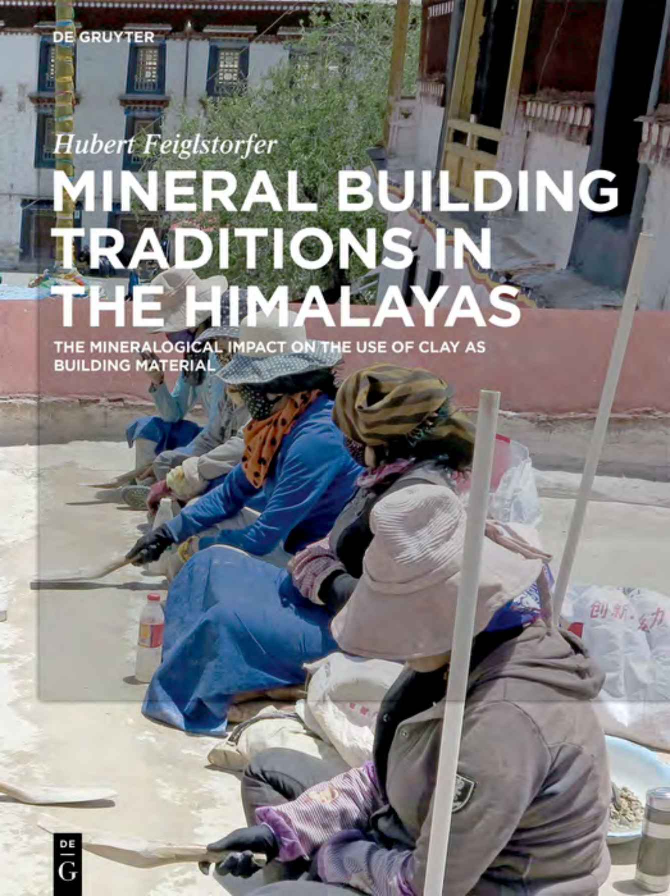


DE GRUYTER

*Hubert Feiglstorfer*

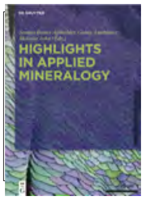
# MINERAL BUILDING TRADITIONS IN THE HIMALAYAS

## THE MINERALOGICAL IMPACT ON THE USE OF CLAY AS BUILDING MATERIAL

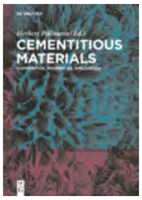
Hubert Feiglstorfer

# **Mineral Building Traditions in the Himalayas**

## Also of interest

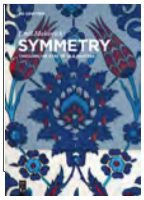


*Highlights in Applied Mineralogy*
Heuss-Aßbichler, Amthauer, John (Eds.), 2018
ISBN 978-3-11-049122-7, e-ISBN 978-3-11-049734-2



*Cementitious Materials*
*Composition, Properties, Application*
Pöllmann (Ed.), 2018
ISBN 978-3-11-054720-7, e-ISBN 978-3-11-054722-1

*Multi-Component Crystals.*
*Synthesis, Concepts, Function*
Tiekink, Zukerman-Schpector (Eds.), 2017
ISBN 978-3-11-046365-1, e-ISBN 978-3-11-046495-5



*Symmetry.*
*Through the Eyes of Old Masters*
Emil Makovicky, 2016
ISBN 978-3-11-041705-0, e-ISBN 978-3-11-041714-2

Hubert Feiglstorfer

# Mineral Building Traditions in the Himalayas

## The Mineralogical Impact on the Use of Clay as Building Material

DE GRUYTER

**Author**
Doz. DI DDr. Hubert Feiglstorfer
Austrian Academy of Sciences
Institute of Social Anthropology
Hollandstraße 11-13
1020 Vienna
Austria
hubert.feiglstorfer@oeaw.ac.at

ISBN 978-3-11-058996-2
e-ISBN (PDF) 978-3-11-059133-0
e-ISBN (EPUB) 978-3-11-059011-1

**Library of Congress Control Number: 201994070**

**Bibliographic information published by the Deutsche Nationalbibliothek**
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at http://dnb.dnb.de.

Cover image: Hubert Feiglstorfer; Lhasa, repair of an *arga* roof
Printing and binding: CPI books GmbH, Leck

www.degruyter.com

# ACKNOWLEDGEMENTS

The author is very grateful to a long list of institutions and individuals who have supported his work at different stages and who have believed in its success. The author sincerely hopes there is no one he forgot to mention. His thanks go to the following:

For financial support, many thanks go to the Austrian Science Fund (FWF), the Austrian Academy of Sciences (ÖAW), the Austrian Research Promotion Agency (FFG) and the Österreichische Forschungsgemeinschaft (ÖFG). Related FWF projects include "Society, Power and Religion in Pre-Modern Western Tibet" (P 21806) and "The Burial Mounds of Central Tibet", Part I (P 25066) and Part II (P 30393). A related project financed by the Innovation Fund "Research, Science and Society" at the ÖAW is the project "Materiality and Material Culture in Tibet". A project which was connected to the present research for this publication and which was financed by the FFG was titled "Tonmineralanlyse".

For institutional support, the author is thankful to the Institute for Applied Geology (IAG) at the Vienna University of Natural Resources and Life Sciences (BOKU), the Institute for Social Anthropology (ISA) at the Austrian Academy of Sciences (ÖAW), the Institute of History of Art, Building Archaeology and Restoration at the Vienna University of Technology (TUW), the Geologische Bundesanstalt (GBA) in Vienna and the Archaeological Survey of India (ASI).

Thanks go to

Prof. Franz Ottner (IAG / BOKU) for mineral analysis supervision and review of this contribution; Dr. Karin Wriesnig (IAG / BOKU) for mineral analysis support; Helene Pfalz-Schwingenschlögl (IAG / BOKU) for taking pictures of the clay samples; Prof. Monika Kriechbaum (DIB / BOKU) and Prof. Marianne Kohler-Schneider (Botany / BOKU) for scientific support in Tibetan botany and archaeo-botany; Prof. Gerhard Sinn (IPM / BOKU) and DI. Martin Meischel (IPM / BOKU) for their support at the REM and the hardness tests according to Vickers; Dr. Doris Österreicher (IKI / BOKU) for review of this contribution; Tsering Gyalpo, former director of the Religious Department of the Tibetan Academy of Social Sciences (TASS) in Lhasa, who passed away in 2015, for scientific support; Dr. Christian Jahoda (ISA / ÖAW) and Dr. Guntram Hazod (ISA / ÖAW) for scientific support on West and Central Tibetan history, respectively; Prof. Erich Lehner (TUW) for scientific support; Mag. Mathias Fermer (IKGA / ÖAW) and Tsering Drongshar (IKGA / ÖAW) for proof reading of Tibetan terms; Dr. Christiane Kalantari (ISA / ÖAW) for scientific support on Tibetan art; BA. Jakob Gredler (BOKU), Dr. Martin Mergili (IAG / BOKU) and BA. Jürgen Schörflinger (ISA / ÖAW) for their support with GIS maps, Mag. Thomas Hofmann (GBA) for his support with geological maps and DI. Ferenc Zamolyi (TUW) for his support with CAD and rendering.

https://doi.org/10.1515/9783110591330-001

For local information, besides many others (see Interviewees in Chapter IX), thanks belong to Jampa Kelsang (*zhépön* living in Lhasa), Penba Tashi (living in Lhasa), Nyema Tashi (living in Lhasa), Tashi (potter from Barab in Tibet), Donchog Tsering (clay sculptor from Lhasa), Wangchuk (ASI Jammu and Kashmir Chapter in Leh), Muhammad Saleem Beeg (INTACH Kashmir Chapter), Dechen Lundup (from Tabo in India), Dorje Tsering (from Keylong in India), David Holler (living in Lhasa), Sonam Wangchuk and Rebecca Norman (living in Ladakh), Tsewang Norbu (black smith and stove maker from Ne in Ladakh), Rigzen Wangyal (potter from Likir in Ladakh) and last but not least Tsering Norbu (from Likir in Ladakh).

For organisational support, the author is thankful to the team of the interlibrary loan at the TUW. For proof reading, thanks go to M.A. Jessica Sloan-Leitner.

The author is thankful to the Austrian Academy of Sciences (ÖAW) for taking over the costs of the Open Access publication and of the revision of the manuscript by the author, both within the project “Materiality and Material Culture in Tibet” funded by the Innovation Fund “Research, Science and Society”.

# CONTENTS

# GENERAL REMARKS

## Abbreviations

| | |
|---|---|
| app. | approximate |
| c. | circa (used for years) |
| sim. | similar to |
| Ø | average |

Institutions:

| | |
|---|---|
| ASI | Archaeological Survey of India |
| BOKU | University of Natural Resources and Life Sciences in Vienna |
| Botany / BOKU | Institute for Botany / see BOKU |
| CIBS | Central Institute of Buddhist Studies in Choglamsar / Ladakh |
| FWF | Austrian Science Fund |
| GERES | Groupe Energies Renouvelables, Environnement et Solidarités |
| IAG / BOKU | Institute of Applied Geology / see BOKU |
| IKGA / ÖAW | Institute for Cultural and Intellectual History of Asia / see ÖAW |
| IKI / BOKU | Institute of Structural Engineering / see BOKU |
| DIB / BOKU | Department of Integrative Biology and Biodiversity Research, Institute for Integrative Nature Conservation Research / see BOKU |
| INTACH | Indian National Trust For Art and Cultural Heritage / ICOMOS |
| ISCEAH | International Scientific Committee on Earthen Architectural Heritage |
| IPM / BOKU | Institute of Physics and Materials Science / see BOKU |
| ISA / ÖAW | Institue for Social Anthropology / see ÖAW |
| LEDeG | Ladakh Ecological Development Group in Leh |
| NIRLAC | Namgyal Institute for Research on Ladakhi Art and Culture |
| ÖAW | Austrian Academy of Sciences |
| ÖFG | Österreichische Forschungsgemeinschaft |
| SECMOL | Students' Educational and Cultural Movement of Ladakh |
| TARA | Technology and Action for Rural Advancement in Delhi |
| TASS | Tibetan Academy of Social Sciences in Lhasa |
| TUW | Vienna University of Technology |

Abbreviations used for materials and constructions:

| | |
|---|---|
| AB | Adobe brick |
| EP | Exterior plaster |
| IP | Interior plaster |
| RM | Raw material |

https://doi.org/10.1515/9783110591330-002

Abbreviations used in the context of analysis:

| | |
|---|---|
| BMA | Bulk mineral analysis |
| BMD | Bulk mineral distribution |
| CMA | Clay mineral analysis |
| GSC | Grain size classes |
| GSD | Grain size distribution |
| IRS | Infrared spectroscopy |
| ML | Mixed layer |
| REM | Scanning electron microscope |
| STA | Simultaneous thermal analysis |

Abbreviations used in GSC/GSD-tables and -graphics, order by size in µm:

| | | |
|---|---|---|
| FG | Fine gravel | 2,000–6,300 |
| GS | Coarse sand | 630–2,000 |
| MS | Medium sand | 200–630 |
| FS | Fine sand | 63–200 |
| GU | Coarse silt | 20–63 |
| MU | Medium silt | 6.3–20 |
| FU | Fine silt | 2–6.3 |
| GT | Coarse clay | 0.63–2 |
| MT | Medium clay | 0.2–0.63 |
| FT | Fine clay | <0.2 |

Abbreviations used in BMA-tables, in alphabetical order:

| | |
|---|---|
| Amph | Amphiboles |
| Calc | Calcite |
| Dol | Dolomite |
| Goeth | Goethite |
| Gyps | Gypsum |
| Haem | Haematite |
| K-fsp | K-feldspar |
| Phy | Phyllo silicate |
| Quar | Quartz |
| Plagio | Plagioclase |
| Pyr | Pyrite |
| 7Å | 7Å mineral |

Abbreviations for languages:

| | |
|---|---|
| Ger. | German language |
| Lad. | Ladakhi language |
| Tib. | Tibetan language |

## FIELD RESEARCH AND RELATED PROJECTS

Field research in the Indian Himalayas was conducted in the time from May 2002 till January 2003. Financial support was given by a scholarship from the University of Technology in Graz in 2002. Field research in Iran was conducted in 2003. From June 2005 till December 2006 field research was conducted in the Indian Himalayas, also in Pakistan and Nepal. In March and April 2010 field research to Central and West Tibet, Xinjiang, Qinghai and Gansu was undertaken as part of an Austrian Science Fund (FWF) project P21806-G19 "Society, Power and Religion in Pre-Modern Western Tibet: Interaction, Conflict and Integration". In July and August 2011 field research to Kashmir and Ladakh was conducted as part of the same project P21806-G19 and sponsored by the Österreichische Forschungsgesellschaft (ÖFG). In June 2014 and also in November and December 2015 field research enabled studies in Central Tibet, both expeditions being part of the Austrian Science Fund (FWF) project P 25066 "The Burial Mounds of Central Tibet". During the mentioned field research the samples treated within this contribution were collected. From September 2014 till February 2015 the project "Clay mineral analysis" under the leadership of the author was granted by the Institute of Social Anthropology at the Austrian Academy of Sciences in Vienna (ÖAW) and The Austrian Research Promotion Agency (FFG) in cooperation with the Institute of Applied Geology at the University of Natural Resources and Life Sciences in Vienna (IAG / BOKU).

This publication is based on the author's second PhD thesis, submitted and approved in 2017 at the Institute of Applied Geology at the University of Natural Resources and Life Sciences in Vienna.

## CONVENTIONS

Common local terms are presented in phonetic transcription. Their transliteration is given in brackets when first noted. Tibetan terms have been transliterated according to the system of Turrel W. Wylie (1959).

