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Preliminary investigation of late Mughal period wall paintings from historic monuments of Begumpura, Lahore

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Abstract

Deterioration of wall paintings caused by environmental pollution is a worldwide problem especially with reference to the present industrial era. The alarming incremental trend of pollution in Pakistan has threatened the cultural assets. The deposition of pollutants on historic fabric is the main source of chemical and mineralogical alterations of wall paintings. The present diagnostic study investigated the main deterioration mechanisms affecting wall paintings of the late Mughal period, in the Begumpura Complex, in Lahore. Micro samples were characterized by XRD and SEM-EDS to identify deterioration products and understand deterioration mechanisms prevalent at the heritage site. The results revealed that red ocher, green earth and calcium carbonate were initially used for red, green and white pigments, respectively. Sodium chloride (halite, NaCl) and gypsum (CaSO\textsubscript{4} \cdot 2H\textsubscript{2}O) were identified as the main deterioration products.

\section{1. Introduction}

The site of Begumpura (located at 31\textdegree 35' N; 74\textdegree 22' E) lies approximately half way between the walled city of Lahore and the Shalamar Garden constructed from mid-17th to mid-18th century (Gulabi Bagh-1655 CE to 1745 CE-Saruwala Maqbara; Hussain et al., 1976; Koch, 1996). The Shahdara gardens and monuments to the north of Lahore lost the
state patronage after the death of Emperor Jahangir in 1627 CE. The Shalamar Garden constructed by Emperor Shah Jahan (1642 CE) to the north-east of Lahore then became the central hub for royal political and cultural activities. The location of the northward wandering Ravi river at that time suggests that the Shalamar Garden and the royal residential quarters in Baghbanpura and Mughalpura area were established along the south bank of the river. This is how the Begumpura Complex started to develop from the mid-17th century (Latif, 1892). It became later the residence of Nawab Zikaria Khan, a.k.a. “Khan Bahadur Khan”, the viceroy of Lahore, who lived there with his family and adorned it with magnificent palaces, elegant gardens, mosques, tanks, aqueducts, baths and taverns (Dar, 1982). This area became the center of political and cultural activities during the late Mughal times. Nowadays, this area is facing negative impacts of urbanization and is in ruined condition. Most of the historic structures are deteriorating with aging without any conservation and restoration efforts.

The wall paintings, an artistic profusion of variegated designs, bright colors, even tonality with rhythmic articulation in Begumpura historic structures were an ultimate Mughal artistic expression (Figure 1) that evolved through centuries (Nath, 1976; Koch, 1996). They need to be investigated for the preservation of cultural ornamental expression of that particular late Mughal era. The currently rapid urbanization and economic growth of Lahore is confronted to the impact of dense urban environment (Mumtaz, 1992; Khan, 2011). This environment combines natural climatic changes and anthropogenic pollution (Steiger, 2003). Lahore falls in semiarid climatic zone comprising of hot summer, cool winter and rainy season (monsoon). Lahore average temperature reaches up to 48 °C in summer while temperature falls to 1 °C in winter season. Average relative humidity is at a minimum in the month of May (32%) which may reach up to 72% during the month of December. Wind speed varies between 22 km per day during winter and 124 km per day during summer. However, on average, 60% of the days of the year are calm and wind speed is negligible (Anjum et al., 2017). The natural shift in climatic patterns of Lahore is towards an increase in both maximum and minimum temperatures and rainfall fluctuations (Zaman et al., 2012). The incremental trend of temperature and humidity levels was also projected in the National Climate Change Policy with increase in the emission of pollutants and their effects (PAK-INDC, 2016). The air quality study of

![Figure 1](image-url) Deteriorated painted murals on: a) arches in drum, b) dome interior, c) entrance hall of tomb, d) inner chambers, e) surrounding arched verandah and f) decorative drum of dome from DaiAnga Tomb, Begumpura complex, Lahore.
Table 1 Description and results obtained from microsamples of painted walls in Begumpura Complex, Lahore.

