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ANCIENT INDIAN PAINTING RECIPES AND MURAL ART TECHNIQUE AT AJANTA

Manager SINGH[1*], Balasaheb Ramrao ARBAD[2]

[1] Archaeological Survey of India, Science branch,Western Zone, Aurangabad-431004, India
[2] Department of chemistry, Dr. Babasaheb Ambedkar Marathwada University, Aurangabad-431004, India.

Abstract

Technological studies on Ajanta painted mortars (3rd – 4th Century A.D) have been attempted for suitable preservation strategy and preparation of paint ground, identification of materials and their decay process. Microstructures of layers along with material structure, composition and additives used in the mortar were investigated through colorimetry, XRF, FTIR, SEM-EDX, etc. Particle size of the clay mortar analyzed by laser scattering showed the use of high silt (70 – 75%) and low clay soil, probably sourced from the ravine of Waghura river and used for the preparation of the mud mortar. Byproducts of weathered basaltic rock, such as celandonite and white zeolites, bounded by organic proteic adhesive were found as filler in mud mortar as well. FTIR spectra of paint ground and pigment layer indicated the addition of organic binder that has now transformed into Calcium oxalate. In addition, the presence of vegetal matter observed with the FTIR analysis, might be due to addition of parts of cereals (such as the rice husk) cultivated in geographical area. SEM – EDX confirmed the presence of four different layers. The technique of painting remained almost identical in all the caves with very minor variation with respect to the ancient Indian painting art described in Indian old texts. An attempt to prepare mud mortar as per ancient recipe has been highlighted for the holistic restoration and preservation of Ajanta murals (World Heritage Site – WHS).

Keywords: *Mud mortar; Stratification; Celandonite; Calcium Oxalate; Technique, Lapis lazuli, Consolidation*

Introduction

Ajanta stands as a single most important record of India's Golden Age (3-4th century A.D) and might be considered the mankind's greatest creative achievement. The 30 Buddhist caves created by the Vakataka's in a remote ravine at Ajanta forms a devotional complex which ranks one of the world's most startling achievements. A lively debate is presently on among the archaeologist and art historians about chronology of Ajanta Caves. The old view [1, 2] that Ajanta later development went for two hundred or even three hundred years, under the succession of different dynasties, can no longer be sustained and questioned by many art historians. After meticulous research and gathering all the scattered information, a short chronology has now been suggested [3] lasting about 20 years. Such an approach to Ajanta's dating has remarkably revealing implications vis-à-vis considered view on longer chronology. It

* Corresponding author: m_singh_asi@yahoo.com

is obvious that excavation of caves and carving out the decoration was quite time consuming but the entire mud mortaring and painting would hardly have taken a year or so, for a few dozen of artists. The short chronology theory is based on the famous Visrutacarita [4] that almost point to point represents the recollection of the great Vakataka empire crepuscule. The subject of the wall narratives at Ajanta are various Jatakas, spread out almost like unrolled scroll [5]. As the short/long chronology at Ajanta is based on archaeologists/art historian's physical features and geometrical designs of paintings and sculptures, necessity was felt to look the mud mortar and pigments layer through scientific investigation to explore any differences in material/painting techniques. Under the Indo-Italian conservation programme (Indo-Italian Conservation Programme Cave no. 17, Ajanta, India from 2005 to 2008), the components of the mud mortar and paint layers were observed under stereo-microscope and through various scientific instruments such as FTIR, SEM, Micro-Raman, XRF etc at the site as well as micro grains in laboratory [6]. It is assumed that component materials or technique of execution may undergo some modification in 200-300 years period

The conservators of Ajanta are also supposed to be able to compare data emerged from the analysis of mud mortar and pigments with what has been described in ancient Indian literature written in Sanskrit language [7-9]. Evidences of flowering artistic tradition in Sanskrit literature are found in texts on mythological subjects. The main ancient literature dedicated for artistic techniques in ancient India and technical aspects of paintings are the Vastustras (treaties of habitat), Vastuoastras (treaties on dwelling) and Silpaoastras (technical treaties). One should have specific knowledge about the technical treaties to write a history of Indian painting art. The narrative mastery and technical knowledge demonstrated by artists at Ajanta suggest existence of several schools of arts already employed in decorative work of structural buildings and temples. Among the aforesaid text, there are many works where painting technique and procedures to be followed are described. The main Indian texts for painting techniques are:

- The Vishnudharmottara Purana [7] composed in 6-7th A.D. shortly after the mural works of Ajanta.
- The Samaraga Sutradhara [8], a silpaoastra attributed to Bhoja king of the Paramara dynasty of 11th century mainly dealing with pictorial and iconographic art.
- The Manasollasa [9], the text of southern India paintings tradition attributed to king Somesvara of early 12th century Chalukya dynasty.
- The Silparatna [10], written in 16th century, a section of which entitled "characteristic of image" which contains lot of information on painting technique.
- The Aparajita Pecha of Bhuvana Deva [11], probably composed after Silparatna [10], that describe architecture and contains concepts on decorative design and preparation of paint ground.

