu, and Buren Jaga, two furnaces were found in each site. The smelting furnaces were made of clay with round shape and narrow top. The outside part of the seven furnaces had a similar roughly round shape but the inside was square with compaction walls. The furnaces were destroyed on the top and it is estimated that the furnace's height was intact at around 1 meter.

According to the ethnohistorical data of Dayak Taboyan, smelting has been abandoned for the past four generations or around 170 years ago. This is in line with the results of radiocarbon analysis ($^{14}$C) from charcoal samples that show the youngest period of 1820 (Buren Jaga) and the oldest from 1360 (Buren Benangin). The community still treasures legacy weapons such as saber, machete, jamiya (small knife) which were made from Montalat also known as Montalat iron weapons [12].

The sustainability of the iron industry in Montalat was supported by natural resources of laterite ore found along the Montalat River, Teweh River, and its tributaries. The data of archaeological survey and excavation depicted that the type of iron ore found in the Buren sites had the same type of rock in the surrounding river and hill, such as the Benangin River near Buren Benangin, and the hill around Buren Japus. The ore type was laterite as the result of ultra-base rocks weathering.

Local peoples informed that the source of ore from Montalat River was precisely in Maninyau cascade. Whenever the water discharge was high, the stones could not be taken even though by diving, because of the deep and heavy current. Maninyau cliff looked like riverbanks with a type of brownish-red laterite rock which contained a lot of iron, during the dry season research in June 2019 [12]. In general, there are three types of iron ore in Indonesia, namely primary iron with an average of iron content (Fe) of 47.14%, iron sand 47.08%, and laterite with a Fe content of 30.26% [18]. Laterite with iron (Fe) content of 40-60% was found in the Kalimantan region [14], higher than the average Fe content in laterites which is 30.26%. The good quality ore for smelting contains hematite (Fe2O3), magnetic (Fe2O4), siderite (FeCO3), and limonite/goethite (FeO) minerals [19].

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The ore was roasted before being put into the smelting furnace to reduce water content. This process was carried out in the open place by burning charcoal over the wet ore until the iron was almost dry, then the ore was broken into small pieces.

After the charcoal, iron ore and flux were put into the furnace then it was ignited (figure 3), and temperature measurements were taken to control the heat (figure 4). There were two methods used to measure temperature quantitatively, thermocouple measuring instrument and steel stirrup. Thermocouple measuring devices functioned as temperature sensors. The K thermocouple sensitivity type starts at 0°C-1767°C, so temperatures above 1767°C cannot be measured. Steel stirrups were inserted into the smelting furnace to help the limitations of thermocouple devices. The iron would melt at a temperature of 1538°C and boil at 2800°C so that the comparison between the two tools would be obtained by cross-checking the obtained temperature.

The comparison of melting temperature between furnaces A, B, C, and D before using the blower was below 1000 °C with the highest temperature amid an average temperature of 800 °C. The comparison after using a blower, however, the temperature was above 1000°C with the highest temperature above 1767°C where the thermocouple could not measure it. An air pump blower was useful to increase the temperature in the melting furnace. The iron ore smelting process took between 4,5 and 9.5 hours, with the results shown in table 1.

Experimental results in table 1 show that the red laterite ore from Buren Temelalo (furnace A) and Buren Benangin (furnace C) produced the crude iron percentage of 60.4% and 50.9%. The percentage above 50% of iron ore is high. The blackish-brown laterite from Semayap River (furnace B) and Buren Benangin (furnace) produced a fairly low percentage of raw iron at 46.9% and 21.7%. Based on the smelting results, it is concluded that ancient iron smelters had the expertise to choose the type of red laterite with high hematite elements similar to those found in the Buren Benangin and Temelalo. Hematite is one of the good constituent minerals of laterite iron ore, besides magnetic, siderite, and limonite [19]. It was found from the XRF analysis that the laterite iron ore from Buren Benangin contained a very high iron (Fe) element with 96.69%, as well as laterites taken directly from Maninyau which had 90.55% iron content (table 2) based on the percentage relative to another mineral or real

Figures 3 and 4. The iron ore smelting experiment process
(Source: Balai Arkeologi Kalsel)
content of iron. Thus, the hypothesis that states that the laterite type of iron ore from the Montalat watershed has a low iron content so they need to gain large amounts of iron ore apparently cannot be accepted.

