INVESTIGATING THE CLAY MODIFICATION PROCESS OF GUA SAGU POTTERY USING DIGITAL MICROSCOPIC IMAGING TECHNIQUE

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Abstract. This paper aims to determine the tempering material structure of Gua Sagu prehistoric pottery by examining the characteristics of clay paste modification through the identification of quartz grain morphology. The analysis was done by using the non-destructive digital microscopy method on selected pottery shards for 3D surface reconstruction imaging of both the cross-section and individual quartz grain, whereby their shape and dimensions were measured and studied. The results of the analysis revealed that the Gua Sagu pottery is highly rich in quartz (sand) mineral. The quartz grain shapes consisted of round-edged, sharp-edged and combination of either round- and sharp-edged or round- and spherical-edged. The presence of round and spherical-edged quartz grains shows that sand was mixed into the clay without undergoing any form of modification while sharp-edged quartz grains in angular form indicated that sand was pounded before being added to the clay. It can be concluded that, based on the findings of the microscopy study, the Gua Sagu pottery production involved two types of clay modification process (i) pottery tempered with pounded sand and (ii) pottery paste without tempering material. These scientific findings have shed new light on the origins of Gua Sagu pottery which could have been locally made or brought in from elsewhere to be used for cooking and/or storage purposes during ancient times.

Keywords: Gua Sagu pottery, tempering material, clay modification, digital microscopy

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1. INTRODUCTION

Gua Sagu, a site with significant archaeological evidence of early human existence, is one of several sites in Malaysia that has received little attention from archaeologists. The site, located in the Bukit Sagu massif of Kuantan, Pahang was first visited and studied by M.W.F. Tweedie in 1935 (Figure 1). A brief report on the archaeological work and findings from Gua Sagu was published in 1937. Archaeological finds from the 1935 excavation included a hoard of pottery shards and several stone artifacts in the form of flaked discoid tool, scraper and broken ground implement [1]. The physical and technological characteristics of artefacts excavated at Gua Sagu in 1935 are unknown.

In 1990 and 1991, Zuraina from Universiti Sains Malaysia (USM) excavated Gua Sagu in collaboration with staff from the Department of Museums and Antiquities. Another site namely Gua Tenggek was also investigated during the Gua Sagu excavation (Figure 1). The 1990-91 excavation revealed a trove of ancient artifacts – among them were stone tools, pottery shards and faunal remains in the form of animal bones and shells. The Gua Sagu pottery were physically studied and classified according to their size, colour and decoration [2]. Based on visual examination, Zuraina, Ang and Jeffri [2] had developed several suggestions on Gua Sagu pottery technology and provenance. For instance, the pottery was reported to have been sand-tempered and fired in an uneven firing condition [2]. The pottery was also said to have been made elsewhere before being brought-in into Gua Sagu and was used mainly as cooking vessels [2]. Currently, the Gua Sagu artefacts (pottery, stone tools and faunal remains) are kept in Muzium Sultan Abu Bakar, Pekan, Pahang [3].

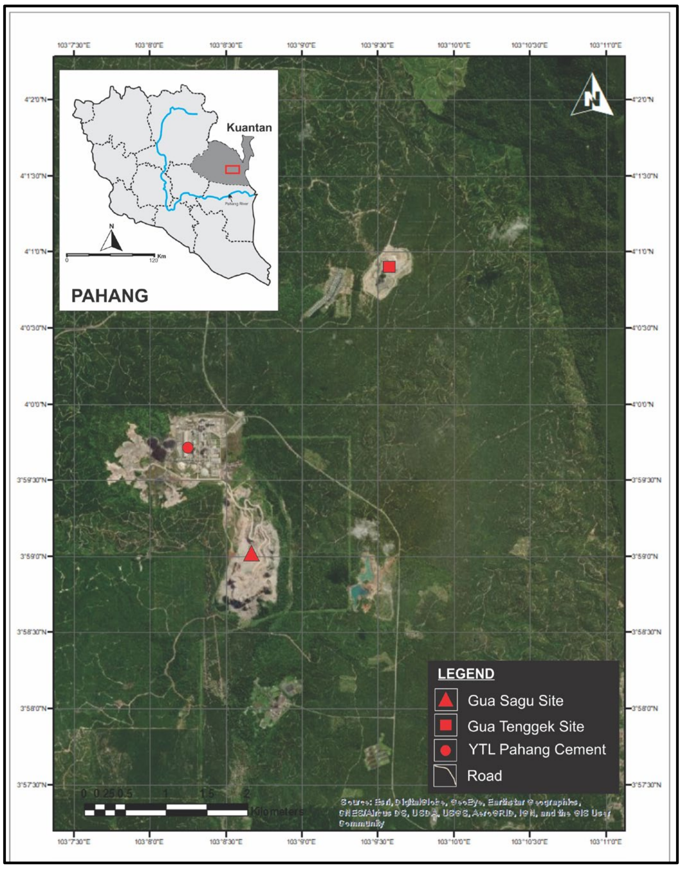

Figure 1: The location of Bukit Sagu dan Bukit Tenggek archaeological sites in Kuantan, Pahang

According to literature, no attempt has so far been made to study the composition of Gua Sagu pottery. Dua to the lack of scientific examination, information on the technology, source and origin of Gua Sagu pottery is unknown. Therefore, it was decided that a preliminary work on the digital microscopic imaging of Gua Sagu pottery should be carried out to, at least, understand the basic technique employed in the manufacturing of prehistoric pottery of Pahang. This study marks the first scientific investigation into Gua Sagu pottery of Kuantan, Pahang.

