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Mineralogical Investigations on Loam Plaster Fragments of the Destroyed Buddha Statues at Bāmiyān, Afghanistan

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Introduction

No detailed investigations on the techniques and materials used as loam plaster and potential restoration existed before the destruction of the two Buddha figures at Bāmiyān. Many fragments of loam plaster were collected from the debris, however, without knowledge of their original position on the figures. Some undestroyed plastered areas exist only on the Eastern Buddha.

The aim of this study is a mineralogical characterization of individual loam coating layers and if possible, a reconstruction of various phases of renovation on the basis of material specific differences. A comparison with local loam samples from the Bāmiyān valley may help in determining the provenience of the raw materials at the time of construction. This contribution presents the results of a study in the interdisciplinary seminar at Lehrstuhl für Restaurierung, Technische Universität München (TUM), under the guidance of Prof. E. Emmerling und S. Pfeffer during the winter term 2007/2008 and summer term 2008.

Sample materials

We studied 175 fragments from the Western Buddha and 104 fragments from the Eastern Buddha. The internal structure of the loam plaster was investigated using a binocular microscope.

The plaster fragments mostly have a size of about 6 x 4 cm. The majority of fragments show two layers with an undercoat and an overlying finish coat (tab. 1). Few fragments consist only of one of the two layer types. Three fragments display three layers with an undercoat and two finishing coats. The additives in the loam plaster are straw, chaff or other plant fragments, and animal hair (goat, sheep). Often remnants of paint layers are preserved. Representative samples were chosen for more detailed examination and analysis (tab. 2).

The loam plaster fragments cannot easily be distinguished on the basis of their colour. The loam fragments of the Eastern Buddha are, however, often slightly more greyish, while that of the Western Buddha is more yellowish (fig. 1). The most common colour is 10YR 7/3 on the Munsell colour chart system.

The specific weight of the two loam plasters from the two Buddha statues is slightly different. Samples with a size of 7 x 4 x 3 cm^3 from the Western Buddha weigh about 5 g more than samples of comparable size from the Eastern Buddha. The loam mixture of the Western Buddha is probably more compact. In all investigated fragments from the Western Buddha only grass has been added, while straw dominates as a plant additive in the Eastern Buddha.

In addition to the fragments of the Buddha statues, we investigated samples from several loam occurrences in the surroundings of Bāmiyān collected by E. Melzl. They derived from deposits that were most probably used in former times:

– **Khami-Kalak**: to the west in the Bāmiyān valley near Deh-e-Mullah-Golam in the alluvium of the Bāmiyān river
– **Surkh-kul**: first tributary valley to the west of the Western

Table 1 Differences between undercoat and finish coat

undercoat	finish coat
• thickness: up to 10 cm	• thichness: 0.5 to 5 mm
• often greyish, lighter	• often yellowish, darker, very compact and hard
• additives: straw, hair, sand	• additives: sand, hair
• uneven distribution of additives; partly in sheaves; hairs: light, dark, thin and thick	• hair: fine, light
• sand content: low	• sand content higher than in undercoat
• more inhomogenous and less compact	• black grains: inorganic as well as organic (charcoal)
• carbonate concretions	• mica