**Table 1.** Comparison of ingredients and result of smelting experiment.

| Furnace/Basic Form | Ore Source | Weight (Kg) | Charcoal (kg) | Flux (kg) | Time (hour) | Smelting Result (Ingot %) | Annotation |
|--------------------|-----------|-------------|---------------|-----------|-------------|--------------------------|------------|
| A Square           | Laterite\(^a\) Buren Temelalo | 10 kg | 58.4 | - | 4.5 | 6.04 kg (60.4 %) | iron was separated from slag but not perfectly |
| B Rounded          | Laterite\(^b\) Semayap River | 10 kg | 48.8 | - | 4.5 | 4.69 kg (46.9 %) | iron was separated from slag but not perfectly |
| C Square combined A & B | Laterite\(^c\) Buren Benangin | 5.3 kg | 82.1 | 22.5 | 9.5 | 2.7 kg (50.9) | Iron was perfectly separated from the slag |
| D Square           | Laterite\(^b\) Buren Benangin | 7.8 kg | 61.4 | 22.5 | 9.5 | 1.7 kg (21.7 %) | iron was perfectly separated from the slag |

\(^a\) red laterite with heavier weights than brown laterite (hematite)
\(^b\) brown laterite with small iron content

**Table 2.** Results of XRF analysis of mineral content based on the real content.

| No. | Sample | Fe  | Al  | Si  | K   | Ca  | Mn  | P    | Others Mineral |
|-----|--------|-----|-----|-----|-----|-----|-----|------|----------------|
| 1.  | Ingot Furnace A (from Buren Temelato) | 79.21 | 5   | 8.4 | 2.3 | 1.28 | 1.0 | 0.34 | 1.34 |
| 2.  | Ingot Furnace B (from Semayap River) | 84.24 | 4   | 7.3 | 1.7 | 0.74 | 0.3 | 0.39 | 1.33 |
| 3.  | Ingot Bure Benangin | 86.79 | 3   | 6.9 | 0.38 | 0.57 | 0.66 | 0.26 | 1.44 |
| 4.  | Red Laterite Buren Benangin | 96.69 | -   | 1.2 | -   | 0.19 | 1.64 | 0.2  | 0.08 |
| 5.  | Brown Laterite Maninyau (Montalat River) | 90.55 | 1   | 4.3 | 0.35 | 0.43 | 1.66 | 0.26 | 1.45 |

The quality of laterite was also seen from the Fe content in raw iron (ingots) produced from the smelting furnace. The XRF analysis of ingot samples from smelting furnace A shows that red laterite from Buren Temelalo contained iron (Fe) as much as 79.21\% rel, while aluminum, potassium, calcium, manganese, each between 1-8\% rel, whereas phosphorus, titanium, chromium, bromine, rubidium, and europium were respectively below 1\% rel. Ingot from furnace B (laterite material from the Semayap River) contained 84.24\% rel iron (Fe), greater than ingot from furnace A. There were different types of minerals found in furnace A and furnace B, titanium (Ti) existed in ingots furnace A but not in furnace ingot B. Likewise the lanthanum mineral (La) was in furnace ingot B but not in furnace ingot A. Even though iron ore and ingot materials were from the same material but the iron minerals were different.
This difference in mineral types was most likely influenced by the quality of the sample and the smelting process where the iron mineral was separated from other minerals that were bound to each other.

The results of the iron ore smelting experiment also prove the second hypothesis that the shape of the inside of the furnace has no effect on time and result from smelting, but only affects the capacity (table 1). The shape contained more iron ore and charcoal material than the round shape. Thus, the hypothesis that a furnace with a square inside takes more time to reach the smelting point than a furnace with a round inside is incorrect.

3.3. The sustainability of the iron industry on the Barito watershed

Industrial archeology aims to explain the development of industrial processes to arouse the enthusiasm of educated generations to continue the research and utilization [20]. Documentation and preservation of archeological sites need to be carried out as evidence of human civilization. The important value of information content in industrial sites can be utilized in the global era, for example as educational material and evoke awareness of the social and cultural problems.

The sustainable iron industry in the Barito's upstream is not directly proportional to the availability of material sources. The ethnohistorical studies from documents mentioned that the iron ore smelting industry in upstream of Barito had stopped at the end of the 19th century due to the entry of cheaper iron from China [11]. Now, the remaining iron industry is in the form of blacksmiths who make plantation and agricultural equipment using scrap metals such as cars, boat plates, and railroads. Recently, every one village in the upper Barito, only has one or two blacksmiths, who have a type of work for sharpening blunted machetes.

