

Mud Plaster Wall Paintings of Bhaja Caves: Composition and Performance Characteristics

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Abstract

The historic mud plaster of Bhaja caves dated back to 1st century BC to 3rd century AD were investigated for their mineralogical, micro – structural and chemical characterisation. The analytical studies were performed using petrological microscope, thin section analysis, XRF, Laser particle size analyser, FTIR, XRD and scanning electron microscope. The traditional mud plaster is applied in two layers and thickness of inner layer depends on the topography of the basaltic stone surfaces. From the analytical examinations, it appears that in high rain fed regions of India's Western Deccan, fine clayey soil (clay>65%, sand 20-28% and silt 7-15%) has been sourced for the preparation of earliest mud plaster of Bhaja caves and its properties modified by deliberate mixing of slaked lime, sand and proteinaceous adhesive to enhance cementing properties. SEM photomicrographs reveal presence of elongated kaolinitic 'verm' and inter wired filamentous clay ribbons of illite- sepiolite in the plaster. The shrinkage property of the plaster has also been modified by addition of rice husk as vegetal additives. The present study favours methodological approach for preparing compatible mud plaster needed for the restoration of Bhaja caves.

Key words: Calcite, Clay soil, Illite-sepiolite, Kaolinite, Mud plaster

1. INTRODUCTION

Bhaja represents the earliest cave architecture in Western Deccan after a century of abandonment and decline of this artistic form. The site benefited from its position on an important maritime trading point connecting the parts of western India with the cities in the interiors and became a stopping place for itinerant pilgrims, monks and merchants. Beside a Brahmanical caves at Udayagiri near Vidisha in neighbouring Madhya Pradesh, cut a little over fifty years earlier, no other sites were excavated in whole of western Deccan for about three hundred years. Architects and workmen employed at Bhaja had to re-discover the technique of rock cutting that has been partly lost to living memory.

As a consequence, the artists were totally unfamiliar with the procedures needed to both

lying out and cutting the caves and not fully aware about the problems presented by flawed basaltic scrap (Sundarajan, 1957-59). As technicians have to struggle in the beginning during their first major excavation at Bhaja, the caves appear to have a rather irregular structure as a result of poor planning and numerous after-thoughts with very simple architectural elements. However, year by year after gaining initial experiences the excavators incorporated more complex and up to date forms. They introduced now peristyles to Vihāra, introduced beautiful ornamental pillars and sculptures were lavishly decorated.

The caves of Bhaja also represent the very first example in Western India where earthen plaster technology was practiced for decorative purposes. The techniques and composition of the earthen plaster were subsequently improved in the

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later caves in the form of selection of better soil type, addition of ingredients etc in the earthen mix. However, it is interesting to explore the earliest earthen plaster technology prepared for application on walls and ceilings at Bhaja caves representing the first major excavation of Buddhist legend in Western India. It is reported that though Bhaja caves were excavated in 1st Century B C, earthen plastering was accomplished in 2nd century A D (Dhavalikar, 1984). Irrespective of time, Bhaja represents first major example of earthen plaster technology in India. The investigation of the composition and characteristics of Bhaja caves earthen plaster will, therefore not only throw light on the development of technology at the initial stage, but also some glimpse about understanding and knowledge of ancient Indians in the field.

The Bhaja caves is situated at a distance of about 50 km to the north of famous city of Pune adjacent to Pune – Mumbai Highway (Fig.1).

The caves been excavated at a steep

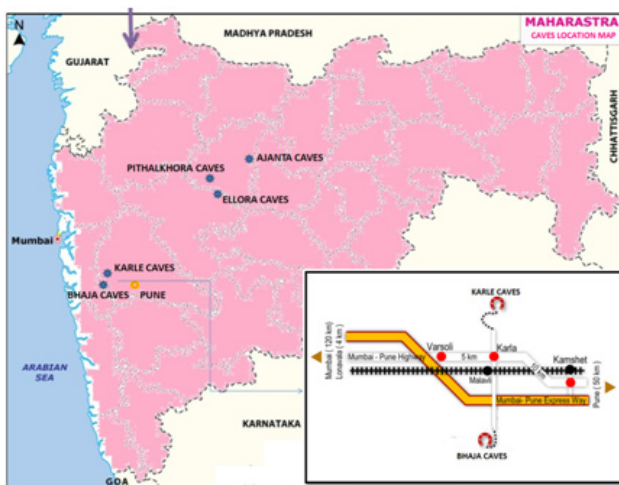


Fig.1. The location map showing the Bhaja caves.

gradient of rugged Sahayadri hills of Deccan on coastal belt of Western India in densely forested area and during monsoon heavy rains lashes the entire coastal belt. The plan of Bhaja caves is shown in Fig.2. The Bhaja caves are facing towards west and many of the caves did not have

facades. As result, the sun rays directly fall to the caves in the afternoon. The caves of Bhaja played an important role as maritime trading centre besides preaching of Buddhism in the area during the period of 100 B C to 300 A D.