2. MATERIALS AND METHODS

In 2022, a visit was made by the authors to Muzium Sultan Abu Bakar, Pahang to obtain samples of Gua Sagu pottery for digital microscopic imaging study. The primary objective of this study was to determine the clay modification process used in Gua Sagu pottery production by focusing on quartz grain morphology. From the grain image, data on the shape and dimension of quartz mineral can be obtained [4]. The variation in quartz mineral was determined by using mean (M), standard deviation (SD) and area percent by grain diameter (D). In total, 28 pottery shards (19 shards from trench Z4 and 9 shards from trench Z5) from different spits were selected with condition that the cross-section or any exposed part of the shards have visible surface morphology. No sample preparation was done but the pottery sampling was done very attentively as the size of the sample must fit the focal length range of the digital microscope. This study was inspired by several geological studies that successfully utilised 2D and 3D microscope imaging techniques to determine and compare rock grain type, shape and size [5-6].

In this study, the pottery shards were examined by using the KEYENCE VHX-7000 digital microscope for 2D particle size (D = diameter) measurement, depth composition analysis and 3D surface reconstruction. Figure 2 demonstrates the sample setup position for cross-section analysis while Figure 3 shows the sample core area selected for 3D image capture.

Figure 2: Sample setup position for cross-section analysis. The potshard was set up 90° on the stage in an upright position. The wide adjustable space between the stage and focal length of the microscope lens enabled accommodation of larger sample

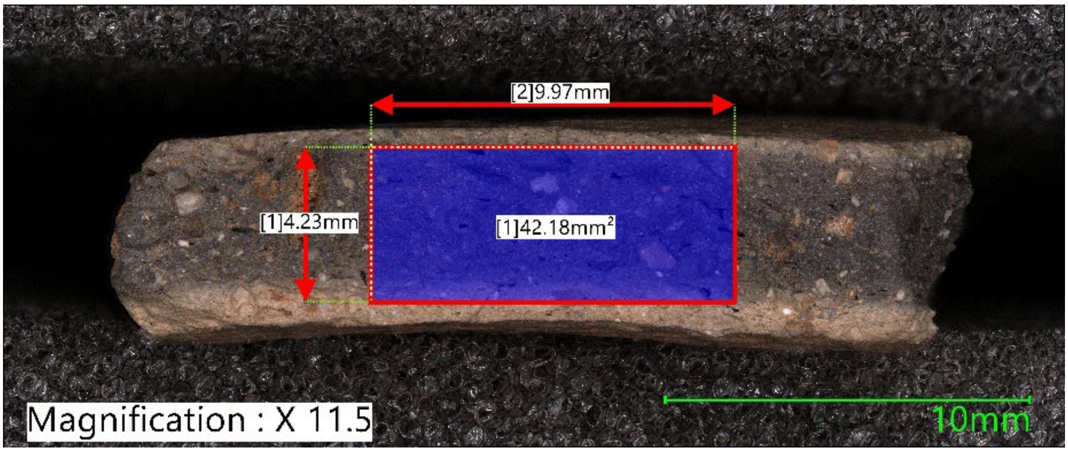

Figure 3: Cross-section image of Gua Sagu potshard. The blue rectangle represents pottery core area of approximately 42 mm^2 for 3D image capture

For quartz grain morphology classification, the two-phase abrasion model was referred to and applied (Figure 4). The shape and size of quartz grain always depends on the type of sand used or the clay modification technique performed during the pottery-making. For instance, high quality clay usually does not require additional material to be used as inclusion. On the other hand, low quality clay with very fine texture and/or sticky composition needs to be modified by a process called tempering [7]. Sand is the most common type of temper used in prehistoric and traditional pottery production. Normally, sand is sieved and pounded, and used in a small ratio, for instance 80:20 clay to sand, 70:30 clay to sand or 50:50 clay to sand [8].

