Jinchuanwan Grotto

Jinchuanwan Grotto

Annual Report 2010–2013

BMBF Project 01 UG1 001

Technische Universität München,
Lehrstuhl für Restaurierung, Kunsttechnologie und Konservierungswissenschaft

Xi'an Center for the Conservation and Restoration of Cultural Heritage

GEFÖRDERT VOM

Bundesministerium
für Bildung
und Forschung

Technische Universität München

Herausgeber: Technische Universität München, Lehrstuhl für Restaurierung, Kunsttechnologie
und Konservierungswissenschaft, Oettingenstr. 15, 80538 München
www.rkk.arch.tu-muenchen.de

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Redaktion: Katharina Meier zu Verl, Dr. Mathias Kocher, Prof. Dipl.-Restaurator Erwin Emmerling
Satz und Layout: Katharina Meier zu Verl
Umschlaggestaltung: Dipl.-Restaurator Felix Horn

Content

Examination of stone consolidation materials for Jinchuanwan Grotto, Shaanxi Province, China

Martin Mach, Erwin Emmerling, Mathias Kocher, Katharina Meier zu Verl

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Introduction

This Report is to be regarded as a follow-up analytical evaluation to the „Untersuchung chinesischer Gesteinsproben aus der Jinchanwan Grotte, Provinz Shaanxi“ [Examination of stone samples from Jinchuanwan Grotto, Shaanxi Province, China]. The aim is to find a consolidation material similar to Jinchuanwan sandstone by comparing different stone consolidation systems. The material is to be identified through appropriate analyses, providing a recommendation for the conservation work in Jinchuanwan. The laboratory tests on the stone consolidation materials produced are discussed below and compared with the specific stone values obtained for Jinchuanwan sandstone.

Stone consolidation materials

Condition of the stone consolidation material

The Jinchuanwan sandstone is basically a carbonatic sandstone with little amount of feldspar. It is slightly grey-green coloured with dark biotite inclusions. The analysed compounds of the stone are 40 % quartz, 40 % calcite, 10 % alkali feldspar, 5 % biotite, glimmer as well as 5 % float pieces of stone (mikroquartz and cliff, alkali feldspar
with partial kaolinite formation).

The stone consolidation material to be developed should be similar to the original sandstone in Jinchuanwan and should fit optically into the image of the grotto. This can happen through pigmenting the material already through the production process, but also through retouching it on the wall after restoration. To make this possible a good handling and cleavability of the plaster should be required, which would lead to an easy application of it to vertical walls.
The stone consolidation material should have similar specific physical values as the original stone, but compression and flexural strength, as well as the E-modulus shouldn’t be higher than the values of the original stone, but rather show the trend of being slightly more elastic and having better water vapor permeability. Thermical und hygric dilatation should also show similar result as the natural stone. The adhesion of the consolidation material on the stone surface needs to be lower than the surface flexural strength of the stone. Aging phenomena, like alteration of the surface should proceed similar in type and time as on the original stone. Another benefit would be the possibility of an additional treatment with corresponding consolidation or hydrophobizing materials.

Five different stone consolidation materials were selected for closer examination. Alongside the known silicic acid ester (SAE) systems, other stone restoration materials (e.g. trass) were also examined for suitability.

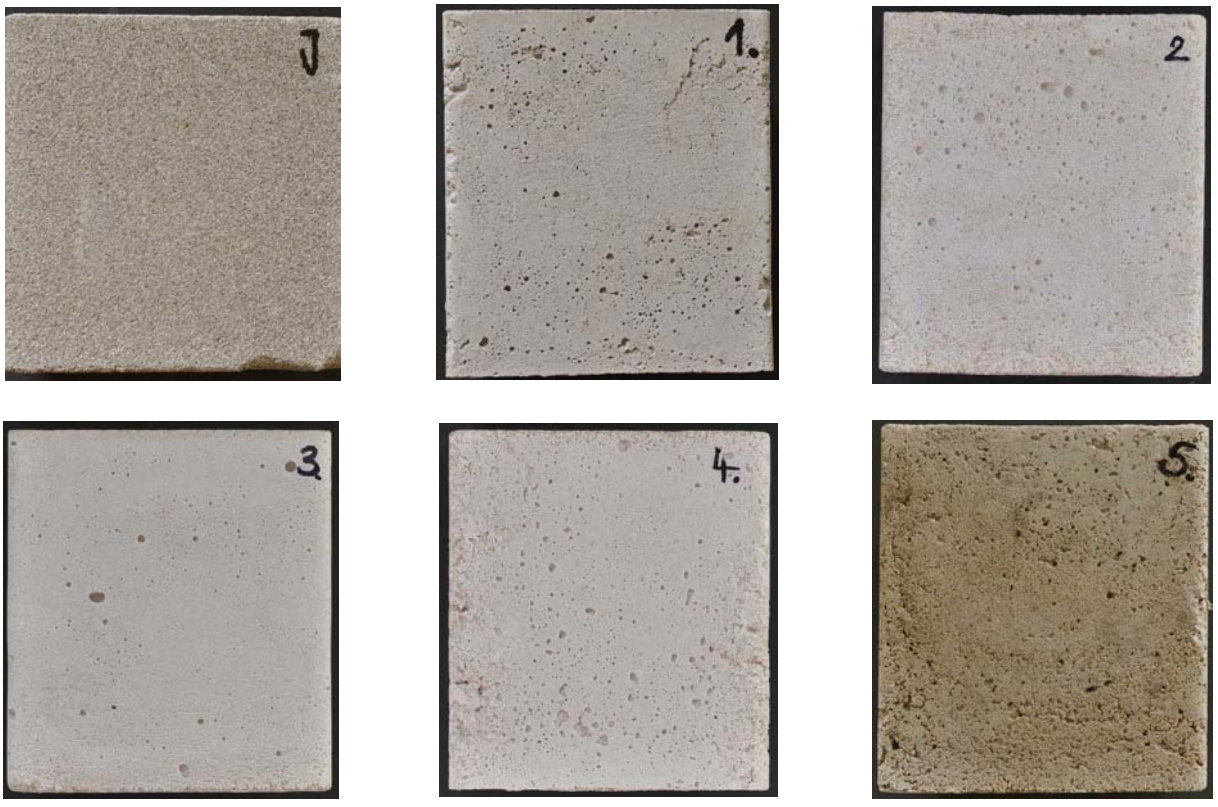


Fig. 1-6: Jinchuanwan sandstone and the five stone consolidation materials analysed, image scale 1:1

Description of the stone consolidation materials

Stone consolidation material 1 consists of Remmers "SAE Module System".
The SAE Module System is based on silicic acid ester (also silicic acid ethyl ester). The effect of the stone strengthener is based on the reaction of the silicic acid ester with water, forming a strengthening silica gel. Ethanol is released as a by-product, and evaporates. The putty in the module system is composed of a Remmers filler combination, quartz sand, ground stone powder and SAE 500 (elasticised stone strengthener).
The putty mixture is made up of 70 g filler A (Mineralpowder), 40 g filler B (Quartzpowder), 150 g quartz powder (Remmers quartz powder F 36) and 150 g ground stone powder produced from Jinchuanwan sandstone (manual crushed, grain distribution graph in annex on p. 35). It is mixed with 100 ml SAE 500 producing a crumbly putty which is difficult to work; the colour is slightly lighter and greyer than Jinchuanwan sandstone.

Stone consolidation material 2 consists of „Remmers restoration plaster".
Remmers restoration plaster is a ready-to-use dry mortar of mineral raw materials. It is made for reprofiling alterated sandstones and for reproduction of building ornaments, sculptures etc.
For the stone consolidation material compression strength „normal" (after 28 days the material should have a compression strength of < 13 N/mm²) was used. The grain sizes have their maximum at 2,0 mm and the colour name is „grey". The mortar is mixed with water into a paste. Hardened it is slightly lighter and less green than the Jinchuanwan sandstone.

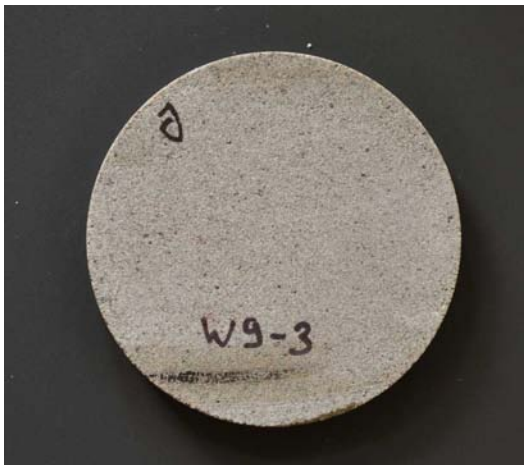
Stone consolidation material 3 consists of „Remmers restoration plaster GF".
Remmers restoration plaster is a ready-to-use dry mortar, which is build up from stone-building minerals. It is produced for exact copying of an original piece of stone by casting method. Flexural strength (after 28 days ca. 5 N/mm²) and compression strength (after 28 days ca. 18 N/mm²) are declared. The consolidation material is used in the colour "grey" and mixed with water into a paste. The colour after the hardening process is slightly grey.

Stone consolidation material 4 consists of „Minéros Grout".
Minéros Grout is a trass-based grout prouduced by the company Krusemark. According to the product information it has high elasticity and particularly high water vapour permeability. It is delivered in different strength groups and grain sizes.
For the stone consolidation material, strength group III (compression strength > 20 N/mm²) and a grain < 0,5 mm was used. The mortar is mixed with water into a paste, so it can be easily worked. Hardened the material shows a grey colour.

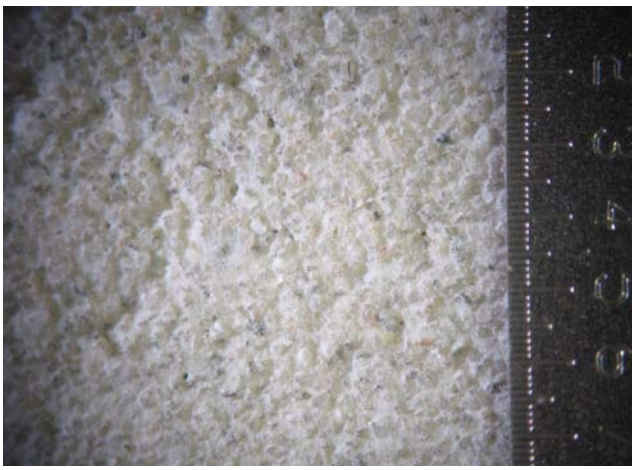
Stone consolidation material 5 consists of „M75 pitch plaster" by the Dutch company Jahn Produkten & Systeemontwikkeling BV. According to the product information it has been developed for the production of statues, sculptures and ornaments in connection to materials like marble, lime or sandstone. The mortar contains mineralic compounds, is low-shrinking and has a high humid and salt resistance.
To the dry pitch plaster there was added 3 % of pigment (KREMER „Umbra green dark" to KREMER „Umbra nature italian" in ratio 1:1). The mortar is mixed with water into a paste, so that it can be easily worked. Hardened the material shows a grey-green colour.

Macroscopic images

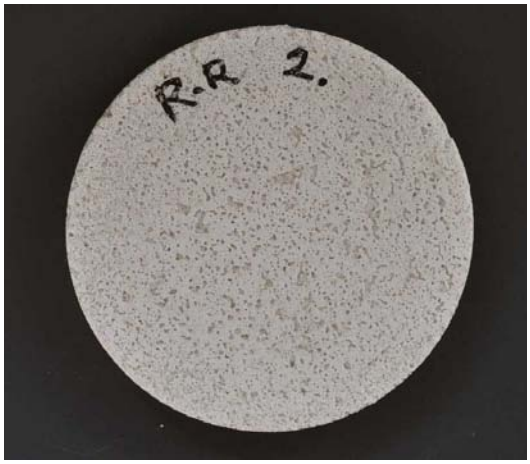
The stone consolidation materials were photographed macroscopically for comparison with Jinchuanwan sandstone (images on the right). On stone consolidation material 1, which has got the Jinchuanwan sandstone powder as a filling material, the colour is already adjusted to the original sandstone and to stone consolidation material 5 there was added 5 % of pigment, to get a colour close to the original stone.

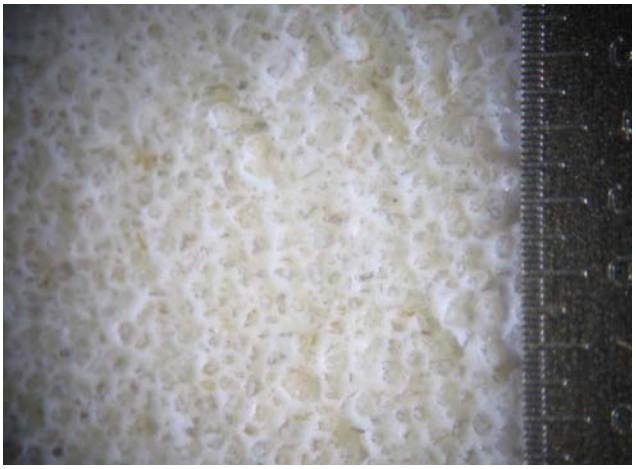


Jinchuanwan sandstone

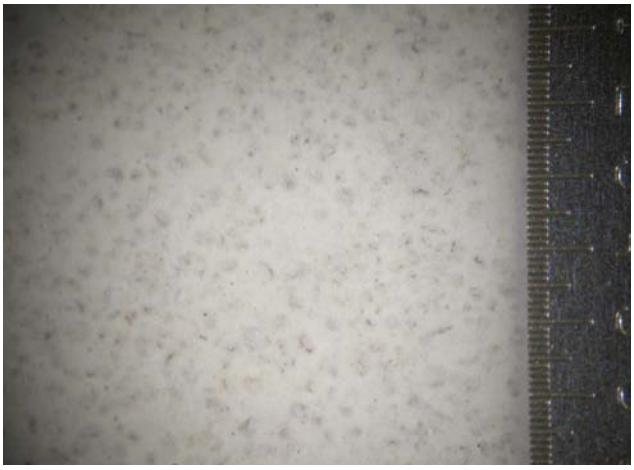


Material 1 (modul system Remmers)

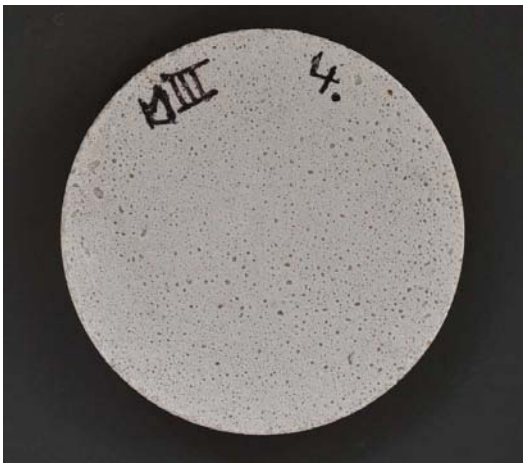


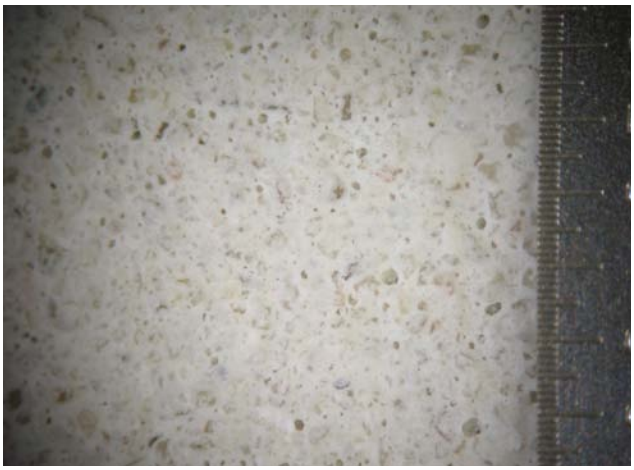


Material 2 (Remmers)

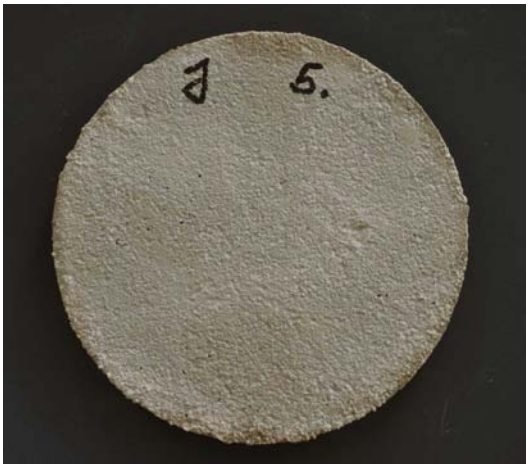


Material 3 (Remmers)





Material 4 (Minéros)



Material 5 (Jahn)

Fig. 7-8: Slice (1:1) of Jinchuanwan sandstone and macroscopic image of Jinchuanwan sandstone
Fig. 9-18: Slices (1:1) of the stone consolidation materials and the related macroscopic images

Note to the laboratory analyses

To examine the specific physical values of the consolidation materials five cubes (5 cm x 5 cm x 5 cm) and 10 slices (Ø 49 mm, 5 mm thick) were produced from each of the above formulas. The individual materials were poured into specially adapted plastic moulds and left to harden under laboratory conditions (20 °C, 60% relative humi dity) for a period of 6 to 8 weeks. Afterwards they were pressed out of the plastic moulds mechanically.

For laboratory analyses each test specimen of each consolidation material was given a number, so that the connection between single specimens from different stone consolidation materials were visual between all analyses as well as the connection between the specimens of one type of consolidation material.

Fig. 19: Production of test specimens

Fig. 20: Production of test specimens

Fig. 21: Test specimens for laboratory analyses

Density and porosity

The better the match between the density of a consolidation or replacement material and the density of the original material, the lower the expected stresses on the area of contact between the two materials.
The same applies to porosity – the closer the porosity of the consolidation material is to the original porosity, the lower the expected stress will be.

To determine the real density, apparent density, porosity and saturation the sample was weighed
- while dry (m_0),
- while saturated with water (saturation under normal conditions) (m_1),
- while saturated with water (saturation after evacuation under vacuum) (m_2), and
- under water (after saturation under vacuum) (m_3).

The difference between the results for weighing under water and weighing while dry provides the volume and hence the density of the material (Archimedes' principle = calculating density through buoyancy).

Density is defined as the ratio of mass to volume.

$$Density = \frac{Mass}{Volume} \qquad \rho = \frac{m}{V} \qquad \left[\frac{g}{cm^3}; \frac{kg}{dm^3}; \frac{t}{m^3}\right]$$

In porous materials a distinction is made between real density and apparent density. Real density is the density of the material not including the pore space. Apparent density, however, relates to the volume of the solid including its pore space.

$$Real\ density = \frac{Mass}{Volume\ of\ solids} \qquad \rho_{Real} = \frac{m_0}{m_0 - m_3} \cdot \rho_{Fl.} \left[\frac{g}{cm^3}\right]$$

$$Apparent\ density = \frac{Mass}{Volume\ of\ solids + pore\ volume} \qquad \rho_{Apparent} = \frac{m_0}{(m_0 - m_3) + (m_2 - m_{0)})} \rho_{Fl.} = \frac{m_0}{m_2 - m_3} \rho_{Fl.} \left[\frac{g}{cm^3}\right]$$

ρ_{Fluid} of water (H_20) at 20 °C = 0.99820 ~ 1 $\left[\frac{g}{cm^3}\right]$

Porosity describes the pore space accessible to water as a percentage of the overall volume of the material.

$$Porosity = \frac{Apparent\ density}{Real\ density} \cdot 100 = \frac{m_2 - m_0}{m_2 - m_3} \cdot 100 \quad [Vol\%]$$

The degree of saturation shows how many pores can be filled with water (under normal conditions), in proportion to the total pore space.

$$Degree\ of\ saturation = \frac{WA_a}{WA_v} \quad [-], \text{ the value always lies between 0 and 1.}$$

Results of the laboratory analyses

Hygric values

Water absorption

The determination of water absorption also allows conclusions to be drawn about the porosity of the stone consolidation materials. To determine porosity the stone consolidation materials were dried to constant mass for 48 hours in a drying cabinet at 60 °C. Before determining the dry weight (m_0) the samples were cooled down to room temperature in a dessicator. Water absorption was then calculated first under atmospheric pressure (WA_a) and then in a vacuum (WA_v).

Fig. 22: Samples being evacuated

Fig. 23: Samples in the dessicator after flooding with water

Water absorption under atmospheric pressure is the maximum possible water absorption of the stone consolidation material under normal pressure. After cooling, the sample is immersed for 48 hours in approximately one to two centimetres of distilled water, in which process the putty absorbs the water through its capillaries until it reaches the surface of the test specimen. By weighing the saturated stone consolidation materials the amount of water absorbed is measured in relation to the weight of the dry sample [mass%].

To calculate water absorption in a vacuum, the consolidation materials have to be evacuated in a dessicator for a minimum of five hours. The dessicator is subsequently flooded with distilled water until the samples are immersed in around five centimetres of water. After 48 hours' immersion in water, the wet weight is determined.

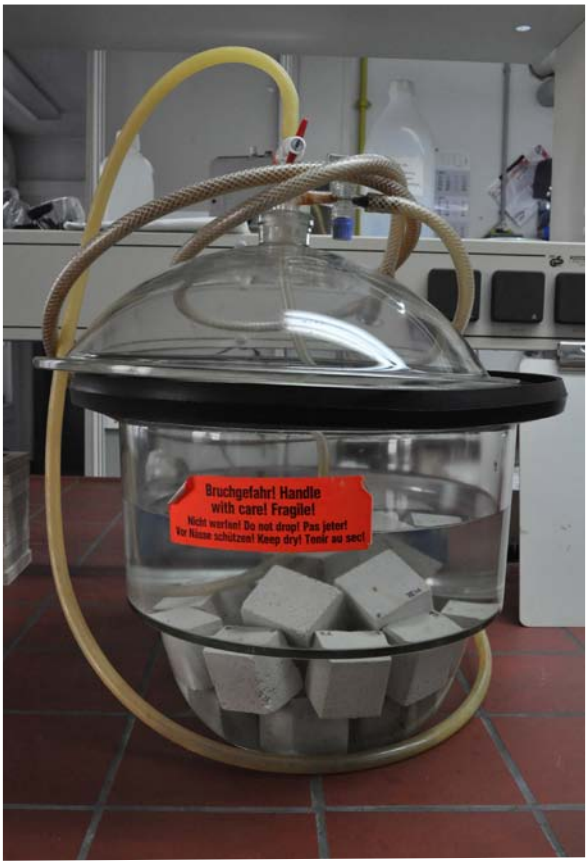


Fig. 24: Samples flooded with water

The following formulas apply:

$$Water\ \ absorption\ \ under\ \ atmospheric\ \ pressure\ WA_a = \frac{m_1 - m_0}{m_0} \cdot 100\ \ [Mass\,\%]$$

$$Water\ \ absorption\ \ under\ \ atmospheric\ \ pressure\ WA_{vol.} = WA_a \cdot Apparent\ \ density\ \ [Vol\,\%]$$

$$Water\ \ absorption\ \ in\ \ a\ \ vacuum\ WA_v = \frac{m_2 - m_0}{m_0} \cdot 100\ \ [Mass\,\%]$$

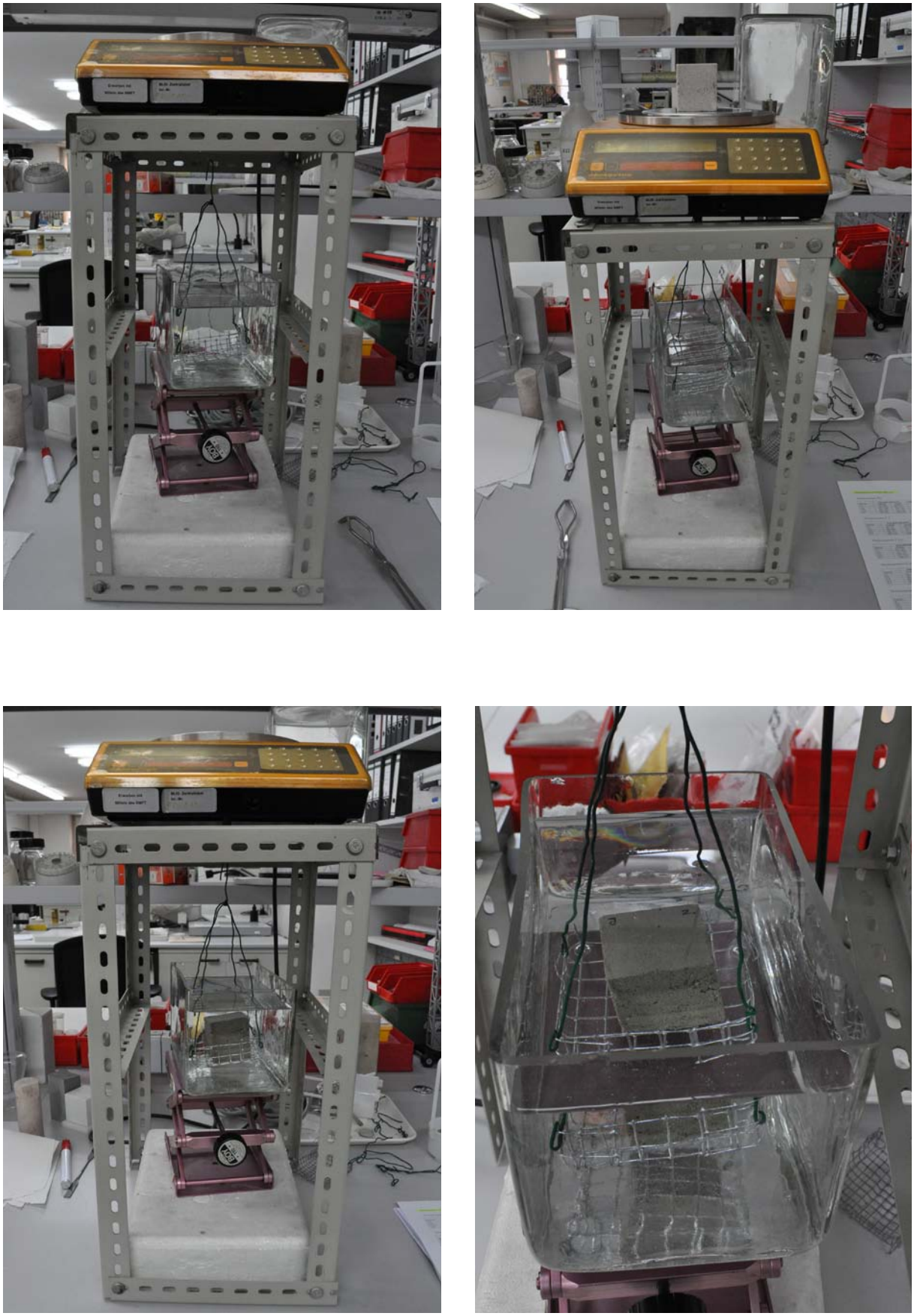


Fig. 25-28: Measuring set-up to determine the mass of a body under water (Archimedes' principle, the weight and buoyancy of the weighing basket are taken into account in the calculation)

Tab. 1: Density, porosity and water absorption tests on Jinchuanwan sandstone

	WA_a [mass%]	WA_v [mass%]	WA_{vol} [vol.%]	**Porosity** [vol.%]	**Saturation** [g/cm³]	**Real density** [g/cm³]	**Apparent density** [g/cm³]
AV	**1.2**	**1.3**	**3.1**	**3.4**	**0.9**	**2.7**	**2.6**

Tab.2: Results of density, porosity and water absorption tests on consolidation material 1 (modul system)

Sample	WA_a [mass%]	WA_v [mass%]	WA_{vol} [vol.%]	**Porosity** [vol.%]	**Saturation** [g/cm³]	**Real density** [g/cm³]	**Apparent density** [g/cm³]
1/I.	8.0689615	13.197420	15.520646	25.385234	0.6114045	2.5779077	1.9234998
1/II.	8.0707407	13.030815	15.566984	25.134061	0.6193581	2.5763616	1.9288173
1/III.	6.1493622	11.889771	12.134407	23.461833	0.5171977	2.5781632	1.9732789
1/IV.	7.2846730	12.560532	14.169835	24.432211	0.5799653	2.5740561	1.9451573
1/V.	7.3466958	12.231924	14.385192	23.950710	0.6006165	2.5747108	1.9580492
AV	**7.4**	**12.6**	**14.4**	**24.5**	**0.6**	**2.6**	**1.9**

Tab. 3: Results of density, porosity and water absorption tests on consolidation material 2 (Remmers)

Sample	WA_a [mass%]	WA_v [mass%]	WA_{vol} [vol.%]	**Porosity** [vol.%]	**Saturation** [g/cm³]	**Real density** [g/cm³]	**Apparent density** [g/cm³]
2/I.	11.458930	17.039578	20.488902	30.467264	0.6724890	2.5714927	1.7880292
2/II.	10.529785	16.478105	19.034423	29.787048	0.6390168	2.5745598	1.8076744
2/III.	10.491509	16.576137	18.960749	29.957175	0.6329285	2.5802030	1.8072471
2/IV.	10.519728	16.677517	18.936265	30.020726	0.6307730	2.5722926	1.8000717
2/V.	11.555602	17.387534	20.556868	30.931599	0.6645912	2.5756389	1.7789526
AV	**10.9**	**16.8**	**19.6**	**30.2**	**0.6**	**2.6**	**1.8**

Tab. 4: Results of density, porosity and water absorption tests on consolidation material 3 (Remmers)

Sample	WA_a [mass%]	WA_v [mass%]	WA_{vol} [vol.%]	**Porosity** [vol.%]	**Saturation** [g/cm³]	**Real density** [g/cm³]	**Apparent density** [g/cm³]
3/I.	10.685586	14.696763	19.714052	27.114353	0.7270707	2.5312529	1.8449200
3/II.	11.163737	15.440715	20.385024	28.194800	0.7230065	2.5429963	1.8260036
3/III.	11.290602	15.447416	20.651502	28.254679	0.7309056	2.5494174	1.8290877
3/IV.	11.215650	15.259756	20.558522	27.971454	0.7349823	2.5448537	1.8330211
3/V.	11.711611	15.825255	21.286636	28.763459	0.7400583	2.5514530	1.8175668
AV	**11.2**	**15.3**	**20.5**	**28.1**	**0.7**	**2.5**	**1.8**

Tab. 5: Results of density, porosity and water absorption tests on consolidation material 4 (Minéros)

Sample	WA_a [mass%]	WA_v [mass%]	WA_{vol} [vol.%]	**Porosity** [vol.%]	**Saturation** [g/cm³]	**Real density** [g/cm³]	**Apparent density** [g/cm³]
4/I.	8.0634253	18.846824	13.864151	32.404990	0.4278400	2.5436601	1.7193873
4/II.	8.5665036	15.356846	15.651183	28.057283	0.5578296	2.5395498	1.8270211
4/III.	8.0367661	15.946673	14.534603	28.839780	0.5039776	2.5414676	1.8085139
4/IV.	8.0341185	16.480735	14.364922	29.467385	0.4874855	2.5349830	1.7879898
4/V.	7.5850515	14.648743	13.945506	26.932465	0.5177954	2.5162355	1.8385513
AV	**8.1**	**16.3**	**14.5**	**29.1**	**0.5**	**2.5**	**1.8**

Tab. 6: Results of density, porosity and water absorption tests on consolidation material 5 (Jahn)

Sample	WA_a [mass%]	WA_v [mass%]	WA_{vol} [vol.%]	**Porosity** [vol.%]	**Saturation** [g/cm³]	**Real density** [g/cm³]	**Apparent density** [g/cm³]
5/I.	10.180134	15.329740	18.913265	28.480514	0.6640774	2.5976979	1.8578602
5/II.	10.696891	16.037619	19.615338	29.408856	0.6669875	2.5976942	1.8337421
5/III.	10.219884	15.959113	18.704029	29.207739	0.6403792	2.5852551	1.8301605
5/IV.	10.468804	16.292642	19.092946	29.714428	0.6425480	2.5948346	1.8237943
5/V.	9.971714	15.038478	18.599292	28.049846	0.6630800	2.5923573	1.8652051
AV	**10.3**	**15.7**	**19.0**	**29.0**	**0.7**	**2.6**	**1.8**

Hygric dilatation

Knowledge of the behaviour of a material with changing humidity levels allow conclusions to be drawn about the expected swelling and shrinkage stresses. If two materials with very different swelling and shrinkage rates are combined, the area of contact is subject to expansion and contraction stresses which lead to cracks forming in the area of contact. This ultimately leads to the separation of the two materials.

As the stone consolidation materials should not have any stratification, the measurements were limited to one direction (direction z).

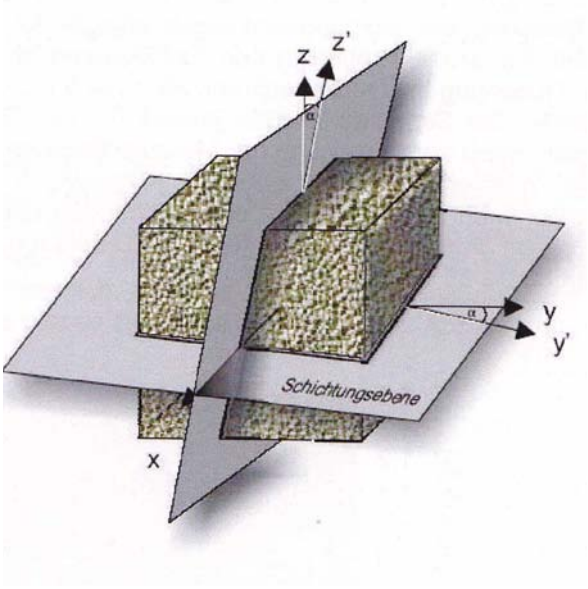


Fig. 29: Position of the stratifications in a stone (Schichtungsebene = stratification)

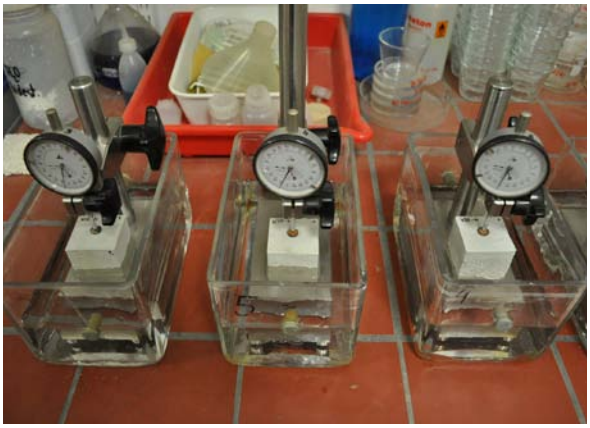


Fig. 30: Measuring set-up to determine hygric dilatation

Hygric dilatation (swelling under water) describes the process of change in the volume of a solid due to the influence of fluids and gases. To this end the dry weight of the samples was determined (drying cabinet at ca. 60 °C followed by cooling in the dessicator). The swelling was quantified by measuring the change in the length of the sample.

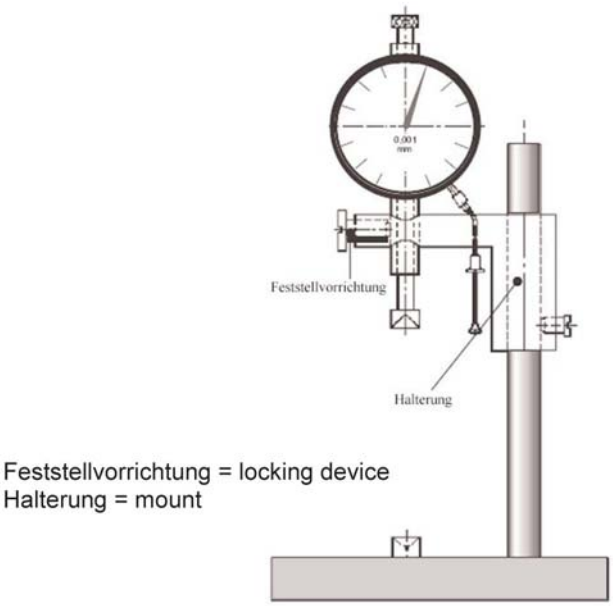


Fig. 31: Measuring set-up to determine hygric and thermal dilatation

Fig. 32: Measuring set-up to determine hygric dilatation

Fig. 33: Soaked sample on the scale

Hygric dilatation under water was measured over 48 hours. Table 7 shows the averages of the results and the individual values; the full results of the analyses with details of the individual measurements are attached in the Appendix to this Report on page 37–49.

The averages each represent one set of 5 individual measurements. The value for the unprocessed stone is provided for purposes of comparison.

Tab. 7: Averages of hygric dilatation

Stone consolidation material	**Hygric dilatation in direction z [mm/m]**
Material 1 (modul system Remmers)	0.822 (5)
Material 2 (Remmers)	0.258 (5)
Material 3 (Remmers)	0.584 (5)
Material 4 (Minéros)	0.523 (5)
Material 5 (Jahn)	0.308 (5)
Jinchuanwan sandstone	**0.852 (6)**

(x) = number of individual measurements

Fig. 34: Samples in the oven

Thermal values

Thermal dilatation

Thermal dilatation indicates how the stone consolidation materials either expand or shrink depending upon temperature. Temperature-induced changes in length Δl of the test specimens are, at moderate temperatures and minor temperature changes, nearly proportional to the original length lo and the temperature difference Δ*l*T.

The formula is: $\Delta l = l_o \cdot \alpha \cdot \mathrm{T} \left[\mathrm{mm}\right]$

where l_o is the length at 0 °C and α is the linear expansion coefficient.

Thermal dilatation was calculated in laboratory tests. The putties were heated to around 60 °C and inserted into a dial gauge, and the change in length on cooling was measured.
Again, thermal dilatation was calculated in one direction only (direction z).

Table 8 shows the averages of the test results for the stone consolidation materials tested. The test result for each specimen of a stone consolidation material is attached to this Report in the Annex on page 49–61.

Fig. 35: Measuring thermal dilatation

Tab. 8: Averages of thermal dilatation

Stone consolidation material	**Thermal expansion coefficient in direction z [µm/m/°C]**
Material 1 (modul system Remmers)	13.394 (5)
Material 2 (Remmers)	14.225 (5)
Material 3 (Remmers)	12.244 (5)
Material 4 (Minéros)	11.895 (5)
Material 5 (Jahn)	11.950 (5)
Jinchuanwan sandstone	**12.237 (6)**

(x) = number of individual measurements

Mechanical values

The mechanical attributes of stone can be described by measuring its strength and hardness. Strength is defined as the mechanical resistance to deformation, and hardness as the resistance of the material to the damage to its surface.

Flexural strength

Flexural strength and E-modulus are determined according to the stress-strain curves from the bending test (Fig. 37). Flexural strength is the maximum bending stress that can be reached in the test.

A special form of this test examines the biaxial flexural strength of slices of stone (Fig. 36 b). A slice (Ø 46 mm) is placed on a support ring (Ø 39 mm) and put under pressure by a second, smaller load ring (Ø 13 mm) until it breaks. Circular pressure is applied, and the different ring diameters produce a bending stress on the structure of the test specimen. The measurements were carried out using Zwick's universal testing machine Z010 (10 kN). The preliminary test force was 10 Newton and additional force was then applied in steps of 0.50 mm/min.

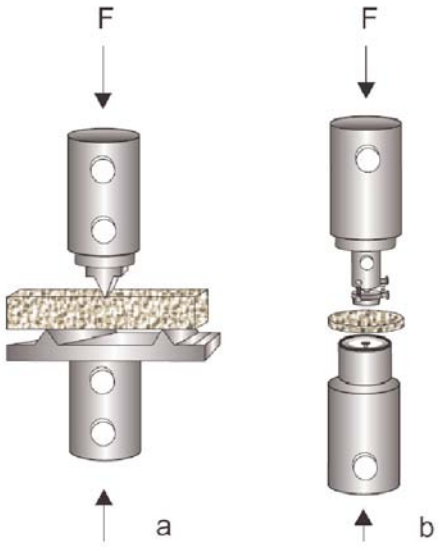


Fig. 36: Test set-up for determining uniaxial (a) and biaxial (b) flexural strength

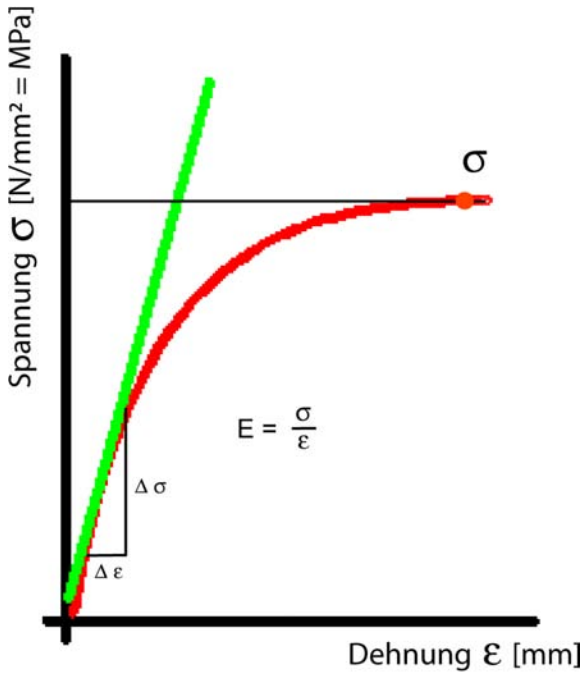


Fig. 37: Stress-strain curves [Spannung = stress, Dehnung= strain] to determine breaking load (σ) and elasticity (E-modulus)

The flexural strength for slices can be calculated as follows (in accordance with WITTMANN and PRIM, 1983):

$$\sigma_{bz} = \frac{3 \cdot F_{br}}{4 \cdot \pi \cdot d^2} \cdot \left[2 \cdot (1+\mu) \cdot \ln\frac{a}{b} + \frac{(1-\mu) \cdot (a^2-b^2)}{a^2} \cdot \frac{a^2}{r^2} \right]$$

σbz in [N / mm2 = MPa]
where

F_{br} =	[N]	maximum force
r =	[mm]	radius of the test specimen
d =	[mm]	thickness of the test specimen
μ =	[-]	Poisson's ratio = 0.25 for stone
a =	[mm]	radius of the underlying support ring
b =	[mm]	radius of the overlying load ring

Fig. 38: Test set-up to measure biaxial flexural strength

The static E-modulus was calculated as a secant modulus at 1/3 F_{max}.
In accordance with WITTMANN and PRIM, 1983, it is defined as:

$$E_{stat.} = \frac{1{,}5 \cdot F_{br}}{f_0 \cdot d^3} \cdot (1-\mu^2) \cdot \left[b^2 \cdot \ln\frac{b}{a} + \frac{(a^2-b^2) \cdot (3+\mu)}{2 \cdot (1+\mu)} \right]$$

$\mathbf{E}_{\mathbf{M}.stat.}$ in [kN/mm² = GPa]
where

F_{br} =	[N]	maximum force
r =	[mm]	radius of the test specimen
d =	[mm]	thickness of the test specimen
f_0 =	[mm]	deflection of the slice at 1/3 F_{max}.
μ =	[-]	Poisson's ratio = 0.25 for stone
a =	[mm]	radius of the underlying support ring
b =	[mm]	radius of the overlying load ring

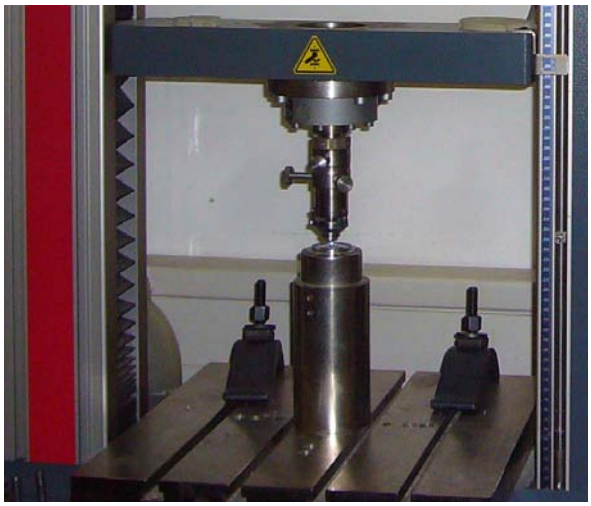


Fig. 39-41: Two column Universal testing machine and test set-up to measure biaxial flexural strength

Table 9 shows the averages of the flexural strength tests for the stone consolidation materials. Figure 42 shows the results of the flexural strength test for untreated Jinchuanwan sandstone. The results of all individual measurements of each stone consolidation material are attached in the annex on page 62– 66.

Tab. 9: Averages of the flexural strength tests for the stone consolidation materials in comparison to Jinchuanwan sandstone

Stone consolidation material	**Biaxial flexural strength σ_{bz}[N/mm² = MPa]**	**E-modulus [kN/mm² = GPa]**
Material 1 (modul system Remmers)	3.66 (6)	6.09 (6)
Material 2 (Remmers)	2.03 (6)	2.48 (6)
Material 3 (Remmers)	1.14 (4)	2.90 (4)
Material 4 (Minéros)	2.40 (5)	2.24 (5)
Material 5 (Jahn)	0.70 (6)	3.15 (6)
Jinchuanwan sandstone	**15.51 (16)**	**30 (16)**

(x) = number of individual measurements

Samples W 1:

samples untreated

Sample	d [mm]	Ø d_0 [mm]	F_{max} [N]	δ_{BZ} [N/mm²]	L (F_{max}) [mm]	E-modulus [kN/mm²]	f_0 [mm]	Time-F_{max} [s]
W 1-1	5,60	44,5	623,62	15,47	0,09	25,07	0,026	26,86
W 1-2	5,30	44,5	640,63	17,74	0,10	31,09	0,025	29,88
W 1-3	5,40	44,5	590,56	16,36	0,19	22,48	0,033	30,02
W 1-4	5,40	44,5	639,30	17,06	0,09	30,56	0,024	22,46
∅ W 1				16,66		27,30		

Grafic:

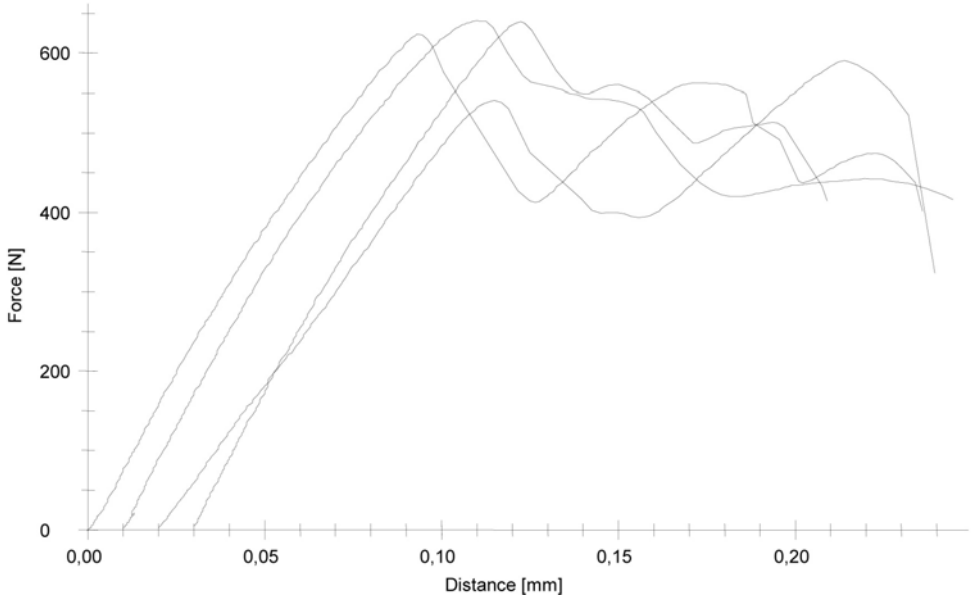


Fig. 42: Results of the flexural strength test for untreated Jinchuanwan sandstone [Kraft = force; Strecke = stretch]

Compression strength

Compression strength $ß_D$ is the most frequently determined and used value of strength. Fig. 44 shows the test set-up for determining compression strength. Between two compression boards the machine puts a strain on the test specimen until it breaks. From the applied maximum force and the outlet cross section area of the cube the compression strength can be calculated with following formula

$$\beta_D = \sigma_{D,\,max} = \frac{F_{max}}{A_0} \left[\frac{N}{mm^2} = MPa\right]$$

where $\sigma_{D,max}$ = biggest compression strength,
F_{max} = maximum load and
A_O = outlet cross section area is.