Table 2 Sample list

sample number	origin	selection criteria / description	layer type	grain size sample no.	XRD sample no.
1	Western Buddha		undercoat finish coat		1 – 301 1 – 302
11	Western Buddha	only finish coat	finish coat	11 – 1001	11 – 501
26	Western Buddha	reference fragment	undercoat finish coat	26 – 1001 26 – 1002	26 – 501 26 – 502
38	Western Buddha	finish coat similar to sample 55	undercoat finish coat	38 – 1001 38 – 1002	--- 38 – 502
43	Western Buddha	very light undercoat	undercoat finish coat	43 – 1001 43 – 1002	--- ---
55	Western Buddha	finish coat similar to sample 28	finish coat	55 – 1002	55 – 502
63	Western Buddha	exceptional sample: paint layer different from other fragments, finish coat darker, sand additives finer	undercoat finish coat	63 – 1001 63 – 1002	63 – 501 63 – 502
65	Western Buddha	very thin finish coat; reddish inclusion in undercoat	coarse loam plaster	65 – 1001	65 – 501
84	Western Buddha	coarse layer is not a loam plaster	undercoat finish coat	84 – 1001 84 – 1002	84 – 501 84 – 502
117	Western Buddha	colour different from other fragments	undercoat finish coat	117 – 1001 117 – 1002	117 – 501 117 – 502
159	Western Buddha	finish coat is not a loam plaster; rare colour coat type	undercoat thin dark brown layer	159 – 1001	159 – 501 159 – 502
174	Western Buddha	exceptional large schist fragment from the undercoat	undercoat finish coat		174 – 501
2	Eastern Buddha	reference fragment	undercoat finish coat	2 – 1001 2 – 1002	2 – 501/301 2 – 502/302
3	Eastern Buddha	three layers	undercoat finish coat (upper) finish coat (lower)	3 – 1001 3 – 1002 3 – 1003	3 – 301 3 – 302 3 – 303
200	Eastern Buddha	three layers	undercoat (brownish) finish coat undercoat (reddish)	200 – 1001 200 – 1002 200 – 1003	200 – 501 200 – 502 200 – 503
205	Eastern Buddha	colour different from other fragments	undercoat finish coat	205 – 1001 205 – 1002	--- ---
224	Eastern Buddha	probably not a loam plaster	undercoat (brownish) finish coat (reddish)	224 – 1001 224 – 1002	224 – 501 224 – 502
277	Eastern Buddha	reference fragment	undercoat	277 – 1001	---
278	Eastern Buddha	reference fragment	undercoat	278 – 1001	278 – 501
279	Eastern Buddha	reference fragment	undercoat	279 – 1001	279 – 501
280	Eastern Buddha	reference fragment	undercoat	280 – 1001	/
281	Kakrak Buddha	reference fragment for comparison with the two Buddha statues of Bamiyan	undercoat	281 – 1001	281 – 501
270	Keule Kochak	loam sample			270 – 301
271	Khami-Kalak	loam sample			271 – 301
272	Surkh-Kul	loam sample			272 – 301
273	Regishad	loam sample			273 – 301

Buddha, approx. 150 m from the Western Buddha
– **Keule Kochak**: between Surkh-kul and the Western Buddha
– **Regishad**: alluvium of the Bāmiyān river, approx. 1 to 2 km west of the Western Buddha

Analytical methods

In order to characterize the composition of the various loam plaster fragments, we analyzed their mineralogical composition, using powder X-ray diffraction analysis and grain size distribution as well as a laser diffraction analysis system. We examined 19 loam plaster fragments and their individual layers. The selection was based on optical differences, such as colour of the plaster, type and amount of additives and layer sequence. Six samples come from the Eastern Buddha, 13 from the Western Buddha. For comparison, a fragment of the Buddha in the Kakrak valley that consists exclusively of undercoat was included in the study. This fragment has a slightly different colour and coarser pebbles as compared to the undercoats of the Bāmiyān Buddha statues.

Particle size distribution
As the investigated loam plaster samples were generally too small and also too fine-grained for conventional sieve analysis, we chose a laser-based particle size analyzer to determine the particle size measurement. We used a HORIBA LA–950 particle sizer based on static light scattering that covers a particle size range from 0.01 µm to 2 mm and requires less than 1 g of material for analysis.

As the different loam plaster layers were inhomogeneous, we took several small samples from various parts of the fragments and mixed them thoroughly. The organic additives of hairs or plant material and rare coarse sand grains were removed using tweezers as they would infer with the measurement. The samples were disaggregated in sodium polyphosphate solution containing 3 g sodium polyphosphate in 15 ml deionized water using a ultrasonic bath. Every sample was measured three times and the results averaged. The results are presented as particle size distribution and the cumulative distribution.

X-ray diffraction analysis
The sample was gently disaggregated by hand using an agate mortar and sieved (< 0.25 mm) to separate organic additives, such as hairs or straw. If sample material was very limited, the sample was ground with an agate mortar by hand and the powder was fixed on a glass slide using acetone ('smear mount'). If enough sample material was available, two grams of the sample were ground for 8 minutes with 10 ml of isopropyl alcohol in a McCrone Micronising Mill using agate cylinder elements. The suspension was filtered, dried, and homogenized in an agate mortar ('powder mount').

