Microclimatic condition in relation to conservation of cave no. 2 murals of Ajanta

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Microclimatic conditions constitute a critical factor in the conservation of cave paintings of Ajanta (2nd century BC to 4th century AD), a World Heritage Site in India. The monitoring campaigns carried in cave no. 2 of Ajanta include recording data for relative humidity, temperature, CO_2 content at different locations inside the cave, and the impact of more than the recommended number of visitors on cave environ and noise level. The fluctuating hygrometric condition and thermal stability of cave no. 2 were compared to the most ancient cave no. 10 situated in the middle of the crescent-shaped scrap of basaltic hillock. The comparatively drastic environmental condition of cave no. 2 has caused severe problems of conservation of murals in the form of detachment of paint layer, falling of the white pigments, and formation of ridges, cracks and gaps in the painted plaster. The lower painted wall surface shows high humidity with increased conservation problems. The CO_2 content is quite high in the central hall of the cave due to exhalation by visitors. The low permeability shellac varnishes applied in 1920 have hindered the breathability of the paint layer. The conservation measures carried out for stabilizing and scientific cleaning of the paintings have also been outlined here along with entomological studies.

Keywords: Cave paintings, conservation measures, microclimatic conditions, relative humidity, temperature.

THE Ajanta caves and their paintings have now been extensively explored by art historians[1]. The unstable microclimatic condition is one of the factors that always affects the state of conservation of mural paintings. In the environmental-monument system, knowledge of the functional environment and climatic conditions of the surroundings are necessary for the identification of causes of decay[2]. As half of the Ajanta caves faces the east and the other half the south, with 178 ft high waterfall in seven stages just near the caves, the environmental condition plays an important role in the survival of the Ajanta murals. The support of the mural paintings is a Deccan trap defined by cleavages, faults and cracks in the body of the basaltic rock for the rainwater to seep through[3]. The mud plaster used as ground contains clay admixed with natural fibres such as rice husk, plant seeds and fibres. Pigment layers have been applied on the dry mud plaster with colour which is inorganic in nature. The painting is executed in temperature technique with binder which is certainly of organic nature, but still has to be precisely identified[4]. The nature of the support and the pigment layer is vulnerable to environmental conditions. Because of this, the Italian conservators of 1920 applied thick protective coating of unbleached shellac resin modifying the physical condition of the painted surface, which in course of time altered the chromatic appearance of the paintings besides causing ridges, gaps and lacuna on the painted surfaces[5].

The pigments used at Ajanta have now been clearly identified with the help of non-destructive/destructive methods of analysis of micro-samples[6]. The scientific studies on pigments of Ajanta at the preliminary stage were carried out with portable ED–XRF, portable microscope, UV light observations and spectro-colorimetry. The micro-chemical analysis of the micro-samples of pigment layers was conducted with mineralogical microscope, SEM–EDX, micro-FTIR, XRD and micro-Raman spectroscopy. This has helped acquire information about pigments, succession of layers and state of conservation of Ajanta murals. Table 1 shows the pigments identified to obtain various colours at Ajanta.

At many places the work of different artists can be understood on the basis of different styles of painting and differences in pigments used in the diverse zones of the caves. Some colours have been obtained by mixing of the pigments, e.g. pink has been obtained by mixing white (kaolin or calcium carbonate) with red colour (red ochre or red lake). Orpiment or realgar is added to the pink to obtain flesh complexion. The pigment layer is applied on a dry plaster with a binder of organic nature, which is probably vegetable or animal glue. The carrier of the painting is a thick mud plaster made up of clay, vegetable fibres, dung, ground rock powder (containing quartz, feldspar, pyroxene, olivine, iron oxide, etc.) which is about 3 mm to 2.5 cm thick on a rough basaltic rock support.