Fig. 2. Plan of Bhaja caves

The present research is inspired by the revival of traditional ancient earthen plaster technology needed for its restoration showing losses and damage to various extents during course of time. The ancient technicians all over the world mainly relied on multi layer system of plastering which considerably enhance resistance of external layer to rain water penetration besides preventing accumulation of moisture within the plaster masonry. This plastering technique also facilitated quick evaporation of moisture from within the masonry. The earthen plasters in ancient structures have exhibited excellent durability and were widely used throughout the centuries for decorative coatings for ceiling and walls of both exterior and interior finish.

In case of mural artworks, the conservation problems can directly be linked to the earthen plaster support in structural building. The knowledge of traditional earthen plaster preparation is also vital in case of both restorations and repair interventions of ancient cultural heritage. However, technological complexity due to composition of several layers with different micro-structures and their role in regulating moisture movement towards external surfaces makes investigation about earthen plaster a little complex. The characteristic and nature of raw materials, their selection criteria as well as relative properties of various components were considered to understand technological development of the period for compatible and correct intervention. Many of the recipes of ancient earthen plaster are still unknown and often co-related to the availability of local resource materials and knowledge and experience of artisans. From restoration point of view, earthen plaster characterization is the first necessary step to design a suitable plaster mix taking into account the compatibility that must exist between the original and new material. For that reason, only analytical characterization of earthen plaster can provide data for planning conservation strategies. In India, the characterization of ancient earthen plaster in diverse geological regions of the country is still in primitive stage (Singh, 2015; Singh, 2014). Conservation of decorated surfaces on earthen plaster support layers constitutes a specialized area within the field of heritage conservation. Published research in this field is quite limited due to complexity of diverse materials in different support layers and availability of sufficient samples for analytical purpose (Warron, 1999; Artioli, 2008, and Singh 2013). Research cannot be accomplished at the cost of damage to the decorative surfaces as it is unethical to collect samples for analysis from sound painted plaster.

The deterioration of wall paintings on earthen support is most often due to loss of cohesion and adhesion of the earthen support layers and its

subsequent detachment. The earthen plaster begins to absorb moisture at 67% relative humidity which causes loss of mechanical strength, degradation of the binder and loss of painted layer due to loss of adhesion with the background. In-situ climatic condition and application of any surface coatings over the paint layer will be further detrimental to decorative art due to differential dimensional changes, shrinkage and swelling of support layers and difference in water vapour permeability. Any preservative coating over murals will inhibit water vapour transmission through various substrate layers as paintings on earthen support is highly water sensitive. When active deterioration is observed, restoration without understanding causes and mechanism of deterioration may cause more damage in the long run (Cathers, 1999). All factors of deterioration affect the original fabric and therefore proper understanding about original earthen plaster layers, clay fabric and deterioration process is essential.

Earth, a highly heterogeneous material were used in the construction of shelters for mankind for thousands of years (Mellaart, 1964). Traditionally, the mud plaster is prepared by exploiting soil mainly composed of sand, silt and clay with straw added to prevent excessive cracking during drying. For earthen support to function well, an equitable distribution of sand, silt and clay is desirable. Too much silt is not a good binder and provides material that is prone to damage by grain breakage on account of large grain size and very less contact cohesion. The non-clays are of grain size greater than clay ($< 2 \mu\text{m}$) and are divided into the grain categories of silt ($2 - 50 \mu\text{m}$) and sand ($50 \mu\text{m} - 2 \text{mm}$) in diameter. Due to small surface areas, non-clays show less attraction for water, more irregular grain shape with reduced grain to grain contact surfaces and contact cohesion much less than clays (Prost, 1998). The clays ($< 2 \mu\text{m}$) have grain shape like a sheet much thinner than wider with grains attracted with electrolytic inter-particle

forces (Basma, 1996). The clay minerals generally consists of equal parts of expandable clays (illite or sepiolite) and non expandable clays (kaolinite or chlorite) with minor quartz, calcite and feldspar mineral (Smith, 1989). The expandable clay minerals are sticky and responsible for effective binding of silt and sand particles together. In order to overcome inadaptability of local soil, other minerals such as vegetal fibre (Miller, 1934), calcite and lime (Jerome, 1993) is added to the clay to reduce shrinkage. It seems that materials like calcite, silica, ferric oxide act like a cementing agent forming chemical bonds between the clay micelles that may reduce shrinkage (Forth, 1990).

Proteins can react chemically with clay by exchange of inorganic cations in the clay with the organic one – a mechanism relating to the ability of amino acid to encourage clay flocculation (Griffin, 1999). Addition of proteinaceous material in the earthen plaster is an ancient Indian recipe (Singh, 2014) to enhance binding properties of clays. It will be interesting to explore addition of any proteinaceous material in the mud plaster of Bhaja to understand composition and technology by the ancient technicians. This will give additional information and help to prepare compatible materials for restoration. Besides, additions of vegetal additives in the earthen plaster works were the common features in the Indian sub-continent. The kind of vegetal additive incorporated in the plaster may vary according to the location of the site and its availability in the surroundings.