The XRD analyses (2–70° 2θ) were performed on top-loaded powder mounts using a Philips-Panalytical PW 1800 X-ray diffractometer (CuKα, graphite monochromator, 10 mm automatic divergence slit, step-scan 0.02° 2θ increments per second, counting time 1 s per increment, 40 mA, 40 kV). For more detailed clay mineralogical investigations, a sample aliquot was dispersed using an ultrasonic bath in a 0.1 molar aqueous ammonium solution. The < 2 µm fraction was separated by sedimentation in Atterberg cylinders. The oriented clay mineral aggregates were prepared by sedimentation and air-drying of the aqueous suspension on glass slides ('oriented mount'). X-ray diffraction scans (2–20° 2θ) were performed on an air-dried, a glycolated (24 hours in saturated glycol vapor at 80 °C), and a heated sample (3 hours at 550 °C).

The identification of crystalline mineral phases was carried out using the characteristic diffraction lines and their d-values with the program IDENTIFY (Philips-Panalytical). Clay minerals were identified using the basal diffraction lines

Fig. 1. Loam plaster fragments of the Eastern Buddha (sample 278, left) and the Western Buddha (sample 280, right) [Höfle, Thiemann]

on oriented mounts and their changes on glycolization.

Two different methods were conducted for quantification of crystalline phases. A small subset of 11 samples were analyzed using relative intensities of single mineral peaks at the Zentrallabor, Bayerisches Landesamt für Denkmalpflege, Munich, (Vojislav Tucic, analyst). This method yields, however, only semiquantitative results. The calcite content was determined for these samples by digestion of the carbonate in 10 wt. % acetic acid and weighing. The quantification of mineral content for most samples (23) was accomplished by the Rietveld method using the program BGMN (Bergmann et al. 1998).

Results

Particle size distribution

Four groups can be defined on the basis of the characteristic particle size distribution patterns shown in figure 2 and table 3. All groups have two characteristic peaks in the size distribution at 0.3 to 0.4 µm and 4 to 5 µm corresponding to the clay fraction and fine silt fraction, respectively. The four groups are distinguished on the variable contents of middle to coarse silt and fine sand fractions. Group 1 has a clearly visible shoulder at about 20 µm and a very small peak (0.2 to 1.2 %) at about 250 µm. In group 2, however, the shoulder at 20 µm is poorly visible and the 250 µm peak is well developed (2.4 to 3.4 %). Almost no particles are found in the 50 to 100 µm interval. Group 3 also has a large 250 µm peak (2.4 to 3.4 %), but an almost continuous distribution of particle sizes between 10 and 100 µm. Group 4 has a very broad peak between 250 and 700 µm that amounts to less than 1 %.

A few samples (84 and 224) cannot be attributed to any of the four groups. They are, as shown below, not original loam plasters, but restoration materials.

All group 1 samples are undercoats, while almost all group 2, 3 and 4 samples are finishing coats with the exception of sample 159. This indicates that in almost all finish coats a fine to medium-sized sand was added mostly to avoid shrinkage cracks. The group 3 and 4 patterns are relatively rare and can be attributed to optically unusual samples (ID 43, 63, 117, 159, 205). Group 4 pattern is only observed at the Western Buddha, while group 3 finish coats come from both Buddha statues.

X-ray diffraction analysis

The investigated loam plaster samples consist mainly of quartz, calcite, feldspars (orthoclase and albite), mica (muscovite), clay minerals, and trace amounts (<2 wt.%) of

Fig. 2. Particle size distribution (blue) and cumulative distribution (pink) curves of the four character groups of loam plaster fragments of the Bāmiyān Buddha statues

