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Case report

Pulau Ampat site: A submerged 8th century iron production village in Matano Lake, South Sulawesi, Indonesia

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ABSTRACT

The population of Indonesia grew dramatically after her people discovered iron sources and started to use iron tools. One of the oldest known iron sources is Luwu in South Sulawesi. Based on historical and archaeological records, Java's 13th to 15th century Majapahit Empire imported iron of exceptional quality, known as *Pamor Luwu*, for forging kris daggers. Research done in 2016 and 2018 by Indonesia's National Research Center for Archaeology confirms previously reported evidence that the primary source of *Pamor Luwu* is smelted ore from the Matano Lake environs. Complementing the remnants of iron production at terrestrial sites, we found evidence for it in an underwater site named Pulau Ampat. This research is the first underwater archaeology research on iron production in Asia, and our discovery broadens the knowledge of iron production in Indonesia dating to the 1st millennium AD.

1. Introduction

The antiquity of iron in Indonesia is similar to the antiquity of bronze and gold (Table 1), which has convinced scholars to recognize a Bronze-Iron Age (Van Heekeren, 1958), Paleometallic Period (Soegondho, 1995), or Early Metal Age (Bellwood, 2017). This situation is different from continental Eurasia where an identifiable Bronze Age preceded the Iron Age by centuries (e.g., Pigott, 2012). Indonesia's Early Metal Age originated possibly as early as 600–500 BC, later than the age of iron metallurgy in continental Eurasia (see Discussion), which indicates that the earliest metal items were imports. However, the evidence suggests local bronze casting in Bali by the 1st century BC and local iron processing in Sulawesi possibly by the early centuries AD (Table 1). Of particular interest is the process by which Indonesia's sources of iron ore were discovered and the technology for iron smelting developed, notably in Sulawesi, whose name means 'Island of Iron'.

Indonesia straddles the two partially submerged Pleistocene continents of Sunda at the west and Sahul at the east, bridged by the islands of Wallacea which have never been joined to either continent (Kealy et al., 2017). Sulawesi, the largest of the Wallacea islands, is renowned for its Pleistocene archaeological discoveries. Examples include: a stone tool dating back to 300,000 years ago in the Lake Tempe area in Soppeng (Alink et al., 2017); cave paintings in Maros which date to 40,000–45,000 years ago, are amongst the world's oldest dated cave art (Aubert et al., 2019; Brumm et al., 2021a, 2021b); cave occupation dated back to 20,000–40,000 years ago at Gua Topogaro 2 in Central Sulawesi and Leang Sakapao 1, Leang Burung 2 and Leang Bulu Betue in Maros (Kaharudin et al., 2020; Fuentes et al., 2021; Brumm et al., 2021a, 2021b); and 22,000 year old jewelry made of animal bones at Leang Bulu Betue (Brumm et al., 2017). Sulawesi is also rich in Holocene sites, notably the South Sulawesi pre-Neolithic 'Toalean' sites with their unique toolkit of backed microliths and serrated projectile points of stone (Suryatman et al., 2019; Perston et al., 2021), and Neolithic to Iron Age sites associated with the ethnic foundations of Sulawesi's current

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inhabitants (see chapters in O'Connor et al., 2018).

Lake Matano (Fig. 1) is located in the Malili region, South Sulawesi Province. At 382 m above sea level, it is one of the highest lakes within its lake complex. It has a depth of 590 m with the bottom of the lake located 203 m below sea level. It is the eighth deepest lake in the world (Herder, 2006) and the deepest lake in Southeast Asia, and has an area of 16,408 ha and a length from west to east of 28 km. Overflow from Lake Matano discharges into Lake Mahalona which connects to Lake Towuti and in turn to the river Larona. Lake Matano lies on the Matano Fault Zone which is still active with tectonic movement of approximately 2 cm per year. Lake Matano is considered to be 1–4 million years old (i.e. to have formed in the late Pliocene) (Tamuntuan et al., 2010).

The Matano Lake region in South Sulawesi is well-known for its present-day nickel mining by the PT Vale Indonesia company. It is also rich in iron, with three of the five commercial deposits of iron ore recognized for South Sulawesi province (Bulbeck, 1996–7: Fig. 1). A previous study conducted by the OXIS Project (Bulbeck and Caldwell, 2000) succeeded in identifying mass iron production along the northern shore during much of the second millennium CE, and iron smelting at Matano village on the western shore from around 1500 to 1900. However, recent re-excavation at Matano village redates the origins of iron smelting there to around AD 1000 (Suryatman et al., 2021). Both studies relate the Matano industry to the production of *Pamor Luwu* (etch-resistant iron from Luwu) imported by the medieval Javanese empire of Majapahit for interweaving layers of iron and nickel to forge the wavy-bladed daggers known as krisses (Solyom and Solyom, 1978; Bronson, 1987; Frey, 1989). Evidence for this connection includes the mention of Luwu in the 14th century Javanese poem known as the Nāgarakṛtāgama (Reid, 1988: 110; Dunham, 1992: 132). The high quality of Luwu iron arises from concentration of the heavy metals found naturally in the local ore, including chromium and belatedly titanium as well as nickel (Sumantri et al., 2013), originating at some point during the 1st millennium CE (Table 2) (Fig. 2).

Recent research conducted by the National Research Center for Archaeology has found a submerged landscape site within Lake Matano, known as Pulau Ampat ('Fourth Island'). The site (section 3.2) was discovered in 2016 following reports from local divers that they often salvaged metal artifacts from there. In contrast to the considerable maritime archaeology at shipwrecks and other marine sites, underwater archaeology of submerged landscapes in a lake has not been done much before in Indonesia (Adhityatama and Yarista, 2019) or, indeed, elsewhere in Asia and Southeast Asia. The archaeology of submerged landscapes has the potential to contribute new and unique data to address significant questions in human history (Benjamin and Hale, 2012; Lemke, 2020).

2. Methods

This study uses inductive reasoning, which in archaeology means taking material culture as the primary evidence, coupled with extensive description and documentation of the evidence with close attention to detail (Tanudirjo, 1995). Our research is explorative and comparative-descriptive, focusing on primary archaeological data and the context of the remains within their terrestrial and underwater environments. The survey was conducted by diving, using SCUBA (Self Contained Underwater Breathing Apparatus) equipment for underwater objects and a dive plan according to DCIEM Tables for high altitude lakes. We performed in situ recording and measurements using underwater archaeological techniques such as the baseline and quadrant methods (Bowens, 2009).