Source references in the text are placed directly following the concerned text passage before the following punctuation character. In the case the source refers to more than one successive sentences, the source reference is given after the punctuation character of the last concerned sentence.

# I. INTRODUCTION

The use of mineral based building material in the Himalayas has a long tradition, probably reaching back to the first settlements. Use of such material was, and partially still is, deeply anchored as an essential material cultural fingerprint and certainly a manifestation of cultural identity. Mineral building tradition influenced the evolution of certain structural features which were inseparably intermingled with daily life and the structuring of the annual rural working cycle.

Different techniques were applied and adjusted to local conditions and needs. Rammed earth structures, adobe bricks, flat roofs, clay plaster, wattle and daub constructions, Tibetan stoves, clay sculptures and pottery are made with locally available resources on a mineral basis. The use of fired bricks in the Himalayas is reserved for the Himalayan border zones while in the Tibetan cultural zone we find fired bricks at only a few historical structures, for example, the Jokhang in Lhasa. Contrary to bricks, kilns for pottery have a long tradition in the Tibetan cultural zone. Within the last years in Ladakh the first known kiln was erected.

The use of clay and the choice of the appropriate building technique are highly dependent on the locally available natural resources such as the type of clay, vegetation and climatic conditions, all of which may change from region to region. The beginning of earth building tradition remains open. We can much better argue for the existence of particular traditions in a historical context of prestigious – primarily religious – structures.

In the Western Himalayas the earliest Buddhist structures using clay as part of the primary structure can be dated back at least to the 10th century, and in the Central Himalayas to the 7th century CE. This dating has to be understood as an imprecise benchmark since we assume that already in earlier days clay was used at least for the preparation of mortar, plaster or flat roof constructions. As an example we can mention the 9th/10th century temple in Ribba, which is primarily a wooden structure (cf. Feiglstorfer, forthcoming a), with clay used for the interior plaster, the rammed earth floor and the flat roof. In this concern, knowledge about the foundation date of particular structures is certainly helpful in addressing the existence of a certain tradition in a particular period. Beyond this it is the question for a specific material culture itself. The availability of classifiable historical data depends on the availability of written sources or empirical examinations. Due to historical data, religious structures can be dated, i.e. by wall inscriptions or other written records, while historical data of vernacular structures usually rely on oral information which may be imprecise or distorted by misinterpretations of the informer or by missing data.

Traditions may have changed by adapting changing conditions and needs. Those we find today may not have existed in the same form at an earlier period at the same place. As mentioned by Nyema Tashi, in Lhasa until roughly 600 years ago adobe and rammed earth structures were prevalent. This changed in the following periods when stone constructions were preferred, for example, during the 5th Dalai Lama in the 17th century (Interview Nyema Tashi 2014).

https://doi.org/10.1515/9783110591330-003

Clay as a building material as such occurs with different compositions and properties related to use within a particular construction. Regarding the use of a specific clay material we are confronted with various influencing aspects which are briefly mentioned in the following. Building traditions based on the harmonisation of material resources and constructive needs are the main focus of this observation.

Availability of a particular material: The local availability of a particular material is defined by nature and the knowledge of the inhabitants regarding the location of quarries. Impact on the present research: The investigation of the respective raw material plays an important role in this matter. The author collected samples of clay, and their use as building material is documented, dependent on oral information from local people. The collected samples are the carriers of material information over which certain traditional characteristics can empirically be examined and understood.

Transport: Mineral building materials have to be transported from the quarry to the place of processing, which is mainly the building site itself. The higher the effort in quarrying and transportation, the higher the costs. The easiest way is to quarry material at the building site or in close vicinity. To achieve a higher quality for prestigious structures, material may have to be transported over longer distances. This need is mainly related to the architectural surface but, as we will see in Chapter III on *arga* roofs, also affects parts of the primary structure. This matter marks a major influence on the choice of a particular mineral building material and is still a driving force for progress and related changes within traditional patterns. The use of a particularly fine plaster as a substructure for wall paintings or the utilisation of *arga* stone material to produce a roof of a higher strength are both examples to be found in buildings of a higher social status. Impact on the present research: The traceability of the origin of certain types of clay can be given by local designation, knowledge of particular properties of the used building materials, and knowledge of particular ways in processing materials. Within all these matters the modes and routes of transportation play a crucial role in the dissemination of knowledge on the use of particular qualities of building material.

Local knowledge: The use of a traditional building material can be understood as a product of a continuous collective cognitive process, not as a definitively defined formula. Its use and related material traditions are the positive result of a continuous process of practical learning, always conforming to the given local conditions. Embedding of a particular material culture within a network of local traditions is in a wider scale a synergetic interaction within a wide network of information and a related dissemination of traditions.

Local knowledge may seem definable by data, primarily collected during field research. At this point a clear limitation to this often given misinterpretation has to be stated: As the researcher is not part of a particular local system as the holder of traditions, only fragments can be ascertained within a smaller or bigger context but always remaining a part of the whole. After documentation we often can not exclude that the researcher may not have detected several important research relevant facts, or even that the informants did not mention these facts. This possible lack should be kept in mind within this contribution so as to be aware of giving a wrong impression of possibly more complex facts.

Local traditions are not the only way to work with particular materials. This can be seen in the different use of clay in different areas, like using a different amount of layers in the roof construction or adding different kinds of organic materials in a different amount. These traditions grew with access to particular natural resources, which predefine the quality of the clay, or the availability of certain types of organic material.

In this context, building with clay is not to be captured with recipes as we know from building with concrete, for example, but it is to be integrated in a wide range of possibilities of mixtures. Besides certain features, as described before, which are certainly related to a specific region, it is also the sticking to use of certain methods as part of a particular tradition that has grown over the years at a particular site. Regarding the possibility of changing qualities – comparing stone, wood and clay – primarily the mineral components enable this kind of a subsequent refinement of the entire building material.

This matter is related to a network of different scientific disciplines. Research on mineral traditions is embedded in a wide net of transdisciplinary synergies. The focus of the present study is on material culture with specialisation on clay as a building material, though this may not cover the wide field of data necessary to determine a comprehensive picture of knowledge transfer. This material focus limits the question for a possible knowledge transfer to particular mineral building materials. Research on the knowledge transfer becomes an essential field in a further investigation on a bigger scale regarding a material-cultural context over distances of hundreds of kilometres.

‘Modern’ understanding versus tradition: The correlation of structures and constructions is related to architectural questions, and in a further aspect deeply connected with qualities of building materials. Knowledge of such qualities is often understood as something that ‘works without discussion’, i.e. an approach to which we are used to in ‘modern’ architecture resulting from the qualities of building products being linked to a particular market and by that to a particular quality-regulating predefinition. In a rather Western sense simply said, “Today we rely on what we can buy” which is not the same with traditionally used natural products since their qualities depend on environmental traditions and individual use. No pre-regulation defines the quality of particular building material. It was the process of tradition with its selection of proper and unsuitable material by trial and error, oral transmission or custom. As part of an ongoing knowledge transfer, the particular raw materials with their respective characteristics found their suitable architectural installation area. Traditional knowledge was not built on science but on experience – a potentially lengthy process lasting generations. Today in most areas, even those that are remote, a break with tradition is taking place and ‘modern’ architectural influences are gaining the upper hand. In many Himalayan villages the preservation of knowledge depends only on a few, mostly elderly people. It is uncertain how long this knowledge will be accessible first-hand. The use of particular building materials, the description of their quality, and where to find them was generally not written down. In most areas of the Himalayas such knowledge based on oral transmission, if not documented within the next decades, will be potentially lost forever. One of the main motivations for this study is saving a piece of this material cultural heritage. Impact on the present research: The material analysis of the used building material and the understanding

> of its architectural relation give important meaning to the motivation for deciding to accept a particular material and its use. One of the main challenges of scientific research in this field is seen in proper documentation and understanding of the analysed material. The understanding of processes within material cultural traditions is an inevitable precondition for answers to the wide and important question of “What can we learn from tradition?”. Since we are concerned with several vanishing structures, this documentation is also an important contribution in keeping information on cultural identities as part of a collective memory.

As study cases for the interaction between raw material and their traditional application, three research topics are chosen. A central aim of this study is to generate a methodical approach for particular study cases. Basically we aim to distinguish between three different cases:

1. The investigation of a historical site.
2. A particular traditional construction technique.
3. A particular commonly known type of clay.

## 1. Research topics

### Chapter I: Introduction

This chapter gives insight into the research topics, the research questions and the methods of survey. Research methods are explained and the geological and tectonic setting of this publication is explained.

### Chapter II: Mineral traditions at the Nyarma Monastery in Ladakh

This chapter deals with method to analyse material traditions of in the village of Nyarma which is located in Ladakh in North India. Raw material resources are brought in relation to their application for adobe bricks and clay plasters. Questions for variations of processing for the single building components are raised.

### Chapter III: *Arga* stone roof construction

This chapter is concerned with Himalayan flat roof constructions in general and a particular stone roof construction specifically. Contrary to research Chapter II, this topic is not related to one specific site but to particular flat roof techniques used over the whole Tibetan cultural zone from North India to East Tibet. In this relation various raw material resources and related techniques are examined.

### Chapter IV: *Markalak* clay

This chapter focuses on the quality of a specific type of clay which is widely known over the Western Himalayas. Similar to research in Chapter III it is not related to one specific site but on the contrary it is related to a type of building material and not primarily to a building technique. It questions specific material qualities as carriers of common knowledge patterns and their possible long-distance dissemination.

## 2. RESEARCH QUESTIONS

A central research question focuses on material features to harmonise qualities of mineral raw material, and then to process this material for traditional architectural application. Regarding the wide field of this study, several further research questions focus on the three research topics and are particularly adjusted to them. In Chapters II to IV research questions are posed before starting with the material analysis, and a conclusion is given at the end of each of the Chapters II to IV. In general these research questions contain the following aspects, which will be adjusted in each of these three chapters according to the respective research topic.

- Are there any material qualities to categorise a particular clay?
- Are the particular material qualities related to specific components?
- What are the material qualities that support the use of a particular raw material for building purposes?
- What are the geological parameters of the particular raw material?

## 3. METHODS OF SURVEY

In the context of a field survey, common tools utilised for on-site architectural survey include measuring, taking pictures, and oral documentation by conducting interviews. Building research within a scientific scope is heavily based on field research which relies on the documentation of three dimensional objects. This also includes when objects no longer or only partially exist and have to be reconstructed.

Working with traditional structures often leads to remote locations. In an article on field documentation (Feiglstorfer 2008), the author attempted to touch upon a topic with which he is continuously confronted: How to act in remote areas, partially as a single surveying researcher, and possibly also with restrictions in applying highly technical equipment. Such circumstances make it particularly challenging to establish methods of survey capable of being conducted by a single person (ibid. 96). In the amount and size of portable equipment we can distinguish between a survey conducted within a survey team and a survey conducted by one's self as an individual and if necessary, with local support. Besides simple equipment such as a hand laser measuring tool, a measuring tape, a bubble level, and a plumb, digital methods for processing image data are helpful. GPS is another important tool that is frequently used within this research (ibid. 98). To generate maps, GPS data are merged with GIS data (cf. Feiglstorfer 2012).

## 4. RESEARCH METHODS

### 4.1 Documentation

During the expeditions the samples were catalogued following parameters such as where they were found. Collected samples were shipped to Austria for further analysis. Before storing the samples in a refrigerated room at the IAG / BOKU (Institute of Applied Geology / University of Natural Resources and Life Sciences in Vienna), they were numbered once more following the consecutive numbering in the institute's book of samples. The label of the samples in this text is related to this numbering at the laboratory, and for further identification in the text, the samples are listed in a table.

The following parameters are part of the research on site:

- Locally specific names of the samples: Local names of specific kinds of clay were used for further identification of the particular material since the names may indicate a certain location of where to find the clay or give information about a certain material quality. Local names were not existent for all kinds of clay. For identification of each sample, the number entered in the book of samples will enable its identification for further tests.

- Description of where material was found: Contains the region, the place's name, the name and type of building and the location within the building. In the case of material collected at clay pits, the location of the pit is described and the locally known use of the material documented.

- General description of the material appearance of the samples, such as colour, taste and smell, haptic perception, grain size, and used additives: These parameters follow a testing with all senses, primarily conducted onsite. The importance of citing such parameters lies in the practical importance for the builder who is not primarily confronted with scientific data but with what can be immediately perceived about the material qualities on site.

- General description of constructions: Local earth building traditions are documented descriptively. Their features are described, and structures as a whole and in detail will be visualised as drawings, plans and photographs. For analysis, the following documentation is required:
  - Architectural survey
  - Description of the natural environment
  - Description of constructions and the processing of materials
  - Plans (ground plans, sections, elevations)
  - Drawings of the constructive properties and details
  - Photographs
  - GPS-position of the single objects
  - Interviews and local reports on the use and processing of building materials

- Constructions: Based on the collected material, examinations were conducted regarding the choice of such a material for a particular construction and the material's particular processing. Technical parameters of the constructive typologies and their dependence on particular clay material are discussed. Analysis focuses on the following points:

- Detailed observation of the single constructions and crafts
- Comparative building traditions
- Technical properties
- Local particularities
- Impact of the natural environment on the use of these constructions
- Possible relation between the use of particular clay material and the type of construction

## 4.2 Laboratory methods

In each of the Chapters II to IV the tables for grain size analysis (GSA), bulk mineral analysis (BMA) and clay mineral analysis (CMA) are given at the end of the sub-chapter "Mineral analysis".

