

Typology assessment of burnt clay roof tiles: A case of ancient burnt clay technology in Sri Lanka

AARK Amaratunga^{1#}, RU Halwathura², TD Mendis³, SM Young⁴, M Rajapaksha⁵, A Judejokkimson⁶ and AASP Amaratunga⁷

¹Senior Lecturer, Department of Quantity Surveying, Faculty of Build Environment and Spatial Sciences, General Sir John Kotelawala Defence University, Sri Lanka

²Professor, Department of Civil Engineering, Faculty of Engineering, University of Moratuwa, Sri Lanka

³Professor, Faculty of Social Sciences and Humanities, University of Rajarata, Sri Lanka

⁴Professor, Department of Environmental Technology, Faculty of Technology, University of Colombo Sri Lanka

⁵Senior Lecturer, Department of Architecture, Faculty of Build Environment and Spatial Sciences, General Sir John Kotelawala Defence University, Sri Lanka

⁶Student, Department of Agree Engineering, Faculty of Agriculture, University of Ruhuna, Sri Lanka

⁷Student, Faculty of School of Architecture, Colombo School of Construction Technology, Sri Lanka

#<ravindraa@kdu.ac.lk>

Abstract- *The building materials which are currently used have technology and development passing by different ancient history periods and many were started from the protohistoric period onward. This research focuses on ancient Sri Lankan clay roofing tiles to identify the status of the ancient's technology and their development in order to come up with a current application that is viable for sustainability in the building construction industry which is able to support reducing cost-saving of energy consumption that using on air conditioning for inner building cooling purpose as well as a solution for mitigating a global warming problem. The artefacts prove ancient clay technology in Sri Lanka has a rich history and radiocarbon dating given the age of old tile as 2250 BP and from that onward it revolution by dramatically with the shapes and dimensions, properties improvement, advancing of production and burning process; the ancestors' applied Nature Inspired Solution for tile design; and lastly, ancestors' application of the top coating of glazed layer proved their ability to advance their application where currently is a concept to establish a sustainable construction.*

Keywords- *typology assessment, burnt clay, roof tiles, Nature Inspired Solution*

I. INTRODUCTION

The clay-based components are widely applied for building construction during ancient periods in the world. Seeing ancient ruins in Anuradhapura in Sri Lanka, the clay application appeared for varieties of usage. For example, building construction – walls (Rajapaksha M. et.al, 2021), roof (clay tiles) and finishes with lime mix plaster; terra cotta floor tiles (Udawatta et. al., 2016); irrigation and water management – bricks and earth bunt; applied for whole structures of the stupa (Pagoda) – bricks and plaster ((Ranaweera, 2010); pottery trades – cooking, food serving, storage and measuring equipment; and Ornaments – beads (Young et. al, 2020). The knowledge of construction technologies and developments related to the above requirement was not transferred properly to the present generation and arises a significant missing gap between both generations. Thus, researchers are using the artefacts found in the archaeological excavations to reinvestigate that hidden gap and resume the current application. Friedman (2007) defined artefacts as “something created by humans usually for a practical purpose; especially: an object remaining from a particular period”. In world history, the technology has numerical examples: mud was for building mortar which goes back to millennium years in history (Moropoulou et al., 2015) as well as for advancing development: Borsoi et al., (2019) confirmed that ‘... modified lime mortar by selecting of raw materials

and artificial pozzolanic materials for mechanical strength and long-term durability of mortars, in Italy'. Young (2021) said that geoarchaeology collaborative research is an interdisciplinary research field enhancing the systematic understanding and disclosure of human history. The research has planned to analyze the variable by technology field and Infar by combing geoarchaeology collaboration, to produce findings scientifically. Hence, the pa paradigm is used in the 'geo-tech-archaeology research' category. The scope of research is a partial component belonging to the PhD degree programme and selected objectives, methodologies and findings are presented to the audience to consider for further study. The overall research focuses to find a novel clay roof material based on ancient's clay roof tile technology (due to rarely found artefacts containing characteristics which have Intelligent Material (IM) status). Gobkis (2015) defined it as 'Intelligent Material' (IM) that has extra functionalities which able to characterize a desired response to some external stimulus, such as temperature, light humidity and the like. The aim of this research portion is only for the typology development of ancient clay roof tiles and findings are planned for further application hence, the following objectives were set: (a) to identify performance and physical characteristics of artefacts; (b) to investigate the technology and development of clay roof tile installation in ancient buildings.