We made a 10 × 10-m baseline and quadrant crossing the concentration of finds (Figs. 3 and 4). All the samples representing each type of findings located inside the baseline and quadrant were collected to make a control sampling, while other findings are only recorded and left in situ. We also performed 3D photogrammetry, following Bedford (2017) and McCarthy and Benjamin (2014), for recording and analysis of sites located at the bottom of a lake. Database recording was also done to obtain a complete data collection of our archaeological findings at Lake Matano. We used ArcGIS for spatial analysis, to examine the distribution of our archaeological findings at Lake Matano and for data transformation.

Site transformation was examined through field surveys and literature study of geological data related to the Lake Matano environment. The description of data was then performed and a comparative analysis with related historical sources was done after all the primary data were collected. We also conducted surveys of terrestrial iron sources and observations on the inhabitants' cultural lifeways We used the C-14 dating methods for estimating the age of the organic archaeological materials found at the Palau Ampat site. There is no reason to suspect any influence of the samples' underwater environment on the calculations of their age; paleoenvironmental analysis of pollen cores, including those in Lake Towuti and Wanda Meir near Lake Matano, consistently applies C-14 dating to charcoal and other inclusions in the cores, without indication of potential contamination issues (Stevenson, 2018). C-14 dating was carried out at the Center for Geological Survey, Bandung (Pusat Survei Geologi - PSG) and at ETH-Zürich. We also undertook stable isotope analysis of a bovid tooth, to find out the environment of the bovid's diet (Ben-David and Flaherty, 2012). The stable isotope analysis was conducted at the Max Planck Institute laboratory for Chemistry.

Table 1
Early dated sites in Indonesia with metal finds.

Site	Island	Metal finds	Local metallurgy	Dating	Reference
Gua Harimau (Burial 1.11)	Sumatra	Bronze axes, iron spatulas	No evidence	638 ± 88 calBC[a]	Fauzi et al. (2016)
Leang Codong	Sulawesi	Bronze leaf, iron spearhead	No evidence	Last centuries calBC[b]	Bulbeck (1996–7)
Sembiran/Pacung	Bali	Bronze, gold	Bronze casting	~100 calBC[c]	Calo et al. (2015)
Sakkarra	Sulawesi	Corroded fish hook, iron slag	Iron working	calBC/AD[d]	Suryatman et al., (2018)
Sabbang Loang	Sulawesi	Iron fragments and spearheads, ironstone	Possible iron roasting	Early centuries CE[e]	Bulbeck and Caldwell (2000)
Gilimanuk	Bali	Bronze, iron, gold grave goods	No evidence	AD 150–350[f]	Soegondho (1995)
Gua Talimbue	Sulawesi	Iron pendant	No evidence	250–400 calAD[g]	Bulbeck et al. (2016)

[a] Calibration of direct AMS dating (Waikato Laboratory) of 2477 ± 25 BP on this burial's teeth. Table 6.5 in Fauzi et al. (2016) erroneously attributes to this burial a conventional C-14 dating of 2290 ± 20 BP, which relates to another burial with a bronze bracelet.

[b] Conventional C-14 date on teeth (under preparation for publication).

[c] Bayesian analysis of multiple AMS dates from the Pacung burials.

[d] Calibrated AMS dates of 2125–1895 and 2062–1867 BP.

[e] Five conventional C-14 and AMS dates whose calibrated range extends up to ~400 calAD.

[f] Appraisal of large number of conventional C-14 dates.

[g] Calibrated range for direct AMS date on the burial with the pendant.