There are many other texts written in Sanskrit slokas in which instructions on mural paintings techniques are systematically stated. Some of the ancient paintings texts have not yet been translated and others [7-9] have been translated in English, Hindi and Tamil languages. Almost all the text describes the methods of preparation of paint ground and stages of its application along with preparation of colors for painting work.

Although Vishnudharmottara was composed one or two centuries after the execution of Ajanta murals, it may be considered as true reference text for proper understanding of painted procedure on site. The other text written at distant time from Ajanta and pertains to various periods. In all the text it seems figurative work precedes the literacy both in iconographic and iconological field. The writing works of silpas were allotted to the poets (and not artists) who grasp the basic concepts of paintings during observation but lack first hand knowledge about the real technique being followed. Due to this reason, the prescription supplied in the ancient text does not dwell on the detailed technical processes. The other reason lies in the fact that the main part is written in sutra forms, which simply serves as guiding principle for the artists to recall

the various passages of execution. Besides, there is diverse interpretations and translations of sutra's by various authors.

In fact, there are many conflicting opinion among experts on particular points regarding various procedures described in the texts. Out of many sutras, the four most important sutras describe the method for preparation of paint ground. Among this the text Vishnudharmottara [7] and Samaraga Sutradhara [8] describe the technique of preparation of paint ground using clays earths. The text Manasollasa [9] and Silpratna [10] represents the preparation of ground under southern traditions of the subcontinent where the basic component is lime or burnt and powdered conch shells or white earth of calcareous nature, available in south of India. Some of the important ancient Indian painting text showing basic ingredients and procedure to be followed in the preparation of paint ground and colors are elaborated.

In India beautiful painted remains can be found from prehistoric period to Mughal period of 16-17th century A.D. Most of the prehistoric paintings are found in sand stone shelter of central India where roughness and porosity of sand stone was utilized for painting. Later paintings are either on mud mortar or lime mortar ground. Known as monument of paintings, clay mortar forms backing of lime layer coat and basaltic stone support at Ajanta. The pigments identified at Ajanta are red ochre, yellow ochre, green earth, lapis lazuli, carbon black and shell/kaolin lime [12]. The pigments found used in India from prehistoric to Mughal period have remained almost identical and same without much variations [13]. The pigments identified at Ajanta also show close resemblance with Roman painted works of fresco [14]. The outlines of the Ajanta paintings are mostly drawn by carbon black or red ochre. The mud mortar thickness varies from few millimeters to an inch [15] in some cases where basaltic stone is very roughly cut. Organic matters such as rice husks, plant seeds and plant fibers are generally found admixed within the mud mortar. The theme of the paintings is Buddhist Jataka tales with beautiful human figures, geometrical designs and animal's figures. Most of the paintings show three dimensional appearances and highlights the artistic skill of Indian painters in 3-4th A.D, known as the Golden Age period. The raw materials used for the preparation of clay ground are mostly locally available materials collected from either Waghura river in front of Ajanta caves or nearby places. Except blue, all the pigments are locally available materials including green which is the product of basaltic rock disintegration. It appears that aggregate used as fillers to the mud mortar at Ajanta are also byproduct of weathered basalt collected from ravine of Waghura. The aggregates mostly identified are quartz, zeolites and celandonite. It is observed that 8-10% lime with organic additives was mixed in the low swelling clay to prepare the mud mortar at Ajanta. The technique of paintings is purely tempera and animal glue has probably been used [16] as binding agent to the pigments at Ajanta and related sites. Unlike fresco painting [17], the paintings technique in India is either tempera or secco and binding medium identified at Ajanta is animal glue. An understanding of the composition of ancient mortar and technology is necessary for creation of new mortar for restoration [18] at Ajanta and other sites.

Along with the primary knowledge of ancient Indian painting technique and preparation of paint ground, identification of materials and their decay process are of great significance. It is also essential to study micro-structures of the layers, their strata and binding media for the paint layer and clay mortar. With the range of scientific methods and experimental procedures, an attempt has been made to identity the method of application of mud layer ground and painting technique followed for Ajanta murals. During the course of studies material structure, composition and additives used in the mortars were also investigated. Such study of ancient technology in terms of materials and its application is essential for undertaking any conservation activity aimed for preserving the painted mortar.