Over the mud plaster, a calcium carbonate layer with thickness ranging from 80 to 200 μm has been applied probably to render the pictorial surfaces flat and homogeneous in colour, in order to better receive the pigment layer. All the painted surfaces are always found covered with superimposed layer of dirt, dust, smoke, altered shellac, natural resins and at a few places, polyvinyl acetate. The presence of such a large quantity of superimposed materials does not always allow clear vision of the original pigment layer and also render the cleaning operations difficult. Besides altering the visual appearance of the original pigment, a variety of superimposed materials restrict the breathability of the underlying surface, thereby causing ridges, gaps, lacuna and sometimes fall of the pigment layer, grain by grain, from its original surface. Such a phenomenon can clearly be noticed in the ceiling of cave no. 2 at Ajanta, wherein fall of white kaolin has been detected. Any stabilizing/cleaning operations at

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Table 1. Identification of pigments at Ajanta

Colour	Pigments	Location
White	Kaolin	All around
	Pure calcium carbonate	Dresses and architecture figures
	Shell white	Lips, necklace and women decorations
	Lead white	Dresses and highlights
Red	Red ochre	All around
	Red lake	Brighter red pigments all around
	Minium	Tools, architectures, inscriptions and dresses
	Cinnabar (very rare)	Identified at one place only
Yellow	Yellow ochre	Background, animals, dresses and figures
	Organic yellow	Bright yellow spots
	Orpiment and/or realgar	Decorations, tools, dresses, animals and composition
Green	Green earth	Leaves, dresses, background of composition
	Orpiment with blue or organic black	
Blue	Lapis lazuli	All around (not present in 2nd BC pigments)
Black	Lamp black	All around

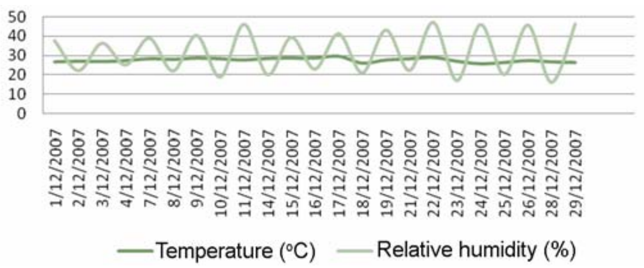

Figure 1. Relative humidity and temperature outside cave no. 2 at Ajanta.

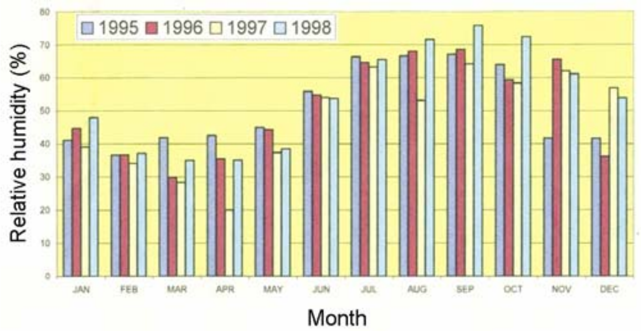

Figure 2. Maximum relative humidity inside the porch at cave no. 2 at Ajanta.

Ajanta must take into account the nature and state of conservation of the painted surface and also avoid the use of aqueous solution, as binding glue is soluble in water.

In front of the entrance to cave no. 2 there is a porch with a large-sized green awning hanging, primarily installed to protect the veranda paintings from splashes of rainwater. Relative humidity and temperature were recorded outside cave no. 2 so as to characterize the climatic conditions during 1–29 December 2007. The relative humidity and temperature both outside and inside the porch are shown in Figures 1 and 2 (temperature between 25°C and 30°C). It can be noted that compared to the overall standard range of temperature from 23°C to 30°C, the relative humidity recorded outside shows wide fluctuations. This fluctuation is due to the change in climatic cycle occurring in the immediate environs of the caves. However, the inertia of the porch has stabilized the temperature constantly between 25°C and 30°C, whereas the relative humidity tends to reflect the climatic trend of the period during which a progressive reduction in relative humidity linked with seasonal variations occurred. Thus, the system works as an effective filter against the external variation in temperature, besides protecting the mural paintings from the direct sun light and splashes of rainwater. It is advisable to hang similar awning in cave no. 11, where the porch painting is showing distress in the form of falling of white pigments.