The aim of this communication is to characterize the earthen plaster of Bhaja caves so as to understand earliest clay plaster technology besides preparing a matching plaster mix for restoration. Material characterisation constituted primary source of our research using both destructive and non-destructive techniques. By using combination of methods this work provides scientific data about chemical and mineralogical composition, micro-morphological characteristics, geological and textural data of earthen plaster of

Bhaja caves. The stereomicroscopy, petrological microscope, laser particle size analyzer, X-ray fluorescence (XRF), X-ray diffraction (XRD), scanning electron microscopy, FTIR and on-site observation under magnifying lens were selected as main analytical techniques. The analytical techniques provided variety of data about the nature and characteristics of Bhaja plaster. The main objective of present communication is to combine the data obtained through analytical techniques in an attempt to establish proper recipe for Bhaja cave plaster in addition to understand early technology practised by ancient Indians.

2. MATERIALS & METHODS

One of the major drawbacks at Bhaja is obtaining sufficient quantity and numbers of decorative earthen plaster samples. Research cannot be carried at the cost of damaging our cultural heritage and we followed the conservation rule that interventions should be minimum necessary. Therefore, analytical investigation methods were limited to those that need micro samples or a few grains of the samples and also proven to be reliable. The samples were extracted from unpainted areas in very limited quantities. As cave no 12 has decorative arts on earthen plaster at Bhaja, samples no. 1-6 were drawn for scientific investigation from this cave. Samples were extracted using scalpel from the edges of the plaster showing damage and detachment from the basaltic stone carrier. This was probably the best technique for sampling that could be used in order to limit the damage to historic plaster.

Visual examination under magnifying lens played the primary role in our understanding about painting technique at Bhaja that yielded relevant information. The examination revealed two layers of earthen plaster applied on a roughly cut basaltic rock from which the caves were excavated. The most common plastering technique employed at Bhaja is to smooth irregular rock surfaces with one or more layers of mud plasters. Generally, two layers of mud plaster is observed



Fig. 3. Photograph showing two layers of mud plaster at Bhaja

at Bhaja (Fig. 3).

There is a coarser lower layer levelling the roughness of the host rock whose thickness depends on the topography of the stone surfaces. The thickness of this layer varies between 15-20 mm in the caves. There is an upper finer layer on top of the inner layer that give base to the painting (layer) with thickness ranging from 10-15 mm at various points. The earthen plaster layers are composed of earth with characteristics very close to soil type available in the surroundings (Tamhane, 1964). In a higher rain fed area of Western Ghats, there is all probability of occurrence of more of a clayey soil for construction work. As local soil is likely to have been exploited for earthen plastering by ancient Indians, there is all probability of higher clay proportions in the mud plaster of Bhaja. The occurrence of 60-80% clay in the surrounding soils has been reported around Bhaja (Website: mpcb.gov.in/relatedtopics/CHAPTER2.pdf). However, in an area of complex geological history, obtaining soil samples of right kind is now a problem especially after the growth of urban localities around ancient structures.

The primary aim of our chemical analysis of earthen plaster samples was to determine its composition by X-ray fluorescence. The major oxides for all the six samples extracted from the caveno. 12 at Bhaja were identified using Phillips

1410, Holland X-ray fluorescence set up as per standard procedure by mounting a compressed pellet in the sample holder.

For particle size analysis, the traditional hydrometer/ sieve analysis was replaced by an electronic particle size analyser (Eye Tech particle size and shape analyser, Netherland) for more precise analysis that need least quantity of samples. Only samples 1-5 which were available in higher quantity were utilised for particle size analysis. The sample particle were made to pass through the path of the laser beam, causing laser light to be scattered that resulted a unique diffraction pattern that solely depends on the dimension of the particles as well as wavelength (Vitten, 1997). The sand, silt and clay percentage derived from particle size analysis provided major findings in our study to earthen plaster.

Petrological microscopy was used to analyse earthen plaster samples. The thin section of sample no. 2 & 3 were prepared to enable identification of the mineral composition. In addition, aggregates in the earthen plaster were identified by dissolving the plaster in distilled water and leaving it for overnight. The aggregate components were subjected to petrological identification to confirm their composition, grain size and shape. The thin section of the earthen plaster prepared using Canada balsam was observed through Carl zeiss JENAPOL petrological research microscope and image taken under plane polarised light at 10x magnification.