The methodology was that artefacts were collected from the archaeological museum in Anuradhapura and laboratory testing was carried out under two categories: (a) checking of physical performance - identification of geographical shapes, weights and features; (b) checking of technical performance - carry out replicate tiles similar to ancient tile samples and identify a laying pattern of roof tiles to understand the ancient's design status.

II. LITERATURE

The clay application by ancient goes back around 24,000 years in the d history (Rio et al., 2022). Warren et al. (2000) mentioned that ancestors learned how control to fire and manipulate clay and a new product termed with which came from the Greek 'keramos' that meaning 'burned earth'. Bondiolo (1998) said solid clay items were created through whereby firing of inorganic powder. This has been widely used due to the various key characteristics: long service life; low density; strong electromagnetic response; corrosion resistance; chemical inertness and nontoxicity; resistance to heat and fire, high strength, and sometimes, electrical resistance or porosity beneficial to a particular application (Cuce, 2022). In terms of clay roof tile a

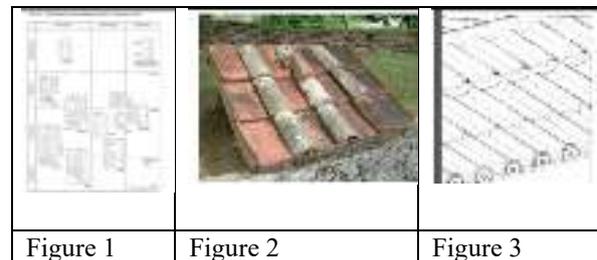
technology development is necessary and ancestors act on it. Because, the usage of roof tiles for a longer period would deteriorate durability due to the physical, chemical and biological weathering damage (Portillo, 2010; Liu, 2020). Matziaris (2011) explained that the roof tile deterioration phenomenon is mainly based on water as it is absorption causes the swelling of clay minerals while its evaporation gives rise to shrinkage and cracking hence, technology development is essential.

A. Varieties of Clay roof tiles in the world

The literature review shows that a variety of shapes of tiles were used by different ancient societies (considered the same period similar to the Anuradhapura era) and a few examples are illustrated in the following Table and Figures.

Table 1:

Sr #	Country	Reference	Figure
1	India	Uesuge et al. (2020)	1
2	Vietnam	Imbrex and Tegula method; Gordana et. al, 2018	2
3	Grece	pkpadmin,+Barry.pdf	3



B. Early Historic and Early Medieval ancient roof tiles in Indian Peninsula

Uesuge et al. (2020) illustrated the ancient roof tile technology distribution in Indian Peninsula and the Tissamaharama located in Sri Lanka. According to Sri Lankan history, the Citadel was the early ancient city of Tissamaharama. The same report included the shape of the tile and drew the cross-section on two sides as shown in Figure 1 above.

C. The ancient clay roof tile application in Sri Lanka

In Sri Lankan applications also, similar conditions exist. Cunningham (1999) stated that "... the impressive number of radiocarbon samples deriving that Anuradhapura archaeologically, is one of the most firmly dated Early Historic cities of the subcontinent". The concepts of Brahmans' teaching and the arrival of Buddhism philosophies during that period influenced

the technology of building constructions and some components only exist in Sri Lanka. For example, rules and guidelines for ancient buildings and infrastructure were based on Manjusri Vastuvidyasastra (Jayasuriya et al., 1995) and Sikkam Jathaka Kata (a story about King's Castle) in Thripitaka Book (fundamental concepts of Buddhist philosophy) illustrated how the clay roof tile structure would construct.

Sri Lanka is an island in the Indian subcontinent and archaeological remains touch with a prehistoric period where the carbon dating on ca. 200,000 – over 40,000 BP (Daraniyagala, 1992), p.685. The earliest clay technology application in Sri Lanka was for different applications: burial of human bodies – plaster cast in Mini Athiliya dated as Radiocarbon Age 3680 +/- 40 BP (Kulathilaka et. al, 2014); for the clay pottery – application goes back to the middle historic period (Daraniyagala, 1992); for clay bricks – oldest stupa (Pagoda) by bricks i.e. 250 – 210 BC (Ranaweera and Aberuwan, 2010).

