Raw Materials in Sa Huynh Ceramic Production According to Petrographic Analyses

Hoang Thuy Quynh[1]

[1] Institute of Archaeology, Vietnam Academy of Social Sciences.
Email: hoangthuyquynhkch83@gmail.com

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Abstract: In regard to the Sa Huynh culture (500 BP - 200 AD), ceramic artefacts are abundant and make up an important source of materials. Aiming at clarifying the ceramic-making techniques during the period, it is necessary to do research on where raw materials came from and how the local potters dealt with raw materials. The Stoltman's technique for the petrographic analysis of thin sections has been used to analyse the ceramic artefacts of the Sa Huynh culture. Based on the findings of the analyses, some preliminary conclusions have been made as follows: (1) Regarding the sources of clay, the clay used to make the Sa Huynh ceramics were obtained from three sources, including the river sediment, the river-marine sediment, and the marine sediment; (2) Regarding the mixture of raw materials, all Sa Huynh ceramic artefacts were coarsely made of clay mixed with some inclusions (called tempers) such as sand, ground rock pieces, and mollusc shells; (3) The proportions of the inclusions vary from area to area and correspond with the functions of the ceramic products; and, (4) As shown by the analyses, the components of the clay mixture used to make cooking utensils are often different from those of the clay mixture used to make non-cooking objects.

Keywords: Sa Huynh ceramics, ceramic raw materials, petrography.

Subject classification: Archaeology

1. Introduction

Ceramic-making is a traditional craft practised early and popularly in prehistoric societies. In the Sa Huynh culture, ceramic production developed vigorously and provided a large number of aesthetically and technically valuable products. To understand ceramic-making, it is important to learn about the raw materials used to make ceramic products. Ceramic craftsmen used various clay-treatment techniques to get appropriate materials, depending on the local geographical conditions and production purposes. Based on the petrographic analysis of thin sections of ceramic artefacts, the paper focuses on analysing the raw materials used to make ceramic artefacts of the Sa

Huynh culture and consequently provides some comments on the selection of raw materials for ceramic production among the Sa Huynh people.

2. Ceramic raw materials and their properties

Ceramics are composed of three basic raw materials: (1) clay; (2) non-plastic inclusions (called tempers), minerals or organic materials found naturally in clay or deliberately added to it with the aim of making the clay more easily workable and minimising shrinkage; and (3) water. Those materials are mixed thoroughly together before being moulded into desired shapes, so as to make ceramic objects become hard and durable after being baked [16, p.9].

Clay is the most important raw material for ceramic production. The flexibility of clay depends on its source and deposit location. There are different types of clay classified into marine clay, river clay, lake clay, and wind-made clay, according to the conditions of accumulation. Marine clay is also divided into some sub-groups, including the deep-sea deposited (usually very fine and smooth), the coastal deposited (usually coarse and rich in organic substances), and the estuary deposited (also coarse and rich in organic substances). Clay found in lakes or swamps usually has a high organic content. Meanwhile, clay in mountains and hills is mainly colluvial, containing many coarse grains (also called particles). It is necessary to screen out those coarse grains. However, it is sometimes unnecessary to screen them out, as the clay can be used immediately without any temper being added.

In Central Vietnam, the rivers play a major role in delivering clay minerals to swamps, lakes, and the sea. In the flooding seasons, however, the rivers have a large discharge, causing floods on both sides of the rivers and depositing more clay in the river basins. As a result, clay is found abundantly in the basins and the estuaries of the rivers. Potters mainly use clay found in the surface layer of the sediment, which is usually 1m thick at most [12, p.21].

The second raw material used to mix with clay is the temper. Natural clay is often too soft to keep the original shape, after being moulded and baked. In addition, natural clay contains too much water, so the surface of ceramic objects will swell out due to the evaporation, causing unexpected cracks. In order to adjust the plastic property, clay should be mixed with non-plastic materials. For some types of clay, especially the colluvial clay, which is usually coarse with grains, it is not necessary to add the temper. On the contrary, potters sometimes have to screen out impurities and large pebbles.

According to most research on ceramic raw materials, the temper added by potters to clay consists of mineral grains and rock pieces, which have a coarse and angular or semi-angular shape. Meanwhile, natural rock pieces usually have a round shape, since they have been eroded by water flows and wind [18], [19], [13], [17].

After being mixed with the temper, the clay will be spongier; the shrinkage will reduce; the drying time will be shortened; and, the property will be improved after being baked. The shapes of the mineral grains and rock fragments also affect the shrinkage, the drying time, and the durability

of ceramic products. The pieces that have a round or a semi-round shape will reduce the cohesion of materials, making ceramic products break easily. It is, therefore, necessary to add angular mineral or rock fragments of different sizes to clay, aiming at making ceramic products more durable.

3. Stoltman's technique for the petrographic ceramic thin section analysis

Stoltman's technique for the petrographic analysis of ceramic thin sections was known quite early and developed further by him to serve research on raw materials in ceramic production, aiming at finding out the origin of ceramics and the interaction between regions on the basis of the characteristics of the ceramic raw materials [17]. An advantage of this technique is to differentiate between naturally occurring and intentionally added mineral like temper. The differentiation helps to highlight some characteristics of ceramic products such as the ceramic-making technique, the function, the origin, and the exchange.