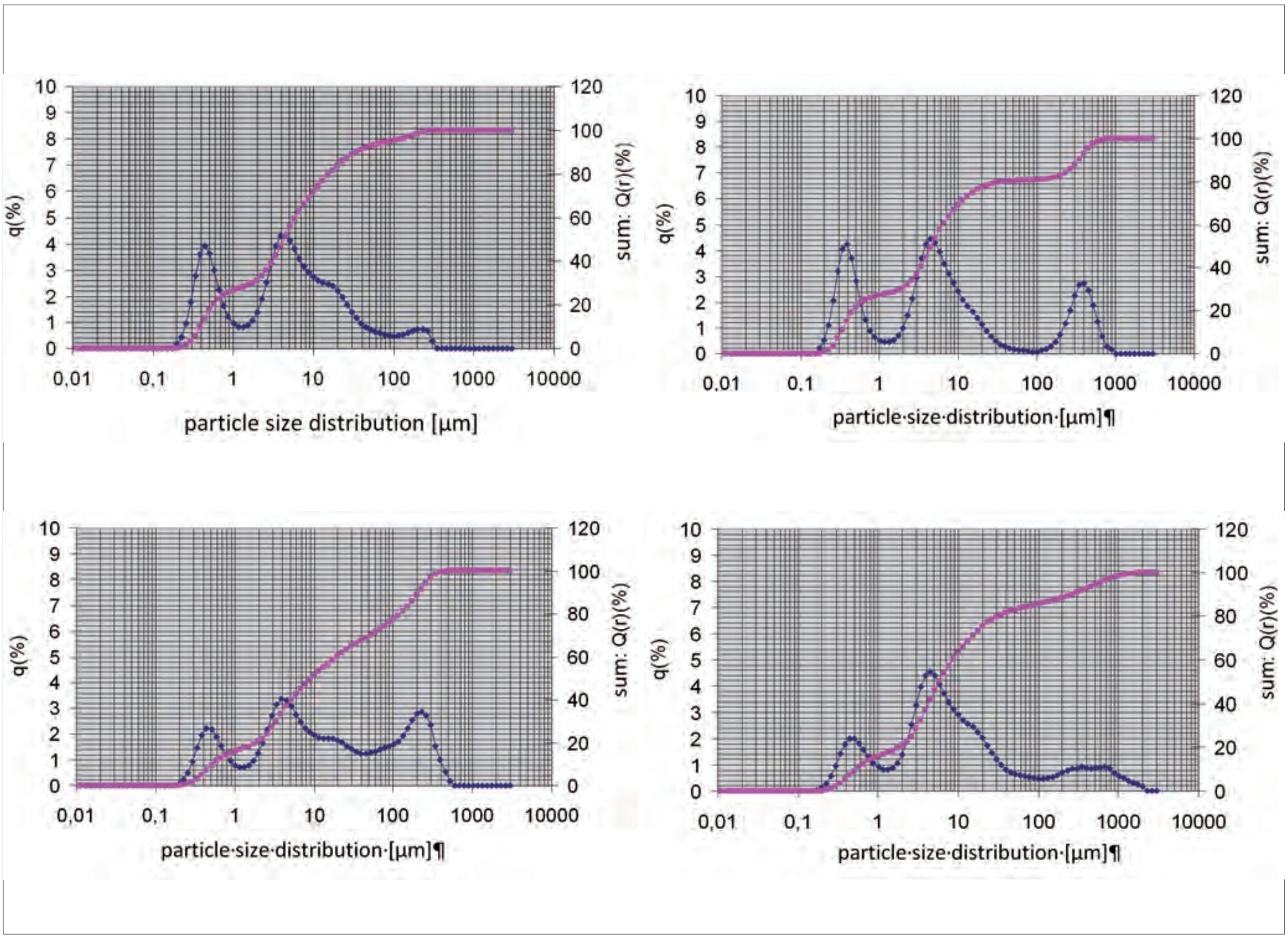

Table 3 Results of particle size distribution analyses

sample number	origin	layer type	analysis number	group
11	Western Buddha	finish coat	11 – 1001	2
26	Western Buddha	undercoat finish coat	26 – 1001 26 – 1002	1 2
38	Western Buddha	undercoat finish coat	38 – 1001 38 – 1002	1 2
43	Western Buddha	undercoat finish coat	43 – 1001 43 – 1002	1 4
55	Western Buddha	finish coat	55 – 1002	2
63	Western Buddha	undercoat finish coat	63 – 1001 63 – 1002	1 3
65	Western Buddha	undercoat	65 – 1001	1
84	Western Buddha	undercoat finish coat	84 – 1001 84 – 1002	- -
117	Western Buddha	undercoat finish coat	117 – 1001 117 – 1002	1 4
159	Western Buddha	undercoat	159 – 1001	3
279	Western Buddha	undercoat	279 – 1001	1
280	Western Buddha	undercoat	280 – 1001	1
3	Eastern Buddha	undercoat finish coat (upper) finish coat (lower)	3 – 1001 3 – 1002 3 – 1003	1 2 2
200	Eastern Buddha	undercoat (reddish) finish coat undercoat (greyish)	200 – 1001 200 – 1002 200 – 1003	1 2 2
205	Eastern Buddha	undercoat finish coat	205 – 1001 205 – 1002	1 3
224	Eastern Buddha	undercoat (brownish) finish coat (reddish)	224 – 1001 224 – 1002	- -
277	Eastern Buddha	undercoat	277 – 1001	1
278	Eastern Buddha	undercoat	278 – 1001	1
281	Kakrak Buddha	undercoat	281 – 1001	1