According to the literature review, the oldest roof tile artefacts were received from archaeology excavation by Cunningham (1999) on Citadel, Anuradhapura and a sample of tile as per Figure 4.



Figure 4 – Ancient roof tile, Circular shape (Cunningham, 1999)

Currently, there are 8 nos of tiles available in Sri Lanka to observe the ancient application and one is taken for research to identify the ancient technology (a balance of 7 nos. of artefacts are at the Museum in Anuradhapura for display purposes). Cunningham's report further stated that other 27nos. of tiles are taken to lab testing in Britain (p.82).

III. RESEARCH METHODOLOGY

The aim of this paper was to conduct an in-depth study on artifacts belongs to the ancient clay roof tile which was collected based on Anuradhapura ancient city in Sri Lanka.

The required information had to be obtained from literature review and laboratory experiments in order to identify the material compositions.

The results were represented through the tables and Pie charts. Finally, use content analysis for analyse the test reports in order to interpret compositions of elements and other variables and outcome is listed and highlighted for applicable audience reference.

IV. SYNTHESIS ANALYSIS

The identified primary and secondary data was planned to analyze in the following manner.

a. Overview of Literature review

The archaeology report by Cunningham (1999) quoted that “The Sri Lankan-British excavations at Anuradhapura, site ASW2 (Anuradhapura Salgaha Watta 2 which is in Citadel), a growing body of data regarding the early history of the site ... the impressive number of radiocarbon samples deriving that Anuradhapura archaeologically one of the most firmly dated Early Historic cities of the subcontinent ...”. This report further described the ancient behaviour up to the c.460 cal BC – 840 cal BC which named as Structures Period K and clues are given on ‘bivouac structure’ which was for resting shaded place based on the postholes identified in the bedrock. The more details the on development of building technology described under the Structure Period J (c. 340 cal BC – 510 cal BC) were circular huts with timber posts and wattle and daub walls. There are much more details mentioned in Structural Period I and quoted as “major change with the introduction of rectangular buildings of timber and wattle and daub ... when solid buildings of burnt brick and occasional limestone blocks, and terracotta roof tiles, appeared for the first time ... similarly, the tile roof over floors 972, 974 and 975 had collapsed in situ, preserving the individual orientation of many of the tiles, together with carbonized elements of the timber superstructure, fired wattle and daub, and tile nails”. For easy reference the following Figures are illustrated: Figure 4 – Context layer on roof tile and status photo on collapsed tiles berried in the ground; Figure 5 – sketch on one roof tile.

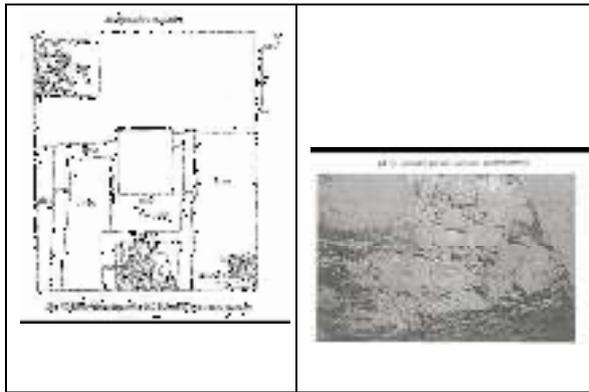


Figure 4: Context of layer and tile collapse and stack on under ground (Coningham, 1999)

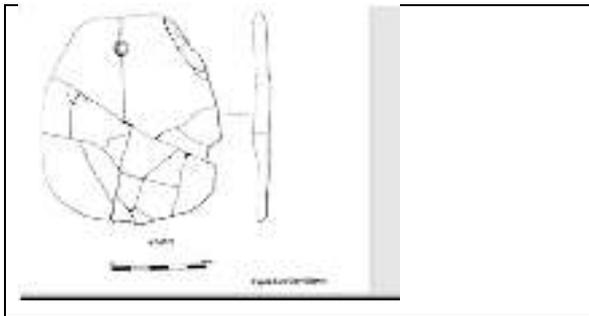


Figure 5: Sketch on one roof tile (Coningham, 1999)

b. Overview of ancients' wisdom

At present situation, there is no ancient building exist with a roof in Anuradhapura ancient town. Therefore, a scientific approach is necessary to identify ancient wisdom. Somadeva (2014) explained the concept of symmetry & dynamic forces which were applied to stone by ancient Sri Lankans in the period between 2400 – 1750 BC.

