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FT-IR Spectroscopic Analysis of Neolithic Pottery from Kashmir Valley, India - A Study of Firing Process and Mineral Composition

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Abstract

This study is an archaeometric research on the Neolithic pottery in Kashmir Valley, India to determine the firing technology and mineral composition, which is influenced by firing temperature and clayey sediment composition through FT-IR Spectroscopy Analysis. The pottery shreds were subjected to analysis as in the powder form for estimation of firing temperature, during manufacturing of the pottery. The characterization studies reveal the skill and style of the artisans who lived in the Neolithic period. In this study, the firing temperature of potsherds from the four Neolithic sites of Gufkral and Haripariganin District Pulwama, Pethpuranteng in district Ganderbal and Qasimbagh in Baramulla, Kashmir, India is predicted. FT-IR spectroscopic analysis of the pottery was backed at an average temperature between a minimum of 400-500^{0}C and a maximum of 800-900^{0}C at the above sites. The common mineral composition of the pottery includes Quartz and Aluminosilicates (Kaolinite, Illite, or Feldspar) with the addition of carbonates as reproduced from the FT-IR spectrum.

Keywords: FT-IR, Neolithic Pottery, Kashmir Valley, Mineral Composition, Firing Technology.

Article Type: Research Article

Introduction

In archaeology, the term ceramic or pottery means vases made of fired clay (Rice 1987: 34-35). Due to the abundance of unfired clay, people have been involved in clay modelling (moist argillaceous soil) for various uses in the neolithic people of Kashmir Valley, India, since the third millennium BCE. The increasing knowledge of pyro technology (firing at the right temperature) is linked to the long-term efforts of the Neolithic people of the valley to maintain the shape of the clay vessels they made. Samples were collected from the four Neolithic sites of Gufkral (33^{0}53'46'' N 75^{0}5'42'' E) and Haripariganm (33^{0}53'18'' N and 75^{0}05'09'' E) in District Pulwama, Pethpuranteng (34^{0}11'23'' N and 74^{0}44'33'' E) in District Ganderbal and Qasimbagh (34^{0}13'25'' N and 74^{0}23'24'' E) in Baramulla, Kashmir (Figure. 1). The first two Neolithic sites are situated in the South, the next is located in the centre and the last site is in the North of the Kashmir valley, respectively. Another stage of this study is XRD, XRF, ICP-MS and SEM-EDX analysis for which the samples are in pipeline in the laboratories. The results from FT-IR can help to get more insights for the future studies.

FT-IR stands for Fourier Transform Infrared (Ciliberto and Spoto 2000: 321) and in this method of spectroscopy, light passes through the sample, in the absorption process, those frequencies of infrared radiation that match the natural vibrational frequencies of the molecule in question are absorbed, and the energy absorbed serves to increase the amplitude of the vibrational motions of the bonds in the molecule. use of the infrared spectrum is to determine structural information about a molecule. The X-Axis (Wavenumbers cm^{-1}) obtained in the graphs represents the vibrational frequencies of molecular bonds. The wavenumbers range from 4000 to 400 cm^{-1}, which covers the mid-infrared region typically used for identifying functional groups and material compositions. The

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Y-Axis (Transmittance) indicates how much of the infrared light passes through the sample. The peaks (dips in the graph) correspond to specific bond vibrations, where the sample absorbs IR light. The type of clay, firing temperature, and firing condition of archaeological pottery are determined by using FT-IR spectroscopy, a popular and proven method for identifying ceramic bodies. (Saravanan *et al*. 2013: 29-31).

The clay used to make pottery includes amorphous materials and primary, secondary, and accessory minerals (Orton, Tyers and Vince 1993; Velde and Druc 1999). Clay minerals consist of chains of the basic structural units of silicates, SiO_4 tetrahedra and AlO6 octahedra (Hemamalini and Velraj 2011: 135-140). The hexagonal network, which is created by the tetrahedral surrounding of silicon atoms by oxygen atoms and hydroxyl groups, can be repeated indefinitely. All bases of the tetrahedrons lie in the same plane and all their tips (O or OH) point in the same direction. The hydroxyl and oxygen atoms of the free tips coordinate with the Al ions to form octahedral layers. The various types of iron hydroxides and oxides are typically considered accessory minerals. They often appear as surface coatings or as finely dispersed particles. The traces of these minerals influence the morphological and mineralogical properties of the clay minerals present in the pottery (Janaki and Velraj 2011: 89-91).

Neolithic Pottery Types in Study Area

The four main categories of pottery identified from the field survey include coarse greyware, burnished greyware, gritty dull redware, and fine greyware. These four categories are believed to be the Neolithic diagnostic pottery of the Kashmir Valley (Bandey 2009: 3; Ghosh 1964: 122-131; Mani 2008: 229-247; Mitra 1984: 22-23; Sharma 1998: 30-31). Gufkral, Kanispur and Burzahom are the only Neolithic sites excavated where these four pottery classes have been found. These four types of pottery were also recorded from various sites in Kashmir during subsequent expeditions to determine the distribution of Neolithic material culture in the region (Bandey 2003a 87-91, b: 10-12; Joshi 1990: 34-38; Mitra 1984: 16-17 Pant. 1982: 38; Yatoo 2012: 197-211).

Coarse grey clay pottery is dully embossed, with a few exceptions for fine grey and coarse red ware.