### 4.2.1 Grain size analysis (GSA)

Particle size analysis was carried out as a combination of wet sieving (fractions >20 µm) along with sedimentation-analysis with Micromeritics Sedigraph III (fractions <20 µm). 50 g of air-dried clay were treated for dispersion and destruction of organic substances over several days with app. 200 ml of 10%-hydrogen peroxide. After completion of the reaction, oxygen in surplus was removed by boiling in a water bath. After sonication, the sample was sieved. Residues of sieving (>2,000 µm, >630 µm, >200 µm, >63 µm and >20 µm) were dried and weighed. The fraction <20 µm is used for the sedimentation analysis in the sedigraph after sonication. Results from sieving and sedigraph are combined.

### 4.2.2 Grain shapes

Grain shapes are determined according to Tucker (1985: 17, 18) using the following code (see Appendix of Chapter IV):

| | |
|---|---|
| 0 | very angular |
| 1 | angular |
| 2 | angular with beginning rounding |
| 3 | slightly rounded |
| 4 | rounded |
| 5 | well rounded |

### 4.2.3 Bulk mineral analysis (BMA) by XRD

Evaluation of an average amount of certain minerals is conducted according to peak intensity in relation to the general peak intensity. The intensities in the BMA tables are given with the following categorisation. Attention is also given amounts that deviate from the average. This semi-quantitative evaluation is given in proportional relation of the samples to each other. Since calcite and gypsum can be added for strengthening constructive features of particular clay mixtures, their amount is given quantitatively (if needed): (.) traces, (*) small amount, (**) medium amount, and (***) high amount. To determine the bulk mineral content, the samples were dried at 70°C and ground to a flour-like consistency (≤20 µm) in a vibratory disc mill. The ground powder was prepared in a 'backload'-procedure. Till 2010 X-ray was conducted with a Philips X-ray diffractometer PW 1710 with a divergence slit (Cu-K α-rays (45kv, 40mA) 2° to 70° 2θ, 1 step per second, step size 0.02° 2θ). The semi-quantitative determination of mineral contents was conducted according to Schultz (1964). For samples analysed after 2010, a Panalytical XPert Pro

MpD diffractometer with automatic divergent slit, Cu LFF tube 45 kV, 40 mA, and an X'Celerator detector was used. The measuring time was 25s, with a step size of 0.017° 2θ. Using a Scheibler-apparatus, the content of carbonate was measured according to Ö-Norm L 1084 by destroying the carbonates with 15% HCl and determining the volume of the $CO_2$ in consideration of air pressure and temperature. The inorganic content of carbon was calculated by multiplying the content of carbonate by 0.12. In order to be able to analyse non-carbonate components at a high carbonate content – in this study particular concerning *arga* stone - the carbonate is dissolved with acetate.

### 4.2.4 Clay mineral analysis (CMA)

The sample preparation was carried out according to Whittig (1965) and Tributh (1970). The destruction of organic substances was the same as at the GSA. The preparation of the sample was conducted parallel to the GSA. The clay fraction was a result of centrifugating (five minutes at 1,000 rpm) from the <20 μm fraction. The complex of sorption of the clay fraction was exchanged by shaking with 4 N $MgC_{l2-}$, respectively, 4 N KCl solutions. An X-ray was conducted with a Philips X-ray diffractometer PW 1710 till 2010 and with a Panalytical XPert Pro MpD diffractometer after 2010 (as described before). Each porous ceramic plate carries 20 mg of clay (Kinter, Diamond 1956). These texture-specimens were dried over night in a dessicator above a saturated $NH_4NO_3$-solution before being X-rayed. Thereafter, for the determination of swellable clay minerals (smectite, vermiculite), all ceramic plates were put into an atmosphere saturated with ethylene glycol. Subsequently, for the identification of well crystallised kaolinite, these plates, which are already prepared with potassium, were additionally treated with dimethyl sulfoxide (DMSO). In addition to this process, the plates were tempered at 550°C for two hours to determine primary chlorite. After each treatment the samples were X-rayed (K- and Mg-plates from 2° to 40° 2θ, with ethylene glycol treated plates from 2° to 32° 2θ, with dimethyl sulfoxide (DMSO) treated plates from 2° to 26° 2θ, and tempered plates from 2° to 14° 2θ). The identification of clay minerals is conducted according to Thorez (1975), Brown (1980), Moore and Reynolds (1989) and Wilson (1987). For the semi-quantitive evaluation, the areas of characteristic peaks in combination with empirical correction factors were used (Riedmüller 1978). The untreated remaining clay fraction is freeze-dried for further investigation.

### 4.2.5 Simultaneous Thermo Analysis (STA)

50 mg of the ground and at a relative humidity of 65% equilibrated samples were heated from 25°C to 1,000°C in a Pt-Rh-crucible at a heating rate of 10°K per minute. Measurement was conducted with an instrument of Netsch (Luxx 429) at a flow of 15 ml of nitrogen and 50 ml air per minute. As a correction, an empty crucible was used. STA results were used for the determination of the content of gypsum and calcite. Several peaks resulting from an endotherm or exotherm process were typical for most of the samples and not additionally quoted.

- A peak at around 75°C points towards the escaping of adhesive water.
- A peak at around 120°C to 180°C indicates the escaping of water of crystallising gypsum.
- A peak at around 350°C to 450°C indicates the combustion of organic material.
- A peak at around 573°C points towards the quartz inversion.
- A peak at around 750°C shows the release of $CO_2$ from carbonate minerals.

For the examination of the content of organic matter methods like *lost on ignition* or *total carbon* as methods for the evaluation of plant additives were not applied. For those samples which required a determination of organics content, the more precise Simultaneous Thermo Analysis (STA) was used. This method indicates the loss of organics in the temperature range between 220°C and 400°C and can be carried out for very small amounts of sample. The aspect of quantitatively minimising the destroyed sample material was another reason for choosing this method of analysis.

### 4.2.6 Infrared Spectroscopy (IRS)

Compacted samples were composed of 250 mg potassium bromide and 1 mg clay, or 1 mg of ground and at 70°C dried clay. IR-spectra were measured with a Bruker Spectrometer Tensor 27 between wave numbers 4,000 $cm^{-1}$ and 500 $cm^{-1}$.

### 4.2.7 Sample colours

Sample colours were determined in a dry and semi-dry state according to the Munsell Soil Colour Chart. In the following detailed mentioning of the single samples' colours, further explanation is only given in the case of deviation from the average appearance of samples within one region. For the determination the colours in the chart mentioned with the appendix YR (Yellow-Red) are used. Munsell categorises between five hues: R (Red), Y (Yellow), G (Green), B (Blue) and P (Purple); and intermediate hues: YR, GY (Green-Yellow), BG (Blue-Green), PB (Purple-Blue) and RP (Red-Purple). The resulting ten hues are again divided into ten steps, in total resulting in 100 hues. Practically, only forty are used, containing four charts titled as 2.5, 5, 7.5 and 10. The two following numbers, which are divided by a dash, categorise the lightness between 0 (black) and 10 (white) and the chroma, which is measured radially. The 10YR chart was the most often used chart within the current research, followed by 7.5YR. This designation is followed by two numbers, e.g. 10YR 5/2. The first number ranges between 0 (absolute black) and 10 (absolute white), and the second number indicating clay colours ranges app. between 2 and 8 in the current research. For all samples, the dry and also semi-dry colours were measured.

### 4.2.8 Shrinkage tests and determining the drying shrinkage

The value for geological shrinkage refers to the weight of the humid sample as 100% while the geotechnical shrinkage refers to the dried sample as 100%. In the following, geotechnical shrinkage is given. Shrinkage tests were conducted according to DIN 18952 (*Baulehm. Begriffe, Arten*). Measured was the change of an initial material length of 20 cm (marked with a stick of a standardised length on the 22 cm long sample) after four days at about 25°C and 50% humidity and consecutively in the oven at a temperature of 70°C till the shrinkage process was finished. Before preparing the samples, a "standard stiffness" (Ger. *Normsteife*) had to be prepared according to DIN 18952 (Minke 1995: 39).

### 4.2.9 Point load tests

Point load test on rocks follow the standards according to the International Society for Rock Mechanics (ISRM 1985). The point load of stone samples is measured, and comparable data of several other stones are collected and juxtaposed. Tests were conducted with a LP 4600 point load tester PLT-2 (100 kN) with two force ranges for a diamter of the samples between 10 and 120 mm. The Schmidt-Hammer test was not applied since it is an invasive method of investigation and would cause irreversible damage to objects.

### 4.2.10 Hardness tests according to Vickers

The hardness according to Vickers is measured at the IPM / BOKU (Institute of Physics and Materials Science). A synthetic diamond in the form of a pyramid is pressed into the surface of the sample with particular force [N] and subsequently imprints a star shaped (= two diagonals) indentation. According to DIN EN ISO 6507-1:2006-03, load and length of the diagonals, which are measured with a microscope, are the relevant parameters for the determination of hardness according to Vickers. The calculation of the HV (hardness according to Vickers) follows the subsequent formula:

$$\text{HV [kg/mm}^2\text{]} = \frac{F \quad x \quad 1.854}{d^2} \qquad d = \frac{d_1 + d_2}{2}$$

In the dry state the diagonal imprints caused by the pyramidal tool[1] are sharper and clearer with a consistent force of 10 kgf. The surface of the sample was coloured dark blue to locate the imprints of a size of about 0.5 mm. This was done under a Leica microscope where the imprints where observed and measured. Hardness is given according to the following example: 72 HV 10; 72 = hardness in kg/mm$^2$; HV = name of the Vickers test; 10 = force F in kg.

### 4.2.11 Plasticity tests, determining liquid and plasticity limit ('Atterberg limits')

The plasticity is tested according to DIN 18122 for the determination of the limit using tests according to A. Casagrande. The calculation of a classification number for the plasticity ($I_P$) was conducted according to Voth 1978 (according to Minke 1995: 42): $I_P$ [%] = $W_L$ [%] – $W_P$ [%].

### 4.2.12 Coefficient for the activity

The coefficient for activity was measured according to Houben and Guillaud (1984: 59).

$$I_A = \frac{W_L - W_P \text{ [percent by mass]}}{\text{Content of clay [percent by mass]}}$$

### 4.2.13 Clay additives

Additives (organic and inorganic) are determined in a first step with the naked eye, and in a second step under a Zeiss microscope with an enlargement between 80 and 500 times. Fibres of straw are categorised by their length: 'very short' <2 mm, 'short' = 2 mm to 10 mm, 'long' = 10 mm to 20 mm and 'very long' >20 mm. Since the inorganic additives (like coal) are in general just traces, they were not quantified in a first step.

### 4.2.14 Method of desludging

This method is used to separate a fine and a coarse fraction of one sample of clay. It is described with the following six steps:

---

[1] Type of testing apparatus: Nexus 4303 (0.02 kgf to 30 kgf).

◦ Step 1: Preparing the sample

The material used for this experiment was divided into three equal parts, each with an amount of approximately 100 grams and collected in a 1-litre glass.

◦ Step 2: Watering the raw material

The raw material in each glass was mixed with water three times its volume, at a proportion of app. 1:3.

◦ Step 3: Stirring the watered raw material

The 1:3-mixture is stirred with a magnetic stirrer at a speed level of 6.5 (of 10). This was the necessary speed needed to keep the mixture in motion and not have the stirrer get stuck in the sandy ground.

◦ Step 4: Period of sinking of the coarse fractions

The period of sinking defines the time between stirring and skimming off. For the present study three periods of sinking are observed, 60 minutes, 1 minute and an immediate skimming off after stirring, in the text mentioned as 60 min-, 1 min- and 0 min- (or immediate) sinking.

◦ Step 5: Skimming off (desludging) the fraction with a reduced amount of sand

After a particular time of sinking as described in Step 4, the fine slurry was skimmed off. The three different portions differ primarily in their different periods of sinking after stirring (60-minutes, 1-minute and immediately).

For skimming, openings in the container were used to regulate the amount and the fineness of desludged grains, used for the 1-minute and 0-minute portions. For this purpose, in a round plastic container, round holes with a diameter of app. 1.2 cm were drilled at the bottom end of the container and closed with plugs made of rubber. The suspension in the container was stirred (see Step 3) and after a particular period of time (see Step 4) the plugs were removed and the desludging process (which lasted about 30 seconds) started. By this the following regulations were possible:

a. Amount of water: It regulates the sedimentation height and the speed of the leaving sludge; more water carries away more coarse material, while less water carries away less coarse material.

b. Size and height of the holes for removing the sludge: The bigger the holes and the more holes opened, the more coarse material is carried away and the less fine the slurry will be. Different heights of the holes above the container's bottom allow for regulation of the amount of coarse material that is carried away.

For the following study from each 1:3-mixture a slurry was desludged (not vacuumed) through holes after a certain period of time with differing periods:

Test A: desludged after 1-minute sinking

Test B: desludged after 0-minutes sinking (= immediate desludging)

◦ Step 6: Testing and comparing of the desludged material

Various desludged samples are compared and juxtaposed to an original plaster.

## 5. Origin of the samples

Samples originate from different sites and were with a few exceptions collected by the author himself. These exceptions concern sample 6073 from Nyarma, the *arga* samples 11078, 14765, and 14766, and the *markalak* samples 14875, 8526, 11934, 14876, 14874 and 15377. Their origin is mentioned in detail in the Mineral Analysis-section of Chapters II, III and IV. Raw material was collected at clay pits, from building sites or new adobe bricks. At Nyarma, the author collected samples of loose earthen debris lying on the ground at various spots along the monastery structures without digging or applying any invasive impact on the structures. Many of the clay pits are difficult to find without local help, as they are often integrated into the surrounding natural environment such as agriculturally used fields. The choice of particular samples is to a certain extent dependent on factors such as proper information from the local population, accessibility of the pit, and, if needed, particular local permission. No material was directly taken out of structures and sampling was limited so as not to cause further damage. The amount of samples was limited by the availability and by the amount needed for particular tests, in average up to 150 g. Names of samples were documented and their particular use and processing were recorded. The sampling points were documented on a map and by photographs.