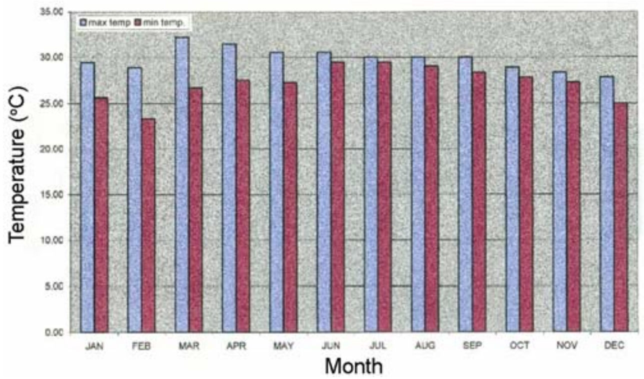

Figure 3. Maximum and minimum average temperature inside cave no. 2 during 2007.

The temperature and relative humidity both inside the cave and the veranda of cave no. 2 are being constantly recorded with a thermo-hygrograph (ISUZU model 3126) on long-term basis. The data recorded for temperature inside the cave are shown in Figure 3. It can be observed that the inner part of the cave is thermally stable with temperature remaining generally between 27°C and 30°C, irrespective of humidity. The recorded data for average relative humidity inside the cave are shown in Figure 4 for a 5-yr period. It can be observed that there is about 50% variation in relative humidity from the rainy season to the dry season, which is one of the main reasons for flaking of the pigments of the Ajanta murals. The impact of variation in relative humidity is so profound on some parts of the paintings that the whole of the painted plaster along with the mud has fallen from its stone carrier. The falling of white pigments from the ceiling of cave no. 2, closely monitored by erecting a test bed about 10 ft from the ground level, is prominently due to this wide fluctuation in relative humidity inside the cave.

Another important factor that affects the microclimate of cave no. 2 is the impact of visitors. Ajanta caves attract around 6000–7000 visitors daily in the tourist season of October to January and 2500–4000 visitors in other months and during the lean period every year (children below 15 years also included). There is a large rush to enter the painted cave nos 1 and 2 as they fall at the main entry point. An electronic thermo-hygrograph (ISUZU model 3126) was placed in the central hall of cave no. 2 with a one-day chart. As the cave remains closed on Mondays, the relative humidity was recorded when there was no visitor inside the cave. On Mondays, the relative humidity inside the cave remained constant at around 36–37%. On the very next day, the number of visitors inside cave no. 2 was counted at 15 min intervals from 0900 to 1730 h by manual counting. The results of our observations are shown in Figure 5. As the visitors entered the cave at 9 a.m., the relative humidity due to their exhalation started showing signs of increasing. Though the entry of visitors is restricted to 40 inside the cave, at some point there were about 100 visitors and at an average more than 60 visitors were always present inside the cave. This resulted in 6–7% increase in relative humidity. As a conservation measure, the Archaeological Survey of India has now constructed two causeways on Waghura River for proper visitor distribution at Ajanta.

The average relative humidity on the painted wall surface of cave nos 1 and 2 was measured with a protimeter all around the central hall at different heights. Figure 6 shows the data recorded for average relative humidity. On the painted wall surface the average humidity decreases from 39.5% at a height of 1.5 ft from the floor level to 38.1% at a height of 10.5 ft in cave no. 2. Interestingly, in the bigger sized cave no. 1, the decrease in humidity is quite high from 41.2% at a height of 6.5 ft to 38.4% at 12.5 ft. This shows that the lower part of the painted wall is more humid than its upper part, and is one of the important contributing factors for causing distress to the paintings. However, the average temperature of the painted wall surface increases only slightly (about 0.5%) with increase in height. On the basis of this observation it can be assumed that the inner cave wall is almost thermally stable.

