

Gypsum Mortars of the Khoja Zainuddin Mosque in Bukhara (Uzbekistan) – A Contribution to Building Archaeological Studies

Jasmin Badr,¹ Christiane Huck-Stiasny² and Rainer Drewello³

¹ Chair of Building Preservation Sciences, Institute of Archaeology, Cultural Heritage Sciences and Art History, Otto-Friedrich-Universität Bamberg, Germany, jasmin.badr@uni-bamberg.de

² Otto-Friedrich-Universität Bamberg, Germany, christiane.huck-stiasny@uni-bamberg.de

³ Otto-Friedrich-Universität Bamberg, Germany, rainer.drewello@uni-bamberg.de

Abstract: The Old City of Bukhara (Uzbekistan), protected as UNESCO world cultural heritage, is one of the most important historical urban fabrics in Central Asia. In the northwest of the city lies the Khoja Zainuddin Mosque – a monument of overarching art historical importance and an outstanding state of preservation. A building archaeological survey has shown that the whole building was erected in one single phase in the middle of the 16th century [1]. However, several later modifications can be clearly determined in the prayer hall and the adjoining rooms. For the classification within the historical context, a detailed analysis of the mortars was executed. Pure gypsum, gypsum-lime and clay mortars were identified. In some samples, the analyses also provided evidence of organic additions, probably to improve the mortar's properties.

1 Architectural Context

The Khoja Zainuddin Mosque (Fig. 1) is dominated by a domed prayer hall that is surrounded by a wooden portico in the north and east. The western part of the building is occupied by four small rooms and a monumental niche with the tomb of the saint Khoja Zainuddin.

According to the different layers of paintings in the prayer hall, at least three phases of decoration can be distinguished. Whereas the first layer probably dates to the construction phase in the middle of the 16th century, the second and third layer point to the middle of the 17th century [1]. Unlike the richly decorated prayer hall, the adjoining rooms are mostly painted in a uniform white or grey beige colour without any ornaments or other decorative elements. However, damaged spots on the walls show that these rooms have also been plastered several times.



Fig. 1 First floor plan of the Khoja Zainuddin Mosque with sampling locations

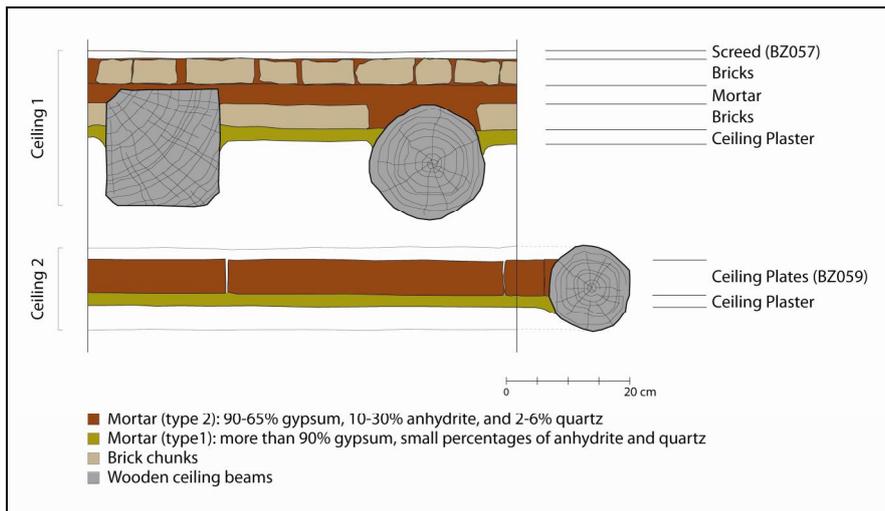


Fig. 2 Cross section of the ceiling construction in room 5



Fig. 3 Ceiling constructions in room 5



Fig. 4 Mortar sample taken in room 7

A particularly interesting element is represented by the ceiling construction in room 4 and 5 (Fig. 3): In between the wooden ceiling beams, brick chunks are fixed with different layers of very delicate mortars. This construction is covered from both the upper and lower side by further layers of mortar. In room 5, a second ceiling was constructed under the original one that burnt through to some extent. Substantially, the same construction system was applied for the new ceiling; the only difference is the usage of mortar plates (Fig. 2) in place of the brick chunks.