The collected samples during Himalayan field research give a unique outline of the clay as material for building and crafts. Table 1.1 shows samples with a specific local designation. The amount of types of clay without specific designation or which are simply known as *field clay* is much bigger. The aim of collecting and examining such a variety is to keep a wide range of comparable samples with high diversity. From the collected samples, those that were representative for the three research topics were chosen. Map 2.1 shows the region of the three research topics studied in Chapters II to IV. A list of the samples is given in each of the three Chapters II to IV on these research topics, always listed before the section on mineral analysis.

- For the first research topic samples were chosen from components of the Nyarma temple structures as well as from clay pits and new bricks (see Chapter II).
- For the second research topic samples were chosen from various *arga* quarries and from building sites in the Western and Central Himalayas (Chapter III).
- For the third research topic *markalak* clay samples and related samples from the Western Himalayas were chosen (Chapter IV).

Table 1.1. Himalayan types of clay.

| **Local term** | **Use** | **Settlement, province or region** |
|---|---|---|
| *arga* | roof, floor | Tibetan cultural zone |
| *cham* | plaster | Thangi, Kinnaur |
| *chit* | exterior plaster | Moorang, Kinnaur |
| *damul* | roof, floor | Hunza, North-Pakistan |
| *duksa* | roof, bricks, rammed earth wall | Tabo, Spiti |
| *dzasa* | roof, plaster | Basgo, Ladakh |
| *golu* | whitewash | Purthi, Pangi |
| *kartsi* | white colour | Tibetan cultural zone |
| *khampa* | red coloured clay for pottery | Barab, Medrogongkar |
| *kirsi* | white colour | Spiti |
| *kit-jan* | building material, field clay | Purthi, Pangi |
| *khusa* | roof, sooted clay | Ladakh, Kinnaur |
| *kum-mating* (also *kum-pating*) | roof | Kinnaur |
| *kosti* | | Purthi, Pangi |
| *makol* | whitewash | Purthi, Pangi |
| *markalak* | roof, plaster | Ladakh |
| *martsi* | red colour | Ladakh, Ngari, Lhasa |
| *nagtsi* | black colour | Ladakh |
| *narkalak* | roof, plaster | Khorchag, Ngari |
| *rzasa* | floor | Alchi, Ladakh |
| *sakalak* | building material | Keylong, Lahaul |
| *ser* | grey (yellow) colour clay for pottery | Barab, Medrogongkar |
| *shaksa* | roof, floor, rammed earth wall, plaster | Tabo, Spiti |
| *sho* | roof, plaster | Purthi, Pangi |
| *shodam* | roof (moistened *duksa*) | Tabo, Spiti |
| *talba* | roof, plaster | Tingrat, Lahaul |
| *thetsa* | floor, brick, plaster | Basgo, Ladakh |
| *thigsa* | roof | Central Tibet |
| *thabsa* | stove | Tibetan cultural zone |
| *thangsa* | plaster | Alchi, Ladakh |
| *thogdag* | coarse clay, first roof layer | Central Tibet |
| *tsak* | red painting | Tabo, Spiti |
| *tua* | roof, plaster | Shelkhar and Nako in Kinnaur |
| *shingsa* | building material, field clay | Western Himalayas |

## 6. Geology and tectonic aspects of the Himalayas

In the subsequent text, this matter is structured in the following way:

6.1 Geology of the Himalayas
6.2 Tectonic plates
6.3 Geological aspects with reference to the Chapters II to IV

### 6.1 Geology of the Himalayas

The Himalayas can be generally divided according to Map 1.1: The west is flanked by the Pamir and the Karakorum with the Nanga Parbat, and the east by the Ningjing Shan and the Nyainqentanglha Shan with the Namche Barwa. The core is the Central Tibetan Plateau. The Western and Eastern Kunlun define the northern Himalayan zones, and the Western, Central and Eastern Himalayas characterise the southern Himalayan zones.

For the definition of the Himalayan tectonic zones, different numbers of zones with varying names have been given. In the *Tectonic Map* by Gansser (1964b), who is one of the early researchers in this field, or later on, for example, in a map by Hodges (2000: 329) or the Geological Survey of India (GSI 2012: 2, 3), the number of belts and names vary. In this contribution, the sequence of the given Himalayan belts follows a map according to Sorkhabi (2010).

Trans-Himalaya:
This belt is located north of the Indus and Yarlung-Tsangpo Rivers, and divided into the areas Kohistan, Ladakh, Kailas, Gangdese, Lhasa and Mishimi (Sorkhabi 2010). It consists primarily of metamorphic and sedimentary rocks (ibid.).

Indus-Tsangpo Suture zone:
This belt is located where the Indian and Asian plates meet and consists of ocean-floor volcanic rocks, subduction-related high-pressure metamorphic rocks (green schist rocks), and deep-sea sediments of the Tethys Ocean (Sorkhabi 2010).

Tethyan (Tibetan) Himalaya:
This belt is located in the southern part of Tibet as well as in Kashmir, Zangskar, Chamba, and Spiti, and consists of Cambrian through Eocene sediments (sandstone, shale and limestone) (Sorkhabi 2010). In this belt, which is the widest in the Himalayas, sedimentation reaches a stratigraphic thickness up to 12 km. Several dome shaped structures from the Cambrian Period contain granite gneiss, and structures from the Miocene-Period contain white granites (leucogranites) (ibid.).

Greater or Higher or Main Himalaya or Central Crystalline zone:
This belt is located at heights exceeding 6,000 m – except for deep ravines – and rises steeper than the Lesser Himalaya (GSI 2012). It consists of metamorphic rocks (schist and gneiss) and granites

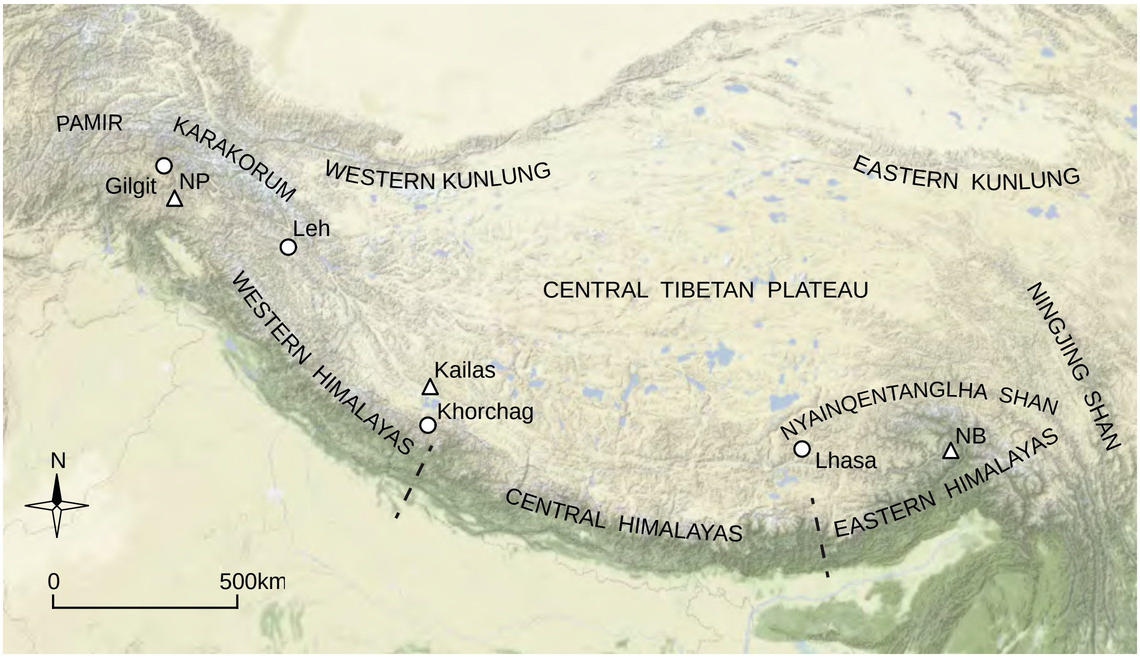
from the Proterozoic-Cambrian Period, and white granites (leucogranites) from the Miocene-Period in the upper parts (Sorkhabi 2010).

Lower or Lesser Himalaya:

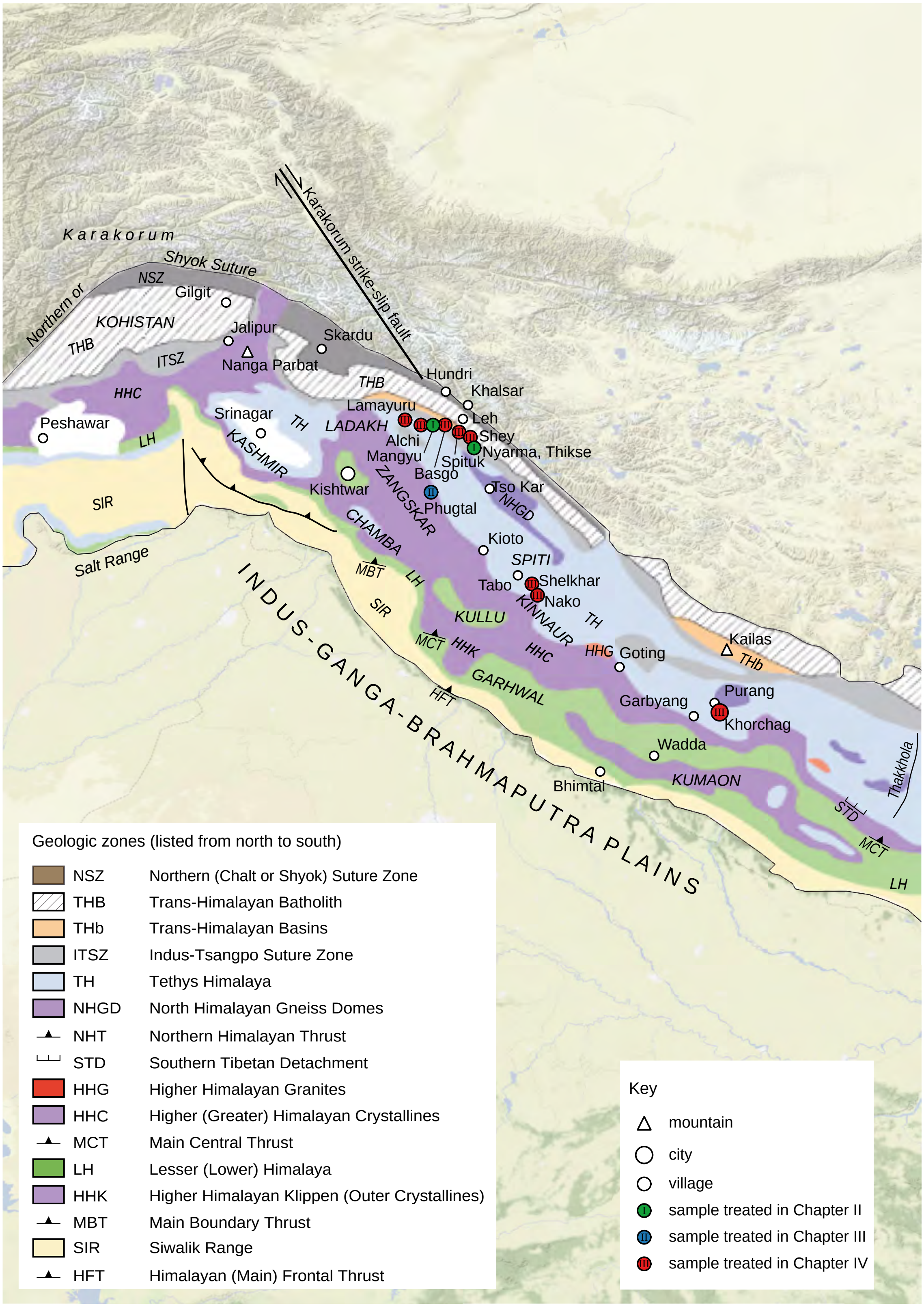
This belt is located to the south of the Greater Himalaya at altitudes between 2,000 m and 3,000 m (Sorkhabi 2010). It consists of metamorphosed sedimentary rocks (quartzite, marble, slate, phyllite, schist and gneiss) and minor volcanic and granitic rocks of the Proterozoic-Cambrian Period (ibid.).

Siwalik or Sub or Outer Himalaya:

This belt is described as "structural and denudational hills separated by sub-latitudinal flat bottomed valleys" (GSI 2012). Sorkhabi (2010) mentions the altitude of this belt to be 250 m to 800 m, and dates the rocks into the Miocene Period. These rocks are described as a "succession of sandstone and mudstone, and carried and deposited by rivers". Additionally he points towards the importance of the Quaternary Phase in relation to the Himalayan Frontal Fault (ibid.).



Map 1.1. Generalised topographic map of the Himalaya and Tibetan Plateau. NP = Nanga Parbat. NB = Namche Barwa. Map after Hodges (2000: Fig.1). GIS data based map: Jakob Gredler. Map adjusted and final graphics: author. GIS data based on data from VD and BM.