In view of above, it is necessary to scientifically investigate the components to fully understand the Ajanta paintings for its future preservation as well as to gain some idea in support to the chronology of Ajanta. Analysis was carried out for material composition and

additives of mud mortar of Ajanta. Further study of the micro-structure of layers and its strata were carried through colorimetry, XRF, SEM-EDX etc.

Deterioration and degradation causes

The major causes of deterioration and degradation of Ajanta murals are variation in temperature and humidity, increase in flow of visitors inside the caves, seepages of waters, insect activity within the mud mortar, human vandalism (graffiti) and urine and excreta of bats. Presence of old varnish coatings used for copying the paintings by earlier artists is also a major conservation issue at Ajanta.

Inside the caves the humidity reaches up to 80% in the rainy season and low up to 40% in the summer season causing expansion and contraction of paint layer and mud ground. This variations in the long run causes flaking of the painted layers, disaggregation of the mud mortar and formations of ridges, gapes and lacunas in the painted layer. There is also large variation in temperature and humidity from outside to inside the caves. Whereas the caves are thermally stable (temp. varies from 27°C to 30°C inside the caves), wide fluctuation in temperature are noticed from outside to inside [19]. In some of the caves with large opening such as Hinyana cave no. 10, temperature and humidity both inside and outside are almost identical with little variations [20].

Ajanta caves attract around 5000 visitors per day in the tourist season from October to February every year. The visitors have to climb Ajanta hill and enter inside the caves with fast breathe and exhale of carbon dioxide. A detailed investigation on impact of visitors on cave murals of Ajanta has already been made [21]. The Archaeological Survey of India, giving top priority for conservation of murals of Ajanta has constructed two causeways for proper distribution of visitors besides providing suitable illumination to all the caves, with some of the important painted caves illuminated with optical fiber light.

The major scientific preservation of murals of Ajanta was carried out in 1920 by Italian conservators when the cave was under the domain of Nizam of Hyderabad State. Besides filling the gaps and lacuna with Portland lime, most of the painted surfaces were applied with unbleached shellac varnish as preservative coating.

The shellac in the Indian climate has oxidized to reddish orange color masking the clear view of the paint layer. Besides it has also hindered the breathability of mud mortar and paint layer thereby causing ridges, gapes and sometimes loss of paint/mortar layers. Figure 1 shows the view of the painted mortar applied with shellac varnish. One of the primary tasks of Ajanta conservators is to slowly remove the varnish layers previously applied during the course of conservation. The most ancient 2^{nd} BCE caves 9 and 10, Ajanta were copied in 19^{th} century by applying different kind of varnishes under the light of an oil lamp causing extensive deposition of many kinds of varnishes admixed with soot and grime. There were also problem of graffiti by visitors when the cave was not under the control of Archaeological Survey of India (ASI), and Figure 2 show one such view from cave no. 10. Besides, some of the painted caves of Ajanta were under worship during $3\text{-}4^{th}$ century A.D. and deposition of soot on the painted surfaces is noticed due to burning of incense Sticks.

The mud mortar contains organic additives such as rice husk, plant seeds and fibers which are the food for insects like silver fishes who thrives on it by making holes into the soft mortar. The movement of the insects within the mud mortar makes it weak and prone to fall. Necessary measures like spraying, fumigation, dusting etc. are regularly under progress to eradicate the insect activity from the caves. Another major problem is roosting of bats in the interior of the caves. Although bats menaces are totally been eradicate from Ajanta, the removal of bats excreta and urine deposited earlier is the major issue of conservation.

Fig. 1. Painted mortar of Cave no.19, Ajanta applied with shellac varnish

Fig. 2. Showing graffiti on painted mortar of cave no.10, Ajanta

Experimental

Paint grounds and binders according to ancient sutras

(A) Vishnudharmottara Purana

For the preparation of paint ground this text prescribes three types of brick dust and three parts of mud mortar to which Guggula (gum or resin), madhucchlliioa (bee wax) are added in equal quantity. According to the text all these must be mixed with one third of powdered burnt lime, pulp from bilva (*Aegle marmelos*) in two to one ratio along with necessary quantity of salt free sand. The text recommends storing this mixture in water mixed with the bark of picchila (a legume, probably *Dalbergia sisoo*, *Bombax heptaphyllum*) for one month. An experienced artist removes this mixture from the container and applies it to the wall and allows drying. Particular care has to be observed that this layer is smooth and uniform and neither too thin nor too thick. If the wall that is starting to dry does appear not properly done, then it must be carefully polished to make it uniform with a layer of intonacco (lepna) made up of earth mixed with a juice of oarja (*Shorea robusta*). The surface is also polished with a fine lamp black (anjana) and repeatedly spread with milk. The text confirms that the wall mortar treated in this way will not deteriorate even after one hundred years. It also says that the same procedures must be followed to prepare various paint grounds.