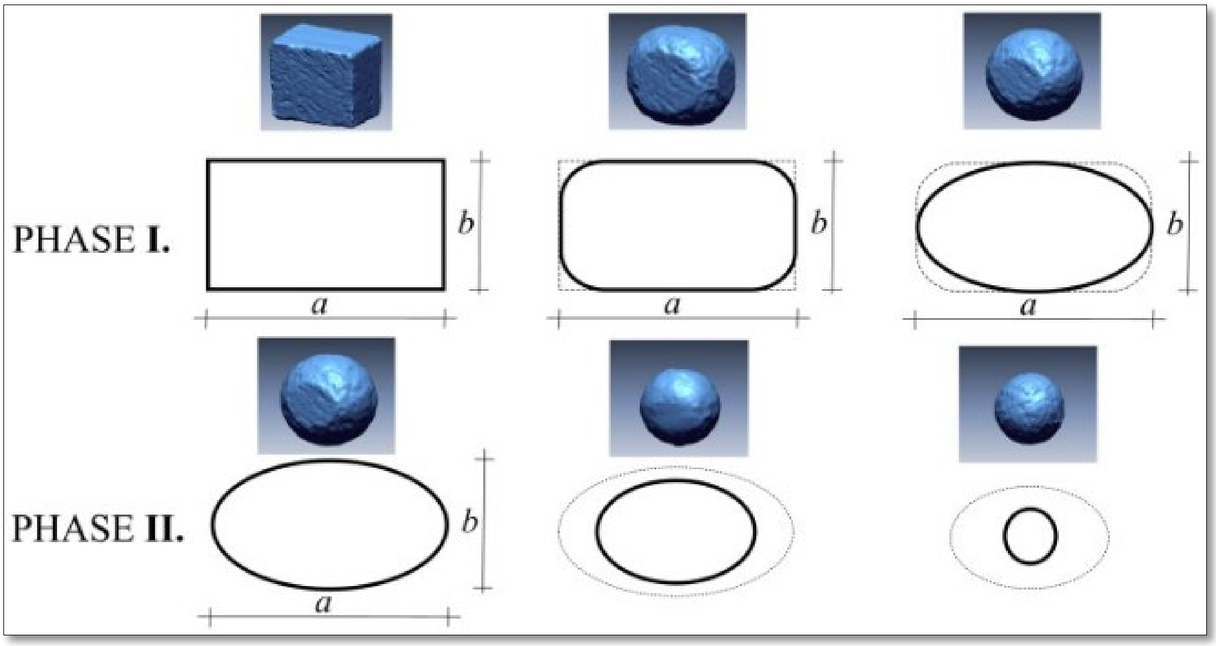

Figure 4: Geometric model of two phases of abrasion with its 2D schematics. In phase 1 edges abrade but axis ratios remain constant while in Phase 2 axis ratios evolve towards the sphere [6]

3. RESULTS AND DISCUSSION

From the results of 2D and 3D surface reconstruction, four types of characteristic composition could be defined. The samples consisted of quartz grain with round-edged, sharp-edged, combination of either round- and sharp-edged, or round- and spherical-edged. Examples of such characteristics are shown in Figure 5(a) to (d).

The dimension of quartz grains and distribution were also analysed in this study. For each cross-section, quartz diameter within the selected 42 mm^2 area was counted, measured and categorized (Figure 3). The hypothetical size of total quartz grain of specific size category was calculated Area=$\pi(D/2)^2$. Grain size distribution was determined by standard deviation calculations (SD) for diameter and size area. Table 1 shows the distribution of counted quartz grains to their respective diameter range while Table 2 represents data for quartz grain shapes and its distribution by studying the mean and standard deviation for both diameter and size area.

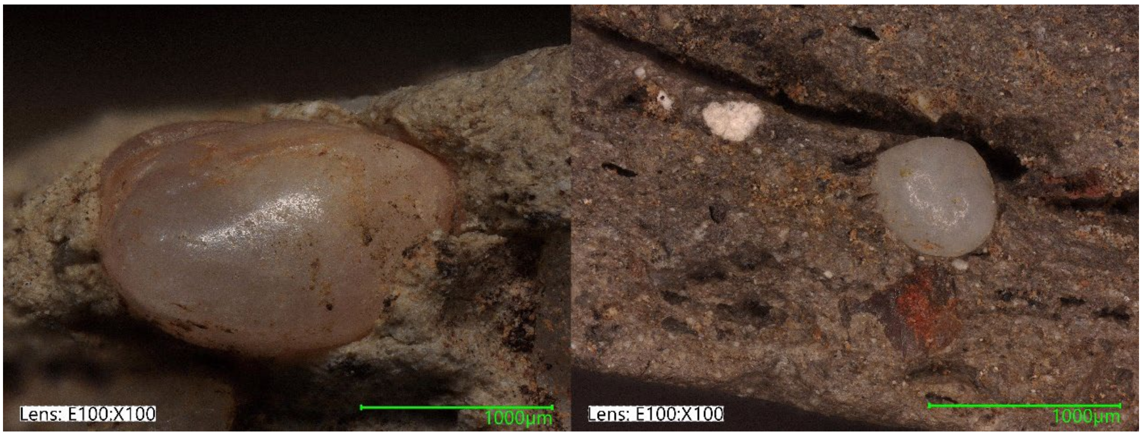

Figure 5(a): 2D images of quartz grain from the cross-section of sample GSa/Z5/S1/49 (right) and close-up view (left). The quartz grain is rounded in shape