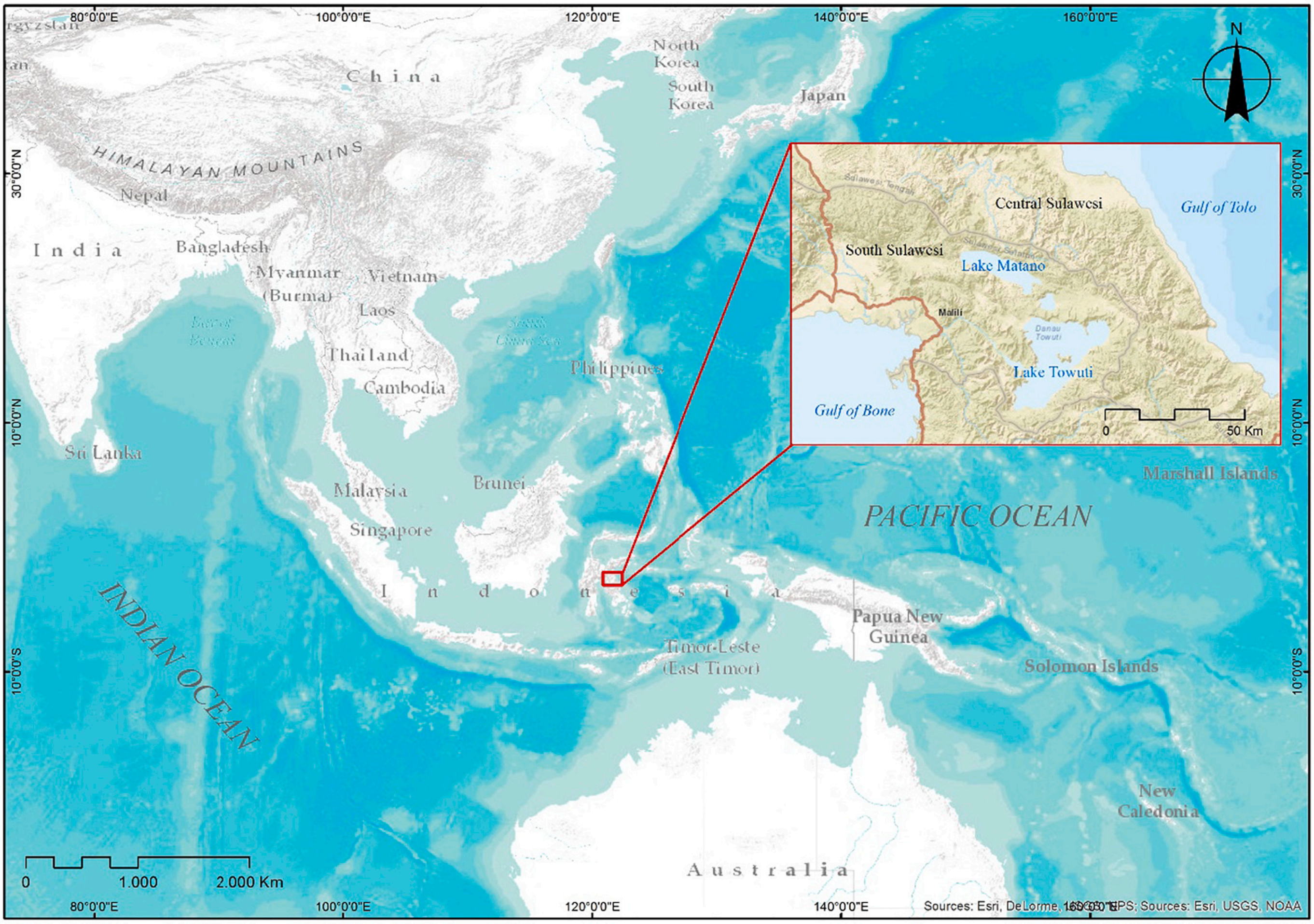

Fig. 1. Maps of the location Lake Matano in Sulawesi Island, Indonesia (Source: Muslim Dimas KD/Puslit Arkenas, 2019).

Table 2
Scanning electron microscope energy dispersive X-ray spectrometer (SEM EDS) stoichiometry analysis of Matano iron samples.

Site	Sample	Age (AD)	%Nickel	%Chromium	%Titanium
Sabbang Loang	Artifact 5015	Early centuries	–	–	–
Sabbang Loang	Artifact 1247A	Early centuries	–	–	–
Katue	Artifact 2545	1st millennium	0.5	1.3	–
Katue	Prill 2816A	1st millennium	43.2	–	–
Nuha	Slag 4628	11th–13th centuries	–	1.7	–
Pinanto	Artifact 1664	15th–17th centuries	1.2, 1.5	0–0.7	–
Rahampu'u	Artifact 164	15th–17th centuries	0.8	0.1	–
Rahampu'u	Artifact 184A	15th–17th centuries	0.4	–	–
Rahampu'u	Slag 512A	15th–17th centuries	–	0.6	–
Rahampu'u	Tuyère residue 4220	15th–17th centuries	3.5, 5.0	–	–
Pandai Besi	Artifact 643A	15th–17th centuries	0.6	0.3	–
Pandai Besi	Slag 888A	15th–17th centuries	–	0.7	0.2
Pandai Besi	Ore 646A	15th–17th centuries	0.3	29.8	0.2
Pandai Besi	Ore 890	15th–17th centuries	0–1.4	0.8, 2.0	–
Pandai Besi	Gangue 897	15th–17th centuries	0.2	0.3	0.4
Lemogola	Ore 704A	19th–20th centuries	–	–	–
Lemogola	Slag 707A	19th–20th centuries	–	1.5–2.5	0–0.5
Lemogola	Slag 713A	19th–20th centuries	–	0.5, 1.1	0.1, 0.2
Bukit Lamolengku	Ore 124	Ethnographic	–	√	–

Percentages for artifacts refer to element composition and for other samples to oxide (NiO, Cr_2O_3, TiO_2) composition. Dashes indicate a presence (if any) below detection limits. All data from Do (2013) except the Bukit Lamolengku data from Bulbeck and Caldwell (2000).

3. Results

3.1. Lake Matano geology

Lake Matano was formed through a pull-apart mechanism, where two opposing segments move away from each other. The segments in question are part of the Matano Fault, a horizontal fault-oriented east–southeast and west-northwest with maximum compressive principal stress axes directed at N38° / 30° (Surono, 2010; Lukman et al., 2016; Watkinson and Hall, 2017).

Fig. 2. Underwater spearhead from Lake Matano was found in good, less rusty condition, potentially attributable to its partial composition of heavy metals (see Table 2) (Source: Triwurjani et al., 2019).