Stoltman's technique consists of two-step analysis, including the qualitative (by observing mineral inclusions) and the quantitative (by making the point-counting analysis). A thin slice (0.03mm thick) is cut from the sample and then put mounted onto a glass microscope slide. A 1mm square grid is used to observe the thin slide. Observations were assigned to the following categories: clay matrix, silt, sand (natural inclusions), temper, and void. The grains of sand or temper are calculated from three aspects: mineral composition, sizes, and quantity. Each of them is classified by size, ranging from fine to coarse, according to the Wentworth scale of the United States as follows: the grains, of which the diameter ranges from 0.0625 to 0.249mm, are considered fine sand; those, of which the diameter ranges from 0.25 to 0.499mm, are medium sand; those, of which the diameter ranges from 0.5 to 0.99mm, are coarse sand; and, those, of which the diameter ranges from 1 to 1.99mm, are very coarse sand; and, those, of which the diameter is larger than 2mm, are gravel. All silt - size grains (with a diameter of less than 0.0625mm) are considered natural particles, as the size is too small to be differentiated.

To differentiate between naturally occurring and intentionally added minerals like temper, according to Stoltman [17], [18], it is very useful to pay attention to the two physical characteristics of grains: the shape and the size. Naturally occurring grains are smaller and more rounded. Meanwhile, temper was identified by its larger size and its angular shape. The edges of naturally occurring grains are often round due to erosion and movement. On the contrary, the edges of the temper inclusion grains are sharp and coarse, as they were made by grinding bigger grains. The presence of angular grains inside the body of ceramics is supposed to stem from the fact that potters intentionally added them to the clay mixture [14, p.52]. Pham Ly Huong and her colleagues argue that naturally occurring grains and the tempers are hardly differentiated from each other, except the clay is used by potters to make the ceramics. Nevertheless, this has never been done by researchers. It is, therefore, necessary to have a new approach and apply interdisciplinary methods [5, p.79].

The types, sizes, and quantities of the temper grains reflect directly the actions done by the potters. As a result, we can learn a lot about their cultural behaviour. The indices of the components of ceramic clay mixtures (including naturally occurring particles) can provide us with independent and significant evidence to consider whether the ceramics were made locally or imported from outside. To presenting the quantitative data derived from the point-count analyses, Stoltman (1991) uses body and paste to find out the origins of the clay. Body refers to the bulk composition including all attributes including temper, but paste refers to the natural materials present before temper was added. When the ceramic components are the same, it demonstrates that the potters preferred and used the same formula for ceramic production. The composition of the clay mixture reveals whether the origins of the clay used to make the ceramic products are the same or different.

A grain size index has been set up and represents the medium size of the natural inclusions and the tempers. The sizes are compared by visual observation and described in the form of a percentage-based table. The findings of the statistical analyses are shown in a ternary diagram. The graphs make it easier to compare and realise the data correlation. Consequently, the origin of the raw materials such as clay and the temper can be found out. It is also possible to differentiate between local ceramic products and imported ones, and learn about the relationship and the exchange of ceramic products between potters and users.

This approach is closely related to the morphological analyses of geological materials, which has been demonstrated to provide a reliable estimation of the mineral components of the thin section.

4. Petrographic analysis of several Sa Huynh ceramic artefacts

4.1. Properties of the Sa Huynh ceramic raw materials

Working with ceramic artefacts, excavators always make visual descriptions of the components and structure of ceramic raw materials. The Sa Huynh ceramics are classified into the group of coarse ceramics. The smoothness of ceramics is defined by the sizes of sand and other grains found in the ceramic body. The material components of the Sa Huynh ceramic artefacts found in Xom Oc (Ly Son District, Quang Ngai Province) consist of clay mixed with shells of molluscs, coarse sand, and plant residue [7]. Similarly, the Sa Huynh ceramic artefacts found in Suoi Chinh (Ly Son District, Quang Ngai Province) also consist of clay mixed with coarse sand, shells of molluscs, and plant residue [8]. Of the ceramic pots and jar lids found in Tien Lanh (Tien Phuoc District, Quang Nam Province), some consist of clay mixed with sand and a small proportion of shells of molluscs; the body is dark grey. Meanwhile, the spinning plumbs were made of clay mixed with plant residue [2, pp. 245-277]. The material components of the Sa Huynh ceramic artefacts found in Binh Yen (Que Son District, Quang Nam Province) were made of clay mixed with large-sized grains of sand and gravel, while the pot and jar lids were popularly made of clay mixed with fine sand grains and plant

residue; the clay bodies are black and coated with yellow colour [3, pp. 929-962]. The Sa Huynh ceramic jars found in Dong Cuom (Hoai Nhon District, Binh Dinh Province) were made of clay mixed with a lot of sand, while some pots were made of clay mixed with sand and plant residue [8]. The raw materials used to make the ceramic pots found in Tien Ha (Tien Phuoc District, Quang Nam Province) consist of a lot of sand and plant residue. Observing the Sa Huynh ceramic jars found in Go Que (Binh Son District, Quang Ngai Province), the excavators believed that the potters had used ground laterite and quartz rocks and then had mixed them with clay and sand to make the ceramic body [11]. Meanwhile, the Sa Huynh ceramic artefacts found in Con Rang were made of clay mixed with coarse sand and many large-sized grains of quartz pebbles.

4.2. Ceramic artefacts used for the petrographic analysis

The sample used for the petrographic analysis includes 43 ceramic pieces, of which 40 belong to the Sa Huynh culture and the rest belongs to the pre-Sa Huynh culture (with two found in Long Thanh and one found in Binh Chau). The Sa Huynh ceramic pieces are broken parts of jars, pots, jar lids, and lamps, which were found in some sites of the Sa Huynh culture such as Con Rang, Go Ma Voi, Go Mieu Ong, Lai Nghi, An Bang, Hau Xa, Thon Tu, Thach Bich, Go Que, Xom Oc, Suoi Chinh, and Dong Cuom.

The petrographic analyses were done at the Department of Petrographic Analysis at the Vietnam Institute of Geosciences and Mineral Resources.

