7. Fabric Analysis

Fabric analysis includes classification of pottery and characteristics of the clay paste from which the pottery was made. The characteristics of the clay paste are largely influenced by three factors: (i) clay matrix, (ii) inclusions and (iii) firing temperature and environments. Pottery fabric consists of two elements: a 'matrix' composed of clay minerals less than 0.002 mm across and 'inclusions' which are larger. While inclusions in a fabric can be seen with naked eye or a binocular microscope, the clay minerals of the matrix can only be seen using high-powered microscopes and thin-sections or through Scanning Electron Microscope (SEM). The terms fabric and clay paste are used interchangeably in pottery studies. The two constituents of the fabric, matrix and inclusions, are largely influenced by the choice of raw materials and preparation of raw materials by the potter and both these constituents undergo change at varying degrees by firing temperatures and environments.

More often it is the inclusions that are studied when fabric is studied. Their larger size in comparison with the clay minerals makes it easier to spot and identify them. Inclusions greatly affect pottery manufacture because they largely influence the plasticity, shrinkage and firing. It is necessary to understand the difference between inclusions and temper. While the term temper means deliberate addition of inclusions to alter the plasticity of the paste, the term inclusions mean both naturally occurring and deliberately added non-plastic material. It has been considered in archaeological literature that tempers are binders and strengthen the body. In fact it is the clay paste that is the binder and the non-plastics in effect weaken the body. Despite this it is used because it reduces shrinkage and assists in uniform drying.
7.1 Advantages of Inclusions

As mentioned above the two major functions of non-plastic inclusions in the fabric are:

- Reduces shrinkage - inclusions are mostly added to the clay in order to alter the plasticity and make it more workable. An adequate amount of non-plastic inclusions added to very sticky plastic clay will add strength to the clay and prevent it from collapsing. An excess of these non-plastic inclusions will lessen the cohesiveness to an extent that will negatively affect shaping. Non-plastic inclusions being coarser reduce firing shrinkage which occurs due to decomposition of clay particles and their eventual sintering.

- Facilitates uniform drying - every clay particle is surrounded by a water film. During drying the water on the surface evaporates and water from the interior moves to the surface through capillary action. The capillary spaces between the clay particles being very fine makes this slower. So, the surface becomes much drier than the interior, resulting in stress and cracks. The presence of non-plastic inclusions makes the texture of the paste coarser and facilitates the movement of water from the interior to the surface easier thus, preventing cracking of the pot.

7.2 Types of Tempers

A wide range of materials are used as tempers by primitive potters. Sand is the most common of all tempers. Rocks of all three types are crushed and used as tempers. Igneous rocks like basalts, diorites, volcanic ash/tuff; sedimentary rocks like sandstone, limestone and dolomite and metamorphics like schists and gneiss are pulverized and used as tempers. Apart from these, organic materials such as chaff,
husks and wood ash are also used as temper. Broken and discarded potsherds are crushed and reused as temper and are called grog.

These tempers differ with respect to the labour required for their preparations, in their effect on the strength and texture of pottery and in their reactions to heating. While the rocks are consolidated and have to be ground before being added to the paste, sand, a well sorted material does not require. The choice of temper is largely influenced by the effect on surface finishing of the pot and also its effect on the strength. The structure, hardness and grain size of inclusions determine the ease with which the plastic, leather-hard or dry surface can be worked to a great extent. For instance, if the inclusions are hard and coarse, grains are dragged by the scraping tool and result in drag marks and pits on surface from where they pop out. Silt and inclusions of fine texture are better suited and do not adversely effect the finishing of the outer surface of the pot.