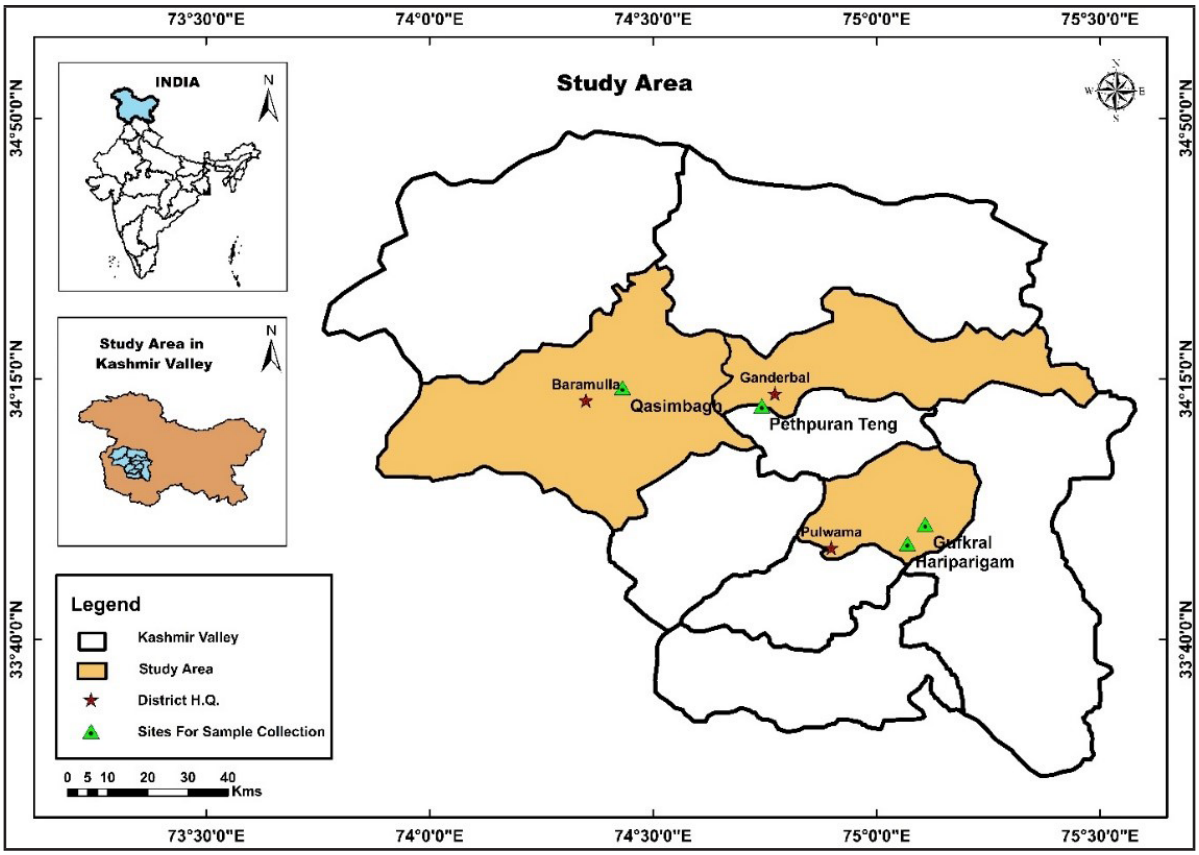


Figure. 1: *The Study Area .*

The pottery is handmade and improperly baked. The majority of pottery is poorly baked and handmade.

The grey tones baked into the fine grey ware are ash grey, matt grey, and dark grey (Figure. 2). The clay is generally fine and varies in hardness depending on the temper. The matrix of this ceramic is finer, with regular cracks, less porosity, and less hardening than previous coarse grey ceramics. In addition to sand and gravel, some specimens also contain quartz as a hardening agent. With the exception of dark spots or mottled cores, the shot is uniform. Fine grey ware produces a metallic sound when struck and has fine texture, colour, thin cross-section, and is lightweight. The strip method dominates the preparation.



Figure. 2: *Neolithic Pot Shreds from the Area of Study.*

Burnished grey pottery comes in a greater variety of shapes and is even more common than fine grey pottery. Burnishing, which can be grey, black, occasionally red or dull brown, is usually carried out outdoors. There are two types of polishing marks: vertical and horizontal. The workmanship is often excellent, and the material is medium to fine.

Another notable Neolithic ceramic type is known as Gritty Red Ware. Although there are some examples of this type of pottery from the Middle Neolithic period, the pottery most commonly found at archaeological sites is from the Later Neolithic period. The clay used to make pottery is often coarse, medium, or coarse to medium and breaks unevenly. Non-oxidized core regions also indicate indifferent ignition. The mixture consists mainly of quartz fragments, coarse sand and occasional stone grit.

A variety of techniques were used to produce pottery, including making pottery on wheel and table-turning, strip and coil methods, and some scholars believe that some pot chips show that they were made using the wrapping technique. At some of the unexcavated Neolithic sites, handmade pottery with dimpled patterns and some pieces of dull, rough, red and black burnished ware have been discovered.

Experimental Details

The Neolithic period of Kashmir valley (3000 BCE-1000 BCE) (Bandey 2009) marked a significant evolution in the technological breakthrough in pottery production, using furnaces of the time, temperature control, and controlled oxygen activity. This period also led to new clay selection and shaping techniques. However, the lack of specific archaeometric studies, particularly interdisciplinary ones, has hindered the study of Neolithic pottery in Kashmir Valley for the last 60 years since the excavation of the first Neolithic site. An FT-IR absorbance study on a ceramic group from the Neolithic culture of Kashmir Valley revealed new aspects of pottery production and technological knowledge in pottery firing and FT-IR transmittance analyses were plotted.