The impact of visitors inside the cave causes not only an increase in relative humidity, but also increases the CO_2 concentration during the daytime. CO_2 monitoring using portable airflow model equipment was carried out at six locations inside cave no. 2, covering almost the entire cave area. To record any gradient in CO_2 concentration, the monitoring was done at the floor level as well as at a height of 8 ft from the floor. The CO_2 recorded was 600 ppm at 5 pm on Monday when the cave is closed for visitors (Figure 7). The slightly higher value is due to the non-circulation of air, as the doors are mostly kept closed on Mondays. However, with 1400 visitors entering the cave the next day, CO_2 concentration reached about 800 ppm in the central hall. Visitors are not allowed to move in the aisle area on all sides due to the barricades installed inside the cave to restrict movement. In the other parts of the cave interior, CO_2 concentration is also high during the day with higher concentration recorded near the east wall centre. As all the visitors have to climb the Ajanta hill and are generally found rushing to enter cave nos 1 and 2 with fast breath, there is slightly more impact on relative humidity and CO_2 levels inside the cave. It is worth mentioning that with the higher relative humidity inside the cave, there is a chance of reaction between the calcium carbonate of white pigments and CO_2 changing into bicarbonates with time, thus causing loosening of the grains. Such a problem is predominantly noticed in those parts of the paintings where kaolin has

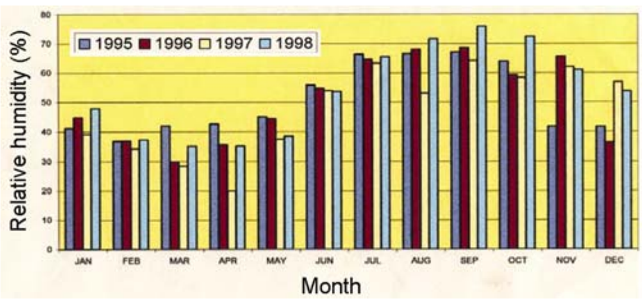

Figure 4. Average relative humidity in cave no. 2.

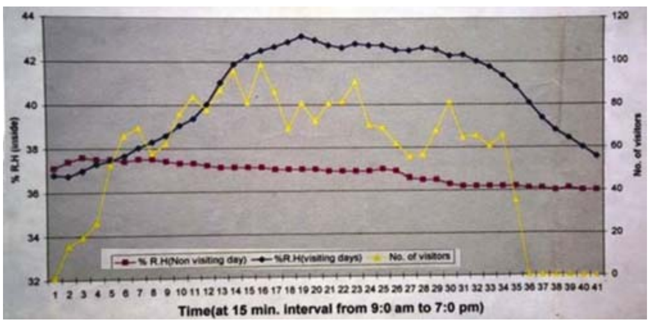

Figure 5. Impact of visitors on relative humidity (%) in cave no. 2 during 24 December 1999–24 January 2000.