Karakorum
Karakorum strike-slip fault
Shyok Suture
Northern or
NSZ
Gilgit
KOHISTAN
THB
Jalipur
Skardu
ITSZ
Nanga Parbat
Hundri
Khalsar
THB
HHC
Lamayuru
Leh
Peshawar
Srinagar
TH
LADAKH
Alchi
Shey
Nyarma, Thikse
Mangyu
Spituk
LH
KASHMIR
Basgo
Kishtwar
ZANGSKAR
Tso Kar
NHGD
Phugtal
SIR
Salt Range
CHAMBA
Kioto
SPITI
MBT
LH
Tabo
Shelkhar
Nako
SIR
KULLU
KINNAUR
TH
INDUS-GANGA-BRAHMAPUTRA PLAINS
MCT
HHK
HHC
HHG
Goting
Kailas
THb
HFT
GARHWAL
Purang
Garbyang
Khorchag
Wadda
Bhimtal
KUMAON
Thakkhola
STD
MCT
LH
Geologic zones (listed from north to south)
NSZ Northern (Chalt or Shyok) Suture Zone
THB Trans-Himalayan Batholith
THb Trans-Himalayan Basins
ITSZ Indus-Tsangpo Suture Zone
TH Tethys Himalaya
NHGD North Himalayan Gneiss Domes
NHT Northern Himalayan Thrust
STD Southern Tibetan Detachment
HHG Higher Himalayan Granites
HHC Higher (Greater) Himalayan Crystallines
MCT Main Central Thrust
LH Lesser (Lower) Himalaya
HHK Higher Himalayan Klippen (Outer Crystallines)
MBT Main Boundary Thrust
SIR Siwalik Range
HFT Himalayan (Main) Frontal Thrust
Key
mountain
city
village
sample treated in Chapter II
sample treated in Chapter III
sample treated in Chapter IV

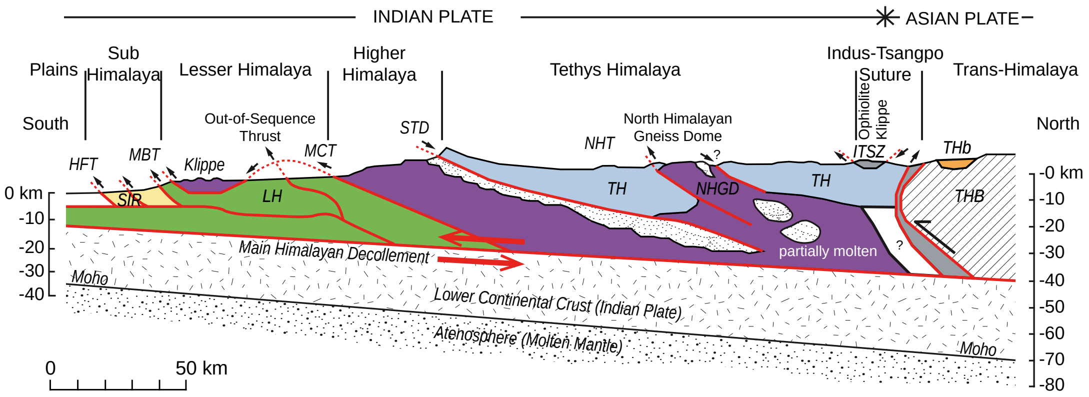
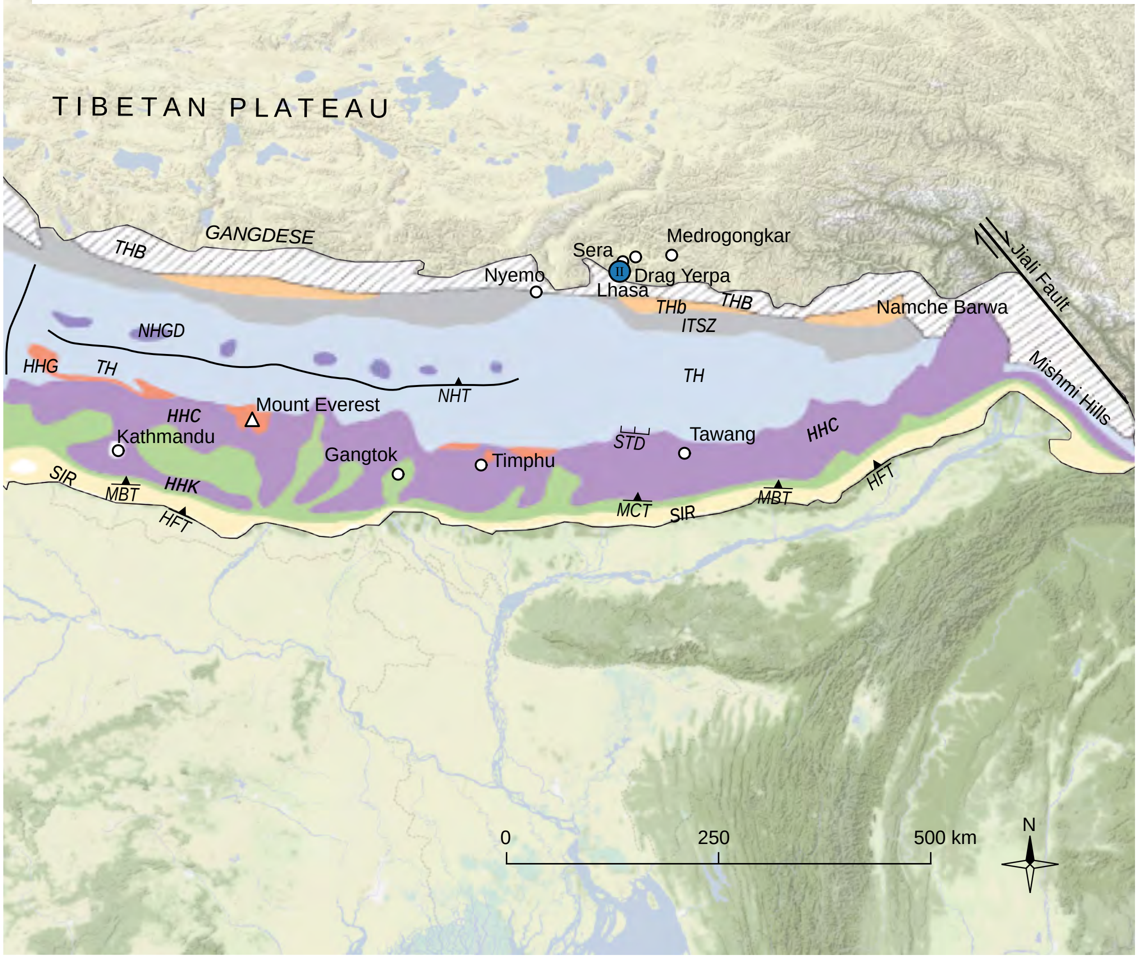


Fig. 1.1 (Top). Structural cross section of the Himalaya. Red lines show the thrust faults with various names. Map according to Sorkhabi (2010) and adjusted by the author.

Map 2.1 (Below, double page). Geological map of the Himalaya. Map after Sorkhabi (2010). For a complete depiction of the direction of faulting (normal fault and thrusts) see Sorkhabi (2010). GIS data based map: Jakob Gredler. Map adjusted and final graphics: author. GIS data based on data from VD and BM.



## 6.2 Tectonic plates

In the late Jurassic (200–145 Ma) the ancient Gondwana started to fragment and various parts (India, Turkey, Iran and Tibet) separated and drifted northwards (Sorkhabi 2010). The Tethys Sea separated India and Africa from the Asian plate. As a result of plate movement with the Indian plate moving northwards, the Indian and Asian plates collided about 50 Ma ago (Hodges 2000: 324). The floor of the Tethys Ocean shifted beneath the southern part of the Asian plate. Sorkhabi (2010) explains this process along the later Karakorum and Tibet due to a mainly basaltic oceanic crust beneath the lighter (mainly granitic) Asian crust. Due to a melting of the subducting slab, a large volume of granitic and volcanic rocks was produced (ibid.). The Himalaya range is a result of this process along the collision zone. A cross section through the Himalayas (see Fig. 1.1) shows the Trans-Himalaya. It is part of the Asian plate that is separated by the Indus-Tsangpo Suture zone – which acts as a transition zone – from the Indian plate. Today, plate movement is not finished and continuous movement is still registered. The Northern Suture Zone in the northwestern Himalayas (see Map 2.1) is a result of the collision of Kohistan-Ladakh Island with the Karakorum margin about 85 Ma ago (ibid.).

## 6.3 Geological aspects with reference to the three chapters II, III and IV

Places mentioned in Map 2.1 are written in italic. (*) marks places within the respective chapter from where samples for this study were collected.

### 6.3.1 Chapter II (Mineral traditions at the Nyarma Monastery in Ladakh)

This chapter concentrates on the village of Nyarma and its surroundings (see Map 2.1). *Nyarma** is located along the right banks of the Indus River, about 16 km to the southeast of *Leh*, which is the administrative centre of Ladakh and close to the monastery of *Thikse**. According to Map 2.1, Nyarma and Leh are both located in the Northern Suture Zone, which consists of metamorphic and sedimentary rocks. Over Ladakh towards the northwest to the *Nanga Parbat*, Fuchs and Linner (1995) divide this belt into (a) the Ladakh Range containing Alpine granites and granodiorites – which is in the area of Leh and Nyarma located along the right banks of the Indus River – and (b) the Indus Molasse flanking the area of Leh and Nyarma to the left banks of the Indus River. The Indus Molasse zone on a geological map of Ladakh by Fuchs (1985) is mentioned as Quaternary rocks. Hereby Leh is still located in the Ladakh Intrusives (Trans-Himalayan plutons) while Nyarma is located in the Quaternary rocks. On a geological map, Shanker et al. (1989) show the area of Leh and Nyarma as granite and granitoide complex.

### 6.3.2 Chapter III (*Arga* stone roof construction)

This chapter concentrates on different quarries of *arga* stones, i.e. in *Phugtal** in *Zangskar*, in *Mangyu** and *Basgo** in Ladakh, in *Khorchag** in West Tibet and in villages in the close surroundings of *Lhasa** in Central Tibet (see Map 2.1). A central feature of the *arga* stone is its high content of carbonate.

### Indian Himalaya:

According to Map 2.1, *Mangyu** and *Basgo** are located along the Northern Suture zone, and *Phugtal** is found along the Tethyan (Tibetan) Himalaya bordering the Higher Himalayan Crystallines, similar to *Khorchag**. According to Gansser (1964a) Mangyu and Basgo are located in the Tertiary Indus Flysch zone and Khorchag on the Quaternary Sutlej Terraces. According to Fuchs (1981), Phugtal is located in the Cambrian Karsha Formation, and bordered to the east by the Panjal Trap. Further on it is bordered by several limestone belts, which are interconnected by the Zangskar River. The tectonic allocation of the single sites explains the availability of limestone.

### West Tibetan Himalaya:

*Khorchag** is located on the intersection of three different belts: towards the northwest (including *Purang*) the belt consists of clastic rocks, intercalated with limestone, marl, gypsum or volcanic rocks; towards the northeast the belt is comprised of gneiss, schist, clastic carbonate and volcanic rock; towards the south the belt first contains schist intercalated with marble, followed by a belt with low grade meta-clastic rock and limestone; and further south the belt consists of limestone and phyllite. (IGS, BGMRX 1989) All in all, Khorchag is surrounded by carbonate rock.

### Central Tibetan Himalaya:

The alluvial location of *Lhasa** borders an area of clastic rocks intercalated with limestone and volcanic rock. Further north, continuing with a Cretaceous Tertiary zone with granite. Moving even more north, the border consists of silicious and volcanic rock. The area of *Sera* and *Drag Yerpa,* where *arga* is quarried, is in a zone of clastic rocks intercalated with limestone. To the south of Lhasa, the area around Medrogongkar contains sandstone and slates intercalated with volcanic rocks. Contrary to the latter, to the west and east of the *Medrogongkar* area we again find a Cretaceous Tertiary zone with granite (e.g. *Nyemo*) and areas of sandstone and slates intercalated with volcanic rocks. Just several kilometres to the northwest of *Nyemo* begins a belt with siliceous shale and limestone. (IGS, BGMRX 1989, Plate 5)

### 6.3.3 Chapter IV (*Markalak* clay)

This chapter concentrates on different types of *markalak* clay quarried in *Lamayuru**, *Alchi**, *Spituk** and *Shey** in Ladakh; in *Nako** in Upper Kinnaur; and in *Khorchag** in West Tibet (see Map 2.1). It is a lacustrine clay, and at least in Ladakh and Spiti it is available as varve clay. Lamayuru is located on the northern edge of the geological Lamayuru Formation, followed to the north by a Flysch belt, which to the north borders the Molasse zone (cf. the *Geological Map of Ladakh* by Fuch 1985). Similar to *Nyarma, Shey** and *Spituk** are located in the Quaternary rocks belt close to the Ladakh Intrusives. *Alchi** on the other hand is located in the Indus Molasse zone (cf. the *Geological Map of Ladakh* by Fuch 1985). Nako in Upper Kinnaur is located in the Crystalline Nappes (Fuchs 1981; described as gneiss and granite zone in Singh, Jain (2007: 50)).

### 6.3.4 Palaeolakes

The Quaternary palaeolakes treated in context of *markalak* clay deposits are connected with a clastic sedimentary process in the form of “lacustrine muds, deltas, fluvial sands and colluvial debris flow” (cf. Kotlia et al. 1998: 185). Seasonal sedimentation in glacial lakes can result in the formation of varves. The making of varve clays depends on the change of a different transport of sediments between summer and winter due to the melting of ice during the warm period. The layer which is made in winter is thinner and darker – in the case of a glacial lake, fine clay and organic material sinks slower – while in summer during snow melt and weak monsoons, coarser material like sand makes up the first layer, followed by silt (cf. Juyal et al. (2009: 437), referring to Ariztegui et al. 1997: 333 ff. and Juyal et al. 2004: 320 ff.). In some cases the upper part of the summer layer may be the coarsest before the fine winter layer deposits start. In the much finer winter layer the content of clay fraction (AN: <2 µm) may become higher than 90% and the upper end of this layer can be sharply truncated (Ridge 2017). The thickness of winter layers remains uniform while the summer layer may vary (ibid.). For example, at the *Goting* palaeolake, the thickness of varves is given in a millimetre-range (Juyal et al. 2009: 438).