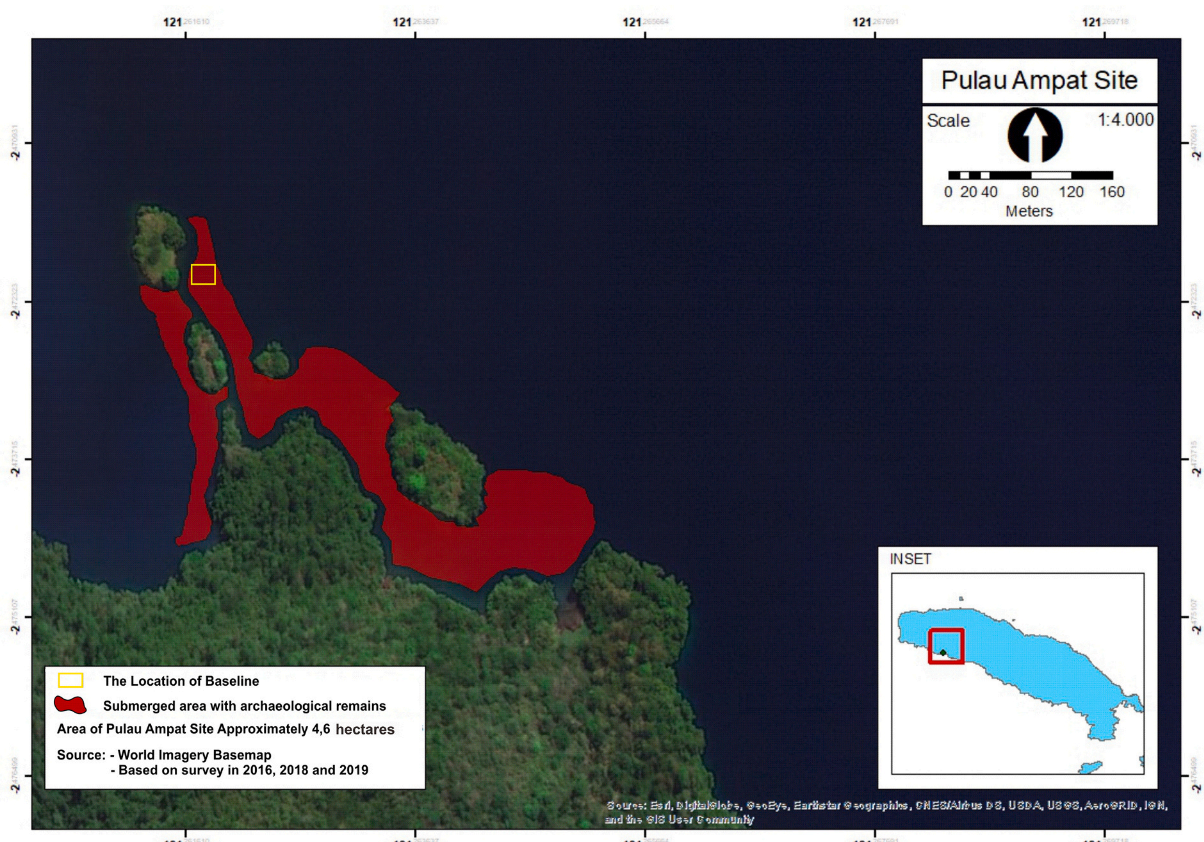

Fig. 3. Location of the Pulau Ampat Site in Lake Matano. Underwater survey showed the area of the site is approximately 4.6 ha, with an average depth of the site of 3–15 m below water level (source: Triwurjani et al., 2019).

A pull-apart mechanism causes deep subsidence in the middle so that it forms a basin or graben. This graben then fills with water and forms a lake, in this case, Lake Matano. Topographic formations, geological maps, and depth maps (bathymetry) around Lake Matano indicate that the graben of Lake Matano, which may have a southeast–northwest direction, crosses the path of the main Matano fault. The Matano fault and graben make an ideal example of the pull-apart basin model as theorized by Schubert (1982), referred to as the rhomboidal shape model (Fig. 6).

From the topographic map, it can be seen that several slopes directly

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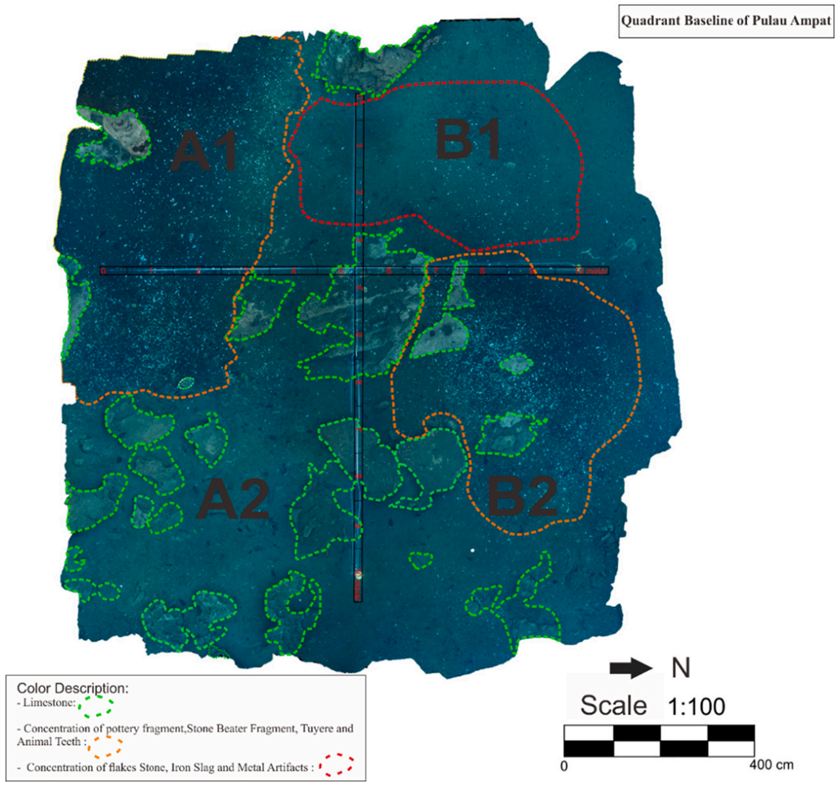

Fig. 4. Photogrammetry of the baseline and quadrant at Pulau Ampat site, showing the concentration of finds. We stretched out the baseline 10 × 10 m to make quadrants named A1, A2, B1, and B2 quadrants.

adjacent to the lake show a steep drop. This field of sharp slopes extends in a generally southeast-northwest direction (Fig. 6). Simandjuntak et al. (1991) have placed several faults on the south side of Lake Matano, although the fault type has not been determined. One fault is directed southeast–northwest, transversely towards the main Matano Fault (Fig. 6).

Our field observations support the above framework, including a terraced waterfall on the Wera River directed at N280° E – N330° E, and steep underwater slopes around Pulau Ampat that have an azimuth of N330° E and slope to the east. The Pulau Ampat site is likely to lie in the Matano graben, so it is possible that the subsidence of the graben caused the site's sinking. The Lake Matano Graben is expected to continue to subside as long as the main fault is active (Bellier et al., 2006; Surono, 2010). Subsidence of the Pulau Ampat site may have resulted from a succession of earthquakes rather than a single, major earthquake at a time before detailed records became available; for instance, earthquake data from 1970 documents 42 significant earthquakes along the Matano fault (Lukman et al., 2016).

The active status of the Matano shear fracture may well trigger other natural disasters, namely landslides and tsunamis at Lake Matano. The walls of Lake Matano, which are steep and filled with cracks (joints), are undoubtedly vulnerable to landslides. The existence of an escarpment that extends to the One Te'engke Region is proof of large-scale landslides.