Materials

Based on the macroscopic analysis of inclusion granulometry and abundance, three primary categories of pottery were identified (Figures. 3 and 4):

(i) Mostly fine grey ware and redware pot shred powder include tiny inclusions (<0.25 mm), which make up 48% of the whole sampling.

(ii) Variants of grey ware contain medium-fine inclusions (0.25–1 mm), which comprise 28% of the sampling and are commonly found in bowls, mugs, and cups.

(iii) Gritty red ware and Coarse grey ware samples, which comprise 24% of the sample, are coarse inclusions (>1 mm).

Five samples of Neolithic pot shreds of various fabrics were identified and finely powdered (Figure. 3) using an agate mortar and pestle. The five samples include Fine Red ware from Gufkral

(GF-R), Fine grey ware from Hariparigam (HP-R), Black ware from Pethpuranteng (PP-B), Coarse grey ware (QB-G) and fine grey ware (QB-R) from Qasimbagh Neolithic sites. The Neolithic pottery of Kashmir valley has common characteristics such as handcrafted, ill-fired, and fragile ceramics with wheel-throne well-fired pottery types. Undercooked specimens, black blotches and over-burning are common hallmarks of the Neolithic culture pottery technology, which was marked by evolution and constant experimentation to establish appropriate standards. Some Neolithic pottery has the inner half of the rim over-burned, indicating that it was burnt upside down in a furnace with a lower chamber. Large black dots with vertical patterns can be identified, potentially indicating open kilns or single-chamber ovens. Sometimes all surfaces of the pot shred were baked, resulting in a typical Neolithic pottery.

Five samples of Neolithic pot shreds of various fabrics were identified and finely powdered (Figure. 3) using an agate mortar and pestle. The five samples include Fine Red ware from Gufkral (GF-R), Fine grey ware from Hariparigam (HP-R), Black ware from Pethpuranteng (PP-B), Coarse grey ware (QB-G) and fine grey ware (QB-R) from Qasimbagh Neolithic sites. The Neolithic pottery of Kashmir valley has common characteristics such as handcrafted, ill-fired, and fragile ceramics with wheel-throne well-fired pottery types. Undercooked



Figure. 3: *Powdered Samples of the Neolithic Pot Shreds .*

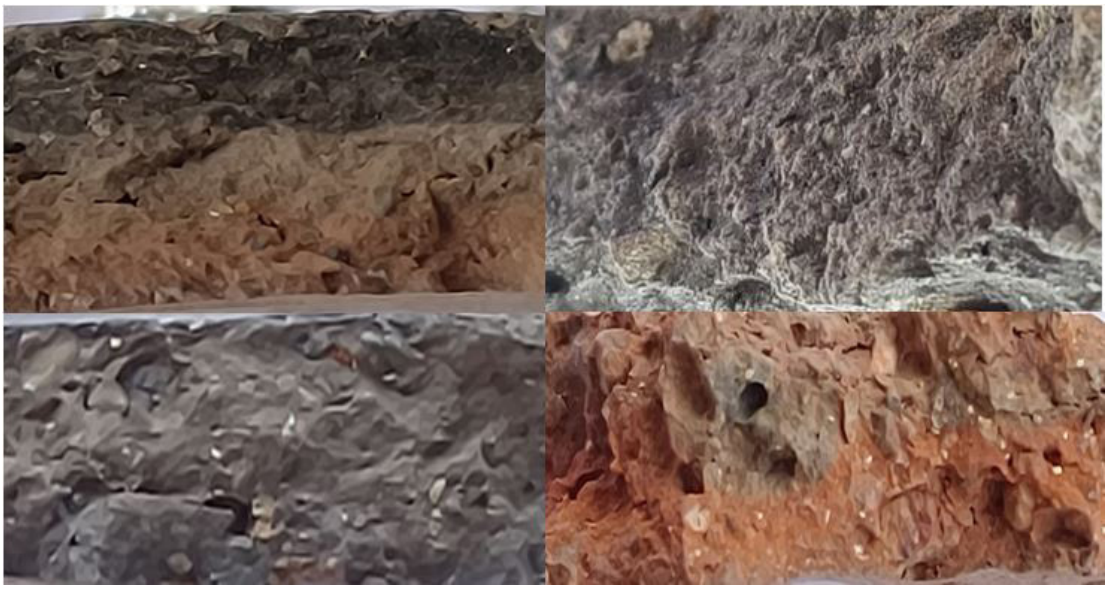


Figure. 4: *The Sections of the Samples of Neolithic Pot Shreds used in the Experiment .*

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Methods

This study used a Bruker IFS 66v/S spectrophotometer for FT-IR measurements from pottery samples. The setup included a Globar lamp source, KBr beamsplitter, and DTGS/MIR detector, with a spectral range of 4000 cm^{-1} - 400 cm^{-1}. About 2 mg of material was drawn from each pot shred to avoid damaging the ceramic body. The samples were powdered, dispersed in a caesium iodide matrix, and reduced in pellets. Because of its great sensitivity, FTIR spectroscopy helps to identify a wide range of components, even in trace levels, tabulated in Table 1. Quartz, feldspar, clay minerals (Kaolinite Illite) and carbonates were among the several mineral kinds identified (Russell 1987: 11; Farmer 1974: 1149-1173 and De Benedetto G.E. *et al.* 2002: 177-186) by tabulating the infrared absorption bands of five powdered Neolithic pottery samples. For future studies it is recommended that use an FTIR spectrometer with an ATR accessory. FTIR-ATR eliminates potential errors caused by impurities and moisture absorption by additives like caesium iodide. The analysis follows the NIST SRM for calibrating the wavelength scale according to the Infrared Transmission Wavelength/Wavenumber Standard 1921b (Gupta *et al*. 1995)(Figure. 5).