<table>
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<th>Sample</th>
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<td>SBC-1</td>
<td>Dai Anga Tomb Internal chamber left wall</td>
<td>Red</td>
<td><img src="image" alt="Sample Image" /></td>
<td>Paint Layer</td>
<td>Ca,Gy, Ha, Si, Ht</td>
<td>Ca, S, Cl, Fe, Al, Si, Na, Mg, K</td>
<td>Red ocher, Gypsum, Halite</td>
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<tr>
<td>SBC-2</td>
<td>Dai Anga Tomb arch opening on entrance</td>
<td>Red</td>
<td><img src="image" alt="Sample Image" /></td>
<td>Weathered Paint Layer</td>
<td>Ca,Gy, Ha, Si, Ht</td>
<td>Ca, S, Cl, Fe, Al, Si, Na, Mg, K</td>
<td>Red ocher, Gypsum, Halite</td>
</tr>
<tr>
<td>SBC-3</td>
<td>Dai Anga Tomb arch opening on entrance</td>
<td>Red</td>
<td><img src="image" alt="Sample Image" /></td>
<td>Paint Layer</td>
<td>Ca,Gy, Ha, Si, Ht</td>
<td>Ca, S, Cl, Fe, Al, Si, Na, Mg, K</td>
<td>Red ocher, Gypsum, Halite</td>
</tr>
<tr>
<td>SBC-4</td>
<td>Dai Anga Tomb Dome drum arches</td>
<td>Green</td>
<td><img src="image" alt="Sample Image" /></td>
<td>Paint Layer</td>
<td>Gy,Ha,Si, Ca,Gy, Ha, Si, Fe</td>
<td>Ca, Cl, S, Fe, Al, Si, Na, K, Mg</td>
<td>Green earth, Gypsum, Halite</td>
</tr>
<tr>
<td>SBC-5</td>
<td>Main chamber of the Tomb</td>
<td>Green</td>
<td><img src="image" alt="Sample Image" /></td>
<td>Paint Layer</td>
<td>Gy</td>
<td>Gy</td>
<td>Green earth, Gypsum</td>
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Preliminary investigation of late Mughal period wall paintings
Lahore district showed the average suspended particulate matter (SPM) was 6.4 times higher than WHO Guideline Values. The levels of sulphur dioxide, carbon monoxide, and oxides of nitrogen also exceed the acceptable standards (Pak-EPA, 2015). This climate change is not only causing extreme weather events but also affects climatic patterns. In addition to lack of understanding of the historic materials interaction with the surrounding environment, the unpredictability on the current climatic development is widening the range of deterioration possibilities of the historic structures.

The interaction of the urban environment with the wall paintings already resulted in discoloration and salt deposits, crust formations, loss of paints, flaking surfaces and detachments (Figure 1; Singh and Arbad, 2014). The main weathering factors affecting Begumpura Complex were found to be climatic (high temperature fluctuations, humidity increase etc.) and urban (increased vehicular traffic, polluted air, congestion areas, toxic emissions, etc.) resulting into modifications of the constituents of the historic fabric (Mahmood, 2009; Gulzar, 2014). The alteration layers were usually formed through both dry (particle-loaded air) and wet (transportation by water) deposition processes (Arnold, and Zehnder, 1987; Alawneh et al., 2011).

The main objective of this study was to characterize the deposition layers covering painted wall surfaces of Begumpura Complex. Before conservation of wall paintings, the original technique, properties of materials employed at construction time and sources of deterioration must be determined. This information will guide the intervention methods towards appropriate conservation work of the wall paintings.

2. Materials and methods

2.1. Sampling

Microsamples were collected from several places on the walls with the help of a clean metallic scalpel (Table 1). The samples were studied in detail with an optical microscope and alteration layers were scraped off to understand the nature and extent of weathering (Stuart, 2007; Bianchin et al., 2009). Small amounts were crushed and milled in an agate mortar to determine their chemical and mineralogical composition.

The samples were also mounted in polyester resin (Technovit 200LC), cross-sectioned and polished with conventional methods using silicon carbide card with successive grid (from 120 to 1000 as required).