Considering it physically the term compression strength is not correct, because the binding of a single component in one material can't be compensated through simple compression exposure from all sites. The distance between two particles is in balanced condition r_o. If the distance is reduced by applying force from the outside, the rejection energy will grow. The closer single particles come, the bigger the energy gets. Fig. 45 shows, how it is not possible to go below a certain distance (r_{min}), because approaching r_{min} will let the rejection energy grow endlessly big. The collapse through compression is only comprehendible, if considering that every longitudinal deformation brings a diagonal deformation with it. The material will only break, when the diagonal deformation reaches the point of critical expansion in the specific material or if the diagonal tensile strength is crossed.

Fig. 43: Compression strength test on one of the cubes of the stone consolidation materials

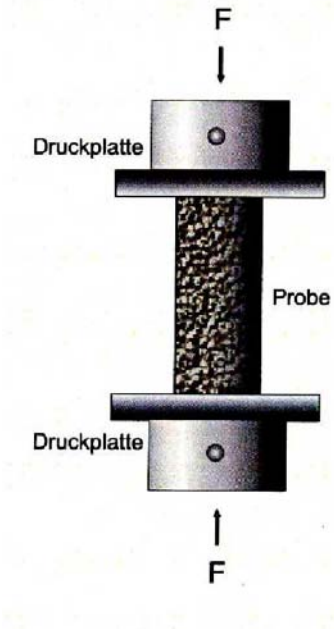


Fig. 44: Test set-up for determining compression strength

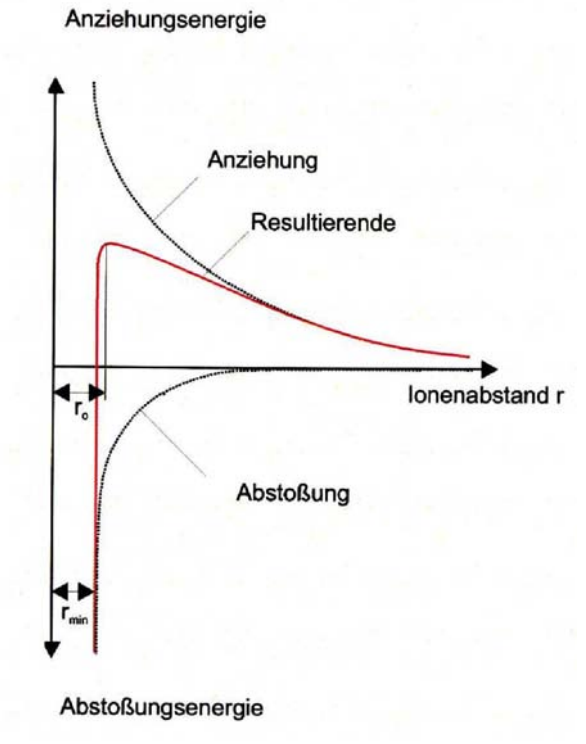


Fig. 45: Influence of ionic distance on ionic binding (according to Wesche, 1977)

Compression strength was tested through laboratory analyses on three to four specimens of each consolidation material. Table 10 shows the averages of the compression strength test. All individual measurements are attached to the annex on page 67–77.

Fig. 46: Testing machine for compression strength test

Tab. 10: Averages of the compression strength test

Stone consolidation material	Compression strength [N/mm²]
Material 1 (modul system Remmers)	7.87 (4)
Material 2 (Remmers)	4.69 (4)
Material 3 (Remmers)	6.95 (4)
Material 4 (Minéros)	12.24 (4)
Material 5 (Jahn)	2.74 (4)
Jinchuanwan sandstone	-

(x) = number of individual measurements

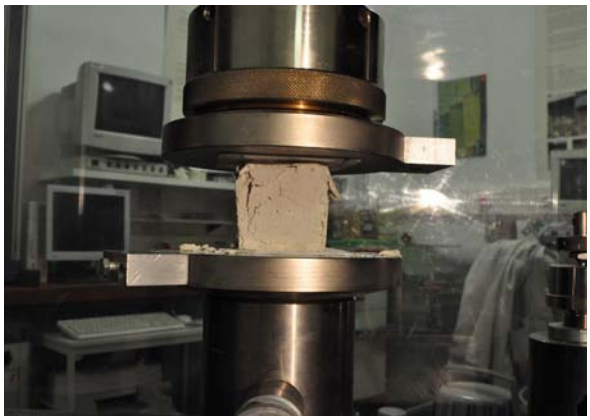


Fig. 47: Compression strength test

Fig. 48: SINT DRMS device with jig

Drilling resistance

The basis for measuring the drilling resistance is the correlation between drilling resistance and strength of the stone. The measurement principle is based on the characterisation of the drilling process using the values drill speed, torque and contact pressure. If the penetration and rotation values are kept constant, the other two values can be used to determine the drilling resistance.

The measurements were produced using SINT's DRMS cordless measuring device. Diaber 5 mm diamond drill bits were used. ARS served as a reference and calibration material.

Before the first bore was drilled in the consolidation materials, a reference bore was drilled in the ARS calibration material. This was repeated after every fifth bore drilled in order to record the percentage increase in drilling force as a result of wear. The measurements were carried out in one spatial direction only. Five bores were drilled in each stone consolidation material. Table 11 shows the average values of the average force [N] applied for the five stone consolidation materials. The diagrams for the individual measurements may be found in the Annex on page 78–81.

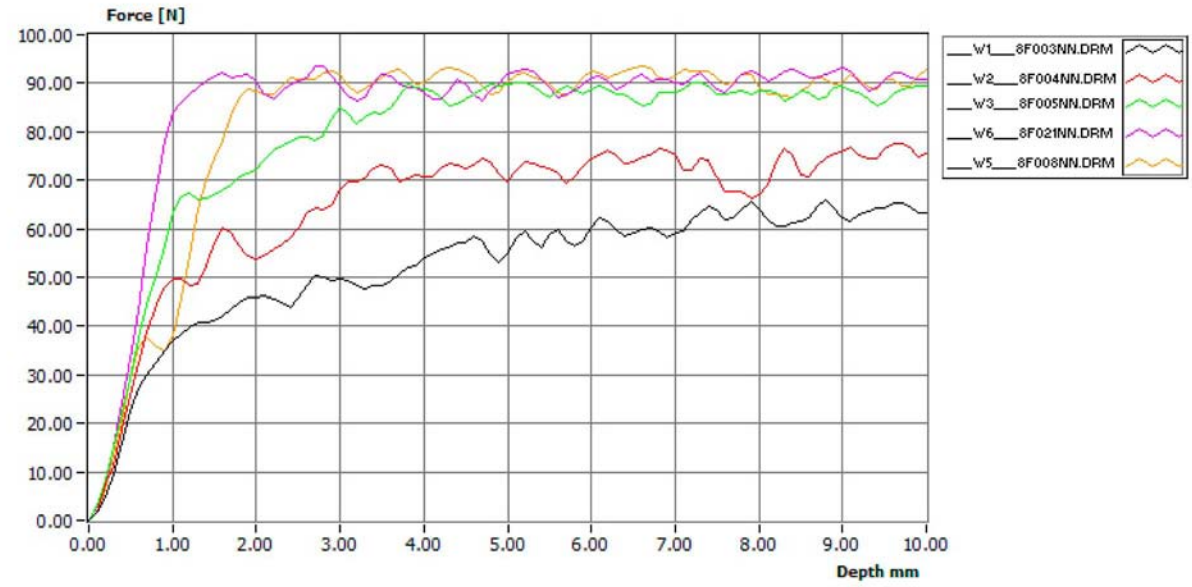


Fig. 49: Drilling resistance of Jinchuanwan sandstone (raw data)

Tab. 11: Corrected averages of the drilling resistance measurements

Stone consolidation material	**Drilling resistance [N]**
Material 1 (modul system Remmers)	2.93 (5)
Material 2 (Remmers)	2.18 (4)
Material 3 (Remmers)	3.88 (5)
Material 4 (Minéros)	15.16 (5)
Material 5 (Jahn)	3.59 (4)
Jinchuanwan sandstone	**55 (6)**

(x) = number of individual measurements

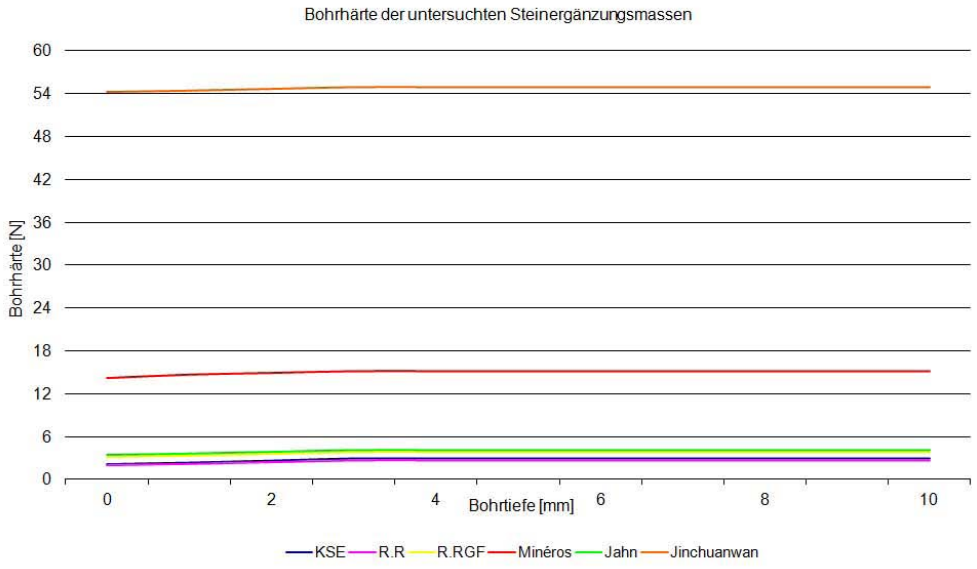


Fig. 50: Corrected averages of the drilling resistance tests on the stone consolidation materials in comparison to the average of Jinchuanwan sandstone

Conclusion

Laboratory tests were carried out with the aim of finding a stone consolidation material similar to Jinchuanwan sandstone. The results obtained for the untreated Jinchuanwan sandstone were applied in the preliminary stages in the production of the stone consolidation materials.

Tab. 12: Comparison of the measurement results for Jinchuanwan sandstone and the stone consolidation materials

Measurement method	Jinchuanwan	Material 1	Material 2	Material 3	Material 4	Material 5
Water absorption under atmosphaeric pressure [mass%]	**1.2** (3)	7.4 (5)	10.9 (5)	11.2 (5)	8.1 (5)	10.3 (5)
Water absorption in a vacuum [mass%]	**1.3** (3)	12.6 (5)	16.8 (5)	15.3 (5)	16.3 (5)	15.7 (5)
Porosity [vol.%]	**3.4** (3)	24.5 (5)	30.2 (5)	28.1 (5)	29.1 (5)	29.0 (5)
Saturation [g/cm³]	**0.9** (3)	0.6 (5)	0.6 (5)	0.7 (5)	0.5 (5)	0.7 (5)
Real density [g/cm³]	**2.7** (3)	2.6 (5)	2.6 (5)	2.5 (5)	2.5 (5)	2.6 (5)
Apparent density [g/cm³]	**2.6** (3)	1.9 (5)	1.8 (5)	1.8 (5)	1.8 (5)	1.8 (5)
Hygric dilatation under water [mm/m = ‰]	**0.852** (6)	0.822 (5)	0.258 (5)	0.584 (5)	0.523 (5)	0.308 (5)
Thermal expansion coefficient [µm/m /°C]	**12.237** (6)	13.394 (5)	14.225 (5)	12.244 (5)	11.895 (5)	11.950 (5)
Biaxial flexural strength [N/mm² = MPa]	**15.51** (16)	3.66 (6)	2.03 (6)	1.14 (4)	2.40 (5)	0.70 (6)
E-modulus [kN/mm² = GPa]	**30** (16)	6.09 (6)	2.48 (6)	2.90 (4)	2.24 (5)	3.15 (6)
Pressure resistance [N/mm² = MPa]	**-**	7.87 (4)	4.69 (4)	6.95 (4)	12.24 (4)	2.74 (4)
Drilling resistance [N]	**55** (6)	2.93 (5)	2.18 (4)	3.88 (5)	15.16 (5)	3.59 (4)
Flexural strength/ E-modulus [-]	**0.517**	0.601	0.818	0.366	1.147	0.222

(x) = number of individual measurements

Tab. 13: Evaluation of the stone consolidation materials

Measurement method	Material 1	Material 2	Material 3	Material 4	Material 5
Water absorption (atmosphaeric)	**o**	**-**	**-**	**-**	**-**
Water absorption (vacuum)	**o**	**-**	**-**	**-**	**-**
Porosity	**o**	**-**	**-**	**-**	**-**
Saturation	**o**	**-**	**-**	**-**	**-**
Real density	**o**	**o**	**o**	**o**	**o**
Apparent density	**o**	**o**	**o**	**o**	**o**
Hygric dilatation under water	**o**	+	+	+	+
Thermal dilatation	+	**o**	++	+	+
Biaxial flexural strength	**o**	**-**	**-**	**-**	**-**
E-modulus	**o**	**-**	**-**	**-**	**-**
Flexural strength/E-modulus	++	**o**	+	**-**	**o**
Pressure resistance	**o**	**o**	**o**	**o**	**o**
Drilling resistance	**-**	**-**	**-**	**o**	**-**
Handling	**o**	+	+	+	**o**
Colour	+	**o**	**o**	**o**	+
Toxicity	**o**	**o**	**o**	**o**	**o**

(+ = positive, - = negative, o = neutral)

Laboratory tests were carried out with the aim of finding a stone consolidation material similar to Jinchuanwan sandstone in the Shaanxi Povince in China. The results obtained for the untreated Jinchuanwan sandstone were applied in the preliminary stages in the production of the stone consolidation materials.

Based on the comparison in table form (Tab. 12 and 13) of the values of the five consolidation materials tested with those of Jinchuanwan sandstone, it can be seen that each of the materials tested has a higher porosity and therefore a higher water absorption capacity.
Only by looking at the Thermal expansion coefficient all five stone consolidation materials show similar behaviour.

Generally speaking it can be shown that the stone consolidation material 1, mixed with Jinchuanwan sandstone powder, comes very close to the values for the Chinese sandstone in terms of water absorption under atmospheric pressure, hygric and thermal dilatation, and also in the ratio of the flexural strength to E-modulus, and therefore are recommended as suitable stone consolidation materials.

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Jinchuanwan Grotto August 2012 - Conservation of the East Wall of the Grotto

Mathias Kocher, Franziska Kolba, Katharina Meier zu Verl, Siegfried Scheder

Overview

Mo, 06.08.12	Common evening takeoff in Munich
Tu, 07.08.12	Noon arrival in Beijing, flight to Xi'an, Collection of Chinese colleagues (Yan Min, …) from the airport, official dinner
We, 08.08.12	Drive to Jinchuanwan Grotto (Town Chong Hua), Purchases of materials (gloves, alcohol, etc.) on the way, visit to the caves and the plant with new porches, discussing the working days and the measures to be carried out, cleaning samples on the sandstone
Th, 09.08.12	Jinchuanwan Grotto: Dry cleaning with Wish-up®, wet cleaning with micro steam, mechanical removal of clay crusts; visit of the Vice-Minister of Education of the District
Fr, 10.08.12	Jinchuanwan Grotto: Completion of the cleaning work, the beginning of the backfilling and border security works on large drawers at the bottom of the wall with the tested stone consolidation material of the KSE-module system of Remmers and a modified version of the backfill
Sa, 11.08.12	Drive to Xi'an; leisure
So, 12.08.12	Leisure in Xi'an; Meeting with German colleagues
Mo, 13.08.12	Drive back to Jinchuanwan Grotto: Backfill works and edge fuses on the east wall
Tu, 14.08.12	Jinchuanwan Grotto: Completion of backfilling and secure shells, post the additions, beginning of retouching, mapping of the west wall of the grotto, visit of Prof. Emmerling, Ma Tao (Vice-Director of the Center for the Conservation and Restoration of Cultural Heritage Xi'an), Yang Sheng (Chengdu), dinner together with the Culture Minister and Vice-Minister of Education of the district followed by a visit to the museum in Chong Hua
We, 15.08.12	Jinchuanwan Grotto: Reworking of the additions, retouching, consolidating the entire east wall with KSE 100
Th, 16.08.12	Jinchuanwan Grotto: Further retouching, consolidating control, cleaning up the site
Fr, 17.08.12	Drive to Lintong, meeting with Prof. Emmerling and the director of the Terracotta Warriors and Horses Museum, tour through the facility, drive back to Xi'an, dinner together with Ma Tao (Vize-Direktor des Center for the Conservation and Restoration of Cultural Heritage Xi'an)
Sa, 18.08.12	Joint trip to Beijing
So, 19.08.12	Flight to Munich

Fig. 1: Stem made of brick (Photo: Sept. 2009)

Fig. 2: New wooden porch (Photo: Aug. 2012)

Fig. 3: Path next to the Grotto (Photo: Sept. 2009)

Preface

The working visit from 06.08–19.08.2012 at Jinchuanwan Grotto, in the north of Xi'an, Shaanxi Province, was mainly focused on the preservation of the east wall of the grotto. The wall was investigated and mapped in 2009 by Mathias Kocher and Martina Klukas. Two axes with consolidation pattern samples with KSE OH, as well as smaller putty samples with the KSE-module system of Remmers were created. The most important data of the preliminary examinations of 2009 are listed together with the description and results of the 2012 measures in this report.
In addition the current situation as well as the cave site with the enclosing system, and the changes in the interior made by the Chinese colleagues since 2009 is described.

Current situation on site

Environment: The some time ago out of gray bricks build wall in front of the cave was demolished during 2011 by the Chinese colleagues and replaced by a new wooden, Chinese temple porch.
The roads to and within the plant have not changed much since 2009. The bagged place west of the grotto was temporarily filled in with clay, so there is no further danger of collapse.

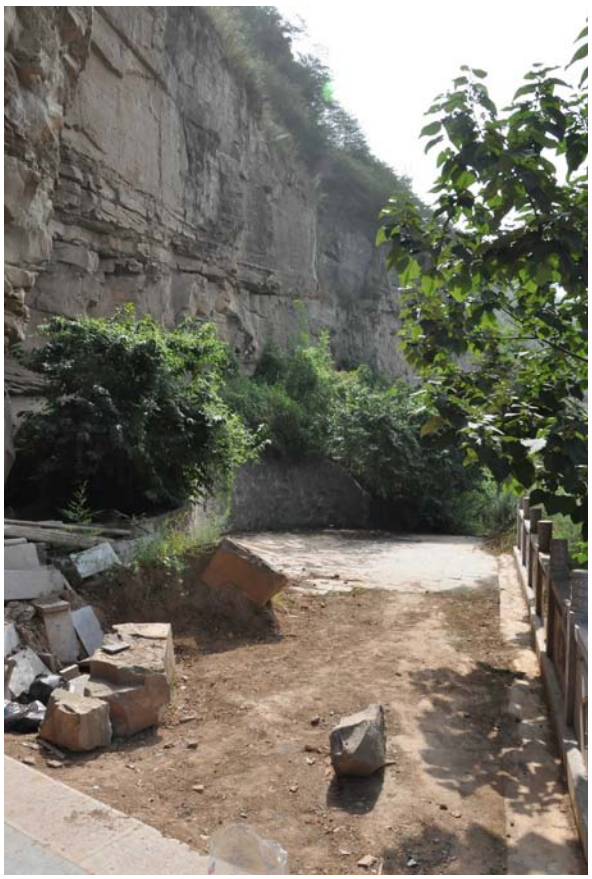


Fig. 4: Path next to the Grotto (Photo: Aug. 2012)

Interior
In the interior of the cave, steel beams have been attached as a supporting structure for the ceiling; on the east wall there are steel cables to secure the slightly tilted forward moving rock. But still, many freshly broken rock fragments are visible on the cave floor, and the southwestern region of the ceiling shows freshly broken rock edges. The brick wall, which complemented the eastern wall, was plastered recently in a neutral shade.

Fig. 5: Steel joists construction

Fig. 7: Steel cables behind/above the East Wall

Fig. 6: New plaster on the East Wall

Fig. 8: Bruck rock pieces in the cave

Fig. 9: Ceiling of the Jinchuanwan Grotto

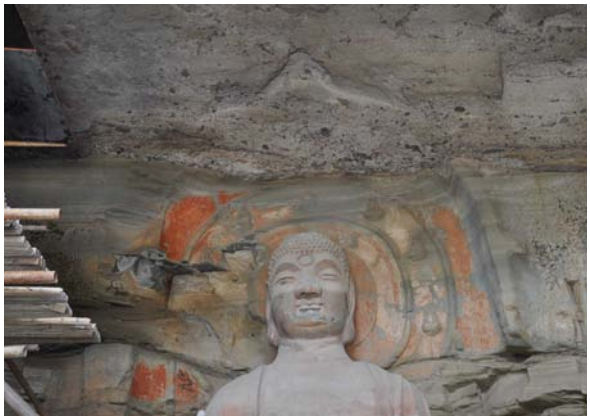


Fig. 10: Buddha with weathered aureole on the ceiling

Fig. 11: Wall area next to the Buddha, south wall

The Buddha on the south wall of the cave is not original, as larger parts were destroyed during the Cultural Revolution and later replenished. In the area of a piece of weathered ceiling then passing over, the Buddha head framing halo is visible. In the wall regions left and right of the Buddha have different machining marks the attachment of smaller scenic representations, possibly suspect accompaniment figures to the Buddha, which were probably removed as well.

Fig. 12: Stage under the Buddha with former floor level

Fig. 13: Ducted plaster fragments of a former Buddha figure in the dirt floor

The recently re-erected steel beams inside the cave gave rise to the question of the original ground level in the cave. After consultation with the Chinese counterparts by Prof. Emmerling, it could be agreed to open the bottom left at the feet of the Buddha to a few centimeters. Here was the original ground level found, about 24 cm lower than the present clay. After assessment and documentation of the ground, it was closed with clay again.
In the bottom on the right side of the Buddha there was several small, red broader plaster pieces found. Presumably, they still belong to another Buddha figure, possibly to that which was destroyed.

Fig. 14: Stacked Steel figure

Probably on the former left side of the cave established as a Steele figure could be found by search and consultation in the garden of the key manager of the grotto. She was photographed, repositioned in the courtyard to dry and should be brought as soon as possible into the museum to Xi‘an.

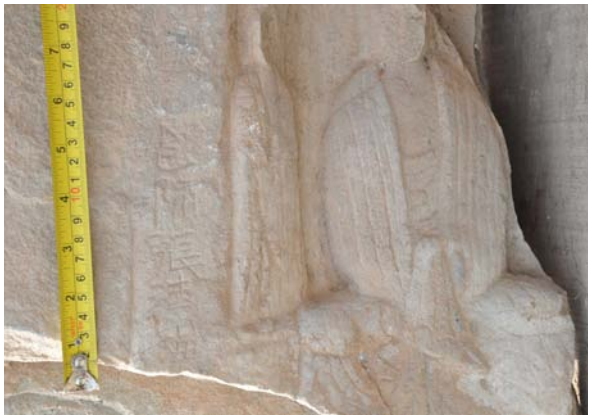


Fig. 15: Inscription on the side of the Steele

Condition of the eastern wall

There have been some changes compared to the state of 2009. The big crack in the eastern wall has been closed. Instead of the earlier build brick wall, which combined the eastern wall with the entrance, aluminium honeycomb plates have been plastered with a colour-coordinated material. Some loose stones above the eroded horizons were removed or glued with either plaster or polyurethane foam.

Especially at ground level and near the water-bearing horizons the east wall is damaged. In some parts the inscriptions are completely lost. Only at parts of the wall in the back of the grotto you can still read the inscriptions engraved in the stone. Similar to the west wall the surface of the east wall has been formed with a moil chisel up to 50 cm. The next 27 cm seem to be abraded. Then the engraved inscription starts at the height of 77 cm. Most likely in the 1980s the base of the east wall was painted red. This colour is proposed to stay.

Fig. 16: East wall with colour-coordinated plaster (left)

Fig. 17: Stabilisation of loose stones (with cement)

Fig. 18: Marks of tools in lower area of the eastern wall

Fig. 19: Remains of red paint

Conservation works on the east wall

Cleaning

Due to the loam dust from outside the whole grotto is extremely soiled. In some places the loam has incrusted on the surfaces. This can happen because calcareous loam and moisture can form compact marl. But it is also possible that the loam crusts are remains of a former conservation, where some of the smaller cracks have been closed with a plaster. In 2009 the crust was analysed with X-Ray Diffraction

as loam, brought into the grotto by wind.
Beside the loam dust and crusts, there are remains of black paint on the wall, because the inscription had been copied. Therefore black ink was brought onto the wall and the inscription was copied by pressing paper or matting on the surfaces.

Fig. 20: Incrusted loam on the surfaces

Fig. 21: Remains of ink on the east wall

Before the stone was consolidated the surface area had to be cleaned. Otherwise the loam dust on the remaining ink would have been consolidated too. The incrusted loam could be reduced by swelling with ethyl alcohol and water and rubbing with a hard brush or a shortened pencil. Insistent remains could be removed mechanically with a scalpel or spatula.
The black ink on the surface was harder to remove, because it migrated already into the pore space of the stone. Therefore cleaning tests with ethyl alcohol, water vapor, Wish-up® cleaning sponges and ammonium chloride were conducted. None of the solvents was able to remove the ink completely. An application with solvent gels or pastes was proposed.

Fig. 22: Dry-cleaning of the wall with a Wish-up® cleaning sponge

Fig. 23: Cleaning of the wall with water vapor

Fig. 24: Surface of the east wall after cleaning with sided light

Fig. 25: Flaking areas with lost inscription on the upper east wall

Fig. 26: Big voids and slaty cleavage near the floor of the east

As a first step the east wall was dry-cleaned with different Wish-up@ cleaning sponges (hard and soft trade named Akapad). Thus loam dust and parts of the black ink could be removed. Afterwards the wall was cleaned wet with hot water vapor. Therefore only a small spot at a time should be moistened and the dirt should be washed away from the top to the bottom. A big sponge absorbed the remaining water from the wall surface.
This cleaning with water vapor further reduced the black ink on the surface and the engraved inscriptions seemed to be clearer.

Back filling of voids and edge fuses
In 2009 the damage of the wall has been assessed by mapping. According to this mapping, the east wall shows the biggest damage in lower areas near the floor. There the stone tends to develop slaty cleavage and thick voids. At the top of the wall, predominantly above the water-bearing horizons, the inscription is completely lost, as a result of lost thin voids. The surface underneath is flaking.

To maintain the still existing inscription the voids had to be backfilled. Voids with open sides could be backfilled through these and closed with mortar after filling. Closed voids needed to be detected by patting the surface of the wall. To backfill these voids they needed to be opened by drilling with a cannula or a needle.

The edges of areas where there had been damage by lost voids were closed with mortar too.
As mortar material a plaster examined in the studies of 2011/12 was chosen. (Mach, Martin; Emmerling, Erwin; Kocher, Mathias; Meier zu Verl, Katharina: *Examination of stone consolidation material for Jinchuanwan Grotto, Provinz Shaanxi, China.* TU München, BLfD).
For application in Jinchuanwan grotto the stone consolidation material 1, which is based on the „KSE-modul-system“, (silicic-acid-ethyl-ester) by Remmers was chosen. The plaster examined in the laboratory was modified for a better use at the construction area. Basically the weight specification was converted into volumetric content. The dry plaster material consists of 7 parts filler material A (mineral powder), 4 parts filler material B (quartz powder), 15 parts quartzsand (Remmers quartzsand F 36) and 15 parts rock flour (grounded sandstone from Jinchuanwan). As required a limited amount of the dry plaster material could be mixed with silicic-acid-ethyl-ester (Remmers KSE 500 STE) to compound the mortar. Only so much of the binder solids was added to a crumbling putty which was good to work with. According to the colour of the wall the mortar was stained with pigments. Ferric oxide, green umbra, yellow ochre and red tierra di siena were used.

To backfill the voids the plaster explained above was modified. The dry material consists of 1 part filler material A, 2 parts filler material B and 1 part rock flour from Jinchuanwan sandstone. The dry putty material was mixed with KSE 500 STE. The plaster should be extrudable. The easiest way was to mix a thin plaster for thin voids with small clearance. A thicker plaster was used to backfill bigger voids. This backfilling material was stained with the same pigments used and explained above.

Fig. 27: Backfilling a void with open sides

Fig. 28: Consolidation of edges with stained plaster

Before the void was backfilled, the free space was damped with ethyl alcohol. On the one hand the approximately size of the void could be estimated on the other hand the prewetting prevents the early stagnation of the plaster. After infilling the plaster the void was damped with solvent V 101 by Remmers to prevent the silicic-acid-ethyl-ester from welling out of the surface as well as staining.
The edges of the voids were prewetted with ethyl alcohol before they were closed with plaster. Thus an ideal adhesion of the plaster was ensured. The next day the plaster could be reworked with sharp spatulas.

Retouching

After drying and reworking the applied plaster was retouched in terms of colour. Earth pigments (ferric oxide black, yellow ochre, green umbra, red tierra di siena) were solved in ethyl alcohol an applied with a paint brush.

Fig. 29: Retouching the edges of an backfilled void after reworking the plaster

Fig. 30: Retouching the edges of bigger voids in the lower areas

Consolidation

After preliminary investigations in 2009 the consolidation of the east wall was determined as the necessary measure to protect and stabilize the engraved inscriptions of the surface. Therefore the whole eastern wall was consolidated with silicic-acid-ethyl-ester (Remmers KSE OH 100) after infilling the voids and retouching the plasters. With this consolidation the structural damage of the stone, concerning an area from 0.03 to 8.00 cm depth should be repaired.
To prevent the surface of the stone from 'over'-consolidation, KSE OH 100 was died out with the solvent V101. By the use of the slow-evaporating solvent V101 the deposit of silica gel is reduced and migration of the KSE to the surface is minimized. The proportion of mixture was 1 part KSE OH 100 with 2 parts solvent V 101. The deposit of silica gel reduces to 20%. To consolidate the whole wall it was useful to have a low-pressure pump (Fa. Keim).

Fig. 31: Applying consolidation material (KSE OH) in spray coat method

Fig. 32: Consolidation with spray coat method

For consolidation usually the surface is saturated until the stone stops absorbing. In this case the wall was consolidated six times from top down. The surface was washed with solvent V101 (Remmers) two hours after consolidation with KSE. In this way consolidation material in areas close to the surface was reduced to achieve a consolidation profile appropriate to the damage.

Fig. 33: Overview of the east wall of Jinchuanwan Grotto, 2009

Mapping of the stock and the damage of the East wall

Fig. 34: Inventory and damage mapping of the east wall, Martina Klukas and Mathias Kocher, 2009

Mapping of the conservation measures of the east wall

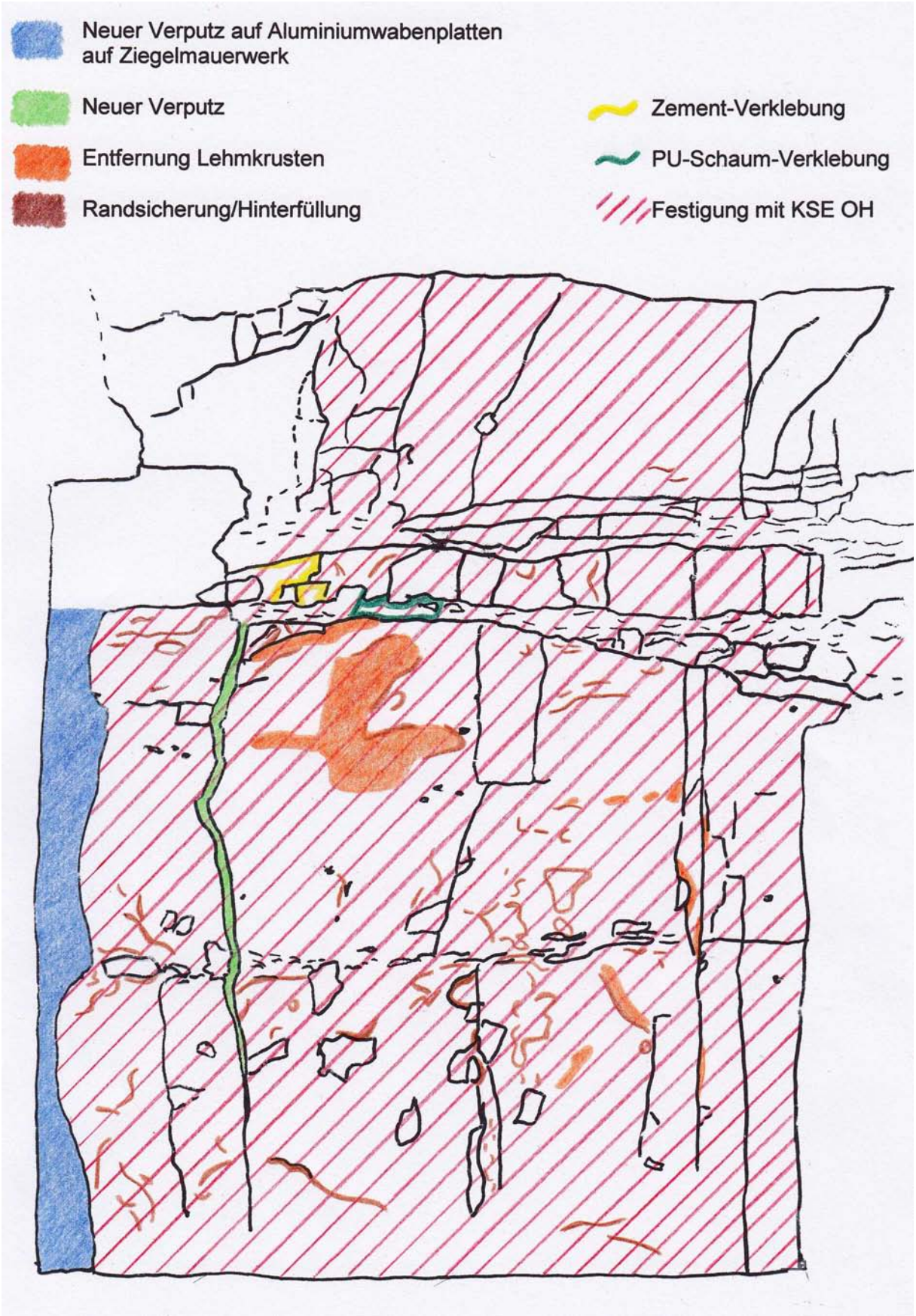


Fig. 35: Conservation measures mapping, Franziska Kolba and Katharina Meier zu Verl, 2012

State and damage of the west wall

The west wall of the cave is similar in structure to the east wall. Above the ground is up to a height of 27 cm initially a pointed area, see above to 77 cm height a smoothed area of the sandstone. From here on, same as on the east side, the letters engraved in stone start (text direction from lower right to upper left). Unlike in the east there are additionally engraved thin grade and vertical lines on the wall, which possibly served as a guide for the chiseling of characters.
It can be in addition to the tipped region, which was created presumably by a pointed iron as rough handling of the sandstone surface, read in the first surface area of the inscriptions smoothed the editing process of the wall surface. It was probably worked with a chisel, which has been handed down for the period of the Tang Dynasty. It is likely that first the rock was rough machined with a chisel and grounded and smoothed with another piece of sandstone. The last step was the characters to be carved into the stone.

Fig. 36: Scoring and characters in stone surface

Fig. 37: Chisel or ax marks in the sandstone surface

The west wall also shows a very similar picture in damage as the east wall, large areas in the upper part of the wall are broken away and in many places with inscription the rock surfaces has placed vesicular and is sanding. Some large cracks run through the wall and have led to increasing delamination. In addition, by the impression of the character extensively black ink residue on the sandstone surface are left.

Fig. 38: Bubble-like shells in the upper wall region

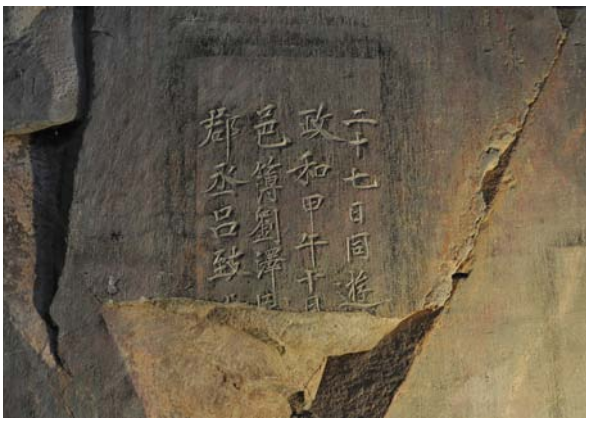


Fig. 39: Ink residues on characters

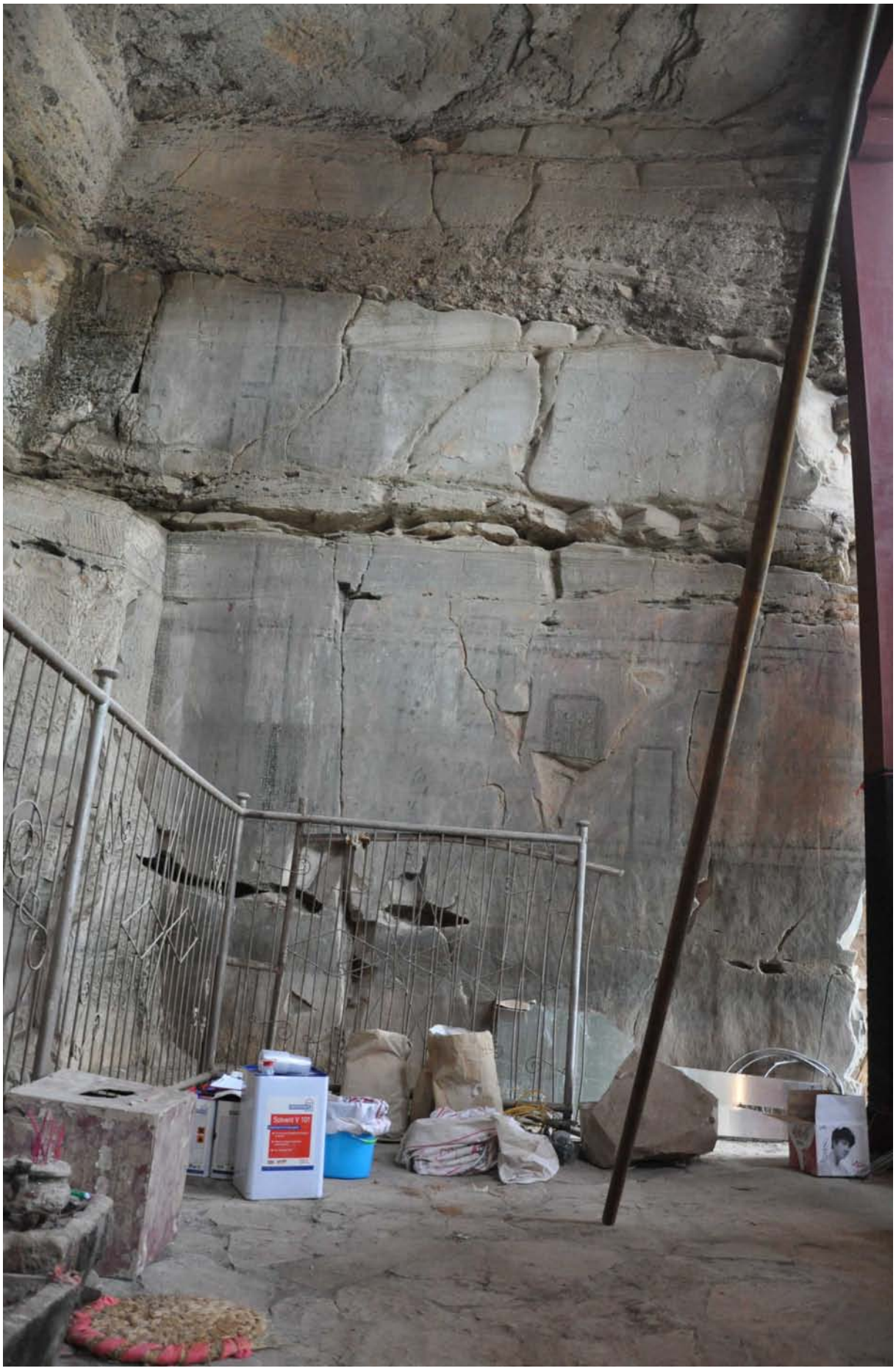


Fig. 40: Overview of the west wall of Jinchuanwan Grotto, 2012

Mapping of the stock and the damage of the West wall

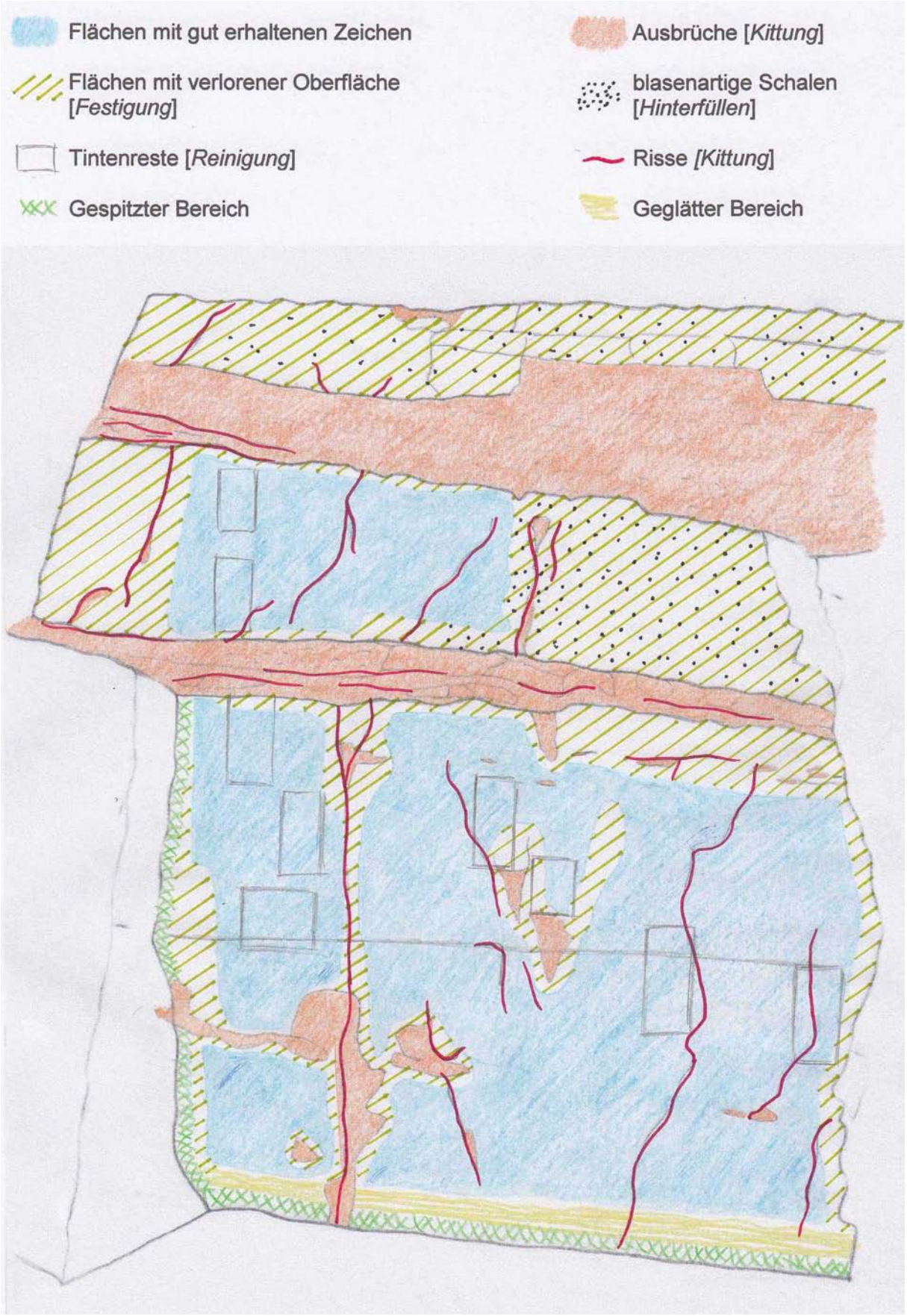


Fig. 41: Inventory and damage mapping of the west wall, Franziska Kolba and Katharina Meier zu Verl, 2012

Fig. 42: Future situation shown on an plan near the highway

Future use concept

Next to the highway G211 which leads from Xi'an to the grotto, a poster shows the planned future situation. It is planned to build a park and a bridge over the small golden river with a huge stairway leading to the grotto. This planned arrangement is supposed to lead more tourists to the grotto, when the near motorway is finished.
To realize this plan the grotto has to be examined geological and mapped hydrological to get detailed information about rock movements, as proposed in the report of 2009. Mainly the ceiling of the grotto has to be examined and secured, because it seems to be instable.
Furthermore the explained conservation work needs to be carried out on the west wall of the grotto.