Lacustrine clay deposits – whose mineral composition seems to be basic for *markalak* clays – are known in Ladakh, in particular in the area of *Lamayuru** and *Spituk**. The study of the use of clay of other palaeolakes for building purpose in the Himalayas, besides those treated in this contribution, is part of future research. Such lakes are mentioned for various sites. Examples for palaeolakes are given in the following publications: in Kotlia et al. (1998: 178) mentioning palaeolakes along the Indus River in Gilgit-Baltistan at *Skardu* and *Jalipur*; in Kotlia et al. (1998: 185) mentioning palaeolakes in Kumaon at *Bhimtal* and *Wadda* and in Ladakh the *Tso Kar*; in Phartiyal et al. (2005: 241) mentioning palaeolakes along the Shyok River at *Khalsar* and *Hundri*; in Juyal et al. (2004: 315 ff.) mentioning palaeolakes in Uttarakhand close to the Chinese border along the Sarda River at *Gabyang* and along the Dhauliganga River at *Goting*.

Observed clays from *Shey** and *Alchi** with *markalak* clay-like mineral compositions point towards further lacustrine clay deposits or possible offsets of the *Leh-Spituk* palaeolake. The palaeolake in Lahaul and Spiti with varve lacustrine sedimentation is a further North Indian example located to the south of Ladakh, stretching eastwards to *Shelkhar** and *Nako** in Upper Kinnaur. Here we find the locally known *tua* clay whose mineral composition is similar to the *markalak* clay. In Uttarakhand, about 40 km west of *Khorchag*,* we find palaeolake deposits, which may point towards the *markalak* clay-like mineral quality of the locally known *narkalak* clay from *Khorchag*.

Different reasons are known for the formation of palaeolake basins. They are either the result of heavy landslides (Kotlia et al. 1998: 185, referring to Fort et al. 1989: 332) or thrusts and faults, which have caused debris avalanches blockade water drainages (cf. Kotlia et al. 1998: 178, referring to Burbank 1983, Valdiya et al. 1992: 509 ff. and Kotlia et al. 1997: 307 ff.). The making up of the *Lamayuru** and *Spituk** palaeolake basins was caused by a damming of the Lamayuru River and the Indus River, respectively (Kotlia et al. 1998: 178).

The palaeolake of *Spituk**, for example, is given with a size of app. 10 km to 11 km in length[2] and 3 km to 4 km in width (Kotlia et al. 1998: 178), and the palaeolake of *Khalsar* is stated to have a length of 60 km (Phartiyal et al. 2005: 241). The thickness of sediments of palaeolakes differs widely. The *Lamayuru** palaeolake is reported to be over 110 m, the *Spituk** palaeolake 22 m, the *Khalsar* palaeolake 150 m, the Hundri palaeolake 100 m (Phartiyal et al. 2005: 241, 245), the *Kioto* palaeolake in Spiti 23 m (Sangode, Mazari 2007: 1), and the *Goting* palaeolake 40 m (Juyal

---

[2] The length of the Spituk palaeolake is stated in Phartiyal et al. (2005: 245) as 40 km.

et al. 2009: 438). For *Lamayuru* the date for the start of formation of the lacustrine sedimentation is stated as app. 35 ka (= 35,000) to 40 ka BP (Kotlia et al. 1998: 178), which is similar to *Bhimtal*, *Wadda* Lake, and *Tso Kar* (Kotlia et al. 1998: 185). For *Spituk**, Phartiyal et al. (2005: 254) mention 50 ka BP[3], and for the *Goting* palaeolake they state 23 ± 2 ka, with the process for sedimentation at *Goting* lasting app. 12 ka (Juyal et al. 2009: 442).

The palaeolake of Lamayuru consists of a "sequence of fluvio-lacustrine deposits" (Kotlia et al. 1998: 178). A characteristic for the Lamayuru Formation is "dark grey to black silty slates, partly phyllitic, and marls with layers of impure, fine-grained sandstone and blue limestones. A zone up to one hundred meters thick exists and contains olistolithic (concerning "the olistolithic nature of some of these limestone intercalations", cf. Bassoullet et al. 1981: 827 and Shah et al. 1976), blue limestone, and partially yielding crinoids (Fuchs, Linner 1995: 659).

The lithology of the Lamayuru lacustrine deposits is given in Kotlia et al. (1998: 178) by dividing in four litho-sequences from top to bottom. This shows similarities to other palaeolake profiles in Ladakh, including carbonate-rich layers[4] (Kotlia et al. 1998:185).

- 1. Litho-sequence A (uppermost part): Colluvial deposit of poorly sorted debris with lenses of coarse sand and occasional clay lenses. (Kotlia et al. 1998:178)
- 2. Litho-sequence B (45 m to 75 m): Dominance of medium-coarse sands showing cross and flaser beddings.
- 3. Litho-sequence C (13 m to 45 m): Dominance of recurring layers of silty muds and medium sands, interbedded with numerous mm-cm scale carbonate layers or lenses and a few thick carbonate beds.
- 4. Litho-sequence D (0 to 13 m): Dominance of recurring layers of organic rich lacustrine muds, clays, silty clays and fine sands.
- 5. Basalmost part (5 cm to 10 cm thick): Mixture of crushed and weathered country rocks and carbonaceous clay.

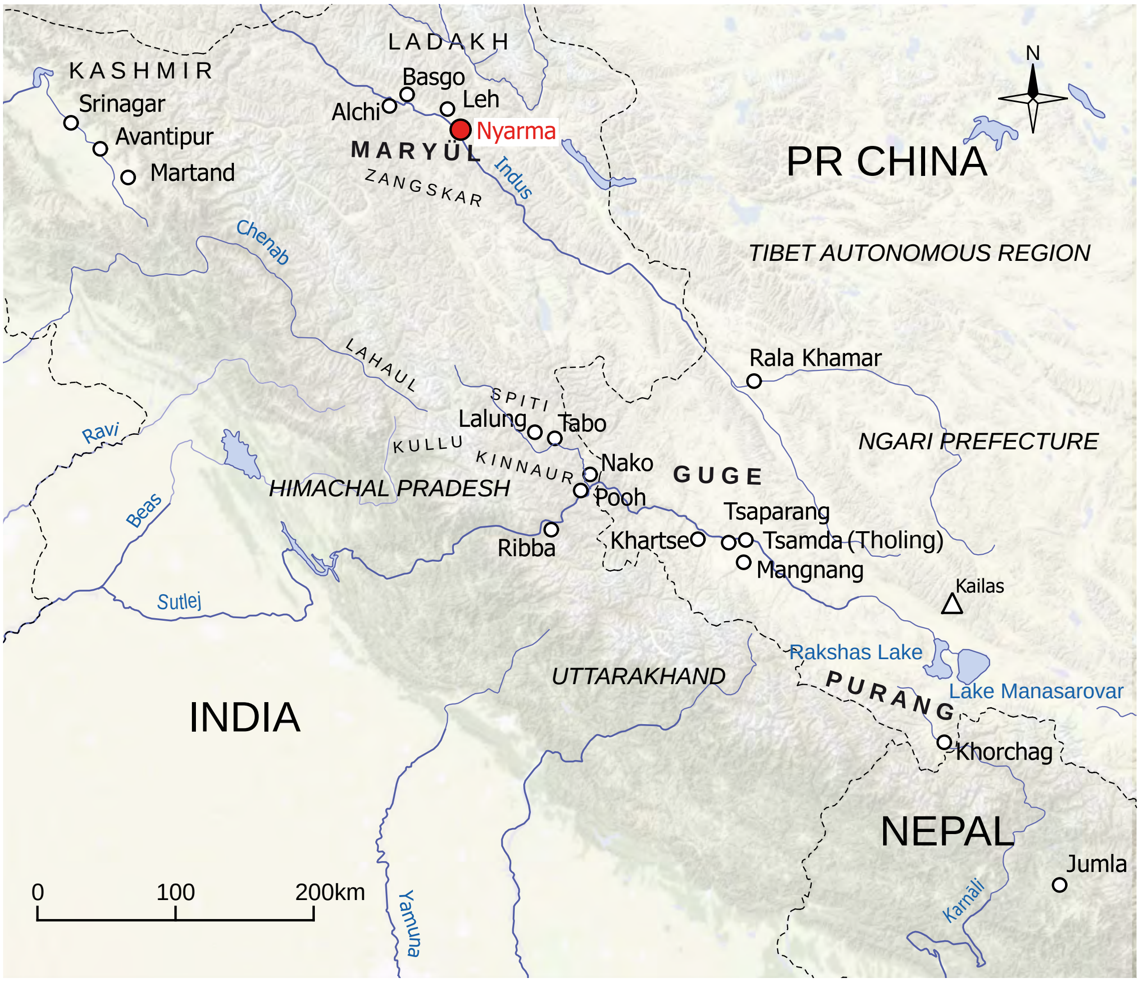
---

[3] Referring to Bürgisser et al. (1982: 53) and Pandey 1975 (the latter publication, which was searched by the interlibrary loan of the TUW could not be found), Phartiyal et al. (2005: 254) mention the possible existence of lakes in Lamayuru and Spituk until human settlement in this region. According to Bürgisser et al. (1982: 53) this hypothesis is emphasised by the depiction of boats in wall paintings in the Alchi temples. According to Christiane Kalantari (ÖAW; correspondence 6.2.2017) the depiction of a boat in the wall paintings of Alchi is most probably – similar to the monastery of Tholing in West Tibet – part of a mythical depiction of the "Eight Dangers". A relation to an early existence of a palaeolake during human settlement can not be traced. In Bürgisser et al. (1982: 53; referring to Pandey 1975) a mythical narration about the change of the lake into a river caused by ritual actions of a Lama and a later drying up of the lake is mentioned.

[4] For the Spituk palaeolake in Phartiyal et al. (2005: 254), the horizons are mentioned as intercalated layers of sand and clay.

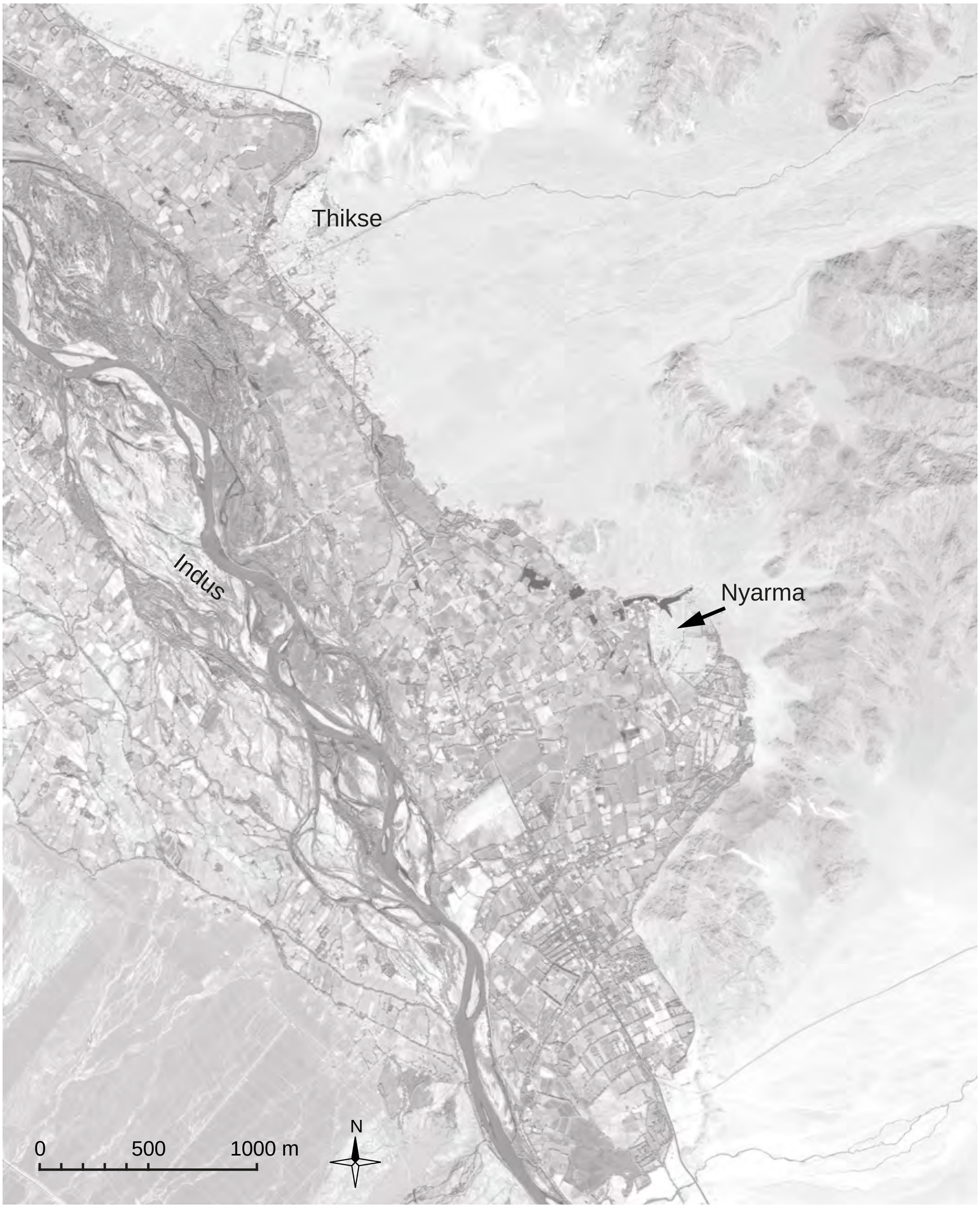
# II. MINERAL TRADITIONS AT THE NYARMA MONASTERY IN LADAKH

The main temple of the monastery of Nyarma was founded in 996 CE and, together with the main temples of Tholing and Khorchag – both located in West Tibet – it is one of the three first monasteries of the West Tibetan kingdom, which marked the centres of Maryül, Guge and Purang (Map 1.2). It is located close to the meandering Indus River (Map 2.2). Besides the main temple, the monastery consists of four further temples and several stupas (Fig. 1.2). Today the monastery of Nyarma is in ruins without any timber remains, which offers a good chance for further investigations of the used clay. The main temple consists of several parts as shown in Fig. 2.2.