The strength of the pot is dependent on the bonding of clay and temper. Clay particles form a weak bond with inclusions which have smooth surfaces. Thus grains that are well sorted by wind and water action weaken the paste more than the rough fragments of rock or sherd of the same size. Also rounded grains weaken the clay body more than the sharp, irregular ones. Inclusions that are platy like mica affect the structure of paste because they are flat and angular and attain a parallel position during finishing. In pottery fired at low temperatures inclusions of this kind reduce cracking against cross fracture on repeated heating and cooling, but cause weakness in their own plane. Thus, the inclusions added indicated the function that is needed to be fulfilled.
7.3 Effect of Heat on Non-Plastics

Different types of inclusions undergo change under different temperatures. Even low temperatures attained during the open-air firing, adopted in the Neolithic times could cause changes in the structure of the inclusions, both favourably and unfavourably. The changes that occur in minerals upon heating are many, including both physical and chemical alterations. They include dehydration, oxidation, reduction, inversion, decomposition and fusion. Dehydration occurs at lower temperatures and results in swelling as water converts to steam. Oxidation and reduction are governed by firing conditions and occur over a considerable firing range. These changes have an effect on colour. Inversion refers to the change in the atomic structure at different temperatures in different minerals. Decomposition occurs at a wide range of temperature and fusion occurs at higher temperatures.

Feldspar is the most common mineral that remains stable at the temperatures achieved by open-air, non-kiln firing. Feldspars have high fusion points and thus act as fluxes only when fired at high temperatures, above 1200°C. Grog also remains stable at low temperatures. Since they have already experienced firing once before, repeated firing will fully oxidize the grog and high temperatures may even increase its hardness and occasionally even cause the grog to vitrify.

Quartz, a major component of common tempers, does not experience much change at low temperatures. Quartz undergoes three inversions of which two are within the temperature ranges of open-air firings employed in the Neolithic times.

Thermal changes in organic tempers are not favourable. They are oxidized and leave behind long, elongated pores in the body, thereby weakening it.

Inclusions such as shell, limestone and calcite are all rich in calcium carbonate. Carbonates undergo decomposition on firing, particularly between 650°C
and 898°C (Shepard, 1985). Carbon dioxide escapes and the resulting calcium oxide takes up moisture and becomes calcium hydroxide. This is similar to what happens during slaking of lime. Hydration increases the volume of the particles, which after calcinations are soft and white. This increase in volume exerts pressure and may result in crumbling of the pot. Very fine particles which cannot have such an effect on the pot with time reunite with carbon dioxide and regain their original composition of calcium carbonate but with cryptocrystalline structure. Calcination takes place at a very slow pace, at lower temperatures and so if the firing is short and rapid, no noticeable change can be seen.

Dehydration of certain minerals is accompanied by swelling. Muscovite mica, a common inclusion in Neolithic pottery exhibits effects of dehydration, which take place at low temperatures well within the ranges of open-air firing. Even though the flakes are not large enough or numerous enough, the ones that are on the surface and parallel to it cause pitting because of the swelling of the particles due to dehydration, which in turn cause them to break off from the paste.

### 7.4 Effects of Firing on Common Inclusions

Inclusions may be present naturally in the clay or may be added by the potter as temper; but whatever their origin, they are important during firing in modifying the expansion, shrinkage and microstructure of the clay body. The melting and fusion of a ceramic can be discussed in terms of sintering and vitrification. In sintering the surfaces of particles begin to stick to or fuse with other particle surfaces and the rate of sintering is more or less inversely proportional to particle size. It is in the sintering process that some minerals like feldspars act as fluxes and begin to melt. When pottery with fluxing agents is continued to be heated to even higher temperatures
vitrification takes place. Sintering and vitrification begin early on in very fine- 
textured materials than in coarse ones, even below the standard vitrification 
temperatures of the constituent minerals. Apart from feldspar, iron in a reduced state 
of ferrous oxide may act as a flux at low temperatures between 800° and 900° C. 
Mica, boron and lead also act as flux agents.

7.4.1 Quartz

The most common and abundant inclusion in most ceramic bodies is quartz or 
free crystalline silica. Silica in its many forms is the earth’s most stable and abundant 
natural mineral. Silica is present in macrocrystalline (quartz and quartz sand), 
cryptocrystalline (chert, chalcedony, agate and jasper) and amorphous (organic, 
biosilica or phytoliths) forms. Although quartz is a refractory mineral resisting 
melting until 1710° C, it undergoes three inversions during firing. These inversions 
occur at 573, 867-70 and 1250° C, along with corresponding changes in specific 
gravity and density.