X-ray diffraction technique was used to identify minerals present in the plaster. X-ray diffraction (Philips 2404, Holland) was used to determine the mineralogical composition of the plaster sample no. 2 & 3 using a graphite monochromator and $\text{CuK}\alpha$ radiation. The samples were scanned from 2θ ranging from 5° to 120° . The presences of minerals were confirmed with the help of data file presented by JCPDS, 1994. For FTIR spectroscopic analysis, small quantity of

plaster sample no. 2 & 3 were taken with the help of sharp tip micro- scalpel and placed on freshly prepared KBr pellet. The FTIR spectra were obtained in the 4000-550cm⁻¹ using Agilent 600 series FTIR spectroscopy equipped with nitrogen cooled MCT detector. The database of FTIR spectra with inorganic and organic materials were used to characterise the unknown components in the sample. The SEM photomicrograph of earthen plaster sample no. 2 & 3 were obtained using Zeiss scanning electron microscope at a range of magnification to identify the components in the plaster. Organic fibres collected after the digestion of the plaster samples were also observed under Olympus magnus MS2 and LABOMED CSM2 stereomicroscope to identify the fibres used as organic additives of binder in the plasterworks.

3. RESULTS AND DISCUSSION

3.1 Chemical composition of earthen plaster

Eighteen caves excavated from Deccan basalt are present at Bhaja. However, only one (cave no. 12) has either layers of earthen plaster or earthen plaster with painted surfaces. The chemical composition of earthen plaster in the form of major oxides determined using X-ray fluorescence is shown in Table 1.

From the data it is observed that slaked slightly dolomitic lime has invariably been mixed in all the earthen plaster to enhance binding properties of the local soil. The combined percentage of calcium and magnesium calcites vary

between 8.57 to 11.30 weight percentage which cannot be impurities on account of decaying basalt stone. The slaked lime was probably added to overcome inadaptability of local soil since it acted as cementing material with earthen mix forming chemical bonds with clay, silt and sand (Mosgnera, 2002; Mollinowski, 1981). The percentage of alumina in the earthen mix vary between 15.69-19.3 weight percentage revealing sourcing of clay rich soil for Bhaja cave in resemblance to the data observed through particle size analysis of earthen plaster. It appears that though the ancient technicians of Bhaja sourced clay rich soil for compactness of the plaster, yet they deliberately mixed slaked lime for its better strength and durability. The clay proportion between 60-80% has already been reported in the surrounding soil near Bhaja caves (Singh, 2015). This indicates sourcing of local soil for earthen plaster works whose properties were further modified by addition of other ingredients. The remarkable red colour of the earthen plaster is due to the presence of iron oxide, detected between 12.29-15.11% in the plaster. As Bhaja caves represents the earliest example of earthen plaster technology, the chemical analysis data reflect historical / technical development of the period and sourcing of better soil type and improvement of technology in later plaster works in India [Singh, 2015; Singh, 2014, and Singh 2015).

3.2 Petrological Analysis

The earthen plasters of Bhaja caves were observed under polarised microscope and the

Table 1: Chemical Composition (% byweight) of earthenplaster of Bhaja caves.

Sample	Na ₂ O %	MgO %	Al ₂ O ₃ %	SiO ₂ %	P ₂ O ₅ %	K ₂ O %	CaO %	TiO ₂ %	MnO %	Fe ₂ O ₃ %	LOI
ASI11M	0.83	2.47	19.3	44.15	0.3	0.56	6.1	2.67	0.14	14.85	8.63
ASI12M	1.29	3.63	15.69	45.2	0.3	0.76	7.96	1.95	0.14	12.29	10.79
ASI13M	0.9	2.52	18.71	43.28	0.24	0.52	6.16	2.69	0.16	14.77	10.05
ASI14M	1.2	2.35	18.38	44.83	0.25	0.61	6.56	2.56	0.15	15.11	8
ASI15M	0.9	3.5	16.58	44.35	0.3	0.88	7.8	1.85	0.16	13.52	10.16
ASI16M	1.1	2.42	17.58	45.2	0.29	0.79	7.3	2.5	0.15	13.49	9.18

principal minerals observed were plagioclase, kaolinite, mica, quartz, iron oxide etc. along with vegetal remains mostly rice husk in all the samples. The creamy white colour lime is found mixed in fine grains of sub – angular to sub – rounded transparent to honey red colour quartz grains.

The thin section of sample no. 2 & 3 were examined under plane polarised light and the result is shown in Fig.4 taken at 10 x magnifications. In Fig.4 light to dark coloured medium to fine textured fabric is seen.

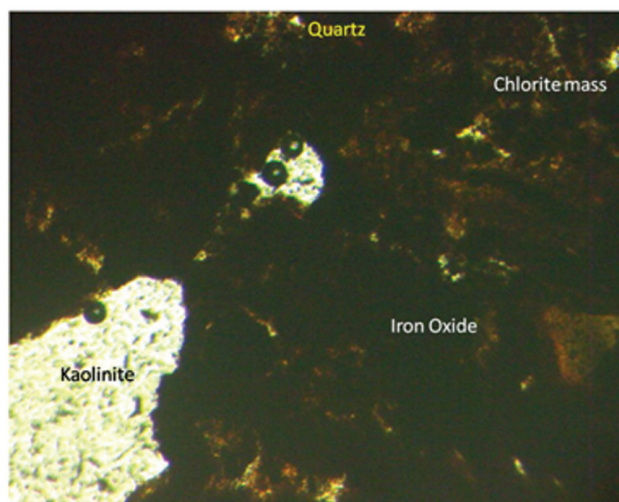


Fig. 4. Thin section Images of Bhaja caves.