Fig. 43: Participant of the conservation measures 2012 at Jinchuanwan Grotto

The Jinchuanwan Grotto - Work Report

Yan Min (Center for the Conservation and Restoration of Cultural Heritage Xi'an)

1. Attachment with steel reinforcement and anchoring

1) Attachment of the mounting board on the north side of the east wall

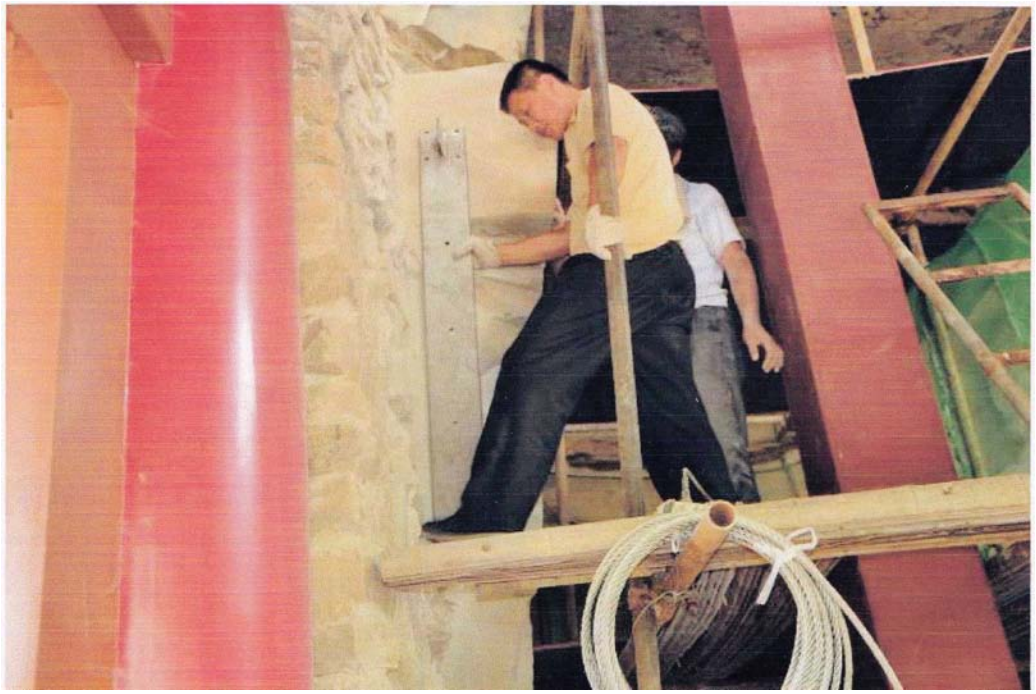


Fig.1: Positioning

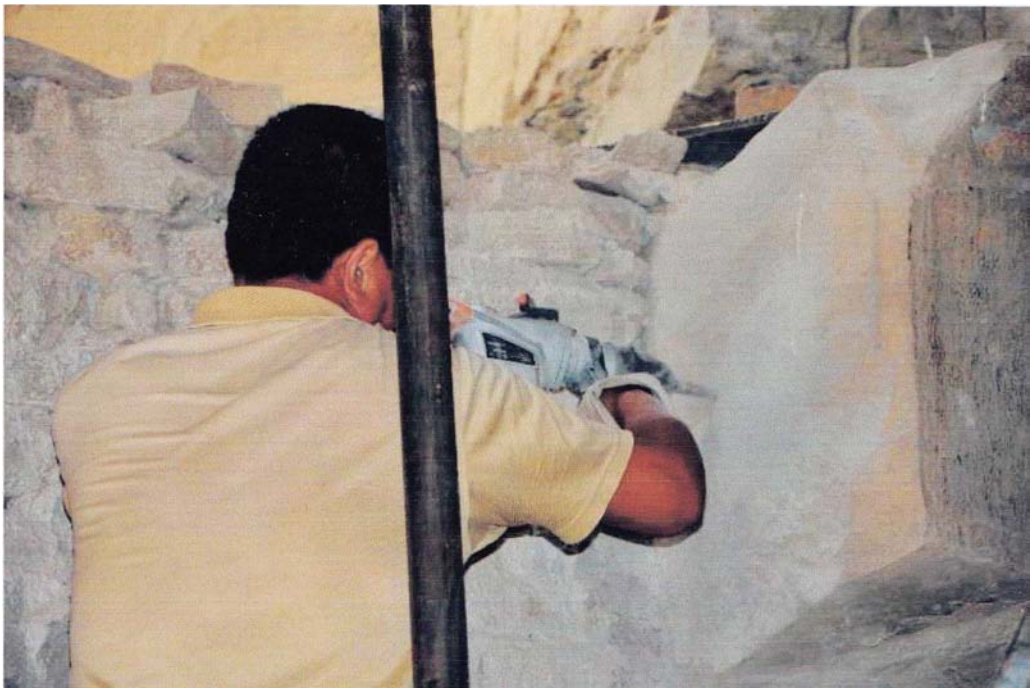


Fig.2: Drilling

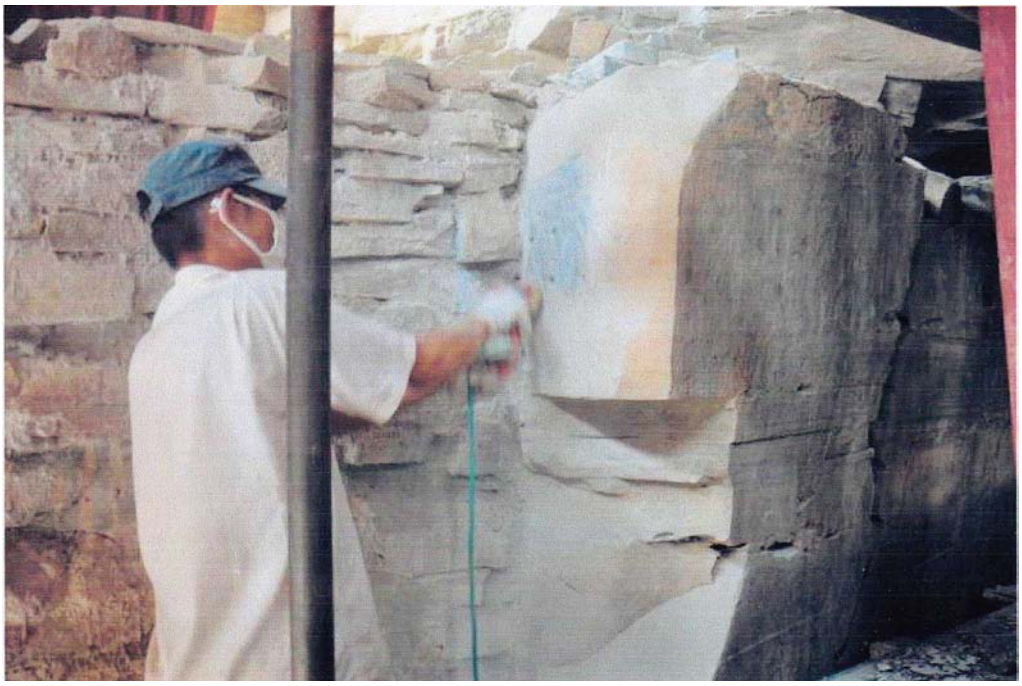


Fig.3: Repairing

Fig.4: Filling with adhesive

Fig.5: Fixing with screws

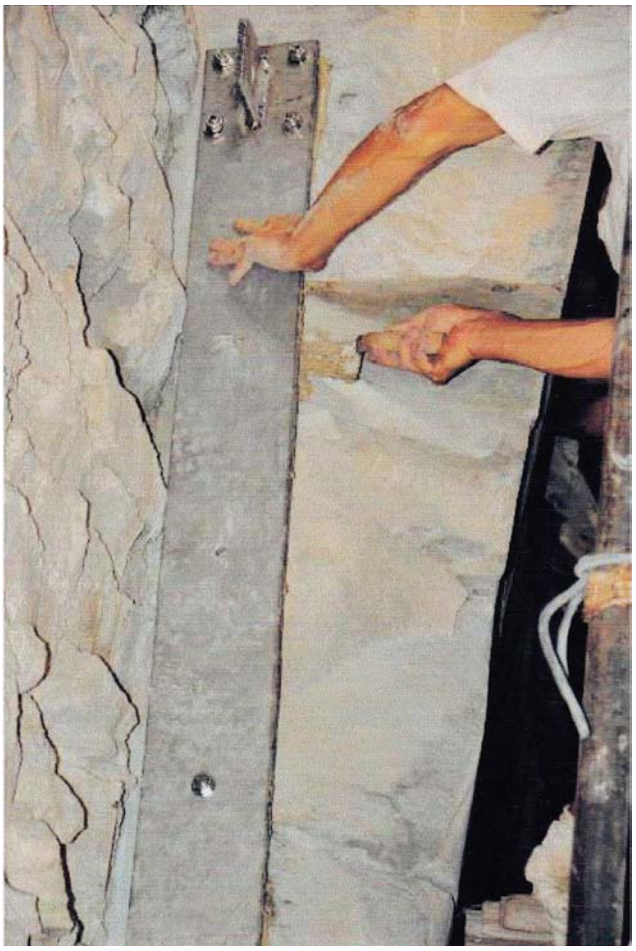
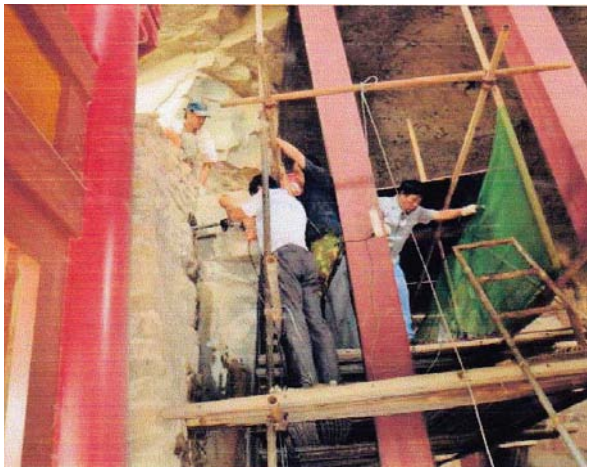


Fig.6: Finished with the mounting

2) Anchorage



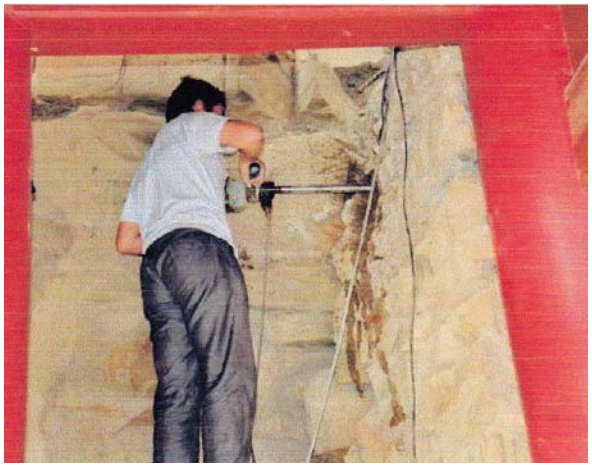
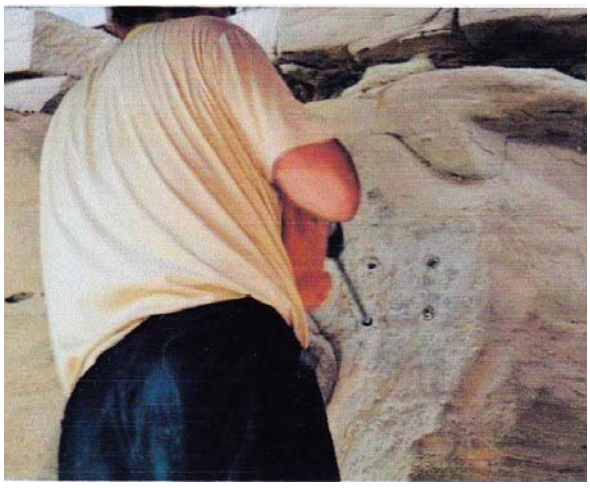


Fig.7/8: Drilling in the outer wall



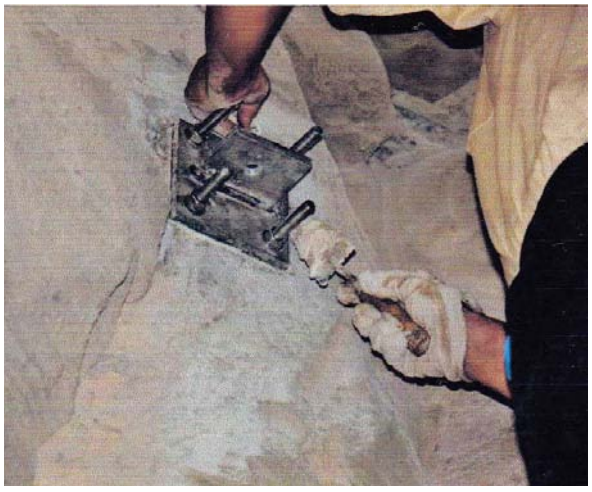
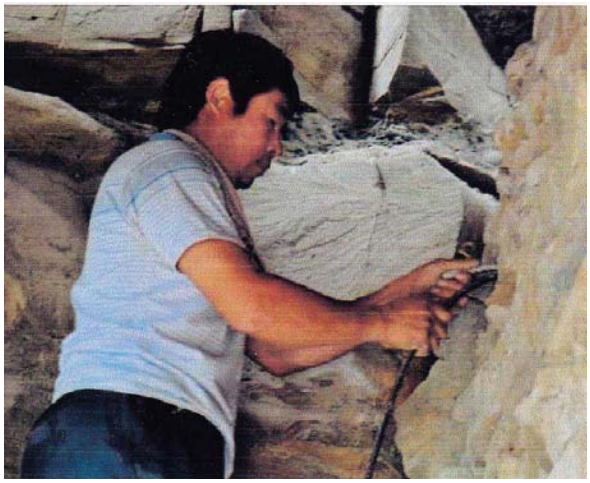


Fig.9/10: Attachment of the outer attachment elements



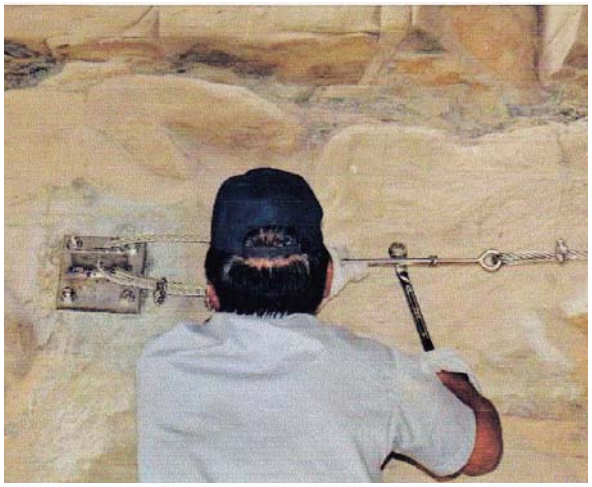


Fig. 11/12: Attachment of the wire

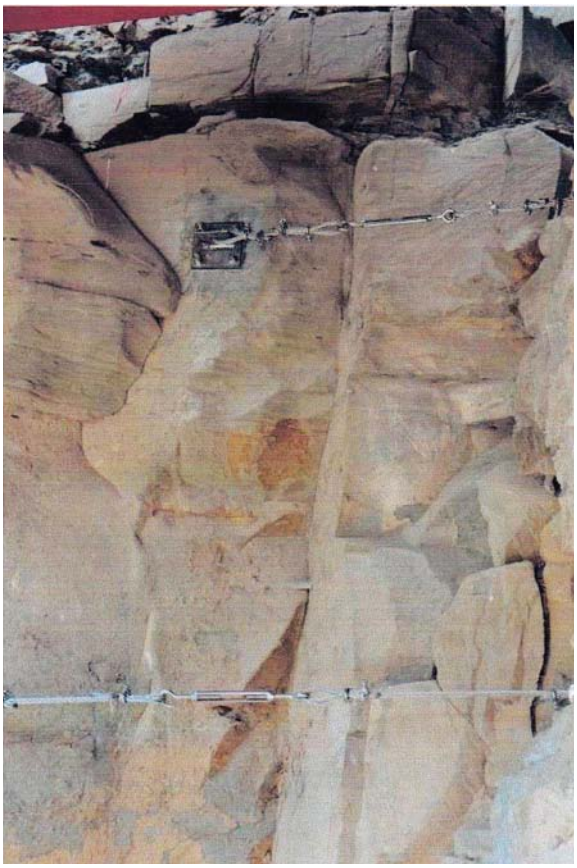


Fig. 13: Completed

2. Hanging boards on the east wall

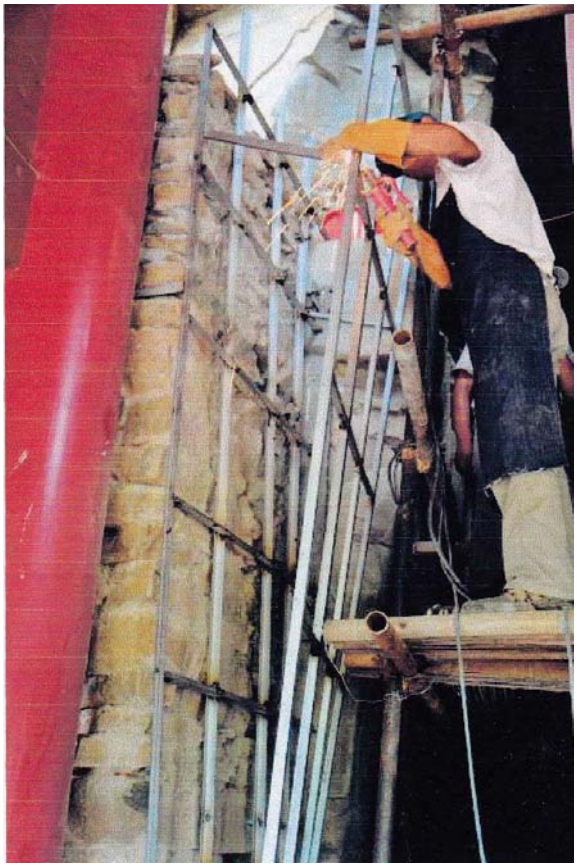
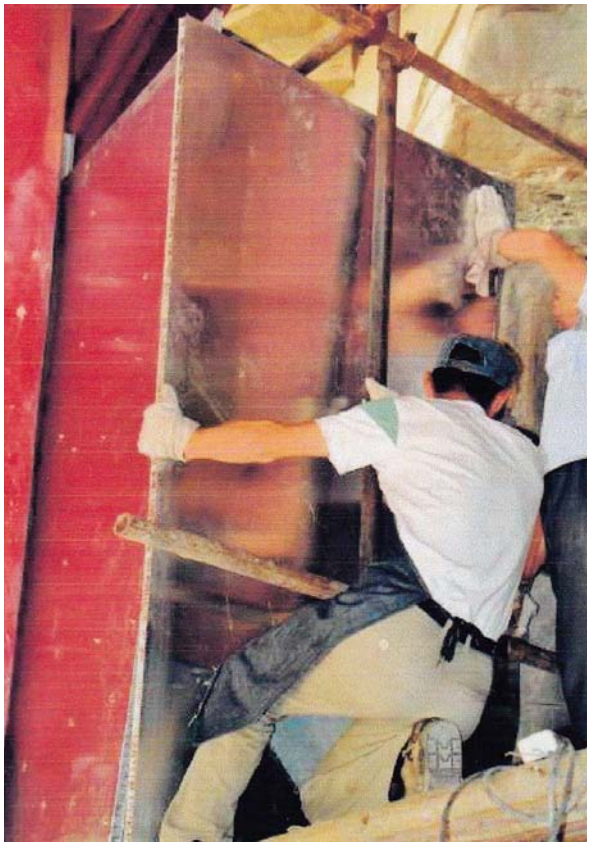


Fig. 14: Attachment of the inner frame



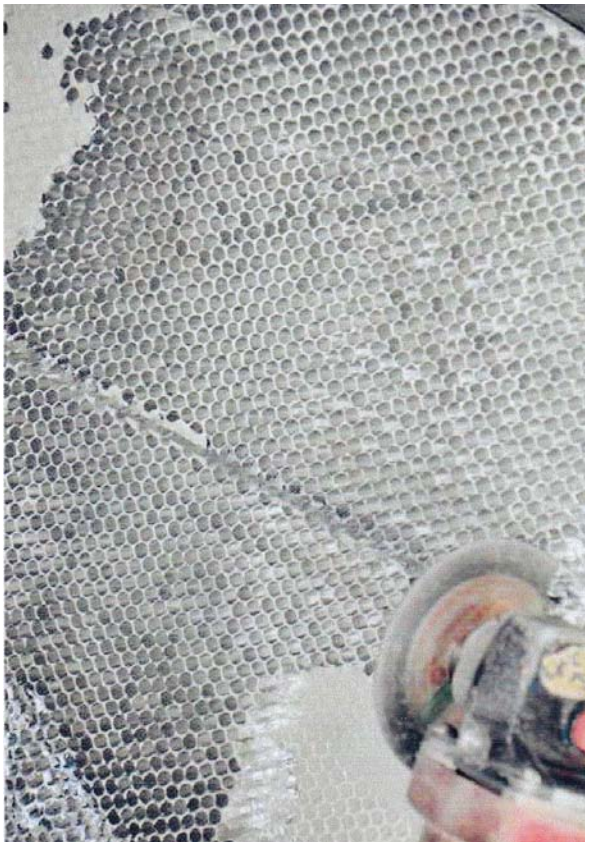


Fig. 15/16: Fixing the boards (honeycombed aluminum sheet)

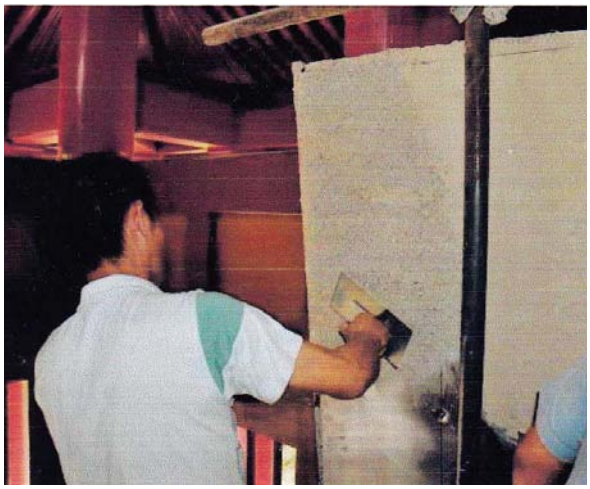


Fig. 17/18: Exterior painting

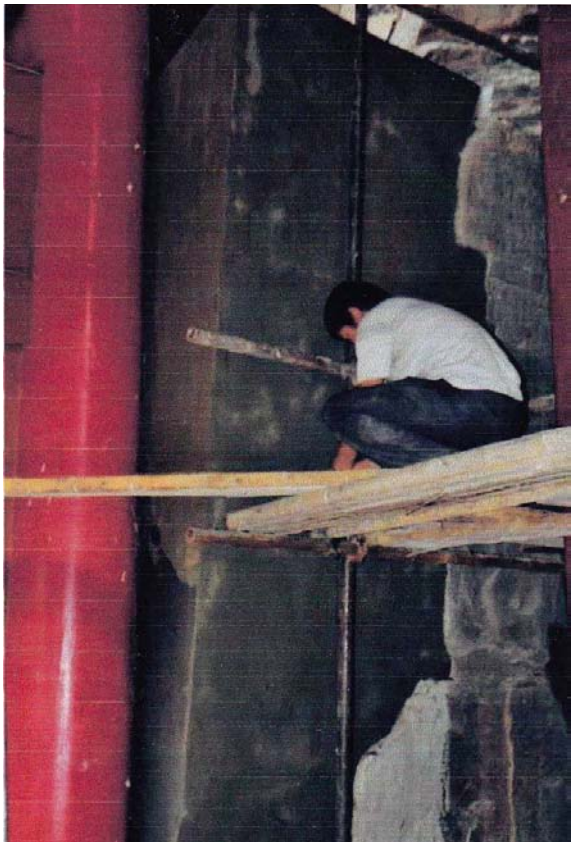


Fig. 19: Completed

3. Roof mounting on the east wall

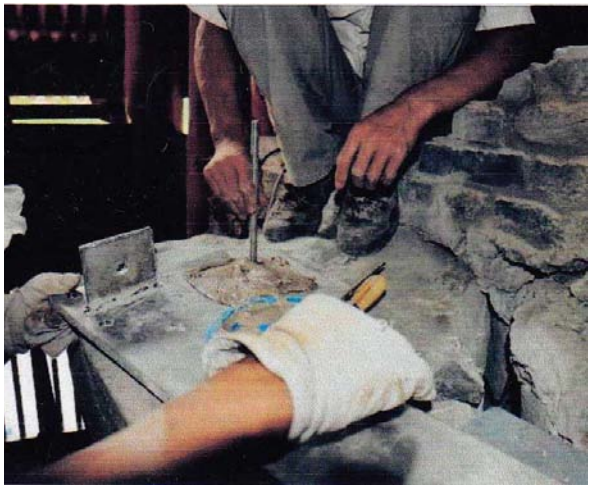


Fig. 20/21: Fastening of the steel sheet on the roof

Fig. 22: Anchorage

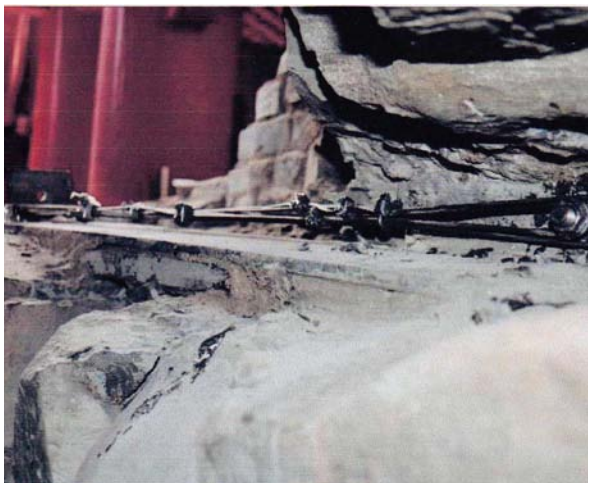


Fig. 23: Completed

4. Repairing and filling in cracks

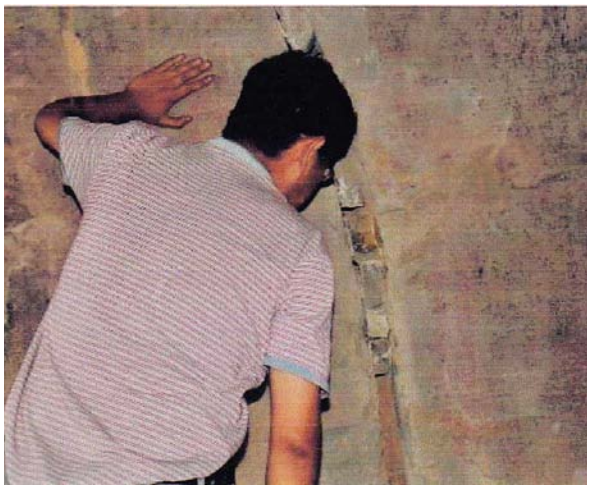


Fig. 24/25: Pointwise bonding

Fig. 26/27: Filling

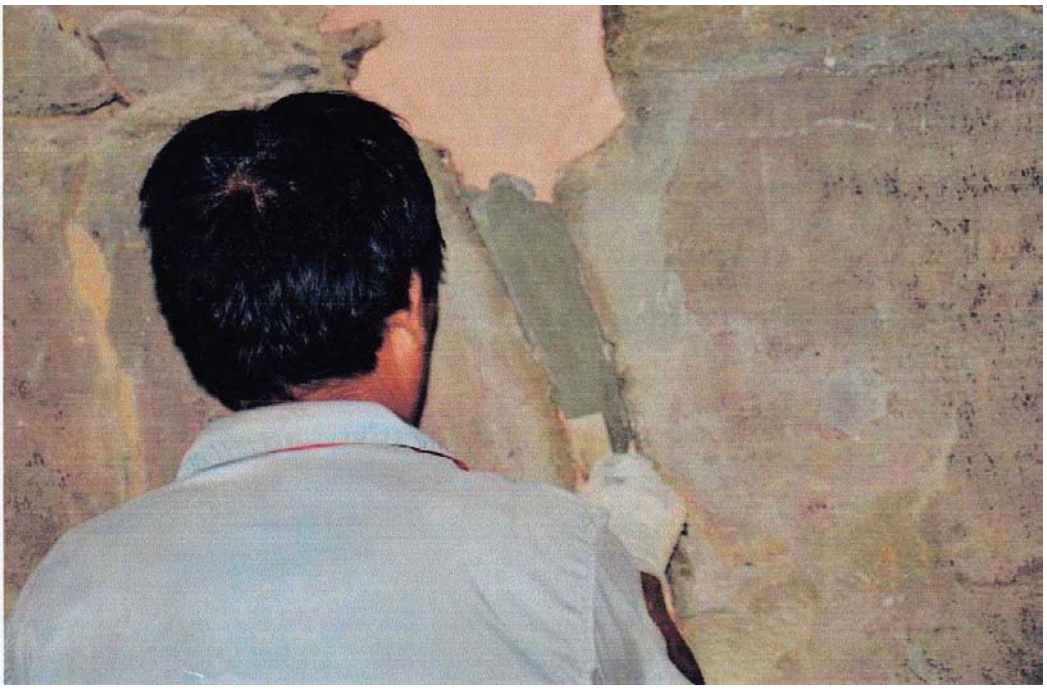


Fig. 28: Covering

Fig. 29: Completed

Sino-German cooperation of Jinchuanwan Grotto protection in 2012

Sino-german cooperation Jinchuanwan protection and research team

Chinese technicians:
Weiqiang Zhou, Min Yan, Yongjin Wang, JianGao (ChunHua tourism bureau of cultural relics)

German technicians:
Mathias Kocher, Siegfried Scheder, Franziska Kolba, Katharina Meier zu Verl

On July 31st to August 21st, 2012, the sino-german cooperation of Jinchuanwan grotto protection team according to the relevant agreement, the Chinese technicians strengthened the rock leaned out of the east wall and recovered the patch wall build bricks or stones for overall consistency.

The specific protection work includes:

1. Anchor reinforcement of dangerous rock in grotto east wall.
According to stability analysis of the east wall dangerous rocks, it may be collapse to the west or north, because the whole rock structure is not uniform, if we adopt transversal bolt to reinforced may cause the wall damage again. The pull anchor method will be more safe and feasible relatively. Adopt drilling, planting bar, combined with pull anchor method keep the dangerous rock mechanical stability, see photos.

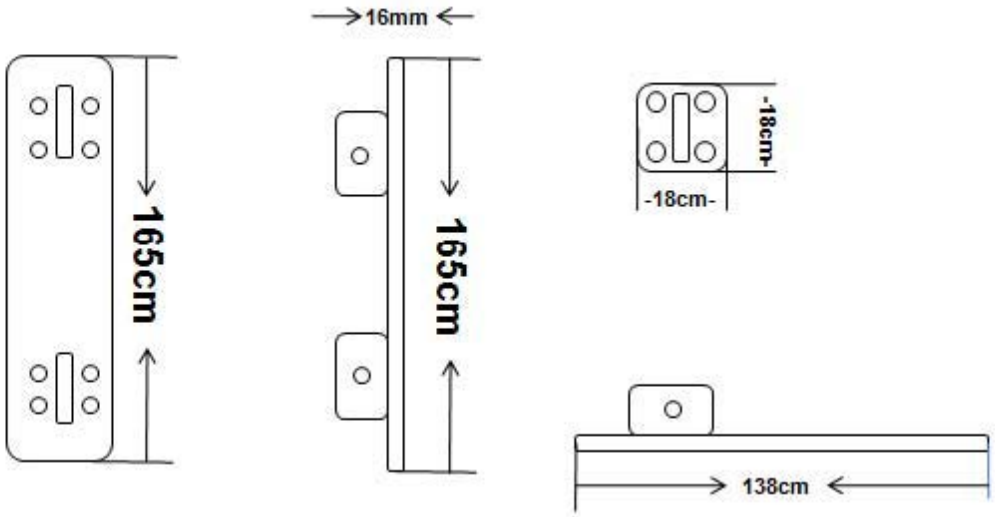


Fig. 1: Custom dies

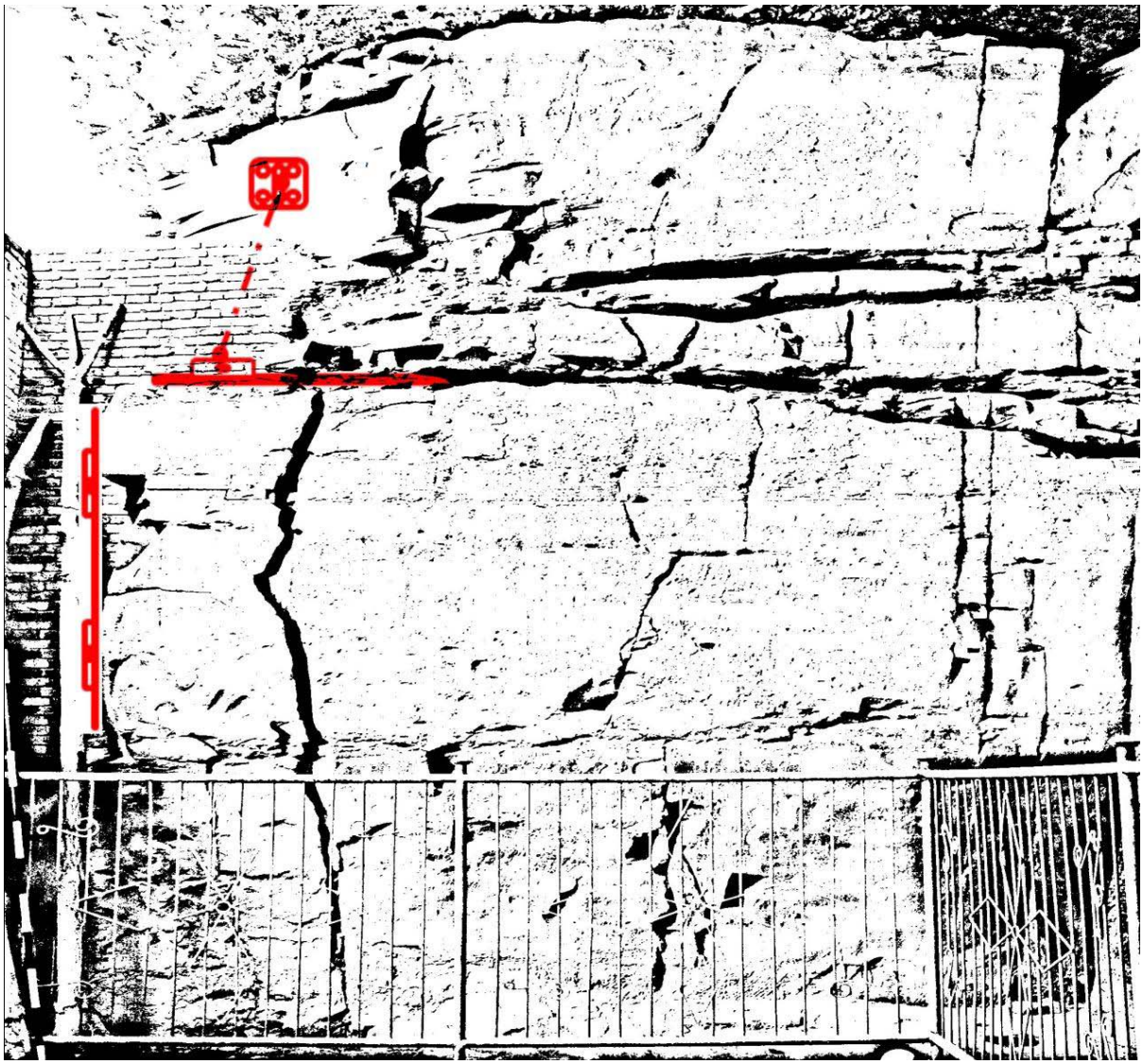


Fig. 2: Construction plan

Fig. 3: Drilling

Fig. 4: Filling glue

Fig. 5: Planting bar

Fig. 6: Steel plate fixed

Fig. 7 and 8: Wall drilling

Fig. 9: Connect with steel plate

Fig. 10: Thread stell cable

Fig. 11: Steel cable tensioning

Fig. 12: Anchor joint outside

Fig. 13: Drilling (Rock top)

Fig. 14: Planting bar (top)

Fig. 15: Steel plate fixed (top)

Fig. 16 and 17: Planting bar connect with cable

Fig. 18: Pull anchor finished (top)

Fig. 19: Planting bar (oblique upward)

Fig. 20: Pull anchor (oblique upward)

2. The patch wall build by bricks or stones of the east wall restoration.

Fixed aluminum honeycomb panels on the stainless steel support installed, then covering with repair mortar, keep the restoration part coordinated with whole, see pictures.

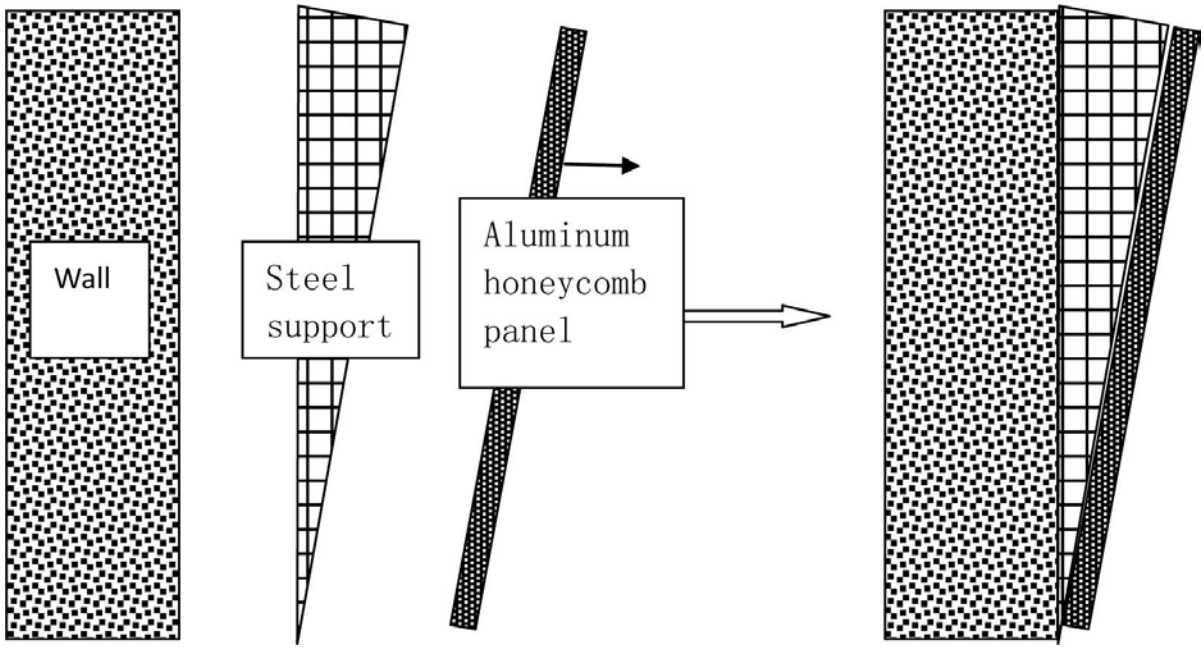


Fig. 21: Patch wall restoration

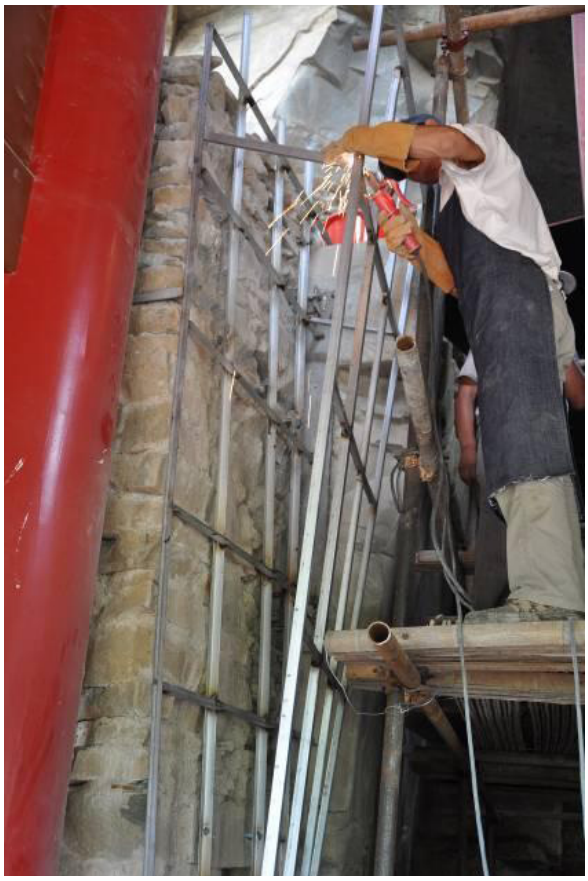


Fig. 22: Support installed

Fig. 23: Aluminum honeycomb panel fixed

Fig. 24: Glue preparation

Fig. 25: Coating (glue)

Fig. 26: Coating (sand processing)

Fig. 27: Coating (repair mortar)

3. Cracks restoration

Cracks filled with right stone and point connection by glue, use lime base mortar make level, processing color by special repair mortar to fit optically into image of the grotto.

Fig. 28: Stone filling

Fig. 29: Point connection by glue

Fig. 30: Lime base mortar make level

Fig. 31: Lime base mortar make level

Fig. 32: Color processing

Fig. 33: Three months later

4. Reinforcement effect

After observation for nearly three months, reinforcement agent preliminary reaction has completed except local area, there are color deepen in few area and no other obvious adverse reaction, reinforcement effect still keep going observation.

The Lotus Sutra Carved in the Jinchuanwan Grotto

Zhao Zhou

The Lotus Sutra and its reception in China in 6th and 7th century

Regarded as the immortal work in the Buddhist history and literature, the Lotus Sutra is one of the most important and popular texts in Mahayana Buddhism. In order to show the great wisdom of entering Nirvana to the sentient beings Buddha preaches the wonderful miraculous Dharma of unifying the three vehicles of *śrāvaka*, *pratyaka-buddha* and *bodhisattva* into one vehicle, Mahayana Buddhism. The sutra harmonizes the various doctrines of Mahayana and Hinayana schools and claims that all sentient beings can reach Buddhahood and all those who preserve, recite or copy the Lotus Sutra can gain limitless virtue. As the "treasure of all Buddhas and the embodiment of all sutras"[1] and the king of all sutras, the Lotus Sutra has been esteemed as a good object for the believers to make virtues after it was translated into Chinese. One chapter of the sutra, the Chapter of Universal Gate of Bodhisattva Avalokiteshvara (*Guanshiyin pumenpin*), narrates the great amount of advantages one can gain by revering and making offerings to the Bodhisattva and thus became the direct canon for the belief in the Bodhisattva. Together with the chapter of guanyin the Lotus Sutra was the mostly worshipped Buddhist Script in East Asian.[2]

Among the several translations, the one translated by Kumārajīva with additions by Dharmagupta, and Jñānagupta in the Sui Dynasty has been the most prevalent one. Especially the briefness and clearness as well as the beauty of the language in the translation by Kumārajīva have decisively contributed to the spreading of the sutra.[3] As an important object of cult in Buddhism, the sutra has been associated with numerous historical and miraculous stories of reciting and copying by a great amount of Buddhist monks and layers.[4] The great quantity of various versions of the sutra preserved in Dunhuang can be seen as the historical witness and proof of the cult of the Lotus Sutra. Among the Chinese manuscripts in Dunhuang there are five thousand numbered copies of the Lotus Sutra in general, ranging from the 5th to 9th century and taking about one sixth of all the copied sutras.[5]

As a special form of copying the sutras, carving texts in stone has reflected the belief in the virtues claimed in the sutra. Due to the material, technique and environment, carving the whole Lotus Sutras was rather difficult. Therefore the carved form of the sutra has mainly been found in form of excerpts, titles and names of Buddhas or Bodhisattvas. Among them the chapter concerning the Bodhisattva *Guanyin* has been predominantly carved because of the wide spread belief in him. For the time up to the Northern Qi Dynasty there was still no complete carved text of the Lotus Sutra at the important historical sites but mostly excerpts, titles of chapters or names of Buddhas from the sutra, such as in the South Cave of Northern Xiangtangshan (568-572), Cave No.4 of the Southern Xiangtangshan (568-572), Zhonghuangshan and Mujing Temple near County Shexian. The carving of the Sutra was succeeded in Sui Dynasty in Dazhushengku in Baoshan (589) and in Bahuisi in Quyang (593).[6]

Under the influence of the thoughts of *mofa*, roughly meaning the end of the world, Buddhists decided to carve the whole text of the Lotus Sutra and thereby

[1] See *Lotus Sutra* scroll 7, CBETA, T09, no. 0262, p.0062.

[2] The chapter is so widely spread and believed in that it became independent from the *Lotus Sutra*. On the spread and worship of the Lotus Sutra in Japan see the catalogue of the exhibition by 奈良国立博物馆：法華経の美術， 奈良：奈良国立博物馆 1979.

[3] There are three from six Chinese translations delivered: Dharmarakṣa in 286, Kumārajīva in 406, Jñānagupta and Dharmagupta in 601. For a detailed study of various versions of the Lotus sutra see the numerous publications of the Japanese Buddhist scholar Kabutogi Shōkō 兜木正亨.

[4] Among others there are plenty of miraculous stories recorded in Shi Zongxiao 释宗晓 (1151-1214), Fahuajing xianyinglu 法华经显应录, Shanghai: shangwu yinshuguan, 1923-1925.

[5] For the statistic of the hand copies in Dunhuang Fang Guangchang, "Dunhuang yishu zhong de *Fahuajing* zhushu" 敦煌遗书中的〈法华经〉注疏. *Shijie zongjiao yanjiu* 2 (1998): 75-79.

[6] For a overview of the carved Lotus Sutra in China, see Kiriya Seiichi, 中国における法華経の石刻，浅井円道先生古稀記念論文集：日蓮教学の諸問題, ed. by 浅井円道先生古稀記念論文集刊行会 1997-02 平楽寺書店 京都, especially p.786-787.

preserve it for the future world.[7] The earliest extant complete text of the carved Lotus Sutra is the one in Thunder Sound Cave by Yunajusi Temple in Fangshan near Beijing.[8] As the longest carved text in the cave, the sutra takes half the length of all the carved texts in the cave taken together, which shows the importance of the sutra cherished by the founder monk Jingwan (? – 639). Carved in the year 616, the sutra covers 76 plates of stone that were carved in advance and then embedded in the walls of Thunder Sound Cave. During the time from 788 to 840 in cave no. 7 of the same site the sutra was carved even once more on stone plates.[9]

In the Sui and early Tang Dynasties the completely carved text of the Lotus Sutra was relatively rare.[10] Besides the ones in Fangshan the small grotto at Jinchuanwan attributed to the School of the Three Levels which had been discovered in recent years was also found with a completely carved text of the sutra dated to the 60s of the 7th century, about fifty years after the one in the Thunder Sound Cave.[11] In the small cave at Jinchuanwan the most valuable texts are definitely those attributed to the founder of the school, Monk Xinxing (540-594), while the Lotus Sutra has also deserved a detailed study for its significance and the information it provides related to the planning of text carving in the whole cave. Some fifty years after Jinchuanwan the whole text was also carved in the era of Kaiyuan in the Cave No. 1 and 2 at Wofoyuan in Anyue County, Sichuan Province.[12] This paper examines the sutra itself carved in Jinchuanwan in detail with a reconstruction and its historical context with the other two versions in stone in Fangshan and Anyue, about fifty years before and after it.

The carved Lotus Sutra in the Grotto at Jinchuanwan

About the Cave at Jinchuanwan

The Jinchuanwan Grotto is named after the nearby village, which is located 100 km northwest from the city of Xi'an. The original entrance together with the northern wall was destroyed a long time ago and was recently rebuilt with grey bricks.[13] Carved at the foot of a hill, facing a small river to the north, the cave is about 10 metres in width and length and 7.1 meters high. Upon entering the cave, one sees a huge statue of Buddha directly at the main wall, and on the east and west side walls various Buddhist texts can be read. The original Buddha statue was almost totally destroyed during the Cultural Revolution in the 1970's. It is likely that there were assisting figures made of clay flanking the Buddha, but they do not exist anymore.[14]

Generally, one scroll of texts was carved on each register of both walls, which consists of about 10,000 characters. Altogether 160,000 characters have been carved on nineteen registers on the sidewalls. Due to more than a thousand years of weathering however, only about one third of it remains legible. On the two sidewalls there are altogether eight carved texts, four on either side. Three of the four texts "compiled by the meditation master Xinxing" are especially invaluable materials for the study of the teaching, as

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[7] In the Chapter of Budda's Life 如来寿量品 it is conveyed that the life of Buddha will be limitless ever since he has become enlightened. See *Lotus Sutra* scroll 5, CBETA, T09, no. 0262, p.0042.

[8] About mofa and the production of stone sutras, see "Ein Programm für den Weltuntergang: Die steinerne Bibliothek eines Klosters bei Peking". In: *Heidelberger Jahrbücher*, Band 36 (1992): 15-33. For the carved text in Jinchuanwan and the context of mofa, see 西本照真，"南北朝隋唐期の仏教思潮と石經事業一金川彎三階教刻經にみられ独自性と普遍性",44 - 46, ed. by 氣賀澤保規，中國南北朝隋唐期における華北仏教石刻の諸相，Tokyo, unpublished, 2009.

[9] Although there is an opinion that after the Thunder Sound Cave sutra texts would not have been carved directly on the inner walls of the grottoes, because the method of carving on stone plates was economically more effective, the new research and discoveries in this field since recent years show that in Tang Dynasty carving texts directly on the inner walls of grottoes could still have been an important form used parallel to carving them on stone plates. See Kiriya Seiichi, 中国における法華経の石刻，p. 806.

[10] Besides the three places mentioned in this article, it is recorded in historical documents that the whole sutra was carved in Chanding Temple in Tang time, which is however not preserved. See *Song gaoseng zhuan*, scroll 27, CBETA, T50, no. 2061, p. 0880.

[11] From a votive inscription carved on the west wall it is known that the cave had been carved in the Tang Dynasty in the years 662 to 670. Zhang Zong 张总 and Wang Baoping 王保平, "Shanxi chunhua jingchuanwan sanjiejiao kejing shiku" 陕西淳化金川湾三阶教刻经石窟, Wenwu 5 (2003): 65-74.

[12] For a brief information of the carved Lotus Sutra in Wofoyuan, see Sichuansheng wenwu kaogu yanjiusuo 四川省文物考古研究所 ed., *Sichuan anyue wofoyuan tangdai kejingku* 四川安岳卧佛院唐代刻经窟 Chengdu: Sichuan chuban jituan, 2009, p.10-11.

[13] A new protective frontal building has been built before the small cave recently. All data about the cave come from the archaeological report by Zhang and Wang.

[4] The cave is special concerning its form and the combination of huge statue and sutra texts in Shaanxin. As one of very few Buddhist cave with carved sutra, Jichuanwan cave is connected with those in Henan and Hebei since the Northern Qi Dynasty, especially the Dazhushenku in Lingquansi of the Sui Dynasty, where parts of Lotus Sutra were carved.

they are not available in other form. The first two texts are focused on an important subject - "arousing the mind to the enlightenment in accordance with the capacity". The third one is an excerpted text from *Dajijing yuezangfen*, a main scriptural source for the belief of "*mofa*".[15] It is interesting to notice that the texts of Xinxing were put intentionally in the easily accessible places, although their status as treatises is hieratically inferior to the "true sutras" taught by Buddha. That shows that Xinxing's texts are not only treasured by the historian of today, but were also highly valued in Tang times.

