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CHEMISTRY OF PRESERVATION OF THE AJANTA MURALS

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Abstract

Dated between 2nd B.C. and 6th A.D., Ajanta hosts exclusive paintings of tempera technique on a mud/lime plaster, in India. After its discovery in 1819, Ajanta attracted hoards of eager copiers, who applied many kinds of varnishes to brighten the colour enough to copy the paintings, thereby causing a long term impact on pigments and plasters. Many physical-chemical conservation measures were also carried out by international/Indian conservators to evolve and develop a suitable methodology for painting conservation. After taking over in 1953, the Archaeological Survey of India gave highest priority and setup an expert panel to regulate and suggest ways and means for the preservation of the Ajanta murals. The work carried out at Ajanta by various agencies are scattered and to the present day conservators are not fully aware about all of them. Since, all previous conservation measures had a direct impact on the state of conservation of the Ajanta murals, compilations of all works, done by a literature survey, were needed for the benefit of conservators, so as to understand and develop an appropriate, newer methodology. The measures adopted ever since the discovery of Ajanta, up to the end of the 19th century are listed.

Keywords: *Preservation; Tempera; Coarse plaster; Mud plaster; Ochre; Fumigation.*

Introduction

In 1829, the first description of the caves appeared in the transaction of the Royal Asiatic Society, Bengal and members of the society were so impressed by the discovery that they addressed the Director of East-India Company for the preservation of those caves and the execution of copies of the fresco. Graham Gill, an artist attached to the Madras army, worked for 27 years (1844-1871) to make copies of the paintings. In 1866 the entire collection was supervised by Graham Gill, except for five, that burned in the crystal palace fire, in London. John Griffiths of Bombay school of arts was subsequently deputed, along with his students, who from 1875 to 1885 made copies of the paintings. On June 12, 1885, in the Victoria & Albert museum fire, in London, 85 of the 125 paintings of Griffiths were lost. In 1896, J. Griffiths was again back to Ajanta and managed to recopy enough paintings to publish a book: "Painting in the Buddhist Cave at Ajanta". From 1906 onwards, Lady Harrigam, the wife of a London physician, worked for three seasons and the result of her successive visits was the sumptuous volume entitled "Ajanta Frescoes", published by the India Society in 1915. In 1918, the

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Japanese copiers Prof. M. Sawamura and painter Kampo Arai of Kyoto University were noticed by Mr. Mukul Dev making copies of Ajanta. Probably, the most monumental work on Ajanta is the four volume work of Gulam Yazdani [1], giving most comprehensive documentation, illustrations and narration of the story of Ajanta.

Methods for copying the paintings

Kampo Arai, who was associated with the copying of the Ajanta paintings, visited India in 1916 to teach Gurudev Rabindranath Tagore Japanese calligraphies. He wrote about his experience and works at Ajanta. A copy of his writings was made available to the author by Prof. Tadashi Sasaki, Dept of Art, Hiroshima City University. Kampo Arai [2] wrote: *"We used lamp for lightening. We thought of placing a Japanese paper on the wall foroge-utsushi (method used by Japanese painters to produce a copy) but it was very dangerous as the wall will fall if we touch it. We put Japanese rice starch glue on tip of a stick and press carefully to the wall to stop from falling and once we make sure that the wall will not fall, we place the paper on the wall. It will be so much easier if we glue it directly on the wall but we were concerned not to harm the wall. The reproduction was to create exact copy of the present state condition. The cave was filled with bad smell of bats droppings and level of unpleasantness was quite unbearable. The reproduction copies were stored at the Tokyo Imperial University but had been destroyed by fire during Taisho earth quake"*

Kempo Arai [2] further wrote: "*When the British conducted their reproduction activity, they covered entire wall surface with varnish which made the surface greasy and rather unpleasant appearance and changed colour of the paintings from the original*". K. Arai painted some of the figures on gold folded screen after his return from Ajanta. Some of the paintings of K. Arai are reproduced below for specialists and art lovers (Fig. 1). It is worth mentioning that in 1916 the gaps and lacuna in the copy of Mr. K. Arai were clearly visible as fixing/filleting work at Ajanta were carried out in 1920-21 onwards by Italian conservators during the period of Nizam of Hyderabad. During the course of copying the paintings, Griffits [2] applied varnish with the double aim of brightening the colours and as protection against dampness. Maindron [3, 4], during his visit to Ajanta in 1884 observed that the varnish flaked off from all parts carrying with it the paint. In 1919 A. Foucher [5] quoted that varnish and smoke has done so much to darken the colour.

Three principal causes of the ruin of paintings were ascertained by the Italian restorers of 1920-21 led by Prof. L. Cecconi [7] as following: the insects generated by vegetable matter mixed in the mud plaster; percolation of rain water along the surface of the rock wall and roosting of bats along the edges of ceiling and wall with the paintings.

Based on the above, the Italians devised a scientific method of treatment for the paintings which is fully explained elsewhere [6]. For the removal of the old dark varnish, the Italians tried alcohol, either alone, or with turpentine. L. Cecconi [7] also favored the use of very diluted caustic soda, alcohol and few drops of hydrochloric acid. Although he never tried ammonia before, he found that it worked satisfactorily at Ajanta. Cecconi's method also consisted of liberal use of shellac in alcohol, or gum dammar in turpentine as fixatives of pigment. Where the color was seen to be peeling off, a very dilute solution of gum dammer was applied until the pigments were fixed.

Fig. 1. Paintings of a Japanese artist (1916): a – Cave 1 Buddha wood print, b – Cave 1 Standing Buddha, c – Cave 1 Great Miracle; d – Cave 1 Ceiling decoration; e – Cave 2 Jataka Notes, f – Cave 2 LHS Wall; g – Cave 10 King Procession; h, i and j – Cave 10 Standing Buddha

Finally, the surface was gently pressed down with a spatula. For fixing detached patches of paintings, L. Cecconi used the following methods:

- Injection of casein in lime where the gap was narrow;
- Filling with plaster of Paris or lime, fine pozzolana where the cavity was large;
- Fixing of copper nails in dangerous parts for supporting the coarse plasters (Fig. 2);
- Strengthening of the plaster by sticking strips of linen on the surface with hot gelatin and removal of the linen by means of hot water, after the parts were secured to the wall;
- Liberal use of unbleached shellac, dissolved in alcohol for general preservation.