Result and Discussion

The key findings of the FT-IR (Fourier Transform Infrared) spectrum observed in the pottery sample GF-R (Figure. 6) from the Gufkral Neolithic site are discussed as under:

The peak at ~1003 cm^{-1} is associated with Si-O stretching vibrations of quartz (silica), which remains stable across a wide range of firing temperatures. This primary peak in pottery clays reflects the presence of quartz as a major constituent. The peak at ~774 cm^{-1} is likely linked to Si-O-Si

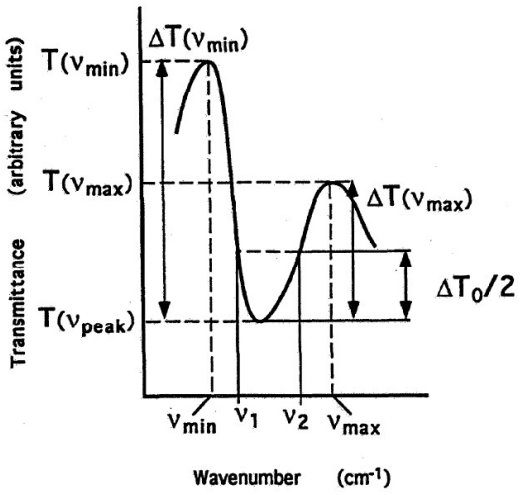


Figure. 5: *Diagram Indicating Parameters used in the Peak Wave Number Determination Method (SRM NIST 1921b) (After:Gupta et al.1995)*

bending vibrations in quartz. This indicates that the quartz structure in the clay has not been significantly altered, suggesting firing below ~1100°C, as higher temperatures would transform quartz into other phases. The peak at ~545 cm^{-1} is typically related to deformation vibrations of aluminosilicate minerals, such as kaolinite or muscovite. This peak suggests the presence of clay minerals, which might partially convert during firing but still retain their structural identity below ~900°C.

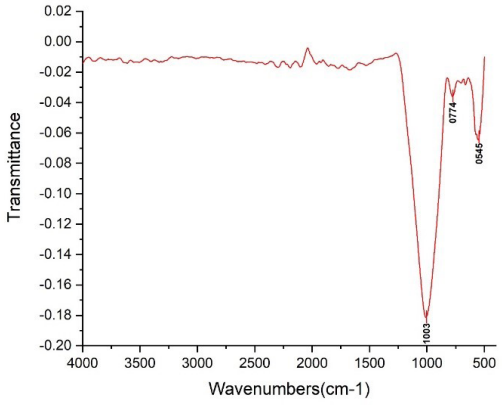


Figure. 6: *FT-IR spectrum of sample GF-R (Geology Lab. Central University of Haryana, India)*

Firing Process and Temperature

The spectrum's lack of broad OH-stretching bands (normally in the 3000–3700 cm^{-1} range) confirms that the pottery was fired at temperatures sufficient to drive off structural water from the clay minerals (typically above 400–500°C). The retention of sharp quartz peaks at 1003 cm^{-1} and 774

Table. 1: *Mineral Composition and the firing temperatures retrieved from the FT-IR Spectra of the Samples of Neolithic Pottery.*

Sample Code/Site	Culture	Fabric	FT-IR Spectra Main Peaks	Minerals	Average Temperature
GF-R Gufkral	Neolithic IC (2000 - 1850 BCE) (Sharma 1998: 37-38)	Fine red ware	~1003 cm^{-1} ~774 cm^{-1} ~545 cm^{-1}	Quartz (SiO_2): Aluminosilicates (Kaolinite, Illite, or Feldspar): Calcite ($CaCO_3$)	~600–900°C
HP-R Hariparigam		Fine grey ware	~1527 cm^{-1} ~1001 cm^{-1} ~769 cm^{-1} ~674 cm^{-1} ~551 cm^{-1}	Carbonates (Calcite $CaCO_3$) Aluminosilicates (Kaolinite Illite) Feldspars or micas	~800–850°C
PP-B Pethpuranteng	Late Neolithic (c. 2500–2000 cal. BCE) (Betts *et al.* 2019: 16)	Burnished ware	~1663 cm^{-1} ~1535 cm^{-1} ~1001 cm^{-1} ~766 cm^{-1} ~674 cm^{-1} ~545 cm^{-1}	Quartz (SiO_2) Kaolinite/Illite ($Al_2Si_2O_5(OH)_4$) Feldspar	~600–850°C
QB-R Qasimbagh	Early Neolithic (2000 - 1500 BCE) (Betts *et al*. 2019: 16)	Coarse grey ware	~2312 cm^{-1} ~1974 cm^{-1} ~1431 cm^{-1} ~1006 cm^{-1} ~774 cm^{-1} ~633 cm^{-1} ~545 cm^{-1}	Quartz (Silica) Carbonates (Likely Calcite Kaolinite or Illite (Aluminosilicates)	~600–800°C
QB-G Qasimbagh	Late Neolithic (1500-1000 BCE) (Betts *et al*. 2019: 16)	Fine grey ware	~2121 cm^{-1} ~1437 cm^{-1} ~1006 cm^{-1} ~777 cm^{-1} ~686 cm^{-1} ~660 cm^{-1} ~548 cm^{-1}	Quartz (SiO_2) Carbonates (Calcite, $CaCO_3$) Aluminosilicates (Kaolinite or Illite)	~600–850°C