The image showed irregular grains of quartz and silicate embedded in kaolinite and chlorite clay ground mass. The shiny calcite grains intermixed with silica ground mass along with muscovite embedded in kaolinite clay are seen. In the thin section in Fig. 5, abundance of kaolinite mass with embedded iron oxide minerals are clearly observed. The presence of iron oxide in the samples is due to preparatory material made up of crystalline and amorphous phase rich in ferrous substances. The petrological data of the earthen plaster are in agreement to XRD analysis of the plaster used for determination of mineralogical composition.

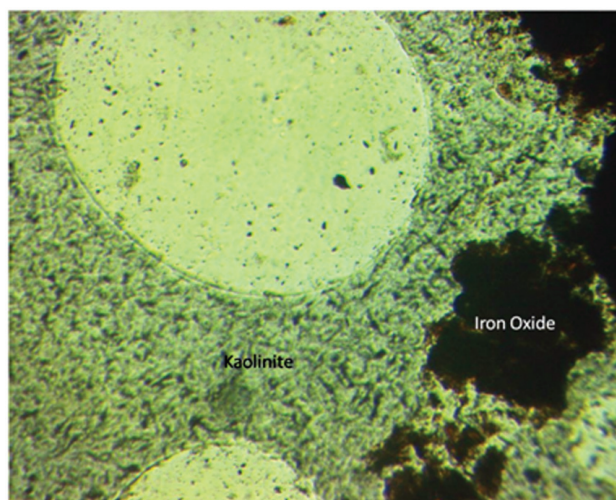


Fig. 5. Thin section images of Bhaja caves.

3.3 Aggregate Analysis

The earthen plaster of Bhaja (sample no. 2 & 3) was dissolved in 10% hydrochloric acid for overnight followed by subsequent washing of the aggregates till neutral pH. The aggregates were sieved after drying and separated as per grain size. Fig. 6 shows the grain size of the aggregates mixed in the plaster. It is observed that coarse to fine sand aggregates of basaltic origin were mixed in the earthen plaster for strength and durability. The proportion of fine sand was observed in higher quantity to that of coarse sand.



Fig. 6. Aggregates in mud plaster of Bhaja caves.

From the grain shape of the aggregates, Fig. 6, it is observed that majority of grains are sub angular to sub rounded which together constitute more than 80 % of the aggregate grains. The rice husk as vegetal additives was prominently noticed in the plaster at Bhaja. The shrinkage of the soil was significantly tailored with the influence by addition of calcite, aggregates and vegetal additives in the plaster works.

3.4 Particle size Analysis

The particle size analysis of earthen plaster of Bhaja provided distribution curve through which the soil was characterised. The type of the earthen support was assessed through the presence of sand, silt and clay in the plaster. As obtaining higher quantity of sample is not possible for the decorative arts of Bhaja, we relied on laser particle size analyser which needs smaller samples and the results are more precise, reliable and faster. The earthen plaster samples no. 1-5 was examined under laser diffraction analysis. Three trials for each measurement were taken and the average reported in the data. The particle size analysis curve of Bhaja plaster is shown in Fig.7.

From the particle size analysis, it is observed that the earthen plaster of Bhaja is much finer and contains far less silt size particles. The grain size analysis showed the majority of grains

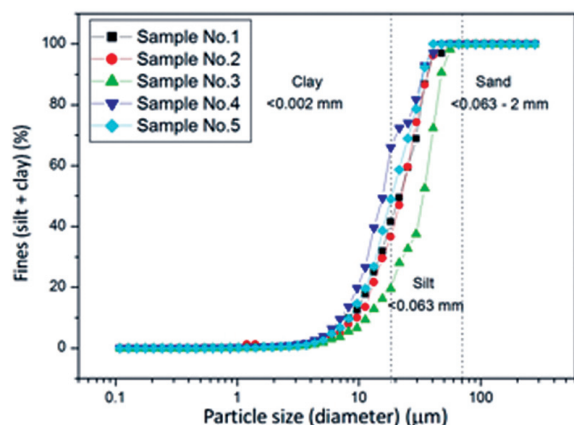


Fig. 7. The particle size analysis curve of Bhaja plaster.

are of clay sized (more than 65%), followed by sand sized (20-28%) and least the silt sized (7-15%). Due to presence of more proportion of clay size particle, the earthen plaster of Bhaja shows compactness. The compactness of the earthen plaster was further improved by addition of slaked lime, iron oxide etc. into the plaster. However, the particle size distribution of soil structure precisely influences humidity transfer within the plaster (Katheen, 1997). The higher

clay proportion consisting of both expandable and non expandable clay envisaged through thin section / SEM analysis may cause moisture movement within the earthen plaster. The Bhaja caves are situated in Western Ghats, a very high rain fall area during monsoon period. The humidity inside the caves reaches around 90% during rainy season. During this period the expandable clay like sepiolite, chlorite etc. present in the plaster starts absorbing moisture whenever humidity reaches above 67%. On absorption of moisture the clay part shows swelling behaviour resulting initiation of disintegration of the earthen plaster. In the summer season, the humidity inside the caves drops down to around 40% causing loss of absorbed water. The regular absorption and loss of moisture from the clay part of the plaster cause disintegration of the plaster in the long run.