Major structural conservation measures, in the form of improvement of drainage and other protective measures were also executed during that period. Five drains to cope up with a run off of 4 inches per hour of rain water, with a slope to develop a velocity of 4 to 6 ft per second were constructed on the top of the cave. A zinc drain was also inserted in the inner aisle of cave no 1 to drain out water from the important paintings of Padmpani & Vajrpani.

Fig. 2. Painted figure with Copper Nails, Cave No. 17

Scientific conservation of the paintings by the Archaeological Survey of India

During the post independence era the Archaeological Survey of India took charge of the Ajanta cave paintings as a monument of national importance. In 1930, S. Parmasivan [8] did some pioneering work on the mural paintings of India by studying the paintings of Ajanta, Sittanavasal, Thanjavur, Lepakshi etc. mainly with the aim to identify the technique of paintings. The grounds of the mural paintings at Ajanta and in some cases at Ellora are composed of mud plaster prepared by mixing ferruginous earth, organic matters, rock grit and sand. S. Parmasivan [9] observed that the organic matter and combined water varies from 1 to 14% which is derived mainly from the fibrous material of vegetable origin in the plaster. A microscopic examination of the painted stucco made by S. Parmasivan revealed that the ground of the paintings at Ajanta/Ellora consisted of 3 or 4 layers of plaster having 2-3 joints between them. The thickness of the paint film is generally 0.1 mm at Ajanta and 0.3 to 0.6 mm at Ellora. The thickness of lime plaster at Ajanta is about 0.1mm. Dr B.B. Lal [10] during his work at Ajanta reported the thickness of lime plaster in the range of 2-3mm. Table 1 shows the thickness of painted plaster at Ajanta.

Table 1. Thickness of various layers of painted plaster at Ajanta (mm)

	Dark red plaster	Light red plaster	Cave II	Cave VIII	Cave XVI
Painted stucco	9.5-54.3	37.47	9.5-54.3	9.5-54.3	9.5-54.3
Rough plaster	9.3-54.1	6.8-46.8	9.3-54.1	9.3-54.1	9.3-54.1
Fine plaster	0.1	0.1	0.1	0.1	0.1
Paint Film	0.1	0.1	0.1	0.1	0.1

S Parmasivan [9] stated that the wide variation in the thickness of rough plaster (9.3 to 54.1 mm) was due to the uneven nature of the carrier. Based on Stroke's law Parmasivan also graded the size of particles in the rough plaster of Ajanta as shown in Table 2.

Table 2. Particle size in the rough plaster at Ajanta

Size of particles	Dark red Cave II	Light Red	Cave VII	Cave VIII	Cave XVI
200µ	16%	57%	75%	40%	47%
200µ-700µ	33%	29%	24%	40%	47%
700µ	51%	14%	1.0%	20%	6%

The data above indicate that the smaller particles in the mud plaster, (less than 200µ) are composed of clay, fine particles of silica and laterite, while the larger particles are mostly silica and laterite.

S. Parmasivan [8, 9] also carried out a detailed analysis of mud plaster samples from Ajanta [11]. The chemical analysis found that the organic matter was mostly due to presence of large quantities of vegetable fibers and paddy husks. The percentage of lime found during analysis was also quite low and present in the form of impurities only. Iron oxide, lime and silica were reported as inert material in the mud plaster. Parmasivan chemically examined the layers of fine plasters. According to him lime plasters, after separating them from rough plasters and the paint film, was treated with dilute hydrochloric acid, which dissolved the fine plaster with efflorescence, with carbon dioxide emission. The solution gave positive test for calcium and traces of sulphate, indicating that amixture of lime and calcium sulphate was used as lime plaster over the rough plaster. According to S. Parmasivan [8], calcium sulphate is present as an impurity in the lime. Although Parmasivan's analysis [9] generated lots of information about the characteristics of mud plaster, in the light of physical appearance and stability it has now been subjected to further analysis by NDT techniques, with many astonishing facts emerging about the mud plaster that will be elaborated and discussed in our next paper.

Pigments and Colours

During the past decades the analysis of pigments has drawn the attention of several restorers of mural paintings. S. Parmasivan in 1939 [9], B.B. Lal in 1967 [10] and H.C. Bharadwaj in 1983 [11] have tried to identify the pigments used at Ajanta-Ellora. It was reported that the pigments and colors used at Ajanta-Ellora were of mineral origin with the exception of black (lamp black). Painters of Ajanta used lime and white clay (kaolin) for white, carbon (soot) for black, yellow ochre for yellow, red ochre for red, gluconate or terraverte for green and lapis lazuli for blue. All the pigments viz. white, red, yellow and green are residual products of the volcanic rock. They are locally available except for Lapis Lazuli, which seems to have been imported, because of its absence in the neighborhood [10, 12]. According to B.B. Lal [10], there is no evidence of any use of copper compounds (viz malachite) for green and azurite for blue. Terraverte, which is minerally called gluconite, is a green complex of ferrous silicate, which is a secondary product of the basalt. There is no scientific data on the analysis of pigment samples from Ajanta-Ellora. However, an attempt is now being made in that direction. The identified pigments at Ajanta by Paramasivan [9] are shown in Table 3.