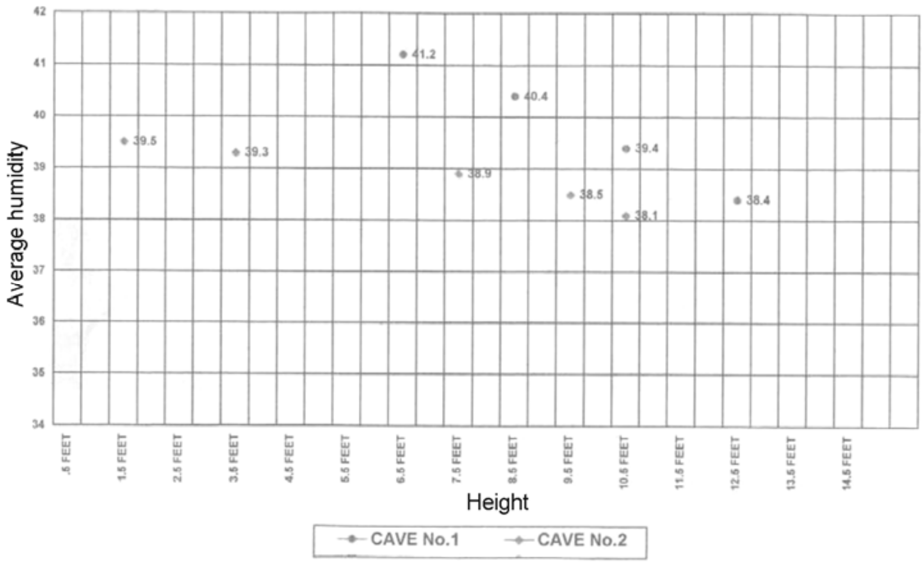

Figure 6. Average relative humidity of painted wall surface at cave nos 1 and 2.

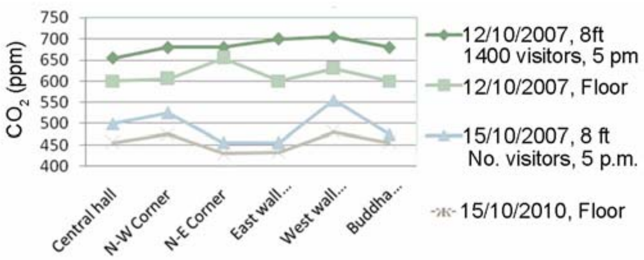

Figure 7. Carbon dioxide content with/without visitors in cave no. 2.

been used as white pigment. In the ceiling painting of cave no. 2, on account of cumulative impact of the above-mentioned factors for many years, the falling of white pigment is noticed. For the survival of the paintings it is essential to introduce proper visitor management at the Ajanta caves.

The conservation of murals inside the caves depends on the microclimatic conditions of the caves, and hence varies from cave to cave at Ajanta. The relative humidity and temperature of cave no. 2, situated on the east part of the crescent-shaped hillock have been compared to those of cave no. 10 situated in the middle of the Ajanta cave. For both the caves the temperature and relative humidity were recorded during 1–18 March 2005 for comparative studies.

Although variation in temperature and relative humidity within the same cave is of greater relevance, a comparative study of these factors has been made to understand the intensity of conservation problems of painted plaster of cave nos 2 and 10.

It is worth mentioning that cave no. 2 has a porch with awning, but cave no. 10 lacks a porch and has a large-sized entrance gate at Chaita Hall fitted with a wide-open metallic mesh in a wooden frame. The relative humidity and temperature recorded from 1 to 18 March 2005 are shown in Table 2. The data show that cave no. 2 is always more humid than cave no. 10, since the variation in average humidity recorded is in the range of about 10%. In consonance to relative humidity, the minimum–maximum average temperature variation observed is in the range of 5.14°C–8.42°C respectively. These variations certainly make the murals in cave no. 2 more vulnerable to deterioration due to high relative humidity and temperature variations vis-à-vis cave no. 10, wherein the circulation of air is quite good due to the large opening and ventilated wire mesh fitted at the entrance. It is to be noted that cave no. 10 has a few square metres of ancient paintings (2nd century BC) still surviving and in a good state of preservation.

The physical and chemical properties of earthen support have a large influence on the nature and extent of deterioration of the paintings that they support. For example, the clayey fraction and its plasticity is a major factor in the interaction of earthen support with the other structural elements, with the painted surface and with environmental changes. Whereas the paintings of cave no. 2 have been executed on mud plaster that contains clayey matter of high to low swelling nature admixed with organic additives, the paintings of cave no. 10 have lime plaster as support, which is in a good state of conservation. Thus, together with variation in temperature and relative humidity the nature of support has an important bearing on the overall condition of the Ajanta paintings.