The earthen plaster of Bhaja based on their sand, silt and clay proportions were plotted on sand-silt-clay ternary diagram (Fig. 8).

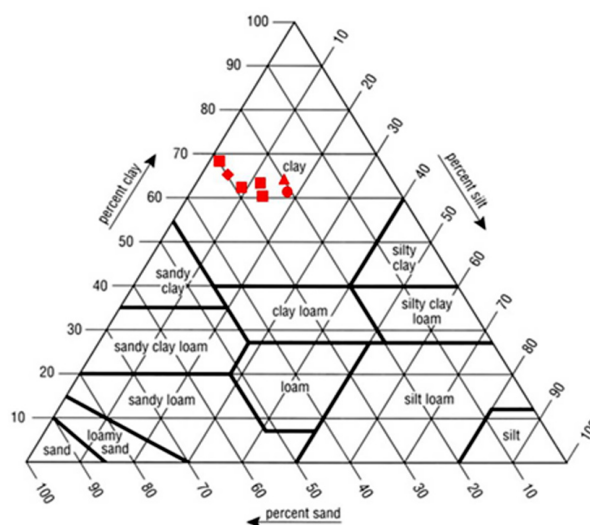


Fig. 8. Sand-silt-clay ternary diagram of Bhaja plaster.

From the ternary diagram, it is observed that clay soil (clay proportion above 65%) was sourced for the preparation of earthen plaster. The higher clay proportion caused extensive damage to the earthen plaster of Bhaja due to its swelling/

contraction behaviour. It is to be mentioned that in the later caves silt-loam type of soil was selected for earthen plaster displaying much higher stability and strength. The ancient earthen plaster in India are also said to be invariably mixed with organic adhesive (Svaramamurti, 1978) for enhanced binding. The protein of the adhesive juices acted with clay particles causing clay flocculation. However, with time owing to high absorption of moisture by clay particle, the adhesive materials also showed tendency to dissolve and loose its properties. This is what happened to the earthen plaster works at Bhaja which in turn caused disintegration and loss of decorative arts at numerous places inside the caves. The particle size analysis supports the data obtained through thin section/ SEM photomicrograph of the plaster.

3.5 FTIR Analysis

A few fragments of earthen plaster of sample no. 1-3, Bhaja caves were observed under Fourier Transform Infrared (FTIR) spectroscopy with identical peaks. The FTIR spectrum of sample no. 2 is only shown in Fig. 9 as an example.

The most characteristic band of silicate as SiO_2 tetrahedra is seen at a spectral region at around 1000 cm^{-1} . A very small calcium carbonate stretching peak at 1423 cm^{-1} is observed in FTIR spectrum of earthen plaster. A very small peak at 748 cm^{-1} denotes presence of magnesium carbonate which is a unique spectra differentiating

magnesium carbonate to calcium carbonate. The IR spectrum also showed a small peak of amides around 1650 cm^{-1} pointing addition of some adhesive juice in the plaster works of Bhaja caves. This N-H band is due to presence of primary and secondary amides from proteinaceous and fatty materials mixed for adhesive purpose. The IR spectra showed characteristic band at around 3500 cm^{-1} due to free hydroxyl ions of the water.

3.6 XRD Analysis

In the present study, the x-ray diffraction of sample no. 1 & 4 of Bhaja were carried out and the mineralogical data obtained from XRD are shown in Fig.10.

The major identified minerals in Bhaja plaster observed through XRD study are quartz [SiO_2] (d in \AA =3.345, 4.265) and sepiolite [$\text{Mg}_4\text{Si}_6\text{O}_{15}(\text{OH})_2 \cdot 6\text{H}_2\text{O}$] (d in \AA =3.345, 4.265, 2.85). Calcite [CaCO_3] (d in \AA =1.981, 1.818) observed in XRD patterns for finer particle size fraction may come from carbonated lime. Peaks of Kaolinite [$\text{Al}_2(\text{Si}_2\text{O}_5)(\text{OH})_4$] (d in \AA =1.672, 1.542) and orthoclase [KAlSi_3O_8] (d in \AA =3.25, 3.19) which is the siliceous clay mineral are also visible in XRD pattern, its occurrence is supported by the SEM and petrological analysis. Identification of the above mentioned constituents confirms the presence of clay base and siliceous filler for Bhaja plaster. As the mineralogical composition depends on the regional geology