Table 3. Pigments of Ajanta

Cave No	Pigments
II	Yellow ochre Red ochre Carbon Lime& Calcium sulphate Terraverte Lapis Lazuli
XVI	Terraverte Yellow ochre

The pigments of the Ajanta paintings are easily softened by water. They show the existence of water soluble binding medium in the paint layer. B.B. Lal [10] expressed the proof after the existence of glue or gum as the binding medium in some of the caves at Ajanta. According to him animal glue was probably employed for that purpose. S. Paramasivan [8, 9] mentions the possibility of the glue or casein. Identification of the binding medium forms a high priority research area at Ajanta.

The problem of preservation of mural paintings can only be solved by a systematic scientific study of materials and the techniques employed in their execution. Paintings are layered structures; however, complex stratified structures cannot be attempted without isolating the different layers. The micro-sections of such painted layers are easier to examine. Their examination involves the preparation of a sizeable number of cross sections of the painted stuccos. The technique was successfully employed by M.S. Mathur [13] in the study of mural paintings of Ajanta-Ellora, both at Institute Royal Dupatrimonie Artistique, Brussels, Belgium and at the Archaeological Survey of India laboratory, at Dehradun. Such cross sections can also be used for the identification of pigments and binding media, by conducting micro spot tests on the polished surface. M.S. Mathur [13] did extensive experiments with Hylak polyester resin for cross sectional studies of mural paintings at Ajanta.

A typical formula used for preparing the cross sections of the wall paintings is as follows: 50 g of Hylak resin HSR 8151, 0.75 g of Catalyst Q 8011, 0.25g of Accelerator Q 8021 for 6h at 28°C.

The method proved of great help not only in determining the stratigraphy of the painted layer but also of the structure of paint films. It is, probably particularly suitable for determining the technique of painting adopted in the execution of various murals, as well as the movement of pigments by diffusion. How the surface accretion affect the painted surface and cause defects in the paint film can also be ascertained by such examination. Once the behavior of the surface accretions is accurately known, the chemical treatment of the painting can be carried out with confidence and, hence, it is essential that a diagnostic process, based on cross sectional examination of murals, is adopted before any chemical treatment. When the Archaeological Survey of India started work in 1954 at Ajanta, one of the first tasks was to remove the shellac coat that had turned yellow or even dark brown, masking the original color of the paintings. It was imperative to formulate a suitable mixture of solvents effective for the removal of shellac.Based on long thorough experimentations, a useful mixture was found suitable: acetone - 1 part, diacetone alcohol - 4 parts, amyl acetate - 1 part, cellosolve - 4 parts and morphline – a few drops.

Turpentine or petroleum spirit was used as a restrainer. The coating material removed with cotton swabs during cleaning showed the presence of mastic and, in some cases, copal varnishes in addition to shellac. These varnishes were probably applied by the many previous copiers of the paintings. The Italian restorers of 1920 were not able to completely remove this earlier varnish coat before their own application of shellac. Due to repeated applications of varnishes in the past, some of the materials seeped into the cracks. Initially, during the chemical cleaning work when the solvents were applied, the coating on the surface was removed and the paint layer seemed to have regained its original look. However, in a few days time a thin, whitish deposit, called chalkiness appeared on the cleaned surface of the paintings. The conservators / restorers had to face a lot of criticism after the appearance of chalkiness, as loss of pigments was feared, as a result of their cleaning. It was a matter of great challenge to the chemists to explain the appearance of chalkiness on the cleaned surfaces and hence an examination of paint samples under cross section was felt necessary. For this purpose, a small paint sample from the cleaned portion was mounted in polyester resin and that cross section was examined under the microscope. The pigments were found to be intact and the whiteness was found to be only a superficial deposit. It was revealed that whiteness occurred because of the break down of particles of shellac, which was no longer a cohesive film transmitting light. When the last trace of varnish was removed and the cleaning was complete, the chalkiness no longer appeared. During the course of works it was also found that Di-methyl formamide was most suitable in the removal of copal varnishes.

Insect wax, oil, greases, tarry matter and smoke present extremely difficult problems of removal and extensive field trial and laboratory test have to be carried out to develop satisfactory techniques for the elimination of those accretions. The choice of a suitable solvent or a mixture of solvents is extremely important for a successful elimination of the accretions. Cleaning is undertaken only after experimenting with the solvents in an inconspicuous corner of the painting, to ascertain their safety and effectiveness. In some cases, it becomes necessary to remove the accretions by using reagents that react chemically with it. The use of amines, like butyl amine, for the removal of oil and greasy matter is one example. Nevertheless, mild basic substances can be used in required cases. Acids, even the weakest ones are completely ruled out, because of their high reactivity with materials in the paintings. During experimentation, it was also noted that the rate of evaporation is an important characteristic governing the choice of solvents. While very volatile solvents evaporate too quickly and may not get enough time to react, those with high boiling point tend to remain in contact with the surface too long, which is also not advisable. Those with medium range boiling point are most suitable. Grease and oil matter is generally removed with solvents like benzene and toluene. For thicker deposits, hardened with age, N-Butyl amine or cyclo- hexyl amine is used in 5% with diluents, natural solvents, like petroleum spirit. The traces of amines are removed by solvents after cleaning. Waxes can be removed with the help of tri-ethanol amine or carbon tetrachloride. For the removal of soot from the paintings, tri ethanol amine mixed with other neutral solvents was found suitable, but they have to be used by very experienced hands, with lot of care and precautions, taking due care not to lose any grain of black outlines, black colors of the original painting, which are also carbon based. As the characteristics and adhesion of black pigments differ with sooty accretions, an experienced conservator can easily confine the action of solvent to accretions without in any way affecting the black pigments. Chemical cleaning of the paintings show that, in the long run, the experience and dexterity of conservators are more decisive than the techniques adopted in cleaning. At the end of the cleaning, all traces of tri-ethanol amine are removed with toluene and subsequently the area is flooded with restrainers such as turpentine.