On the east wall are eleven registers: beginning from the bottom one reads three texts compiled by Xinxing from register one to three. Register four to eleven are covered with the entire text of *the Sutra of Ten Wheels*, arranged in approximately one scroll per register reaching up to the ceiling of the cave. On the west wall there are eight registers and four texts: on the first register there are three short texts preserved: a short ritual text by Xinxing, the *Diamond Sutra* and *Sutra where Tathāgata Reveals Teachings to King Prasenajit*;[16] starting from the second register and above is the whole text of the *Lotus Sutra*.

Description and reconstruction

The Lotus Sutra on the west wall begins from the second layer with one scroll on each layer and seven scrolls in total reaching up to the ceiling. Since the upper part of the grotto has been exposed to the air for several hundred years, the upper part of the sutra is seriously weathered while the lower part is relatively well preserved.[17] The last scroll of the sutra, namely the seventh scroll, has been totally weathered without a single word being left, and of the sixth scroll there are only about one hundred characters of the latter part still visible. Respectively the first to the fifth scroll have also been weathered to certain extent. General information about the number of lines and characters of each layer is listed in Table 1, while more detailed information on the characters in each layer in Table 2.

From the table it can be seen that the number of characters in each line of different layer varies. Thus it can be assured that the text was not carved directly by copying from a hand scroll, since in a hand scroll the number of characters in each line is generally the same, no matter how many characters in each line.[18] The text in Jinchuanwan keeps changing the numbers of character in each line, because the numbers of lines of each scroll and characters in each line have been formally arranged and planned in order to carve orderly on the stone wall, which will be further analysed in the text below. On the basis of the extant characters, roughly one third of the original number, a reconstruction has been made, and the layout of the last scroll is made with reference to that of the sixth, since the last one has been completely lost. The following is a detailed description of each scroll:

Scroll 1: (Chapter 1, 2)

The beginning parts of each scroll on the west wall have been destroyed and thus remain unknown. In respect of the beginning parts of the texts on the east wall especially *the Sutra of the Ten Wheels*, the Lotus Sutra might have been carved accordingly, that is, the first line for the title of the sutra, then closely followed by the names of chapters and without that of translators. Therefore in the reconstruction the first line of each scroll shows the name of the sutra and that of the chapter, i.e. "妙法蓮華經序品第一" without the number of the scroll. The main text begins from a new line on, which is also in correspondence with the reconstructed text. Meanwhile, the names of each chapter within the scroll do not always begin from a new line, as will be seen in the following parts. Thanks to their lower position in the grotto the first and the second scroll are best preserved. The first scroll originally has 9120 characters in 280 lines, now 240 lines preserved with 6068 characters visible and mostly 33 characters per line. 33 characters in each line is just the doubled number of those in an official hand scroll of Tang times. Probably this version was copied from a certain handscroll of an official version with two lines on paper into one on stone. The first scroll is arranged relatively loosely, for instance, the second chapter begins from a new line and before "爾時" or "偈曰" there is always a empty space (in the line 13, 68, 158, 175,170 etc.). Although at the end of the last chapter there is still space, the title and numbering of the scroll "妙法蓮華經卷第一" is placed in a new line, as seen in most of the scrolls.[19]

[15] For the English translation of the four texts attributed to Xinxing, see Annual Report 2007-2009 Jinchuanwan (BMBF Projekt 01GWS079), p. 33-118.

[16] It is unclear what might have been the text before the one by Xinxing on this register, since it has been destroyed long before.

[17] The river brought loess into the small cave and covered the lower registers until the third or fourth ones, so that the carved texts there have been fortunately preserved. See Zhang and Wang, p. 66.

[18] In an official version of a hand written Buddhist script in the Tang Dynasty there are normally approximately 15 to 17 characters per line.

[19] The only exception is the scroll 3, where the title and scroll number are not carved in a new line but directly after the text.

Scroll 2: (Chapter 3, 4)
Similarly preserved like the first one, this scroll has originally 9892 characters in 278 lines, now 240 lines preserved with 6855 characters visible and mostly 36 characters per line. In this scroll the number of characters in each line differs from the first one in 36 characters. Seemingly this is the case because the second scroll has about 700 characters more than the first one. In order to keep the same length of text as the first, three characters more have been added to each line. Another similar feature of layout to the first scroll is the placing of the names of the chapters, for instance "信解品第四" begins from a new line.

Scroll 3: (Chapter 5-7)
This scroll has been heavily weathered. About one third of the upper part of the text is invisible and the extant characters are only half of the whole scroll. The scroll has originally 9432 characters in 281 lines, now 208 lines preserved with 2941 characters visible and mostly 34 characters per line. Its layout is similar to scroll number one and the names of chapters begin from new lines as well.

Scroll 4: (Chapter 8-13)
While most of this scroll has been erased, about only one fifth of the whole text survived. The scroll originally has 11341 characters in 281 lines, now 156 lines preserved with 2243 characters visible and mostly 41 characters per line. The characters in each line in this scroll are definitely more than in the last two chapters, mostly counting 41 characters per line (altogether 261 lines, including the reconstructed lines) and several lines with 40 characters per line. In this scroll there are about 2000 characters more than in the former three scrolls, so in order to keep the width of the scroll similar to that of the other ones, the number of characters in each line has been increased to 41. In this scroll there is no enough space, so the names of each chapter do not begin from a new line any more. For instance, "法師品第十" is placed directly after the last chapter with two empty spaces before. Similar arrangement can also be found in the title of chapter 13 "勸持憑第十三.

Scroll 5: (Chapter 14-17)
The fifth scroll has also been damaged in a similar fatal way as the fourth one with about only one fifth of the text visible. The scroll has originally 10751 characters in 280 lines, now 77 lines preserved with 1564 characters visible and mostly 39 characters per line. Since the names of the chapters are all invisible, their layout is not clear.

Scroll 6: (Chapter 18-23)
Most of the scroll is destroyed. Only at the end there is a small amount of characters still visible. The scroll has originally 10342 characters, now 45 lines preserved with 116 characters discernible. On hands of the few preserved characters it is presumed that originally there might have been 35 characters in each line and 299 lines. The apparent difference in layout of this scroll from the former five scrolls is that this scroll does not keep the same width as the former ones, but has 20 more lines. Seemingly it is because there has not been enough space under the ceiling for the whole sutra, if one just added characters to each line to keep the same width of each scroll. In general it seems that there have been plan for each scroll, but no systematic plan for the whole text in advance. The original planning and carving of the sutra will be discussed in detail in the following part.

Scroll 7: (Chapter 24-28)
Not a single word of the seventh scroll outlived to this day. It is a pity that the widest spread chapter concerning the bodhisattva *guanyin* is missing here. The reconstruction is made according to the layout of the sixth scroll. The scroll has originally 9374 characters in 298 lines, with 32 characters per line.
Since the added chapter 12 Devadattais found here in the scroll number 4, which was translated by Gupta in 601 AD, the version of the Lotus Sutra carved here should be the so called "*tianpin*" version, – with additional chapter on the basis of the translation by Kumārajīva. The *gata* in the chapter of *guanyin* should be included in the last scroll, but the whole scroll is not extant.

Layer	Scroll	Chapters	Lines			Characters			C/L
			Visible	Invisible	Original	Visible	Invisible	Original	
Layer 08	Scroll 07	Ch. 24-28	0	298	298	0	9374	9374	32
Layer 07	Scroll 06	Ch. 18-23	45	254	299	116	10226	10342	35
Layer 06	Scroll 05	Ch. 14-17	77	203	280	1564	9187	10751	39
Layer 05	Scroll 04	Ch. 8-13	156	125	281	2243	9098	11341	41
Layer 04	Scroll 03	Ch. 5-7	208	73	281	2941	6491	9432	34
Layer 03	Scroll 02	Ch. 3-4	240	38	278	6855	3037	9892	36
Layer 02	Scroll 01	Ch. 1-2	240	40	280	6068	3052	9120	33

Tab. 1: Information of lines per scroll and characters per line

Scroll 01		Scroll 02		Scroll 03	
C/L	Lines	C/L	Lines	C/L	Lines
33	275	35	6	32	2
others	5	36	265	33	24
		37	2	34	239
		others	5	35	9
				36	1
				others	6

Scroll 04		Scroll 05		Scroll 06	
C/L	Lines	C/L	Lines	C/L	Lines
40	12	39	270	34	1
41	261	40	1	35	283
others	8	35	1	36	6
		others	8	others	9

Tab. 2: Detailed information of numbers of characters per line in each scroll

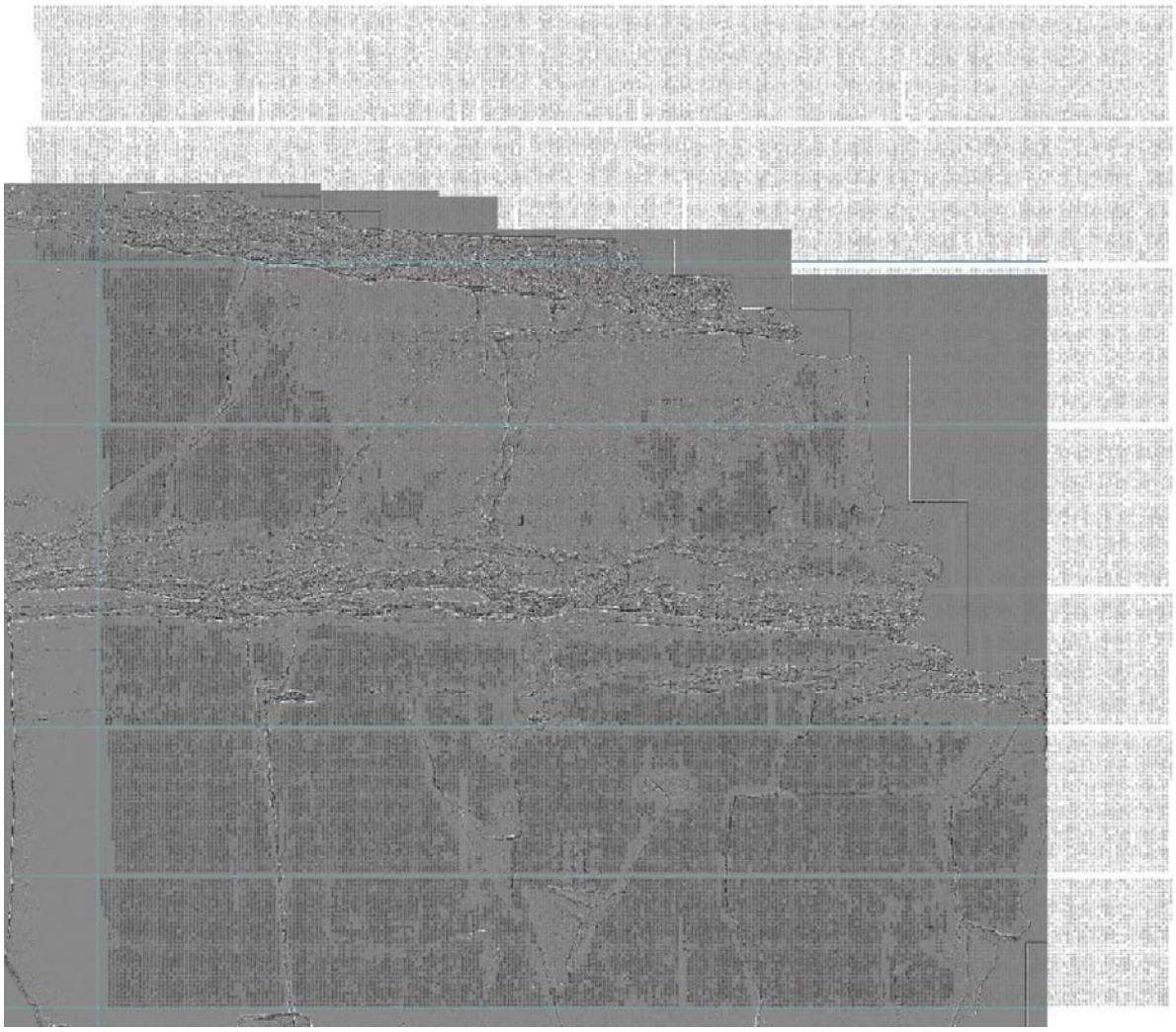


Fig. 1: Reconstruction of the Lotus Sutra

Planning of the Carving

Principally the layout of the whole sutra is simple, as shown in the reconstruction, each scroll begins strictly from a line and ends with the same length, only the second scroll has two lines less than the first one, the third two lines more than the second, the fourth one line less than the third, and the fifth one line less than the fourth. As the reconstruction shows, the first five scrolls were carved almost within one rectangular area, although the number of characters in each line varies slightly.

Presumably, there had been a plan for the west wall before the work began. The sutra might have been planned to be carved within a rectangular field with slim empty space between each scroll as the layout of the first five scrolls show. In order to reach that goal, one had to calculate in advance the number of lines, characters per line and the size of characters. Provided the number of lines of all scrolls is certain, due to the various numbers of characters in each scroll, one had to calculate how many characters must be in each line. That is why the numbers of character in each line of the first five scrolls are always different. But if one wants to carve eight layers orderly on the west wall, one has to pay attention to the general height of all layers. If the height of the whole text is higher than the ceiling, the characters in each line should be accordingly reduced. To demonstrate it in a formula it will look like this:

number of characters in st scroll/numbers of lines + number of characters in 2nd scroll/numbers of lines + ... + number of characters in 7th scroll/numbers of lines ≦ the height to the ceiling

If the sum of the left side is bigger than the height to the ceiling, the numbers of lines have to be changed, and one must change the characters of each line to fulfil that formula. In addition, the planner should still keep the texts in the first layer in mind (number of characters per line = sum of characters of all sutras/lines). Therefore it must be calculated for each scroll in advance in order to carve the texts on the west wall orderly.

Nonetheless, the texts in the highest two layers, the 6th and 7th scroll, have 20 lines more than the lower layers. The reason is that the last two scrolls could not be carved underneath the ceiling while keeping the width or number of lines of the first five scrolls. One had to change the number of characters in each line of the last two chapters, to reduce the height. Such situation is probably due to the inaccuracy while planning before the carving began, because the surface of the wall is suitable for carving longer text at all.

The texts in the first layer should have been carved together or a little earlier than the Lotus Sutra, but since the first layer consists of several texts and the exterior part is destroyed, the missing part of texts cannot be restored. Logically from the well-arranged Lotus Sutra one could presume that the beginning of the first layer should have the same starting line as the layer above. That means, before *the Sutra of the Seven Staged Names of Buddhas* there must have been so many characters as it can contain. From the reconstruction it can be seen that there are 60 lines destroyed and in the first layer there generally are 40 characters per line, which makes 2400 characters in total. There is unknown if it once had been a text by Xinxing or a short sutra.[20]

The carved Lotus Sutra in Jinchuanwan in the historical context

The relation of Lotus Sutra and the Three Levels School

For such an important Sutra of Mahayana Buddhist script as the Lotus Sutra, like other Buddhist Schools, the Three Levels School has shown its utmost respect, and drawn nutrition from it in supporting the doctrines of its own school. The practice proclaimed by the founder Master Xinxing, the so-called "Universal Buddha" came directly from the chapter 20: "Chapter 20: Never-Slighting Bodhisattva". According to the sutra the bodhisattva showed great reverence and praises to whomever he met, whether they were monks or layers. He told them, that he deeply honour them and dared not slight them, because they all practiced the way of bodhisattva and would reach the Buddhahood. Even after many years of being always cursed and blown, he had never got angry, but constantly told people that they will reach the Buddhahood.[21] By admitting that it was the practice of his former life, Buddha shows his support to such practice of "Universal Buddha" in the Lotus Sutra. According to *Xinxing yiwen* it was emphasized by the master that one should follow the Lotus Sutra and learn and practice the practice of the Not-Slighting Bodhisattva".[22] Although such practice of recognizing Buddhahood in everyone has its theoretical roots in the thought of *Tathāgatagarbha*, it is the Lotus Sutra where the master Xinxing found his model of practice. Therefore, it is no wonder that the Lotus Sutra is quite often quoted in the writings of Xinxing, for instance in the two texts compiled by Xinxing on the east wall in the cave, or other Xinxing scripts found in Dunhuang.[23]

As a school of Chinese Mahayana Buddhism, it is no wonder that the Three Levels School highly cherished the Lotus Sutra, but the imitation and underlining of the comparative special practice found in the sutra is still noteworthy. "Universal Buddha" means in fact the refusal of the orthodox doctrine and the denial of the confinement between the schools as well as a rejection to the status of dominating monks. As eccentric and extraordinary movement it was deemed to be objected and hated by the upper layer of Buddhists.[24]

A Comparison of the three carved versions of the Lotus Sutra

Although the version in Jinchuanwan is the one with additional contents, the three Lotus Sutra carved from 6th to the 7th century in Leiyindong, Jinchuanwan and Wofoyuan, are all based on the translation by Kumarajiva. However, it is noticeable that the form of the three is rather different: the cave Leiyindong is a naturally formed cave, which was not suitable to carve text directly on the walls. Therefore the precast stone plates with carves texts were imbedded on the walls of the cave; in Jinchuanwan there is one scroll on each layer, still with the traces of the classical form of written sutra scroll on paper or silk; in Wofoyuan the caves were especially opened for the sutras running from the ceiling to the ground.[25] All the carved texts have their own concrete reason or historical origins for their forms.

[20] Accidentally the sutra *Fo chui boniepan lueshuo jiaojie jing* 佛垂般涅槃略說教誡經 has about 2400 characters which could have been suitable for the space.

[21] See *Lotus Sutra* scroll 6, CBETA, T09, no. 0262, p. 0050.

[22] See *Xinxing yiwen* 信行遺文, in Lan Jifu 藍吉富 ed. Xiandai foxue daxi I – sanjiejiao canjuan 現代佛學大系 I – 三階教殘卷, p.7.

[23] On the east wall there are quotations from among others the metaphor of the burning house, the Chapter 2 and 20, etc.

[24] For the rise and prosecution of the movement see Jamie Hubbard, *Absolute Delusion, Perfect Buddhahood: The Rise and Fall of a Chinese Heresy,* Honululu: University of Hawaii Press, 2001, especially the part of "Suppressions of the Three Levels Movement", p. 189-222.

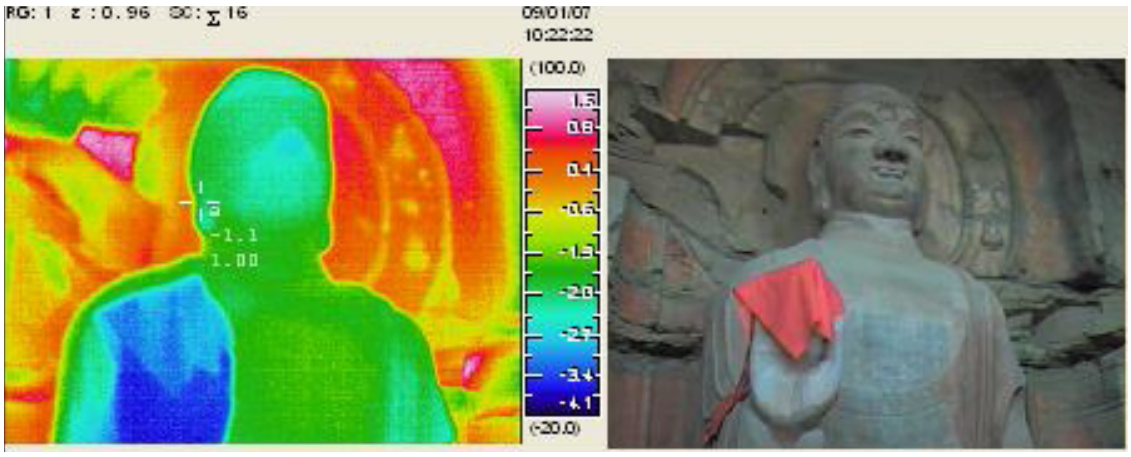
[25] It is comparable with those in Zhonghuangshan in County Shexian and Xiangtangshan near Handan in Hebei province; therefore it can be regarded as a continuum of the tradition initiated since the Northern Qi Dynasty.

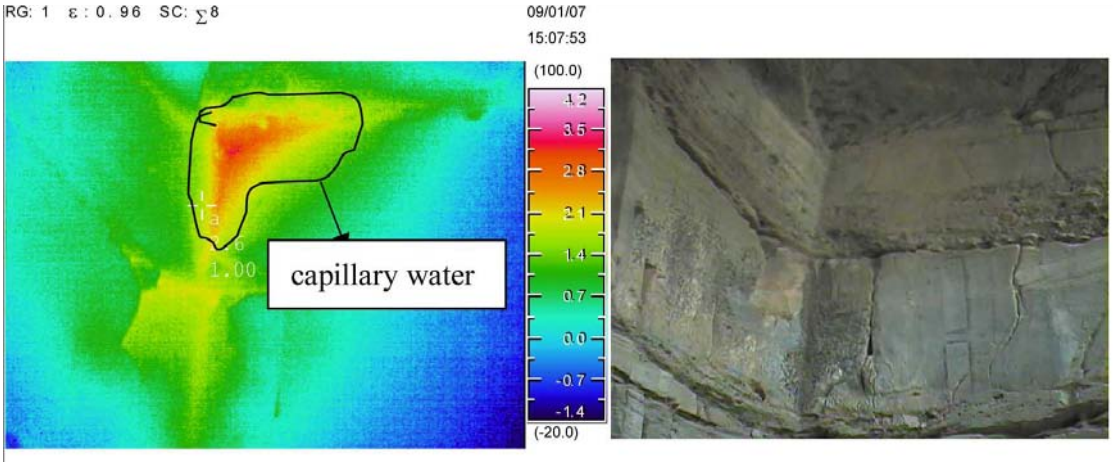
The supporters of the Three Levels School had no ably selected the texts cherished by the school to be carved, which showed a strong self-consciousness and differs from the other places where all sutra were carved for eternity. Jinchuanwan as the single cave with carved texts in Shaanxi province its form is seemingly related with the caves in Henan and Hebei province, where for instance in Dazhusheng-ku the texts were also carved in a similar format to that in Jinchuanwan.

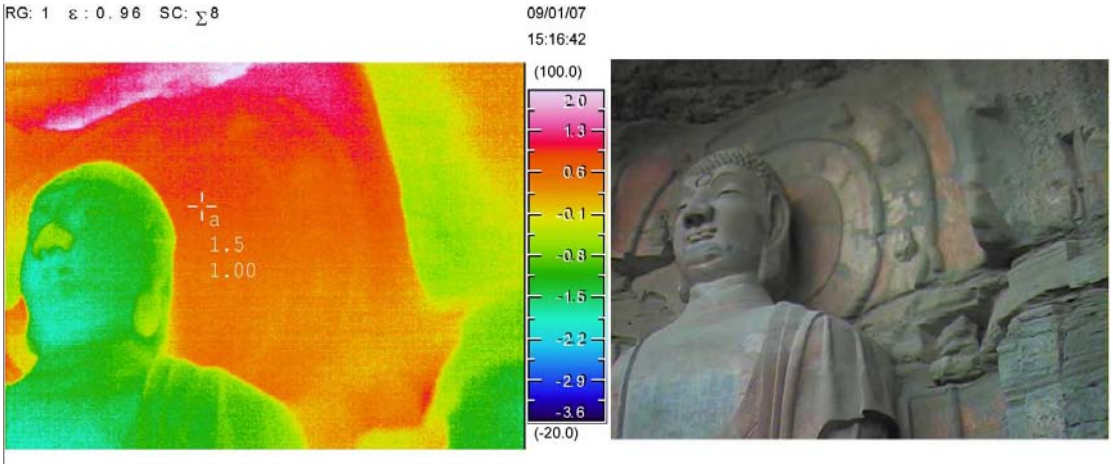
Together with the version in Taisho Tripitaka the three versions are compared with differences and variations of characters listed in the Table 3. Since the text in Jinchuanwan is heavily weathered, only the preserved texts have been compared. The comparison shows that the three texts in general have no great difference. Despite of several alternations concerning the wording, the meaning remains unchanged most of the time. The most notable thing is the variation of characters in various versions. Probably because the Leiyindong text is the oldest one, the variations appear quite often there. The phenomenon of character variations is slightly chronological, i.e. many ways of writing disappear in the later versions. Another reason for the variation of the characters is due to the simplification of carving on stone, for instance the character "辭"has at least 4 or 5 ways of writing in Leiyindong by sinplifying the left part of the character. Comparatively to say, of the three versions the one in Jinchuan comes nearer to the one in Taisho Tripitaka. In the meantime it should not be neglected that there are still many exceptions so that it is not proper to identify one with another. The changes might have already happened in the process of copying on paper or silk by various copyists at various times in various places. Since the version of the text in Jinchuwan might come from the nearby capital Chang'an, where several temples of the School could still be found at the time of carving, and the version from the capital was widely spread for its higher authority, therefore the one in Jinchuanwan comes nearer to the one delivered up to today.

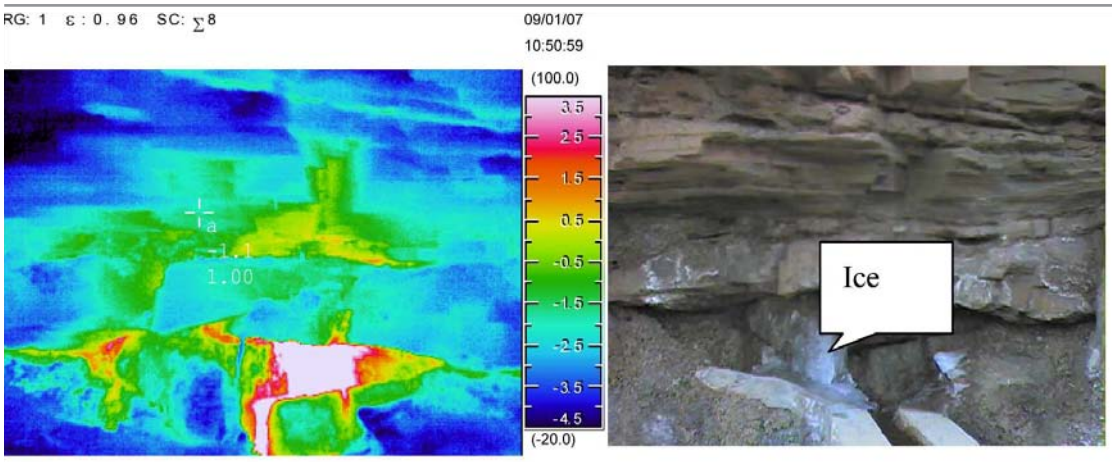
Thermographic images of Jinchuanwan Grotto

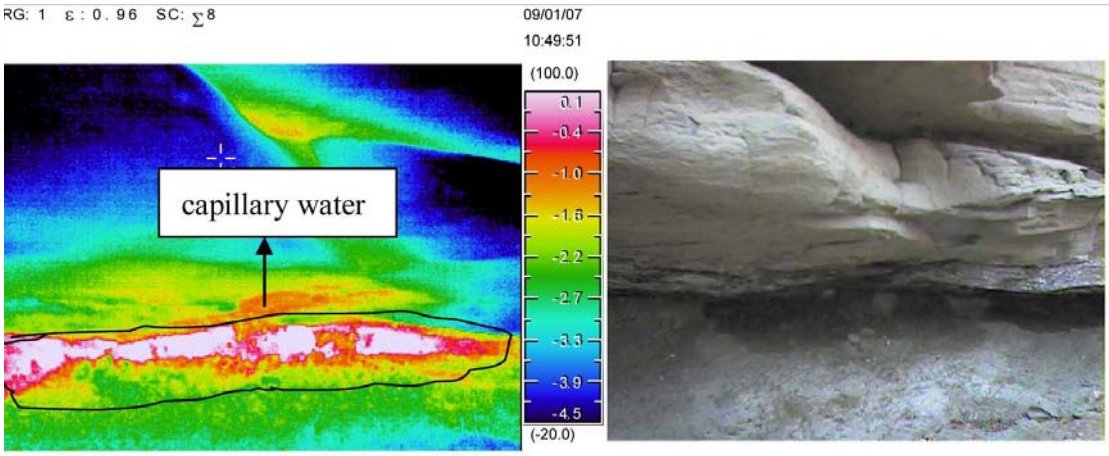
Center for the Conservation and Restoration of Cultural Heritage Xi'an

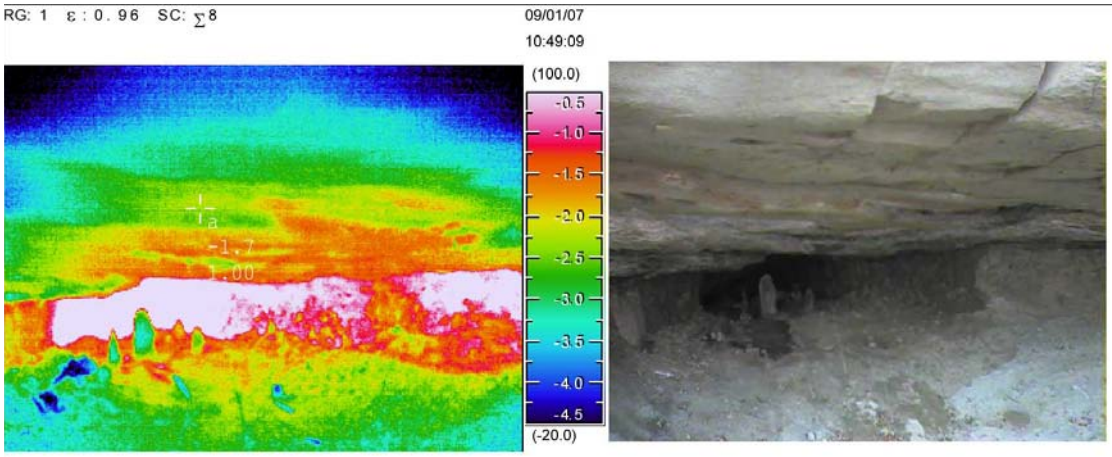








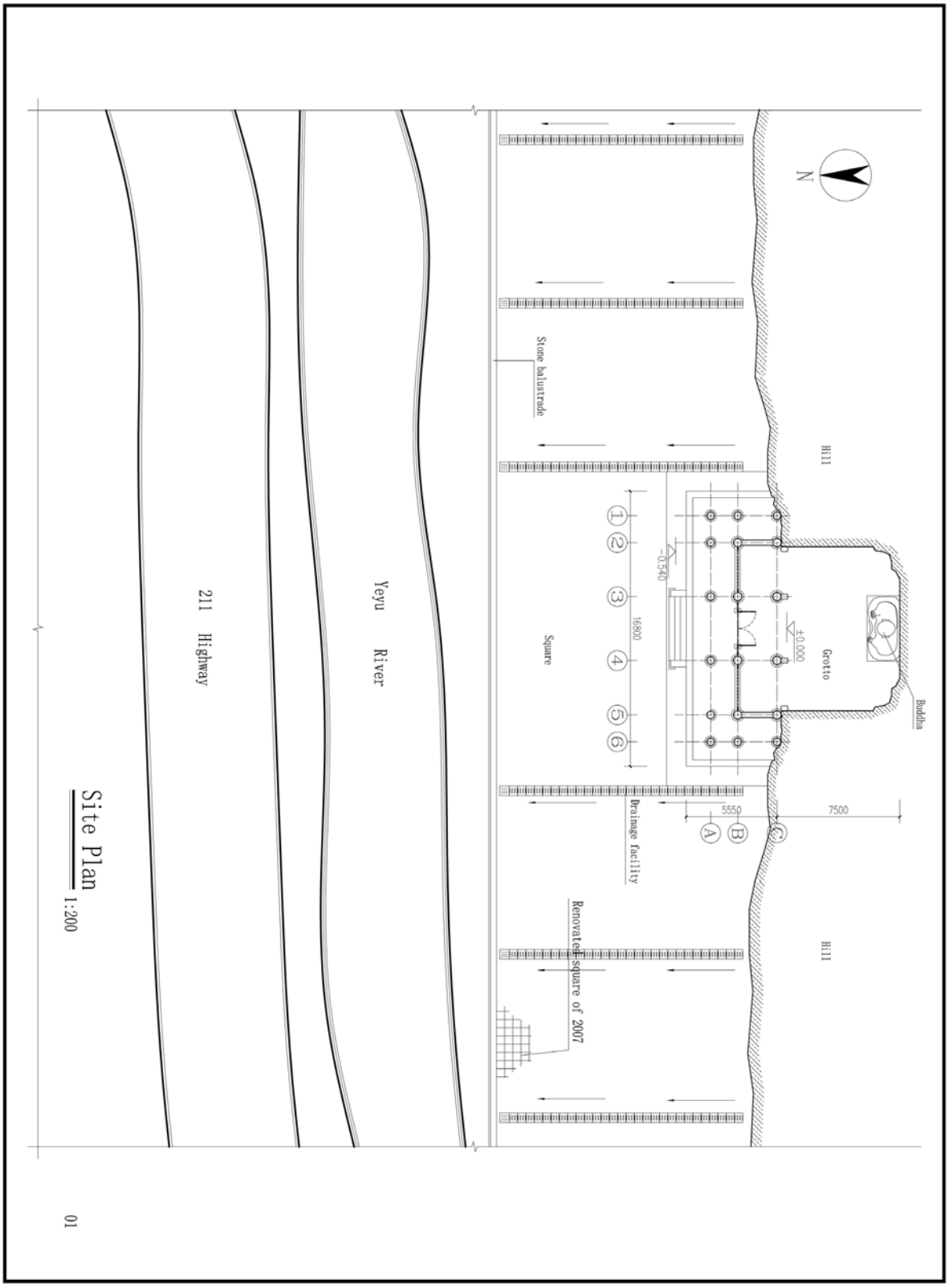


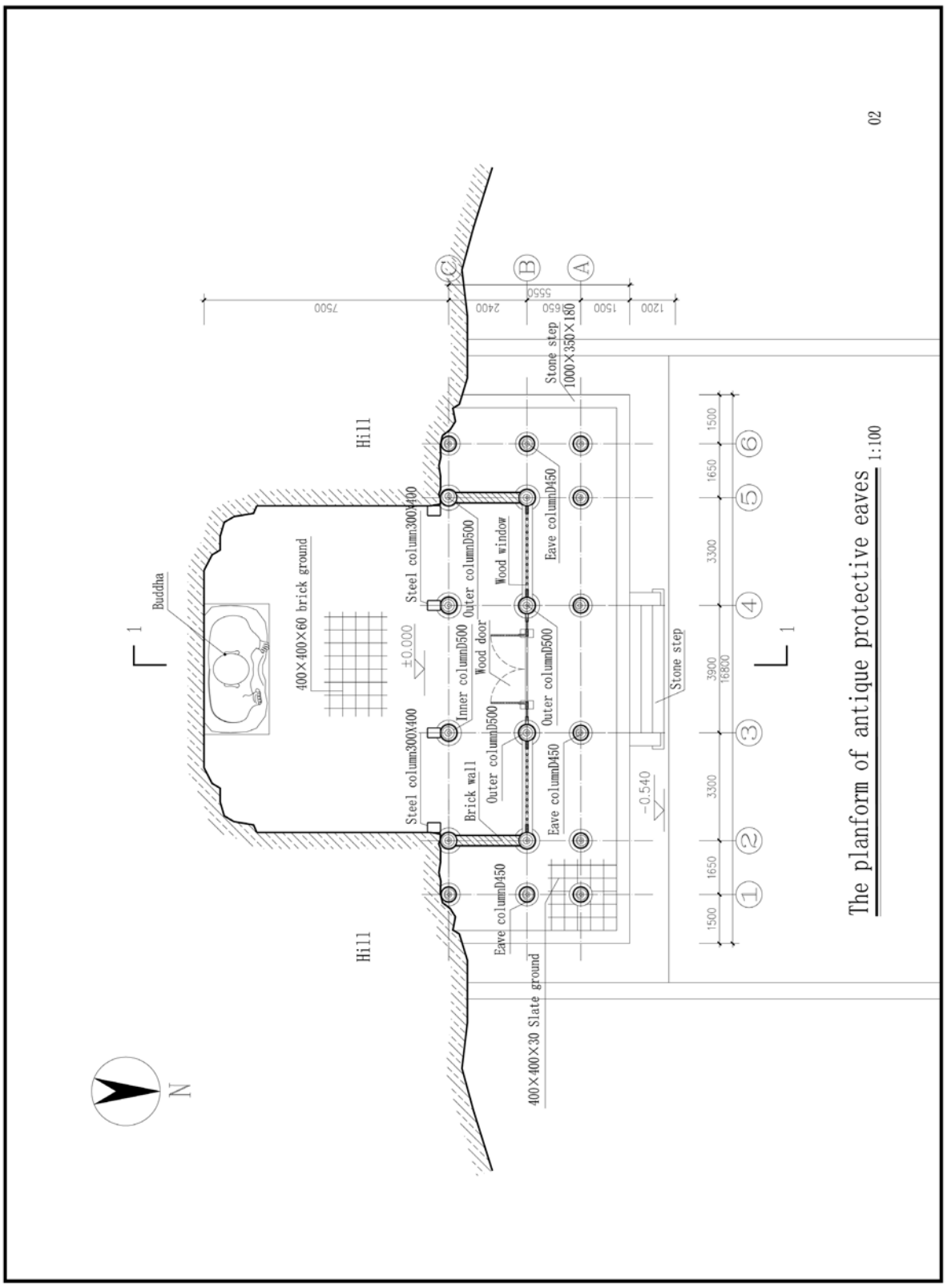


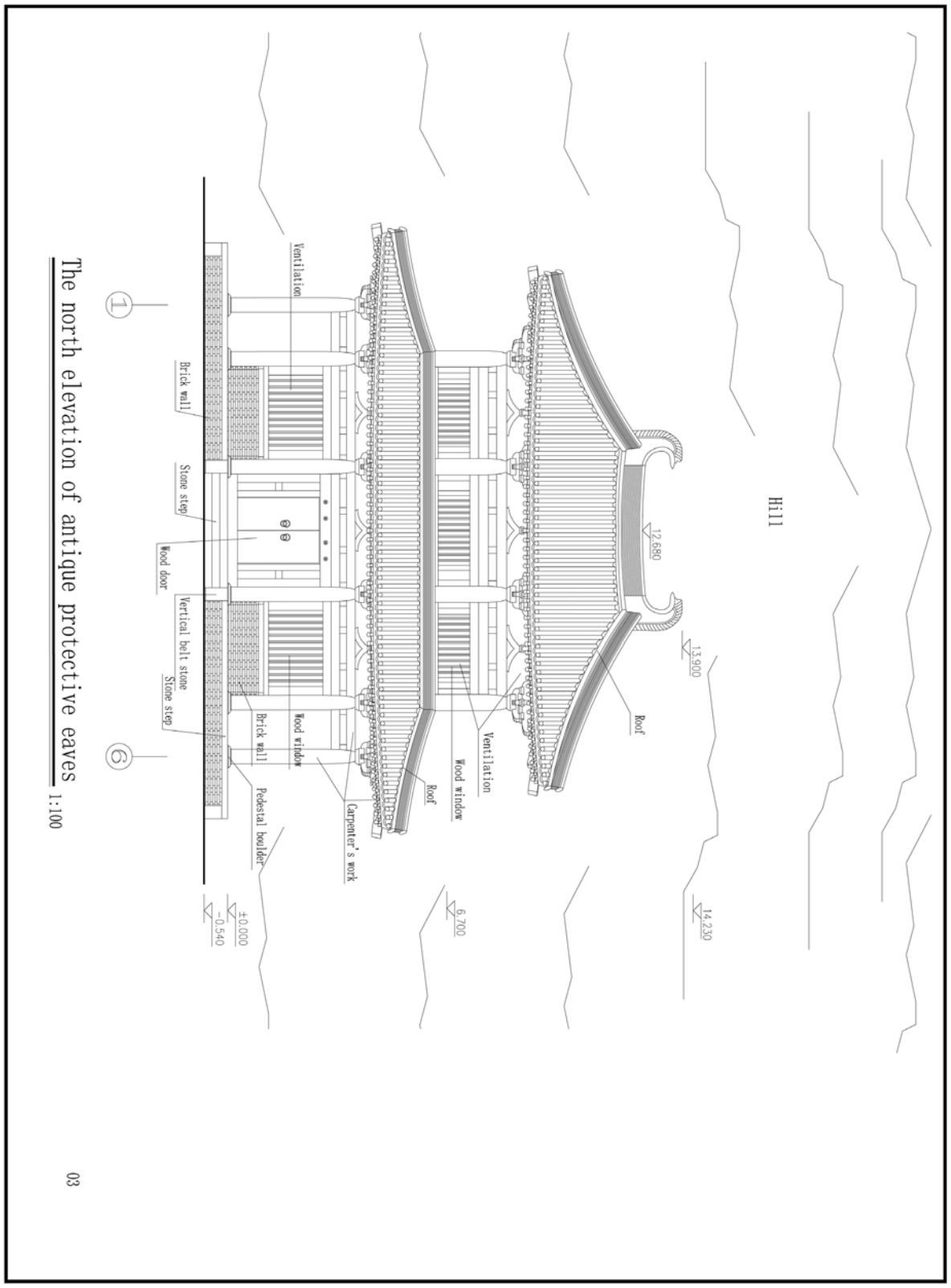
The image above shows the capillary water distribution in the back of the Lord Buddha of Jinchuanwan grottoes, we can distinguish the frequent area of capillary water activity according to different color in thermal image. If the stone contain no capillary water inside, the thermal image color distribution is single and uniform, whereas thermal image will display a different color in the position that stone contain water inside, The image shown the capillary water-intensive areas in red rcolor, because of the image was taken in winter, cave temperature below 0, and the capillary water inside rock tends to condensation, it released a certain heat to increased ambient temperature significantly in the process of condensation, the high temperature was displayed by red color in thermal image.

Ground plans of Jinchuanwan Grotto

Center for the Conservation and Restoration of Cultural Heritage Xi'an

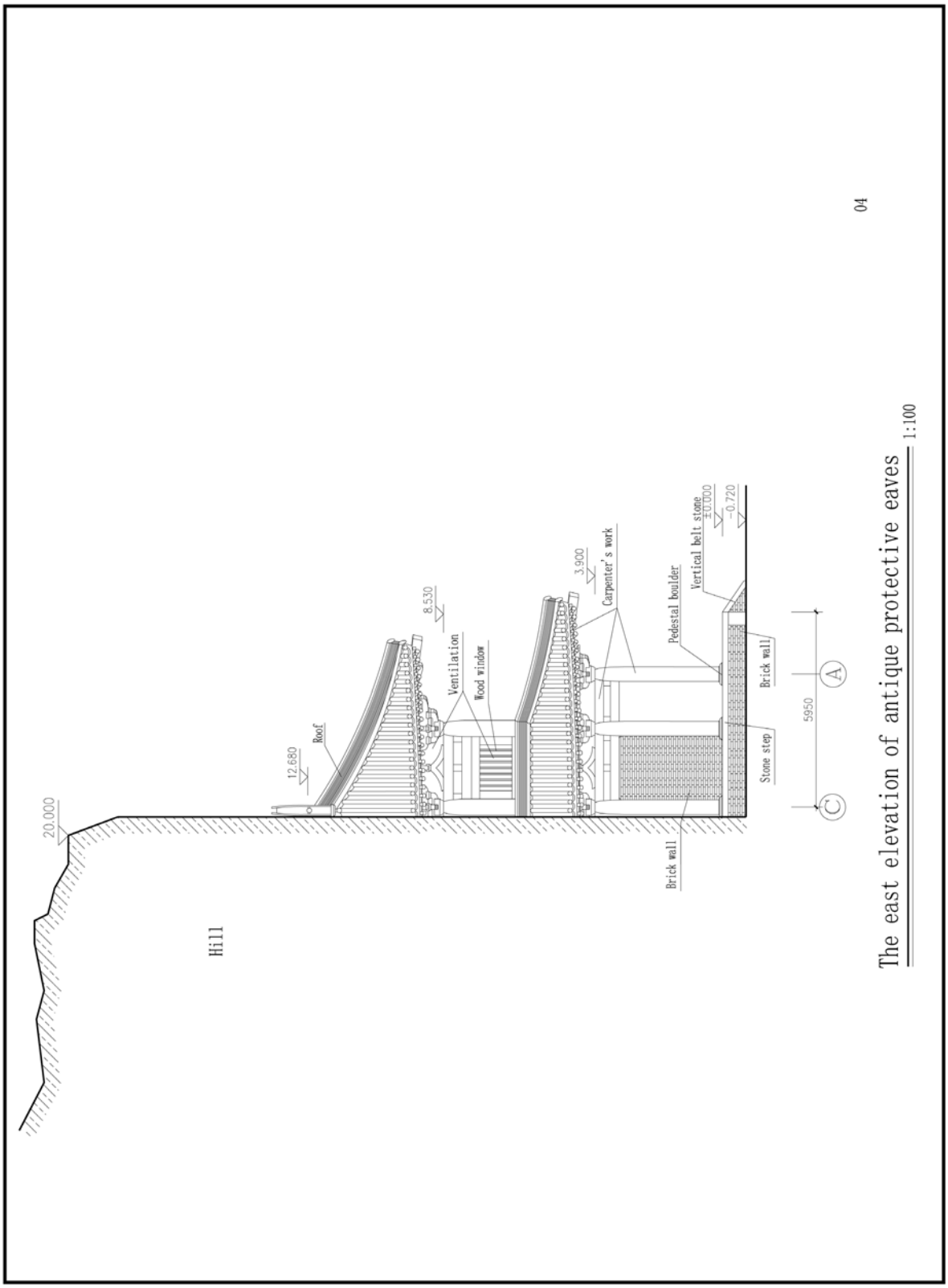

N
Stone balustrade
Hill
Square
Grotto
Buddha
Drainage facility
Renovated square of 2007
Hill
Yeyu River
211 Highway
Site Plan
1:200
01

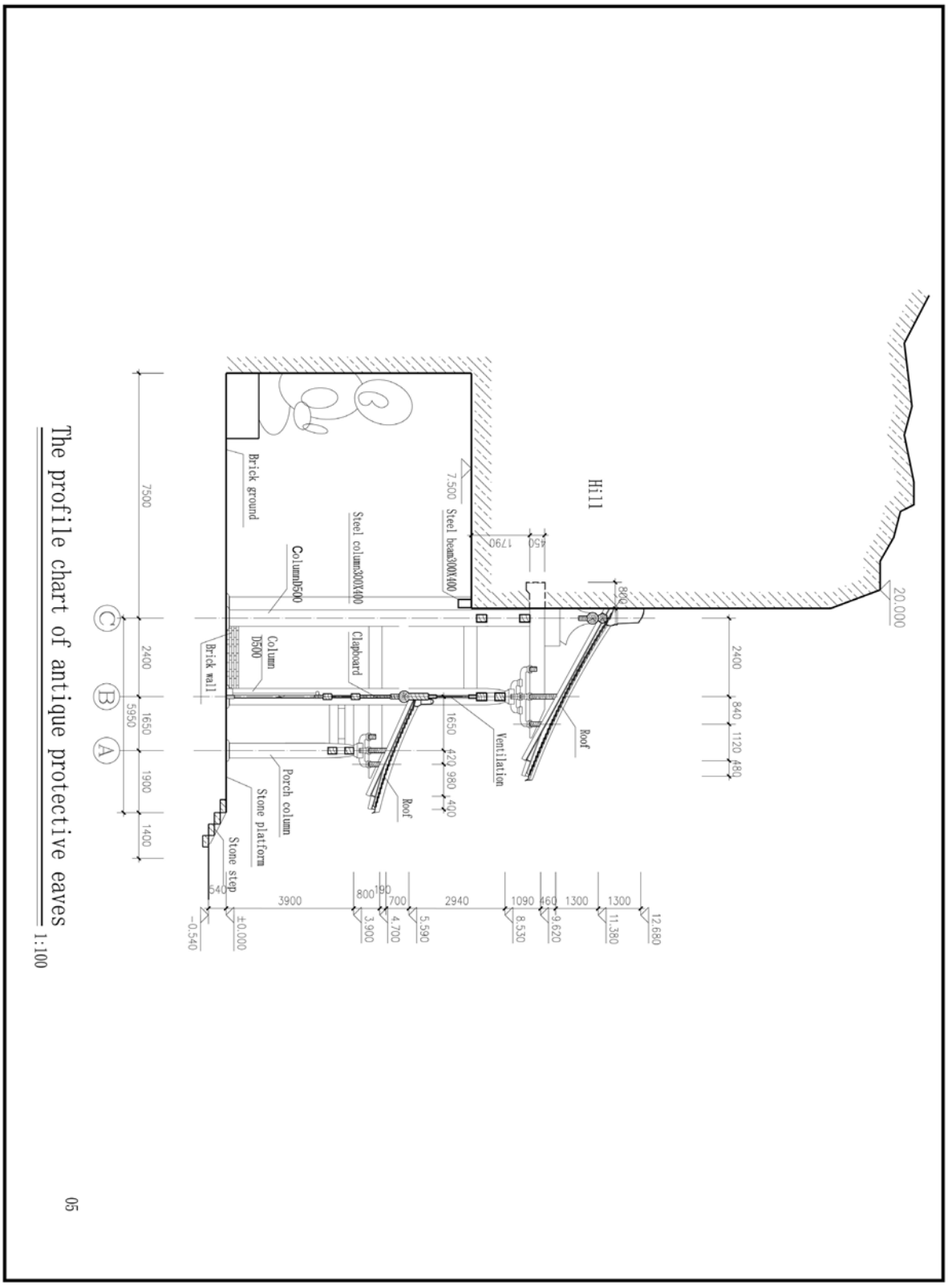

02
The planform of antique protective eaves 1:100
Buddha
400×400×60 brick ground
±0.000
Steel column300X400
Inner columnD500
Outer columnD500
Wood door
Wood window
Eave columnD450
Brick wall
Stone step
1000×350×160
-0.540
Hill
Hill
400×400×30 Slate ground
N
A
B
C
1
2
3
4
5
6
1200
1500
650
2400
7500
5550
1500
1650
3300
3900
16800



The north elevation of antique protective eaves 1:100

03


04
The east elevation of antique protective eaves
1:100
Hill
20.000
12.680
Roof
8.530
Ventilation
Wood window
3.900
Carpenter's work
Pedestal boulder
Vertical belt stone
±0.000
-0.720
Brick wall
Stone step
Brick wall
5950
A
C



The profile chart of antique protective eaves

1:100

05

The Three Texts compiled by Xinxing (540-594) and the Sutra of the Great Ten Wheels carved in the Cave at Jinchuanwan in Shaanxi Province

Zhao Zhou

An Overview of the East Wall

Content

On the eastern wall there are eleven layers: beginning from the bottom one reads the three texts compiled by the master Xinxing on the first three layers. Above them from the fourth layer on the wall is covered by a whole scripture, *the Great Collective and Extensive Sutra of Ten Wheels*, which runs on each layer with one scroll to the ceiling of the cave.
Needless to say, the most valuable historical information preserved in the cave are the three texts of Xinxing, which are to be found nowhere else. It is interesting to notice that the texts of Xinxing, though as treatises they are hieratically inferior to the "true sutras", allegedly taught by Buddha, were carved intentionally at the easily accessible place. It shows that Xinxing's texts are not only treasured by the historian of today, but were also highly evaluated in the Tang Dynasty.