3.2. Pulau Ampat site

The National Research Center for Indonesian Archaeology (Puslit Arkenas) conducted the initial 2016 survey of Lake Matano that found the Pulau Ampat site with much material culture spread over the lake floor. The Pulau Ampat site is at a depth of 3–15 m from the surface of the lake water, and visibility at the site is quite high, with a vertical distance of almost 10 m. Its geographical coordinates are 2°28′20.0“ S 121°15’42.2” E. The investigators suspected that the site had Early Metal Age origins, based on the recovery of stone flakes, pottery fragments decorated with various geometric patterns, animal bones, and several metal tools (Fig. 4 and 5) (Adhityatama et al., 2017; Triwurjani, 2018; Triwurjani and Adhityatama, 2019). This supplementary research data on the results of our analysis can be visited on the link: doi:10.17605/OSF.IO/2CN4H

When we returned in 2018, we found more evidence of iron production activities, such as accumulated iron slag and dispersed charcoal. We also found remains of tuyères from a smelting furnace, which still had residues of molten iron slag (Fig. 5). We also found that the site was more extensive than our initial survey had suggested; we measured an area of approximately 4.6 ha (Fig. 3). We suspect this represents the approximate size of the entire submerged village.

It is fascinating to explore what happened at this site. Why are there so many pottery fragments dispersed across the bottom of the lake, lodged between rocks, but which conjoin? What about the other relics, such as stone flakes and iron slag remains from processing iron? Looking at the context of discovering these findings, they seem to be related to one another (Fig. 7). The distribution of the pottery and remnants of processed iron are mixed and closely correlated. Also, some pottery remains show traces of iron, charcoal, and ash, suggesting combustion at high temperatures, including semi-complete vessels with hints of combustion in their bases. The types of pottery mostly found at this site are crockery, bowls, tuyères that presumably functioned as air conduit pipes in furnaces, and thick-walled pottery, which we identify as crucibles for local production of iron implements. Our proposed identifications of tuyères and crucibles are based on ethnohistorical and ethnographic descriptions of iron smithing in Indonesia (Reid, 1988: 110–4; Dunham, 1992: 164, 169) including the use of 'Malay bellows' to generate high furnace temperatures and crucibles to melt-processed iron. In all, the pottery and slag found at the site are associated and interrelated.

Ecofacts found at the site, both in 2016 and 2018, include animal teeth which are thought to be Bovidae teeth, and vertebrate animal bones, which might belong to Anoa (*Bubalus depressions*), Sulawesi's

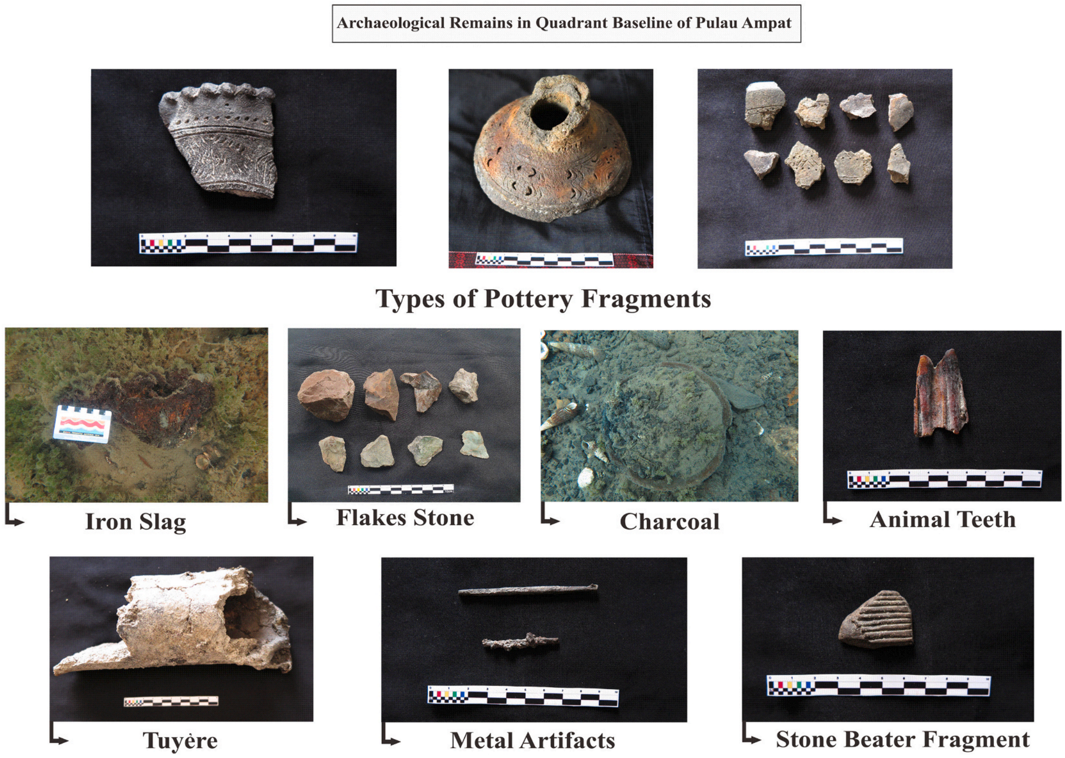

Fig. 5. Inside the quadrants, we found archaeological data such as many fragments of plain and decorated potteries, animal bones and teeth, metal artifacts, stone barkcloth beater fragment, flaked stone, charcoal, and iron slag associated with an iron production settlement (Source: Triwurjani et al., 2018).

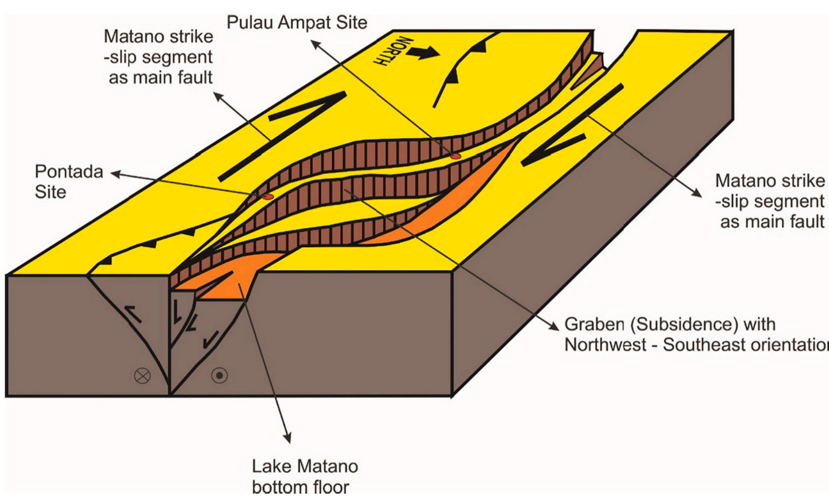

Fig. 6. Lake Matano was modeled as a rhomboidal pull-apart graben, with the Pulau Ampat site lying in the graben's path (source: Triwurjani et al., 2018).

endemic water-buffalo (Adhityatama et al., 2017). These bones are probably remnants of the diet of the people who lived at the Pulau Ampat site.