For the binder, the Vishnudharmottara prescribes the use of decoction of skins (Carmakvatha) which corresponds to famous Vajralepa glue, used in the mixture to cover the surface that act as protective coat. The text provides five different recipes for the preparation of vajralepa. One of the recipes lists ox or buffalo horns among the ingredients, a buffalo or cow or goat skin mixed with juice of bimbo (*Momordica monadelpha*) and kapittha (*Feronia elephantum*). In Vishnudharmottara the use of binders with vegetable origin is also prescribed. One such recipe is the juice of bakula (*Minusops elengi*) and sindura (*Grislea tomentosa*) which are mixed with Carmakvatha.

For protective agent or fixative the text recommend application of juice of *Cynodon dactylon* (durva grass) to the finished paintings with the help of cloth soaked in it.

(B) Samaragao Sutradhra

The Samaragao Sutradhara describes very clearly to Vishnudharmottara between the first preparatory layer known as bhumibandhana and intonaco, known as Lepkarma. It recommends that juice from various plants, such as Snuhivastuka (*Euphoria antiquorum*), kuimaoa (a cucurbit, *Beninacasa cerifera*), kuddali (*Bouhina variegata*), Opamarga (*Achyrantes aspera*) and Ikika (*Sugarcane* sp.) are let to rest for a week and them mixed with the juice of Siaoapa (*Dalbergia sisso*), Ashoka tree, Nimba (*Azadirachta indica*), Triphala (*Myrobalan* sp.), kuooja (*Wrightia antidysenterica*) and kaiayaka (*Acacia catechu*) together with sea salts (about 2%). This mixture is sprayed in previously leveled wall where the painting work has to be undertaken. The juices of these plants are used to wash the wall surface that also probably works as insecticides.

Some of the fine earth is mixed with double quantity of sand, to which juice of kakubha (*Terminlia arjuna*), maia (seeds of beans or other legumes), oalmali (*Salmalia malabarica*) and oriphala (*Aegle marmelos*, bilva or bel tree) in variable proportions are added. The mortar thus prepared by mixing the ingredients are applied to the wall in sufficient quantity to get what has been described as thickness of elephant skin. When the wall is dry it must be washed with care. Whitish lime stone fine powder is mixed with boiled rice and starch in correct proportions and applied three times to the prepared wall.

After the application of first preparatory layer (bhumibandhana), neutral colored, red or brown clay collected from different places (such as bank of lotus pond, side of the wall under the roof of tree or along the bank of the river etc.) is applied on the wall. For the third layer the text says that earth from anthill (free from stone grains) should be added to the juice of Oalmali

(*Salmalia malabarica*), kakubha (*Ferninalia arjuna*), triphala (myrobalan), chopped betel nuts (*Areca catechu*, kramukha), bilva pulp (*Aegle marmelos*, bel tree), horse hair, ox hair, coconut fiber, a certain quantity of rice husk, and double quantity of mud and sand in one to two ratio in respect to mud is applied on the already prepared wall. A further mixture of mud slip and marble dust, gypsum or sugar dust is applied to the mortared ground with a brush. Finally, the mixture of lime putty and wax is applied.

(C) Silpratna

Silpratna is the southern Indian traditions of preparing paint ground with lime based materials. The text prescribes that the mixture of first layer is prepared with lime obtained from conch-shells burnt in wood fire and grounded into powder, mixed with a quarter part of mudga juice (*Phaseolus mungo*), a quarter parts of sand and molasses and a quarter part of paste of banana burnt in fire. After proper mixing these are stored for three months, after which it is grounded in the form of a mortar with molasses until it has the consistency of fresh butter. In the mean time, the wall is first leveled and polished with coconut coir brush. It is then tampered with molasses water to keep it wet for at least a day. The lime mortar prepared as above slowly applied layer by layer to the wall so that the surface becomes smooth and uniform. While intanaco application is under progress water must be sprayed on to the surface using coconut coir brush. For the preparation of upper preparatory layer, powdered shells or white earth fine powder mixed with kapittha (*Feronia elephantum*) and nimba (*Azardirachta indica*) is applied to the wall. This compound must be applied using the bark of ookooa (*Trophis aspera*) tree or with a brush made up with the stem of ketaki plant (*Pundunus odoratissimus*) plant until the wall becomes smooth and polished. The same powdered lime having been moistened with the milk of a tender coconut is again grounded and diluted with hot water and applied again to the intonaco as described above.