The noise level measured with the help of the Cygnet System inside cave no. 2 shows that against the recommended 45–55 dB noise in the silent zone, the noise level mostly recorded is around 70–75 dB, with occasional rise up to 95 dB that causes the delicate pigments to detach and flake from the ground in the course of time.

During visual inspection of the cave, the biological traces identified were a wasp hole in the plaster and

Table 2. Difference in temperature and relative humidity at cave nos 2 and 10

Date	Cave no. 2 Temperature (°C) Min.	Cave no. 2 Temperature (°C) Max.	Cave no. 2 Relative humidity (%) Min.	Cave no. 2 Relative humidity (%) Max.	Cave no. 10 Temperature (°C) Min.	Cave no. 10 Temperature (°C) Max.	Cave no. 10 Relative humidity (%) Min.	Cave no. 10 Relative humidity (%) Max.	Difference in temperature between cave nos 2 and 10 (°C) Min.	Difference in temperature between cave nos 2 and 10 (°C) Max.	Difference in relative humidity between cave nos 2 and 10 (%) Min.	Difference in relative humidity between cave nos 2 and 10 (%) Max.
1 March 2005	20.5	21	45.5	57	26.5	29.5	32	51	6	8.5	13.5	6
2 March 2005	20.5	21	41	50	27.5	30.5	26.5	40	7	9.5	14.5	10
3 March 2005	20.5	21.5	43	50.5	27	30	33.5	38.5	6.5	8.5	9.5	12
4 March 2005	20.5	21.5	36.5	49.5	25.5	30.5	22.5	42.5	5	9	14	7
5 March 2005	20	20	41	48	28	29.5	30	37	8	9.5	11	11
6 March 2005	20	20	40	49	27	30	30	32	6.5	9.0	10	17
7 March 2005	20	20	42	49	28.5	30	32	42	8.5	10	10	7
8 March 2005	20.5	21	49	65.5	26	29.5	42	62	5.5	8.5	7	3.5
9 March 2005	20	21	50	64	24	29	44	63	4	8	6	1.0
10 March 2005	19.5	21	45	50.5	23	28	33	47.5	3.5	7.0	12	3
11 March 2005	20	21	39	49.5	24	28.5	29	42	4	7.5	10	7.5
12 March 2005	20	21	35	44.5	25.5	28	25.5	29	5.5	7	9.5	15.5
13 March 2005	19.5	21	34.5	44	22	28	21	35	2.5	7	13.5	9
14 March 2005	20	21	32	38	22.5	28.5	25	36	2.5	7.5	7	2
15 March 2005	20	21	30	36	23.5	29	20.5	30	3.5	8	9.5	6
16 March 2005	20.5	21	28	36	25	30	21	27	4.5	9	7	9
17 March 2005	20.5	21.5	27.5	34.5	25	30.5	19	24	4.5	9	8.5	10.5
18 March 2005	20.5	22	27.5	47	25.5	31	20	23.5	5	9	7.5	23.5

Figure 8. Scientific conservation of painted medallion at cave no. 2.

pigment layer, and traces of bat excreta and urine along with silver fish thriving on the organic matter present in the mud plaster. No trace of microbiological colonization on the painted surface was observed. Studies have shown that microorganisms develop on the paintings when the relative humidity is high (about 70%) and there is increase in temperature[7]. The presence of organic materials such as vegetable fibres in the mud plaster along with bat excreta support the growth of heterotrophic microorganisms. The actual absence of alteration of microbial nature on mural paintings suggests that the disinfection and protection treatment being carried out at Ajanta has inhibited microbial colonization. Regular spray of 2% pyrethrum extract in kerosene is carried out at Ajanta every fortnight on the unpainted parts and cave floor along with pathway, which has proved effective in the control of micro-organisms inside the cave to a large extent. The insects identified at the Ajanta caves are mainly *Thysanura lepismantidae* and *Coleoptera ptinidae*, which attack mortars, plasters and paint layers, including vegetable material present in mud plaster as they feed on cellulose[8]. The fine wire mesh sealing of the window has helped in controlling flying insects from entering inside the cave. Occasionally, some crawling insects are noticed inside the cave, but due to regular disinfection and dusting, the site is mostly free from damage due to microorganisms.