Also the niche in the east wall of room 7 marks a special point of interest. The original opening towards the northern portico was later closed with reused mortar chunks (Fig. 4) that still bear traces of ornaments and paintings.

2 Geological Background

Even though there is only little historical evidence for mineral deposits in Central Asia, it can be assumed that many of them have been known and exploited from the 16th century to this day.

An overview shows the most relevant raw materials and their deposits in the region of Bukhara (Fig. 5).

Gypsum and anhydrite: Large Paleogene gypsum deposits are situated in Mamzhurgat (thickness 4-15 m) [2, 3] in the region of Kagan, about 12 km southeast of Bukhara. This gypsum is of white or greyish-white colour, fine-grained and crystalline.

Celestine: Beside the deposits of the Fergana Valley another celestine deposit is situated in the Surkhandaryo Province within sulphur deposits [4].

Quartz: A large deposit (thickness 18 m) of very pure quartz (content of SiO₂ is up to 99,3%) is situated in Tozbulak in the southern Kulzhuktaw Mountains. The deposit of Bitab in the southern mountains of Nurataw also contains microcline deposits, convenient for the production of fine ceramics [2, 3].

Limestone: The deposits of Korovulbazar (about 43 km in the southwest of Bukhara) and Proletarabad (about 25 km in the southwest of Bukhara) are characterized by grey or greyish and fine grained limestone [2, 3].

Thermal waters: The water sources in the region of Bukhara contain a high percentage of strontium ($> 300\text{mg/l}$).

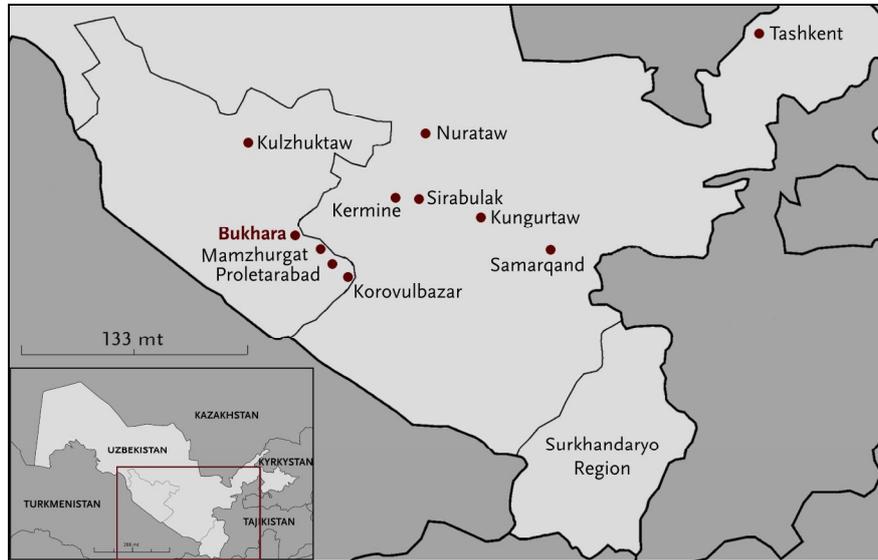


Fig. 5 Gypsum, celestine, quartz and limestone deposits in the region of Bukhara

3 Mortar Analysis

The investigation of the mortars was started with a macroscopic study of all samples. Polished and thin sections of the most significant mortars were analysed using reflected-light microscopy. For the determination of specific components and compound percentages, x-ray diffraction (PW 1800 by Philips, detector: Xenon proportional counter, SemiQuant), FTIR-spectrometry (Spektrum 2000 and Auto Image System by Perkin Elmer, diamond cell, aperture $100 \times 100 \mu\text{m}$, wavenumbers $4000\text{-}550 \text{ cm}^{-1}$) and scanning electronic microscopy were used (SEM, Philipps XL 40). The latter was fitted with an energy-dispersive x-ray spectroscopy application (EDS, microanalysis system Quantax by Bruker, HV 20kV, WD 11.5, Spot size 6).