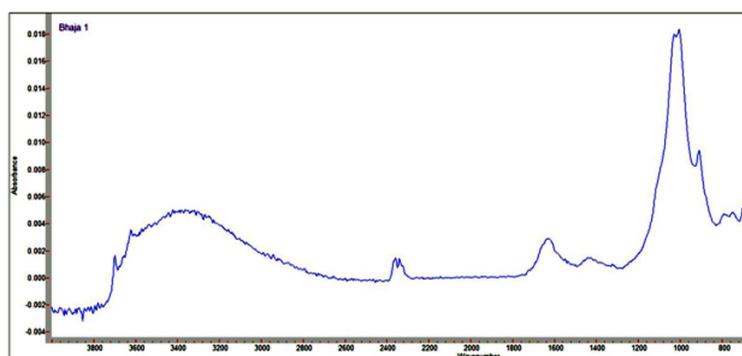


Fig. 9. FTIR Spectrum of Mud plaster sample No. 2.

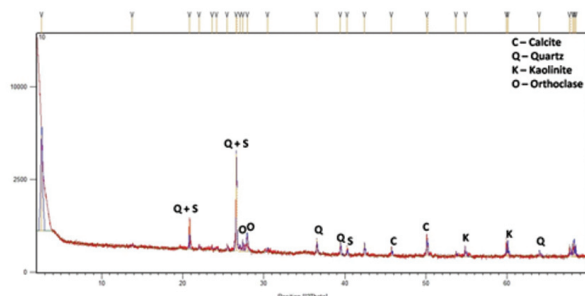


Fig. 10. XRD Spectrum of Mud plaster sample, Bhaja caves.

and climatic conditions, it denotes occurrence of clayey soil in the surrounding of Bhaja caves in which local sand was mixed as aggregate.

3.8 SEM Analysis

The scanning electron microscope photomicrograph of the earthen plaster of Bhaja cave for sample no. 2 and 3 are shown in Figs. 11 and 12(a-d). In the photomicrograph of sample no. 2 taken at magnification of 1000x, patches of calcites are seen between detrital quartz grains and calcite appears slightly dissolved in quartz grain. Quartz grain is porous, well rounded with minor authigenic quartz overgrowths and pore lining clays are present in SEM image. From Fig. 11 the presence of iron oxide particle cluster and the remains of vegetal root is also observed. The figure also shows thin coating of filamentous illite on the surface of detrital grain.

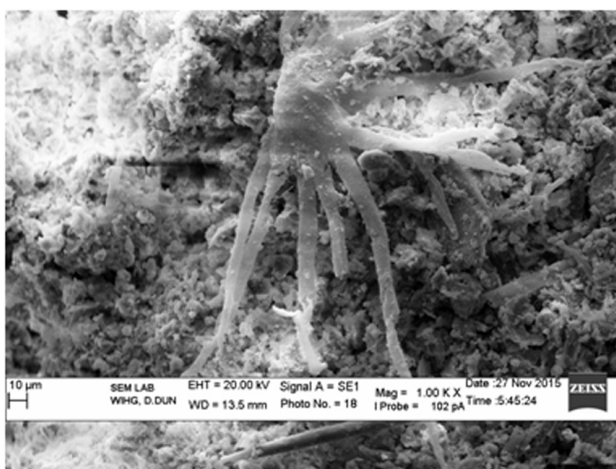


Fig. 11. SEM images of Mud plaster, Bhaja caves showing quartz, calcite, remains of vegetal root and iron oxide.

The SEM photomicrograph (Figs. 12 a, b and c) of the sample no. 3 taken at magnification of 2000, 1000x and 3000x are shown in Figs. 12 a & c pointing clay mineral structure of Kaolinite. The individual Kaolinite arranged face to face into an elongated stack, called a 'verm'. In this, a secondary growth of blocky kaolinite crystals can be observed in a crack within the verm. Along with Kaolinite, elongated detrital biotic mica grain compacted between quartz grains within clay matrix is seen. An open interconnected pore lined with ribbons forming a mat like structure coating the detrital grain surfaces and also bridging the pores between grains is observed in the SEM image. Due to this permeability barrier is created for moisture flow. This type of clay structure severely reduces permeability without affecting porosity. The higher magnification photomicrograph of the bridge revealed that the earthen plaster is composed of inter wired clay ribbons of filamentous illite-sepiolite clay minerals. In Fig. 12 b at magnification 1000x the microstructure of albite feldspar along with filamentous illite can be observed.

In photomicrograph of sample no 3 in Fig. 12 d taken at the magnification of 3000x, presence of an authigenic chlorite platelets (arrow) stacked face to face is observed. The smaller stacks of circular chlorite are indicated by arrows.