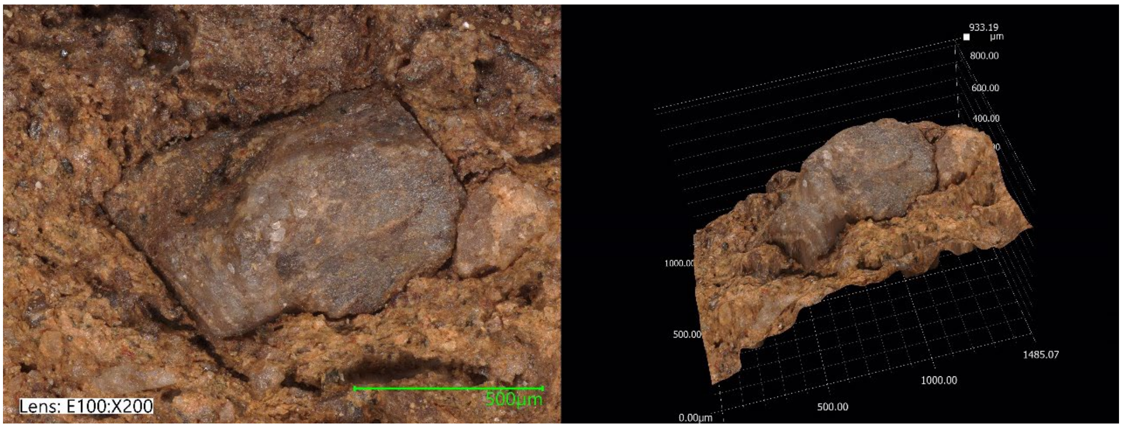

Figure 5(b): 2D and 3D images of quartz grain from the cross-section of sample GSa/Z5/S2/26(6) (right) and close-up view (left). The quartz grain is angular in shape with sharp edges

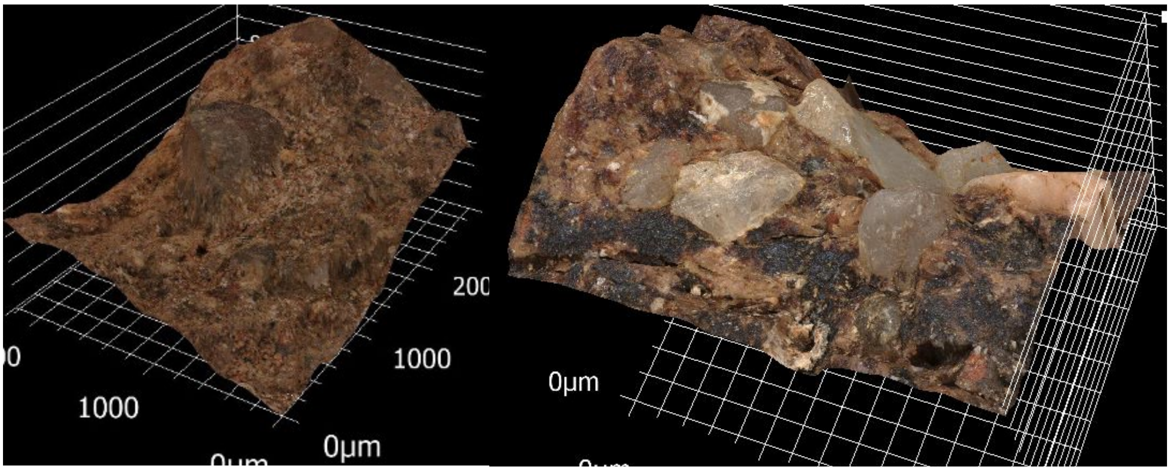

Figure 5(c): 3D images of quartz grain from the cross-section of sample GSa/Z4/S1/62 (right) and GSa/Z4/S1/59 (left). The quartz grains from both samples are angular in shape with sharp and rounded edges

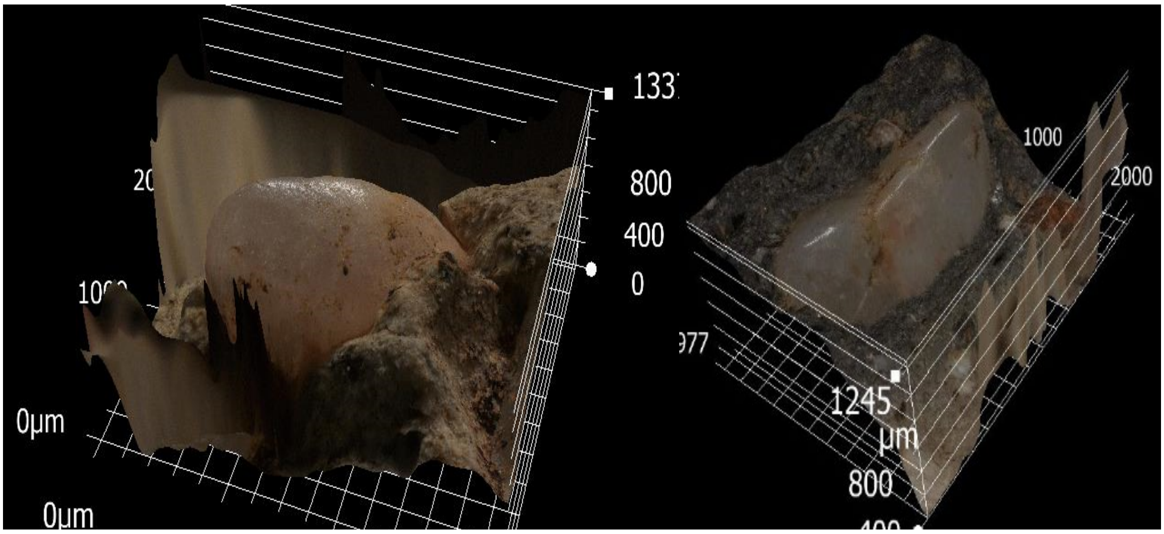

Figure 5(d): 3D images of quartz grain from the cross-section of sample GSa/Z5/S1/49. Both quartz grains have rounded edges that have been completely abraded

The homogeneity of quartz grain diameter among the four identified morphologies were assessed by the value of standard deviation (SD). SD was used to identify the dispersiveness or deviation of the data set from its mean or average value [9]. A more homogenous quartz grain size would have lower SD value and vice versa.