Sometimes, it was found that the paint surface was too fragile to be cleaned by normal methods. In such cases a filter paper sheet, soaked in the solvent mixture was applied over the surface and kept in contact for about 10 minutes. The sheet was covered with tin foil to slow down the evaporation of solvents. When the filter paper sheet was removed at the end, it was found to have absorbed the dissolved varnishes. After the surface has dried, a second application may be made and the process is repeated until cleaning is complete. In some places, particularly the upper portion of the wall, the white deposits occur, due to remnants of bat droppings. The Italian restorers did not succeed in removing completely the droppings of bats. The shellac coat merely masked them. A combination of extremely carefully mechanical methods and a selective use of alcoholic ammonia solution (5%) was successful in removing those deposits. In rare cases, there may be accretions containing insoluble salts, which are not amenable to any of the normal method. A typical mixture which gave good results is: ammonium bicarbonate: 30g; sodium bicarbonate: 50g; desogene of 10% strength: 25 g; carboxy methyl cellulose: 6g; distilled water: 100mL.

When accretions are sulphated, they are likely to be converted to soluble ammonium sulphate by bicarbonates. Desogene (Quaternary Ammonium salt) acts as surface-active agent as well as powerful disinfectant against microorganisms. CMC give a paste like consistency to the mixture and ensure a moist condition for a longer time for reaction with the incrusted surface.

For the preservation of chemically treated painted surfaces, polyvinyl acetate in toluene, ethylene-di chloride and ethyl alcohol mixture was employed in 1-2% strength. Poly methyl methacrylate was limitedly tried, as it was found that under the tropical conditions, prevailing at Ajanta, it may tend to become insoluble, after exposure to the atmosphere. In view of that and to its marked tendency to attract dust, it was also not employed in the fixing of the pigments. Instead, surface impregnation with thin dilute solution of poly vinyl acetate was carried out.

Biological degradation of murals

It is estimated that nearly one fourth of the paintings were lost due to insects which live in the rough plaster of the painted surface, where food is available in plenty due to organic matter present in the plaster [14]. Out of all the insects, a silver fish called Lepsima Saccharina caused most of the damage to the paintings. Silver fishes live to a large extent on carbohydrates such as starch and dextrin and are said to be able to digest certain forms of cellulose. They also thrive on small amounts of proteins (from the dead insects) and gum or glue used as binding media in wall paintings. Silver fishes are nocturnall and generally live in damp plasters and come out at night for food. In dark areas of caves, they sometimes emerge out in the day and carry out their damage. An experiment on the east wall of cave no 1, Ajanta was carried out, were the painted layer was found infested with numerous small holes. A filter paper, coated with flour paste was placed on the painted surface and after three-four days the paper revealed the feeding marks of the silver fish. It is often possible to get rid of silver fish by creating warm and dry conditions, unfavorable to them. But such an exercise is not possible in caves and even more so in painted caves. Hence, in the beginning, a solution containing 5% DDT was applied trough the cracks and crevices in the wall paintings, which resulted in the control of the silver fish. A test conducted by M.S. Mathur [13] with 6% by weight D.D.T, sprayed in petroleum distillate, controlled silver fishes for four months. Mathur also carried out an experiment with carbon disulphide vapours in caves, with success in the eradication of silver fish. The use of sodium fluoride or pyrethrum powder, or a mixture of the two in the form of dust was usually recommended for the control of silverfish. Those dusts can be shot behind the plaster through holes and cracks. Pyrethrum dust adheres to the mouth and hairs of silverfish and paralyzes them within 3 to 10 minutes. Sodium fluoride acts as a slow, but long-lasting toxic agent. However, initially those dusts were found effective on the walls with thick plasters under the paint layers at Ajanta/Ellora Caves. M.S. Mathur [13] succeeded in killing the insects present in the deepest layers of plaster by Gamma radiation, without any damage to the surface of the paintings. But it was not possible to remove the effects of radiations from the surface , as it was quite dangerous for the operators and, hence, further experiments were abandoned at that stage.

An expert committee on Ajanta was established in 1971, to suggest ways and means for the preservation of the Ajanta paintings and to monitorthe chemical conservation works. Dr. R. Sengupta, the then Director (Conservation) reported a lot of insect activity in 1981 in the caves and the matter was filed to an expert committee. On the recommendation of the expert panel, the cells of cave no. 1,2,16 &17, devoid of paintings, were given insecticidal treatment, with pyrethrum, mixed with mar vex, pine oil and kerosene. The mixture was sprayed on the wall, ceiling and floor of the cells twice in a month. Spraying of 2% pyrethrum extract in kerosene was regularly carried out in unpainted areas of the caves. During the course of time, in the year 1997-98 , it was noticed that most of the silver fish migrated from the river bed through pathways to the caves and also from cave to cave through the openings of windows ,doors etc. Hence, it was decided to eradicate the insect menace at the entrance point. Regular spraying of insecticides, 2% pyrethrum extract in kerosene, was carried out since 1981 twice a month. From 1999 onwards the pathways and junctions of adjacent caves were regularly sprayed with pyrethrum extract and the result was very encouraging. During the fumigation of Caves 16 and 17, in Feb/ March 1999, no silver fish was noticed, in contrast to the fumigation of cave 1 and 2 in Feb/March 1998. Therefore, regular spraying of pyrethrum was being carried out on the unpainted part of the cave, along with the path ways at Ajanta (Fig. 3).

Fig. 3. Showing the fumigation of the Ajanta Caves

In the year 1985, at the right side wall of cave no.2, a number of 26 insect holes was recorded in an area of 1 sq. feet. The expert committee then decided that more spraying of insecticides was not sufficient to eradicate the insect activity. Hence, for the first time, Cave no 2 was fumigated with ethoxide gas by the Pest Control of India in 1985, but the result was not satisfactory. The reason stated for that failure was the recommendation of the National Archives, New Delhi, for a 3.6 lbs pressure per 1000 cubic ft of the space within the caves. Based on those results, the Pest Control of India recommended 10-75 Lbs per 1000 cubic ft pressure, with a 36 hours exposure. However, subsequently 70 gm of E.O.T. gas per cubic meter of volume was taken as standard value and all subsequent fumigation works were carried out at thas pressure, with a 36 hours exposure. A chronology of fumigation carried out at different caves at Ajanta is listed in Table 4.