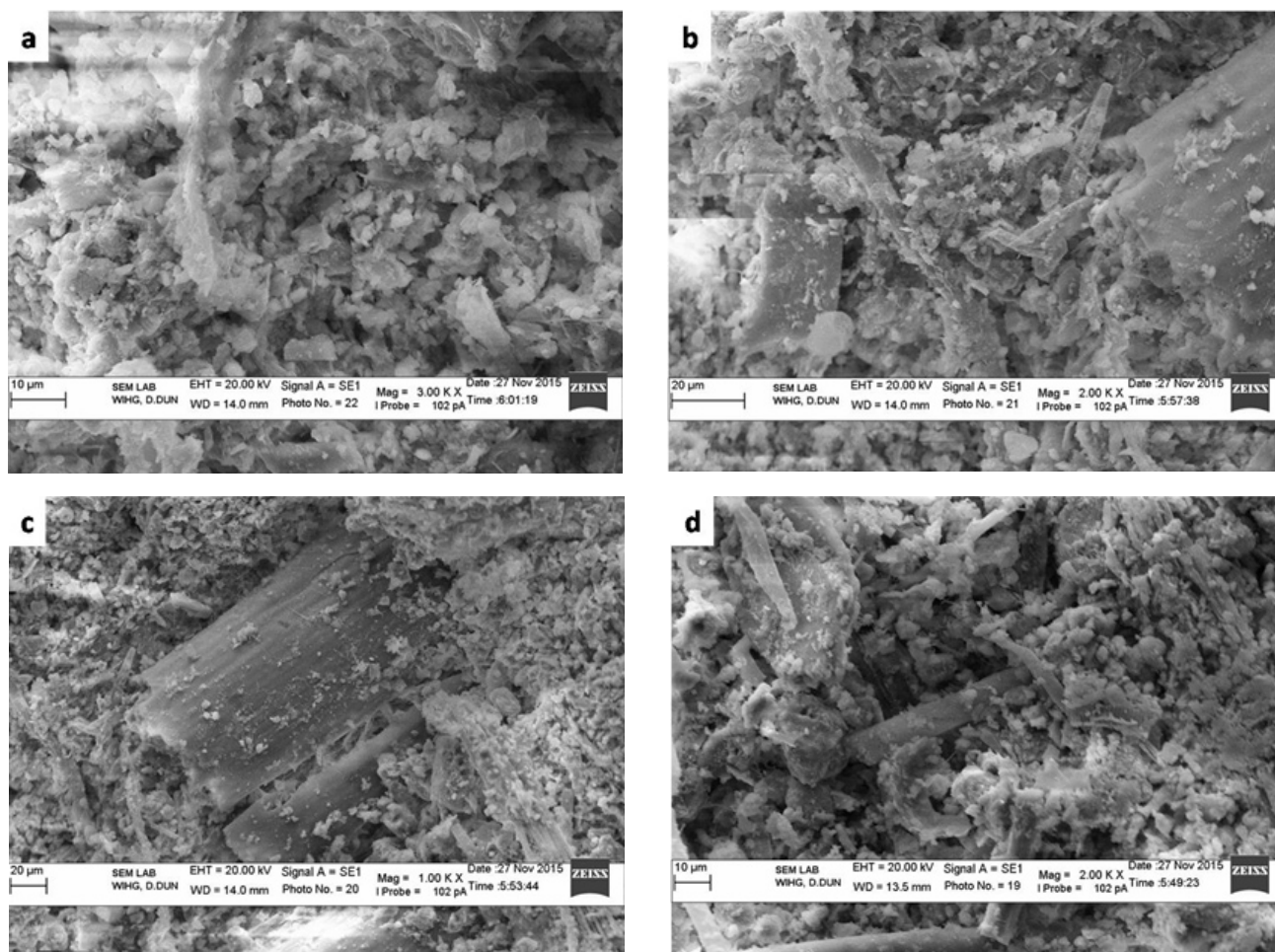


Fig. 12 (a-d) SEM images of Mud plaster, Bhaja caves showing Kaolinite, Sepiolite, Illite, Mica, Feldspar and Calcite.

The chlorite is formed in a depression within an altered rock fragment. This interpretation is consistent with petrological, XRD and other analysis techniques of the earthen plaster.

4. CONCLUSION

From the analytical examination, it is observed that the earthen plaster of Bhaja contains many fine particles due to presence of >65% clay that gave flexibility, strength and cementing properties to the plaster. To overcome inadaptability of raw soil slaked lime and rice husk were deliberately mixed to give strength and stop cracking during drying for the plaster. The majority of the aggregates ($H \approx 80\%$) mixed in the plaster are sub rounded to sub angular shape of basaltic

origin. The major minerals noticed are plagioclase, kaolinite/ sepiolite, clay, mica, quartz, iron oxide etc. reflecting byproduct of disintegrating basaltic rock. The presence of N-H band in FTIR spectra reflects addition of proteinaceous adhesive in the plaster. The plaster is mainly composed of thin filamentous illite embedding quartz and silicate minerals. The result is important for preparation of compatible mud plaster for restoration of Bhaja caves.

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