The first inversion occurs at 573° C with alpha quartz transforming to beta 
quartz. This is accompanied by structural change and resulting expansion of quartz 
grains. This expansion does not have any negative effect on the fired pottery since this 
occurs at the same time as the loss of water (between 500° and 600° C). The second 
and third inversions take place at 867° and 1250° C respectively, leading to the 
formation of tridymite from beta quartz and further to cristobalite from tridymite. 
Along with the high temperatures, it is also necessary that the high temperatures are 
maintained for a long time. Cristobalite stabilizes at 1470° C and such high 
temperature conditions are required to persist long for tridymites and free crystalline 
silica to transform to cristobalite. It is possible that the quartz could be altered to the
tridymite structure with the help of fluxes. At high temperatures fluxes hasten the
inversion of quartz. Open-air firings could attain temperatures of 900° to 1000° C
(Shepard, 1985). The open-air firings of the Neolithic pottery were too rapid and did
not attain high temperatures to transform quartz to the cristobalite.

Quartz as inclusion has both desirable and undesirable properties. Quartz
reduces shrinkage during drying and firing. If the size of inclusions is large, then
quartz will reduce the strength from both expansion occurring during alpha-beta
inversion and also microcracking resulting from heating of large particles at high
temperatures.

7.4.2 Feldspar

The second most important inclusions in ceramics is feldspar. Feldspars are
described as a large family of silicate rocks that constitute the most abundant mineral
category in the earth’s crust. These minerals are present primarily in granites and
pegmatites, mostly in association with mica. They are also the parent materials of clay
minerals and are present at least in small amounts in clays, especially those resulting
from incomplete weathering. The feldspar family consists of potash, alkali and lime
feldspar. Feldspars do not undergo inversion when heated to high temperatures but
melt and so are used as fluxing agents. They support sintering when finely ground.
The temperatures at which potash, soda and lime feldspars melt are as high as 1150°,
1118° and 1550° C respectively. But these can be lowered when limestone and quartz
are added as inclusions. The finely ground particles readily sinter and fuse
consequently making the body dense and low in porosity.

Feldspar especially potash and soda feldspars are deliberately added as
inclusions and so also crushed feldspar containing rock like granite and basalt. But
these inclusions are not adequately fine particles so as to cause fluxing. Many primary clays contain feldspar in unweathered or partly weathered state, as residual minerals along with quartz.

7.4.3 Calcium

Calcium occurs as calcium carbonate in limestone, calcite and shell and as calcium sulfate or gypsum. Lime or calcium may occur naturally in clays which are then called calcareous clay or marl. Calcium may also be added to clays in the form of bone ash. Calcium decomposes at 870° C. Consequently, calcium oxide or lime is formed with the escape of carbon oxide. Therefore, when pottery is heated beyond this temperature and cooled, calcination takes place by absorbing moisture from the atmosphere. This is accompanied by expansion in volume, which will cause stress in the clay body causing spalling and cracking. This is known as lime popping. It is more frequent when lime particles are larger and expansion in volume after calcination is greater. This is a major hindrance that the Neolithic potter had to overcome. The expansion of volume due to calcination can be reduced by adding finely ground lime as inclusions. This in turn will reduce the cracking and crumbling. Another method to prevent the adverse effects of heating on calcium is to fire pottery either at temperatures lower than 700° C or higher than 1000° C. At temperatures higher than 1000° C, calcium along with the clay particles undergo sintering and vitrification. When pottery is fired at temperatures below 700° C, the body tends to be porous and soft. During the Neolithic times pottery was set on fire in open air which did not facilitate high temperature conditions. Thus, Neolithic pottery tempered with lime were either not hard and porous or were at the risk of spalling and crumbling unless very finely ground particles of lime were added.
7.5 Effects of Firing on Clay Matrix

The changes that begin at the lower levels of temperature and last longer are the movement of water and organics to the exterior from the interior of the paste. Both water and organic matter volatilize and escape as gases causing weight loss and shrinkage. The effects are more pronounced at the relatively low temperatures, up to 800-900° C, the range at which most Neolithic pottery is fired. At higher temperatures above 900-1000° C changes like sintering occur, changing the clay mineralogy to a greater extent.

Most of the weight loss and shrinkage in the clay body occurs due to the loss of water which is completed by 200-300° C. If there is too much water due to incomplete drying or if the clay is very fine causing differential levels in water on surface and interiors, hairline cracks may appear during firing. The rate of loss of water varies with the clay mineralogy. Kaolinite has a two layered structure. Smectites on the other hand have a three layered structure and thus retain more water. Cracking due to rapid heating and removal of water from smectite clays is a probable hazard.