Methods of investigation of mortar and pigments

The grains of mud mortar samples of cave no. 1, 15 and 17 were investigated in this study along with pigment layer of cave no. 1 and 15 of Ajanta.

In order to conduct different analytical analysis many test were conducted on site using non-destructive technique, while micro-invasive methods were applied in laboratory on micro fragments sampled on site. Cross-section view of mud mortar under stereomicroscope (WILDE) indicated succession of layers of painted mortar. Laser light scattering methodology (Beckman Coulter make particle analyzer) was used for partied size analysis as it requires least quantity of sample. Optical microscopy was used for initial examination of the sample to identity painted layer and mortar structure. Physical methods provided useful information on the mineralogical composition and surface structure of mud mortar. Stereomicroscopic analysis was performed for succession of layers to investigate the painting technique. The mud mortar samples were analyzed using XRF, FTIR and SEM-EDX [22, 23]. The specific gravity of the mud mortar was determined using classical methods.

The ancient mud mortars of Ajanta were also observed through FTIR using KBr pallet for absorption.

Preparation of mud mortar as per Ancient Recipes

An attempt was made to prepare mud mortar at Ajanta as per ancient recipes reflected in the ancient text as above. First, the river bank soil from Waghura River just in front of Ajanta caves was collected and mixed with about 15% lime, 10% of sand and 15% of aggregates in different grain sizes.

In the second experiment different plants or parts of the plant were collected and cut into small pieces: Guggul (*Boswellia serrata*), Behada (*Terminalia pellerica*), Jaw (*Linum usitatissimum*), Bargad ka ped (*Ficus recemosa)*, Urad ki Dal (*Vigna mungo*), Roots of ladies finger (*Abelmoschus esculentus*), Kale sawar (*Bombax ceiba*), Bel or bilva (*Aegle marmelos*).

The aforementioned plants in equal ratio were cut and tied in a cotton cloth and dipped in water for about a month. This process ensures complete oozing out of all gummy adhesive material into the water solution. The process was continued for about a month by keeping the container in a dark place.

The extract from these plants were mixed with the mixture (soil + lime + aggregates) prepared in the first step and some rice husk (*Oryaza sativa*) was also added to this mix in minimum quantity. The plant extract mixed in the soil + lime + aggregate is as per requirement avoiding any excess pouring. Figure 3 shows various steps applied in the preparation of mud mortar at Ajanta as per ancient recipes.

Fig. 3. Shows various steps in the preparation of mud mortar as per ancient recipe:
a - ingredients for the preparation of mud mortar, b - preparation of adhesive extract,
c - preparation of soil + lime + aggregates mixture,
d - final step showing the preparation of mud mortar)

For the application of mud mortar on the wall, the basaltic stone surface was previously prepared. It was dry brushed and plant extract juice was applied with paint brush on the required area. Thereafter, the mortar mix was applied on top of the surface with care and precautions. The thickness of the mud mortar layer was kept to about 1 to 1.5 cm. Figure 4 shows the experimental area where mud mortar was applied for testing on basaltic stone surface as per ancient recipes. The mortar is being observed since about 15 years for its behavior in the identical environment. The shrinkage observed in the mortar after drying in the cube was negligible.

For application of this mortar mix during scientific consolidation, the edges of the old mortars were first secured with the plant extract juice and the prepared mud mortar mix was filled in the gaps following all norms of consolidation of painted mortar. Figure 5 depicts an area consolidated with mud mortar mix at Ajanta. It was observed that mortar has properly

adhered within the filled area of gap in the painting where loss of earlier mud mortar was observed on the painted surface. Such filling not only ensures continuity of the similar material but also show similar aging effect.

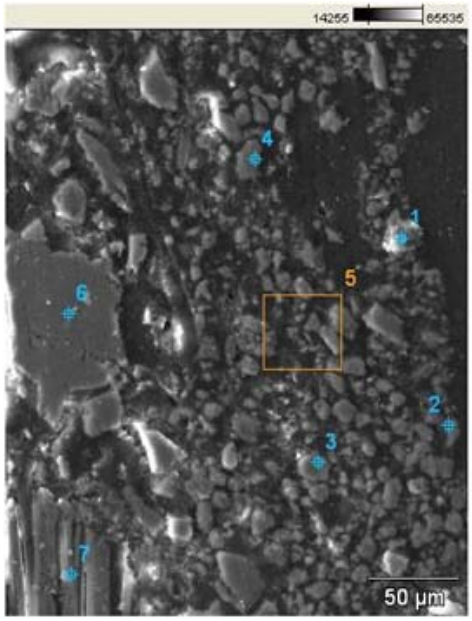
Fig. 4. Application of mud mortar on basaltic stone

Fig. 5. Consolidation of paintings with newly prepared mud mortar

Results

The samples observed using electron microscope revealed a coarse substrate with clasts even larger than 200mm. this is followed by a second layer of fine grained finishing layer.