A distinctive finding in 2018 involves fragments of a 'horned' stone beater (*batu ike*) contextually associated with iron-processing equipment. The stone beater is one of the tools used to make barkcloth, which is usually done by women while waiting for the harvest after planting the rice and is a characteristic of Sulawesi tradition. A barkcloth is a type of cloth that resembles paper. It is made from the bark of *kampollo* and *sumasa* trees after removing the outer skin to expose the fibers overlying the tree's core. These fibers are then cooked, fragmented, and beaten until smooth using stone (or ceramic) beaters. Barkcloth was manufactured using horned beaters throughout Central Sulawesi, and some areas in Sulawesi still utilize barkcloth today (Aragon, 1990).

Stone beaters are known from archaeological sites of mainland China, Taiwan, and the Philippines. Ancient seafarers carried their barkcloth culture from mainland South China (Yunnan, Guangxi, and Guangdong) across the ocean as early as the Late Neolithic. This culture began to spread across the ocean by ca. 4000 BP, and by ca. 3500 BP, it existed on both Mainland and Island Southeast Asia. (Tang et al., 2019). In West Sulawesi, horned stone barkcloth beaters are dated to around 3000 BP at the Neolithic sites of Kamassi and Minanga Sipakko (Anggraeni., 2012) and 2000 BP at the early Iron Age site of Sakkarra (Suryatman et al., 2018).

Based on the identifications in the present study, we concluded that this settlement site was associated with an iron production industry of

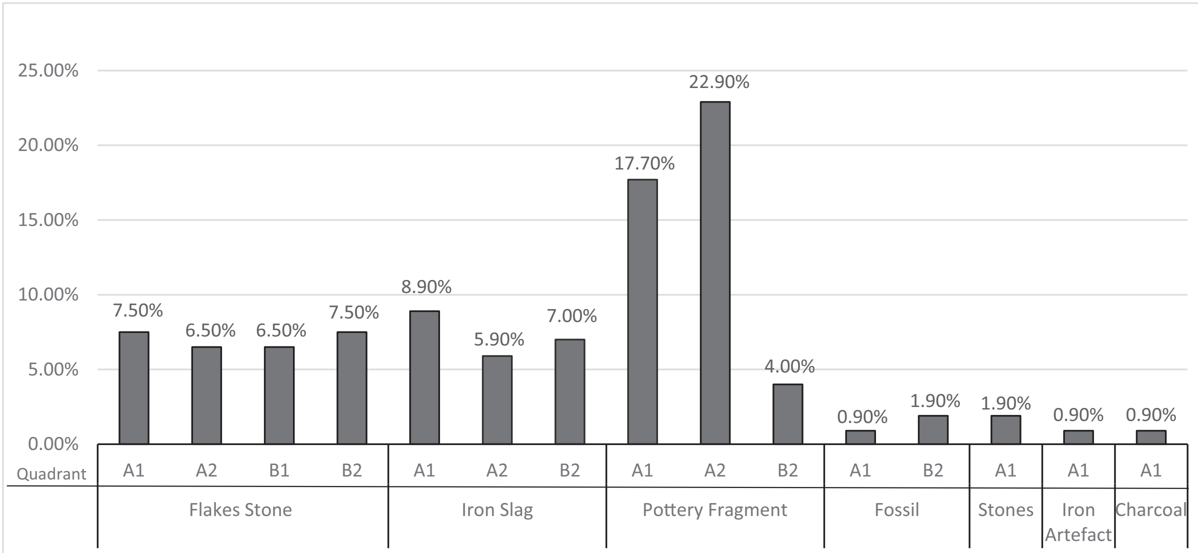

Fig. 7. Archaeological finds graphs located on grids A1, A2, B1, and B2 at a baseline of 10 × 10 meters spread over the concentration of findings at the Pulau Ampat Site (Triwurjani et al., 2018).

Fig. 8. The bovid tooth sample recovered from Pulau Ampat for stable isotope analysis and C-14 AMS dating (Adhityatama et al., 2017).

substantial size. We suspected that this large iron production industry developed around the 5th to 10th centuries AD. Therefore, we collected samples for dating the exact age of the site.

3.3. Radiocarbon (^{14}C) dating of charcoal sample

Through rigorous selection and careful sampling, we successfully collected suitable, in situ samples of charcoal and a bovid molar (Fig. 8) from the site at a depth of 12 m, associated with archaeological remains such as fragments of pottery, stone flakes, and iron slag. The charcoal originated from quadrant A1 and the bovid molar from quadrant B2 (Fig. 4). The charcoal sample was sent to the Bandung PSG laboratory, where they were processed by the C14 calendar expert Drs. Darwin A Siregar and analyst Yudystira P Ruslia, A.Md., working with the team. The bovid molar was sent to ETH-Zürich for analysis, as is routinely done on extracted collagen from the tooth material on a MICADAS mass spectrometer (Talamo and Richards, 2011; Wacker et al., 2010). The calibrated results show that the samples originate from the late 1st millennium AD, with an overlap of the dates between the mid-7th and mid-8th centuries (Table 3).

This dating result is interesting enough to be explored further. In the context of the construction history of temples and other monumental buildings in Java, those were built earlier than 7th–8th centuries were not made of andesite (Soekmono, 1995). Thus, we suspect a requirement for mass quantities of metal tools, more specifically iron, began at around this time, based on our hypothesis of their effectiveness for masonry.

3.4. Interpretation of the Pulau Ampat bovid molar

We ran a stable isotope analysis on the lower third bovid molar (Fig. 8) from Pulau Ampat, before taking a sample for C14 analysis AMS dating. Enamel of the molar was analyzed for δ13C and δ18O. As a lower third molar it represents intake at an age of ∼10 to ∼20 months (with weaning in bovids at ∼6–12 months). One sample set was measured without any pre-treatment; a second set was measured after leaching the powders in acetate-buffered acetic acid, a commonly used method to remove secondary carbonate. We expect the values of the leached samples to be closer to the original in vivo values. The results are in Fig. 9.