4.3. Analysis results

4.3.1. Paste

Paste is the mix of naturally occurring particles found in sediments chosen by potters before they added other tempering inclusions. Sedimentary sources usually contain non-plastic mineral grains such as silt, sand, and rock fragments, of which the size is larger than that of clay grains. The natural inclusions found in the clay sediment often have a round or semi-round shape, since their edges were eroded during the movement along the water flows. The clay fineness is shown by the proportions of clay, silt -sized grains, and sand in the clay sediment used to make ceramics.

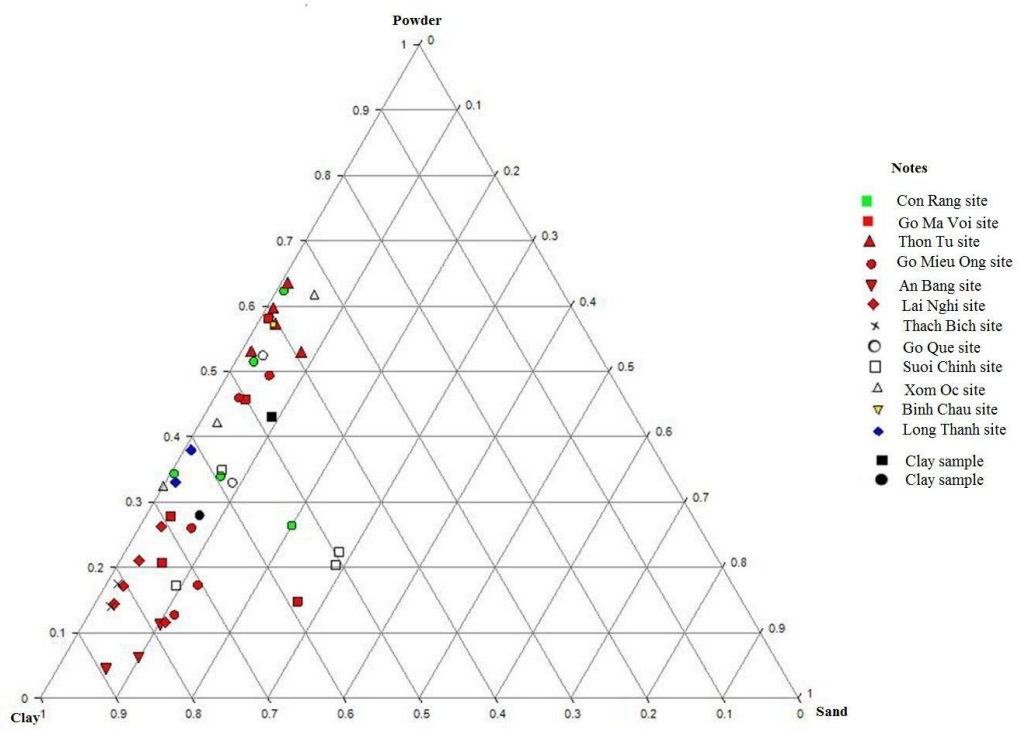
According to the petrographic analyses, the proportion of sand grains in the sample ranges from 0.47% to 28.78%. Of all the sample pieces, the ceramic artefact found in Suoi Chinh has the highest proportion of sand grains. The average size of the sand grains in the ceramic pieces found in Go Ma Voi is the largest (ranging from 0.50 to 0.99mm); whereas, the sand grains in the ceramic pieces found in Con Rang have the smallest size (ranging from 0.0625 to 0.249mm). Meanwhile, one of the ceramic pieces found in Xom Oc does not contain any sand in the body. On average, the proportion of clay ranges from 32.94% to 73.56%, reaching the lowest in the ceramic pieces in Xom Oc and the highest in those in Go Ma Voi.

The mineral composition of the clay sediment and some properties contribute partly towards the identification of the clay origin. *First* of all, traces of marine organisms

are found in a number of ceramic artefacts. In the ceramic pieces found in Suoi Chinh and Con Rang, there are traces of molluscs and sponges (a simple marine creature), which demonstrates that the clay used to make two ceramic artefacts in Suoi Chinh and one in Con Rang has the origin in the marine sediment.

Secondly, another factor for identifying the origin of clay is the comparison of the proportions of the components in the ceramic artefacts with those of the local clay.

Figure 1: Paste Percentage Inclusion Ternary Diagram



Source: Hoang Thuy Quynh (2016), *Ceramic-Making Techniques in Sa Huynh Culture in Central Vietnam*, Doctoral dissertation in Archaeology, Graduate Academy of Social Sciences.

The geological data in the basin of Thu Bon River (Quang Nam Province) shows the compositional characteristics of the sediments from the middle-late period of the Holocene as follows:

The geologists carried out research on the river sediments from the middle to the late period of the Holocene (aQIV2-3) by making boreholes in the sand dunes in Ky Lam and Chiem Son rivers (Quang Nam Province) through three layers, of which the third one (the top layer) consists of silt- clay mixed with grey yellow sand. In regard to the composition, the percentages of sand, silt

and clay are 9%, 43%, and 48% respectively [6, p.23]. After making a comparison of the component percentages of the clay sediment, we have realised that they are very similar to those of the ceramic artefacts in Go Ma Voi (the sample coded 99.GMV.D147.5) (Figure 1). Thus, the clay used to make the ceramic artefacts in Go Ma Voi was obtained locally from the river sediment.