The EDX analysis of the mud mortar sample is shown in figure 6. The elements present in greater quantity in the sample are calcium, silicon, aluminum and iron. The calcium is located in the inner most layer, silicon and aluminum in the layer immediately above and iron associated with silicon and aluminum in the outermost layer. The elemental map with energy dispersive microprobe also indicates a layer of calcium carbonate and a layer of kaolin due to presence of aluminum. However, a clear line of demarcation between calcium containing layer and kaolin (silicon & aluminum) containing layer is not evident.



Weight %

	Na	Mg	Al	Si	P
pt1	8.58	0.17	6.63	15.08	0.86
pt2	3.20	0.14	5.66	31.52	2.53
pt3	0.00	0.78	0.00	0.00	0.06
pt4				0.37	
pt5	0.87	0.71	6.70	18.26	0.81
pt6	0.14	9.81	0.63	38.88	0.00
pt7	0.30	3.69	4.54	42.77	0.08

	S	Cl	K	Ca	Ti	Fe
pt1	4.77	21.52	14.67	22.84	0.56	4.31
pt2	0.76	5.77	6.59	37.73	0.77	5.34
pt3	0.03	0.10	0.13	98.42	0.10	0.38
pt4				99.63		
pt5	0.65	0.63	0.98	63.24	0.49	6.68
pt6	0.19	0.17	0.21	22.20	1.17	26.61
pt7	0.91	0.49	7.90	5.84	0.43	33.05

Fig. 6. SEM-EDX of mud mortar of Ajanta

Particle size analysis of Ajanta mud mortar shows that the mortar is non- plastic with average distribution of silt 70-75%, sand 9-14% and clay around 12-15%. The mud mortar shows specific gravity around 2.75. From this it can be made that low clay mud has been used for the preparation of Ajanta mud mortar that also contains high amount of silt. Since such kind of high silt soil can be found on the bank of river Waghura at Ajanta, the question of its use during the preparation of Ajanta mud mortar cannot be ruled out as silt found in this soil is more than 70%. This is in consonance to the ancient text where it is recommended to collect soil from river bank for the preparation of mud mortar. It appears that sand and aggregate in different grain sizes obtained from basaltic rock were mixed in the collected soil of river bed for the final preparation of mud mortar.

Figure 7 shows the FTIR image of the mud mortar of Ajanta. The intense band of silicate around 1000cm^{-1} is present in the infra red spectrum as the mortar consists mainly of

silicate materials. The weak absorption band centered at 1400cm^{-1} would indicate presence of small quantity of calcium carbonate. The absorption band of proteic material at 2900cm^{-1} and amide band at 1650, 1550 and 1450cm^{-1} signal the presence of small quantity of calcium oxalate. The presence calcium oxalate tends to indicate the use of organic additives which functioned as a binder for the mud mortar. Oxalate is the byproduct of the oxidative decomposition of organic materials. Thus, the FTIR investigation has ensured uses of organic binder in the mortar mix of Ajanta during the course of its preparation and application.

The efflorescence noticed on the painted mortar of south-west wall (cave no. 17, Ajanta) were chemically analyzed using XRF and main component found are sulphates, nitrates, ammonium ion, calcium and magnesium.