2.2. Optical microscopy

The optical microscopy was performed to identify the different layers under both visible and ultraviolet lights with an optical Axioplan Zeiss microscope using Epiplan-Neoflaur objectives from 2.5 × to 50 × magnifications. The photomicrographs were obtained with the attached Axio-cam Zeiss camera (Figure 2).
2.3. Scanning electron microscopy (SEM-EDS)

The samples were analyzed by Scanning Electron Microscope (SEM), JEOL JSM 6390 LA coupled with EDS (EDS, Oxford-1 NCA) spectrometer. The examination provided information about mineral morphology, crystal forms and weathered layers.

2.4. X-ray powder diffraction analysis (XRD)

X-ray diffraction (XRD) was carried out using Ni-filtered Cu Kα radiation, with a step size of 0.05° at 2 s per point and 2θ ranging from 5° to 60°. The samples were grinded in an agate mortar to determine the crystalline phases. Two types of fractions were analyzed; (1) the fraction corresponding...
to the deposited layers and (2) the other fraction consisting of paint layer examined during optical microscopy.

3. Results and discussions

Pakistan stands among one of the most vulnerable countries in terms of climate-induced challenges based on the current scenario of adverse climatic changes and the growing pollutants emission rate (Pak-INDC, 2016). The heritage of Pakistan is the most affected and neglected sector in terms of adaptation to the urban pollution (UNESCO, 2017). Therefore, historic structures are facing major threats, particularly in the city of Lahore (the second in the vulnerability index cities of Pakistan). This statement is supported by the analyzed samples from the Begumpura Complex.
3.1. SEM-EDS analysis

The SEM micrographs of analyzed samples are shown in Figure 3. The image of a surface salt deposit (SBC-1, Figure 3a) taken from the internal chamber of DaiAnga tomb disclosed a dense coat of halite crystals. The cross sectioned deposition layer (SBC-1) further revealed the halite waxy and hollow-faced coat of halite crystals nearly distinguished from the base (Figure 3d). EDS microanalysis of SBC-1 (Table 2) indicated Ca, S, Cl and Fe as the major ions with minor contents of Al, Si, Na, Mg and K.

The SEM image of a surface deposition layer (SBC-4, Figure 3b) obtained from higher arches in drum of the bulbous dome also showed that Ca, Cl and S are the major ions. The concentrations of Na, Al, Si, Fe, Mg and K were low while only traces of Ti were found (Table-2).

SBC-6 (black coloured) EDS microanalysis of a deposition layer from the main chamber was found to be mainly composed of Ca, S, Cl and Si in addition to minor Al, Na and Mg and traces of K and Fe (Table 2).

3.2. Mineralogical characterization

The XRD results are summarized in Table 1; representative XRD patterns of the studied deposition layers are given in Figure 4. XRD patterns of alteration-layer deposited on sample SBC-1 depicted calcite (CaCO3), gypsum (CaSO4·2H2O) and halite (NaCl) while hematite (Fe2O3) is also present in the paint layer. The triple layered dark red sample (SBC-2) also showed hematite (Fe2O3), calcite (CaCO3), gypsum (CaSO4·2H2O), halite (NaCl) and quartz (SiO2) in small amounts. SBC-3 XRD patterns are similar to those of SBC-1.

The black layer on green coloured sample SBC-4 revealed mainly gypsum, quartz and halite. The second white spotted layer (between the black-coloured deposition and the paint layer) consists of calcite, gypsum, quartz and halite while the paint layer contains ferrous celadonite in addition to calcite, gypsum, quartz and halite.

The dark green SBC-5 sample comprises of only gypsum. The white-coloured sample SBC-6 showed calcite (CaCO3), gypsum (CaSO4·2H2O) and halite (NaCl). The red SBC-7 sample showed calcite (CaCO3) and gypsum (CaSO4·2H2O) for its deposition layer while paint layer also showed calcite (CaCO3), gypsum (CaSO4·2H2O), quartz (SiO2) and halite (NaCl).