In the basin of Thu Bon River, the river-marine sediments from the middle-late period of the Holocene were mainly found in the lower areas of Thu Bon, Cau Do, and Cu De rivers. The vertical section of the boreholes reveals that the sediment consists of three layers, of which the third layer in the top is comprised of silt- clay mixed with dark grey sand and contains a lot of coalified plant remains. Regarding the composition, the percentages of clay, silt, and sand are 65%, 28%, and 7% respectively [6, p.25]. The figures also demonstrate that the sedimentary sample is very close to the clay used to make the ceramic artefacts in Go Ma Voi. It is, therefore, possible that the river-marine sediments located along the lower section of Thu Bon River were also used as raw materials for the ceramic production in Go Ma Voi, in addition to the river sediment.

As shown in Figure 1, the clay of the ceramic artefacts in Go Ma Voi has the same or almost the same composition as that of the ceramic artefacts in Thon Tu. Two geological samples of the boreholes, of which one is drilled in the river sediment and the other in the river-marine sediment, have a similar composition to the ceramic artefacts in Go Ma Voi. Particularly, the type of clay of the river sedimentary sample, the ceramic artefacts in Go Ma Voi, and those in Thon Tu is largely concentrated in one area. It is therefore likely that the clay used to make the ceramics in Thon Tu and that of the ceramics in Go Ma Voi have the same origin. This further proves the opinion raised by Lam Thi My Dzung, who supposed that the ceramic artefacts in Thon Tu and those in Go Ma Voi had the same date and the same owner [1, p.18].

Thus, Sa Huynh ceramic potters in Go Ma Voi did not use only the local source of clay, but they used various sources, since there was abundant clay in the surrounding areas.

In the basin of Thu Bon River, geologists discovered three mines of clay from the middle-late period of the Holocene, according to the Map of Mineral Resources published by Vietnam Institute of Geosciences and Natural Resources. They include: (1) a river-marine sedimentary clay mine in the area of Que Phu (amQIV2), where many vestigial sites of the Sa Huynh culture have been found, such as Go Ma Voi, Go Mieu Ong, Thon Tu, and Go Cam; (2) a river-marine sedimentary clay mine from the late period of the Holocene in Hoa Tien (Dien Ban), close to the group of vestigial sites of Lai Nghi, An Bang, Hau Xa, Dien Hoa, and Dien Ngoc; and, (3) a river sedimentary clay mine in the area of Duy Chau, close to the group of vestigial sites of Go Dua and Phu Da. As described by Arnold Dean, the distance from the place of ceramic production to the sources of clay is often one kilometre and can be six or seven kilometres at most [12, pp.51-52]. The convenience and availability of raw materials are factors affecting the formation and development of ceramic production. According to the findings of geological research, there is

certain suitability between the distribution of clay sources and the concentration of the Sa Huynh vestigial sites.

4.3.2. Temper choice

The petrographic analyses show that the main components of the materials used as the tempers were quartz, feldspar, and rock pieces (Table 1). Quartz and feldspar and quartzite rock were found at almost every sample. At many samples, however, granite rock was also used as the temper.

Remarkably, observing directly a cross-section of the ceramic artefact in Xom Oc, we can see quite a lot of mollusc shells and carbonate rock fragments, which account for 35 or 36%. At the same time, there is no feldspar in this ceramic sample at all, although feldspar is a common mineral found in ceramics as it helps to increase the thermal resistance of the ceramic pots; the proportion of quartz is much lower than that in other ceramic artefacts. Mollusc shells were seen as one of the minerals that helped to increase the thermal resistance. Thus, they were probably used as the temper to replace the common materials, which contained feldspar and a lot of quartz. The marine sand on Ly Son island from the Quaternary period also contains mollusc shells. The proportion of the mollusc shells is, however, high and the grains of the mollusc shells mostly have angular shapes. The diameter of some grains is even larger than 2mm. Thus, we can suppose that potters ground mollusc shells and added them to ceramic clay as temper. This matches the research findings of Rice Prudence [13], who supposes that the mollusc shells found in marine sand and sedimentary clay just make up a little proportion; whereas, the mollusc shells added to the ceramic clay by potters as temper make up quite a large proportion, ranging from 20% to 30%. The rock fragments have the origin in sedimentary, magma, and metamorphic rocks.

Based on the petrographic analysis of the ceramic artefacts found in Go Mieu Ong, cooking and mixing tools contain a smaller proportion of the temper than jars. On the contrary, among the ceramic artefacts in Lai Nghi, cooking pots contain a higher proportion of the temper than jars. In both the vestigial sites, the size of the temper in the ceramic jars is larger than that of the temper in the ceramic pots. According to Carla M. Sinopoli, the composition of the materials used to make cooking pots is usually different from that of the materials used to make non-cooking objects. In order to improve the thermal resistance of the cooking pots, potters applied some methods. For example, they added organic substances or temper, which had a high expansion ratio, such as calcite, plagioclase, and feldspar, to the ceramic clay for the purpose of enlarging the size and quantity of gaps inside the ceramic body [16, p.85]. The results of the petrographic analyses show that pieces of ceramic cooking pots usually have a higher proportion of feldspar grains than ceramic jars. In addition, all pieces of the cooking pots found in Go Mieu Ong contain a small proportion of organic substances. Consequently, the Sa Huynh ceramic potters comprehended the ceramic-making techniques whereby they made and used materials appropriately to the functions of the ceramic products.