Nature inspirations can be new strategies for achieving new technologies for solving human problems. The principles of nature are more sophisticated than technologies developed by humans and can create new ideas and technologies from these natural mysteries. The ancestors understood this, as well as present scientists, do. Kim and Park (2018) said hexagonal designs are inspired by nature, buildings design are inspired by flowers, cable structures are inspired by spider webs, curved structures are inspired by seashells, Nervi (1891-1979), a structural engineer developed new shell structures applying rib and vault system to improve strength and eliminate columns for large space.

There are different types of stupas and their designs defend on nae activities. For example: The shape of Ruwanwali Maha Seya is a bubble kara (way of bubble on water); danaya kara (the way harvesting of paddy).

i. Have ancestors been a scientist and inspired the shape of tile by nature?

The flowers are the nature of beauty and the culture and Sri Lankan traditions are built along with that combination. Looking at Canyon daisy the answer found and comparison as per Figure 6.



Figure 6 – comparison of flower and tile

From per naked view, the feather in the Canyon daisy flowers is more or similar to the circular tile. One piece of a feather (figure 7) has been used to identify the proportional allocation of tiles.



Figure 7 – one piece of feather on a Canyon daisy flower

Based on AutoCAD computer software the design comparison was done and the result is illustrated in Figure 8 below.

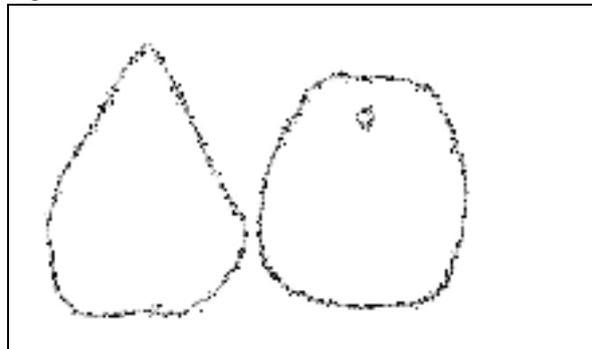


Figure 8: Computer generated feather and roof tile

When both pictures are superimposed the result is highlighted in the Figure 9

The outcome of AutoCAD activity indicated that the ancestor's NIS application on circular roof tile was acceptable.

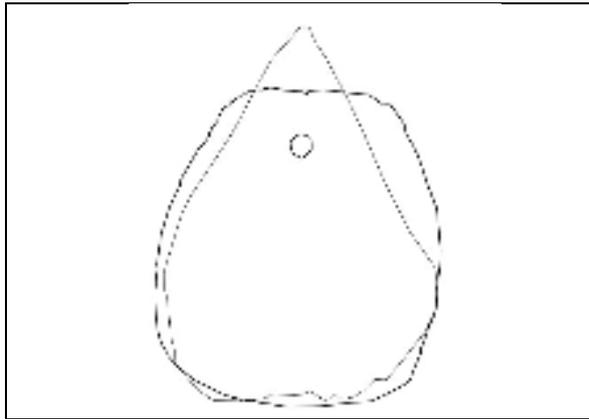


Figure 9: Super impose objectives

ii. Was the mass of tiles consistent?

Based on a total of 8 nos. of tiles the weight of tiles was checked and data was as per Table 2 below.

Table 2: Weight of circular tiles

Sr.	Artefacts reference	Code	Weight (g)
1	Display sample at	Z - 429	688
	Anuradhapura Museum		
2	Ditto	Z - 433	646
3	Ditto	Z - 434	680
4	Ditto	Z - 440	794
5	Ditto	Z - 441	440
6	Ditto	Z - 449	650
7	Ditto	16517	605
8	Pro -Green lab		576

The average weight of tiles was calculated and readings were given as 634g per tile. This can be identified that mould had been used and little variance occurred due to the thickness differences. iii. Was it applicable for vertical application?

To assess the requirement, the simple plum test was carried out to check the centre gravity of the axis. The majority of tile samples are not permitted to touch and are available only for display units at the museum. Therefore, replicates from the hardboard are prepared and carried out a small plum test and activities on the event as per Figure 10 below.