Table 1: Diameter of quartz grains measured and recorded into ranges

Sample	Diameter (D) range										No of grains
	100 (µm)	200 (µm)	300 (µm)	400 (µm)	500 (µm)	600 (µm)	700 (µm)	800 (µm)	900 (µm)	>1000 (µm)	
Z4/S1/1	7	10	8	6	3	2	4	2	0	3	45
Z4/S1/23	44	19	13	5	5	5	2	0	1	3	97
Z4/S1/62	12	25	15	15	5	6	2	1	1	1	83
Z4/S1/70	10	22	7	3	6	2	2	0	1	4	57
Z4/S1/72	11	10	3	5	6	4	1	0	2	5	47
Z4/S1/72(2)	7	9	8	6	0	9	6	4	0	10	59
Z4/S1/73(2)	6	4	13	14	9	5	5	6	3	4	69
Z4/S2/11	60	15	8	1	2	3	2	2	0	2	95
Z4/S2/19	52	20	14	6	2	1	0	0	0	0	95
Z4/S2/47	7	19	17	12	7	4	4	2	1	2	75
Z4/S2/68	7	5	4	3	6	5	7	1	2	8	48
Z4/S2/86	23	26	6	6	2	1	0	2	0	4	70
Z4/S3/5	29	14	2	2	1	3	1	0	0	2	54
Z4/S3/5	7	6	10	4	9	2	3	5	0	0	46
Z4/S3/9	61	34	6	4	2	1	0	0	0	0	108
Z4/S3/34(6)	78	66	30	17	3	0	1	0	0	0	195
Z4/S3/44	29	17	5	3	0	1	0	0	0	4	59
Z4/S2/8	28	17	9	11	6	1	1	0	0	2	75
Z4/S4/81	13	2	2	1	0	1	1	1	0	4	25
Z5/P-SO/31	3	3	2	3	1	4	4	3	1	17	41
Z5/S2/7	15	28	18	19	6	5	1	1	0	0	93
Z4/S2/26(1)	63	21	14	13	1	7	1	2	0	8	130
Z5/S2/26(5)	40	46	22	6	5	3	2	2	1	5	132
Z5/S2/26(6)	49	46	32	17	8	4	4	1	0	8	169
Z5/S2/39	7	10	8	7	5	4	1	1	1	3	47
Z5/S2/74	79	29	18	6	10	2	1	2	1	1	149
Z5/S3/3	4	6	2	1	3	1	1	2	3	8	31
Z5/S3/40	32	9	5	7	1	1	0	4	2	1	62

Table 2 shows SD value for quartz grains with sharp-edged (0.7-1.56) and size area SD value (0.46-2.4). SD value diameter for combination of rounded and sharp-edged quartz grains were between 0.77-2.6 and for size area SD value were 0.49-4.06. Quartz grain with rounded edge diameter SD value were between 0.77-1.14 and for size area SD value were between 0.46-1.81. Sample with abraded quartz grain morphology diameter SD value were 0.78-0.84 and size area SD value were between 0.98-1.00. The lowest SD value for both diameter and size area were found in sample GSa/Z4/S2/23 (abraded) with SD value of 0.86 (diameter) and 0.98 (size area), respectively. On the other hand, the highest SD value was found in sample GSa/P-SO/31 (mixture of rounded and sharp-edged quartz grains) with value of 2.6 (diameter) and 4.05 (size area). To visualize the differences between high and low SD, two samples were selected and the result is presented in Figure 6.

Table 2: Quartz grain shapes and its distribution by studying the mean and standard deviation for both diameter and size area

Quartz shape	Trench	Spit	Sample number	Sample name	Diameter Mean (M) (mm)	Diameter (SD) (mm)	Size (Area) Mean (M) (mm2)	Size SD (mm2)
Sharp-edged	Z4	1	62	Z4/S1/62	0.324	±1.04	1.140	±0.89
			72(2)	Z4/S1/72(2)	0.510	±1.56	1.638	±2.40
		2	19(4)	Z4/S2/19	0.183	±0.81	0.434	±0.46
			68	Z4/S2/68	0.533	±1.37	1.686	±2.03
			86	Z4/S2/86	0.270	±0.86	0.788	±0.93
		3	5	Z4/S3/5	0.398	±0.96	1.142	±1.78
			34 (6)	Z4/S3/34(6)	0.200	±1.34	0.924	±1.00
	Z5	2	26 (6)	Z5/S2/26(6)	0.287	±1.36	2.078	±2.06
		3	40	Z5/S3/40	0.265	±0.70	0.676	±0.60
Rounded- and sharp-edged	Z4	1	73(2)	Z4/S1/73(2)	0.484	±1.24	1.999	±1.67
		2	11	Z4/S2/11	0.206	±0.77	0.710	±0.49
			47	Z4/S2/47	0.368	±1.02	1.370	±1.19
		3	3	Z4/S3/5	0.224	±0.61	0.450	±0.48
		4	8	Z4/S2/8	0.261	±0.82	0.883	±1.16
	Z5	P-SO	31	Z5/P-SO/31	0.700	±2.60	1.945	±4.05
		2	7	Z5/S2/7	0.297	±1.16	1.078	±1.22
			26 (5)	Z5/S2/26(5)	0.268	±1.14	1.444	±1.18
			74	Z5/S2/74	0.214	±1.00	1.330	±1.79
		3	3	Z5/S3/3	0.571	±1.42	1.227	±1.92
Rounded-edged	Z4	1	1	Z4/S1/1	0.391	±0.77	0.907	±0.79
			70	Z4/S1/70	0.337	±0.87	1.058	±1.31
			72	Z4/S1/72	0.402	±0.92	1.178	±1.48
		3	9	Z4/S3/9	0.166	±0.89	0.403	±0.46
			44	Z4/S3/44	0.231	±0.76	0.492	±0.95
		4	81	Z4/S4/81	0.352	±0.77	0.475	±0.95
	Z5	2	26(1)	Z4/S2/26(1)	0.268	±1.14	1.407	±1.81
Spherical- and rounded-edged	Z4	1	23	Z4/S1/23	0.257	±0.84	1.085	±0.98
	Z5	2	39	Z5/S2/39	0.387	±0.78	1.001	±1.00