Table 1: Main Tempers in Ceramic Composition

Sample codes	Mineral grains											Rock fragments					Others	
	Qz	Fs	Amph	Mica	Epid	Pyro	Tml	Biot	Zr	Qzite	Mm	Vig	Base	Acid	Shale	Epid	Mm Glass	Mollusc shells
02CR.H5.M45	x	x	x		x		x			x	x	x						
02CR.M52	x	x	x		x				x									
02CR.M172	x	x	x					x		x				x				
02CR.H5.M155.2	x	x	x		x										x	x		
02CR.H5.M155.1	x	x		x	x		x			x								
03.GMO.5	x	x	x		x			x		x		x			x			
03.GMO.4	x	x	x	x	x					x	x	x						
03.GMO.3	x	x	x		x	x		x		x				x	x			
03.GMO.2	x	x	x	x	x					x		x						
03.GMO.1	x	x	x		x		x	x	x	x					x			
99.GMV.Đ147.1	x	x	x	x						x	x	x						
00.GMV.Đ147.2	x	x	x		x					x								
00.GMV.Đ147.5	x	x	x															
00.GMV.Đ147.3	x	x	x		x			x								x		
00.GMV.Đ147.4	x	x	x		x		x			x					x			
00.TT.Đ151.1	x	x			x		x			x								
00.TT.Đ151.2	x	x		x	x					x				x				
00.TT.Đ151.3	x	x			x		x	x		x				x				
00.TT.Đ151.4	x	x	x		x	x	x											
00.TT.Đ151.5	x	x			x									x				
04..LN.H1.M27	x	x	x		x				x						x			
04..LN.1	x	x						x					x	x				
04..LN.2	x	x	x		x		x		x	x				x		x		
04..LN.3	x	x	x		x			x						x		x		
04..LN.4	x	x	x		x			x	x									
95.AB.1	x	x	x	x			x			x								

Sample codes	Mineral grains											Rock fragments					Others	
	Qz	Fs	Amph	Mica	Epid	Pyro	Tml	Biot	Zr	Qzite	Mm	Vig	Base	Acid	Shale	Epid	Mm Glass	Mollusc shells
95.AB.2	x	x	x		x				x	x		x						
95.AB.3	x	x	x	x	x				x	x	x							
TB2	x	x	x		x			x		x				x				
00.SC.H1LII.4.2	x	x	x		x					x		x			x			
00.SC.H1LII.3.3	x	x	x	x	x					x	x	x			x			
00.SC.H1LII.5.1	x	x	x	x						x	x						x	
00.SC.H1LII.5.4	x	x	x			x		x							x	x		
97.XO.TS.Đ121	x	x	x		x					x								
97.XO.TS3.Đ121	x									x								x
97.XO.TS3.H1L6	x	x	x		x													
05.GQ.H9M6.1	x	x		x		x				x		x						
05.GQ.H14M1.1	x	x	x		x					x	x							
05.GQ.H9M6.2	x	x	x		x	x												
77.LT2	x	x	x		x		x			x								
77.LT1	x	x	x		x							x						
78BC	x	x	x			x		x							x			

Notes:

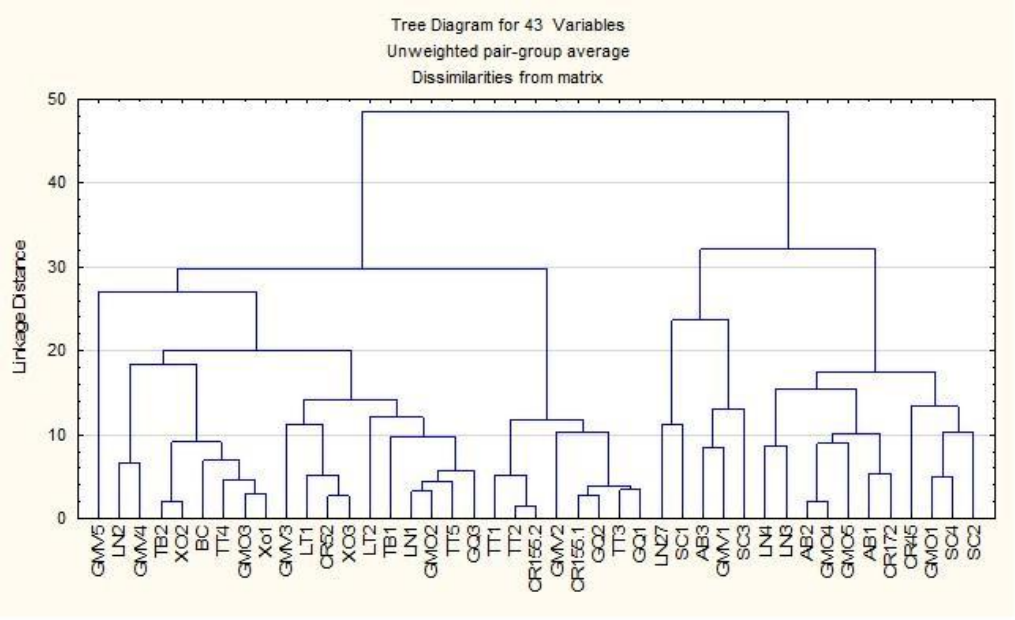
Qz: Quartz
Fs: Feldspars
Amph: Amphibole
Epid: Epidote
Pyro: Pyroxene
Tml: Tourmaline
Bio: Biotite
Zr: Zircon
Qzite: Quartzite
Mm: Metamorphic
Vig: Vigranite

4.3.3. Temper inclusion grain size

Temper inclusion grains mostly are silt-size and sand- size grains. Very few of them are gravel-size grains. In the ceramic artefacts found in Go Que and Thon Tu, the sand grains are very coarse and the average size of the temper is the largest; with some uneven sizes (some are big and some are small).