Besides water, organic material found mostly in all clays also volatilizes and contributes greatly to the weight loss and shrinkage. The oxidation or burning out of carbon begins at 200° C or slightly higher. But complete removal of carbon from the paste completes when temperatures reach 600° to 750° C.

At higher temperatures, after water is lost from clay minerals, the clays undergo major alterations in their chemical and mineral structures.

When kaolinite is heated above 500° C, it changes into an altered mineral metakaolinite with a slightly disordered crystalline structure. In smectite minerals
which have a three-layer structure, the loss of inter-layer moisture may cause changes at lower temperatures than in kaolinite, which has a two-layer structure. At still higher temperatures 900° C and above, the lattice structure of kaolinite collapses irreversibly and recrystallization takes place. Two more changes in the crystal structure take place between 1050° and 1275° C and around 1460° C.

Similar changes take place in smectites but at different temperatures. The lattice structure of montmorillonites collapses between 800° and 900° C. Above these temperatures, there seem to be two kinds of changes that montmorillonite may undergo, either spinel begins to form or in clays with lower iron, quartz begin to form. Illite clays retain their structure until 850° C or beyond, sometimes as high as 1000° C.

7.6 Technological Groups and Inclusions

The pottery from Sannarachamma and Hiregudda mainly consist of inclusions which can be identified as quartz, mica and feldspar. The potsherds from these sites were studied under a hand lens 10x and some selected samples were studied under a binocular microscope. The studies indicate that throughout the habitation of the site the choice of inclusions has not changed. This is in tandem with the pottery producing techniques that were employed. Throughout the habitation at the site, pottery was handmade using the coiling technique. The presence of mica can be largely seen in technological Groups A and B and very occasionally in technological Groups C, D, E, G, H and M. Quartz has been almost exclusively noticed in the unburnished technological groups like C, D, E and very rarely in Group J and Group L. A large number of samples containing quartz as inclusion were studied under Binocular Microscope and majority of them revealed presence of quartz particles with
crystalline structure that formed under very high temperature of over 1300° C (Hema Achyutan: personal communication 2006). These could possibly be quartz particles with a cristobalite structure resulting from inversion of tridymite to cristobalite. Since it is not possible that the non-kiln open air firing techniques of the Neolithic times could achieve temperatures as high as 1470° C (the temperature required for cristobalites to form) or retain it for required duration. It is very likely that the ash from the ashmounds were used by the Neolithic potters. Burning episodes of cow dung, which resulted in the formation of monumental ashmounds, attained high temperatures of at least over 1200° C (Johansen, 2004). Boivin is of the opinion that the “layers of vitrified ash indicate that substantial burning temperatures were achieved” (Boivin et al., 2004). For vitrification to be achieved the temperature should indeed be at least over 1300° C. The burning episodes at these ashmounds were not rapid and high temperatures were retained. This suggests the possibility of the free crystalline silica in the clay and biosilica or phytoliths altering to cristobalites at such high temperatures and the eventual utilization of these deliberately or otherwise as inclusions in the manufacture of Neolithic pottery.

Very few instances of feldspar presence were noticed mostly in the unburnished technological group like Group D.

Another interesting observation that has been made is the presence of very few sherds with limestone inclusions. These sherds belong to the contexts 3132 and 3147 from the Post-Ashmound Village Phase of the site on Hiregudda. These sherds unmistakably consist of particles of reddish-purple limestone as inclusions, visible under the binocular microscope. Interestingly all these sherds with limestone inclusions belong to the Patapadu Ware. The Patapadu Ware is largely confined to sites in the Kunderu Basin. This Patapadu ware consists of a red slipped surface
sometimes burnished with dark brown paintings. This has been first noticed and described by Allchin (1962). The presence of sherds with black paintings on red slipped surface would have given scope to believe that these could be like the many other sherds with painting. But the unmistakable presence of limestone fragments has beyond doubt placed these sherds under the category of Patapadu ware. This provides evidence for the possible contact and exchange between the communities of the two regions.