Based on Figure 6, it can be inferred that two key factors contributed to standard deviation value which are the volume of grain size of larger diameter and how it balanced across different diameter categories. In sample with higher standard deviation value, size composition was heavily weighted on one category (high count) especially at maximum grain diameter. For example, in sample Z5/P-S0/3, the composition was heavily weighted to 1.0 mm grain diameter count that the value overshadowed other grain diameter categories. More well-balanced composition can be observed through sample Z4/S1/23 which have the lowest standard deviation value. The sample had lower count on 1.0 mm grain diameter but higher count on 0.5, 0.6, and 0.9 mm combined.

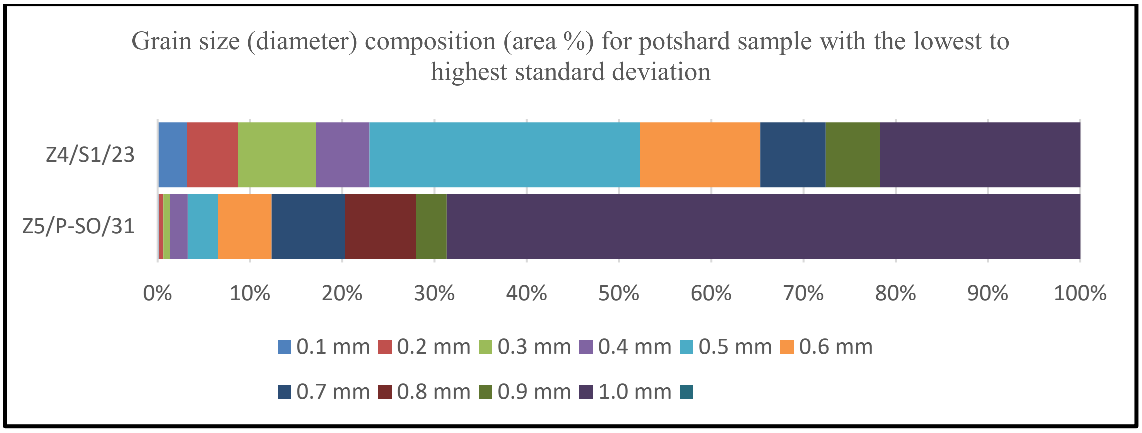

Figure 6: Sample Z4/S1/23 represents a potshard sample with round- to spherical-edged quartz grain. It also has the lowest grain size standard deviation value of 0.98. Sample Z5/P-S0/31, on the other hand, represents a potshard sample with sharp- to round-edged quartz grain. This sample has the highest grain size standard deviation of 4.05

According to Table 3, a ternary diagram was made to present quartz size (area) ratio to clay/silt composition for all pottery samples studied (Figure 7). Based on Figure 7, it can be observed that the majority of samples with abraded quartz grain concentrated on the bottom left of the ternary diagram, indicating the ideal characteristic of how the sand quality should be for pottery production. Highlighted in orange is the region considered to be the most desired quartz size characteristic among all the samples studied. Samples seen outside the pattern were either with sharp-edged or combination of both round- and sharp-edged characteristics. To investigate the origin of sand temper in Gua Sagu pottery, clay samples from Sungai Batu, a river located just a few metres away from Bukit Sagu was collected and tested for comparison.

Sungai Batu is the most possible source of raw materials for Gua Sagu pottery production (Figure 8). This is because potters generally do not go far to collect their clay. Ethnographic studies have shown that traditional potters do not travel very far (normally less than 7 kilometres) to gather their clay [10]. For instance, traditional Malay potters in the states of Perak, Pahang and Kelantan customarily obtain their clay from a single source usually located near to their homes [11-16]. Similarly, many prehistoric settlements and pottery sites in Peninsular Malaysia were found along or adjacent to major rivers like Sungai Perak, Sungai Pahang and Sungai Kelantan [17-19]. Compositional studies have revealed that local clay possibly from riverbanks was employed to manufacture prehistoric pottery of Peninsular Malaysia [17].