Table 4 Mineral composition of loam samples and plaster fragments based on semiquantitative XRD analysis

loam samples								
sample number	**quartz**	**calcite**	**mica**	**albite**	**chlorite**	**hornblende**	**gypsum**	**calcite***
270	50	25	11	6	8	-	-	28
271	62	14	8	9	7	-	-	13
272	66	11	10	9	4	-	-	14
273	51	22	10	10	7	-	-	24

loam plaster fragments									
sample number	**origin**	**quartz**	**calcite**	**mica**	**albite**	**chlorite**	**hornblende**	**gypsum**	**calcite***
undercoats									
1	WB	49	30	9	9	3	-	-	28
2	EB	51	27	9	9	3	1	-	25
3	EB	45	31	9	11	4	-	-	31
finishing coats									
1	WB	63	9	10	12	4	1	1	11
2	EB	68	6	10	14	2	-	-	8
3 lower	EB	56	19	11	11	3	-	-	22
3 upper	EB	61	13	9	15	2	-	-	16

* Calcite content determined by the acid digestion method
WB: Western Buddha; EB: Eastern Buddha

Table 5 Mineral composition of plaster fragments based on XRD analyses using the Rietveld method

sample number	origin	quartz	calcite	mica illite	feldspars (albite, orthoclase)	clay minerals (K, C, S)	hematite	gypsum	anhydrite
undercoats									
26	WB	49	14	14	14	8	1	-	-
63	WB	29	34	10	15	13	<1	-	-
65	WB	33	23	12	14	16	<1	-	-
117	WB	47	14	14	15	11	<1	-	-
279	WB	37	15	10	16	17	<1	-	-
2	EB	32	31	13	14	9	<1	-	-
200	EB	28	31	12	14	13	-	-	-
224	EB	15	6	7	22	2	-	25	21
278	EB	27	33	12	14	14	<1	-	-
281	KB	39	-	16	16	22	<1	-	-
finish coats									
11	WB	54	2	19	18	6	1	-	-
26	WB	55	4	17	17	8	<1	-	-
38	WB	52	3	13	21	12	1	-	-
55*	WB	49	3	14	19	14	1	-	-
63*	WB	44	11	9	21	12	1	-	-
84#	WB	24	11	9	22	13	-	19	1
117#	WB	30	4	15	36	14	1	-	-
2	EB	53	4	18	18	7	1	-	-
200	EB	38	5	15	18	12	<1	-	-
224	EB	18	4	10	4	-	-	39	26

smear mount, large uncertainties * conatains about 1% honrblende K: kaolinite; c: chlorite; S: smectite
WB: Western Buddha; EB: Eastern Buddha; KB: Kakrak Buddha