As presented in Figure 2, the statistical analysis shows the coarseness of temper inclusion grains in the ceramic body. The ceramic artefacts, which have similar proportions and sizes of temper inclusion grains, are classified into the same group. As a result, all the ceramic artefacts have been classified into five groups. The ceramic artefacts in the same group may have different types and origins. The fifth group consists of 11 artefacts, of which six are broken pieces of ceramic jars. This is the group that contains most artefacts of ceramic jars. Thus, ceramic artefacts, which have the same type or were found in the same site, do not necessarily share the same formula of fineness or coarseness. For example, all four samples coded LN1, LN2, LN3, and LN4 are pieces of the ceramic jars found in Lai Nghi, but they are classified into two different groups. This demonstrates that the artefacts coming from the same site may have different proportions of temper inclusion grains. Similarly, the samples of the ceramic jars found in Go Mieu Ong are classified into two different groups. Meanwhile, the three samples of the ceramic jars found in Go Que are arranged in the same group, which shows the similarity of the artefacts in this site.

Figure 2: Relationships of Ceramic Samples by Proportion of Temper Inclusion Grains



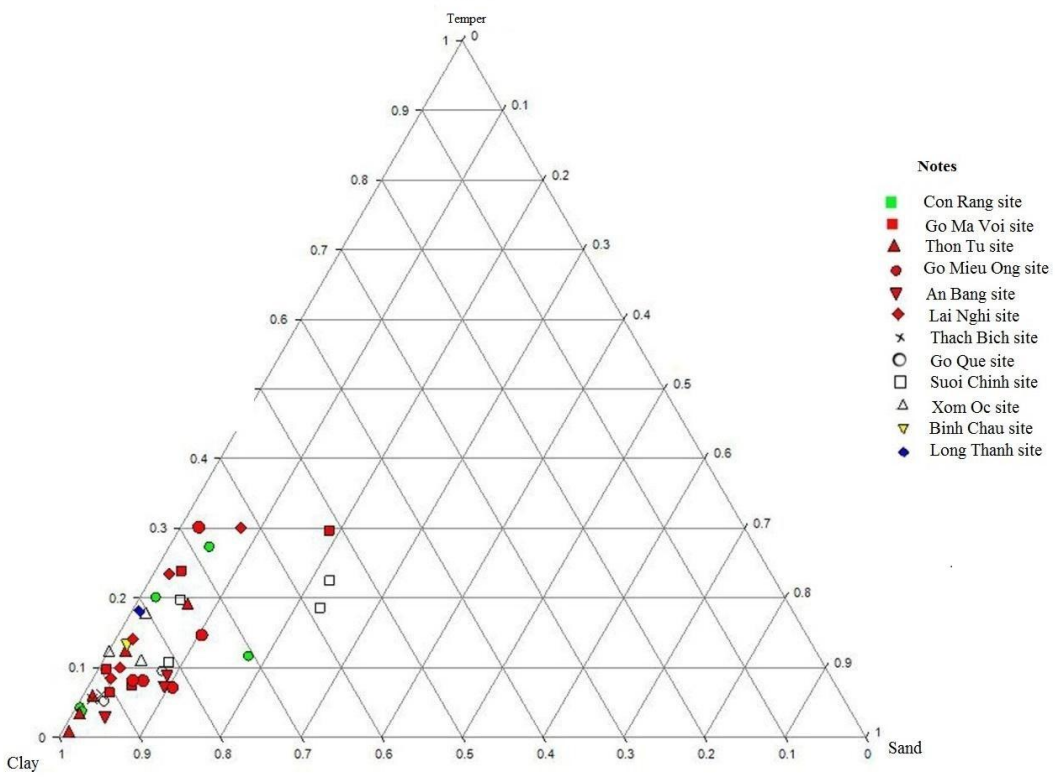
Source: Hoang Thuy Quynh (2016), *Ceramic-Making Techniques in Sa Huynh Culture in Central Vietnam*, Doctoral dissertation in Archaeology, Graduate Academy of Social Sciences.

4.3.4. Body

The petrographic body considers the composition of the vessel as a whole, including temper and any other added material. While the study of paste aims at finding out the origin of the raw materials used to make ceramic products, the study of body aims at finding out the way to mix clay with temper.

According to the petrographic analysis, all ceramic products contain temper. The proportions of the temper vary from site to site, ranging from 0.87% to 29.7%. The highest proportion of temper is found in a slide cut from the rim of the ceramic jar in Go Ma Voi, and the lowest proportion of temper is in the sample of Thon Tu. Pieces of jars and jar lids usually contain a higher proportion of temper than other ceramic objects. In regard to the ceramic sample coded 97.XO.TS3Đ121 (0.4-0.8) found in Xom Oc, there is not any naturally occuring grains in the clay, that was tempered with the high proportion of mollusc shells, while that of the temper inclusion grains, including quartz and stone pieces, is low.

Figure 3: Body Percentage Inclusion Ternary Diagram



Source: Hoang Thuy Quynh (2016), *Ceramic-Making Techniques in Sa Huynh Culture in Central Vietnam*, Doctoral dissertation in Archaeology, Graduate Academy of Social Sciences.

In the basin of Thu Bon River, where a very large number of the Sa Huynh cultural sites has been found, the similarity between the ceramic artefacts Go Ma Voi and those in Thon Tu is relatively high, according to the petrographic analysis of the artefacts found in various sites such as Go Ma Voi, Go Mieu Ong, Thon Tu, An Bang, Thach Bich, and Lai Nghi. However, some ceramic artefacts, such as pieces of the rims of the ceramic jar, are greatly different from the rest, as shown in the diagram (Figure 3).

The size of the temper grains is also related to the thickness and size of the ceramic artefacts. In thick ceramic artefacts, the temper grains often have a large size; whereas, those in smaller ceramic artefacts often have a smaller size. The clay used to make the body of ceramic jars is mostly mixed with coarse sand grains. On the contrary, some types of ceramic products such as spinning plumbs and earrings were often made of a fine clay mixture.