Status and Reconstruction

The east wall is also heavily damaged. Most of the upper part is weathered while on the lower part there are some more characters preserved due to the covering under loess. Similar to the west wall, the outward part of the east wall has collapsed partly and thereof about 50 to 60 lines of texts do not exist anymore. Fore that reason especially the three texts by Xinxing in the lower part are pitifully incomplete.
There are three layers more than on the west wall, altogether eleven layers. The heights of each layer on the east wall, i.e. the numbers of characters carved in each line, differ from that on the west wall. The three texts by Xinxing have more characters in each line, respectively 38, 43 and 31 in average, while the *Sutra of the Ten Wheels* above has 28 characters at most in one line in the eight layers (scroll 3). While the height of each layer is generally similar to that on the west wall, that on the east has larger difference, there are around twenty characters in general in the *Sutra of the Ten Wheels* and in the lowest eighth layer there are only 17 characters. Definitely it is decided by the amount of characters in each scroll how many characters should be carved in each line (Table 1 and 2).
The planning of carving texts on the east wall should be similar to that on the west wall, namely the amount of characters in each scroll, number of characters in each line as well as the size of characters should all have been calculated carefully before one

wrote on the wall, in order to keep them all orderly within a roughly rectangular field (Fig. 1). Although the last layer is completely invisible, it seems that there had been no irregularity on the east wall as the last two layers on the west wall. The east wall might have been better planed and presumably finished later than the west wall.[1]

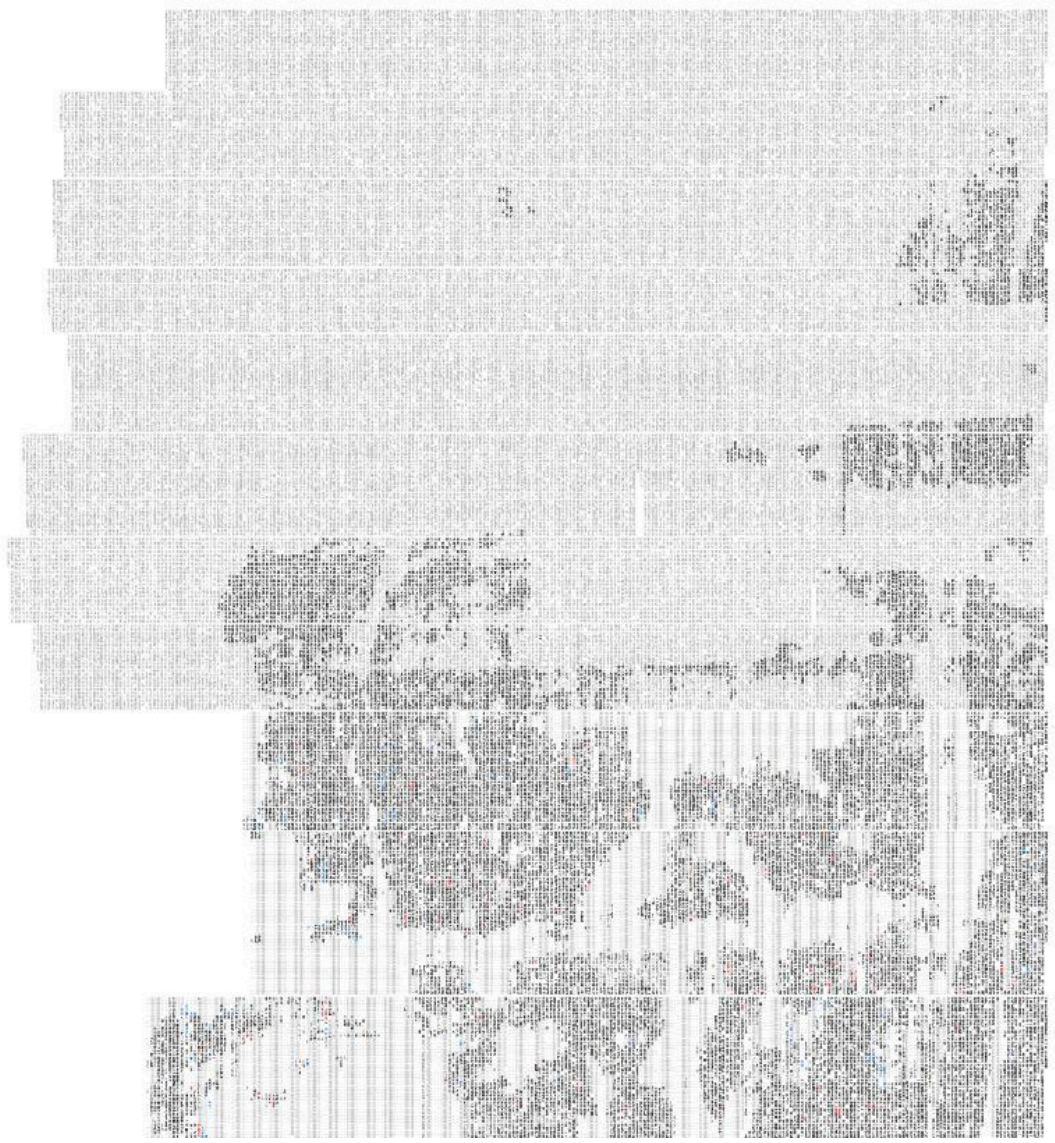


Fig. 1: Reconstruction of the carved texts on the east wall

[1] There is no inscription of date found on the east wall, but considering the order of reading from the left to the right and the importance of carved texts this observation could be reasonable.

Layer	Scroll	Chapters	Lines			Characters			C/L (A)
			Visible	Invisible	Original	Visible	Invisible	Original	
Layer 11	Scroll 08	Ch.13-15	0	236	236	0	5185	5185	22
Layer 10	Scroll 07	Ch.09-12	15	249	264	47	6005	6052	23
Layer 09	Scroll 06	Ch.08	46	220	266	483	5626	6109	23
Layer 08	Scroll 05	Ch.07	35	232	267	236	4297	4533	17
Layer 07	Scroll 04	Ch.06	45	217	262	138	6909	7047	27
Layer 06	Scroll 03	Ch.04-05	79	195	274	721	6884	7605	28
Layer 05	Scroll 02	Ch.02-03	138	140	278	1544	4269	5813	21
Layer 04	Scroll 01	Ch.01	61	210	271	2179	4014	6193	23
Layer 03	Scroll 03		202			4129			31
Layer 02	Scroll 02		203			4263			43
Layer 01	Scroll 01		229			4622			38

Tab. 1: Statistic of the Lines and Characters in each Layer

Scroll 01		Scroll 02		Scroll 03	
C/L	Lines	C/L	Lines	C/L	Lines
23	260	21	268	28	264
22	5	20	3	27	5
24	3	22	4	others	5
others	3	others	3		

Scroll 04		Scroll 05		Scroll 06	
C/L	Lines	C/L	Lines	C/L	Lines
27	259	17	264	23	262
26	1	16	1	24	2
others	2	others	2	others	2

Scroll 07		Scroll 08	
C/L	Lines	C/L	Lines
23	262	22	235
others	2	others	1

Tab. 2: Lines and Characters in each scroll of the *Sutra of the Great Ten Wheels*

The Three Texts compiled by Xinxing

The Value of the Three Texts

The three texts of Xinxing, which are not delivered in Buddhist cannon or any other historical manuscripts, concerne an important subject of the theory and practice of the movement, "Arousing the mind to enlightenment" (发菩提心). The concept has been mentioned many times in other manuscripts of Xinxing preserved in Dunhuang, but since the texts themselves have not been delivered there, the subject has been unclear to the historian for many years.[2] The two carved texts concerning "arousing the mind to enlightenment" and the *Abridged Excerpts from the "Chapter on Bodhisattva Moon Storehouse* reveal direct historical material comprehensively on the thoughts of Xinxing on that subject.

A Detailed Investigation of the Carving

*1. Clarifying the Methods in the Scriptures about Arousing the Mind to Enlightenment in Accord with One's Depth of Capacity*明諸經中對根淺深發菩提心法

The content of the text, as explained in the title, is about "arousing the mind to enlightenment", which is clarified in four sections. 1. The dimension and degree to arouse the mind to enlightenment; 2. The dimension and degree of the cause to arouse the mind to enlightenment; 3. The capacity to receive the teachings; 4. The practices which arise in accordance with the capacity. In the text it is explained in the very beginning, "Therein are four sections clarifying the significance." In the first section there are five levels; the second has four levels; the third section seemingly only three and in the fourth section there are five levels. A diagram shows the construction of the text with the different levels marked with numbers (Fig. 2).

Xinxing frequently quoted numerous Buddhist scriptures in his texts. In this text 34 titles of the quoted scriptures appeared in total, either the title of scripts or that of chapters. He reconstructed the excerpts to build his own theory by means of an extraordinary way of structuring. In a manuscript from Dunhuang (P.2412) *Sanjie fofa miji,* an exegesis about the *Sanjie fofa* of Xinxing by his disciples, it is cleared about the structure of Xinxing's most important work. It is explained that in the text there are four levels, namely *daduan* (大段 sections), *duan* (段 parts), *ziduan* (子段 subparts) and sentences (子句 *ziju*). Further as Xinxing himself has once explained there might be still the levels between *duan* and *ziduan* and under sentence. Usually certain words were used such as *diyi* (第一 first), *zhe* (者part) or *jie* (阶stage) to mark the structure. But in fact the structure can be much more complicated, especially when the text is partly damaged, as the case in the Jinchuanwan Cave shows.

This text is placed in the first layer of the east wall, where is mostly easily accessible for reading. In comparison to the second text some more characters are preserved here with 229 lines altogether 4622 characters visible. The original text might have about 10,000 characters, as the length of a scroll of a sutra. According to the width formed by the above *Sutras of Ten Wheels* there are approximately 30 lines around 1000 characters from that text lost. The first line is the title, under which is the valuable signature of the master "信行禪師撰"－compiled by the meditation master Xinxing.

The multi-levelled structure seems quite systematic and belongs to the Indian manner of thinking rather than to the Chinese. Such a structure might originate from the Buddhist sutras and if one compares it with the *Sutra of the Ten Wheels*, the close relation is fairly noticeable, which will be further discussed in the following text. Nevertheless, the system by Xinxing is not always perfect, for instance the parts 1.5. and 1.6. are not given inexplicably in the upper level. From the part 4.4. the structure is not quite clear due to the incompleteness of the texts.

2. Clarifying the Methods in the Scriptures of the Great Vehicle about the Difference of the Mundane and Transmundane Persons Arousing the Mind to Enlightenment 明诸大乘修多罗中世间出世间两阶人发菩提心同异法

This text explains the methods of arousing the mind to enlightenment for the two kinds of people, namely those who leave their homes (the monks and nuns) and those who stay at home (the laymen and laywomen). Xinxing defined the monks as "endowed with ten kinds of goods" and the layman as "endowed with ten kinds of evils". In this text the people with "ten kinds of evils" are the main concern. For the people "with ten kinds of goods" he had only one sentence, "as extensively expounded in the *Flower Garland Sutra* and the scriptures and treatises of the Great Vehicle", but for the mundane people he had written four parts: 1. Contemplating the emptiness; 2. Revering the sentient beings; 3. Revering all teachings; 4. Severing the evil to accomplish the good practice.

In this text the third part is short but noteworthy. According to Xinxing's doctrine, in the degenerated age the sentient beings have no capacity to learn Buddha's Teachings in a traditional way, but have to revere and learn all teachings. Based on the quotation from the *Nirvana Sutra* that "all various kinds of different theories, sorceries, languages and words

[2] The concept is found in various text attributed to Xinxing. In 1970 the publication of the manuscript P.2283 from Dunhuang arouse the interests on the topic, however, the Dunhuang manuscript is partly damaged and can render only limited information.

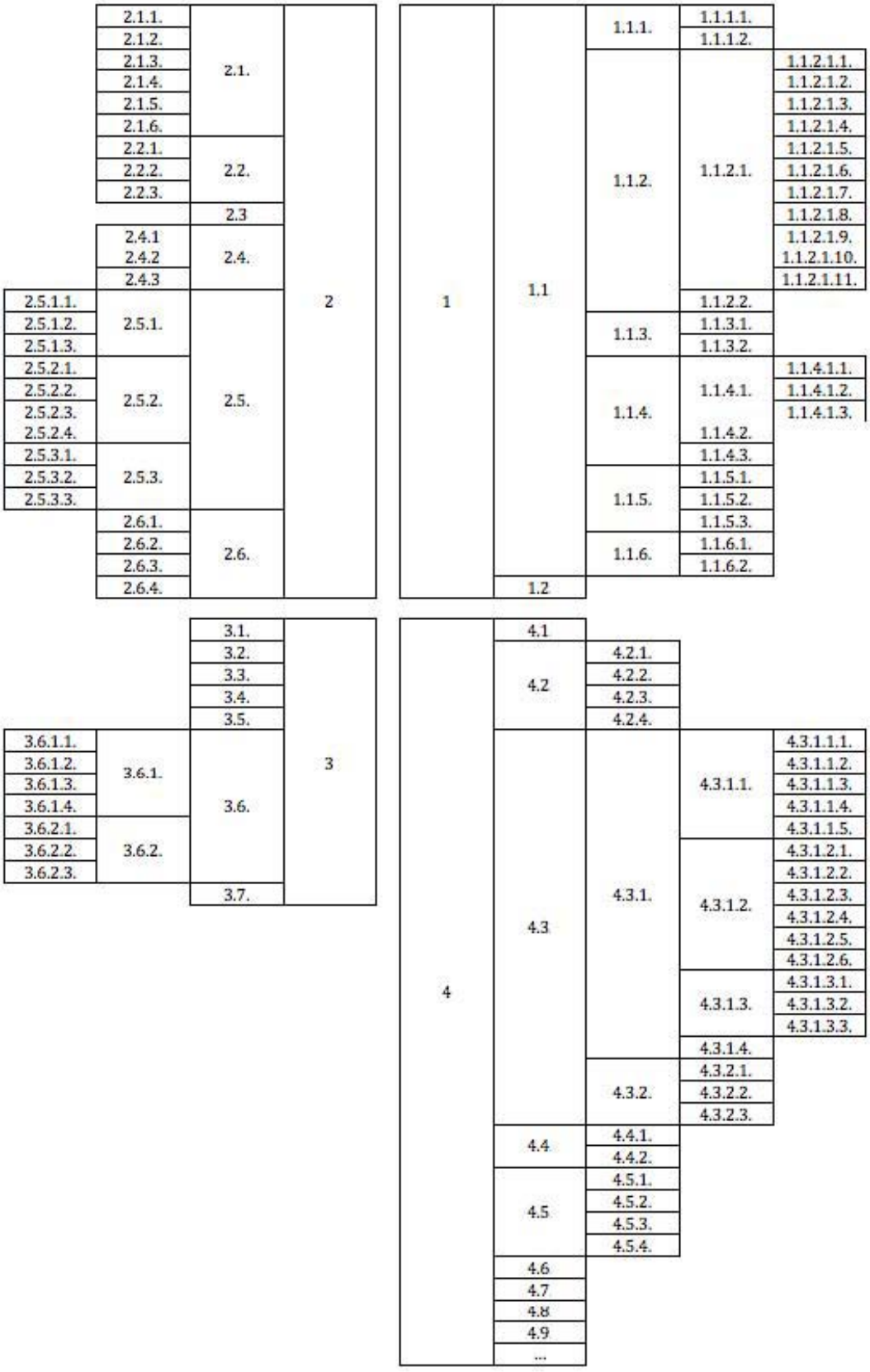


Fig. 2: Structure of Xinxing's First Text

are all the Buddha's teachings, not that of the heretics."[3] He did not differentiate the Three Vehicles (voice-hearers, solitary realizers and bodhisattvas) and the One Vehicle (the Great Vehicle), but further he included Confucianism and Taoism into the category of Buddhism. Thus he expanded Buddhism to include all teachings, since he believed all those teachings were made for the goods and evils of the sentient beings. Xinxing's remarkable theory has a trait of syncretism that developed in the later Song time.

The text was carved as the second layer that lost approximately 60 lines about 2000 characters due to the damage of the wall. In this text there are 203 lines still extant with 4263 characters legible. Similar to Xinxing's first text there might have been originally 10,000 characters. Both texts discuss the "method of arousing the mind to enlightenment" with each 10,000 characters, which shows the importance of the subject to the movement.

The text begins also with the title in the first line with the signature of the master Xinxing, and similarly organized like the first text with only one scroll and a multi-levelled structure. As aforementioned the text argues rather unbalanced –the whole text is a systematical discussion of the second point while leaving the first untouched. Due to the large amount of the lost characters the structure of the last part is not quite clear. According to the preserved text the structure and levels can be shown in Fig. 3, from which can be seen that the texts from 2.4.11 are lost.

3. The Abridged Excerpts from the "Chapter on Bodhisattva Moon Storehouse" of the Great Collection Sutra

The "Chapter on Bodhisattva Moon Storehouse" of the Great Collection Sutra was translated by Narendrayaśas in the Northern Qi Dynasty (550-577) and had great influence upon the Chinese Buddhists. The announced End of the World (*mofa*, 末法) in the Sutra is confirmed by the prosecution and deterioration of Buddhist monks. The activities of carving Buddhist sutras on stone were under its influence and the movement of the Three Stages led by Xinxing was inspired by the notion proclaimed in this sutra. The sutra is so influential that in the Sui Dynasty (581-618) the great monk Lingyu (518-605) has made passages from the sutra carved on the cave *Dazhushengku*, where he has practiced meditation. The manner of Xinxing's compilation is similar to *chaojing* –copying sutras, which gather citations from various Buddhist sutras to support one's own assessment.[4] Different is here that the master used the excerpts from the sutras to support his position: "Above are the human words and below are scriptural texts." In each part it firstly clarifies the points and then the quotations of the scriptures. In comparison to his other complicated structured texts, this text has only one level, but thirty-one parts.

The third layer is covered by that text, from which 202 lines with altogether 4129 characters are still visible. Its original length is around 8000 characters and about 60 lines from the 32nd part have been destroyed. From the Chapter on the Bodhisattva Moon Warehouse with twenty parts actually only four were excerpted, namely the 16th, 17th, 19th, and 20th part, while the 16th and 20th part are mostly quoted.

The whole text can be divided into three sections. The first is from 1st to 11th part, wherein are ten kinds of people who have the causes and conditions to become Buddha in the future. Actually the ten kinds of "good" persons are quoted from a passage from the "Chapter on Forbearance and Humiliation", in which Buddha praised the good sentient beings in the present and future world. Xinxing divided this continual passage into 10 categories of people. In the second section, from 12th to 30th part, all scriptural texts are quoted from the same chapter as the first section. In this section it is discussed how to offer, sustain and protect the monks as well as how they should be punished if they break the precepts. In the 15th part it is stressed that even a king should not beat or curse the monks or rob the necessities from them. Such narrations reflect the hard situations that the Buddhist had to face both in India and China. The third section is only one part, the 31st part, actually the direct quotation of the main verse from the "Chapter on the Extinction of the Teachings", which repeats the main points of the chapter. Though it is partly damaged, it can be verified that the whole verse is carved.

In this text the points on how to treat the monks play a central role, which is consistent with the main content of the following *Sutra of Ten Wheels* on the eastern wall.

Sutra of the Great Ten Wheels

About the Sutra

The *Sutra of the Great Ten Wheels*大方广十轮经 included in the Taisho Vol. 13 No. 410, was anonymously translated in the Northern Liang Dynasty (397-439).[5] In Tang Dynasty it was retranslated by the great monk Xuanzang (602-664) in 651, which is much "clearer and complete" than the anonymous translation and thus widely spread.[6] It is noticeable that when the sutras was carved on the east wall in

[3]《大般涅槃經》卷8：「所有種種異論呪術言語文字。皆是佛說非外道說。」(CBETA, T12, no. 374, p. 412, c29-p. 413, a1).

[4] About copying sutra text see the entry "*chaojing*" 抄经 in Foguang Buddhist Dictionary.

[5] It is noted that the sutra title has no prefix "佛说" as does in the carved version here.

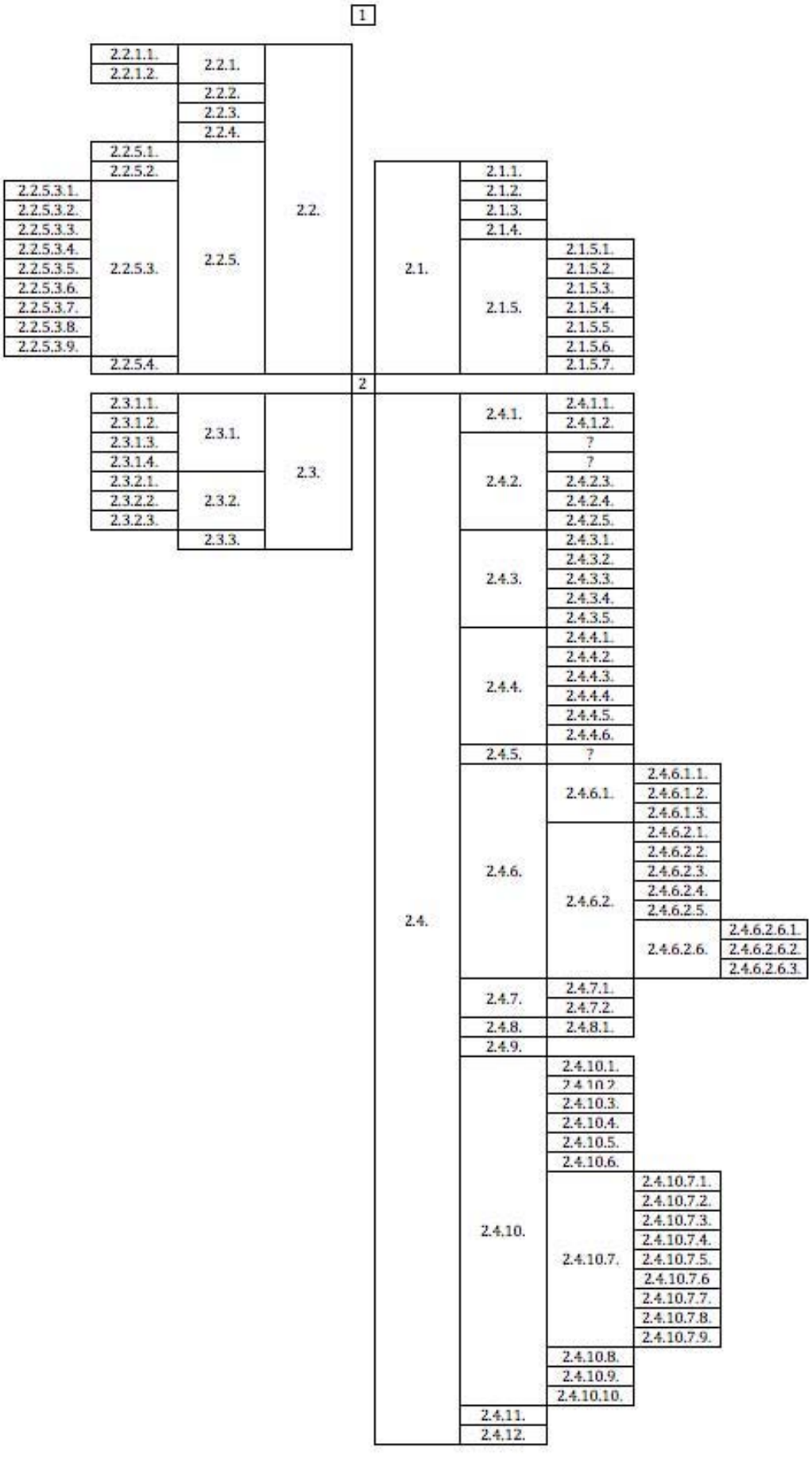


Fig. 3: Structure of the second Xinxing Text

Jinchuanwan, Xuanzang had finished his new translation for more than ten years. Although one translation by Xuanzang was used in this cave on the west wall, the old translation of *Sutras of the Ten Wheels* was chosen for the east wall. Presumably the version had a strong influence on the movement, especially on the master Xinxing, as seen in his scripts.
In the carved version there are eight scrolls and fifteen chapters, while in Xuanzang's translation ten scrolls and eight chapters. The key figure in the sutras is the bodhisattva Ksitigarbha, who shows himself as a monk and preaches the Mahayana Buddhism to the sentient beings at the time of the Latter Law. The ten wheels in the sutra's title refer to the ten kinds of power of Buddha or Bodhisattva.

A Detailed Investigation of the Carving
The *Sutra of Ten Wheels* on the east wall begins from the fourth layer with one scroll on each layer and eight scrolls in total reaching up to the ceiling. Like the west wall the upper part of the east wall is also seriously weathered leaving only a small part recognizable. The last scroll of the sutra, namely the eighth scroll, has been totally erased, and of the seventh scroll there are only a dozen characters at the beginning part still discernible. With only small part left, most of the characters from the first to the sixth scroll have been destroyed. The general information about the number of lines and characters of each layer is listed in Table 1, while more detailed information on the characters in each layer can be seen in Table 2.
Like in the Lotus Sutra the number of characters in each line varies in different layer, and thus it cannot have been carved directly by copying from a hand scroll either. The texts on the east wall also keep changing the numbers of character in each line due to the arrangement in advance. On the basis of the extant characters, roughly one eighth of the original, a reconstruction has been made, and the layout of the last scroll is imagined with reference to that of the seventh. A detailed description of each scroll is following:

Scroll 1: (Chapter 1)
The beginning parts of scroll 1, 5 and 6 on the east wall have been preserved and carved with the first line for the title of the sutra, then closely followed by the names of the chapters. The first line shows the name of the sutra and that of the chapter, i.e. "佛說大方廣十輪經序品第一" without the number of the scroll and the main text begins from a new line. Due to the lower position in the cave the first scroll is mostly preserved in comparison to other ones. The first scroll has originally 6193 characters in 271 lines, now 61 lines with 2179 characters visible and mostly 23 characters per line. In the Text before "爾時" there is always an empty space. No ending text preserved on the east wall, but according to the west wall the title and numbering of the scroll "（佛說）大方廣十輪經卷第一" might have been placed in a new line at the end.

Scroll 2: (Chapter 2, 3)
Similarly preserved like the first one, this scroll has originally 5813 characters in 278 lines, now only 140 lines with 1544 characters visible and mostly 21 characters per line. In this scroll the characters in each line have two less than the first one with 23 characters, since the second scroll has about 380 characters less than the first one. In order to keep the same length of text as the first, two characters have been reduced from each line.

Scroll 3: (Chapter 4, 5)
This scroll is heavily weathered. The scroll has originally 7605 characters in 274 lines, now only 79 lines with 721 characters preserved and mostly 28 characters per line. It has 5 or 7 characters more than the first or second scroll, since there are more than 1500 characters in addition.

Scroll 4: (Chapter 6)
Most of this scroll has been obliterated, with only a small part of the whole text left. The scroll has originally 7047 characters in 262 lines, now 45 lines with 138 characters visible and mostly 27 characters per line.

Scroll 5: (Chapter 7)
The characters remained from fifth to seventh scroll are only visible in the beginning part. The shortest fifth scroll has originally 4533 characters in 267 lines, now 35 lines with 236 characters visible and mostly 17 characters per line. Of all the layers on the east wall this is the lowest one.

Scroll 6: (Chapter 8)
The sixth scroll has also been damaged in a similar fatal way as the fifth one with about only a small part of the text visible. This scroll has originally 6109 characters in 266 lines, now 46 lines preserved with 483 characters discernible. It has generally 23 characters in each line.

Scroll 7: (Chapter 9-12)
Most of the scroll is destroyed. Only at the beginning there is a small amount of characters. The scroll has originally 6052 characters in 264 lines, now 15 lines with only altogether 47 characters recognizable. On hands of the few preserved characters it is believed that originally there might have been 23 characters in each line.

[6]《大乘大集地藏十輪經》卷10：「舊本已有今更詳明。舊本所無斯文具載。」(CBETA, T13, no. 411, p. 777, b26-27)

Scroll 8: (Chapter 13-15)
Not a single word from the eighth scroll survives. The reconstruction is made according to the layout of the seventh scroll. The scroll has originally 5185 characters and possibly in 236 lines with 22 characters per line.

Sutra of the Great Ten Wheels and the Three Texts of Xinxing

To the movement of the Three Stages the meaning of this sutra is unsurpassable. The elementary belief, the universal Buddhahood in the time of the Latter Law when the sentient being has only weak rudiment, comes from the sutra. Thus it is no wonder that the whole text of the sutras was carved in the cave together with the texts of the founder. The importance of the sutra can be shown through the comparison with the texts of Xinxing concerning the aspects of thought, structure and citation.

The Universal Buddhahood, namely showing respect to all sentient beings, even those who have broken the rules, Universal Dharma, showing respect to all the school of Buddhists, either Mahayana or Hinayana, can all be found in the sutras. The sophisticated structure of two texts "Arousing Minds to the Enlightenment" by Xinxing can also be found in the sutras, where the contents are numbered and explained, such as "What are the ten (points)?","There are two kinds of making efforts for the bodhisattvas: the first is mundane; the second transmundane."[7] Also there are so many citations from the sutra in the texts complied by Xinxing, so that one would regard Xinxing's text as a kind of exegesis. Such as the relation of falling into the hell and breaking the Buddhist laws, the story of the king and his ministers, the idea of protecting monks, or the parable of killing worms by pressing oil etc. can all be found in the sutra. It is proper to regard the Sutra of the Ten Wheels as the classic of the School. It is no wonder that Xinxing's works appeared heretic somehow to the contemporary since he gathered selected passages from one or more sutras and interpreted them according to his own understanding.

Considering the west wall where the Guayin of Lotus Sutras dominates, the east wall is dedicated to the Bodhisattva Ksithigarbha, both bodhisattvas have similar capability and function of salvaging people from troubles and sufferings by calling their names and with various apparitions in accordance with the saved. The combination of Guanyin and Ksithigarbha in this cave is noteworthy, although they are in the form of carved sutras.

Following: Transcription of the Three Texts compiled by Xinxing.

[7] 《大方廣十輪經》卷8〈13　精進相品〉：「菩薩摩訶薩精進有二種。一者世間。二者出世間。」(CBETA, T13, no. 410, p. 716, a9-10)

注：蓝色文字为新补文，淡藍色文字为推测，紅色為与原文不同的文字，并注footnote，深紅色者爲簡體
繁體異體字的脩改，灰色為錄文有，但是現在已經看不到的文字

明諸經中對根淺深發菩提心法一卷　信行禪師撰
於中有四段明義一者明發菩提心寬狹長短法二者明發菩提心寬狹因淺深法三者明發菩提心
能受根機淺深法四者明發菩提心對根起行淺深法　第一大段明發菩提心寬狹長短法者於
中大判有兩段一者境盡二者行周　第一段境盡者於中大判有四段一者明一切佛盡二者明
一切法盡三者明一切僧盡四者明一切衆生盡　第二段行周者於中大判有兩段一者明離一
切惡盡二者明脩[1]一切善盡　第一明一切佛盡者於中大判有兩段一者明真身佛二者明應身
佛第一真身佛者由上同諸佛成第二應身佛者由下同衆生成法僧等義通二處與真相應屬真
與應相應屬應　第二明一切法盡者於中大判有兩段一者明大乘十二部經二者明小乘十二
部經　第一大乘十二部經者一者梵音名脩多羅經漢語名爲本經二者梵音名爲祇耶經漢語
名爲重誦經或名不等偈三者梵音名爲□伽羅那經漢語名爲受記經四者梵音名爲伽陁[2]經漢
語名爲等偈經亦名不通上偈五者梵音名憂陁那經漢語名爲无問自說經六者梵音名爲尼陁
□經漢語名爲因□□七者□□□□□□陁那經漢語名爲譬喻經八者梵音名爲伊帝曰多伽
□□□□□□□□□□□□□□□□□□漢語名爲本生經十者梵音名爲毗佛略經漢語名
爲□□□□□□□□□□□□□□□□□□□□□□□□□□□者梵音名爲優波提舍
經漢語名爲論義經　第二□□□□□□□□□□□□□名□□□□我□□□□□□□□
三明一切僧盡者於中大判有三段一者□□僧二者□□□□□□□□　□□□□□□□□
者於中大判有三段一者明一切諸佛菩薩所度衆生人淺深盡二者明一切□□□□□□□□
根機淺深盡三者明一切諸佛菩薩所度衆生行淺深盡第一明一切諸佛菩薩所度衆生□□□
盡者於中有四階如維摩經說一者度正見凡夫如方便品說二者度二乘如弟子品說三者度菩
薩如菩薩品說四者度一切衆魔及諸外道如文殊師利問疾品說第二明一切諸佛菩薩所度衆
生根機淺深盡者於中有四階如勝鬘經中說四乘是第三明一切諸佛菩薩所度衆生行淺深盡
者於中亦有四階如華嚴經賢首菩薩品中說同行隨喜見聞等是　第五離一切惡盡□□中大
判有三段一者離煩惱障二者離業障三者離報障　第六脩一切善盡者於中大判有兩段一者
福德莊嚴二者智慧莊嚴又福德智慧二種莊嚴於中有三階一者從一地乃至十地是名慧莊嚴
福德莊嚴者謂檀波羅蜜[3]乃至般若非般若波羅蜜二者慧莊嚴者所謂諸佛菩薩福德莊嚴者謂
聲聞緣覺九住菩薩三者福德莊嚴者有爲有漏有有果報有礙非常是凡夫法慧莊嚴者无爲无[4]
漏无有无果報无礙常住如涅槃經第二十七卷師子吼品中說　第二大段明發菩提心寬狹因
□□□□□□有六□□□一明一切佛盡者上明寬狹長短盡此明見佛因淺深義於中有六階
□□意業如華嚴經□□□□□□□□□佛命終之後生佛□□　无量壽佛經廣說即於經
□敬人觀行時即唯□□時□□□事□□□□□□□□□□□□□餘一切衆生得聞是五十
□佛名者是人於百千万[5]億阿僧祇劫不墮惡道三者□□若複有人能称是五十三佛名者生生
□□常得□□十方諸佛四者身業若複有人能至心敬禮五十三佛者□□□□□□□□□□
□□□□□以是□□□□□故於念念中即得除滅如上諸罪即於經中教還禮諸佛晝夜六時
□□明利□如流水行懺悔法然後繫念念藥王藥上二菩薩清淨色身如觀藥王藥上二菩薩經
中说□□□人行道一切□行道見□□□□□□□□一一諸佛手摩我頂聽我悔過如大方等經
□□知佛　六者明□不□□□□□□□□故是比丘臨□終時於虛空中具聞威音王佛先所說
□華經二□□□□□□□□□□□□□六□清淨更□壽命二百万億那由他歲命終之後得
值二千億佛即於經中□□□□□□□□□□□□□□經典但行禮拜如法華經第六卷不輕
菩薩品說　第二明一切法盡者上明寬狹長短盡此明聞法因淺深義於此有三階一者一聞涅槃
經賣身供養佛唯能□持一偈　如□證□槃　永□於□死　若能至心聽　常得□□樂　受
是偈已即□□至彼□人家□□子我□□複日□□三兩肉以念偈因緣故不以爲痛日日不廢

足滿一月如涅槃經
諸行无常是生
說得淺深[6]菩薩如是佛无有財錢庫寶藏等事而不能捨[7]於此物中不生
難想但於說法者生難遭想是菩薩佛法故无有所財[8]而不能捨无有內財而不能捨
有所作供給尊事而不能行无有慢大慢等而不能捨貿直柔軟故无有身苦而不能受是
菩薩得成就勝財心若一句未聞法勝得滿三千大千世界珍寶是菩薩得聞一偈正法生上
財想勝得轉輪聖王位複得勝財心若得未曾聞法能淨菩薩行勝得釋提桓[9]因梵天王處无量劫
住是菩薩若有人來作如是言我與汝佛所說法一句能淨菩薩行汝今若能入大熾然火坑受大
苦者當以相與是菩薩作如是念我受一句佛所說法能淨菩薩行故尚於三千大千世界滿中大
火從梵天投下何況入小火坑我等法應盡受一切諸地獄苦猶應求法何況人中諸小苦惱菩薩
如是發精進行脩諸正法隨所聞法於寂靜處悉能正觀第三明一切僧盡者上明寬狹長短盡
此明歸僧因淺深義於中總證於一切衆僧莫問行住坐臥[10]三業起作皆須體順不違種種恭敬種
種供養如一切大小乘脩多羅中具足廣說處處皆言上妙藥水供養衆僧第四明一切衆生盡
者上明寬狹長短盡此明度脫衆生因淺深義於中有三段一者作是念我當悉令一切衆生得无
上智王安隱住處不爲自度但欲令彼出生死淵得一切智心拔出衆生惡道嶮[11]谷[12]救无量苦度生
死流二者複作是念我當爲一切衆生受无量苦令諸衆生悉得免出生死沃燋[13]我當爲一切衆生
於一切一一切地獄中受一切苦終不捨離我當於一一惡道盡未來[14]劫代諸衆生受无量苦何以
故我盡[15]諸苦不令衆生受諸楚毒當以我身免贖一切惡道衆生令得解脫三者唯我一人志
无侶脩諸善根迴[16]向欲爲度脫一切衆生普照一切衆生分別一切衆生了達一切衆生令一切
衆生一一切衆生成就一切衆生悅樂一切衆生柔[17]一切衆生滅除一切衆生疑或
如向品第一護衆生迴[18]向說第五明離一切惡盡者上明寬狹長短盡此明離惡
因大[19]有三段一者身業一願從今身乃至成佛願不煞生二願從今身乃至成佛願
不偷盜三欲二者業一願從今身乃至成佛願不妄語二願從今身乃至成佛願
乃至成佛願身乃至成佛兩從今身乃至成佛願不諦[20]語三者意業
一願從今身不貪二乃至不嗔三願從今身乃至成佛願不癡此十
法正是法界作故莫聞大乘小乘一切說者所以得知最是衆惡根本第
六明脩一切善盡長短信此明法淺深義於中有四段一者六波羅蜜二
者衆生[21]如是四行是一切身行根本何以故見一切大乘經中處處
皆說如是第三大段明發菩提心能受根機淺深法受於中有七段一者明三業具足如華
嚴經淨無煩惱經第二卷純陁品說三者明種性成
四者明久行六波羅密多供養諸佛種善根與善知識相隨
若經隨喜品說五者明四親近此一親近善知識二聽聞正法
第廿五卷第七功德所說六者明能受一乘法人於中有兩段
一方佛土來者受法身二從天道來者第二三從人道來者第
三人明能受一乘法人一致諸菩薩摩訶薩二正見成就人
三漏多供養種善根親近善知識有利根如大般若經幻人聽法品
說七者具明能使得利根智慧多佛道者乃可爲說若人曾見
億百千佛殖諸善本如是之人乃可爲說若人常脩命乃可爲說若人
恭敬无有異心離諸處如是之人乃可爲說若利若善友
如是之人乃可爲說若見淨如大乘如是之人乃可爲說直
柔軟常愍[22]一切恭敬諸佛如是之人乃可爲說複有佛子於大衆中
說法无礙如是之人乃可爲說若有比丘爲一切智四方求法合
不受餘經一偈如是之人乃可爲說如人至心求佛舍利如是求經
亦未曾念外道典籍如是之人乃可爲說告舍利弗我說是相求

信解汝當爲說妙法華經　如法華經第二卷火宅品中說　第四大段
深法者於中略說九門一者明下根菩薩敬法師法二者明下根菩薩所知善是[23]多少
根菩薩所依善知識法四者明下根菩薩菩提種子法五者明下根菩薩所受戒及戒法空
菩薩行法七者明下根菩薩說法法八者明下根菩薩敬三寶法九者明
但作淺深相對說者皆是爲明上下淺深義何以故或就時相上[24]
世惡明諸佛滅後成就世界明上下淨土爲上穢土爲下
凡夫二乘一處共說者爲下或就世間出世
爲下或就多少明上下
菩薩飾
身持戒
難大乘法
人爲聲聞弟子說若如是
齊法者何以故初明人四依
依煩惱能以是上法四依義與經
一切別四依聲所以知是諸衆生得說是四依終不教於有慧
眼者是故得知爲下根菩薩說依法者即是如來大般涅槃一切佛
法如上所說四人出世護持法者是不依人者即是聲聞二者依義不
依語依義者即是三寶常住不變不辭三者依智不依識依智者所言智
者即是如來不依識者若有不能善知知識不應依止四者依了義經不依不
了義經依了義經不依不經脩聲聞乘名不上大乘乃名了義如涅槃經第六卷如來
性品說明依經引義非次第抄盡第三明下根菩薩所依善知識者於中有兩階第一諸佛菩薩與
二乘凡夫一處說者上與下同名爲下善知識第二唯諸佛菩薩一處說者名爲上善知識何以故
第一段善知識中唯明順而明其違所以是下第二段中違順具說所以是上第一下根菩薩
善知識者於中有四種一者善友二者專心聽法三者繫念思惟四者如法脩行第一親近
善友者即是善知識異名善知識善知識者能教衆生遠離十惡脩行十善以是義故名
善知識又善知識者如法說脩行於中有五段一者明自離十惡亦教他離十惡二者自脩菩
提亦能教他脩行菩提三者能脩行信戒施多聞慧亦能信戒佈施多聞智慧四者所
作之事不求自樂常爲衆生而求於樂五者見他有過純善之事以是義故名善
知識能令善法如月生相以經說第二明一者
識複得了達作十二部經甚深之義三明因十二部經
受大涅槃經四者明因聞正法名八聖道以八聖
於一切法不作相貌六者明因此聞法乃至譬如病
名字不能愈病以服食故能得差病雖聽一切煩惱要因
得除斷第三繫念思惟者於中有三空於二十五有不見一實二者
有不作願求三者明无相无有十相所謂色相聲相香相味相觸相生相住相滅相男
明如法脩行者即是脩行檀波羅蜜乃至般若波羅蜜知陰入界真實之相亦知聲
於道而般涅槃法者即是常樂我淨不生不老不病不死不飢[25]不渴不苦不惱不沒第二
上善知識者有四種如上說於中有三段一者持說是第一真實善知識二者明人後所謂菩薩
諸佛世尊三者明出行分齊一畢竟軟語二畢竟呵責三軟語呵責如涅槃經第一[26]十五卷中說上
依經明義非次第於也第四明下根菩薩菩提種子實直心是如維摩經說何以故於世界一中切

者名爲下後者名爲上直　解　行首故知爲　根菩薩說於中有兩段一者就他身明直心
二者就自身明直心第　者於他身　唯　有過惡揚善　上人語下經文　雲何直心菩
薩摩訶薩於諸衆　遇因緣　經[27]　菩薩不爾何以故善解諸法悉因緣
故菩薩摩訶薩　之何以故　生煩惱若生煩惱則墮　如是菩薩若
見衆生有少善　讚　佛性讚[28]佛性故令諸衆生發阿耨多羅三藐三菩提心
乃至結句善男　讚[29]人善不訟彼缺名賢直心　第二明自身直心者
於自身中唯明專　經文複次善男子云[30]何菩薩賢真心菩薩摩訶薩
常不犯惡設有過失於時　覆藏　自責不敢複作於輕罪　想若人
詰問答曰實犯複問是　善不善答言不善複問是罪是善果耶不
善果耶答曰是罪　諸佛法僧所作答曰非佛法僧我所作也乃
是煩惱之所構集以　名一闡　名佛弟子若受衆
生衣服飲食臥具醫　如涅槃經第二十六卷第九功德
品說　第五明下根　明所受戒略[31]說二十四二者明護
法以陀羅尼咒戒　及在家出家七　四者明護戒
大德明是所明者皆　得　及等受戒護戒等皆爲下根菩
薩　兩　一　餓衆　飲食臥具不與者犯重二者婬
不擇禽獸　意說過者犯重四者見人憂愁欲自喪身以
他瞋敗他命根　重六者見他欲害命以美言贊令他瞋恚
七者見他欲燒僧坊不盡心諫者　者　若聞他犯重罪若不作三到喚教悔者
者見有人作五逆罪不呵勸捨者犯重十　欲興大善事更起瞋恚壞他者犯重十
他眈食嗜酒當以己情往呵除自因緣　見人婬他婦女語他夫者犯重十三者
作怨家想者犯重十四者見他視怨家　如赤子語他何能視此人如赤子犯重十五者見
他　助力撾[32]打者犯重　六者見他伏匿事向　大瞋恚者犯重七[33]七者見　善事云
都不　作者犯重十八者行　見人營塔廟營精舍不助者犯重十九者見聞有人　和識
親近惡友讚[34]　不勸捨者犯重二十者於旃陀羅家惡人處惡狗處聲聞二乘人家除己事急往者
犯重二十一者見聞　疑想食此肉者犯重二十二者見聞　不
食　肉者犯重二十三者　於方　衆生根若謂不說者犯重二十四者或見諸菩薩及余諸見
不得向　身得鄣　得白　病或時　痴　時青[35]盲或
賢劫千佛　作王子時　不者作行諸佛求受二十四戒人
養　佛　受　佛　來　經弟一卷中說此依經此義
　佛　　大弟子心有少疑佛知其
脩五事持諸戒　不　見他
衆生　行如　行
三時塗[36]地亦应日诵一遍
丘行此法者　不得
神亦不得轻　彼人
方等經家往來不得
說比丘　人[37]往來如是五事　是午者业护戒境界复善男子复有五事不得与脑破家往来不得
興蓝　往來不　養
業　界復次
　人
　鸡
　來