Table 4. Chronology of Fumigation at Ajanta

Year	Cave Number
1984-1985	2
1986-1987	16 & 17
1993-1994	17
1994-1995	1 & 2
1995-1996	6 & 17
1996-1997	6,11 & 22
1997-1998	9,19 & 20
1998-1999	1 & 2
1999-2000	16 & 17

Surprisingly, during the fumigation of Caves no. 16 and 17, in 1999-2000, no silverfish was noticed within the caves, probably due to the intense spraying of pyrethrum around the caves, so as to stop the migration of insects. In France, it was reported that the green infection noticed on paintings was caused by bacteria carried on the shoes and sweat of visitors. In 1970, a question arose, whether such an infection also existed at Ajanta. To find out the answer to the query, a preliminary survey of the air spore and bacterial infection at Ajanta/Ellora was done. Microorganisms develop on the paintings if there is high a humidity, around 70 %, and in the presence of organic materials, such as the vegetable fibers present in the plaster The paint layer is also not immune to biological attacks, as ochre and lamp black are severely attacked by micro organisms. The binding medium gum/glue can easily succumb to the action of biological agents. Dust and dirt collected on the paintings absorb moisture and, in turn, they absorb microbiological spores. Bats excreta provide nutrients and a carrier for microorganisms. At Ajanta, cave no 1, 16 and 17 were selected to study the air spores both inside and outside the caves. Results show [15] that fungal spores inside the caves varied and are more numerous than outside the cave. The spore types, such as Aspergillus, Curvalaria, Cledosporium, Ascosporous etc., are common in all the caves, which suggest some Ceprophilous fungi predominate in the decomposition of paintings. Moreover, the eradication of bats from the monuments of Ajanta /Ellora was discussed with the Director, of the Punjab museum, Chandigarh and based on his suggestion, the following chemicals celphes (II) and Ethylene di-bromide were used for their eradication.

Consolidation of painted plaster

The painted plasters were found to have suffered considerable degradation, as a result of the adverse effects of the unfavorable environment, with wide fluctuations in relative humidity and temperature inside the cave. In the course of time, the plaster lost it hold to the rock surface. The pigment layer itself was found to have become very dry and it showed a tendency to peel off. The degradation of plaster and paint layer was slow and progressive through the centuries, as they remained exposed to an unfavorable environment for the last 1500-2000 years.

The environmental fluctuations brought about a loosening of the painted plaster, flaking of the pigment and the development of fungal growth and of insects. As a result of prolonged desiccation, the color developed a tendency to flake off and the paint layer became friable and powdery, due to its alteration, decomposition and the disappearance of the organic binding medium. While working on Indian mural paintings, it was observed that the best consolidator used from the beginning of conservation in this country, was the plaster of Paris. The earliest use of that material was by L. Cecconi [7], in 1920-21, who used plaster of Paris, mixed with a little cement, in the consolidation of the Ajanta paintings. The areas consolidated by him are in a good state of preservation. Plaster of Paris is attacked by water and, hence, its use was stopped in countries with high humidity. At present, many European countries use different doughs andclays as fillers and P.V.A. as adhesive, for the preparation of filleting materials. But POP withstood the Indian climate well.

In many places, plaster of Paris was exclusively used . Dr.B.B. Lal [10] reports the use of POP in the famous cave of Bamiyan, in the year 1930-32, by a French team,It is white in color and does not match the colour of the surrounding plaster and painted layers. These days POP is used mixed with earth color, to match the surrounding. M.S. Mathur [16] worked the following standardization for edging and filleting of murals. The standard mixing proportion is listed in Table 5.

Table 5. Standard mixing proportions for filleting works

	Colour	Proportions
1	Light grey	10.00 g POP + 2.00g black colour
2	Dark grey	10.00 g POP + 1.00g black colour
3	Light yellowish grey	10.00 g POP + 2.50g yellow ochre + 0.50g black colour
4	Yellow Indian red	10.00 g POP + 2.00g yellow ochre + 2.50g Indian red.
5	Light Indian red	10.00 g POP + 2.50g yellow ochre + 2.00g Indian red.
6	Burnt sienna	10.00 g POP + 2.50g Indian red + 0.50g black.
7	Brown	10.00 g POP + 2.00g Indian red + 1.00g black.
8	Light Brown	10.00 g POP + 1.50g Indian red + 1.00g black.
9	Dark Brown	10.00 g POP + 2.50g Indian red
10	Burnt umber	10.00 g POP + 2.50g Indian red + 1.00g yellow ochre + 1.00g black
11	Red	10.00 g POP + 4.00g Scarlet.
12	Light Red	10.00 g POP + 2.00g Scarlet
13	Prussian blue	10.00 g POP + 4.00g Prussian blue
14	Light blue	10.00 g POP + 0.02g blue
15	Black	10.00 g POP + 5.00g blue

Fixing/filleting works were continuously carried out to 1987 including on the ceiling of the cave no 2, in the years 1984-85. In the years 1989-91 filleting work at Ajanta caves was temporarily halted for want of suitable replacement of plaster of Paris. However, during this period neither the filleting work could be undertaken nor any replacement material was suggested by the expert authorities, which could have meant loss of pigment and plaster. The mater was reviewed in the years 1991-92 and the work was continued.

Chemical Preservation

The cleavage, faults and cracks in the body of the rock give rise to a system of channels for the rain water to seep through and, water being an excellent solvent, it gradually and systematically washes the painted plaster and creates damp conditions. Much dampness was noticed in the cave no 1 north aisle, with the famous paintings of Padmapani and Vajrapani and, hence, this cave was selected for our measurement of moisture content in the stone, as well as in the plaster, in the year 1980. For moisture analysis of rocks, a number of holes, at the depth of 6 cm, in the cells of the cave no 1 were made in 1980 and each was given its number for identification. A survey of the data show maximum and minimum readings of moisture in the rock, as shown in Table 6.