As the macroscopic and microscopic analyses already show different compositions, the x-ray diffraction permits a more detailed classification of the mortars. Five types could be distinguished:

- 1) More than 90% gypsum, small percentages of anhydrite and quartz

- 2) 90-65% gypsum, 10-30% anhydrite, and 2-6% quartz
 - 3) 64-55% gypsum, 35-42 anhydrite, and 1-5% quartz
 - 4) Less than 55% gypsum, 45% of lime, quartz, charcoal and brick chippings in variable concentrations
 - 5) Clay mortar, mixed with gypsum, lime, charcoal and brick chippings
- The spectrum of compositions is presented in table 1.

Table 1 Analysis results of the x-ray diffraction, the scanning electronic microscope (SEM) and the FTIR-spectrometry

Sample No.	Room Type	X-ray Diffraction	SEM	FTIR-Spectrometry	Remarks
BZ028	roof 2	80% gypsum, 15% quartz, 5% anhydrite	<i>main components:</i> C, O, S, Ca <i>secondary component:</i> Mg, Si	<i>main component:</i> gypsum <i>secondary components:</i> calcite, quartz, long-chain unsaturated fatty acids, calcium oleate, protein, calcium oxalate	the occurrence of acids, oleates, oxalates and proteins indicate the addition of an organic compound; most probably whey
BZ050.1	4.1 2	78% gypsum, 18% anhydrite, 4% quartz	<i>main components:</i> O, S, Ca <i>secondary components:</i> C, Na, Al, Si, Cl, Fe, Sr	<i>main component:</i> gypsum <i>secondary components:</i> hemihydrate/ anhydrite, calcite, calcium oxalate	-
BZ058.2h	5 4	65% gypsum, 32% anhydrite, 3% quartz	<i>main components:</i> O, S, Ca <i>secondary components:</i> C, Si	<i>main component:</i> gypsum <i>secondary components:</i> quartz, calcite, hemihydrate/ anhydrite	-
BZ058.2d	5 3	41% gypsum, 27% quartz, 15% calcite, 8% anhydrite, 3% albite, 3% clinocllore, 3% muscovite	<i>main components:</i> C, O, S, Ca <i>secondary components:</i> Na, K, Al, Si, Fe, Sr	<i>main component:</i> gypsum, calcite (mol ratio 1:1), clay minerals, quartz	-
BZ059	5.0 4	45% gypsum, 29% quartz, 15% calcite ; 5% albite, 2% muscovite, 2% clinocllore	<i>main components:</i> C, O, S, Ca <i>secondary components:</i> Na, Mg, Al, Si, P, Cl, K,	<i>main components:</i> gypsum, calcite and quartz <i>secondary components:</i> long-chain unsaturated fatty acids, calcium	the detected nitrates and phosphorous may be due to infiltration of excrements; the acids, oleates,

				Fe	oleate and protein, calcium oxalate, potassium and sodium nitrate	oxalates and proteins probably indicate the addition of whey
BZ065.1	4.0	1	99% gypsum, < 1% anhydrite, < 1% quartz	<i>main components:</i> gypsum O, S, Ca <i>secondary components:</i> C, Na, Mg, K, Sr	<i>main component:</i> gypsum <i>secondary components:</i> calcite and quartz	the detected strontium (celestine) may indicate the addition of celestine crystals
BZ071h	7	1	95% gypsum, 2% quartz, 2% anhydrite, 1% muscovite	<i>main components:</i> gypsum O, S, Ca <i>secondary components:</i> (varying Na, Al, Si, K percentages), quartz, calcium oxalate	<i>main component:</i> - <i>secondary components:</i> calcite	-
BZ071d	7	1	94% gypsum, 3% anhydrite, 3% quartz	<i>main components:</i> gypsum O, S, Ca <i>secondary components:</i> hemihydrate/Na, Al, Si, K anhydrite, calcite, quartz	<i>main component:</i> - <i>secondary components:</i> gypsum	-
BZ076	7	5	53% quartz, 17% calcite, 13% albite, 8% gypsum, 4% anhydrite, 3% clinocllore, 2% muscovite	<i>main components:</i> C, O, Al, Si, S, K, Ca, Fe <i>secondary components:</i> Na, Mg, Cl	clay minerals, clusters of lime, gypsum, iron silicates	-

3.1 Characteristics of Particular Samples

In table 1, examples of the five defined groups are briefly presented. The results show the composition of the mortars and the percentages of crystalline components. However, some samples show additional features. Three samples have been chosen for further analyses. Sample BZ028, a joint mortar, was taken on the exterior of the building, BZ059 from one of the mortar plates in the ceiling construction (Fig. 2). Sample BZ065.1 represents a pure gypsum mortar which was affected by heat.