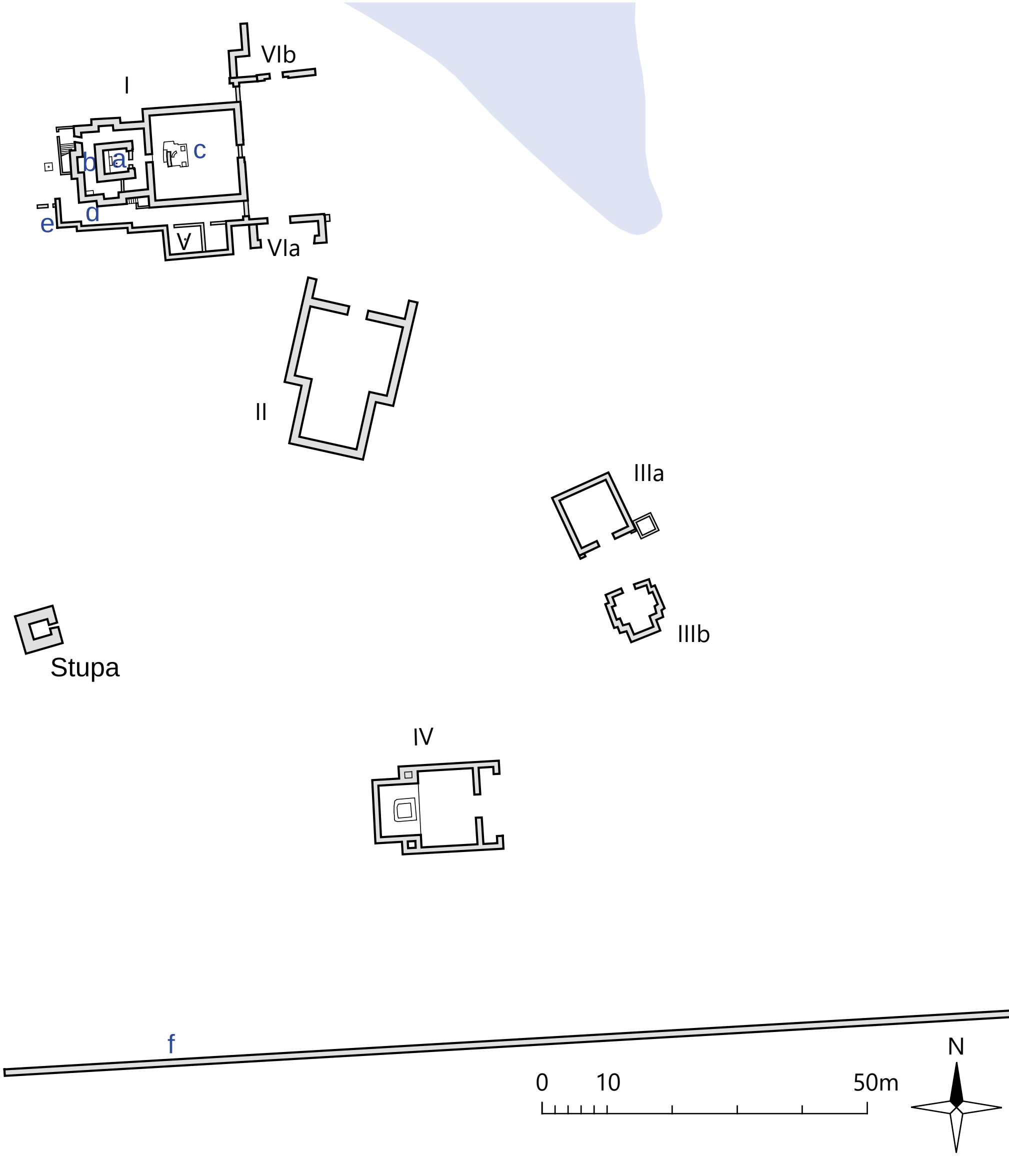


Map 1.2 Historical Western Tibet with Nyarma as a centre of Maryül, today located in Ladakh. GIS data based map: Jakob Gredler. Final graphics: author. Map based on data from VD and BM.

https://doi.org/10.1515/9783110591330-004



Map 2.2 Nyarma settlement.
Source: Satellite image with additions by the author; Earth Data Analysis Center, University of Mexico, Albuquerque, Sept. 9, 2006; courtesy of the FWF research project P21806-G19 (Society, Power and Religion in Pre-Modern Western Tibet).



*Key:*

Temple structures: I, II, IIIa, IIIb, IV, V, VIa and VIb
Main temple I includes structures V, VIa and VIb

| | |
|---|---|
| a | *Cella* |
| b | Inner ambulatory |
| c | Assembly hall |
| d | Outer ambulatory |
| e | Enclosure wall of the main temple |
| f | Enclosure wall of the monastery compound |

Fig. 1.2 Nyarma Monastery. Ground plan. Source: Feiglstorfer (Forthcoming b).

Fig. 2.2 Nyarma Monastery. East view. Numbers of structures according to the groundplan in Fig. 1.2. Source: Feiglstorfer (2011: Abb.4). I = main temple including attached structures V, VIa and VIb (which are not marked on the picture). II, IIIa, IIIb and IV = temple structures. Stupa = accessible stupa within the monastery compound.

The samples will be divided in specific categories of actual former use within the building compound. Before the detailed analysis of the single samples, an overview will be given considering the following topics.

1. Material aspects
2. Research questions
3. Mineral analysis
4. Further material analysis

## 1. MATERIAL ASPECTS OF THE NYARMA MONASTERY

The commonly known *field clay* is not an indication of a certain type of clay but instead defines the location where such clay is found. In several cases, like in the villages of Alchi or Lamayuru, both located in Ladakh, the *shingsa* (Tib. *zhing sa*), as the *field clay* is referred to in Tibetan language, is also known as clay for common building purposes, for example, for making adobe bricks. In general this kind of clay is not as fine as, for example, the *markalak*[1] clay, but it contains a higher amount of coarse grains, which, in certain cases, make the field-clay improper for use as a plaster. Nevertheless, this kind of clay is commonly one of the best known materials for earth building purposes.

---

[1] See detailed examination of *markalak* clay in Chapter IV.

Local knowledge on the location of clay pits as the prime supplier of raw material goes hand in hand with knowledge of different material qualities and related methods of processing. In other words, someone who knows about the particular use of a particular clay is able to understand the need for the particular raw material. On the other hand, people must have found and processed a particular material for a specific purpose the first time, and in following steps started to learn about its useful properties – by practical learning. This process of getting experience may not be understood over a short period of time – e.g. as one learns about statics when a pillar cracks due to a too heavy roof load – but over a much longer period since types of clay are difficult to categorise, particularly in a supralocal context.

Furthermore certain qualities of different kinds of raw material may not be the result of a completely different mineral composition but may show changes of certain mineral parameters due to a slightly different location of the clay pit or as a result of a different depth in digging. The more sensitive the final product to certain external influences, such as water, temperature, pressure, etc., the more significant are the particular changes within the parameters of the raw material – such as clay content and type of clay minerals (shrinking, swelling, cracking), amount of less binding and coarse components (erosion, cracking), content of calcite, contents of iron oxides (oxidation, colour), etc.

Knowing about the place where to find proper raw material increases the final quality of the building and reduces the amount of effort in preparing the right composition. The ideal case is finding the proper material within one clay pit which allows fulfilling different technical requirements like those for bricks and plaster. In several cases there remains the need for mixing of the raw material with sand to make it, e.g. less sensitive to shrinking and cracking or more workable. In other cases there is a need to mix a too sandy raw material with a raw material with a higher clay content, or to mix it with a material with a higher content of silt to make it more workable while still keeping it fine and not increasing the possibility of cracks. These variations are so numerous that it is difficult to make a particular recipe for a specific mixture, as is often attempted these days. It is much more knowledge of the qualities of locally available raw material and the intuitive feeling of the builders that help to find the proper raw material supplement. In any case, the need for mixing greatly increases the effort in preparing a proper material since a complementary material has to be found, transported and, in particular, mixed by hand.

In earlier days this knowledge was crucial for the use of building materials with specific properties since the transport of proper material from the pit to a building site, such as the monastery in Nyarma, required immense effort. Today this physical effort is compensated by motorised transport, which is detrimental to the environment and costly. The availability of raw material is one of the reasons for the choice of a building site. The challenge is to find the proper material at a particular site not too far from the building site or in the best case on the site itself. At the time of foundation of the temples of Nyarma there must have been the need for clay pits containing a proper quality and quantity of building material, which could have been used for both, as base material for adobe bricks and as various types of plasters. The following examinations will give detailed insight into the knowledge of particular qualities of local clay. The existence of a lake, which is still today located just beside the main temple (probably of a changing size), may have facilitated digging for proper clay and its processing.

Due to partially lost knowledge about the location of former clay pits, either the distance of transport becomes longer or the quality of the used material is decreased since the builders still use the material close by, as is the case in urban areas like Leh today. At several building sites in Leh in Ladakh the author observed recently prepared relatively sandy bricks, very different from the less coarse quality found, e.g. in Nyarma.

Comparing the size of assembly hall and *cella* in total, the main temples of Nyarma and Tabo are of similar size, the Nyarma main temple being slightly bigger. For the Tabo main temple the amount of bricks was calculated with app. 61,000 by processing app. 487 m$^3$ of clay.[2] When digging for clay for about one metre, one would need an area of app. 480 m$^2$ (60 m x 80 m) to receive the necessary quantity of clay. In Nyarma, a depression is visible on satellite pictures at the south eastern corner of the monastery compound. We can not say whether this depression points towards a former bed of the lake during its former extension or to a former clay pit. Its use as a former clay pit could have optimised the working process due to a short distance of transport and due to the place of processing the clay close to the temple structures. We know that processing of bricks is being practiced on the ground of the Tabo Monsatery with the clay from the site still today. As observed by the author in 2006, for conservation works the bricks were made from the clay directly available at the monastery site within the enclosure walls. Also Dechen Lundup,[3] a resident from Tabo, mentions a site close to the monastery structures where clay was collected for former bricks of the Tabo Temples (Correspondence Dechen Lundup 2014).

Using clay as building material means digging and learning about the location of the quality of clay which can be found in different pits.[4] Since this knowledge must have existed for most early earth buildings, there must be a long tradition of clay-related knowledge in this area. As far as we know, no written evidence is available on this matter and still today we are confronted with an undocumented field. Due to this lack of documentation, we still refer to local information given by villagers based on their local knowledge. Following local tradition, we can distinguish between two categories of clay used for building purpose.

---

[2] For the Tabo main temple in Spiti in Himachal Pradesh, which was also founded in 996 CE, about 61,000 bricks were processed using the following calculation with an average brick size of 40 x 20 x 10 cm; a height of the walls of app. 560 cm in the *cella* and an area of the walls in the ground plan of app. 36 m$^2$ equals a volume of app. 204 m$^3$; a height of the walls of app. 480 cm in the ante chamber to the *cella* and an area of the walls in the ground plan of app. 9 m$^2$ equals a volume of app. 43 m$^3$; a height of the walls of app. 460 cm in the assembly hall and an area of the walls in the ground plan of app. 52 m$^2$ equals a volume of app. 240 m$^3$. In total the approximate volume of clay used for the main temple in Tabo equals app. 487 m$^3$. An adobe brick with the size of 40 x 20 x 10 cm has a weight of app. 10 kg (0.008 m$^3$ x 1300 kg/m$^3$). 487 m$^3$ ⁒ 0.008 m$^3$ = 60,875 bricks. When calculating one workday to be eight working hours and estimating a time of production of one brick in a mould (including collecting clay, separating gravel and its lifting to a drying place) with about two minutes per brick for one person, it would take about five weeks with eight persons working seven days a week just to make the bricks. When calculating at least one full season for building the shell construction of the temple, this would mean that the bricks must be prefabricated at least one year before installation.

[3] Telephone conversation with Dechen Lundup from Tabo in Spiti in September 2014.

[4] In the present context of this contribution, the term "clay pit" is used for all places where clay is quarried, primarily for use as a building material but also for pottery, stoves or clay sculptures.

The first category concerns clay found all over a village and in the fields; in Tibetan language this type of clay is referred to as “shingsa”. This can be seen as a kind of ‘ordinary’ clay, not to be mixed with clay of less quality. It is a type of clay, which is used for a broad range of building purposes, i.e. a kind of multi-functional building material. Uses include adobe bricks, plasters, or roofs and, if required, the clay is mixed with sand, clay, straw or other additives. By comparing the mineral analysis of the single samples and their different use within a construction, within this contribution it will be explored if the today’s use of local clay equals with the clay which was historically applied at the Nyarma Monastery.

The second category concerns all kinds of clay which are known for a particular purpose, such as repairing a roof, repairing cracks or making sculptures. These clays are in most cases finer than the *field clay* and the property of clays of this second species is better comparable among each other according to more similarity of their mineral compositions – for example, regarding the species of *markalak* clay.