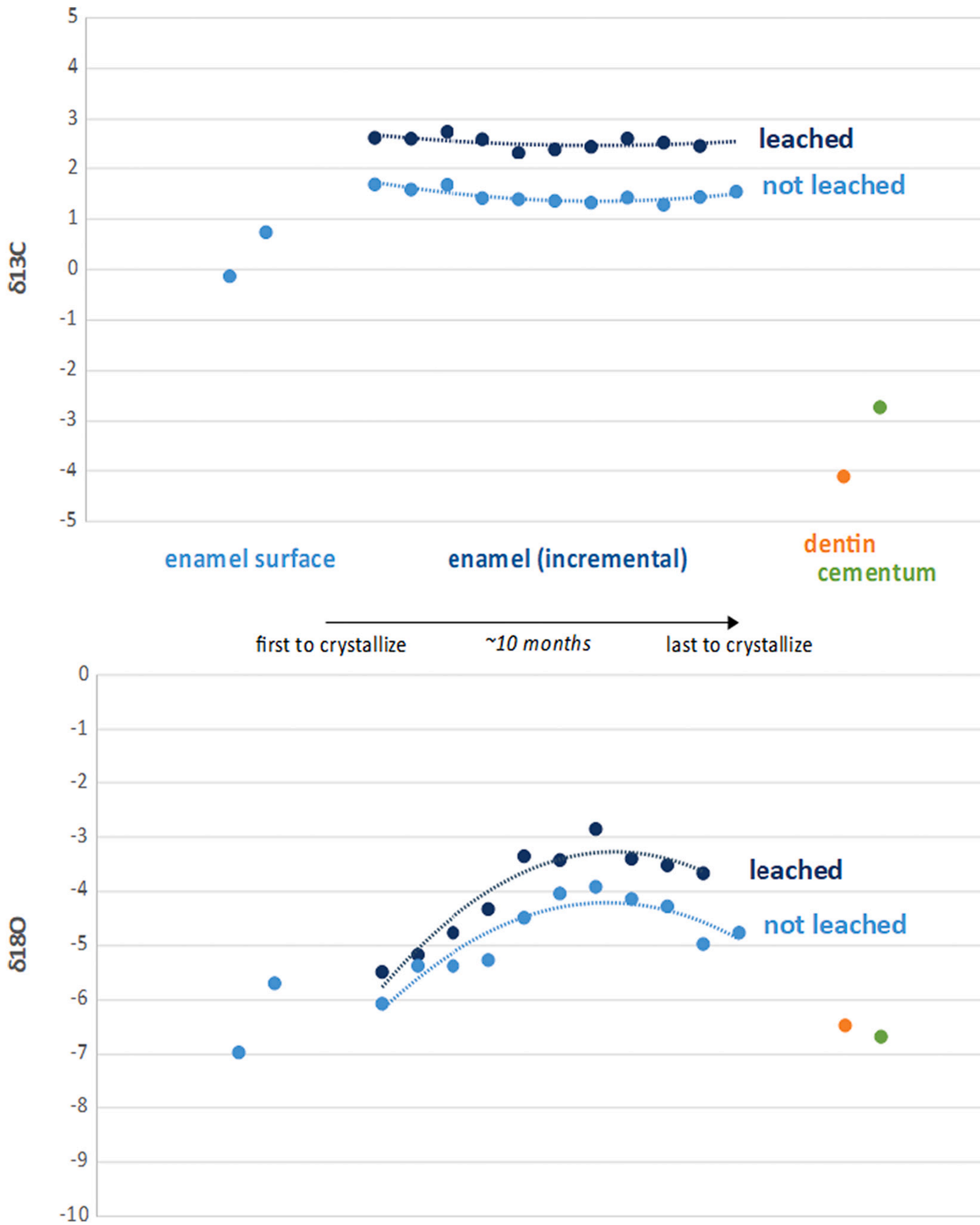

Fig. 9. δ13C and δ18O values of the Pulau Ampat bovid molar.

Table 3
The dating results of charcoal and molar samples in 2018 from Pulau Ampat site, Lake Matano. Calibrations based on Intcal 20, without Southern Hemispheric correction, using Oxcal 4.4 (Bronk Ramsey, 2020).

Sample	Depth (m)	C14 age BP	Calibrated range BP (95% confidence interval)	Cal AD
Charcoal 057/D/GL/P4/03/10/2018	12	1250 ± 90	1304–964	646–986
Bovid molar 024/D/GL/P4/26/08/2016	12	1390 ± 55	1385–1176	565–774

3.4.1. Carbon isotopes

For bovids, δ13C fractionation between enamel and diet is ~14‰ (Cerling and Harris, 1999) so if the leached enamel sample values represent the in vivo values, the diet of this animal was ~ −11‰ δ13C, and constant year-round. These values indicate a diet of C4 vegetation (grasses, shrubs), as opposed to C3 vegetation (tree leaves). By 2000 BP, farmers had colonized the shores of Lake Matano and begun clearing the shoreline forest (Bulbeck and Caldwell, 2000:22); this molar may reflect that cleared lakeside environment persisting into the late 1st millennium AD. Shoreline deforestation to produce wood fuel for local iron smelting is another likely impetus for this cleared lakeside environment.

3.4.2. Oxygen isotopes

GNIP models show modern Sulawesi precipitation δ18O varies from −11 to −3‰ (VSMOW) seasonally, with the lowest values in

June–September. However, note that under dry conditions evaporation may enrich leaf δ18O in relation to atmospheric water by as much as 8–10‰ (Luz et al., 1990). A large herbivore may source up to 30–50% of its oxygen from food. Evaporation from surface water bodies may also cause enrichment.

δ18O values for the leached enamel samples were − 6 to −3‰ (VPDB). This implies intake δ18O values of around ~ − 8 to −5 permille (VSMOW), falling within the range of Sulawesi's modern precipitation isotope values. Comparing the δ18O curve seen in the molar (Fig. 9) to the seasonal pattern, it appears to represent a period from around August to May (give or take 1–2 months). We expect the signal in the tooth to be dampened by a body water residence time of several weeks and the inevitable averaging between incremental samples, so the smaller range of values in the tooth does not necessarily imply a smaller seasonal variation in precipitation values.