□□□千劫於阿鼻地獄中大苦惱其□中四火地獄□□□□□□□□□□□□□□□□
□□□□菩薩□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□
□□□深多者□道人□少者爲下人□□□□□□□□□□□□□□□□□□□□□
□□明多二者明少如法華經第六卷藥王菩薩本事品□□□□□□□□□□□□□□
□□□□□經中但道爲菩薩請不論□□□□□出具足煩惱□□□□□□□□□□□□□
□□□□□□答或能七七日日別食米一□□□□□□等□□□□□□□□□□□□□□
□□□□□□□皮肉蘇油灌之燒以爲炷□□□□□是苦者□□□苦百□□□□□□□□
□□□□□□□受大苦惱都无利益汝若不□□□□□云[52]何而能□□□□□□□□□□摩
□□□□□□□不覺苦其心不退不動不轉□□□□□□□□□□□□□□□□□具足頌[53]
提□□□□爲法因緣能以頭目髓骼[54]手足血肉施以众生以釘釘身投岩赴火□教□受如此等[55]
□□□□得[56]菩提如涅槃經第三十三卷師子吼□□□□□□若行分齊法者有□□階一者兩
□□□□此兩階[57]□□文廣說三者於一食中三分□□□□者[58]一食中食半五者□□食中三分
□□此三階如正[59]法念經說六者一食中四分食一□□□□□□寶雲經第六卷十二頭陁中說
□□行者於天□日□唯廣三衣如大乘小乘經之□□處□十二頭陁中具說坐中苦行者一
□□□□□二者露坐露坐者露地坐春秋冬夏不依牆壁住亦不依樹下住亦不依聚草積住不
依山掩處住不依河岸住不作鄣寒具不作鄣風具不作遮雨具不作遮熱具不作鄣露具菩薩在
於露地而身有痛形體羸弱應至僧坊如寶雲經第六卷十二頭陀中說寶雲經是大乘經略説□
□□□□□大乘經處處廣說 後依经明義非为尽抄 不發菩提心略說竟廿來廣明有義空□□
□□□□□□義□義解說 佛藏經第三卷明如來得救記 上人語下經文 □□□□□如來[60]□□
□□□□□□□□□供養二百六十三佛所脩道供養佛□由不得□解故不得佛授記乃至□
□□□□□□□□於其中間聞複是万劫中毗□□□□万劫中初一千劫初五百劫中供養九
□□□□□□□□□□□万四千□諸□波佛□□□□□第二卷初明如來得□□□□□□
□□□□□□□□□□□□□□□□□行詣□□□□□□多□□□□□□□□□□□□

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1 此後多処都為·脩　錄文為··休
2 此後多処都為·陁　錄文為··陀
3 錄文為··密
4 此後多処都為··無　錄文為··无
5 此後多処都為··萬　錄文為··万
6 錄文2 沒有補
7 此後多処都為··捨　錄文為··舍
8 出入
9 錄文為··恒
10 錄文為··臥
11 錄文為··峻
12 錄文為··穀
13 錄文為··焦
14 錄文為··來
15 錄文2 盡為寧
16 錄文為··回
17 錄文為··軟

[18] 錄文為：回
[19] 錄文2 大爲深
[20] 錄文為：綺
[21] 錄文2 為四辯
[22] 錄文為：澹
[23] 錄文為：真
[24] 錄文為：異
[25] 錄文為：饑
[26] 錄文為：廿
[27] 錄文2 為詔
[28] 錄文為：贊
[29] 錄文為：贊
[30] 錄文為：雲
[31] 錄文為：明
[32] 錄文為：槌
[33] 錄文為：十
[34] 錄文為：贊
[35] 錄文2 為嘗
[36] 錄文為：贊涂
[37] 錄文2 為家
[38] 錄文為：贊
[39] 錄文為：行
[40] 錄文為：丘
[41] 錄文為：承
[42] 錄文為：鄉
[43] 錄文為：於
[44] 后刪除一行（刪除此行無文字〈錄文204 行〉
[45] 錄文为：此
[46] 錄文為：持
[47] 錄文為：三
[48] 錄文为：上下
[49] 錄文為：輕
[50] 錄文为：不
[51] 錄文為：二
[52] 錄文為：雲
[53] 錄文2 為貌三菩
[54] 石面上面的字为：骨〈部首〉忽 此字不是簡的异体字
[55] 錄文为：当得阿耨
[56] 錄文2 為三

[57] 此後多処都為‥階 - 錄文為‥阶

[58] 錄文為‥若

[59] 錄文为‥三

[60] 錄文為‥始

明諸大乘脩多罗內[1]世間出世間兩階人發菩提心同異法一卷　信行禅师撰
就內有兩段一者明出世間十種善具足人發菩提心法二者明世間十種惡具足人發菩提心法　第一大段
明出世間十種善具足人發□□心法者如華嚴經□諸大乘經論內廣說□□二大段明世間十種惡具足人
發菩提心法者於內有四段一□明世間十種惡具□人觀空淺深分齊二者明世間十種惡具足人敬衆生淺
深分齊三者明世間十種惡具足人敬法淺深分齊□者明世間十種惡具足人自知已惡多少及離惡成善行
淺深分齊　第一段明世間十種惡具足人自知已觀空淺深分齊者何以故爲破我見增上慢謗人謗法耶[2]三
業等種種惡故　一者就凡聖相對明空有淺深爲凡夫說有爲聖人說空如大般涅槃經說　二者就大乘法
內明空有淺深方便品內爲凡夫說法明有多明空少弟子□內爲二乘聖人說法明空多明有少菩薩品內爲菩
薩說法空有俱廣說如維摩經說　三者就四乘根機中□□□□□淺深人天位內明有不明空二乘位內明有
多明空少大乘位內空有俱說如諸經論□□　□□□□□□□□□□□□□明新學菩薩得學空不得學空
□曰若學空捨[3]有者不合先學空若能親近善知識學空□□□□□□□□□□□□□□□□足[4]一乘
□薩及三乘人所學法證世間十種惡具足人等皆得空有並學　一如大□□□□□□□□□□□□□□念
□□說空定不說有定　二如法華經說爲末法衆生□□於內廣說空□三如七[5]集月藏分經[6]說明爲天龍□
□□生說法於內廣說空　四如大方廣十輪經說爲五濁惡世界衆生說法於內廣說空　五如佛藏經說廣
□□法出家人犯戒等多少於內一部廣說空　六□□□般若經說一部明空從首至末數數說法欲滅時有
□□薩能行　七如月燈經說從首至末廣說空法□□□无邊勸爲佛滅後惡時內衆生說於內一部廣說
□□□□□□□□□□□□□滅度五百年後出家人行□□□廣說空何以故空有是法界法體性若空有異學
□□□□□□□□□□□□□者戒當凡夫二乘法所□□□種惡具足人發菩提心先須學空即空起有　觀
□□□□□□□□□□□□□□□佛菩薩亦應得□□一如華嚴經梵行品說就十法明觀空法一身二身
□□□□□□□□□□□□□□□□□□□□□□□□□訶衍經說解了諸法如幻如炎如水中月如虛空如
□□□□□□□□□□□□□□□□□□□□□□□□□乃□□□□□大乘經論內所明空皆悉是　第二段
□□□□□□□□□□□□□□□□□□□□□□□□□我□□□□□□□□謗法耶三業等種種惡故　第
□□□□□□□□□□□□□□□□□□□□□□□□□因爲□□□□□□□有三段一以常因收常果一切[7]
□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□如楞伽經說　二以常果收
□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□因成果就乳酪提胡喻
□□說一二
□□□
□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□爲異世何以故□□□□□
□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□乘藏作善者□□□□□□
□□□□□□□□□□□□□□佛□□徒鬼徒日□□□□□□□□以量喻善惡□□□□□□
□□□□□□□□□□□遍法界如汝□□□輪經說一□□□□□□□出家人作佛想一明□□□□
□□□□□□□□□□□明於出家□□□□爲成大□第四明□□□□生內有人行佛法□□□□
□□□□□□□□□□□佛佛時□□□□等等種種行□□□□□□□作經□□□□□□□□
衆皆作菩薩□□□□□□□□衆內教類□□□作菩薩行□三□□□□□□□□於一□□□□□□
成善　第五明一切衆生內有行□足[8]佛盡□□□□□□六者如□□□□□□□□種所□佛□□□□□
佛四年等智慧佛後二佛同是一見佛□□□□□□□說明佛□□□□□□□有同名異名同名異名佛□
十方大地皆作微塵多少一種　三者如□□□□□□□□□□□□□□□□□多少能與一切衆生世明
出世間樂盡二明如來大悲多少能代一切□□□□□□□□苦盡一切畜生苦盡一切餓鬼苦盡一切人天莫
問凡聖所有苦事悉代受盡如大般涅槃經華□經□□□三明如來解法多少善男子如來說法不可窮[9]盡能於
一時普爲十方衆生說法若一劫百千万[10]億劫□□□□□劫作□是說一切衆生无[11]有能知如來說法邊際本
末假使无量衆生一時問難而如來於一念中□□□□□□能答然如來辨才无有窮盡四明如來禪定多少
如來有无量阿僧祇禪定三昧之所行處善男□□□□□□生皆得十住各各皆入无量三昧於百千劫中各
入[12]異定如是經无量劫猶不能盡知如來三□□□□□□修身多　如來又作无量阿僧祇應身令一切衆
生應受化者悉見如來皆現其前於一念□□□□□□□□□有差別如來又復一時皆現其前隨其所應

而為說法令諸衆生悉皆受行六明如來
念中悉皆見之如觀掌中阿摩勒口[13]七明
切衆生異類音聲隨其於一念頃
一切衆生若心口[15]知隨其
所得業報如來能於三遠
七日七夜着[17]鮮淨口[18]恭
亦得見佛四者如諸
論說四如實雲經說若華若
皆作盡虛空遍法界想第
人謗法耶三業等種種惡故
上說明知能說之教亦皆得有是佛教義
佛教二者道教說道教所爲衆生善惡作道教
三乘教亦是佛教口[22]四者一乘教說一乘所爲衆生
皆作佛法解亦須敬四階能說師皆作佛師想
若[24]是佛說非外道說又上十種惡具足人敬惡
者意業唯教普敬如上何以故一由不別惡人
以唯合普敬如大方廣十輪經說二者立業
除見人作五逆等罪對面呵勸捨者[26]不犯或
持戒破戒空有佛教道教大乘小乘福智三寶
執着[29]小乘三藏學者亦不得共同[30]住如法華經
經中亦具出能敬人所得利益多少分齊一
涅槃果第四段明世間十種惡具足人
謗法耶三業等種種惡故第一明世間十
見增上慢謗人謗法耶三業等種種惡故一者如
摩經八法內說教菩薩於惡世界內明菩薩行如有明
具足人自知己所學法分齊何以故爲破我見增上慢謗人
皆是何以故此經爲種種顚倒衆生出世於
生所說法即是世間十種惡具足人所學法
者大方廣十輪經一部皆是何以故從首
是何以故從首至末皆爲天龍夜叉
說出家人惡无量者皆法為[32]末[33]而
七[34]者法華經四安樂品說
請於此世界行菩薩之法
下者定[36]是凡夫法華經
聞十種惡
種惡具足人少佛為[37]破我見增上慢謗
一微薄善二者第四卷內說善
了信說亦於三乘各得少信心信此不信
種惡具足人自知己耶解多少何以
經說於佛[38]十二部經內增加人情至
說一自言盡知佛法二出諸經中相
說法佛言此人當墮地獄不至涅槃六
无教及者法墮地獄人如來悉知我諸

如來天眼所見境界无量无邊如來於一
聞境界无量无邊如上天眼所見境界一[14]
有无量无邊无得智慧无與等
隨彼衆生各各所念各各所
不[16]定心多少普男子如來常
如來有大生
去一七一
大口方便[19]經說三
三夜三[20]行供養福田供事
法為明我見
一為之人作惡大小皆得有是
衆生善惡作儒教所以佛亦
三乘亦[21]說三乘亦為衆生善惡
即是佛教此明敬四階所說
言語[23]文字
乘教與佛教等者[25]於內有三階一
由不別大乘內小乘小乘內大乘故所
有佛教道教大乘小乘福智三寶唯
者亦不犯三者身業不得共讚[27]說
聖人謗法人同住[28]乃至儒教道教
經等諸經廣說又上敬人重法
於法界行自然具足三乃至得大
何以故為破我見增上慢謗人
自見惡見他善淺深分齊何以故為破我
明自見惡見他善二者如維
所與知[31]第二明世間十種惡
三者大般涅槃經一部
眼衆生說法為衆
人
皆是經內
須勝鬘經就解明上下[35]
此等類以可知何以故具出世
少自知病多少第三明世間十
種種惡故如大方廣十輪經說
第四卷內說求三乘各得少信心信
少智黑暗力故五者第六卷內說微
慢謗人謗法耶三業等種種惡
在者唯舍慧又復[39]總[40]判耶說者多正[41]
法中疑不信四自以[42]所知非也
明是非不順正[43]法七[44]身末
一種緣種

和僧還說出家人長短　持戒
而是三乘器第一義僧攝　戒
覆藏　戒以
於　持戒以己之惡
　後一　先轉　法內亦名死屍是可棄者於
　世尊我滅度後　心法僧聖戒自不起惡
已所作惡數數懺悔能除　種種諸罪作如是複令我九
　修功德之所能及如大方廣十輪經說　又大般涅　故
一　慧眼成就菩薩治罰衆生淺深或打或煞皆得或贊毀持戒破戒或贊設
乘　或贊毀福智皆得如經內說　仙與國王煞婆羅門等皆漏
深雖不打不煞有畜人不淨財犯重也　未使　三明[75]教肉[76]眼菩薩
應相似　九者大集[77]月藏分經內亦　擇法淺深
者即是大方廣十輪經內判一切在家出　者是及與
大方廣十輪經內佛開國王大臣助　上人語下經文
　十者如其見有於我法中而出　大偷盜大
　法儐出國土出城邑村落不聽在寺　養之物悉不
亦不應口業罵辱一切不應加其身　是人便於
必定歸趣阿鼻地獄何況鞭打為佛　明世間十種
故爲破我見增上慢謗人謗法耶三　他知犯戒
三寶　四者　畏不消他信施罰道　經文殊師利
　二汝等上　百[78]數歸俗　五者由懺　經大
即論此五種法所以知　第十二明　已不
今人論發　惡故　一者明
　合　明　合　求出法人
同行相
心男
持戒　得與
等說　如此
知

[1] 錄文為‥中
[2] 此後多処都為‥耶　錄文為‥邪
[3] 錄文為‥舍
[4] 錄文為‥是
[5] 錄文為‥大
[6] 錄文缺
[7] 錄文為‥以
[8] 錄文為‥是
[9] 錄文為‥聽
[10] 此後多処都為‥万　錄文為‥萬
[11] 此後多処都為‥无　錄文為‥无
[12] 錄文為‥人
[13] 錄文為‥果　右面此字只能辨認為草字頭
[14] 石面僅有三個字的位置
[15] 錄文為‥合　，石面非合或其異體字
[16] 錄文為‥有
[17] 錄文為‥著
[18] 錄文為‥衣服　右面僅有一個字　疑似為‥衣
[19] 錄文為‥成大乘諸
[20] 錄文為‥有
[21] 錄文為‥教
[22] 錄文缺
[23] 錄文為‥語言
[24] 錄文為‥皆
[25] 錄文缺
[26] 錄文為‥身
[27] 錄文為‥寶
[28] 錄文為‥律
[29] 錄文為‥著
[30] 錄文缺
[31] 錄文為‥智
[32] 錄文缺
[33] 錄文為‥未
[34] 錄文為‥廿
[35] 錄文缺
[36] 錄文為‥已

[37] 鎍文為‥法
[38] 鎍文缺
[39] 鎍文為‥複
[40] 鎍文為‥舍
[41] 鎍文為‥由
[42] 鎍文為‥少
[43] 鎍文為‥從
[44] 鎍文為‥化
[45] 鎍文為‥正法
[46] 鎍文為‥關
[47] 此後多処都為‥陁　鎍文為‥陀
[48] 鎍文為‥業
[49] 此後多処都為‥万　鎍文為‥萬
[50] 鎍文為‥入
[51] 此後多処都為‥繫　鎍文為‥系
[52] 鎍文多‥比丘二字
[53] 鎍文為‥虫
[54] 鎍文為‥萬
[55] 鎍文為‥多
[56] 鎍文為‥假
[57] 鎍文為‥旃
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[59] 鎍文為‥幹
[60] 鎍文為‥叶
[61] 鎍文為‥令
[62] 鎍文為‥爾
[63] 鎍文為‥師
[64] 鎍文為‥锈　右面为禾字旁加秀　非锈的异体字　。
[65] 鎍文為‥可
[66] 鎍文為‥聚
[67] 鎍文為‥舍
[68] 鎍文為‥聚
[69] 此後多処都為‥布　鎍文為‥佈
[70] 鎍文此處多一個‥知字
[71] 鎍文為‥九
[72] 鎍文為‥聖賢
[73] 鎍文為‥在
[74] 鎍文此處多一個‥一字　為紅色
[75] 鎍文為‥乘

[76] 錄文為：內

[77] 錄文此處多了一個：經字

[78] 錄文為：比

大集月藏分经略抄出一卷　信行禅師撰
一者明供養三寳時節　上人語下經文　若復有諸衆生若現在世及未來世　二
者明能自發心出家勤脩道者現得不捨諸佛乃至成佛　上人語下經文　於我法
中出家脩道三業相應　　三者明放人出家人現得不捨諸佛乃至成佛　上人
語下經文　若復放人出家脩道　　四者明守護供養聲聞弟子不斷現得不捨
諸佛乃至成佛　上人語下經文　若復有人能勤加護持養育供給我諸聲聞比丘
比丘尼優婆塞優婆夷令三寳種得不斷絕　　五者明脩六波羅蜜人現得不
捨諸佛乃至成佛　上人語下經文　若有能脩檀波羅蜜乃至般若波羅蜜　　六
者明造新□新像及脩故塔故像人現得不捨諸佛乃至成佛　上人語下經文　若
有營造塔□□像及以脩故　　七者明供養四方僧造新寺及脩營故寺人現
得不捨□□□□至成佛　上人語下經文　種種捨施供養供給四方衆僧置立寺舍
及以□□　　八者明守護不聽他奪三寳財物人現得不捨諸佛乃至成佛　上
人語□□□　□復於彼四方僧寺捨施種種衣服臥具器物所須及施田宅財寳
園林□□□□□乃至畜生若復見他捨施諸物還追奪者以力遮護　　九者明
佈施□□□□□飲食臥具湯藥一切所須人現得不捨諸佛乃至成佛　上人語下
經文　若複施我聲聞弟子衣服飲食臥具湯藥一切所須　　十者□□□□□□□
□□□□□□現得不捨諸佛乃至成佛　上人語下經文　我之所有聲聞弟子或有
因緣□□□□□惱若以自力若假他力方便令脱□□□□□□□□□□□□□
現得不捨諸佛及成佛經文佛以上十種人等□□□□□□□□□□□□□
刧千佛乃至得入无畏涅槃大城　上人語下經文　□□□□□□□□□□□□
十方現在一切諸□及付賢刧所□□□□□□□□□□□□□□□□□□□
刼諸佛□□□□□□□□□□□□□□□□□□□□□□□□□□□□□
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□□□□□□□□□□□惡　　十四者明□種毀壞三寳人聞止損益多
少怖怕□□願供養守護持戒破戒无戒三種比丘　上人語下經文　既見此已所
有毀壞三□者皆无佛斎誠心懺悔護持三寳於佛一切聲聞弟子乃至若复不
持禁戒□□□□□着袈裟片者作師長想護持養育與諸所須令无乏少
十五者明禪定比丘三寳人願遮護國王大臣等不令毀壞三寳　上人語下經文
若复有诸刹利國王作諸非法惱亂世尊聲聞弟子若以毀罵刀杖打斫及奪衣
□□□□□具若他□施作留難者我等令彼自然卒起他方怨敵及自國土亦
令兵起病疫飢饉非時風雨鬪諍言訟誹謗讒調又令其王不久復當亡失已國
如是若復諸婆羅門□□□陁男夫婦人童男童女若餘天龍乃至迦吒富單那
等於佛所有聲聞弟子作其惱亂若奪精氣氣噓其身乃至惡心以眼視之我等
悉共令彼天龍乃至迦吒富單那等所有諸根缺減醜漏不依處所　　十六者
明復有諸天等於三寳中作罪過者懺悔願供養守護持戒破戒无戒三種比丘

□□□□□□□□亦勿令彼飢渴乏少以乏少故於三善業不得相應退捨禁戒
□□□□□□尒時復有諸梵天王諸釋天王諸龍王諸夜叉王諸阿脩羅王諸鳩槃□王□□眷屬合掌向佛而作是言大德婆伽婆已有一切如來堪寺及阿蘭若□□□□□□□聲聞弟子所有住處及未來世剎利婆羅門毗舍首陁若在家人二若□出□□□爲於世尊聲聞弟子造塔寺處隨有世尊聲聞弟子三業相應及與□種□□□□□應有學无學住於持戒多聞善行我等悉共守護於彼令□□切□□□□□□□世尊聲聞弟子所立塔寺及阿蘭若處如有給施飲食衣服臥具湯藥一切所須如是施主我等亦當護持養育若復世尊聲聞弟子乏少晝夜所須衆具□□之者我為彼等作大施主受其寄付護持養育除諸怖畏佛時讚言善哉善哉諸□□汝等一切於四天下應當如是如□等受我□□如說脩行我以汝等及諸眷屬付囑弥勒　　卅一者明偈誦重誦　上人語下經文　尒時佛申金色右臂□□偈言　汝等共諦聽一切有為法无常火所燒无有少□□□如諸戲人作於種種戲如是等衆生皆為煩惱轉猶如幻芭蕉亦如水中月□界有為法一切皆如是諸法我自覺道成如先佛我今大衆會天人作證明正法付天神護持□苦盡成於三界尊能令法熾盛顯現八正路耶意惡覺滅沙門剎利王激動相□惱我今當不久涅槃滅无餘大智諸聲聞亦隨我涅槃餘方諸佛國一□□菩薩具大神通者復還向他方福德諸國王大臣長者滅限滿百年後佛法漸隱□薄福衆生等於我法出家不樂於三乘亦不畏後世活命故出家多詐无羞恥貪求諸名利處處諂嫉妬遠離於禪誦複於諸善法晝則樂言訟夜則多睡眠樂讀□□□□捨離佛所說復與女人通嚴飾身衣服為求名利故但營世俗業常為他□□使通致諸信命往返俗人家販賣以自活樂作諸田業又復喜鬪諍見諸善比□□梵行多聞者嫉妬復瞋罵不□□□□而作麁穢語誹謗及毀呰於諸俗人□□□□□業言此詐比□是□□□人若有供養者多得惡名聞於彼不獲福亦□□□□□諸寺惡比□□□□行者種種不善事是以剎利瞋彼諸惡□□□以□□□□□□□□□利□□□□利喜□舍婆羅門利喜亦如是以是得供養持□□□□□□□□□□□戒者嫌恨持戒故致使諸天瞋弃xiii捨彼國土剎利輔相臣□□□□□□士在彼而安住輕賤持戒故菩薩亦捨離諸天捨離後其國大可畏□□□□夜叉羅剎鳩槃荼入國奪精氣及食其肉血惡王婆羅門毗xiv舍首陁等共護國城邑及以諸村落宮舍國園林惡鬼遍充滿常奪彼精氣觸惱諸剎利婆羅毗舍□男女等皆瞋復令心變惡互共相鬪諍彼等鬪諍故布薩行檀絕其國水枯涸非時風□□飢饉□短乏少資生具菓xv苗不成熟地味衆生味法味及精氣一切皆損減興動諸兵□互共相劫奪如是慳貪國惡比丘往返復以佛僧物飲食諸菓藥持用與俗人因此得供養奴婢及田宅與彼令攝受不善比丘等以之為尊長少智詐多聞不亨禪戒者禪戒者去後為財共鬪諍剎利聞生瞋打害惡比丘還俗捨□□□□於牢獄以是諸天瞋迭xvi共相告語如是國土中梅xvii陁羅王治朋黨惡比丘毀破袈裟服自壞己國土不久當敗亡墮在阿鼻獄受苦極長遠於是賢劫中无脫地獄時是梅陁羅王眾聖所猒xviii賤聽讀檀尸xix法諂曲虛詐現是王多詐偽速滅己國土苗稼不成熟亢旱及水澇蟲xx鼠惡象暴自他國兵起曜入非常宿大地普震動白虹妖星墮時氣多病疫焚燒諸聚落速壞國城邑剃頭着袈裟諸佛所加□一人出家者天人所供養唯除諸如來无有自在者彼梅陁羅王謫罰惡比丘毀壞三世佛一二種淨法身煩惱瘡深重難得值諸佛諸天皆捨離彼梅陁羅王如是國土壞法眼當散滅諸天捨離故如是國土壞三種精氣滅毀滅天宮殿白法善朋少黑法惡黨增於彼濁惡世无有明智人所住阿蘭若樂法安隱住彼持戒正法能令多衆信鬼神敬信故遮障諸怖畏增長三精氣熾然我

[i] 錄文為：师

[ii] 此後多处都為：着　錄文為：著

[iii] 此後多处都為：无　錄文為：無

[iv] 此後多処都為‥万　錄文為‥万

[v] 錄文缺

[vi] 錄文為‥士

[vii] 錄文為‥比丘名字

[viii] 此後多処都為‥耶　錄文為‥邪

[ix] 錄文多‥寶　一字

[x] 錄文為‥王

[xi] 此後多処都為‥弥　錄文為‥弥

[xii] 錄文為‥歸此　右面此処有三字　未　为推測

[xiii] 錄文為‥棄

[xiv] 此後多処都為‥毗　錄文為‥毗

[xv] 此後多処都為‥菓　錄文為‥果

[xvi] 此後多処都為‥迭　錄文為‥疊

[xvii] 此後多処都為‥栴　錄文為‥旃

[xviii] 此後多処都為‥猒　錄文為‥厭

[xix] 此後多処都為‥尸　錄文為‥屍

[xx] 錄文為‥懿

[xxi] 錄文為‥默

[xxii] 錄文為‥鹹

[xxiii] 錄文為‥童

[xxiv] 錄文為‥悲

[xxv] 錄文為‥殺

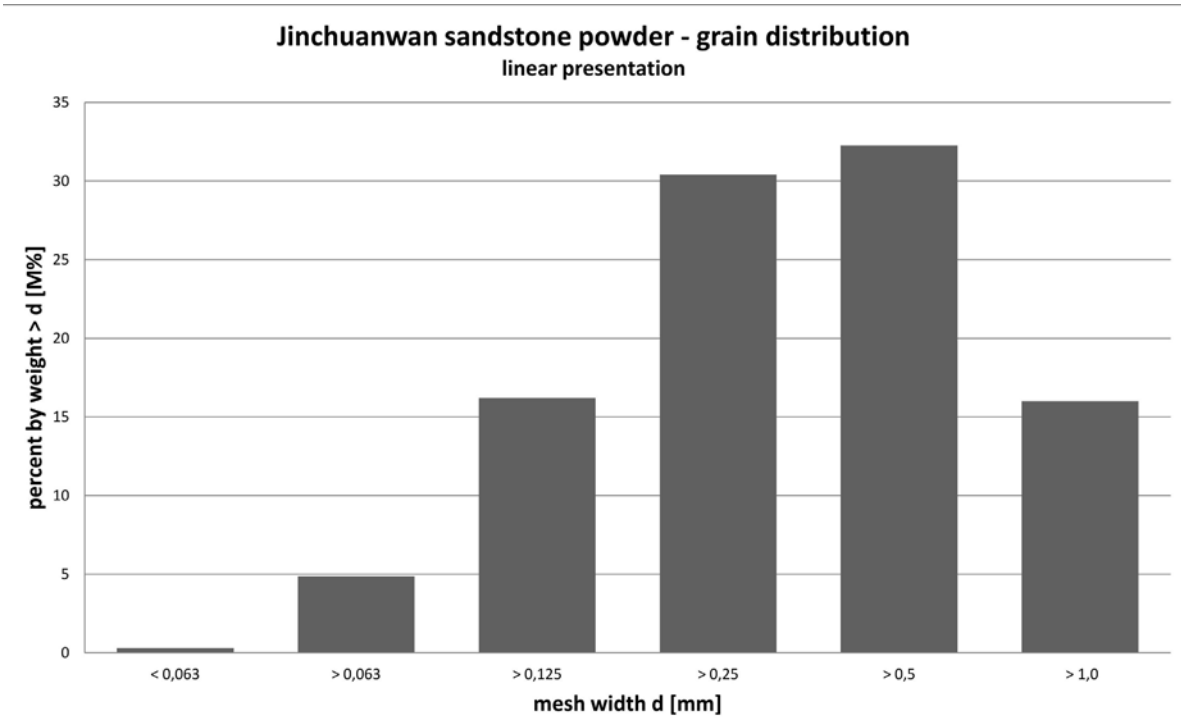
[xxvi] 錄文為‥屬

Examination of stone consolidation materials for Jinchuanwan Grotto, Shaanxi Province, China - Appendix

Martin Mach, Erwin Emmerling, Mathias Kocher, Katharina Meier zu Verl

Jinchuanwan sandstone powder – grain distribution graph

Mesh width d [mm]	< 0,063	> 0,063	> 0,125	> 0,25	> 0,5	> 1,0
Percent by weight > d [M%]	0,30	4,85	16,20	30,40	32,25	16,00



Water absorption in the stone consolidation materials

Stone consolidation material 1

	Atmospheric pressure W_{Aa}		Vacuum W_{Av}		
Sample	**Dry weight [g]**	**Wet weight [g]**	**Dry weight [g]**	**Under water [g]**	**Wet/air [g]**
1/ I.	187.583	202.719	186.491	114.149	211.103
1/ II.	189.933	205.262	188.837	115.541	213.444
1/ III.	187.678	199.219	185.504	113.552	207.560
1/ IV.	187.819	201.501	185.852	113.650	209.196
1/ V.	189.786	203.729	187.820	114.872	210.794

Stone consolidation material 2

	Atmospheric pressure W_{Aa}		Vacuum W_{Av}		
Sample	**Dry weight [g]**	**Wet weight [g]**	**Dry weight [g]**	**Under water [g]**	**Wet/air [g]**
2/ I	183.333	204.341	183.332	112.038	214.571
2/ II.	186.604	206.253	186.411	114.006	217.128
2/ III.	185.083	204.501	184.838	113.201	215.477
2/ IV.	186.155	205.738	185.861	113.606	216.858
2/ V.	182.206	203.261	182.211	111.467	213.893

Stone consolidation material 3

	Atmospheric pressure W_{Aa}		Vacuum W_{Av}		
Sample	**Dry weight [g]**	**Wet weight [g]**	**Dry weight [g]**	**Under water [g]**	**Wet/air [g]**
3/ I.	191.763	212.254	190.940	115.507	219.002
3/ II.	190.232	211.469	189.499	114.981	218.759
3/ III.	190.291	211.776	189.488	115.162	218.759
3/ IV.	190.573	211.947	189.813	115.226	218.778
3/ V.	188.343	210.401	187.542	114.038	217.221

Stone consolidation material 4

	Atmospheric pressure W_{Aa}		Vacuum W_{Av}		
Sample	**Dry weight [g]**	**Wet weight [g]**	**Dry weight [g]**	**Under water [g]**	**Wet/air [g]**
4/ I.	178.919	193.346	178.481	108.314	212.119
4/ II.	189.704	205.955	189.199	114.698	218.254
4/ III.	189.305	204.519	188.798	114.511	218.905
4/ IV.	186.878	201.892	186.448	112.898	217.176
4/ V.	192.207	206.786	191.327	115.290	219.354

Stone consolidation material 5

	Atmospheric pressure W_{Aa}		Vacuum W_{Av}		
Sample	**Dry weight [g]**	**Wet weight [g]**	**Dry weight [g]**	**Under water [g]**	**Wet/air [g]**
5/ I.	189.526	208.820	190.923	117.426	220.191
5/ II.	183.960	203.638	185.439	114.053	215.179
5/ III.	187.644	206.821	189.008	115.898	219.172
5/ IV.	181.291	200.270	182.653	112.262	212.412
5/ V.	190.910	209.947	192.187	118.051	221.089

Hygric dilatation of the stone consolidation materials

Hygric dilatation			
Sample	KSE-Modul-System 1		
Notes	Stone consolidation material 1		
Direction	z		
Date	2. Nov 2011		
Room temperature [°C]	24		
Relative humidity [%]	46		
Length [mm] at room temperature	49.33		
Mass [g] before test	187.583		
Mass [g] after test	202.719		
Water absorbed [g]	15.136		
Dial gauge number	3		
Position of the needle on starting measurement	Small needle : 0 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
2. Nov 2011	10.00			Start of measurement Direction z
	11.00	0.019		
	12.00	0.020		
	14.00	0.022		
	16.15	0.023		
3. Nov 2011	15.00	0.025		
4. Nov 2011	10.00	0.027	0.547	

Hygric dilatation			
Sample	KSE-Modul-System 2		
Notes	Stone consolidation material 1		
Direction	z		
Date	2. Nov 2011		
Room temperature [°C]	24		
Relative humidity [%]	46		
Length [mm] at room temperature	50.26		
Mass [g] before test	189.933		
Mass [g] after test	205.262		
Water absorbed [g]	15.329		
Dial gauge number	4		
Position of the needle on starting measurement	Small needle : 0 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
2. Nov 2011	10.00			Start of measurement Direction z
	11.00	0.018		
	12.00	0.020		
	14.00	0.021		
	16.15	0.022		
3. Nov 2011	15.00	0.025		
4. Nov 2011	10.00	0.027	0.537	

Hygric dilatation			
Sample	KSE-Modul-System 3		
Notes	Stone consolidation material 1		
Direction	z		
Date	2. Nov 2011		
Room temperature [°C]	24		
Relative humidity [%]	46		
Length [mm] at room temperature	48.25		
Mass [g] before test	187.678		
Mass [g] after test	199.219		
Water absorbed [g]	11.541		
Dial gauge number	6		
Position of the needle on starting measurement	Small needle : 0 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
2. Nov 2011	10.00			Start of measurement Direction z
	11.00	0.008		
	12.00	0.020		
	14.00	0.027		
	16.15	0.032		
3. Nov 2011	15.00	0.039		
4. Nov 2011	10.00	0.043	0.891	

Hygric dilatation			
Sample	KSE-Modul-System 4		
Notes	Stone consolidation material 1		
Direction	z		
Date	2. Nov 2011		
Room temperature [°C]	24		
Relative humidity [%]	46		
Length [mm] at room temperature	48.68		
Mass [g] before test	187.819		
Mass [g] after test	201.501		
Water absorbed [g]	13.682		
Dial gauge number	2		
Position of the needle on starting measurement	Small needle : 0 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
2. Nov 2011	10.00			Start of measurement Direction z
	11.00	0.022		
	12.00	0.034		
	14.00	0.039		
	16.15	0.040		
3. Nov 2011	15.00	0.046		
4. Nov 2011	10.00	0.049	1.006	

Hygric dilatation			
Sample	KSE-Modul-System 5		
Notes	Stone consolidation material 1		
Direction	z		
Date	2. Nov 2011		
Room temperature [°C]	24		
Relative humidity [%]	46		
Length [mm] at room temperature	48.74		
Mass [g] before test	189.786		
Mass [g] after test	203.729		
Water absorbed [g]	13.943		
Dial gauge number	5		
Position of the needle on starting measurement	Small needle : 0 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
2. Nov 2011	10.00			Start of measurement Direction z
	11.00	0.026		
	12.00	0.036		
	14.00	0.041		
	16.15	0.044		
3. Nov 2011	15.00	0.049		
4. Nov 2011	10.00	0.055	1.128	

Hygric dilatation			
Sample	Remmers Restauriermörtel 1		
Notes	Stone consolidation material 2		
Direction	z		
Date	25. Oct 2011		
Room temperature [°C]	24		
Relative humidity [%]	43		
Length [mm] at room temperature	50.22		
Mass [g] before test	183.333		
Mass [g] after test	204.341		
Water absorbed [g]	21.008		
Dial gauge number	5		
Position of the needle on starting measurement	Small needle : 0 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
25. Oct 2011	10.00			Start of measurement Direction z
	11.00	0.007		
	12.00	0.009		
	14.15	0.010		
	16.00	0.0105		
26. Oct 2011	9.00	0.0125		
	13.15	0.0125		
27.Oct 2011	12.45	0.0135	0.269	

Hygric dilatation			
Sample	Remmers Restauriermörtel 2		
Notes	Stone consolidation material 2		
Direction	z		
Date	25. Oct 2011		
Room temperature [°C]	24		
Relative humidity [%]	43		
Length [mm] at room temperature	50.98		
Mass [g] before test	186.604		
Mass [g] after test	206.253		
Water absorbed [g]	19.649		
Dial gauge number	4		
Position of the needle on starting measurement	Small needle : 0 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
25. Oct 2011	10.00			Start of measurement Direction z
	11.00	0.003		
	12.00	0.008		
	14.15	0.010		
	16.00	0.010		
26. Oct 2011	9.00	0.012		
	13.15	0.013		
27. Oct 2011	12.45	0.014	0.275	

Hygric dilatation			
Sample	Remmers Restauriermörtel 3		
Notes	Stone consolidation material 2		
Direction	z		
Date	25. Oct 2011		
Room temperature [°C]	24		
Relative humidity [%]	43		
Length [mm] at room temperature	50.80		
Mass [g] before test	185.083		
Mass [g] after test	204.501		
Water absorbed [g]	19.418		
Dial gauge number	3		
Position of the needle on starting measurement	Small needle : 0 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
25. Oct 2011	10.00			Start of measurement Direction z
	11.00	0.004		
	12.00	0.007		
	14.15	0.008		
	16.00	0.009		
26. Oct 2011	9.00	0.011		
	13.15	0.0115		
27. Oct 2011	12.45	0.012	0.236	

Hygric dilatation			
Sample	Remmers Restauriermörtel 4		
Notes	Stone consolidation material 2		
Direction	z		
Date	25. Oct 2011		
Room temperature [°C]	24		
Relative humidity [%]	43		
Length [mm] at room temperature	51.11		
Mass [g] before test	186.155		
Mass [g] after test	205.738		
Water absorbed [g]	19.583		
Dial gauge number	2		
Position of the needle on starting measurement	Small needle : 0 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
25. Oct 2011	10.00			Start of measurement Direction z
	11.00	0.005		
	12.00	0.010		
	14.15	0.010		
	16.00	0.010		
26. Oct 2011	9.00	0.011		
	13.15	0.012		
27. Oct 2011	12.45	0.0125	0.244	

Hygric dilatation			
Sample	Remmers Restauriermörtel 5		
Notes	Stone consolidation material 2		
Direction	z		
Date	25. Oct 2011		
Room temperature [°C]	24		
Relative humidity [%]	43		
Length [mm] at room temperature	50.67		
Mass [g] before test	182.206		
Mass [g] after test	203.261		
Water absorbed [g]	21.055		
Dial gauge number	6		
Position of the needle on starting measurement	Small needle : 0 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
25. Oct 2011	10.00			Start of measurement Direction z
	11.00	0.0055		
	12.00	0.0085		
	14.15	0.0095		
	16.00	0.010		
26. Oct 2011	9.00	0.0125		
	13.15	0.0125		
27. Oct 2011	12.45	0.0135	0.266	

Hygric dilatation			
Sample	Remmers Restauriermörtel GF 1		
Notes	Stone consolidation material 3		
Direction	z		
Date	15. Nov 2011		
Room temperature [°C]	24		
Relative humidity [%]	40		
Length [mm] at room temperature	50.99		
Mass [g] before test	191.763		
Mass [g] after test	212.254		
Water absorbed [g]	20.491		
Dial gauge number	3		
Position of the needle on starting measurement	Small needle : 0 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
15. Nov 2011	9.45			Start of measurement Direction z
	10.30	0.0015		
	11.30	0.004		
	13.00	0.0085		
	15.30	0.0135		
16. Nov 2011	10.00	0.0265		
	15.00	0.028		
17. Nov 2011	13.00	0.030	0.588	

Hygric dilatation			
Sample	Remmers Restauriermörtel GF 2		
Notes	Stone consolidation material 3		
Direction	z		
Date	15. Nov 2011		
Room temperature [°C]	24		
Relative humidity [%]	40		
Length [mm] at room temperature	50.72		
Mass [g] before test	190.232		
Mass [g] after test	211.469		
Water absorbed [g]	21.237		
Dial gauge number	5		
Position of the needle on starting measurement	Small needle : 0 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
15. Nov 2011	9.45			Start of measurement Direction z
	10.30	0.000		
	11.30	0.001		
	13.00	0.005		
	15.30	0.0085		
16. Nov 2011	10.00	0.0185		
	15.00	0.019		
17. Nov 2011	13.00	0.0205	0.404	

Hygric dilatation			
Sample	Remmers Restauriermörtel GF 3		
Notes	Stone consolidation material 3		
Direction	z		
Date	15. Nov 2011		
Room temperature [°C]	24		
Relative humidity [%]	40		
Length [mm] at room temperature	50.91		
Mass [g] before test	190.291		
Mass [g] after test	211.776		
Water absorbed [g]	21.485		
Dial gauge number	6		
Position of the needle on starting measurement	Small needle : 0 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
15. Nov 2011	9.45			Start of measurement Direction z
	10.30	0.001		
	11.30	0.003		
	13.00	0.0075		
	15.30	0.012		
16. Nov 2011	10.00	0.029		
	15.00	0030		
17. Nov 2011	13.00	0.034	0.668	

Hygric dilatation			
Sample	Remmers Restauriermörtel GF 4		
Notes	Stone consolidation material 3		
Direction	z		
Date	15. Nov 2011		
Room temperature [°C]	24		
Relative humidity [%]	40		
Length [mm] at room temperature	50.63		
Mass [g] before test	190.573		
Mass [g] after test	211.947		
Water absorbed [g]	21.374		
Dial gauge number	4		
Position of the needle on starting measurement	Small needle : 0 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
15. Nov 2011	9.45			Start of measurement Direction z
	10.30	0.005		
	11.30	0.009		
	13.00	0.011		
	15.30	0.015		
16. Nov 2011	10.00	0.032		
	15.00	0.033		
17. Nov 2011	13.00	0.036	0.711	

Hygric dilatation			
Sample	Remmers Restauriermörtel GF 5		
Notes	Stone consolidation material 3		
Direction	z		
Date	15. Nov 2011		
Room temperature [°C]	24		
Relative humidity [%]	40		
Length [mm] at room temperature	51.00		
Mass [g] before test	188.343		
Mass [g] after test	210.401		
Water absorbed [g]	22.058		
Dial gauge number	2		
Position of the needle on starting measurement	Small needle : 0 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
15. Nov 2011	9.45			Start of measurement Direction z
	10.30	0.001		
	11.30	0.003		
	13.00	0.0075		
	15.30	0.0125		
16. Nov 2011	10.00	0.0225		
	15.00	0.0225		
17. Nov 2011	13.00	0.0235	0.547	

Hygric dilatation			
Sample	Mineros Fugenmörtel 1		
Notes	Stone consolidation material 4		
Direction	z		
Date	20. Oct 2011		
Room temperature [°C]	24		
Relative humidity [%]	45		
Length [mm] at room temperature	50.73		
Mass [g] before test	178.919		
Mass [g] after test	193.346		
Water absorbed [g]	14.427		
Dial gauge number	4		
Position of the needle on starting measurement	Small needle : 0 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
20. Oct 2011	11.00			Start of measurement Direction z
	12.00	0.002		
	12.30	0.0035		
	13.30	0.006		
	15.00	0.010		
21. Oct 2011	10.30	0.021		
	15.00	0.022		
24. Oct 2011	10.00	0.022	0.434	

Hygric dilatation			
Sample	Mineros Fugenmörtel 2		
Notes	Stone consolidation material 4		
Direction	z		
Date	20. Oct 2011		
Room temperature [°C]	24		
Relative humidity [%]	45		
Length [mm] at room temperature	50.82		
Mass [g] before test	189.704		
Mass [g] after test	205.955		
Water absorbed [g]	16.251		
Dial gauge number	3		
Position of the needle on starting measurement	Small needle : 0 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
20. Oct 2011	11.00			Start of measurement Direction z
	12.00	0.002		
	12.30	0.0045		
	13.30	0.0075		
	15.00	0.0115		
21. Oct 2011	10.30	0.024		
	15.00	0.025		
24. Oct 2011	10.00	0.034	0.669	

Hygric dilatation			
Sample	Mineros Fugenmörtel 3		
Notes	Stone consolidation material 4		
Direction	z		
Date	20. Oct 2011		
Room temperature [°C]	24		
Relative humidity [%]	45		
Length [mm] at room temperature	51.09		
Mass [g] before test	189.305		
Mass [g] after test	204.519		
Water absorbed [g]	15.214		
Dial gauge number	5		
Position of the needle on starting measurement	Small needle : 0 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
20. Oct 2011	11.00			Start of measurement Direction z
	12.00	0.001		
	12.30	0.003		
	13.30	0.006		
	15.00	0.010		
21. Oct 2011	10.30	0.022		
	15.00	0.022		
24. Oct 2011	10.00	0.0265	0.519	

Hygric dilatation			
Sample	Mineros Fugenmörtel 4		
Notes	Stone consolidation material 4		
Direction	z		
Date	20. Oct 2011		
Room temperature [°C]	24		
Relative humidity [%]	45		
Length [mm] at room temperature	50.64		
Mass [g] before test	186.878		
Mass [g] after test	201.892		
Water absorbed [g]	15.014		
Dial gauge number	2		
Position of the needle on starting measurement	Small needle : 0 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
20. Oct 2011	11.00			Start of measurement Direction z
	12.00	0.002		
	12.30	0.003		
	13.30	0.005		
	15.00	0.010		
21. Oct 2011	10.30	0.022		
	15.00	0.0225		
24. Oct 2011	10.00	0.027	0.533	

Hygric dilatation			
Sample	Mineros Fugenmörtel 5		
Notes	Stone consolidation material 4		
Direction	z		
Date	20. Oct 2011		
Room temperature [°C]	24		
Relative humidity [%]	45		
Length [mm] at room temperature	50.83		
Mass [g] before test	192.207		
Mass [g] after test	206.786		
Water absorbed [g]	14.579		
Dial gauge number	6		
Position of the needle on starting measurement	Small needle : 0 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
20. Oct 2011	11.00			Start of measurement Direction z
	12.00	0.002		
	12.30	0.0035		
	13.30	0.005		
	15.00	0.007		
21. Oct 2011	10.30	0.019		
	15.00	0.019		
24. Oct 2011	10.00	0.0235	0.462	

Hygric dilatation			
Sample	Jahn Stampfmörtel 1		
Notes	Stone consolidation material 5		
Direction	z		
Date	28. Nov 2011		
Room temperature [°C]	23.5		
Relative humidity [%]	40.5		
Length [mm] at room temperature	50.93		
Mass [g] before test	189.526		
Mass [g] after test	208.820		
Water absorbed [g]	19.294		
Dial gauge number	3		
Position of the needle on starting measurement	Small needle : 0 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
28. Nov 2011	13.45			Start of measurement Direction z
	14.30	0.0015		
	15.30	0.003		
	17.30	0.004		
29. Nov 2011	9.30	0.0095		
	11.00	0.010		
	12.30	0.010		
1. Dez 2011	10.00	0.0125	0.245	

Hygric dilatation			
Sample	Jahn Stampfmörtel 2		
Notes	Stone consolidation material 5		
Direction	z		
Date	28.Nov 2011		
Room temperature [°C]	23.5		
Relative humidity [%]	40.5		
Length [mm] at room temperature	50.56		
Mass [g] before test	183.960		
Mass [g] after test	203.638		
Water absorbed [g]	19.678		
Dial gauge number	5		
Position of the needle on starting measurement	Small needle : 0 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
28. Nov 2011	13.45			Start of measurement Direction z
	14.30	0.004		
	15.30	0.005		
	17.30	0.007		
29.Nov 2011	9.30	0.012		
	11.00	0.013		
	12.30	0.013		
1. Dez 2011	10.00	0.014	0.277	

Hygric dilatation			
Sample	Jahn Stampfmörtel 3		
Notes	Stone consolidation material 5		
Direction	z		
Date	28. Nov 2011		
Room temperature [°C]	23.5		
Relative humidity [%]	40.5		
Length [mm] at room temperature	50.97		
Mass [g] before test	187.644		
Mass [g] after test	206.821		
Water absorbed [g]	19.177		
Dial gauge number	4		
Position of the needle on starting measurement	Small needle : 0 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
28. Nov 2011	13.45			Start of measurement Direction z
	14.30	0.004		
	15.30	0.006		
	17.30	0.0075		
29. Nov 2011	9.30	0.0125		
	11.00	0.014		
	12.30	0.014		
1. Dez 2011	10.00	0.016	0.314	