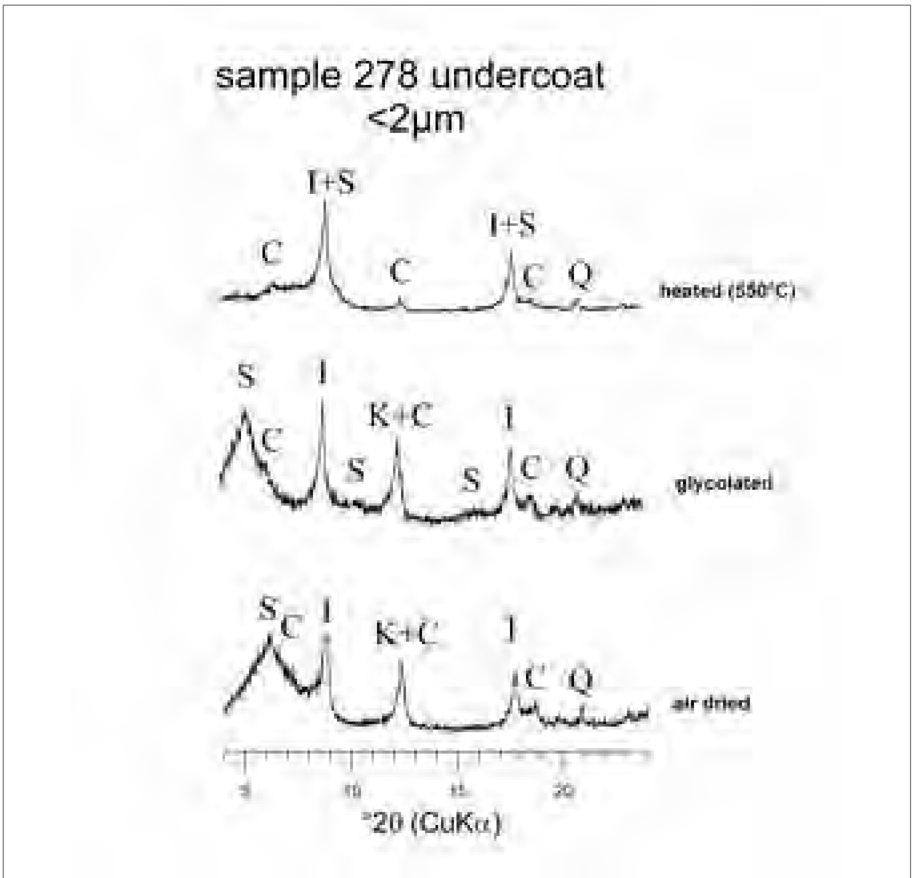

Fig. 3. XRD patterns of air dried, glycolated, and heated oriented mounts (sample 278, undercoat) showing the presence of smectite (S), illite (I), chlorite (C), kaolinite (K) and traces of quartz (Q).

other phases such as hematite, amphibole (hornblende), and gypsum. Detailed investigation on two < 2µm-fractions show that the dominant clay minerals are illite, chlorite, kaolinite and smectite (fig. 3). In a few samples (ID 84, 159 and 224), gypsum, anhydrite, and amorphous materials could be detected in major quantities suggesting that these fragments contain filling materials added during the Indo-Afghan restoration (1969-1978). The results of the semiquantitative analysis are presented in table 4, while the results of Rietveld approach are shown in table 5. The carbonate contents determined by the semiquantitative method are in good agreement with the independent measurements using the acetic acid digestion method. The two layers of sample ID 2 were analyzed by both quantification methods. The results are comparable considering the problems of sample aliquotation and heterogeneity, but clay mineral, mica, and feldspar contents were slightly underestimated by the semiquantitative method, and consequently the quartz contents were overestimated.

Nevertheless, the mineralogical composition of all investigated loam rendering fragments is very similar with major variations being detected mainly in the carbonate and quartz contents. The quartz contents of the finish coats (38 to 68 wt. %) are generally higher than those of the undercoats (15 to 51 wt. %). A sample with an unusual particle size distribution pattern of group 4 (low fine sand fraction) shows a relatively low quartz content (30 wt. %). The calcite content of the undercoats ranges from about 14 to 33 wt. %, while the finish coats have less than about 19 wt. % calcite. No significant differences were observed between the loam plasters of the Western and the Eastern Buddha. The higher quartz contents of the finish coats indicate the addition of quartz sand.

The local loam samples have very similar mineralogical compositions as the loam plaster fragments suggesting that the plaster material was locally sourced.

The single undercoat sample from the Kakrak Buddha, however, reveals no calcite and a high clay mineral content. This might indicate a different mud source for the coating of this Buddha; however, further investigations are warranted.

Conclusions

Microscopic, granulometric, and x-ray diffraction analyses of loam plaster fragments from the two Bāmiyān Buddha statues have shown that two distinct loam coatings exist. Both consist mainly of quartz, calcite, mica, feldspars (albite, orthoclase), clay minerals (illite, chlorite, kaolinite, smectite) and accessory hornblende, hematite and gypsum with additives of plant fragments (straw, chaff) and animal hairs. However, the undercoats clearly show lower quartz contents and lower proportions of fine to middle sand fractions as compared to the finishing coats. This suggests that fine quartz sand has been added to mud. Additionally, the finish coat appears more compacted and is devoid of coarse additives.

A few fragments contain major amounts of gypsum, anhydrite, and some amorphous substances that were probably added as filling materials during the Indo-Afghan restoration campaign (1969–1978).

Mineralogical analyses of neighbouring alluvial material show that the raw materials for preparation of the loam plasters of the two Bāmiyān Buddha statues were locally derived.

Acknowledgements

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The particle size distribution was analysed firstly at Retsch Technology GmbH, 42781 Haan, Germany. Further analysis was performed at the University of the Federal Armed forces, Institut für Wasserwesen, Munich, with the support of Steffen Krause and Christina Schwarz.

Fig. 1. Grains and husks from the coarse clay of the Eastern Buddha

Fig. 2. Wheat (*Triticum aestivum*) from the Eastern Buddha

Fig. 3. Barley (*Hordeum vulgare*) from the Eastern Buddha