Table 6. Maximum/Minimum of moisture in the rock at Ajanta

April	1980	1%-2%
May	1980	1%-2.2%
June	1980	1.2%-3.2%
January	1981	1.41%-2.09%
May	1982	1.40%-1.85%

The measurements of moisture in the rock of cave no 1 continued up to the year 1986. A copy of the data sheet was also submitted to the Chief Engineer, C.P.W.D, Vidyut Bhavan, New Delhi [17]. The usefulness of this data and inferences drawn for conservation measures have not been mentioned anywhere. However, the number of holes made in the cells of cave no 1 gave it a very ugly appearance.

Moistures analysis of plasters in the unit cell of cave no. 1 at its North wall, East wall, West wall and ceiling was also carried out in December 1980 and January 1981 and that data was also compiled and sent to the chief engineer Vidyut Bhavan, New Delhi for reasons still not known. Some of the data on moisture analysis of plaster is presented in Table 7 for the benefit of conservators.

Table 7. Percentage moisture in the mud plaster at Ajanta (%H_2O_h)

	Location	Date	Surface layer	Middle layer	Ground layer	Surface rock
UNIT 9	North wall	15/12/80	-	2.04	4.47	1.42
	Ceiling	15/12/80	1.90	2.26	5.77	1.70
UNIT 22	East wall	16/12/80	2.07	2.27	5.65	1.91
	West wall	16/12/80	2.04	2.14	4.90	1.45
	Ceiling	18/12/80	2.38	2.37	5.31	1.77
UNIT 24	Ceiling	18/12/80	-	2.25	4.73	1.56
	West wall	05/01/81	-	2.14	4.57	1.26
	North wall	05/01/81	-	2.18	4.88	1.60
UNIT 27	Ceiling	09/01/81	1.96	2.20	4.80	1.70
	North wall	11/01/81	1.74	2.05	4.35	1.37

A workshop was held in February 1983 to discuss problems of conservation of paintings, methodology and new trends and techniques in the field and some representatives of Rome Centre for Conservation also participated. In the year 1983, a Yugoslavian expert performed some drastic cleaning with ammonium carbonate, using paper pulp techniques in cave no 17. The spots developed too much chalkiness and figures were no longer visible. That area was re-cleaned by A.S.I conservators and the mistakes rectified. A similar demonstration of cleaning was done by Laura and Paulo Mora [18] at the Ellora caves, which later also developed chalkiness.

Loss of white pigment from the ceiling of cave no. 2 was an important development pointed out by the Director (Science) in his inspection in the year 1993. Initially it was proposed to apply a very thin preservative coat of polyvinyl acetate (0.5% two coats) so as to consolidate the white pigments with the wall. For this purpose, the ceiling of the east aisle was treated first . During the course of work it was noticed that the ceiling had very thin accretions of soot. Hence, it was felt essential to remove the soot accretions before application of any preservative coating. However, intense black outlines and black pigment in the paintings was noticed in this case. As the chemical composition of soot and black pigments are more or less the same, it was feared that any application of solvents may also harm the original black outlines of the paintings. However, marked contrast was noticed in the adherence of soot to the painting layer vis-a-vis the adherence of the black pigment to the ground and this characteristic difference of stability was exploited for conservation works [19].

During the course of works, it was also noticed that the solvents recommended after long experimentation for the removal of soot are being absorbed by the painted surface at a very high rate. As such absorption of organic chemicals is not advisable in the long run and it may probably be one of the reasons for the frequent appearance of chalkiness on the paintings, necessary corrective measures were taken in that regard for scientific cleaning works at Ajanta. The partly cleaned painted surface of cave no. 17, at pilaster of Ajanta, is shown in Figure 4.

Fig. 4. Partly cleaned painted surface of cave no 17, pilaster of Ajanta

Temperature and humidity

Of the various environmental factors affecting the degradation of the Ajanta caves painting, the single most important one is the humidity inside the caves. Archaeological Survey of India is maintaining records of temperature/humidity of the painted caves 1, 2, 16 and 17 at Ajanta. A chemical conservation laboratory was established at Ajanta in the year 1976 specifically to look into the conservation needs of Ajanta paintings. The data for relative humidity from 1995 to 1998 was complied so as to know the average variations of humidity inside the cave. From figure 5 it is inferred that the average R.H. in cave no. 17 inside is 70 % in the month of September, whereas from figure 6 it is observed that the average R.H. outside is 77% in the same month. Similarly the average R.H in the month of March is 30 % inside the cave 17 and 21 % outside the cave 17 in the same month. Hence a 40% variation in humidity is noticed inside cave no 17 in different seasons, which is one of the most important factors in the peeling of paint.