The wrought iron industry is still ongoing in the downstream part of the Barito, in Nagara (Hulu Sungai Selatan, South Kalimantan). There are still hundreds of blacksmiths in the area, especially in Tumbukan Banyu and Sungai Pinang villages. They no longer use raw iron from smelting, but scrap metal from car pears and plate iron [21]. In the past, Nagara blacksmith obtained raw iron from iron ore smelting craftsmen from Dusun Hulu or Barito upstream, but since it had stopped, Nagara’s blacksmith craftsmen have used scrap metal as their raw material. The raw materials are supplied by iron traders from Banjarmasin.

In the South Kalimantan precisely Sebuku Island, Kotabaru, there was an iron smelter, namely PT SILO. During the year of 2004 until 2014, the company had exported 9-10 tons of laterite iron ore to China annually. After limiting the export of raw minerals (without processing) in early 2014, the company tried to build a smelter that produced laterite concentrate with Ferrum (Fe) content of 53% [22]. However, shortly afterward, in 2017 the company stopped operating due to the licensing issues with the Gubernur Provinsi Kalimantan Selatan (South Kalimantan Provincial Government) [23]. There is no more iron ore processing industry in Kalimantan, so raw iron has been imported for the national steel materials industry and it continues until now [24]. This is an irony because the source of iron ore is available but almost 100% raw iron in the national steel industry for PT Krakatau Steel is imported from China. It is proven from geological and mineral surveys that the source of iron ore in South Kalimantan is around 500 million tons [25].

The traditional technique of ironworking in Indonesia known today is the iron forging carried out by blacksmiths. Iron forging techniques are needed to condense iron particles so that a solid, strong iron surface is obtained. There are several blacksmith technology studies to get more effective performance and results, for example using a closed furnace with a blower [26]. There are also hitting machine technology and carbonization technology to simplify the production process and produce quality products with a strong surface and high wear resistance [27]. However, the results of these studies have not been applied by the blacksmith.

In the iron industry, iron forging techniques are still used as a method of compacting iron particles to make them more homogeneous, solid, and robust. In fact, the surviving iron industry in Kalimantan consists only of blacksmiths who utilize scrap metal into new tools. The decreasing number of blacksmiths has been caused by the lower public orders due to a large number of cheaper manufactured iron tools on the market. Blacksmith has a high risk in its technical work, so it is necessary to think of
practical technologies that will simplify the production process. These practical technologies include hitting machines instead of hammers and sledgehammer, or robotic blacksmiths to make large-sized metals that cannot be done by a human. Blacksmith robots that began to be applied in modern countries is an improvised blacksmith's art with new digital capabilities. The basic principle is the automation of the process of forming parts, but with a blacksmith's basic approach, to make parts larger, more efficient, and reproducible [28]. The modern blacksmith's model is a hope that someday Indonesia can realize it. Hopefully, the government will encourage to revive the iron-making industry and modern blacksmith-based smithing technology to meet the national iron needs.

4. Conclusion

The experiment of simple furnaces found that the shape of the smelting furnace had no effect on the time to reach of smelting point and smelting result, but it gave the effect of the amount or volume of material that was inserted into the furnace. Square shaped furnaces could contain more iron ore and charcoal than round furnaces. The results of experiments in furnaces A and C with hematite laterites (red laterites) content showed the high percentage of the production of raw iron (between 50 to 60%), while brown laterites (furnaces B and D) produced quite low raw iron (ingots) which was between 21 to 46%. In the Barito watershed, there were two types of laterite, red laterite which had more weights with a high content of iron elements, and brown laterite which contained little iron.

The iron ore smelting industry in the Barito's upstream has stopped, but the iron forging industry in the old village with its center on the banks of the Nagara River continues until the present. In Indonesia, especially in Kalimantan, there is no more raw iron produced from iron ore smelting, so blacksmiths use the scrap metal. Blacksmiths who are using scrap metal have an impact on cultural sustainability as well as the utilizing of reused items that reduce metal waste on the earth. The existence of reused items is a continuation of the traditional iron industry chain. Learning from the history of our ancestors and the existence of an abundance of iron ore, reviving the iron ore smelting industry and modern forging is an important necessity.

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