Hygric dilatation			
Sample	Jahn Stampfmörtel 4		
Notes	Stone consolidation material 5		
Direction	z		
Date	28. Nov 2011		
Room temperature [°C]	23.5		
Relative humidity [%]	40.5		
Length [mm] at room temperature	50.20		
Mass [g] before test	181.291		
Mass [g] after test	200.270		
Water absorbed [g]	18.979		
Dial gauge number	2		
Position of the needle on starting measurement	Small needle : 0 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
28. Nov 2011	13.45			Start of measurement Direction z
	14.30	0.0055		
	15.30	0.0075		
	17.30	0.009		
29. Nov 2011	9.30	0.0145		
	11.00	0.0145		
	12.30	0.015		
1. Dez 2011	10.00	0.018	0.358	

Hygric dilatation			
Sample	Jahn Stampfmörtel 5		
Notes	Stone consolidation material 5		
Direction	z		
Date	28. Nov 2011		
Room temperature [°C]	23.5		
Relative humidity [%]	40.5		
Length [mm] at room temperature	50.58		
Mass [g] before test	190.910		
Mass [g] after test	209.947		
Water absorbed [g]	19.037		
Dial gauge number	6		
Position of the needle on starting measurement	Small needle : 0 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
28. Nov 2011	13.45			Start of measurement Direction z
	14.30	0.004		
	15.30	0.006		
	17.30	0.008		
29. Nov 2011	9.30	0.014		
	11.00	0.0145		
	12.30	0.015		
1. Nov 2011	10.00	0.0175	0.346	

Thermal dilatation of the stone consolidation materials

Thermal dilatation			
Sample	KSE-Modul-System 1		
Notes	Stone consolidation material 1		
Direction	z		
Date	13. Oct 2011		
Room temperature [°C]	27		
Relative humidity [%]	47		
Temperature [°C]	61		
Length [mm] at room temperature	49.33		
Mass [g] before test	188.39		
Dial gauge number	4		
Position of the needle on starting measurement	Small needle : 2 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
14. Oct 2011	12.30			Start of measurement Direction z
	13.00	-0.018		
	13.30	-0.023		
	14.30	-0.023		
	16.30	-0.023	0.4662	
17. Oct 2011	10.00	-0.022		

	Δ l / l [mm/m]	**Δ l / l [µm/m]**	**Δ l /ΔT [µm/°C]**
Direction z	0.4662	466.2	13.712

Thermal dilatation			
Sample	KSE-Modul-System 2		
Notes	Stone consolidation material 1		
Direction	z		
Date	13. Oct 2011		
Room temperature [°C]	27		
Relative humidity [%]	47		
Temperature [°C]	61		
Length [mm] at room temperature	50.26		
Mass [g] before test	190.70		
Dial gauge number	3		
Position of the needle on starting measurement	Small needle : 2 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
14. Oct 2011	12.30			Start of measurement Direction z
	13.00	-0.0175		
	13.30	-0.023		
	14.30	-0.0235		
	16.30	-0.0235		
17. Oct 2011	10.00	-0.0235	0.4676	

	Δ l / l [mm/m]	**Δ l / l [µm/m]**	**Δ l /ΔT [µm/°C]**
Direction z	0.4676	467.6	13.753

Thermal dilatation			
Sample	KSE-Modul-System 3		
Notes	Stone consolidation material 1		
Direction	z		
Date	20. Oct 2011		
Room temperature [°C]	24		
Relative humidity [%]	43		
Temperature [°C]	60		
Length [mm] at room temperature	48.25		
Mass [g] before test	188.87		
Dial gauge number	5		
Position of the needle on starting measurement	Small needle : 2 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
21. Oct 2011	10.30			Start of measurement Direction z
	11.00	-0.021		
	12.00	-0.023		
	13.00	-0.023		
	15.00	-0.023		
24. Oct 2011	10.00	-0.023	0.4767	

	Δ l / l [mm/m]	**Δ l / l [µm/m]**	**Δ l /ΔT [µm/°C]**
Direction z	0.4767	476.7	13.242

Thermal dilatation			
Sample	KSE-Modul-System 4		
Notes	Stone consolidation material 1		
Direction	z		
Date	13. Oct 2011		
Room temperature [°C]	27		
Relative humidity [%]	47		
Temperature [°C]	61		
Length [mm] at room temperature	48.68		
Mass [g] before test	188.94		
Dial gauge number	2		
Position of the needle on starting measurement	Small needle : 2 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
14. Oct 2011	12.30			Start of measurement Direction z
	13.00	-0.016		
	13.30	-0.021		
	14.30	-0.0215		
	16.30	-0.0215		
17. Oct 2011	10.00	-0.0215	0.4416	

	Δ l / l [mm/m]	**Δ l / l [µm/m]**	**Δ l /ΔT [µm/°C]**
Direction z	0.4416	441.6	12.988

Thermal dilatation			
Sample	KSE-Modul-System 5		
Notes	Stone consolidation material 1		
Direction	z		
Date	13. Oct 2011		
Room temperature [°C]	27		
Relative humidity [%]	47		
Temperature [°C]	61		
Length [mm] at room temperature	48.74		
Mass [g] before test	190.90		
Dial gauge number	6		
Position of the needle on starting measurement	Small needle : 2 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
14. Oct 2011	12.30			Start of measurement Direction z
	13.00	-0.0155		
	13.30	-0.0215		
	14.30	-0.022		
	16.30	-0.022		
17. Oct 2011	10.00	-0.021	0.4514	

	Δ l / l [mm/m]	**Δ l / l [µm/m]**	**Δ l /ΔT [µm/°C]**
Direction z	0.4514	451.4	13.276

Thermal dilatation			
Sample	Remmers Restauriermörtel 1		
Notes	Stone consolidation material 2		
Direction	z		
Date	12. Oct 2011		
Room temperature [°C]	23.5		
Relative humidity [%]	52		
Temperature [°C]	53		
Length [mm] at room temperature	50.22		
Mass [g] before test	184.7		
Dial gauge number	4		
Position of the needle on starting measurement	Small needle : 2 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
13. Oct 2011	10.00			Start of measurement Direction z
	10.30	-0.018		
	11.00	-0.020		
	12.00	-0.020		
	14.00	-0.020	0.3982	
14. Oct 2011	10.00	-0.019		

	Δ l / l [mm/m]	**Δ l / l [µm/m]**	**Δ l /ΔT [µm/°C]**
Direction z	0.3982	398.2	13.498

Thermal dilatation			
Sample	Remmers Restauriermörtel 2		
Notes	Stone consolidation material 2		
Direction	z		
Date	12. Oct 2011		
Room temperature [°C]	23.5		
Relative humidity [%]	52		
Temperature [°C]	53		
Length [mm] at room temperature	50.98		
Mass [g] before test	187.7		
Dial gauge number	3		
Position of the needle on starting measurement	Small needle : 2 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
13. Oct 2011	10.00		0.4609	Start of measurement Direction z
	10.30	-0.0235		
	11.00	-0.021		
	12.00	-0.021		
	14.00	-0.021		
14. Oct 2011	10.00	-0.023		

	Δ l / l [mm/m]	**Δ l / l [µm/m]**	**Δ l /ΔT [µm/°C]**
Direction z	0.4609	460.9	15.624

Thermal dilatation			
Sample	Remmers Restauriermörtel 3		
Notes	Stone consolidation material 2		
Direction	z		
Date	12. Oct 2011		
Room temperature [°C]	23.5		
Relative humidity [%]	52		
Temperature [°C]	53		
Length [mm] at room temperature	50.80		
Mass [g] before test	186.2		
Dial gauge number	5		
Position of the needle on starting measurement	Small needle : 2 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
13. Oct 2011	10.00			Start of measurement Direction z
	10.30	-0.0175		
	11.00	-0.019		
	12.00	-0.019		
	14.00	-0.019	0.3740	
14. Oct 2011	10.00	-0.016		

	Δ l / l [mm/m]	**Δ l / l [µm/m]**	**Δ l /ΔT [µm/°C]**
Direction z	0.3740	374.0	12.678

Thermal dilatation			
Sample	Remmers Restauriermörtel 4		
Notes	Stone consolidation material 2		
Direction	z		
Date	12.Oct 2011		
Room temperature [°C]	23.5		
Relative humidity [%]	52		
Temperature [°C]	53		
Length [mm] at room temperature	51.11		
Mass [g] before test	187.2		
Dial gauge number	2		
Position of the needle on starting measurement	Small needle : 2 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
13. Oct 2011	10.00			Start of measurement Direction z
	10.30	-0.017		
	11.00	-0.019		
	12.00	-0.019		
	14.00	-0.019	0.3717	
14.10.2011	10.00	-0.0185		

	Δ l / l [mm/m]	**Δ l / l [µm/m]**	**Δ l /ΔT [µm/°C]**
Direction z	0.3717	371.7	12.600

Thermal dilatation			
Sample	Remmers Restauriermörtel 5		
Notes	Stone consolidation material 2		
Direction	z		
Date	12. Oct 2011		
Room temperature [°C]	23.5		
Relative humidity [%]	52		
Temperature [°C]	53		
Length [mm] at room temperature	50.67		
Mass [g] before test	183.5		
Dial gauge number	6		
Position of the needle on starting measurement	Small needle : 2 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
13. Oct 2011	10.00			Start of measurement Direction z
	10.30	-0.020		
	11.00	-00225		
	12.00	-0.023		
	14.00	0.023		
14. Oct 2011	10.00	-0.025	0.4934	

	Δ l / l [mm/m]	**Δ l / l [µm/m]**	**Δ l /ΔT [µm/°C]**
Direction z	0.4934	493.4	16.725

Thermal dilatation			
Sample	Remmers Restauriermörtel GF 1		
Notes	Stone consolidation material 3		
Direction	z		
Date	28. Sep 2011		
Room temperature [°C]	23		
Relative humidity [%]	57		
Temperature [°C]	67		
Length [mm] at room temperature	50.99		
Mass [g] before test	193.7		
Dial gauge number	4		
Position of the needle on starting measurement	Small needle : 2 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
29. Sep 2011	10.00		0.5491	Start of measurement Direction z
	10.30	-0.025		
	11.00	-0.028		
	12.00	-0.028		
	14.00	-0.0275		
30. Sep 2011	10.00	-0.027		

	Δ l / l [mm/m]	**Δ l / l [µm/m]**	**Δ l /ΔT [µm/°C]**
Direction z	0.5491	549.1	12.479

Thermal dilatation			
Sample	Remmers Restauriermörtel GF 2		
Notes	Stone consolidation material 3		
Direction	z		
Date	28. Sep 2011		
Room temperature [°C]	23		
Relative humidity [%]	57		
Temperature [°C]	67		
Length [mm] at room temperature	50.72		
Mass [g] before test	192.4		
Dial gauge number	3		
Position of the needle on starting measurement	Small needle : 2 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
29. Sep 2011	10.00		0.5323	Start of measurement Direction z
	10.30	-0.023		
	11.00	-0.027		
	12.00	-0.027		
	14.00	-0.0265		
30. Sep 2011	10.00	-0.022		

	Δ l / l [mm/m]	**Δ l / l [µm/m]**	**Δ l /ΔT [µm/°C]**
Direction z	0.5323	532.3	12.098

Thermal dilatation			
Sample	Remmers Restauriermörtel GF 3		
Notes	Stone consolidation material 3		
Direction	z		
Date	28. Sep 2011		
Room temperature [°C]	23		
Relative humidity [%]	57		
Temperature [°C]	67		
Length [mm] at room temperature	50.91		
Mass [g] before test	192.3		
Dial gauge number	5		
Position of the needle on starting measurement	Small needle : 2 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
29. Sep 2011	10.00		0.4911	Start of measurement Direction z
	10.30	-0.022		
	11.00	-0.025		
	12.00	-0.025		
	14.00	-0.025		
30. Sep 2011	10.00	-0.018		

	Δ l / l [mm/m]	**Δ l / l [µm/m]**	**Δ l /ΔT [µm/°C]**
Direction z	0.4911	491.1	11.161

Thermal dilatation			
Sample	Remmers Restauriermörtel GF 4		
Notes	Stone consolidation material 3		
Direction	z		
Date	28. Sep 2011		
Room temperature [°C]	23		
Relative humidity [%]	57		
Temperature [°C]	67		
Length [mm] at room temperature	50.63		
Mass [g] before test	192.6		
Dial gauge number	2		
Position of the needle on starting measurement	Small needle : 2 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
29. Sep 2011	10.00		0.5135	Start of measurement Direction z
	10.30	-0.023		
	11.00	-0.026		
	12.00	-0.026		
	14.00	-0.0255		
30. Sep 2011	10.00	-0.019		

	Δ l / l [mm/m]	**Δ l / l [µm/m]**	**Δ l /ΔT [µm/°C]**
Direction z	0.5135	513.5	11.670

Thermal dilatation			
Sample	Remmers Restauriermörtel GF 5		
Notes	Stone consolidation material 3		
Direction	z		
Date	28. Sep 2011		
Room temperature [°C]	23		
Relative humidity [%]	57		
Temperature [°C]	67		
Length [mm] at room temperature	51.00		
Mass [g] before test	189.9		
Dial gauge number	6		
Position of the needle on starting measurement	Small needle : 2 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
29. Sep 2011	10.00		0.6078	Start of measurement Direction z
	10.30	-0.023		
	11.00	-0.027		
	12.00	-0.027		
	14.00	-0.031		
30. Sep 2011	10.00	-0.023		

	Δ l / l [mm/m]	**Δ l / l [µm/m]**	**Δ l /ΔT [µm/°C]**
Direction z	0.6078	607.8	13.814

Thermal dilatation			
Sample	Mineros Fugenmörtel 1		
Notes	Stone consolidation material 4		
Direction	z		
Date	27. Sep 2011		
Room temperature [°C]	22.5		
Relative humidity [%]	56.5		
Temperature [°C]	65		
Length [mm] at room temperature	50.73		
Mass [g] before test	178.4		
Dial gauge number	4		
Position of the needle on starting measurement	Small needle : 2 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
28. Sep 2011	10.00		0.5125	Start of measurement Direction z
	10.30	-0.023		
	11.00	-0.0255		
	12.00	-0.026		
	14.00	-0.026		
	15.00	-0.024		
29. Sep 2011	10.00	-0.018		

	Δ l / l [mm/m]	**Δ l / l [µm/m]**	**Δ l /ΔT [µm/°C]**
Direction z	0.5125	512.5	12.059

Thermal dilatation			
Sample	Mineros Fugenmörtel 2		
Notes	Stone consolidation material 4		
Direction	z		
Date	27. Sep 2011		
Room temperature [°C]	22.5		
Relative humidity [%]	56.5		
Temperature [°C]	65		
Length [mm] at room temperature	50.82		
Mass [g] before test	189.3		
Dial gauge number	3		
Position of the needle on starting measurement	Small needle : 2 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
28. Sep 2011	10.00		0.5313	Start of measurement Direction z
	10.30	-0.0235		
	11.00	-0.027		
	12.00	-0.027		
	14.00	-0.027		
	15.00	-0.026		
29. Sep 2011	10.00	-0.022		

	Δ l / l [mm/m]	**Δ l / l [µm/m]**	**Δ l /ΔT [µm/°C]**
Direction z	0.5313	531.3	12.501

Thermal dilatation			
Sample	Mineros Fugenmörtel 3		
Notes	Stone consolidation material 4		
Direction	z		
Date	27. Sep 2011		
Room temperature [°C]	22.5		
Relative humidity [%]	56.5		
Temperature [°C]	65		
Length [mm] at room temperature	51.09		
Mass [g] before test	188.8		
Dial gauge number	5		
Position of the needle on starting measurement	Small needle : 2 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
28. Sep 2011	10.00		0.5578	Start of measurement Direction z
	10.30	-0.0165		
	11.00	-0.028		
	12.00	-0.0285		
	14.00	-0.0285		
	15.00	-0.028		
29. Sep 2011	10.00	-0.022		

	Δ l / l [mm/m]	**Δ l / l [µm/m]**	**Δ l /ΔT [µm/°C]**
Direction z	0.5578	557.8	13.125

Thermal dilatation			
Sample	Mineros Fugenmörtel 4		
Notes	Stone consolidation material 4		
Direction	z		
Date	27. Sep 2011		
Room temperature [°C]	22.5		
Relative humidity [%]	56.5		
Temperature [°C]	65		
Length [mm] at room temperature	50.64		
Mass [g] before test	186.5		
Dial gauge number	2		
Position of the needle on starting measurement	Small needle : 2 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
28. Sep 2011	10.00		0.3752	Start of measurement Direction z
	10.30	-0.018		
	11.00	-0.019		
	12.00	-0.019		
	14.00	-0.019		
	15.00	-0.019		
29. Sep 2011	10.00	-0.0175		

	Δ l / l [mm/m]	**Δ l / l [µm/m]**	**Δ l /ΔT [µm/°C]**
Direction z	0.3752	375.2	8.828

Thermal dilatation			
Sample	Mineros Fugenmörtel 5		
Notes	Stone consolidation material 4		
Direction	z		
Date	27. Sep 2011		
Room temperature [°C]	22.5		
Relative humidity [%]	56.5		
Temperature [°C]	65		
Length [mm] at room temperature	50.83		
Mass [g] before test	191.3		
Dial gauge number	6		
Position of the needle on starting measurement	Small needle : 2 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
28. Sep 2011	10.00		0.5508	Start of measurement Direction z
	10.30	-0.024		
	11.00	-0.028		
	12.00	-0.028		
	14.00	-0.028		
	15.00	-0.027		
29. Sep 2011	10.00	-0.027		

	Δ l / l [mm/m]	**Δ l / l [µm/m]**	**Δ l /ΔT [µm/°C]**
Direction z	0.5508	550.8	12.960

Thermal dilatation			
Sample	Jahn Stampfmörtel 1		
Notes	Stone consolidation material 5		
Direction	z		
Date	17. Oct 2011		
Room temperature [°C]	23.5		
Relative humidity [%]	46		
Temperature [°C]	60		
Length [mm] at room temperature	50.93		
Mass [g] before test	191.61		
Dial gauge number	4		
Position of the needle on starting measurement	Small needle : 2 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
18. Oct 2011	10.00		0.4712	Start of measurement Direction z
	10.30	-0.021		
	11.00	-0.023		
	12.00	-0.024		
	14.00	-0.023		
20. Oct 2011	10.00	-0.020		

	Δ l / l [mm/m]	**Δ l / l [µm/m]**	**Δ l /ΔT [µm/°C]**
Direction z	0.4712	471.2	12.909

Thermal dilatation			
Sample	Jahn Stampfmörtel 2		
Notes	Stone consolidation material 5		
Direction	z		
Date	17. Oct 2011		
Room temperature [°C]	23.5		
Relative humidity [%]	46		
Temperature [°C]	60		
Length [mm] at room temperature	50.56		
Mass [g] before test	185.91		
Dial gauge number	3		
Position of the needle on starting measurement	Small needle : 2 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
18. Oct 2011	10.00			Start of measurement Direction z
	10.30	-0.018		
	11.00	-0.021		
	12.00	-0.022		
	14.00	-0.022	0.4351	
20. Oct 2011	10.00	-0.020		

	Δ l / l [mm/m]	**Δ l / l [µm/m]**	**Δ l /ΔT [µm/°C]**
Direction z	0.4351	435.1	11.920

Thermal dilatation			
Sample	Jahn Stampfmörtel 3		
Notes	Stone consolidation material 5		
Direction	z		
Date	17. Oct 2011		
Room temperature [°C]	23.5		
Relative humidity [%]	46		
Temperature [°C]	60		
Length [mm] at room temperature	50.97		
Mass [g] before test	189.72		
Dial gauge number	5		
Position of the needle on starting measurement	Small needle : 2 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
18. Oct 2011	10.00			Start of measurement Direction z
	10.30	-0.018		
	11.00	-0.021		
	12.00	-0.022	0.4316	
	14.00	-0.0215		
20. Oct 2011	10.00	-0.018		

	Δ l / l [mm/m]	**Δ l / l [µm/m]**	**Δ l /ΔT [µm/°C]**
Direction z	0.4316	431.6	11.825

Thermal dilatation			
Sample	Jahn Stampfmörtel 4		
Notes	Stone consolidation material 5		
Direction	z		
Date	17. Oct 2011		
Room temperature [°C]	23.5		
Relative humidity [%]	46		
Temperature [°C]	60		
Length [mm] at room temperature	50.20		
Mass [g] before test	183.12		
Dial gauge number	2		
Position of the needle on starting measurement	Small needle : 2 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
18. Oct 2011	10.00			Start of measurement Direction z
	10.30	-0.016		
	11.00	-0.019		
	12.00	-0.0195		
	14.00	-0.0195	0.3884	
20. Oct 2011	10.00	-0.0165		

	Δ l / l [mm/m]	**Δ l / l [µm/m]**	**Δ l /ΔT [µm/°C]**
Direction z	0.3884	388.4	10.641

Thermal dilatation			
Sample	Jahn Stampfmörtel 5		
Notes	Stone consolidation material 5		
Direction	z		
Date	17. Oct 2011		
Room temperature [°C]	23.5		
Relative humidity [%]	46		
Temperature [°C]	60		
Length [mm] at room temperature	50.58		
Mass [g] before test	192.67		
Dial gauge number	6		
Position of the needle on starting measurement	Small needle : 2 Large needle: 0		

Date	**t[h]**	**Δ l [mm]**	**Δ l / l [mm/m]**	**Comment**
18. Oct 2011	10.00			Start of measurement Direction z
	10.30	-0.019		
	11.00	-0.022		
	12.00	-0.023	0.4547	
	14.00	-0.0225		
20. Oct 2011	10.00	-0.018		

	Δ l / l [mm/m]	**Δ l / l [µm/m]**	**Δ l /ΔT [µm/°C]**
Direction z	0.4547	454.7	12.457

Biaxial flexural strength of the stone consolidation materials

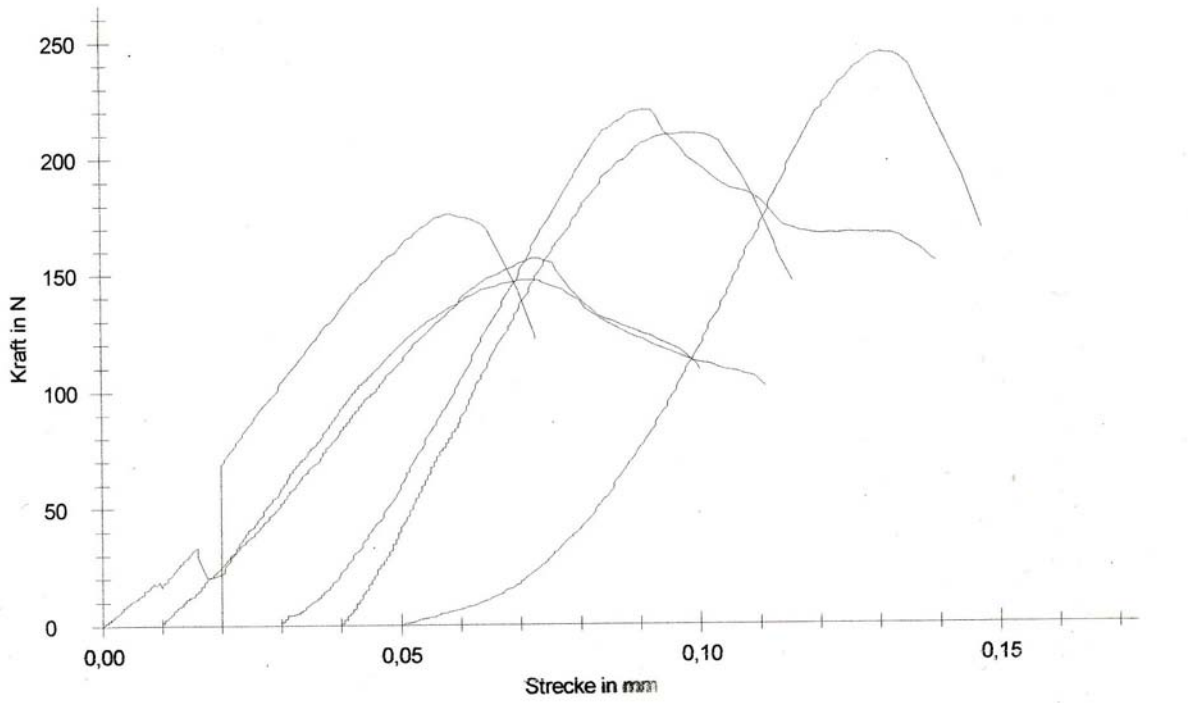
Parameter

Material	Stone consolidation materials sandstone Jinchuanwan Grotto
Examinator	Katharina Meier zu Verl
Drilling force	10,00 N
Top radius	6,50 mm
Bottom radius	19,50 mm
Poisson's ratio	0,25
Speed for each step	0,50 mm/min

Stone consolidation material 1

Sample	**Size d** [mm]	**Diameter d_o** [mm]	**F_{max}** [N]	**σ_{bz}** [N/mm²]	**L at F_{max}** [mm]	**Flexural-E-modulus** [kN/mm²]	**f_0** [mm]	**Test period-F_{max}** [s]
1	6,38	49,55	147,16	2,76	0,07	3,86	0,027	25,46
2	6,26	49,24	156,74	3,06	0,06	5,81	0,020	26,02
3	6,44	49,63	175,61	3,24	0,04	-4,52e	-0,000	20,76
4	No evaluation possible							
5	6,29	49,39	220,23	4,64	0,06	8,05	0,023	19,54
6	No evaluation possible							
7	6,53	49,52	210,05	3,77	0,06	8,69	0,016	31,16
8	6,45	48,88	244,25	4,51	0,08	4,03	0,042	24,64

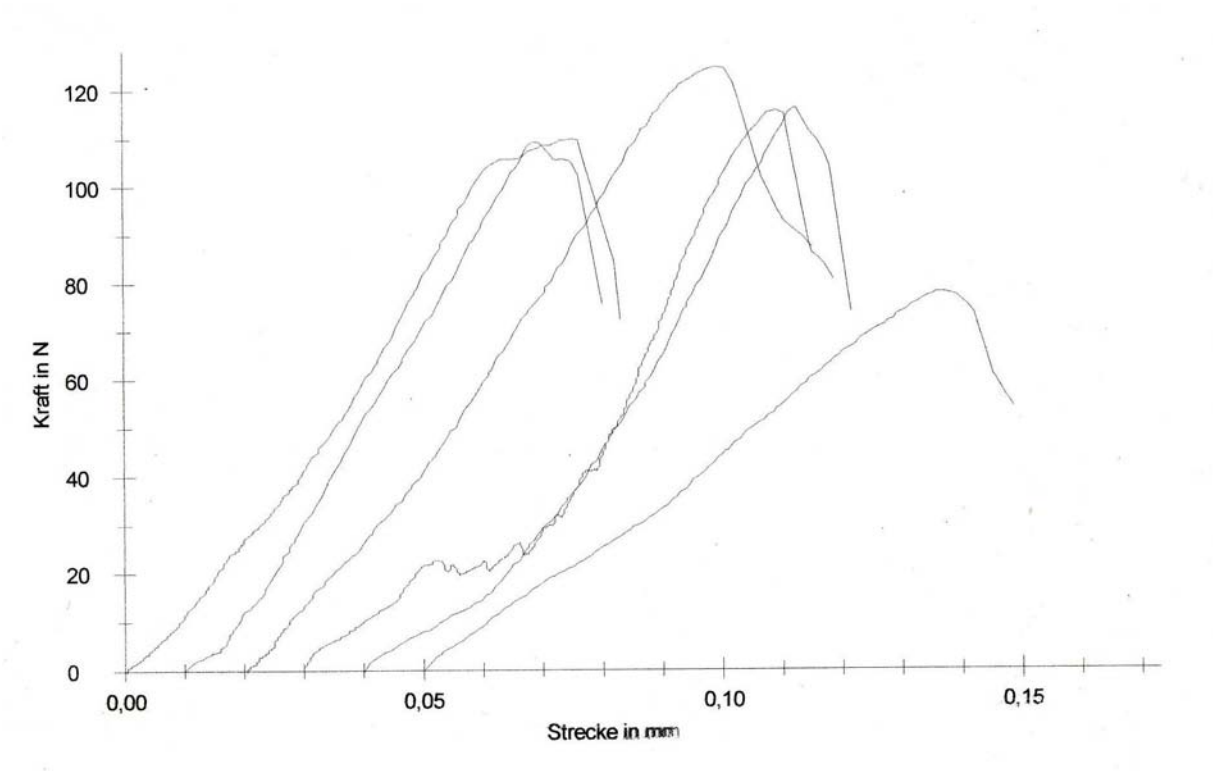
[Kraft=Force; Strecke=Distance]



Stone consolidation material 2

Sample	**Size d** [mm]	**Diameter d_O** [mm]	**F_{max}** [N]	**σ_{bz}** [N/mm²]	**L at F_{max}** [mm]	**Flexural-E-modulus** [kN/mm²]	**f_0** [mm]	**Test period-F_{max}** [s]
1	6,59	49,83	109,89	1,93	0,07	2,60	0,027	20,36
2	6,47	50,20	109,24	1,99	0,06	3,21	0,023	13,10
3	6,29	50,21	124,51	2,40	0,08	3,04	0,030	21,24
4	6,63	49,83	115,68	2,01	0,08	1,59	0,046	31,30
5	6,44	49,84	116,10	2,14	0,07	2,20	0,036	13,52
6	5,90	50,06	77,81	1,70	0,09	2,25	0,031	13,26

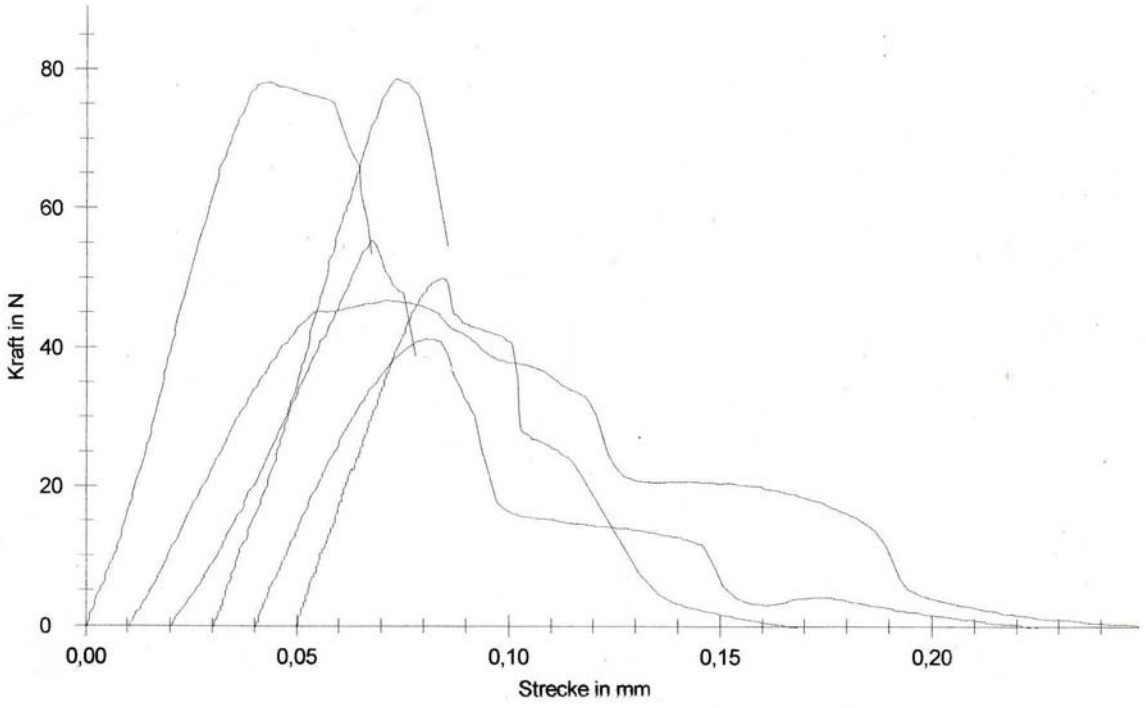
[Kraft=Force; Strecke=Distance]



Stone consolidation material 3

Sample	**Size d** [mm]	**Diameter d_O** [mm]	**F_{max}** [N]	**σ_{bz}** [N/mm²]	**L at F_{max}** [mm]	**Flexural-E-modulus** [kN/mm²]	**f_0** [mm]	**Test period-F_{max}** [s]
1	6,56	49,67	78,11	1,39	0,04	3,49	0,015	13,76
2	No evaluation possible							
3	No evaluation possible							
4	No evaluation possible							
5	6,27	49,93	55,40	1,08	0,05	2,30	0,018	11,44
6	No evaluation possible							
7	6,77	50,04	78,57	1,31	0,04	2,92	0,016	12,76
8	No evaluation possible							
9	6,94	49,89	49,83	0,79	0,03	2,89	0,010	25,42

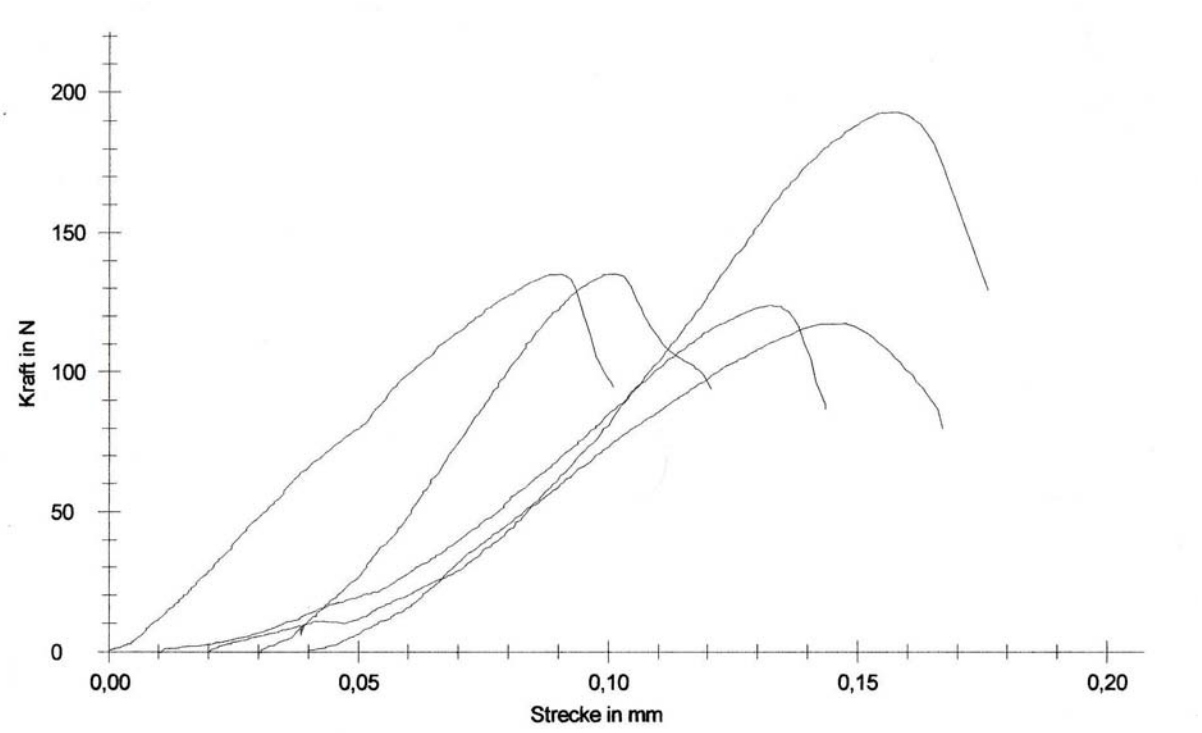
[Kraft=Force; Strecke=Distance]



Stone consolidation material 4

Sample	**Size d** [mm]	**Diameter d_O** [mm]	**F_{max}** [N]	**σ_{bz}** [N/mm²]	**L at F_{max}** [mm]	**Flexural-E-modulus** [kN/mm²]	**f_0** [mm]	**Test period-F_{max}** [s]
1	6,54	49,77	134,99	2,41	0,09	3,17	0,028	24,02
2	6,59	50,12	123,65	2,17	0,12	1,30	0,061	22,80
3	7,16	49,78	192,79	2,87	0,14	1,35	0,072	28,22
4	No evaluation possible							
5	6,51	49,72	135,15	2,44	0,07	3,15	0,029	15,22
6	No evaluation possible							
7	6,53	49,96	117,14	2,10	0,11	2,21	0,035	19,98
8	No evaluation possible							

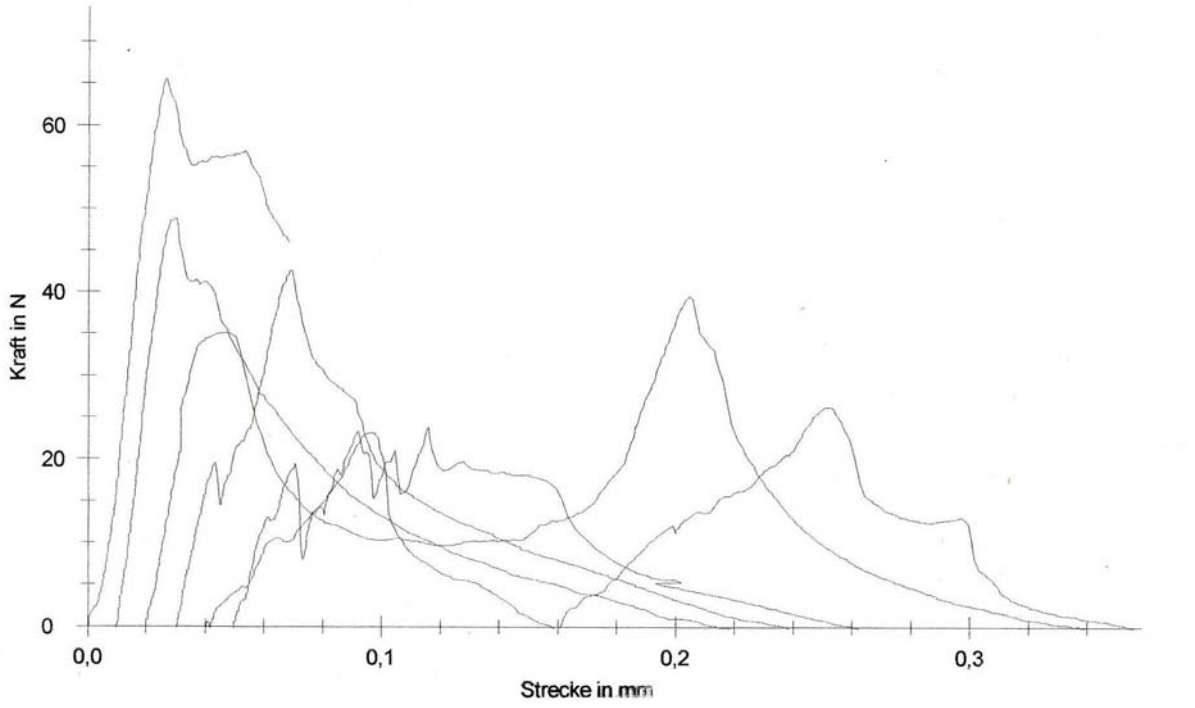
[Kraft=Force; Strecke=Distance]



Stone consolidation material 5

Sample	**Size d** [mm]	**Diameter d_O** [mm]	**F_{max}** [N]	**σ_{bz}** [N/mm²]	**L at F_{max}** [mm]	**Flexural-E-modulus** [kN/mm²]	**f_0** [mm]	**Test period-F_{max}** [s]
1	7,09	49,86	65,59	1,00	0,03	3,05	0,011	18,78
2	6,62	50,14	48,86	0,85	0,02	5,13	0,006	10,32
3	6,81	49,97	39,42	0,65	0,18	3,12	0,007	25,10
4	No evaluation possible							
5	6,71	49,85	42,62	0,72	0,04	3,04	0,009	20,46
6	6,88	49,82	26,28	0,42	0,21	0,75	0,020	35,08
7	No evaluation possible							
8	5,63	50,23	23,80	0,57	0,07	3,78	0,006	21,46

[Kraft=Force; Strecke=Distance]

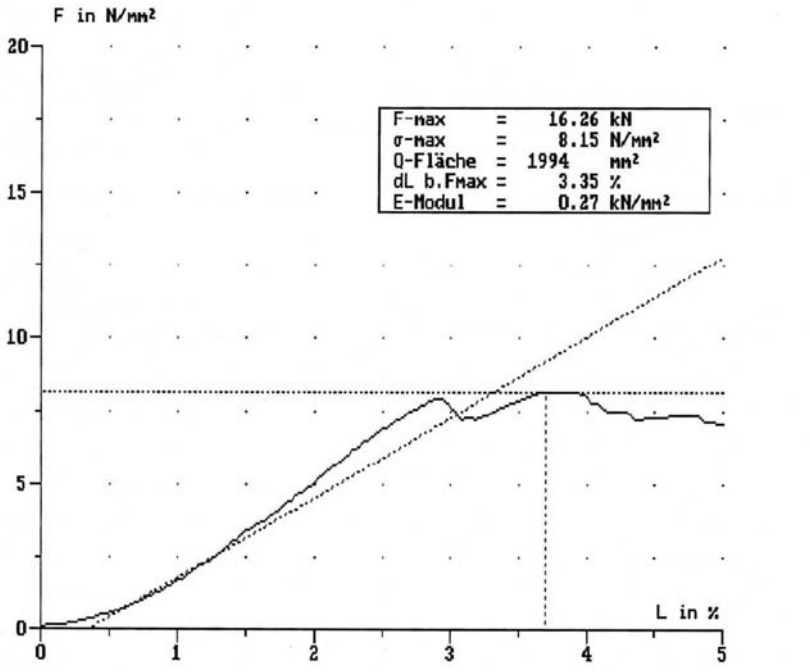


Compression strength

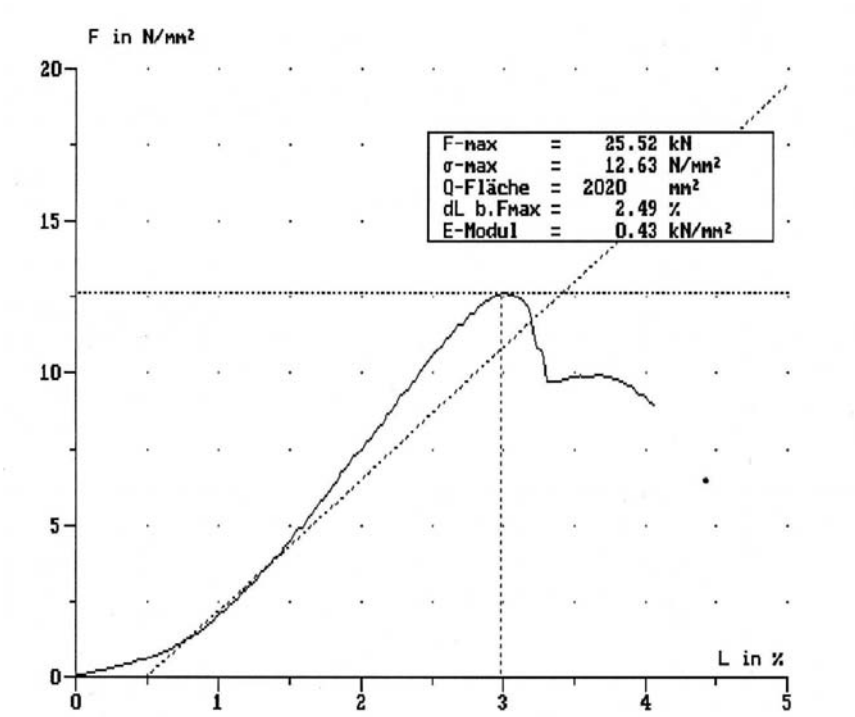
Parameter	
Test	Compression/Fmax./Cube
Material	stone consolidation materials
Examinator	Katharina Meier zu Verl
Compression Force Fv	100 N
Test velocity	1mm/min

Stone consolidation material 1

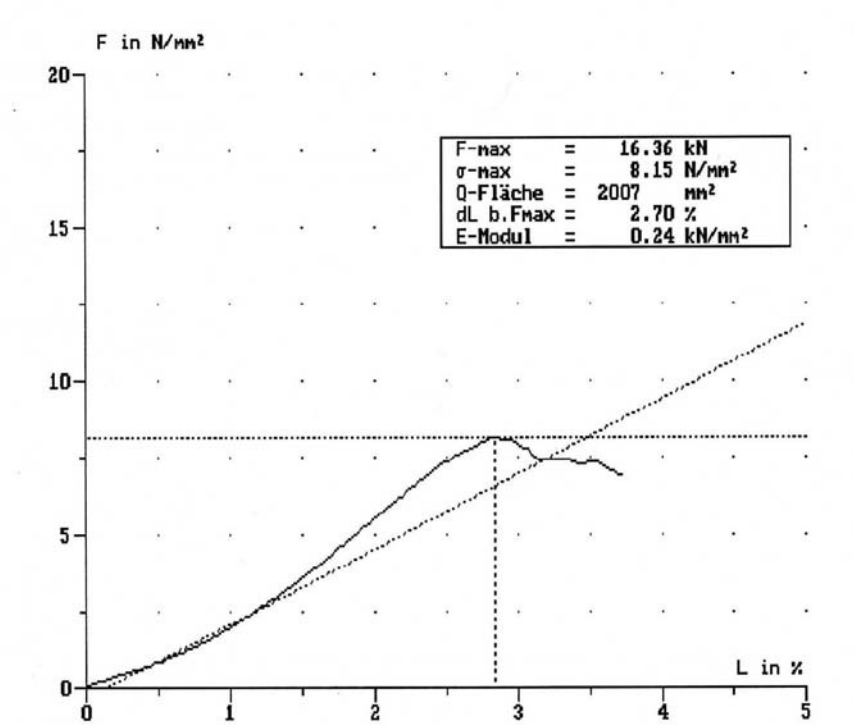
Sample-ID	F-max kN	dL b.Fmax %	Q-surface mm²	σ-max N/ mm²	E-Modulus kN/ mm²
E1_1	16.26	3.35	1994	8.15	0.27



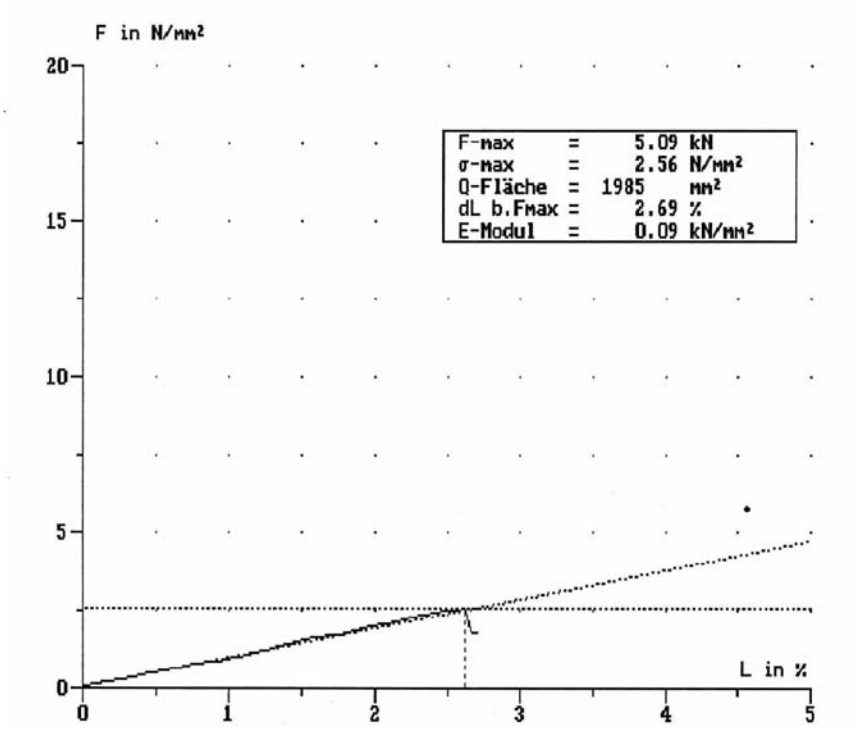
Sample-ID	F-max kN	dL b.Fmax %	Q-surface mm²	σ-max N/ mm²	E-Modulus kN/ mm²
E1_2	25.52	2.49	2020	12.63	0.43



Sample-ID	F-max kN	dL b.Fmax %	Q-surface mm²	σ-max N/ mm²	E-Modulus kN/ mm²
E1_3	16.36	2.70	2007	8.15	0.24