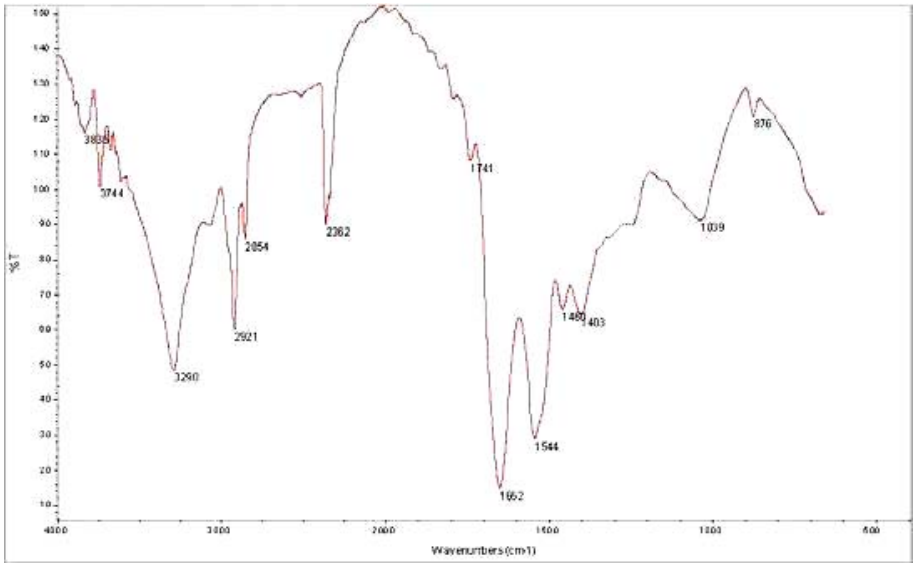


Fig.7. FTIR Spectrum of preparatory mud mortar layer of Ajanta

Although ancient Indian painting text were written after Ajanta, it is worthwhile to explore where what is written in the text are in consonance with the technique employed at Ajanta. Further, it is also interesting to explore whether the technique of Ajanta painting remained same in all the caves or it differs. As the sampling is a problem, only two samples extracted from cave 15 and cave no.1 were photographed with stereomicroscope and recorded with video microscope. On observing the sample of cave no. 15 under stereomicroscope Figure 8, it appears to be made up of thin layer of yellow ochre color (IV) with occasional red particles, below it is a thin white layer (III).

A thicker pinkish yellow preparatory layer (II) can be observed below white layer (III) with black granular impurities, the deeper layer of grey color represent preparatory layer (I) within the granular mass. On observing the sample under stereomicroscope after attack with 10% hydrochloric acid solution, effervescence develops and pinkish yellow layer dissolves completely indicating a carbonic composition. It is also observed that grey mud mortar (I) does not dissolve but loses aggregation due to the reaction of acid to the traces of lime present in mortar. The layer IV and III do not react with the acid.

On observing the sample of cave no.1 through stereomicroscope Figure 9, a very hard and compact white layer (III) is observed on top of which bright blue ultramarine pigment (IV) are present. Below the white layer, an irregular layer of red orange pigment (II) is observed below which grey brown preparatory layer (I) is detected. In the preparatory layer (I) yellowish brown color organic material is observed, probably vegetal remains.