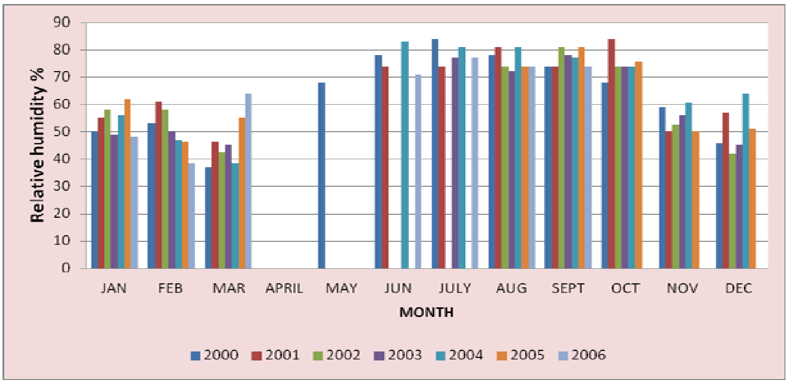

Fig. 5. Relative Humidity Inside Cave No 17

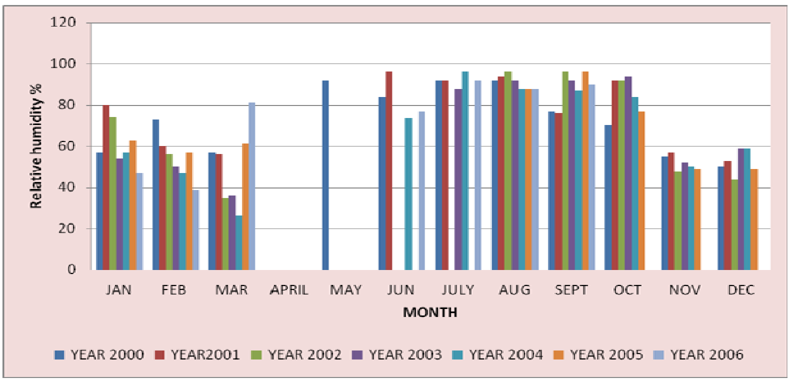

Fig. 6. Relative Humidity Outside Cave No 17

The maximum and minimum relative humidity for the year 1995-98 was also marked for cave no. 1 and as per the data, the maximum humidity is 80% in September and 30% in March inside the cave. Thus, a variation of 50% in relative humidity is a big factor for the degradation of paintings. From the data it is also seen the that minimum humidity is 62% in September and 20% in March, inside the cave no. 1. All the data compiled from 1995-98 is represented in a graph for the benefit of the readers and also to understand the contribution of humidity to the peeling of pigment/plaster layers at Ajanta.

Illumination of Mural Paintings

The inadequacy of natural light inside the caves hampers a proper appreciation of the artistic merits, as well as the color scheme of the paintings. Furthermore, the most beautiful of the painting near or around the Buddha chamber in all the caves are the least illuminated. It seems that the monks must have supplemented the feeble daylight with lamps and reflectors. Today, however, with thousands of tourist visiting the caves, artificial light is obviously necessary.

In 1930, when the Ajanta caves were in Hyderabad state, the visitors were shown the caves by a guide holding a portable tungsten lamp of 500 to 1000 watts, mounted on enamel reflectors of 24 cm in diameter and keeping them a few meters away from the paintings. Where the paintings were very dark, the lamp used to be taken very close to the wall. The heating effects of such a system on the painted surfaces were investigated [20] with very interesting results. The data recorded in table 8 show a considerable rise in temperature on the painted surface produced by short exposures to light. In fact, the rise has been found to be as much as 0.3ºC to 5.6ºC following a short exposure. When the paintings are repeatedly exposed to such lights every day, the effect becomes quite damaging.

Table 8. Showing rise in temperature on the surface wall painting Ajanta

Cave no	Wattage of bulbs (W)	Distance of the surface of illumination (cm)	Temperature of painted wall before illuminations (ºC)	Temperature of painted surface after illumination			Rise in surface temperature		
				3min (ºC)	5 min (ºC)	10 min (ºC)	3 min (ºC)	5 min (ºC)	10 min (ºC)
17	500	50	31.4	32.2	33.1	34.4	0.8	1.7	3.0
17	500	100	32.2	32.5	32.8	33.6	0.3	0.6	1.4
17	1000	50	32.2	33.5	35.3	37.8	0.3	3.1	5.6
17	1000	100	32.2	32.8	33.1	33.3	0.6	0.9	1.1
2	500	50	32.8	33.4	34.4	35.0	0.6	1.6	2.2
2	500	100	32.8	32.8	32.8	33.3	-	-	0.5
2	1000	50	32.8	33.4	35.3	37.8	0.6	2.5	5.0
2	1000	100	32.8	33.1	34.2	36.1	0.3	1.4	3.3

(For light surface, tungsten bulb with enamel reflectors of 24 cm was used).

From the data it is inferred that the mode in which the temperature rises depends considerably on the nature of the painted surface. The paintings in caves no. 2 are brighter and colored, whereas those in cave no. 17 are much darker. In the case of cave no 2, there is a marked rise in temperature initially, followed by a less rapid rise thereafter. It seems that radiation comes into play when the exposure is prolonged beyond 5 minutes, as the rise in temperature after that period is not very steep, on account of a loss of heat from the painted surface, by radiation. In the case of the darker paintings of cave no. 17, the rise in temperature is at a uniform rate.

This method of illumination suffers from a number of drawbacks. Besides the formation of cracks, by expansion/contraction and efflorescences of trapped moisture in the paintings, the area of illumination is very limited and, therefore, the lamps have to be moved from place to place. The accidental breaking of a high wattage tungsten lamp close to a painted surface could cause material damage.

In 1964, a cave was lit experimentally with candlelight. It was seen that a single candle was sufficient to light cave 2 with 12 pillars and 3 candles for cave no. 17 with 16 pillars. The other precaution against damage to paintings by light is the use of ultra violet filters. Tungsten lamps have the advantage of not requiring ultra violet filters but the disadvantage of emitting excessive heat. Hence, florescent lamps, having the advantage of economy and low heat radiation over tungsten bulbs, were recommended at Ajanta Caves.

The caves 1, 2, 16 and 17 were illuminated by Philips Tungsten Comtalux bulbs (220-230V, 70W) placed approximately 2m from eachother, directly illuminating the paintings from a distance of approximately 1m from the painted wall. The direction and position of bulbs can be varied in the desired direction. The normal luminance measured is around 150lx and the maximum UV radiation is 0.1%. The lamps are meant to switch off whenever the visitors leave the caves. As such, the lighting system meets the technical requirements recommended for the museum, but it suffers from certain drawbacks. The paintings in the system are not illuminated uniformly, the on/off of the bulb is not monitored regularly, resulting in an increase in temperature on the part of the painting directly under the illumination of comtalux bulbs. The other shortcoming is the protection of the electric wirings, which are not safe for the visitors.