cm^{-1}indicates that the firing did not exceed ~1100°C, avoiding quartz's phase transitions to cristobalite or tridymite. The persistence of aluminosilicate peaks (545 cm^{-1}) suggests that firing temperatures did not fully transform the clay into new crystalline phases like mullite, which would occur above ~1000°C. Therefore, the estimated firing temperature ranges between ~600–900°C (Ravisankar *et al*. 2011: 370; Velraj *et al.* 2009: 307 and Shillito *et al.* 2009: 133).

Mineral Composition

Quartz (SiO_2) is the dominant component, as indicated by the strong 1003 cm^{-1} and 774 cm^{-1} peaks. Quartz contributes mechanical strength and is ubiquitous in clay deposits used for pottery. Aluminosilicates (Kaolinite, Illite, or Feldspar) presence is inferred from the peak at 545 cm^{-1}, which aligns with Al-O-Si vibrations. Kaolinite is a common clay mineral in pottery, partially converting to Metakaolinite around 600°C.

The key findings of the FT-IR Spectrum observed in the sample HP-R (Figure. 7) from the Neolithic site Hariparigam are discussed as under:

The peak of ~1527 cm^{-1} is likely associated with carbonate compounds, such as calcite ($CaCO_3$), which often remains in pottery that has not been fired at very high temperatures. ~1001 cm^{-1} corresponds to Si-O stretching, indicating the presence of quartz (SiO_2), a common mineral in pottery clay. ~769 cm^{-1} and 674 cm^{-1} are typical of quartz (SiO_2) and feldspar minerals. These peaks are often due to Si-O bending

The interpretation of the features observed from the Peaks in the FT-IR Spectrum (Figure. 8 obtained from the sample PP-B from the Neolithic site Pethpuranteng is given as under:

The peaks 1663 cm^{-1} and 1535 cm^{-1} corresponds to the bending of hydroxyl (OH) groups vibration. The lower the intensity, the higher the firing temperature, as water is driven off at elevated temperatures. The 1001 cm^{-1} peak is associated with Si-O stretching vibrations, characteristic of quartz, a common mineral in pottery clay. Other peaks, 766,

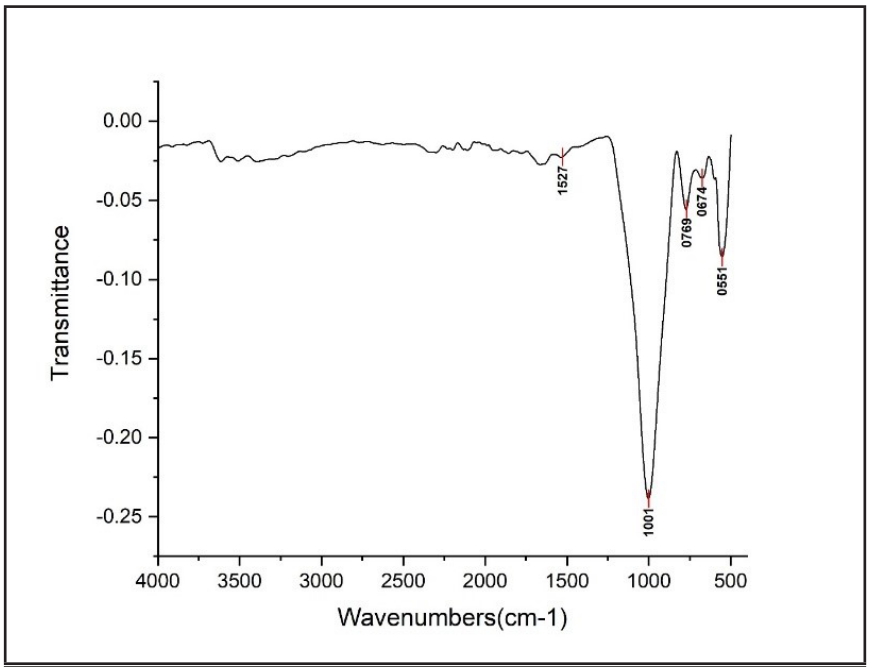


Figure. 7: *FT-IR spectrum of sample HP-R*

(Geology Lab. Central University of Haryana, India)

vibrations. ~551 cm^{-1} is associated with vibrations of aluminosilicates or clay minerals like kaolinite or illite. The presence of a peak around 1527 cm^{-1} suggests the firing temperature did not exceed 800–850°C. At higher temperatures, calcite decomposes to form calcium oxide (CaO) and releases CO_2 It shows the presence of Calcite ($CaCO_3$) in the sample. If kaolinite (clay mineral) peaks were present but degraded, this indicates firing in the range of 450–600°C. Its transformation to Metakaolinite occurs around 500–600°C. Therefore, Kaolinite is present in the sample. The presence of Quartz Peaks (769 cm^{-1} and 674 cm^{-1}) suggests that the Quartz remains stable up to very high temperatures (~1000°C). Their persistence indicates that the pottery was not vitrified at excessively high temperatures (>1000°C).