Table 3: Normalised data in percentage for three categories of quartz shape and size based on 1934 Krumbein's model [20]

Sample	Quartz shape	Fine to medium (0.1 mm-0.5 mm) (Area %)	Coarse-very coarse (0.6 mm->1.0 mm) (Area%)	Clay/Silt (<0.1mm) (Area %)	Total %
Z4/S1/62	Sharp-edged	16.69	10.46	89.54	100.00
Z4/S1/72(2)		3.95	35.06	60.99	
Z4/S2/19		9.65	0.67	89.67	
Z4/S2/86		8.21	10.55	81.24	
Z4/S3/5		17.10	10.08	72.82	
Z4/S3/34(6)		21.08	0.92	78.00	
Z5/S2/26(6)		26.96	22.52	50.52	
Z5/S3/40		5.72	10.36	83.91	
Z4/S2/68		11.17	28.98	59.85	
Z4/S1/73(2)	Round- and sharp-edged	20.43	27.16	52.41	
Z4/S2/11		6.92	9.99	83.09	
Z4/S2/47		18.61	14.01	67.37	
Z4/S3/5		4.04	6.68	89.28	
Z4/S2/8		15.70	5.33	78.97	
Z5/P-SO/31		3.03	43.27	53.70	
Z5/S2/7		20.19	5.48	74.33	
Z5/S2/26(5)		17.27	17.12	65.62	
Z5/S2/74		23.63	8.04	68.33	
Z5/S3/3		5.71	23.50	70.80	
Z4/S1/1	Round-edged	8.57	13.02	78.41	
Z4/S1/70		13.00	12.18	74.82	
Z4/S1/72		12.05	15.99	71.96	
Z4/S3/9		8.92	0.67	90.40	
Z4/S3/44		3.55	8.16	88.29	
Z4/S4/81		1.03	10.27	88.70	
Z4/S2/26(1)		10.51	22.99	66.49	
Z4/S1/23	Spherical-round-edged	13.51	12.33	74.16	
Z5/S2/39		11.90	11.94	76.17	

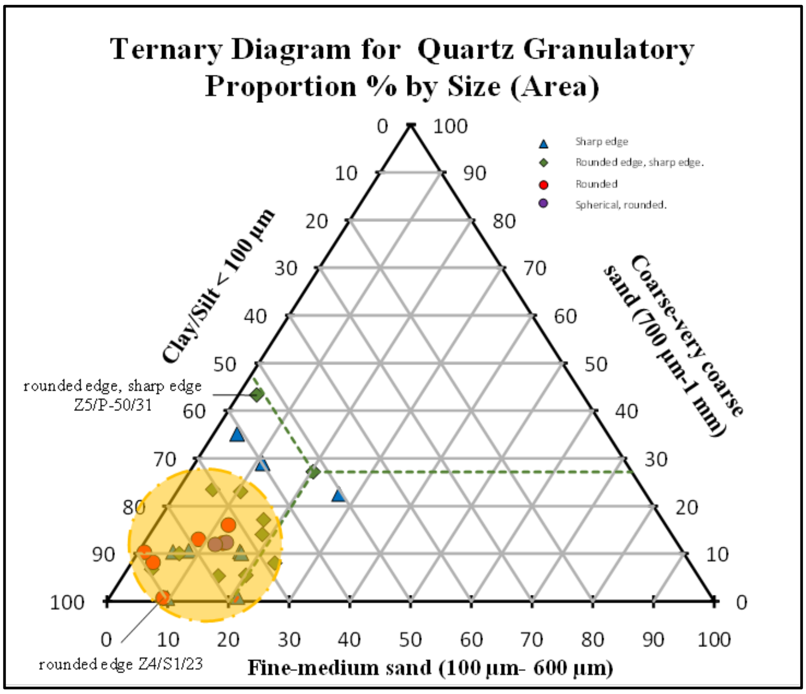

Figure 7: The ternary diagram illustrates the quartz size (area) ratio to the clay/silt composition for all pottery samples investigated in this study