In the year 1987 Mr. Milan Korac [21], a Swedish Architect (Preservation of cultural heritage group) offered a prototype protective lighting system, which is a comprehensive system, both for illumination, as well as for protection of the paintings. This system is absolutely free from UV radiation. The system consists of a metallic lighting box made of aluminum, which has light fittings of special halogen bulbs, the intensity of which can be regulated with the help of dimmers controlled by transformers. The light is not directly focused on the painted surface but is reflected to the desired area with the help of mirrors. The UV radiation is completely filtered off by using appropriate filters mounted on the lights. A small box, fitted in the main lighting box works as ventilator, to circulate the air and draw out the heat from the lighting box. The lighting box can be fabricated to the desired length, as per requirement. The prototype system for illumination was installed in cave no. 17 anti – chamber, to illuminate the painting on the left wall. The intensity of the light was initially set in the range 20-40 lx and illumination was observed to be definitely better than the comtalux bulbs [22]. It has been observed that when all the walls are illuminated, the intensity of light in the range of 14-20lx will be sufficient to view and aesthetically appreciate the details of the paintings.

To evaluate the performance of the system, a study on the influence of the lighting system on the micro climatic condition of the caves, by measuring certain parameters, such as variation in temperature, relative humidity, illumination intensity etc. was carried out.[15] The light intensity measurement carried out at five different places on the painted surface was found between 15-20 lx. No variation in temperature and relative humidity was noticed on account of the installation of the illumination system. However, on the basis of a few draw backs in the design, the modifications suggested were: dust traps need to be provided near the inlet of the light box to prevent the accumulation of fine dust particles on the mirrors and inside the box. The arrangement for the mirrors needs improvement. However, the important painted caves no. 1, 2, 16, 17 and 19 are now illuminated with an optical fibre light system, absolutely free from heat.

Conclusions

This paper outlines a significant debate on the suitability of the application of shellac varnish as a preservative coating in a tropical climate, specifically for paintings executed on clayed mud plaster. Right from its discovery the development of conservation methodology and improvement of techniques helped in the conservation of the Ajanta murals. Any new conservation measures need to be planned keeping in view the earlier treatments carried out on painted surface and hence, it is imperative to know the past work, to plan any future intervention.

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References

[1] G. Yazdani, **Ajanta**, Vol. I –IV, Swati Publications, Delhi, 1983.

[2] * * *, **Annual Report of the Archaeological Department of Nizam**, Calcutta, 1923, p. 15.

[3] M. Maindron, **L'art indien**, Paris, Quantin IX, 314 S, 1898, p. 148.

[4] L.N. Owen, *Ajanta: History and Development: Painting, Sculpture, Architecture-Year by Year*, **Journal of Asian Studies**, **69**(1), 2010, p. 317-319.

[5] A. Foucher, **Annual report of Archaeological Department of Nizam**, Calcutta, 1919, p. 12.

[6] * * *, **The Annual Report of the Archaeological Department of His Exalted Highness the Nizam's Dominions**, Calcutta, 1920-21, p. 14-16.

[7] O.C. Gangoly, *The preservation of Ajanta Frescoes (Report of the restoration work of L. Cecconi and Count Orsini)*, **Rupam**, **18**, 1924, p. 97.

[8] S. Parmasivan, *Technique of painting process in the Kailasanatha and Vaikunthaperumal temples at Kancheepuram,* **Nature**, Vol. CXLVII, 1938, p. 757.

[9] S. Parmasivan, *Technique of painting process in cave temples of Ajanta*, **Annual report of the Archaeological Department of His Exalted Highness the Nizam's Dominions**, Calcutta, 1936-37, p. 25-30.

[10] B.B. Lal, **The murals: their preservation, Ajanta Murals**, Gosh, New Delhi, 1969, p. 56-59.

[11] H.C. Bharadwaj, Some Observation on the Conservation of Murals, **Conservation of Art and Cultural Property in India**, vol.1, 1966, p.37-46.

[12] S. Subbaraman, *Conservation of mural paintings,* **Current Science**, **64**(10), 1993, p. 736-753.

[13] M.S. Mathur, *Cross Sectional Studies of Indian Mural Paintings: A New Approach, Conservation of cultural property in India***, Proceeding of 3rd National Seminar, Vol. 1-5**, 1968, p. 10-14.

[14] R. Srinivasan, *Insects in the Ajanta caves*, **Current Science**, **101**(10), 2011, p. 1265.

[15] S. Tilak, B. Sharma, S. Sengupta, R. Kulkarni, *Deterioration and Microbiological Studies of Ajanta and Ellora Paintings***, Seminar on the Conservation of Cultural Property in India**, National Museum New Delhi, 1970, p. 77-82.

[16] M.S. Mathur, *Mural Wall Paintings: An Investigation into the Technique of Ground***, Seminar on the Conservation of Cultural Property in India**, National Museum New Delhi, 1969, p. 13-15.

[17] * * * , **Technical Report**, Archaeological Survey of India, Ajanta Caves, 1986.

[18] * * * , **Technical Report**, Archaeological Survey of India, Aurangabad, 1980-81.

[19] M. Singh, *Microclimatic condition in relation to conservation of cave no. 2 murals of Ajanta*, **Current Science**, **101**(1), 2011, p. 89-94.

[20] M.S. Mathur, *Problem of Illumination of the Mural Paintings in the Rock Cut Caves of Ajanta***, Seminar on the Conservation of Cultural Property in India**, National Museum New Delhi, 1967, p. 66-75.

[21] * * *, **Technical Report**, Archaeological Survey of India, Ajanta Caves, 1983-84.

[22] R. Sharma, V. Rao, V. Khare, *Evaluation of prototype for protective lighting system for illuminating cave paintings*, **Seminar on the Conservation of Cultural Property in India**, National Museum New Delhi, **27**, 1994, p. 74-80.

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