674, and 545 cm^{-1}, are related to deformation or bending vibrations of Si-O or Al-O bonds, reflecting the presence of feldspar or other aluminosilicate minerals.

Firing Process and Temperature

The absence or weakening of OH-related bands (around 3000–3700 cm^{-1}, not visible here) suggests that the pottery was fired above 400–500°C, where water is fully removed. The sharpness and positions of Si-O peaks provide clues about firing temperatures. Above ~800°C, clay minerals begin to transform into new crystalline phases like mullite or glassy phases. The peaks reflect the Firing Process and Temperature Estimation in three levels. First the low-Temperature Firing between (400–600°C), which characterized by the retention of OH

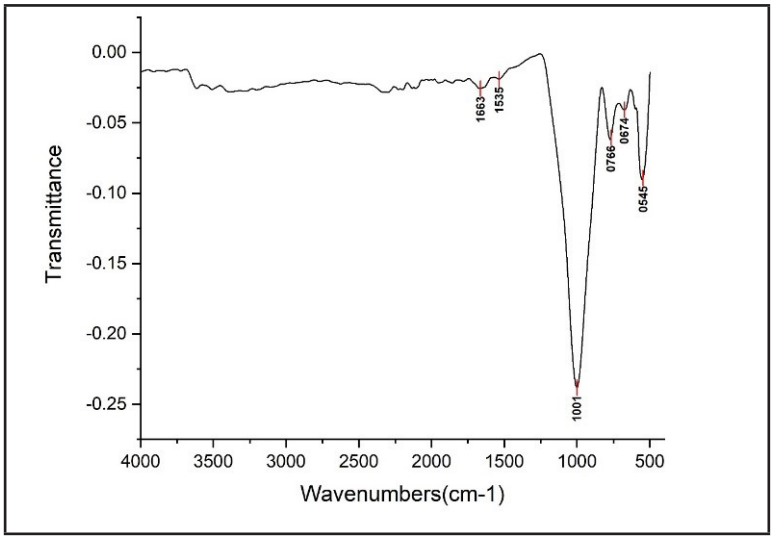


Figure. 8: *FT-IR spectrum of sample PP-B*
(Geology Lab. Central University of Haryana, India)

vibrations (1663 cm^{-1}, 1535 cm^{-1}). It suggests the pottery was air-dried or fired in a low-temperature kiln, typical for early Neolithic techniques. Secondly, the intermediate Firing between 600–900°C shows OH peaks diminish, and clay minerals begin to transform (dehydroxylation of kaolinite into metakaolinite). The quartz and feldspar remain stable, and peaks at 1001 cm^{-1} and below persist without significant shifts. The third includes High-Temperature Firing >900°C, which highlights the transformation of clay minerals into crystalline phases (e.g., mullite, cristobalite). A broadening or shift in Si-O peaks indicates vitrification or partial glass formation, which is absent in your spectrum, suggesting firing below 1100°C (Ravisankar *et al.* 2011: 370; Velraj *et al*. 2009: 307 and Shillito *et al.* 2009: 133-136).

Mineral Composition

The dominance of quartz-related peaks indicates that silica is a primary component of pottery clay. The presence of feldspar or kaolinite could also be inferred from specific bands below 800 cm^{-1}. Quartz (SiO_2) is dominant, identified by the strong 1001 cm^{-1} and 766 cm^{-1} peaks. Quartz is stable in most clay pastes and contributes to the mechanical strength of the pottery. Kaolinite/Illite ($Al_2Si_2O_5(OH)_4$), indicated by the 674 cm^{-1} and 545 cm^{-1} peaks, are common in clay minerals. Al-O-Si vibration around 674 cm^{-1} might also indicate feldspar, which acts as a flux to lower the melting temperature during firing. Thus, FT-IR spectrum of the Neolithic pottery sample QB-G (Figure. 9 from Qasimbagh, includes the peaks, providing insights into the material composition and firing conditions of the pottery.

Key Peaks and Their Interpretations

The 2121 cm^{-1} peak could be organic impurity that stay in pottery or maybe related to noise that appears due to the magnification of the spectrum. Furthermore, the peak in this region could related to triple bonds C≡C or C≡N or Isocyanates. If related to carbonates, this might indicate minimal decarbonisation, suggesting firing temperatures below ~800°C, where carbonates like calcite ($CaCO_3$) decompose. The peak of 1437 cm^{-1} likely corresponds to the asymmetric stretching vibrations of carbonate ions (CO_3^{2-}), suggesting the presence of calcite or other carbonate minerals. The persistence of this peak implies firing at moderate temperatures (<800°C), as carbonates decompose at higher temperatures. The peak 1006 cm^{-1} shows strong Si-O stretching vibration of quartz (silica), confirming its presence as a primary mineral component. The peak 777 cm^{-1} is associated with Si-O-Si bending vibrations in quartz, further supporting the significant presence of quartz. The peak 686 cm^{-1} likely represents Al-O-Si vibrations, potentially related to feldspar or illite within the clay. 548 cm^{-1} deformation vibrations of aluminosilicates, often indicative of kaolinite or related minerals.