At the sites, where both fine and coarse ceramic artefacts are found, potters probably had different methods of making clay mixtures, depending on the functions of the ceramic products. Bowls and trays such as those found in Suoi Chinh, Go Ma Voi, and Con Rang were made of clay mixed mainly with fine and some medium-sized sand grains; whereas, the pieces of the jars and jar lids contain more coarse sand grains.

5. Conclusion

Based on the results of the petrographic analyses of the ceramic artefacts, we can make some preliminary conclusions as follows:

- Regarding the paste, the petrographic analysis of some ceramic artefacts has provided us with factors indicating the origin of the sedimentary clay. In addition, the comparison of clay has revealed that potters obtained clay from three sources available locally, including: the river sediment, the river-marine sediment, and the marine sediment. They took advantage of the local clay to make ceramic products. In other words, the ceramic production was formed and developed in those areas where appropriate materials were found. The Sa Huynh cultural sites can be found in various terrains, including plain, mountainous, coastal, and island areas, of which the sedimentary properties are different from each other. The clay used to make the Sa Huynh ceramics has the origin in the river sediment, the river-marine sediment, and the marine sediment. The petrographic analyses have also demonstrated that those sources of clay have different proportions of clay, silt, and sand. The higher the proportion of clay is, the more pliant the mixture will be and vice versa. Potters had different ways to make clay mixtures, depending on the specific pliancy of the source of clay.

- Regarding the body, all Sa Huynh ceramics are coarse and contain temper such as sand, rock fragments, and mollusc shells in the body. The proportion of the temper varies according to the sites and functions of the ceramics. For making ceramic jars, potters usually mixed clay with a lot of coarse sand, very coarse sand, and rock fragments. For making household products, however, they used medium-sized and coarse sand as temper. Some types of

ceramic objects such as spinning plumbs and three-notch earrings were made of a fine clay mixture. The materials used as temper also vary from area to area. For most of the ceramic artefacts, the clay was mixed with sand grains, of which the mineral composition contains quartz and feldspar; whereas, for some ceramic objects found in Xom Oc, mollusc shells were used as temper, instead of the above-mentioned minerals.

- The petrographic analyses have demonstrated that the mineral components of the clay mixtures used to make ceramic cooking pots are usually different from those of ceramic non-cooking objects. According to Owen S. Rye [14], two of the most important properties of the ceramic cooking pots are thermal shock resistance and thermal absorption. In regard to the ceramic cooking utensils, the resistance to thermal shock enables them to resist repeated cycles of quick heating and cooling flows without being damaged or broken. When a ceramic object is heated from below, its outside becomes much hotter than its inside. With low thermal conductivity, the outside surface will expand much more than the inside. There are three factors that potter can use to improve the thermal shock resistance of ceramic products, namely (1) the porosity; (2) the type, size, and quantity of mineral grains in the body; and, (3) the thermal expansion. To strengthen the thermal shock resistance, potters can apply some methods to increase the size and quantity of gaps; for example, they add more organic substances or unevenly angular grains as temper to the clay mixture; or, they may add more elastic materials such as super-fine clay grains or other mineral grains such as calcium and feldspar, similar to the way they make the body of containing objects.

For cooking utensils, the porosity of the body should be quite high (reaching 10% at least) and the gaps should be distributed equally all over the body. In regard to technique, organic materials such as grass and straw were added as temper to the clay, aiming to create big gaps inside the bodies of ceramic pots. After the baking process, the grass and straw were completely burnt, leaving gaps of the corresponding sizes. Such materials were used popularly in ceramic production in the prehistory of the world. The raw materials used to make the Sa Huynh ceramics were also mixed with organic materials. As they all were burnt during the baking process, it is hard to know exactly what they were. Observing the dark body of the Sa Huynh ceramics, however, researchers have seen many gaps. Consequently, most of them have supported the above-mentioned opinion.

Appropriate materials were chosen to make ceramic products. Minerals such as feldspar, plagioclase, zircon, and augite have a lower or nearly similar degree of thermal expansion, compared to clay. They were, therefore, used as temper to make cooking utensils. This is shown quite obviously by the above-mentioned findings of the petrographic analyses. In addition to the use of those minerals, the minerals of high calcium content, such as mollusc shells were seen as an appropriate option among the Sa Huynh ceramic potters.

According to the study of a piece of the ceramic pot in Xom Oc, mollusc shells were used as the temper instead of the minerals of high feldspar content.

In regard to the ceramic products used as coffins, durability was one of the properties considered the most important. The durability of ceramic products depends on many factors such as the raw materials, the size of temper inclusion grains, the composition of clay, the preparation technique, the shaping methods, the drying time, the temperature and environment of the kiln, and the shape as well as the size of the products. When clay grains are fine, they easier be softened and mixed. As a result, the cohesion of grains will improve after the baking process. The durability also depends on the shape and the surface characteristics of non-plastic grains. As demonstrated by Sherpard Anna on the basis of the durability tests [15, p.131], coarse grains make a stronger attachment to clay than fine ones. Broken ceramic pieces, rock fragments, and volcano ash make the structure of ceramics stronger and more durable, compared to sand grains, which have a smooth surface due to erosion. Mineral inclusions mixed with clay to make ceramic jars, typically those found in Go Que, Go Mieu Ong, and Lai Nghi, are mostly coarse or very coarse. According to the findings of an anthropological research work conducted by Nguyen Thi Hoai Huong in the present-day ceramic-making villages of Khmer people, local people do not add temper to clay when they want to make ceramic utensils. When making water-containing jars (which have a far bigger size), however, they have to mix clay with some sand [4].