3.4.3. *Diagenetic influence*

The unleached enamel samples have lower δ13C values and slightly lower δ18O values than the leached samples, which we expect to show less diagenetic influence. The dentin, cementum, and surface enamel also have lower δ13C and δ18O values. These lower values are likely to be the result of heavy diagenetic influence. By comparison, the enamel seems much less affected. We thus assume that the measured isotope values for the enamel samples – and especially the leached samples - are close to original in vivo values.

4. Discussion

This paper is intended to highlight the chrono-cultural aspects of Sulawesi's Iron Age. The onset of ironworking in northern Europe is dated to c. 1000 BCE (Erb-Satullo, 2019) and to a slightly later date at Hastinapura in India (Wolpert, 1989: 30). The earliest claims for iron slag (evidence for local ironworking) and artifacts in northeast Thailand relate to the 'Middle Period' of Ban Chiang, dated to c. 800–400 BC (Pigott and Marder, 1984; White and Hamilton, 2018). Further south, in Peninsular Thailand, iron smithing workshops are dated to the 3rd century BC at Khao Sam Kaeo and Khao Sek (Petchey et al., 2017) and iron smelting is dated to the BC/AD transition at Phu Khao Thong (Biggs et al., 2013), while evidence of iron production in Peninsular Malaysia includes iron smelting remains at the proto-historical site of Bujang Valley, Kedah, dated to the 3rd–5th centuries AD (Rahman et al., 2020). Early evidence for production of iron has also been recently found on Kalimantan (Indonesian Borneo) at a site which is thought to originate from the first millennium (Hartatik and Sofian, 2018), as well as the coastal site of Katue in Luwu, South Sulawesi (Table 2). With the current study we've added to this the evidence of the Pulau Ampat site.

In Luwu, the OXIS project recovered traces of iron smelting dating from approximately AD 1000 at five sites on the shores of Lake Matano (Bulbeck and Caldwell, 2000; Do, 2013). Smelting of the local iron ore continued at Lake Matano until c. AD 1900, as evidence both archaeologically and by historical accounts in the 17th century of the steel-like quality of Lake Matano iron and, in the early 20th century, of the trade of Lake Matano iron tools to Maluku and iron ore to northern Sumatra (Bulbeck and Caldwell, 2000: 11, 30–32). However, there is no trace of this knowledge amongst the present-day communities. The subsequent availability of mass quantities of iron wares (cf. Dunham, 1992: 147–148) favored the simpler technology of puddled iron, as still practiced at Soroako on the eastern shore of Lake Matano (Suryatman et al., 2021). Lake Matano's indigenous iron industry is still represented at sites in the Lake Matano area, both on land and under water.

On current evidence, the Pulau Ampat dates would be the earliest possible age for iron processing by the Matano community. During an interview with the team, the Mokole (the traditional chief of Matano) said that in the past Matano was a large kingdom that controlled iron production and trade in the region. However, pre-Islamic texts record Matano as a tributary of the Luwu kingdom, which rose to pre-eminence through its 14th to 16th century control over the export of Luwu's iron (Bulbeck and Caldwell, 2000). Both previous research at terrestrial sites and the Pulau Ampat site date Matano's iron production back to a time before the Luwu Kingdom was founded. The results thus indicate that the iron originated from Matano, and Matano iron became known as Luwu iron (*pamor luwuk*) because it was exported through coastal Luwu.

Previous research at terrestrial sites dates Matano iron production back to around AD 1000 (Suryatman et al., 2021), but the Pulau Ampat site shows that iron production at Matano is older than that. Its 8th century dating precedes the 9th century dating of Java's major, Classic monumental buildings, for example the Borobudur and Prambanan temples. Accordingly, it is worthwhile investigating the possibility that they were built with iron tools produced at Lake Matano. Anyway, turning to Luwu's prehistory, excavations demonstrate farmers' colonization of the Lake Matano shoreline by 2000 BP, which is also the antiquity of the establishment of sedentary communities at Sabbang Loang and Bola Merajae on the coastal plain to the south of Lake Matano. The Sabbang Loang site is particularly relevant for its iron spearheads and traces of ironstone (Bulbeck and Caldwell, 2000).

At Pulau Ampat, the extensive archaeological evidence was spread virtually across the site. This cultural heritage is in the form of pottery, flaked stone tools, *batu ike* fragments, animal bones and teeth, charcoal and also processed iron slag (Fig. 5). Technological analysis of the flaked stone excavated at the Matano village site indicates its use as flints to spark fires for the abundant iron smelting undertaken there (Suryatman et al., 2021). This use can be extrapolated to the flaked stone tools at Pulau Ampat, indicating that these finds are also a component of the site's iron-smelting industry.

What happened to this site leading to its submergence in Lake Matano? Why are so many cultural remains found at a near-shore lake bottom? Geological observations show that it is possible that a natural disaster caused the site to sink into the lake. Lake Matano was formed by tectonic activity and the region is still very active tectonically. Thus, it seems likely that a large earthquake sank this blacksmith/iron production settlement into Lake Matano.

5. Conclusion

The Lake Matano area is unquestionably a major source of iron in the region, and archaeological evidence shows that iron mining activities in this area have been going on for many centuries. The current C-14 chronology shows that iron smelting has been done here since the 8th century, and previous research shows that the iron production activity lasted until the beginning of the 20th century. Future stoichiometry analysis is planned of the Pulau Ampat iron artifacts and slag to place in the context of previously analyzed samples (Table 2).

The presence of submerged sites on the shores of Lake Matano is indicative of a large earthquake and landfall in the past. The Matano fault system should be studied more comprehensively by archaeologists and geologists working together, including as a basis for future disaster mitigation.

Population growth in Indonesia evidently flourished during the Common Era after its people discovered iron (Hall, 1992; Reid, 1988: 11–18). There is still uncertainty about precisely when Indonesia's Metal Age began and the degree to which local culture and knowledge were involved in its development. Study of archaeological sites at Lake Matano will expand our knowledge of cultural development in Indonesia, especially in terms of iron mining and production.

Declaration of Competing Interest

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

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests.

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