After ascertaining the cause of ruin of the painted plasters of Ajanta, the Italian restorers of 1920 devised a scientific method[3] for the treatment of the paintings such as: (i) Injection of lime–casein when the gap in the painting is narrow. (ii) Filling with plaster of Paris or lime, fine pozzolana where the cavity is large. (iii) Fixing of nails in the affected part of the supporting coarse plaster. (iv) Liberal use of unbleached shellac dissolved in alcohol for general preservation.

In cave no. 2 shellac varnish is found applied on all parts of the porch paintings, including the ceiling. In the cave interior varnish has been applied on all the side walls of the painted plaster and on some parts of the ceiling paintings that directly face the main door of the cave. The shellac part has become harder showing cracks, ridges, gaps and has also changed the chromatic appearance of the inner pigment layer. The variation of relative humidity inside the cave has further enhanced the deterioration of painted plaster.

For conservation, the painted plaster was first consolidated by injecting lime–casein mixture wherever there was a gap between the pigments and plaster layer followed by gentle pressing with rubber roller and allowing it to dry for about two months. Bigger gaps and cracks were filled with lime mortar and tinted suitably to match

Figure 9. Photographs of ceiling painting at cave no. 2 before (left) and after (right) cleaning.

the surroundings. For the removal of shellac varnish, a mixture of morpholine, *n*-butylamine, butanol, ethanol and dimethylformamide were taken in the ratio of 0.5 : 1 : 1.5 : 2 : 1 and properly mixed. This mixture of chemicals was applied slowly with sable brushes on the shellac portion with utmost care so as to restrict its action only on the outer varnish surface. After softening by wetting the surface for 2–3 min, the varnish was removed carefully with cotton swab so as not to touch the original pigment layer. The main intention of the cleaning is to reduce the thickness of the varnish layer to make the painted plaster breathe naturally. Figure 8 shows the result of scientific conservation of a painted medallion at the central hall of cave no. 2, leaving a small strip to show the actual condition of the painted surface before cleaning.

The falling of white kaolin from the ceiling of cave no. 2 is one of the major problems of conservation here. On careful observation, the ceiling paintings were also found encrusted with soot layer that has to be removed before consolidation of the white pigments. For these, 3–4 grains of EDTA were dissolved in 1–2 drops of distilled water, and 18–20 ml of ethanol, 1–2 drops of ammonia and 2–3 drops of triethanolamine were mixed into it to make 25 ml of solution (pH about 9). After complete mixing, this mixture was applied gently with cotton bud for a short duration with care and precaution. Particular attention has to be paid to restrict its action only to sooty accretions without in any way affecting the black original outlines of the paintings. As the nature of adherence of black soot is different to the original black outlines (it has been applied admixed with glue), an experienced conservator can definitely carry out this delicate operation satisfactorily. Figure 9 shows a part of the ceiling painting recently cleaned using this technique. After complete drying the cleaned part of the painting was applied with two coats of 0.5% polyvinyl acetate solution when the temperature inside the cave was about 27°C and relative humidity 55–60% for better results. After this procedure, no falling of white pigment has been noticed in the 9–10 year period. The whole ceiling paintings of cave no. 2 have been cleaned and white pigment properly conserved for the posterity now at Ajanta.

The variation in relative humidity and temperature has a more pronounced effect in the case of caves with paintings on mud plaster, than in the case of paintings on lime plaster. This is quite natural on account of the characteristics of the mud plaster, which has a better absorption and affinity to moisture compared to lime plaster.

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