3.3. Deterioration mechanisms of wall paintings

The deterioration mechanisms are physical, chemical and biological (Honeyborne, 1998; Rodriguez-Navarro and Doehne, 1999; Rodriguez-Navarro et al., 2000; Zeng et al., 2010). Our analyses document that deterioration of wall paintings in the Begumpura-Lahore monuments is dominantly physiochemical. Water (moisture, high humidity, capillary action) is the major initiator in physical erosion and transportation of salts triggering chemical alteration. The biological activity is found to be negligible in the studied monuments. The rise of water level to the ground surface in the historic monuments of Begumpura is mainly due to inadequate storm water disposals and drainage system outflows. Most of the garden area surrounding the historic monuments is occupied by illegal expansion of houses. The improper infrastructure of these unauthorized constructions is one of the main factors in the modification of local environmental conditions of the heritage site of Begumpura.

The mineralogical and SEM-EDS analyses of the weathered layers showed halite and gypsum as main deterioration products with salt crystallization facilitated by water ingress on the paint layers. The other phenomenon is the salts recrystallization during wetting and drying cycles and differential thermal expansions that forms the weathered surfaces. The dry deposition of pollutants from air (soot, dust, bird's droppings) directly on the painted surfaces is an additional factor responsible for the deterioration of the investigated samples (Casellato et al., 2004; Tullianiet al., 2013; Singh and Arbad, 2014).

Gypsum crystallization in layers results from transported sulphur containing particulate matter through air (dry deposition) and salts through water (wet deposition). Sulphur undergoes chemical reaction in the presence of moisture and high temperature fluctuations causing surface deposits on the investigated wall paintings (Figure 3c). Deterioration is amplified by the crystallization pressure generated by gypsum crystal formation (Steiger, 2003; Charola et al., 2007). As gypsum has a low solubility (257.5 mg/100 g water at 20 °C), it is recrystallized under high levels of humidity (Tullianiet al., 2013; Singh and Arbad, 2014). This recrystallization generates bigger crystals due to enhanced humidity levels, consequently triggering rupture, cracks, crusts and discoloration of the enclosing wall paintings. The climatic record on the Begumpura region of Lahore showed higher humidity levels and more rainy days than in the past (Imran et al., 2014). The process of gypsum recrystallization in fresco paintings under high humidity levels was also observed in other historical buildings of the Indian subcontinent (Singh and Arbad, 2014).

Halite (NaCl) was found to be mainly transported by water through capillary action. This mechanism usually undergoes repeated evaporation and precipitation and results in salt efflorescence in the Begumpura Complex. This salt forms rough deposition layers (Figure 3d) that further attract other pollutants from air and further enhance the deterioration phenomenon. Halite is also indicative of osmotic-swelling of clay minerals, which causes loss of paint surfaces and disintegration of the paint layers (Mahmood, 2009; Zeng et al., 2010). The swelling of the exposed paint layer in the presence of salt (NaCl acts as an electrolyte) occurs with osmotic expansion to produce tension zone between the wet and dry portions. These induced stresses generate fractures in the upper paint layer, which instigates flaking/ scaling with the accelerated evaporative cycles in the presence of high temperatures and winds. This possibility needs to be further ascertained with experimentation on the investigated samples.

4. Conclusions

Halite and gypsum are predominant deterioration products deposited on the surface of painted wall of the Begumpura Complex in Lahore (Pakistan). Salt crystallization is the
main deteriorating phenomenon facilitated by the ingress of water through capillary penetration from subsurface into the walls. The wall dampness is further enhanced by the retention of water in the walls. Increased humidity in the environment results from changes in the climatic patterns over the centuries in addition to the particulate matter suspension. The main weathering factors affecting the heritage site are therefore both climatic changes and urban pollution. Both augment deterioration of porous wall paintings whose dampness is due to increased water level, smog, etc. The first and foremost step in the case of Begumpura Complex is the demolition of surviving illegal constructions and the creation of a buffer protecting the monuments. This should be followed by the treatment of the rising damp through proper application of moisture barriers (damp-proof membranes) and suitable moisture sinks to control the moisture at the source. The routine maintenance including surface water drainage, air-pressure cleaning and environmental monitoring can further help to control the deterioration of the irreplaceable fresco paintings at Begumpura Complex.

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