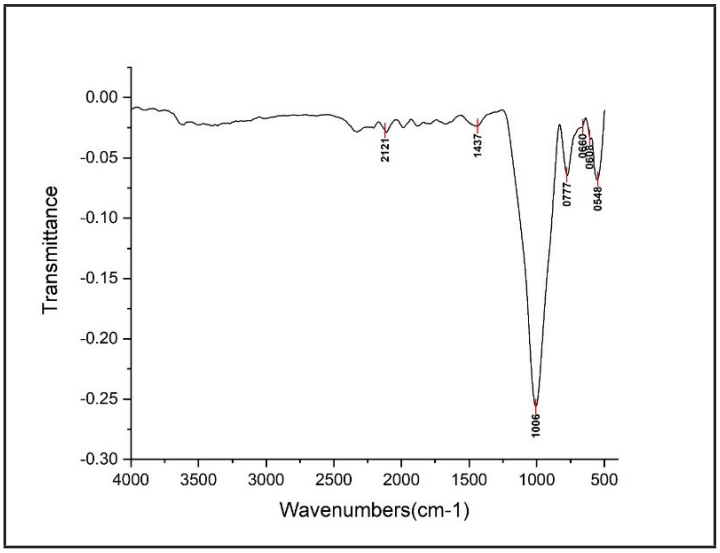


Figure. 9: *FT-IR spectrum of sample QB-G.*
(Geology Lab. Central University of Haryana, India)

Firing Process and Temperature

The presence of carbonate (Calcite) peak 1437 cm^{-1}) suggests that the pottery was fired at relatively low to moderate temperatures, not exceeding ~800°C. At higher temperatures, carbonates would decompose into oxides (e.g., CaO) and CO_2, causing these peaks to disappear. Quartz peaks (1006 cm^{-1} and 777 cm^{-1}) indicate that the pottery was not fired at excessively high temperatures (>1100°C), where quartz undergoes polymorphic transformations. Kaolinite-related peaks (548 cm^{-1}) suggest that the clay minerals were only partially transformed, consistent with moderate firing temperatures (~600–900°C). Therefore, the estimated firing temperature ranges from ~600–800°C (Ravisankar *et al*. 2011: 370; Velraj *et al.* 2009: 307 and Shillito *et al*. 2009: 133).

Mineral Composition

Quartz (SiO_2) is a dominant component present in this sample, as indicated by the strong peaks at 1006 cm^{-1} and 777 cm^{-1}. Quartz contributes to the structural strength and durability of the pottery. thermal resistance and is common in clays added as temper materials. The carbonate (Calcite, $CaCO_3$) peak 1437 cm^{-1}) suggest calcite or other carbonates were present in the raw clay or as temper material. Their presence indicates firing temperatures were not high enough to fully decompose these minerals. Peaks at 686 cm^{-1} and 548 cm^{-1} suggest these common clay minerals, Aluminosilicates (Kaolinite or Illite), which partially transformed during firing. There are possible minor components like feldspars or micas may also contribute to the aluminosilicate peaks, depending on the clay source.

Therefore, this FT-IR spectrum suggests the pottery was composed primarily of quartz, aluminosilicates (like kaolinite), and carbonates (e.g., calcite), fired at moderate temperatures (~600–800°C) and were backed as the simple kilns or open-pit firing methods used in Neolithic time. These conditions point to a utilitarian purpose and a basic level of technological skill typical of Neolithic ceramic production. The persistence of carbonate peak (1437 cm^{-1}) strongly indicates firing temperatures between 600–800°C. At higher temperatures, carbonates would decompose into lime (CaO) and release CO_2, resulting in their absence from the spectrum. Quartz is unaffected at the observed temperature range, but its strong presence in the spectrum suggests careful control of firing temperatures to maintain structural integrity. The partial dehydroxylation of Clays due to the absence of hydroxyl (OH) stretching bands (typically observed around 3000–3700 cm^{-1}) indicates firing above 400–500°C. This temperature drives off-bound water in clay minerals, a critical step in ceramic production.

The FT-IR (Fourier Transform Infrared) spectrum of Neolithic sample QB-R from Qasimbagh (Figure . 10 provides information about a material's chemical bonds and functional groups. The data break based on the graph is as follows:

The 1974 cm^{-1} peaks may indicate overtones or combinations of molecular vibrations, possibly associated with carbonate or silicate minerals. These peaks correspond to weak overtone or combination bands related to carbonates or silicates. These represent trace impurities or remnants of carbonates not fully decomposed during firing. If the material is ceramic, incomplete decomposition indicates insufficient firing temperature. Likely 1431 cm^{-1} is related to C-O stretching in carbonates or organic compounds. Associated with the asymmetric stretching vibrations of C-O bonds in carbonate minerals such as calcite or aragonite. A strong, sharp peak of 1006 cm^{-1} often indicates Si-O stretching, typical in silicates or quartz. 774 cm^{-1}, 633 cm^{-1}, 545 cm^{-1}, these peaks correspond to bending vibrations in silicates or metal oxides.