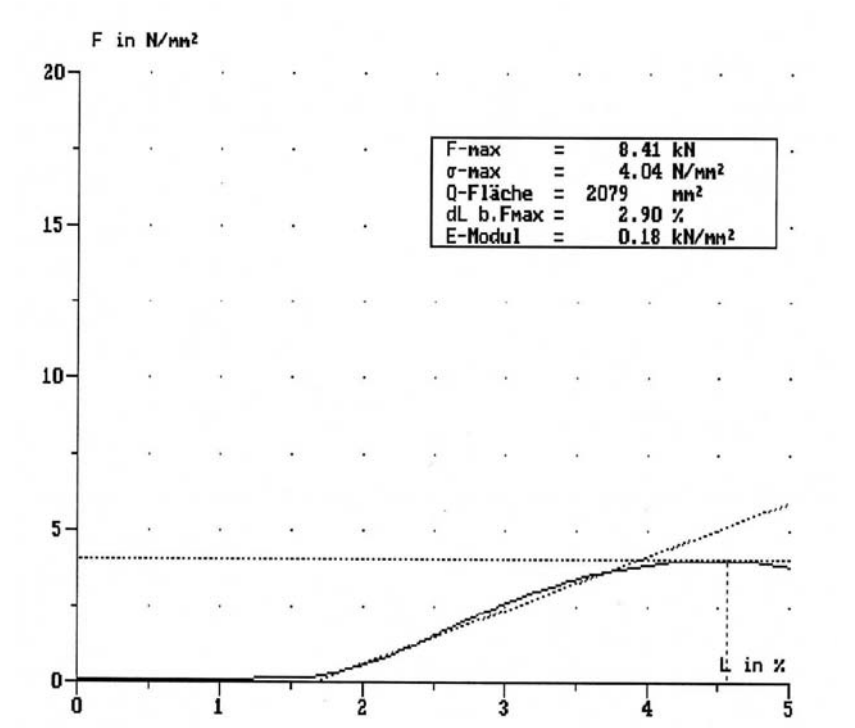


Sample-ID	F-max kN	dL b.Fmax %	Q-surface mm²	σ-max N/ mm²	E-Modulus kN/ mm²
E1_4	5.09	2.69	1985	2.56	0.09

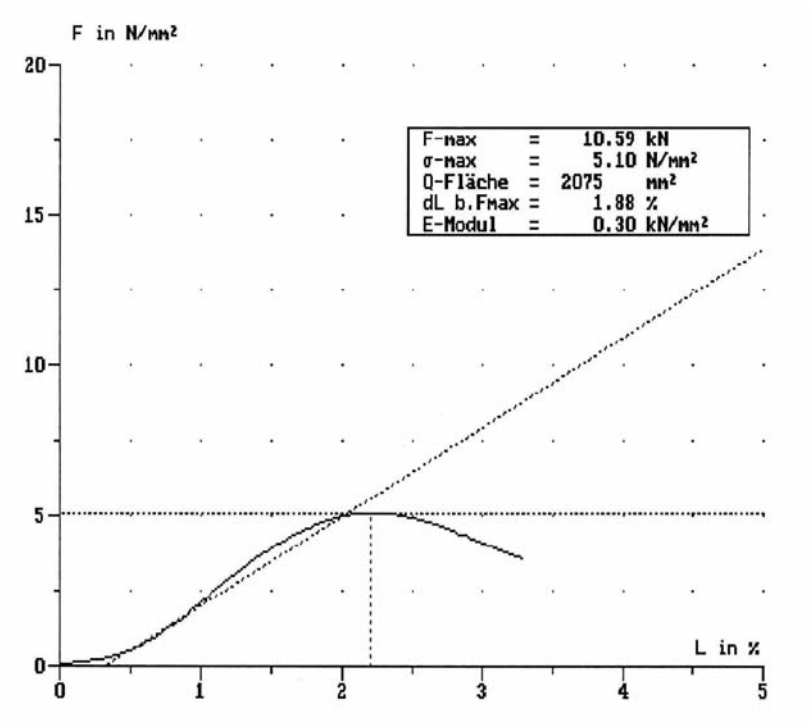


Stone consolidation material 2

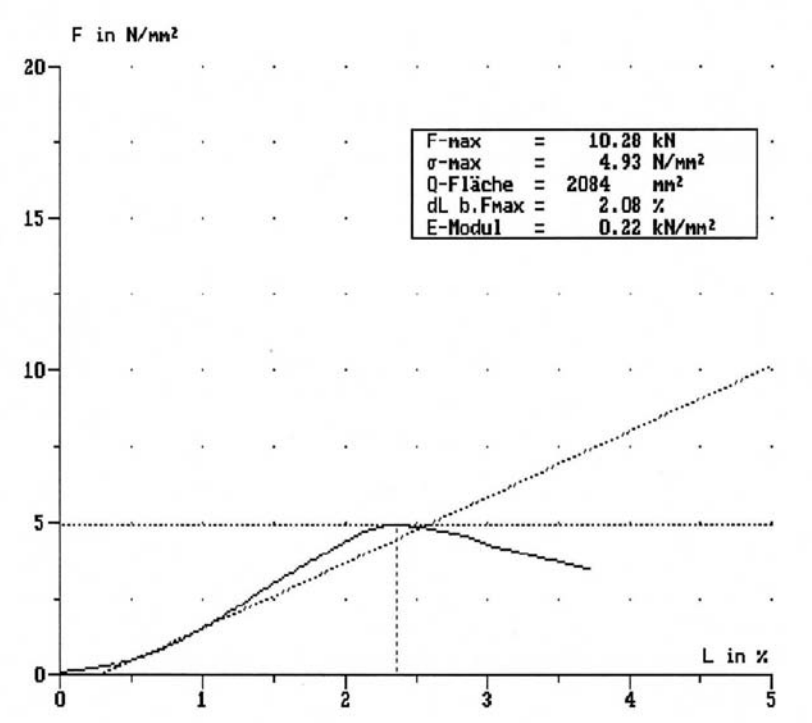
Sample-ID	F-max kN	dL b.Fmax %	Q-surface mm²	σ-max N/ mm²	E-Modulus kN/ mm²
E2_1	8.41	2.90	2079	4.04	0.18



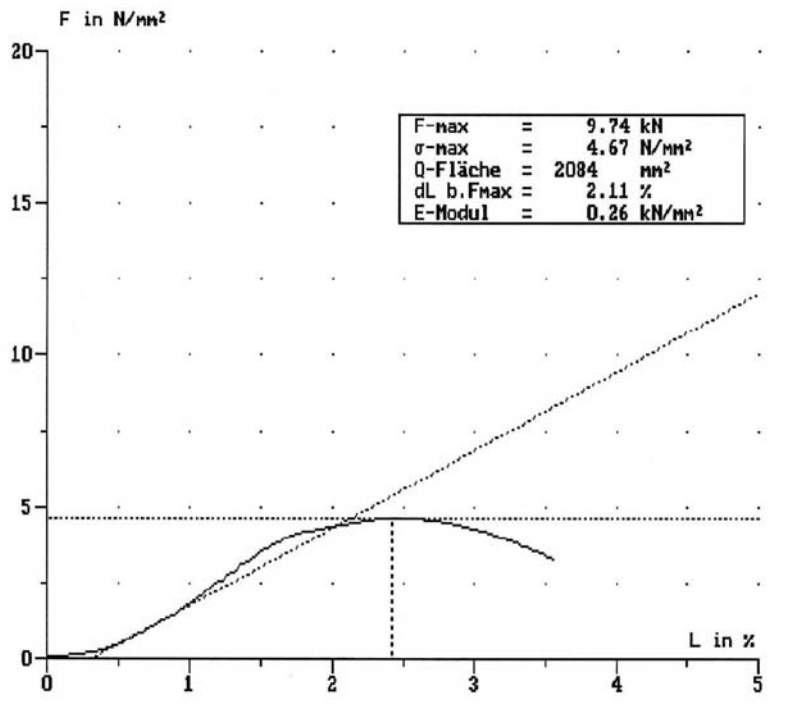
Sample-ID	F-max kN	dL b.Fmax %	Q-surface mm²	σ-max N/ mm²	E-Modulus kN/ mm²
E2_2	10.59	1.88	2075	5.10	0.30



Sample-ID	F-max kN	dL b.Fmax %	Q-surface mm²	σ-max N/ mm²	E-Modulus kN/ mm²
E2_3	10.28	2.08	2084	4.93	0.22

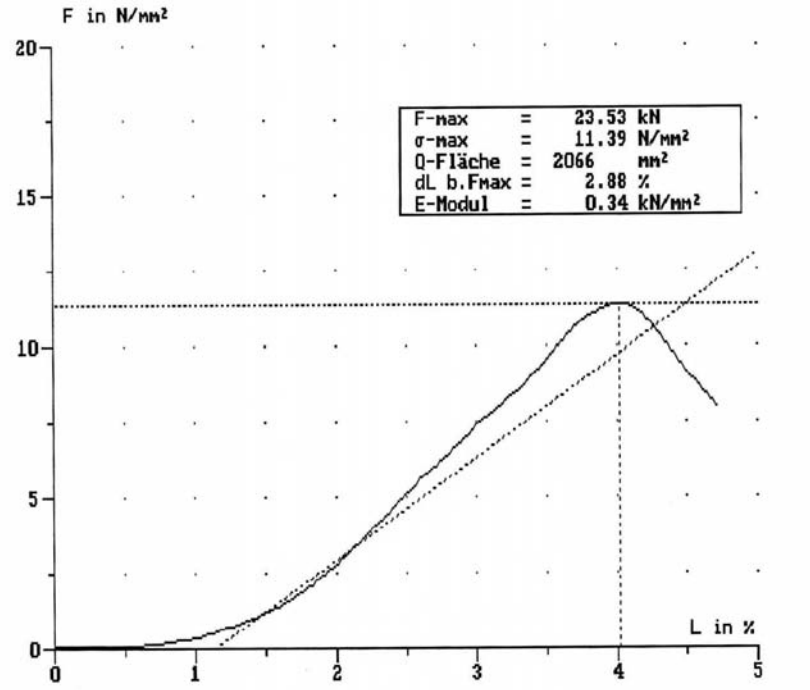


Sample-ID	F-max kN	dL b.Fmax %	Q-surface mm²	σ-max N/ mm²	E-Modulus kN/ mm²
E2_4	9.74	2.11	2084	4.67	0.26

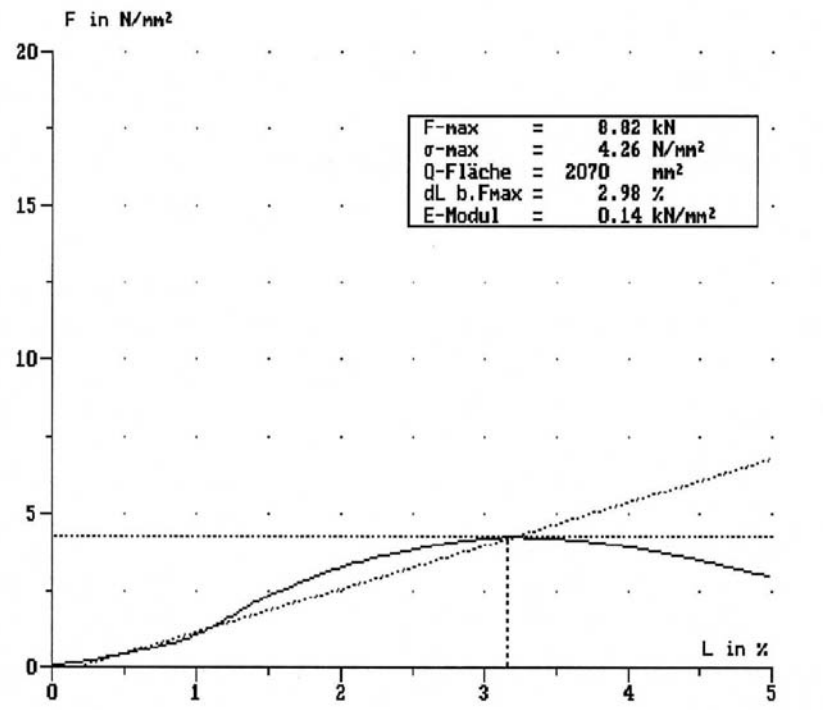


Stone consolidation material 3

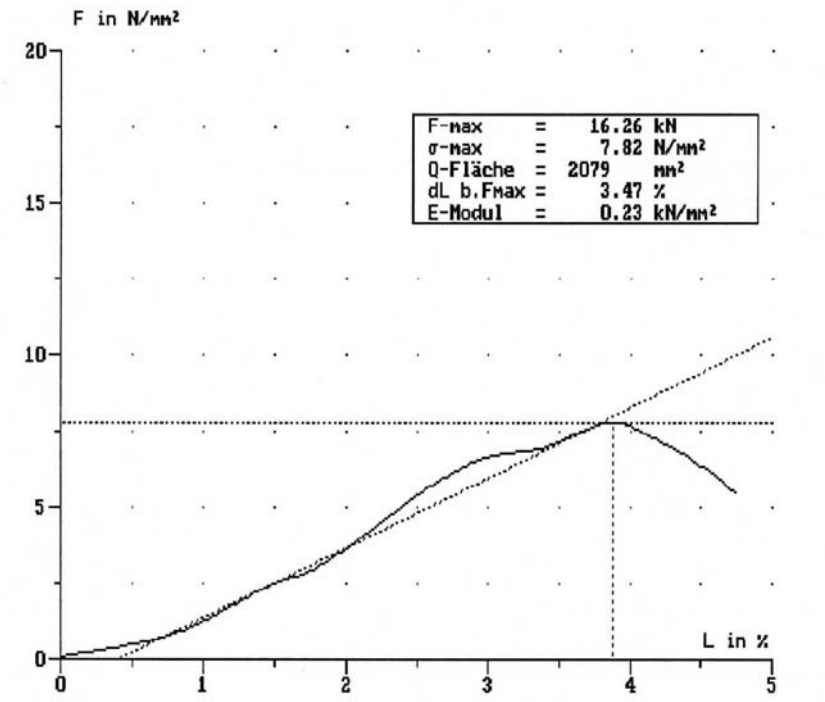
Sample-ID	F-max kN	dL b.Fmax %	Q-surface mm²	σ-max N/ mm²	E-Modulus kN/ mm²
E3_1	23.53	2.88	2066	11.39	0.34



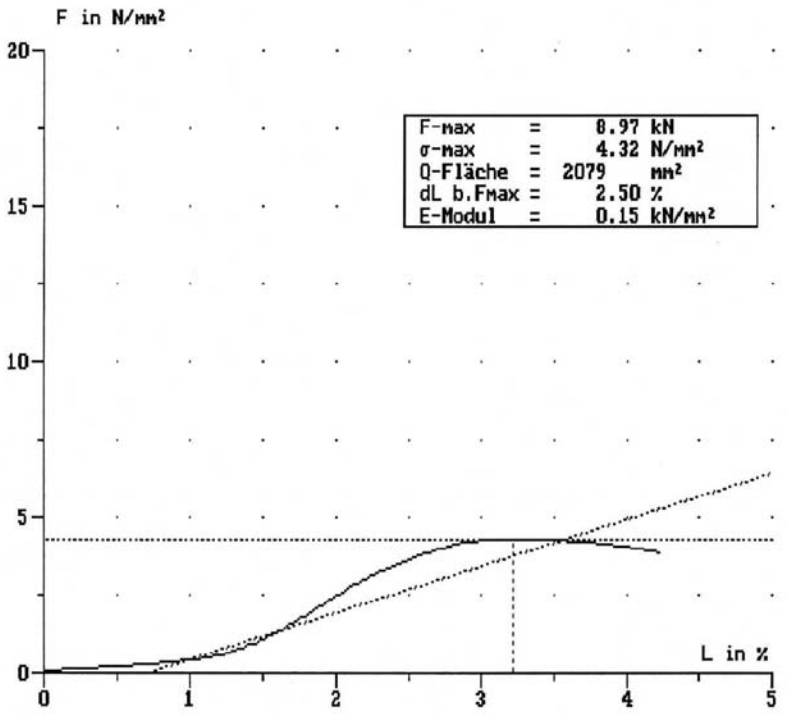
Sample-ID	F-max kN	dL b.Fmax %	Q-surface mm²	σ-max N/ mm²	E-Modulus kN/ mm²
E3_2	8.82	2.98	2070	4.26	0.14



Sample-ID	F-max kN	dL b.Fmax %	Q-surface mm²	σ-max N/ mm²	E-Modulus kN/ mm²
E3_3	16.26	3.47	2079	7.82	0.23

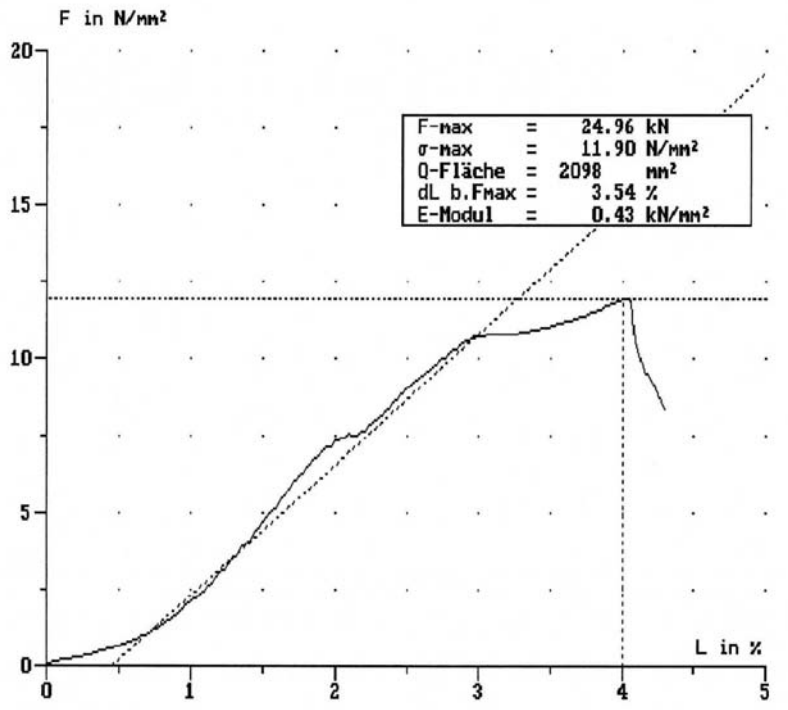


Sample-ID	F-max kN	dL b.Fmax %	Q-surface mm²	σ-max N/ mm²	E-Modulus kN/ mm²
E3_4	8.97	2.50	2079	4.32	0.15

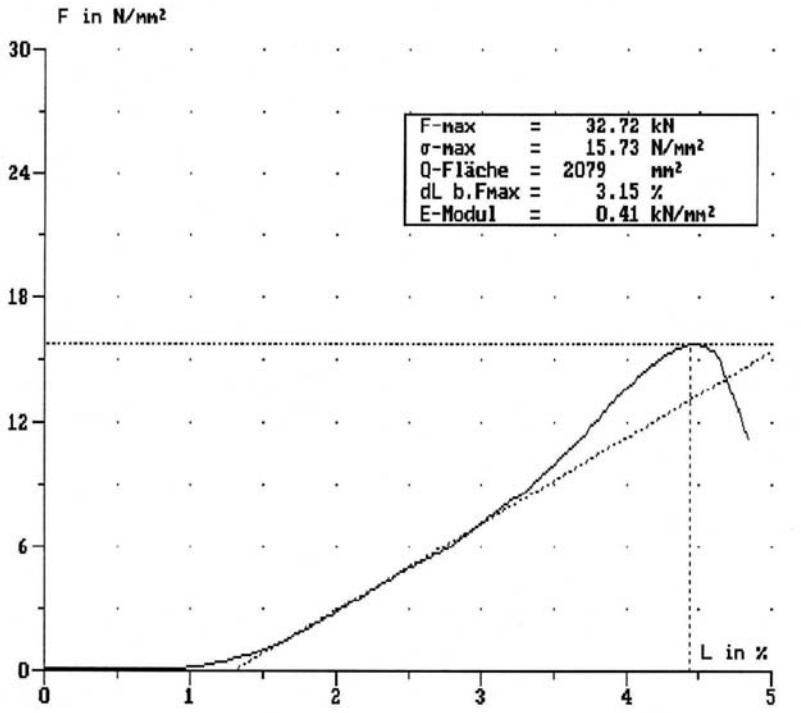


Stone consolidation material 4

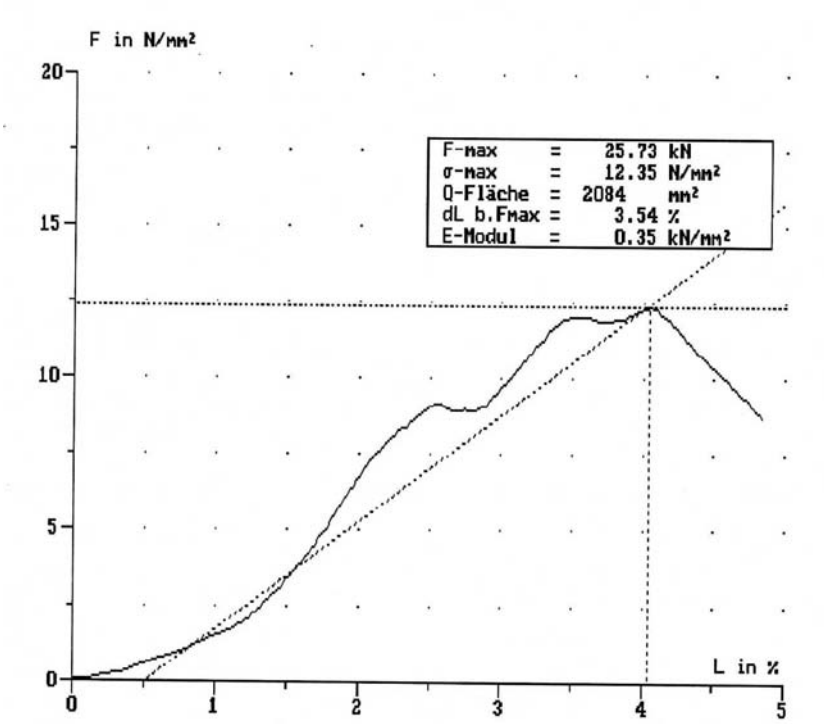
Sample-ID	F-max kN	dL b.Fmax %	Q-surface mm²	σ-max N/ mm²	E-Modulus kN/ mm²
E4_1	24.96	3.54	2098	11.90	0.43



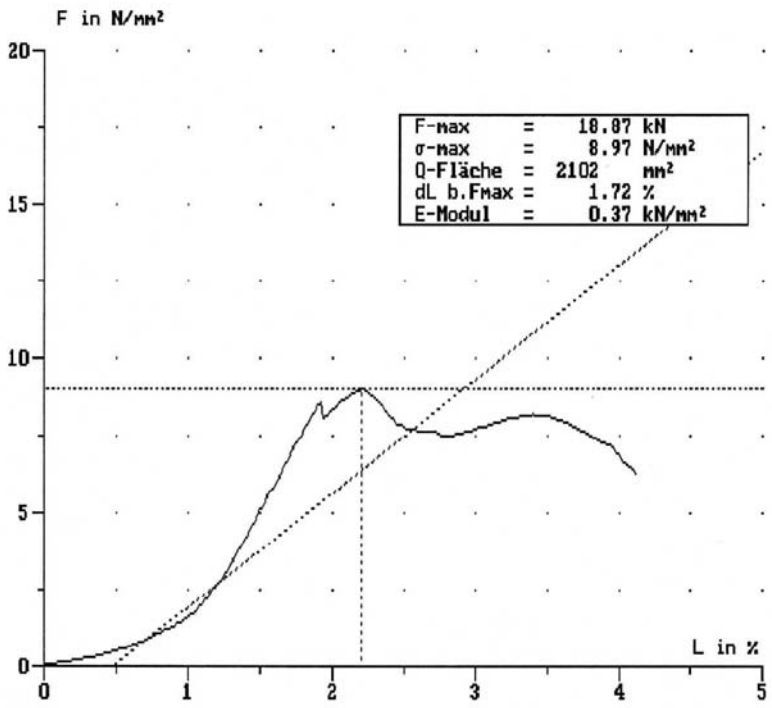
Sample-ID	F-max kN	dL b.Fmax %	Q-surface mm²	σ-max N/ mm²	E-Modulus kN/ mm²
E4_2	32.72	3.15	2079	15.73	0.41



Sample-ID	F-max kN	dL b.Fmax %	Q-surface mm²	σ-max N/ mm²	E-Modulus kN/ mm²
E4_3	25.73	3.54	2084	12.35	0.35

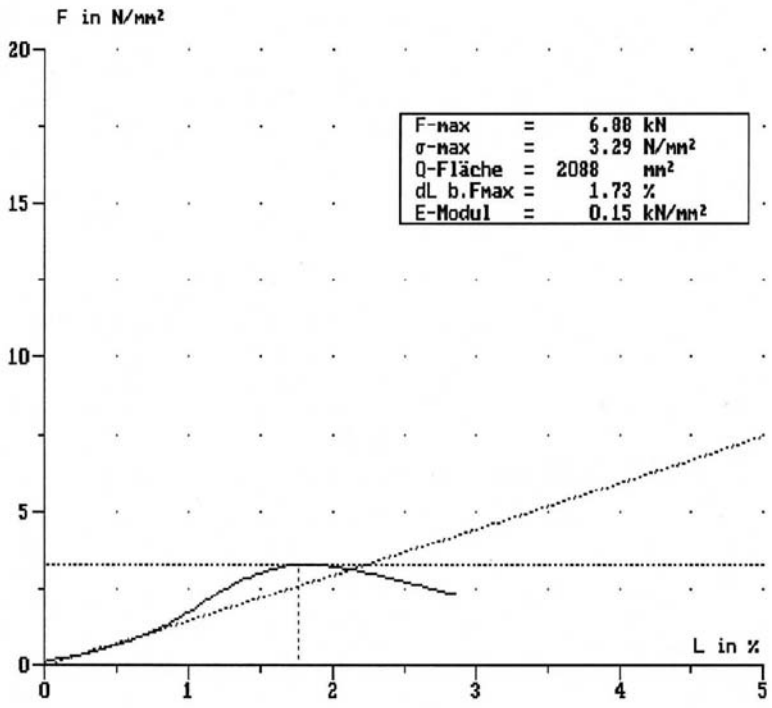


Sample-ID	F-max kN	dL b.Fmax %	Q-surface mm²	σ-max N/ mm²	E-Modulus kN/ mm²
E4_4	18.87	1.72	2102	8.97	0.37

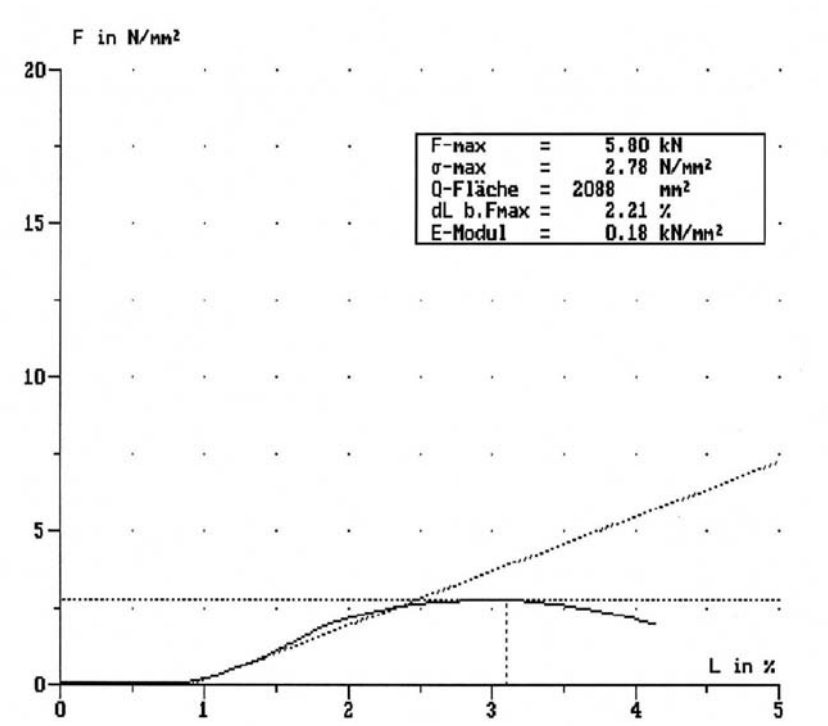


Stone consolidation material 5

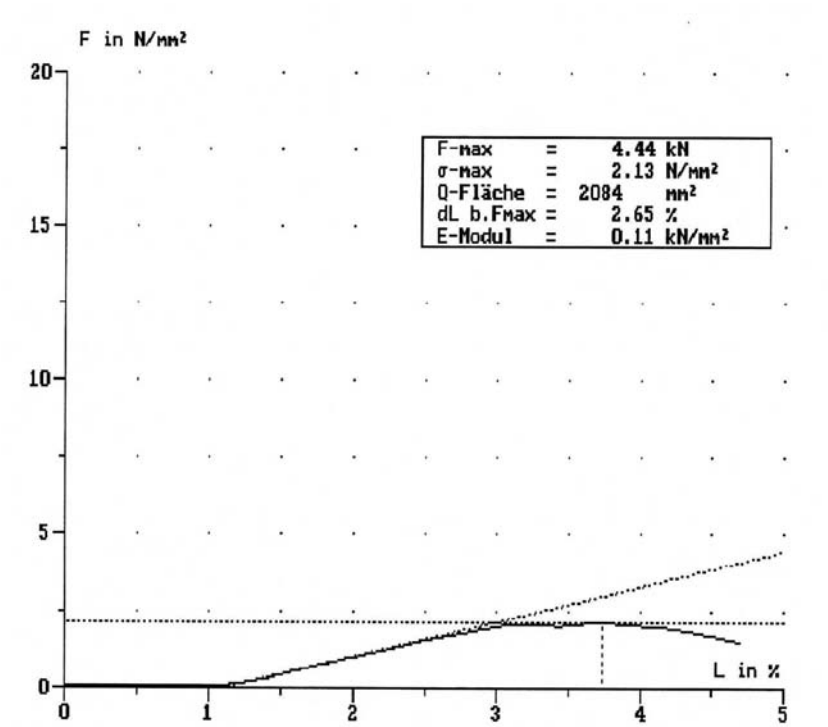
Sample-ID	F-max kN	dL b.Fmax %	Q-surface mm²	σ-max N/ mm²	E-Modulus kN/ mm²
E5_1	6.88	1.73	2088	3.29	0.15



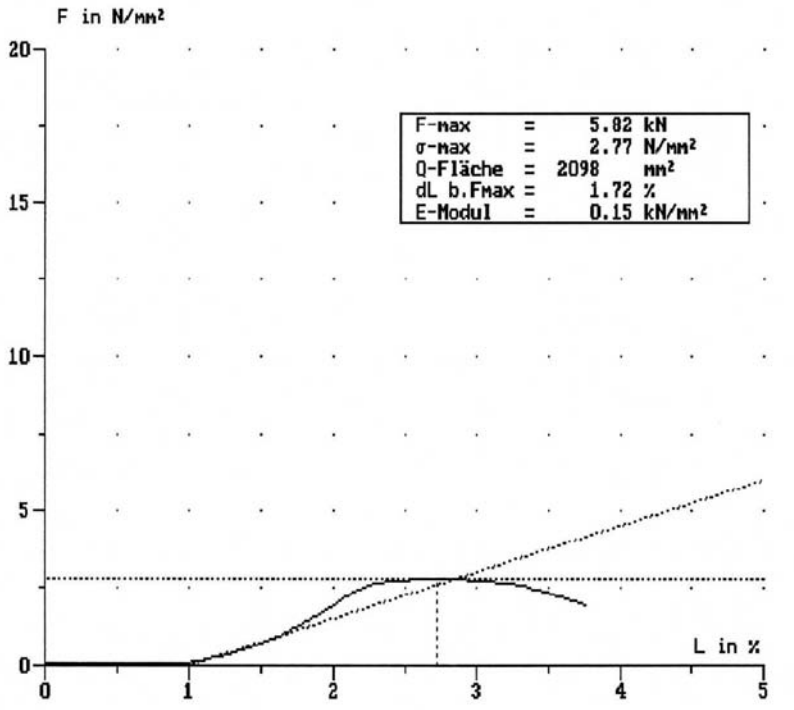
Sample-ID	F-max kN	dL b.Fmax %	Q-surface mm²	σ-max N/ mm²	E-Modulus kN/ mm²
E5_2	5.80	2.21	2088	2.78	0.18



Sample-ID	F-max kN	dL b.Fmax %	Q-surface mm²	σ-max N/ mm²	E-Modulus kN/ mm²
E5_3	4.44	2.65	2084	2.13	0.11



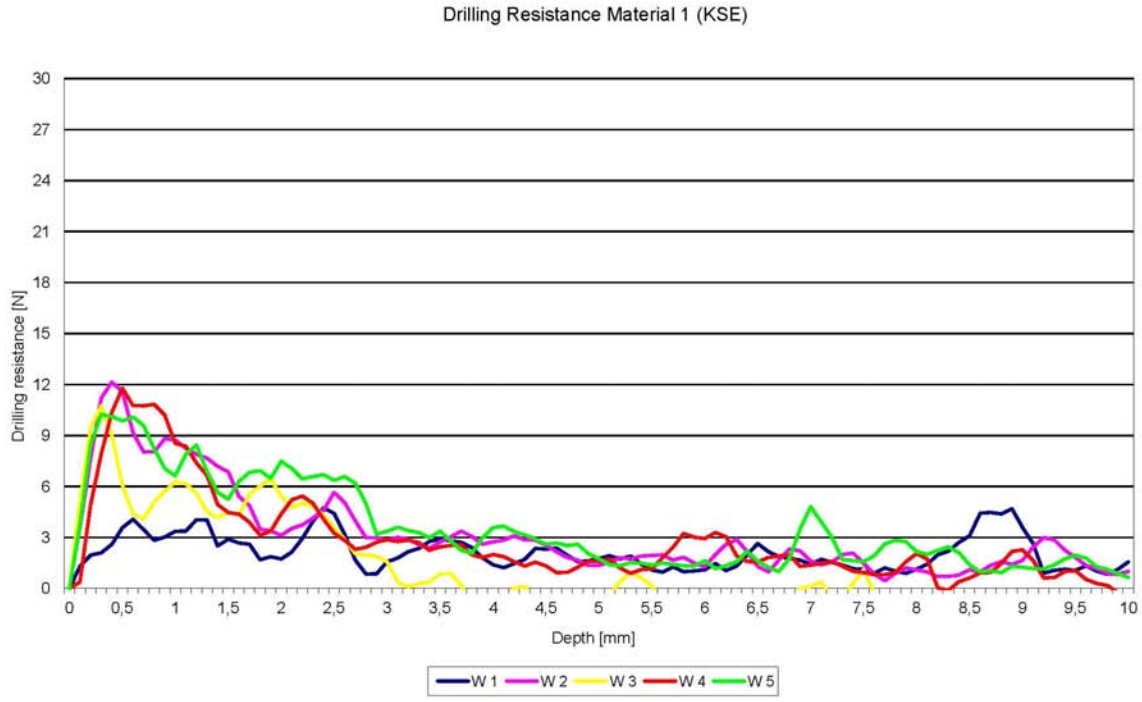
Sample-ID	F-max kN	dL b.Fmax %	Q-surface mm²	σ-max N/ mm²	E-Modulus kN/ mm²
E5_4	5.82	1.72	2098	2.77	0.15

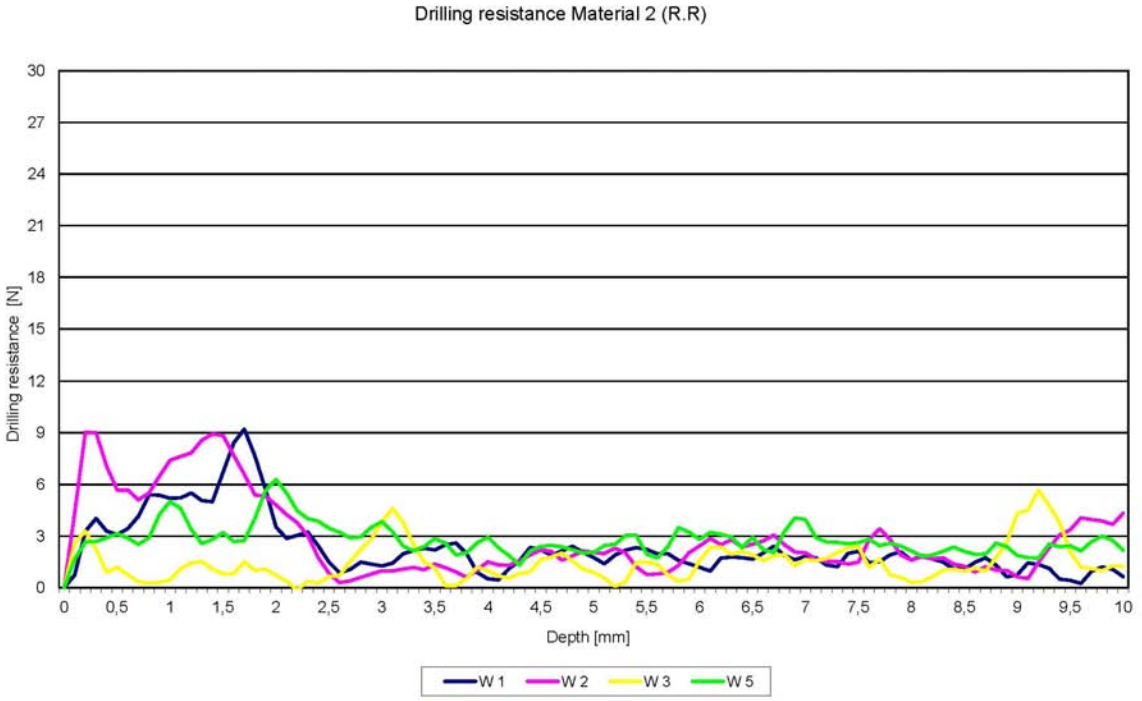


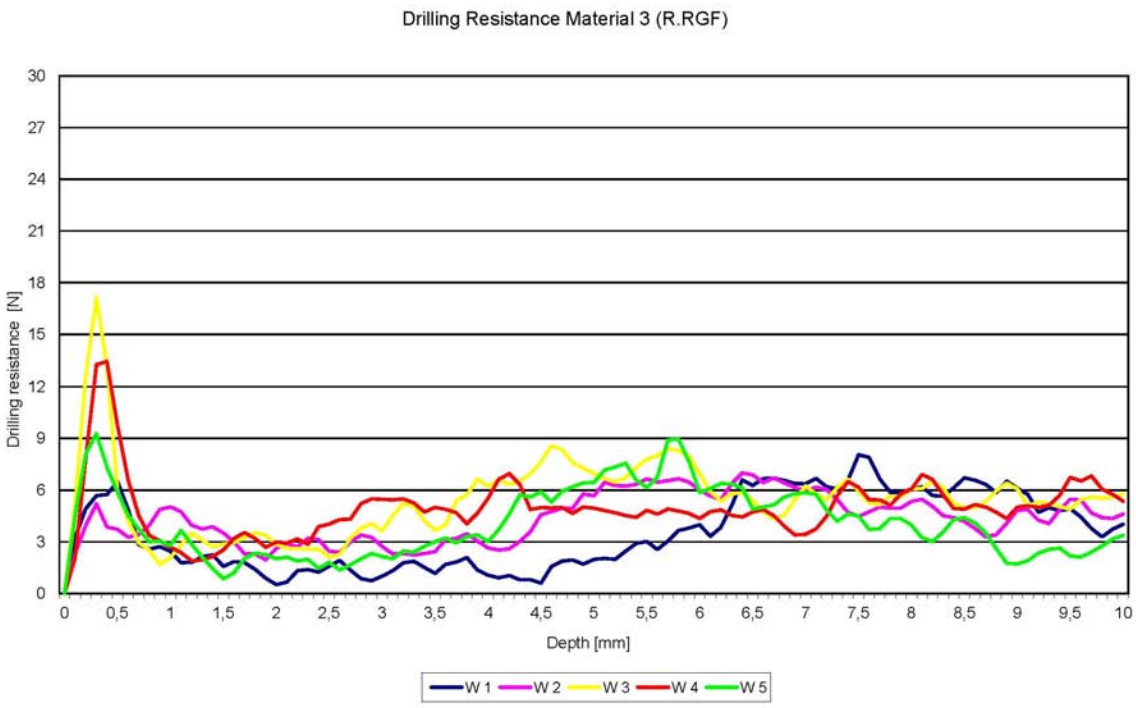
Drilling resistance

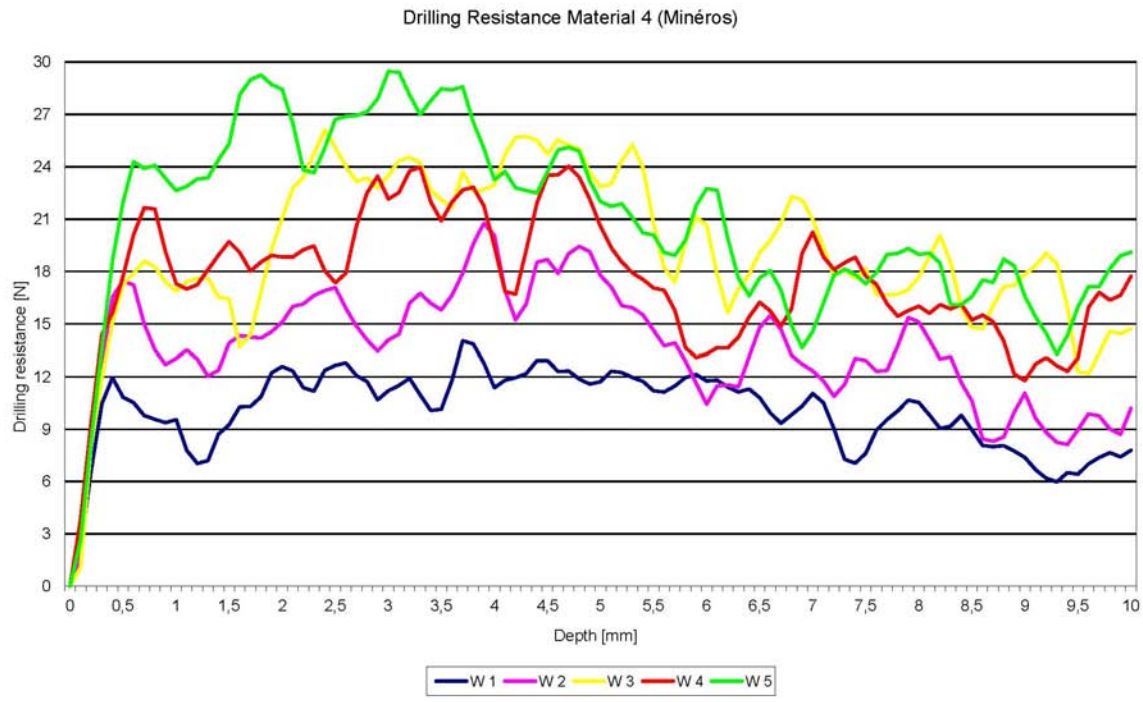
Abrasion table

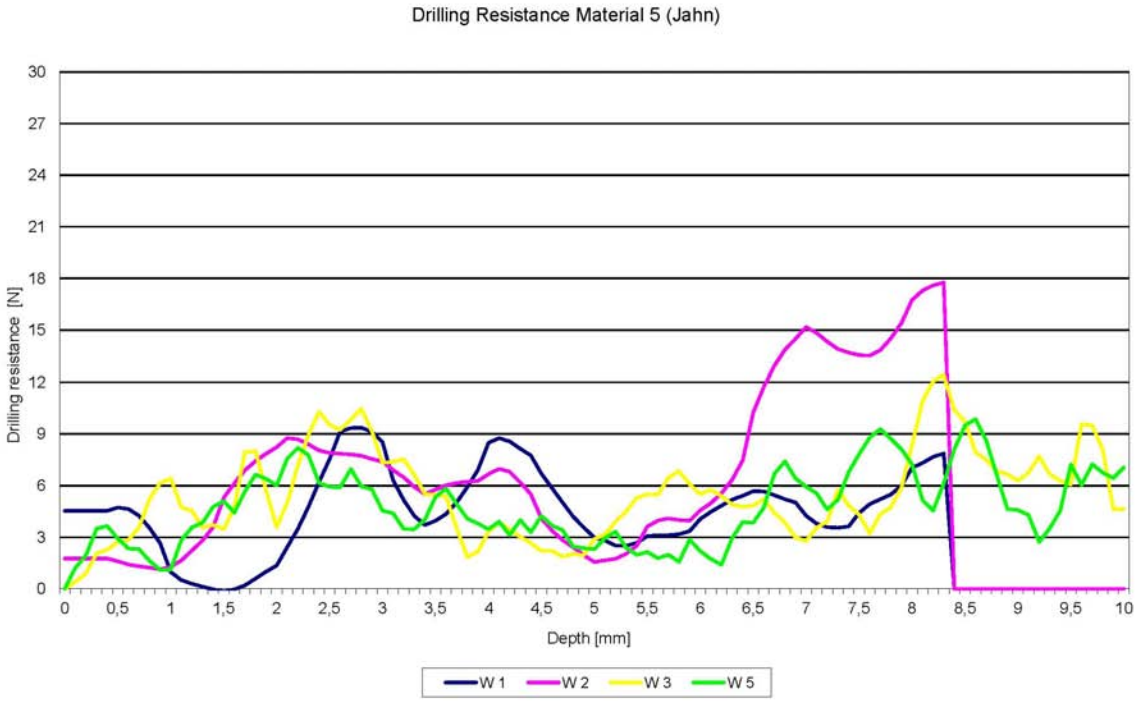
Measurement	Material	Drilling resistance [N]	Abrasion rate	Corrected value [N]
1	**ARS 2**	**6.24**	**0**	**-**
2	KSE 1	2.12	0.02	2.10
3	KSE 2	2.95	0.04	2.91
4	KSE 3	3.87	0.06	3.81
5	KSE 4	2.63	0.08	2.55
6	KSE 5	3.37	0.11	3.26
7	**ARS 3**	**6.35**	**0.11**	**-**
8	R.R 1	2.28	0.13	2.15
9	R.R 2	2.71	0.15	2.56
10	R.R 3	1.59	0.18	1.41
11	R.R 4	4.81	0.20	4.61
12	R.R 5	2.81	0.23	2.58
13	**ARS 4**	**6.47**	**0.23**	**-**
14	R.RGF 1	3.50	0.32	3.18
15	R.RGF 2	4.41	0.41	4.00
16	R.RGF 3	5.29	0.51	4.78
17	R.RGF 4	4.79	0.61	4.18
18	R.RGF 5	3.97	0.70	3.27
19	**ARS 5**	**6.94**	**0.70**	**-**
20	M 1	10.24	0.95	9.29
21	M 2	13.86	1.21	12.65
22	M 3	19.73	1.47	18.26
23	M 4	17.82	1.72	16.10
24	M 5	21.47	1.98	19.49
25	**ARS 6**	**8.22**	**1.98**	**-**
26	J 1	5.43	2.06	3.37
27	J 2	7.22	2.14	5.08
28	J 3	5.68	2.23	3.45
29	J 4	8.43	2.31	6.12
30	J 5	4.83	2.39	2.44
31	**ARS 7**	**8.63**	**2.39**	**-**


Drilling Resistance Material 1 (KSE)
Drilling resistance [N]
30
27
24
21
18
15
12
9
6
3
0
0 0,5 1 1,5 2 2,5 3 3,5 4 4,5 5 5,5 6 6,5 7 7,5 8 8,5 9 9,5 10
Depth [mm]
W 1 W 2 W 3 W 4 W 5


Drilling resistance Material 2 (R.R)
Drilling resistance [N]
30
27
24
21
18
15
12
9
6
3
0
0 0,5 1 1,5 2 2,5 3 3,5 4 4,5 5 5,5 6 6,5 7 7,5 8 8,5 9 9,5 10
Depth [mm]
W 1 W 2 W 3 W 5


Drilling Resistance Material 3 (R.RGF)
Drilling resistance [N]
Depth [mm]
W 1
W 2
W 3
W 4
W 5


Drilling Resistance Material 4 (Minéros)
Drilling resistance [N]
Depth [mm]
W 1
W 2
W 3
W 4
W 5


Drilling Resistance Material 5 (Jahn)
Drilling resistance [N]
30
27
24
21
18
15
12
9
6
3
0
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
5
5,5
6
6,5
7
7,5
8
8,5
9
9,5
10
Depth [mm]
W 1
W 2
W 3
W 5