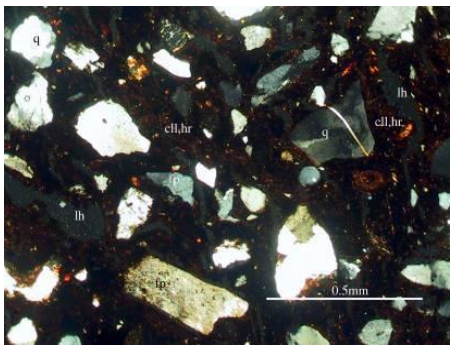
- The local geological and environmental characteristics affect the way to add temper to the ceramic materials. The selection of raw materials varies from area to area, while other aspects related to the production technique such as the shaping, the patterning, and the baking are quite similar. Due to the differences in the raw materials, various substances were mixed with clay as temper in the Sa Huynh ceramic production. The culture-based mixture of raw materials is, however, quite unanimous; the raw materials used to make jar-shaped coffins often contain big-sized grains of the temper, while the temper inclusion grains in the household ceramics are finer.

Thus, though the Sa Huynh potters did not know exactly which types of minerals the temper or the clay contained, they selected appropriate raw materials according to their experience. They learnt about the actual properties and functions of the materials in order to make the right mixture for expected ceramic products. Due to various demands for ceramics in society, potters had to study and search for different techniques, aiming at creating the ceramic products that could meet the socio-cultural requirements of the Sa Huynh people. With such ceramic techniques, they produced high-quality products such as durable ceramic jars, which were the biggest in the prehistory and used popularly in diversified forms, making the ceramic production become a very significant craft in the Sa Huynh culture.

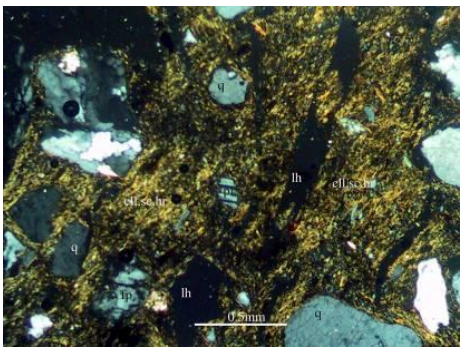
ILLUSTRATIONS

Analysed ceramic sample	Photomicrograph of ceramic thin sections by petrographic microscope	Cross-section

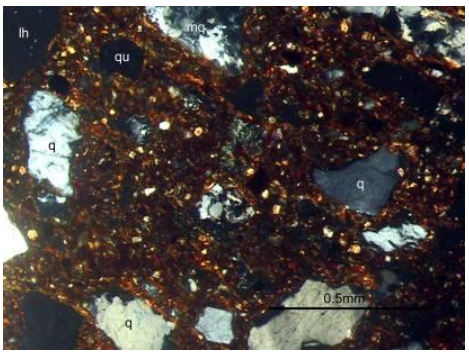
Photos 1 - 2 - 3: Ceramic Sample in Lai Nghi - 4.LN.H1M27



Photos 4 - 5 - 6: Ceramic Sample in An Bang - AB2



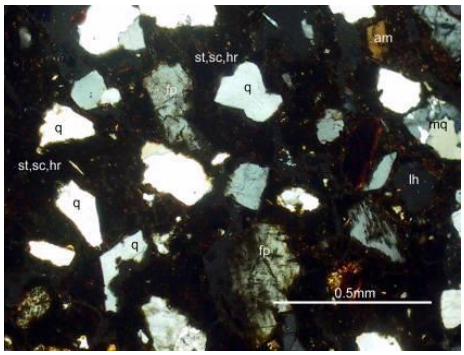
Photos 7 - 8 - 9: Ceramic Sample in Go Que - 05.GQ.H9M6.2



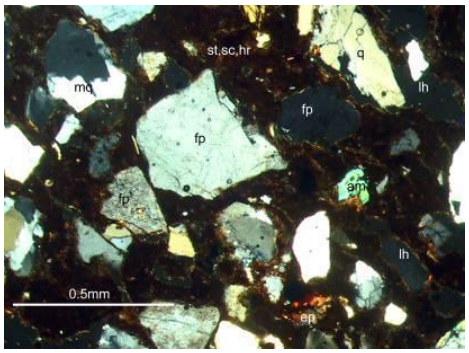
Analysed ceramic sample	Photomicrograph of ceramic thin sections by petrographic microscope	Cross-section

Photos 10 - 11 - 12: Ceramic Sample in Xom Oc - 97.XO.H1L6

Photos 13 - 14 - 15: Ceramic Sample in Con Rang - 02.CR.M172

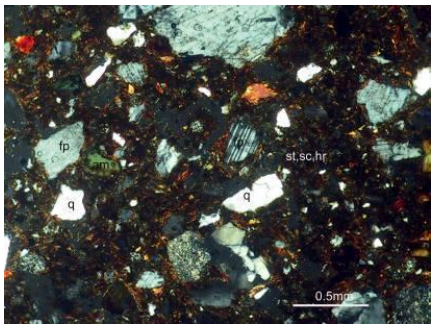


Photos 16 - 17 - 18: Ceramic Sample in Suoi Chinh - 00.SC.H1LII5.4



Analysed ceramic sample	Photomicrograph of ceramic thin sections by petrographic microscope	Cross-section

Photos 19 - 20 - 21: Ceramic Sample in Go Ma Voi - 99.GMV.Đ147.2



Source: Author, Vietnam Institute of Geosciences and Mineral Resources.

Note

[1] The paper was published in Vietnamese in: *Khảo cổ học*, số 1, 2019. Translated by Nguyen Tuan Sinh, edited by Etienne Mahler.

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