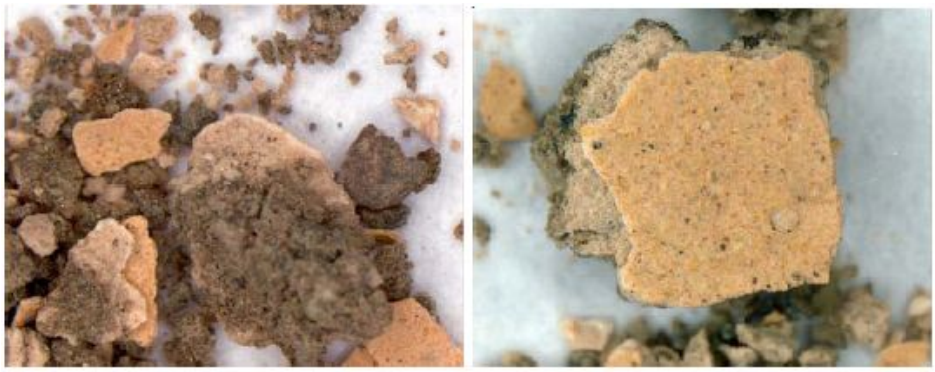


Fig. 8. Stereomicroscopic image of painted mortar of cave no. 15, Ajanta

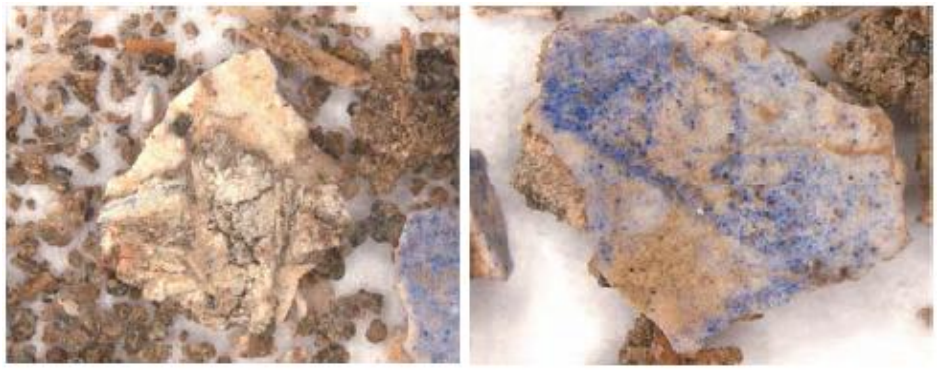


Fig. 9. Stereomicroscopic image of painted mortar, Cave no.1, Ajanta

Fig. 10. Stereomicroscopic image of Vegetal remains found in mud mortar

The fibrous material of green-brown color were removed with needle and observed with an optical microscope. Observation indicated cellular structure Figure 10, indicating vegetal remains from agricultural waste commonly mixed in mud mortar. The cellular elements are compatible with the remains of cereals cultivated in geographical area probably the rice husk. On dilute hydrochloric acid attack; effervescence did not develop like earlier sample, however blue color varnished immediately. The complete decomposition of pigment layer indicates the presence of feldspathoid blue (lazurite) in Ajanta. Preparatory grey layer lost aggregation probably due to reaction of traces of lime present in it.

Discussion

From the thin section analysis of mud mortar, four layers can be identified. A grey preparatory layer (I) that contains coarse black ferruginous silicate material along with green celandonite and white silicon or aluminum inclusion. All those materials are bound with some kind of proteic adhesive as evidence of appearance of calcium oxalate peaks are seen under FTIR images. Above this layer, a pinkish white layer (II) with dark small size inclusion of irregular thickness is present. The primary function of this layer is to level the coarse surface of preparatory layer (I) before application of pigment layer. The preparatory layer (II) consists mainly of calcium carbonate & silicate materials. Above the preparatory layer (II), a thin coat of kaolin based white color (III) layer is present to receive the color. The outer most external layer (IV) is the pigment layer where inorganic mineral color such as red ochre, yellow ochre, green earth as gluconite, lime white & black carbon have been identified at different points. Proteic material has also been identified in the paint layer as peaks of calcium oxalate are seen under FTIR images of the layer.

SEM-EDS analysis revealed that in the paint layer iron based pigment is always associated with silicon & aluminum. This leads us to think that the pigment is always linked to kaolin, which was probably used as binder for paint layer along with animal glue as peaks of proteic material is also observed. The SEM-EDS analysis also confirms the succession of layers in Ajanta paintings and throws lights about paintings technique.

From the analysis of sample of cave no. 1, a very minute variation in preparation of surface application of color was noticed. The preparatory layer in contact with the basaltic support rock was made with mud mortar (I) containing ferruginous silicate material as well as vegetal fibers and probably organic binders such as glue. A sufficient quantity of these organic substances has not remained in its original state enabling it to be characterized by FTIR as they have now been transformed into calcium oxalate. The preparatory design was probably carried out directly on the preparatory layer (I) with red ochre, traces seen under FTIR. A thick and compact layer of kaolin mixed with probably proteic organic binder was applied on the preparatory design. The layer of lapis lazuli was applied on kaolin layer using some organic binder which has now transformed into calcium oxalate. Form the careful observation of pigment layer of cave no.1 under microscope; it is also observed that at least 2-3 layers of pigments have been applied in succession at some points probably to get depth and impression in the very important painting.

Figure 11 shows one such view where inner pigment layer are seen due to the loss of fraction of outer pigment layer. Perhaps, the reasons for application of succession of pigment layers is to get very good depth to the paintings.

From the analysis of mud mortar layers of various caves it is observed that low clay soil containing silt as major part was universally chosen for Ajanta mud mortar. The soil was mixed with celendonite, quartz, mica etc. as aggregate and the mud mortar prepared. The proportions remained almost identical in all the caves denoting the use of similar technology and similar raw materials.

Fig. 11. View of inner pigment layer due to loss of fraction of outer layer, cave no.1, Ajanta

The new mud mortar applied during consolidation at Ajanta about 15 years back stood the test of time and perfectly integrated with the original mud mortar.

Conclusions

Analysis of mud mortars and its composition reveals that there are no changes either in composition or technology of preparation of mud mortar and execution technique of murals at Ajanta supporting the short chronology. The investigation showed that the organic binder has invariably been used in the preparation of mud mortar of Ajanta in accordance with ancient text which might have now transformed into calcium oxalate, observed through FTIR images. The mortar is also found mixed with organic additives such as rice husk, plant fibers and seeds for re-enforcement. With minor variations, almost similar technology was used for the preparation of mud mortar and pigment layers were also found mixed with organic binder and sometimes with kaolin as per ancient text. With minor modification, the technique of painting at Ajanta remained almost identical and the pigments used are always natural mineral colors. All the pigments are of local origin except lapis lazuli which was probably imported from Persian countries through trade on silk route. The studies are of great importance in planning future conservation measures of Ajanta murals and understanding of execution technique.

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