The key absorption peaks are observed at the following wavenumbers, 1974 cm^{-1}, 1431 cm^{-1}, 1006 cm^{-1}, 777 cm^{-1}, 685 cm^{-1}, and 545 cm^{-1}. Each peak can be associated with specific functional groups or mineral phases in the pottery. The strong peak of 1006 cm^{-1} associated with the Si-O stretching vibrations, indicating the presence of quartz (SiO_2), a dominant mineral in pottery. 777 cm^{-1} and 685 cm^{-1} peaks may also relate to quartz or other silicate minerals. They are often associated with low-temperature phases. The 1431 cm^{-1} peak may indicate the presence of carbonates, such as calcite ($CaCO_3$), which are often seen in pottery fired at low to moderate temperatures. Likely, 545 cm^{-1} associated with alumino-silicates (clay minerals like kaolinite or illite).

Mineral Composition

From the observed peaks, the major minerals can be inferred as Quartz (SiO_2) due to their dominance in the spectrum. Carbonates, because of the presence of calcite ($CaCO_3$) is indicated at 1431 cm^{-1}. Likely Alumino-silicates kaolinite or related clay minerals, represented in the lower regions (e.g., 545 cm^{-1}).

Firing Temperature

The firing temperature of pottery influences its mineral composition:

At low firing temperatures, (<600°C), clay minerals like kaolinite remain intact and carbonates like calcite are present. At moderate temperatures (600–800°C), the decomposition of calcite occurs, and clay minerals begin to transform. At high temperatures (>900°C), quartz and mullite become dominant phases, and carbonates disappear entirely (Ravisankar *et al*. 2011: 370; Velraj *et al*. 2009: 307 and Shillito *et al*. 2009: 133-139).

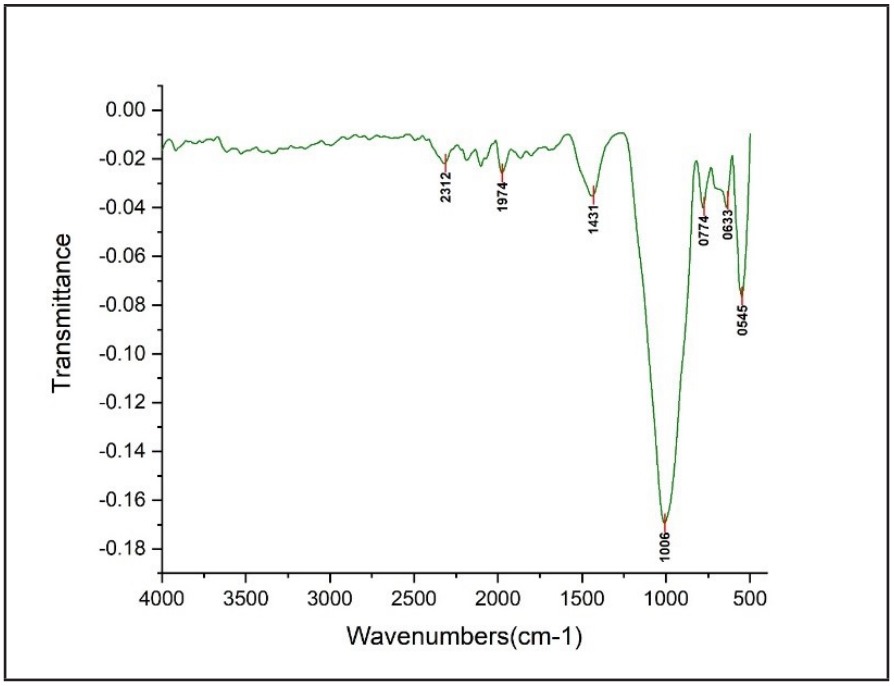


***Figure. 10**: FT-IR spectrum of sample QB-R.*
(Geology Lab. Central University of Haryana, India)

Conclusion

The variation in the fabric and control of firing temperature indicates an evolution in the knowledge of basic ceramic technology. The absence of high-temperature vitrification points to the use of rudimentary kilns during the Neolithic period of Kashmir. The difference in the use of fire technology exhibits that the samples are taken from the three sites situated in the south, centre and North of the Valley. Pottery with quartz and kaolinite is often robust and suitable for storage or cooking. Pottery with both quartz and carbonates is typically robust and might have been used for storage or light cooking. The retention of clay mineral features suggests that the pottery was not primarily decorative but utilitarian. The presence of carbonates suggests firing in open or low-temperature kilns with limited control over maximum temperatures. The temperature range (~600–800°C) aligns with early ceramic production techniques used in Neolithic cultures. The firing temperatures suggest the pottery was not vitrified, emphasizing functionality over aesthetics. The spectrum reflects a mix of natural and intentional inclusions (e.g., temper), which could provide insights into the raw materials and techniques employed in the Kashmir Valley. Comparing the carbonate content and firing conditions with other Neolithic sites may help trace technological or cultural connections. The mineralogical composition (quartz, aluminosilicates, carbonates) indicates the use of locally available clay, likely from calcareous deposits in the Kashmir Valley. This reflects an intimate knowledge of regional resources. Pottery with carbonate inclusions and moderate firing suggests a subsistence-oriented society, focused on utilitarian ceramics for daily use. The mineralogy reflects the geological conditions of the Kashmir Valley during the Neolithic period, providing insights into the interaction between humans and their environment.

The FT-IR spectrum reveals that the Neolithic pottery from Kashmir Valley was composed primarily of quartz, aluminosilicates, and carbonates, fired at moderate temperatures (~600–800°C). These findings highlight the resourcefulness of Neolithic potters, who effectively utilized local materials and firing methods to create functional ceramics. This research contributes to our understanding of early ceramic technology and its role in the subsistence strategies of Neolithic societies in the region.

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