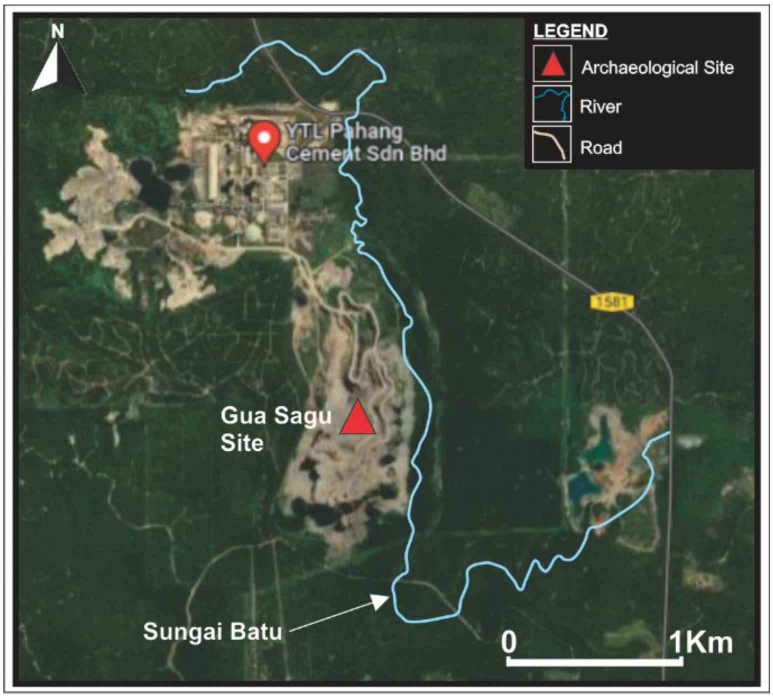

Figure 8: Sungai Batu, located along the eastern part of Bukit Sagu massif

Clay from Sungai Batu may be classified as silt (a sediment material with an intermediate size between sand and clay). Ethnographic literature shows that this type of clay is suitable for making pottery but sometimes needs to be modified by adding tempering materials like sand in order to improve its workability [8]. Based on 2D and 3D microscopy imaging, it was found that the diameter of the quartz grain in Sungai Batu clay is between 100 µm to 200 µm (Figure 9). In addition, they are typically angular in form and have some abrasions. This finding is different from what was found in Gua Sagu pottery in terms of quartz shape and size. However, some pottery from Gua Sagu do exhibit very small quartz diameter in various concentrations which matches the clay sample of Sungai Batu but do not correspond to the other larger particles found in the pottery. Hence it is hard to mention if clay from Sungai Batu was used to manufacture Gua Sagu pottery. Sungai Batu has become exceedingly shallow and isolated today due to palm oil plantation and quarry activities in the area which might have affected the flow, sedimentation and ecosystem of the river. Therefore, at this point, it is reasonable to assume that the Gua Sagu pottery was not made by using clay from Sungai Batu. The pottery could have been a trade item brought in from elsewhere, perhaps to be used for cooking or storing. A similar suggestion has been proposed by Zuraina who had previously studied the Gua Sagu pottery [2].

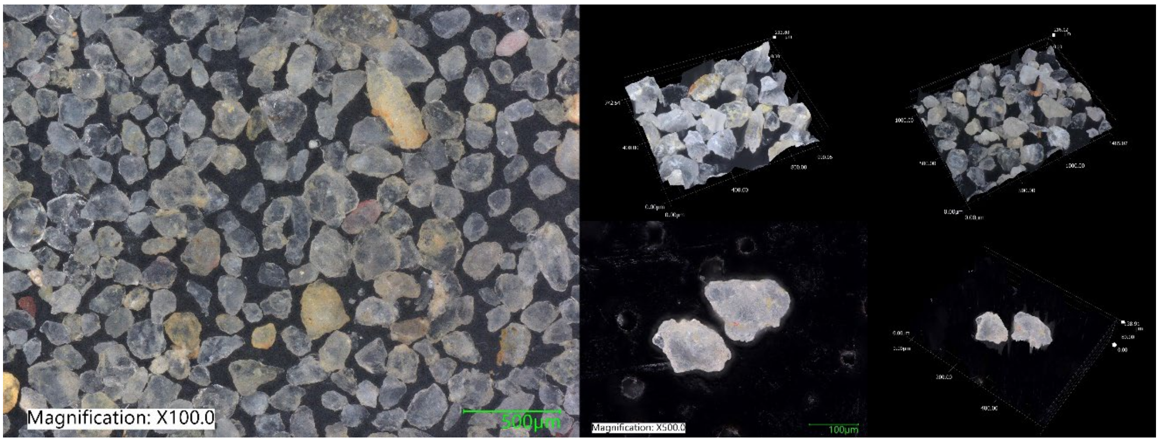

Figure 9: The 2D and 3D images of quartz grain in clay sample from Sungai Batu, Kuantan. The sample was taken at a depth of 100 cm using auguring method

4. CONCLUSION

In a nutshell, digital microscopic imaging technique employed in this study has revealed important data on the internal structure of Gua Sagu ancient pottery. This method is very useful in determining the type of temper and clay modification process employed during the pottery-making activity. The presence of both round- and sharp-edged quartz grains in different sizes confirmed that sand was used as tempering material in the Gua Sagu pottery production. The sharp-edged quartz grains clearly indicate that the sand was pounded before being added to the clay. This clay modification process is widely observed among various ancient and traditional pottery-making communities in Malaysia and Southeast Asia. Conversely, round-edged quartz grains implies that no alteration was done. Based on these findings, it can be deduced that the manufacturing of Gua Sagu pottery involves two distinct clay modification techniques. The pottery could have been made by the inhabitants of Gua Sagu or imported from elsewhere, possibly bartered with the community living nearby or the coastal region. Further elemental, mineralogical and comparative studies using raw materials like clay and sand from the site and its surrounding areas are essential to determine the source, technology and provenance of Gua Sagu pottery. Also, the availability of such data allows for comparative studies with other prehistoric pottery discovered in Malaysia. This will undoubtedly contribute to our understanding of various pottery cultures that existed in Malaysia during the Neolithic Period and their relationships with other pottery cultures in Southeast Asia.

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Author Contributions

All authors contributed toward data analysis, drafting and critically revising the paper, and agree to be accountable for all aspects of the work.

Disclosure of Conflict of Interest

The authors have no conflict of interest to declare that are relevant to the contents of this article.

Compliance with Ethical Standards

The work is compliant with ethical standards.

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