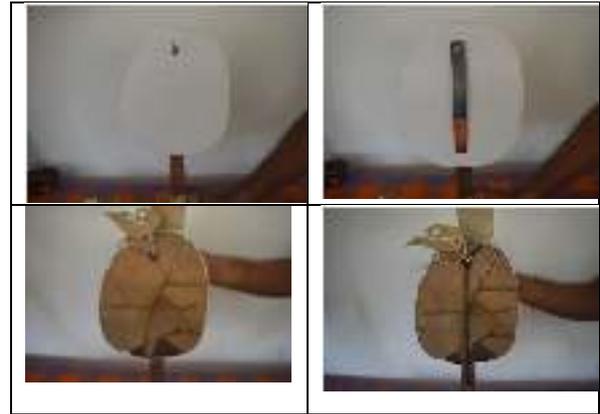


Figure 10: Plum testing on circular tile

The vertical axis in all tiles are same as the gravity axis and indicated that tiles even can be used for vertical application i.e. protection of the vertical edge of rafters (currently as valance board).

iv. Roofing tile installation pattern by NIS application

There are few varieties of Canyon Daisy flowers based on the number of feathers. Considering the 16 nos. of feathers the roof tile laying pattern is possible to understand through NIS application. This has been illustrated in Figure 11 below.



Figure 11: Comparison of feather pattern in flower and old sloping roof

The sample of sloping roof structure frame was prepared and replicates were arranged to observe the pattern of clay roof tile application and finding as follows.

Figure 12 is for adjustable timber roof frame with the adjustable reapers according to the dimension of tile.

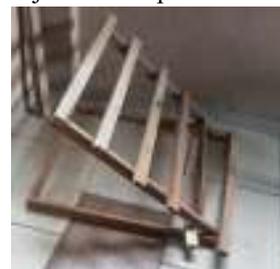


Figure 12: Adjustable pitch roof timber frame



Figure 13: Tile laying pattern A

In this pattern (A), tiles are vertically overlapped based on left side of tile with the nearest tile in the same row and the top layer always taken care of the bottom layer top side of tile (hole area). The reapers are to be adjusted to match with line of hole in tile each row.

The fixing method also possible in two methods i.e. tying with reapers by thread (always protecting and covering up by top layer) or applying metal nails.

Due to the thickness of tile small opening would forming at the vertical overlapping area. Some part of tile gets additional weight by adjacent tile.

One of main disadvantage is a quality of tying material. It has to be more durable, less thickness and need flexibility to make a knot. Observing the hole in available samples the formation appeared not to use nail (holes are not formed propyl to apply hard nails)



Figure 14: Tile laying pattern B

The laying pattern (B) has no vertical side overlapping and water proofing method is to arrange more covering of whole tiles based on top layer tiles. It given more number of tile requirement for roof laying comparing to the pattern A. It forms more stability to rest on reapers

properly. The fixing method would be same as option A.

V. CONCLUSION AND RECOMMENDATIONS

Further research

After the circular clay roof tile application, the ancestors deviated to the rectangle tiles and the findings of this research focused to start the chemical properties testing and firing status to identify a burnt clay technology as per the main research.

Conclusion:

The present study examined the ancient application in clay technology through physical performance evaluation and their characteristics and revealed that ancestors had applied Nature Inspired Solutions to their problems developed their knowledge through NIS application and adopted it for their usage. They based their intuitive knowledge and non-scientific experience on the selected and applied materials. The ancients instinctively followed ways of ecology and economy.

The forming of holes in the tile indicated the ancients' wisdom when compared with the axis of gravity and the vertical centerline of the tile had the same and even it is suitable for vertical application though it had applied for horizontal application. The fabrication of the tile was based on the mould to form a shape of tile consistency and the hole was marked but when it forming a mass of tile varied and to maintain the axis of gravity and vertical centerline same the forming of tile had little adjusted on the left side of the tile. This paper aimed to identify construction technologies that have action to be taken.