BZ028 (Table 1, Fig. 6): The white outdoor gypsum mortar shows moderately sorted grains in a homogeneous matrix with low porosity. The aggregates consist of natural xenomorphic and partly idiomorphic gypsum and anhydrite crystals (approximately 80%) measuring up to 0.2 cm.

Using FTIR microscopic spectroscopy, a residue of the organic add-on could be identified. The extraction of the powder using organic solvents (methanol, methyl ethyl ketone) resulted in a mixture of long-chain unsaturated fatty acids, calcium oleate and protein. The spectrum of substances is a strong hint for the addition of an organic compound. Most probable is the add-on of whey. The organic modified binder might have been used to refine the plaster and to improve its properties. The detected oxalates are assumed to be the result of the microbially induced corrosion of calcite forming a precipitation of calcium oxalate underneath the surface layer of secondary precipitated gypsum.



Fig. 6 Sample no. BZ028, 50x



Fig. 7 Sample no. BZ059, 50x

BZ059 (Table 1, Fig. 7): the FTIR-spectrum bears great resemblance with sample no. BZ028. The occurrence of calcium oxalate in combination with calcium oleate and proteins indicates the use of whey.

BZ065.1 (Table 1, Fig. 8): This sample represents an extremely pure and homogeneous gypsum mortar of very low porosity. Only few gypsum crystals were added, measuring up to 0.5 cm. Celestine was detected in the sample using SEM and EDS. The yellowish-brownish colour of the white mortar is a result of its location at the bottom side of a chimney opening [5].

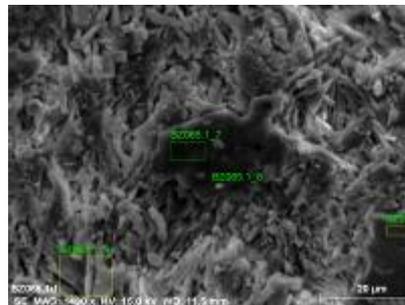


Fig. 8 Sample no. BZ065.1, polished section, 50x (left), SEM image (right)

4 Conclusion

Regarding all samples taken at the Khoja Zainuddin Mosque, it can be stated that the mortars contain important percentages of gypsum. As the geographical factor surely played an essential role in the 16th and 17th century, it can be assumed that the natural deposits in the region of Bukhara were consistently exploited.

A great number of samples show a rather homogeneous gypsum matrix with gypsum and anhydrite as aggregates in different proportions (type 1-3). In some cases, gypsum-lime mortars (gypsum-lime ratio nearly equals 1:1) were applied (type 4). The high lime percentage is due to lime clusters that were intentionally added [6]. They can be clearly identified within the homogeneous matrix using cross section analysis (Fig. 7). In addition, clay mortars were mainly used for the masonry. In contrast to the extremely hard and well preserved gypsum mortars, the latter contain only little percentages of binding material (type 5).

Considering the mortar samples in the historical context and comparing the different compositions, it is evident that the pure gypsum mortars were applied in early construction phases while the composite mortars appear in later phases. The latter are mostly situated in the ceilings and particularly in the lower layers (Fig. 2). Organic compounds were obviously added (see BZ059) in order to increase the properties of the mortar, likely to improve its mechanical stability and water resistance [7, 8]. However, the same components were also applied for external mortars (see BZ028). The use of whey is suggested, although animal milk products are still – and surely were – an extremely valuable addition for simple building materials. If so, the thesis of the importance of the Khoja Zainuddin Mosque as one of the most significant buildings of 16th century in Bukhara might be supported.

5 References

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6 Sources

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