VI. REFERENCES

- Bondioli, F., Ferrari, A.A.M., Leonelli, A.C., and Manfredini, A.S., (1998). Syntheses of Fe O /Silica Red Inorganic Inclusion Pigments for Ceramic Applications. *Materials Research Bulletin* Volume 33, Issue 5, May 1998, Pages 723-729. [https://doi.org/10.1016/S0025-5408\(98\)00047-6](https://doi.org/10.1016/S0025-5408(98)00047-6)
- Borsoi, G., Silva, A.S., Menezes, P., Candeias, A., and Mirão, J., (2019). Analytical characterization of ancient mortars from the archaeological roman site of Pisões (Beja, Portugal). *Construction and Building Materials* Volume 204, 20 April 2019, Pages 597-608. <https://doi.org/10.1016/j.conbuildmat.2019.01.233>

- Coningham, R. (1999). Society for South Asian Studies Monograph No. 3, The British-Sri Lanka Excavations at Anuradhapura Salgaha Watta 2. Archeopress. ISBN 1841710369
- Deraniyagala, S.U. (1992). The Prehistory of Sri Lanka – Part II, Department of Archaeological Survey, Government of Sri Lanka.
- Friedman, K. (2007). Behavioral Artifacts: What is an Artifact? Or Who Does it? ARTIFACTS 2007 | Volume I, Issue 1 | Pages 6–10. ISSN 1749-3463 print/ISSN 1749-3471
DOI: 10.1080/17493460600610764
- Gordana, T.C., Ana, M.P., and Aleksandra, C. (2018). ARCHITECTURE AND CERAMIC MATERIALS, DEVELOPMENT THROUGH TIME: CERAMIC TILES AND CERAMIC ROOF TILES : Architecture and Civil Engineering Vol. 16, No 2, 2018, pp. 315-327
<https://doi.org/10.2298/FUACE200521011T>
- Liu, S., Wang, W., Yu, J., Peng, X., Cai, Y., and Tu, B., (2020). Effectiveness of the anti-erosion of an MICP coating on the surfaces of ancient clay roof tiles. Construction and Building Materials Volume 243, 20 May 2020, 118202.
<https://doi.org/10.1016/j.conbuildmat.2020.118202>
- Matziaris, K., Stefanidou, M., and Karagiannis, g., (2011). Impregnation and superhydrophobicity of therm clay wall panel system for indoor cooling, pp. 1–6, 2021, doi:10.1109/fiti52050.2020.9424896
- Ranaweera, M.P., (2010). SUSTAINABLE DEVELOPMENT, ANCIENT WISDOM AND SRI LANKAN TECHNOLOGY.
URI: <http://dl.lib.mrt.ac.lk/handle/123/9131>
- Somadeva, R. (2014). Science and Technology in Ancient Sri Lanka. VOLUME 31 NUMBER 01 VIDURAVA
http://dl.nsf.gov.lk/bitstream/handle/1/24684/VIDU_31_1_3.pdf?sequence=1
- Udawattha, C., Arooz, r., and Halwatura, R. (2016). NEW EARTH WALLING MATERIAL: INTEGRATING MODERN TECHNOLOGY INTO ANCIENT MUD WALL. ICSBE2016-55 (p24 – 31)
- Uesugi1, K., Oya2, I., and Peter, J., (2020). Roof Tiles in Ancient South Asia: Its Developments and Significance. ISSN 2347 – 5463 Heritage: Journal of Multidisciplinary Studies in Archaeology 8.2: 2020
- Warren, M.P., Forrester, P.L., Hassard, J.S., and Cotton, J.W., (2000). Technological innovation antecedents in the UK ceramics industry. coated porous low-fired clay building materials. Progress in Organic Coatings Volume 72, Issues 1–2, September–October 2011, Pages 181-192.
<https://doi.org/10.1016/j.porgcoat.2011.03.012>
- Moropoulou, A., Bakolas, a., and Anagnostopoulou, S., (2015). Composite materials in ancient structures. Cement and Concrete Composites Volume 27, Issue 2, February 2005, Pages 295-300
<https://doi.org/10.1016/j.cemconcomp.2004.02.01>
- Portillo, M.C., Gazulla, M.F., Sanchez, E., and Gonzalez, M., (2010). A procedure to evaluate the resistance to biological colonization as a characteristic for product quality of ceramic roofing tiles. Journal of the European Ceramic Society Volume 31, Issue 3, March 2011, Pages 351-359
<https://doi.org/10.1016/j.jeurceramsoc.2010.10.012>
- Rajapaksha, M., and Halwatura, R.U., (2021). PoroYoung, S.M., Mendis, D.T. and Ishiga, H. (2020). New perception to proto history burial site in Andarawewa and Archaeological and Geochemical prospection. International Journal of Production Economics Volume 65, Issue 1, 1 April 2000, Pages 85-98.
[https://doi.org/10.1016/S0925-5273\(99\)00092-4](https://doi.org/10.1016/S0925-5273(99)00092-4)