In comparison, regarding the species of *shingsa* we are talking much more about its wide range of use and its easy accessibility. The different mineral compositions of *shingsa* demand a flexible approach by the users in finding the right mixtures, which may have local variations. In this chapter on the Nyarma Monastery, the author’s prime interest is in *field clay* in terms of identifying the base material of bricks and plasters. Regarding the right choice of clay, of importance for the optimised and most sustainable use of clay, builders always needed to know about the material’s properties and to have experience in processing the various types of clay.

### 1.1 Clay pits and new bricks

The role of the building site as a material source is an important matter in vernacular architecture. Regarding the building material itself, the question arises if the clay was directly taken from the site or – for prestigious buildings like the temples of Nyrama – clay was brought from other further away locations. In this concern, the comparison of different types of clay used for today’s building constructions, with the clay found in historical constructions of religious buildings, should take precedence. It can not be excluded that a specific traditional knowledge, also in using a specific kind of clay, was transmitted over generations to present day. In settlements – which have extended immensely since their foundation – like the administrative centre of Ladakh in Leh, one has to consider that certain traditional clay pits are no longer accessible as they have been overbuilt or become part of the urban land and lost their meaning as a material source. To reduce the distance of transportation, nowadays clay pits are opened not too far from the building site, which is a possible reason for preferring the economical factor to the material quality. Currently, several good quality materials are locally often no longer commonly known or are no longer accessible since, for instance, clay pits have been covered by growing settlements. For this reason longer distances of transport by motorised vehicles must be accepted for carrying proper material from further away. In this relation this matter is very recent since there still is a demand for proper material. With such increased effort the question may arise of why clay is still used and not seemingly easier available concrete. An answer lies again in the knowledge of the raw material and its proper adjusting for a specific use, which makes it possible to find clay of different qualities in close vicinity to a building site.

Fig. 3.2 Nyarma. Ladakh. Clay pit.

Fig. 4.2 Nyarma. Bricks laid for drying.

For a comparison of the locally available *field clay* as material used for bricks and plaster, two samples were collected at Nyarma village at a contemporary building site located along the link-road from the monastery compound towards the Leh-Upshi highway. At one of these sites adobe bricks were prepared at the time of the author's visit (Fig. 3.2, Fig. 4.2). In this case we are very much dependent on locals giving proper information on their recent habits in working with clay.

As a first step towards research on the raw material, clay pits and new bricks, which were recently produced, were examined. When examining bricks and detecting calcite, a central question is whether the content of calcite has a natural or an anthropogenic source. In the case of a natural source, this central question leads us towards qualities of mineral compositions and by this towards naturally given circumstances. In the case of anthropogenic source, this means an additional effort for processors in handling and particularly in adjusting the mixture. We are then further brought to the question of human influences.

Several times the author was confronted with questions of why local resources from the site were not used, why natural resources were adjusted and why proper local and un-mixed material was not used. Questions like these are of relevance as they are fundamental to the exploration of the evolution of particular building traditions. Before specific behavioural patterns in using clay were able to turn into traditions, they had to be verified, accepted and successfully used by a local community. In other words, when a particular material like a specific type of clay turned out as proper for preparing, for example, adobe bricks within a certain sphere of action, people knew where to find and how to use it. A neighbouring settlement could have had a different geologic and mineral situation, and the same kind of material specification might no longer be available. In this case either another proper quality of clay was found, different qualities of clay were mixed or the construction changed, e.g. by using rammed earth or stone constructions instead of adobe bricks.

This very simplified explanation has a lot to do with minimising distances of transport. In pre-modern times when people were more dependent on man- or animal-power, the easiest was to use the local clay of the building site itself. This fact was emphasised by the following observation at early temple sites of the late 10th century where the determining of a particular site as a proper to become a temple site must have followed the finding of a proper raw material, and not vice versa. According to the author's findings in Nyarma, Tabo and Khorchag – three of the earliest monasteries of West Tibet with a foundation date of 996 CE – it is much more the case that the availability of proper clay on a particular site must have been an important fact for its choice as a building site. Builders had to empirically prove the availability of local clay and its workability before use. To make such a decision, according to local tradition water is traditionally poured in a hole that had been dug in the ground and the water's behaviour – if remaining or draining off – was analysed.

This dependence on natural resources was finally an economic and technical decision since before starting the construction it had to be determined, whether ground humidity would cause issues, whether cracks would occur from ground movement, whether increased distances of transport would be required or whether, due to difficulty in manipulating the local material, there would be an increase of labour costs and a longer construction period.

Returning back to the question of whether there is a need to adjust locally available clay, e.g. by mixing or desludging, the clay may be proper without being manipulated for making bricks, yet too sandy for preparing a plaster. Further, it may not have proper inner reinforcement resulting in cracks within the plaster, or potentially contains too much clay or swellable clay minerals, like smectite, which may again result in cracks due to shrinking. This means that a particular raw material must not necessarily be proper for the preparation of a good plaster when it works well for making bricks or vice versa. A base material, which should be used for general purposes, still needs to be treated by skilled workers to adjust it with as little effort as possible for the particular building purpose; but still the base material may come from the same site as a result of knowing about different qualities of clay and also where to receive proper organic fibres for reinforcing the clay when necessary.

This contribution is not primarily to be understood as a handbook for finding the proper clay but aims to make deep traditionally settled knowledge understandable and accessible – the goal is also to "re-search" and not invent already existing natural and sustainable methods of building. It has to be emphasised that this critical point of view should in no way romanticise traditions. Conservation of cultural heritage, certain technical developments and particular needs may explain necessary changes.

### 1.2 Historical adobe bricks

What knowledge on the choice and use of particular base material existed for the temples of Nyarma in regard to the clay or clay mixtures and additives? This question includes the observation of the knowledge about the properties of particular types of clay and their use, and about possibilities of mixing of particular base materials and additives for strengthening and preparing an adequate building material. Since there are no written sources for the foundation date of the temples, except the main temple, the used clay will be examined to determine if it shows any similarity between the single structures. By this evidence will be given of parallels in the knowledge used for the single structures. Looking for and finding answers may bring us further to certain traditions in finding and processing the proper material, distances of transport, or places of processing. Besides the question for the proper clay, there is also the question of the construction itself. Which constructive features can be observed at the main temple and how do they relate with those of the other temples within the compound? This concerns the size of bricks, the brick bond, the width of walls, the sloping of walls, sizes of bed and settlement joints or the way the foundation was made.[5]

Each of the results of this observation is of particular relevance for further research questions. The examination of the clay itself will provide an important link in understanding relations in traditions using particular material qualities for particular purposes. For the Nyarma temples themselves, we may not expect an answer regarding a dating of the temples but instead support in further dating at future observations. In the case that properties of clay are clearly different between the single temples, the question for different places where to collect clay and different methods in processing would arise. Nevertheless this fact would not necessarily emphasise an argumentation towards different dating since for different temples at the same time different types of clay could have been used.

### 1.3 Plasters

Plaster samples have their origin in the main temple (Tib. *gtsug lag khang*) in the *cella* (Tib. *gtsang khang*), in the adjoining assembly hall (Tib. *'du khang*) and in the adjoining side temple which is located along the circumabulation path passing the *cella* and the assembly hall. Other plaster samples have their origin in the temple structures within the temple compound and in an accessible *stupa* (Tib. *mchod rten*) – which is one of the early structures within this compound (see Fig. 1.2). The *cella* in the main temple, the adjoining assembly hall and the attached side temple belong to the temple's earliest core of the whole monastery as part of the original foundation layout in 996. The other temples have yet not been dated.

Pictures taken by Romi Khosla (Khosla 1979: plates 43 and 44) in the 1960s of the monastic compound in Tabo in Spiti, where the main temple was also founded in 996 CE, still show most of the temple facades in an unplastered state (Fig. 5.2, Fig. 6.2). The plastering in the temples in Tabo, as we find it today, is a result of conservation conducted by the Archaeological Survey of India (ASI) in 1973 and 1974 in a still controversial approach.[6] This may hint at the exterior plaster of Nyarma having been a later addition but not as recent as the conservation in Tabo, since all interviews with elders gave no such evidence.

Regarding the strong compound between the plaster and the adobe walls, we can state that knowledge of preparing and adding a high-quality and long living plaster did exist. In this respect, by regarding the mixtures of the plaster, we obtain a good idea about the right handling of the material, even for today's advanced technical purposes. At this point one has to emphasise the

---

[5] The author presented matters of construction at the TERRA 2016 conference held in Lyon, published in Feiglstorfer (2018). Within the present contribution, focus was on material qualities.

[6] Lecture given by the author in Kraków on January 13th 2014 titled *Tabo Tsuglagkhang – Various aspects of integrative conservation*. Traditionally adobe walls lead the water into the ground. In the case of Tabo, new stone basements were added, which do not allow the capillary rising moisture to escape via the open basement but to climb within the wall and as a result keep the wall surface continuously humid. The thick plaster added on the facades supports this effect, altogether leading to a continuous moisture penetration of the wall and the endangering of wall paintings.

Fig. 5.2 Tabo Monastery. North India. West elevation of the main temple. Source: Khosla (1979: plate 43).

Fig. 6.2 Tabo. South elevation of the Maitreya Lhakhang. Source: Khosla (1979: plate 44).

interaction between the knowledge about the choice of the right materials, their mixing and their processing. Concerning processing, we have the possibility to infer from the material findings and compositions in relation to historical research and knowledge about recent methods of processing. Bulk and clay mineral analysis will be an important key in determining particular types of clay.[7]

### 1.3.1 On the burnishing of plasters

One important fact for a strong adhesion of the plaster with the adobe brick below is the method in treating the upper surface of the plaster. This follows a still existing Himalayan tradition in smoothening and burnishing the upper surface with stones,[8] in particular in buildings of a higher social status to prepare the ground for a later application of colour. The result of the plastic deformation by burnishing is a compression of the surface with several important properties. It becomes smooth and shiny. By closing the pores the surface is reduced, and dirt and dust no longer remain as easily on the plaster as with open pores. It becomes more resistant to humidity, and the application of a sub-layer for mural painting or oils for a finish is improved. Satish Chandra (2003: 528) also describes a reaction between amino acid groups of natural organics with alkali from the hydration of the binding material; resulting complexes are described as acting hydrophob. Since the use of any fluids, like oil, during burnishing is uncommon in the Tibetan cultural zone, the question of the role of vegetable fibres, like straw or animal dung,[9] which are traditionally used for the preparation of plasters, is raised. This influence was not treated in this study and is an important question for future research.

As an example, monks in Spituk explained the method used in preparing the upper plaster's surface in the protector's chapel (Tib. *mgon khang*) in the following way: "As soon as the upper surface of the plaster reaches a semi-dry state and becomes leather-hard, surface-irregularities are

---

[7] When talking about clay, we have to distinguish between clay minerals and clay, the first identifiable by their crystal structure. In geo sciences the size of clay minerals is defined according to EN ISO 14688 with <2 µm.

[8] In the following this process will be mentioned as "burnishing". Besides making the surface smooth and shiny, an aim of this process is to compress the surface by using a certain contact stress and causing a plastic deformation.

[9] Contrary to straw, whose content in the samples could be studied precisely, remains of dung are difficult to trace, in particular in samples which are several centuries old.

removed with trowels or with the edge of flat stones. Thereafter the surface is smoothened by rubbing it with stones of different sizes held in one's hand." Such a method is still practised on *arga* roofs (as discussed in Chapter III). For the *arga* technique, after crushing stones as the upper layer of the roof during a continuous application of water, the surface is smoothened and burnished in a similar way as described for the plasters.[10] Also in Himachal Pradesh in North India, the method of burnishing is traditionally known. Dave et al. (2013: 70) describe the applied technique as rubbing with stones or hands and thereafter using a thin slurry of clay, dung and pigment for the purpose of cleaning.

Fig. 7.2 Uru Katsel Temple. Central Tibet. On the left side of the picture the still unburnished wall surface which turned into smooth and even.

In 2014 the author had the chance to observe the application of this method at the Uru Katsel Temple in Central Tibet (cf. Feiglstorfer, forthcoming a). The temple, which was destroyed during the Cultural Revolution, was rebuilt and the upper surface of the plaster treated in a similar manner as described at the monastery of Spituk. Along a portion of the wall within app. 10 m, women were smoothening the surface with stones of different sizes and rounding. This made the plaster shine when the pores closed (Fig. 7.2).[11]

---

[10] The *arga* method will be explained in detail in Chapter III. In comparison, for the Italian influenced method of burnishing terrazzo, Eltgen (2004: 450) mentions until the beginning of the 20th century the traditional use of blocks of sand stone. Additionally to the use of a sandstone for burnishing, Wiebeking (1826: 218) mentions for Venetian *terrazzo* the use of a whetstone for very coarse surfaces.

Burnishing of wall surfaces is known from the *tadelakt* technique, which originates from Morocco. A mortar, which is applied in several layers of a similar thickness (app. 3 cm to 4 cm) with a trowel, is compressed and treated with a stone by applying soft pressure in circular movements (Schönberg 2012: 271).

Other common applications onto a wall are the *stuccolustro* and fine lime plaster (Ger. *Kalkglätte*) technique: the first with a surface of calcium carbonate and silicate, the latter with a surface of carbonate. Both surfaces are compressed and burnished (Schönberg 2012: 271). The *stuccolustro* technique was already common in ancient times and practised at Pompeii and Herculaneum (Schönberg 2011: 177).

[11] The method of burnishing mineral surfaces with different tools, such as bones or stones, has been known since early days. Jaenicke reports this method as used on ceramics during the Bronze Age and being of a high quality conducted by the Etruscans. At his time, around 1900, this technique was known, especially in the Orient and in Spain (Jaenicke 1980: 22, 23). The method of burnishing ceramic surfaces is globally known in a wide context.

According to DIN 8589, the technique of polishing (Ger. *polieren*) is not regulated as an autonomous technique but mentions several methods of processing and describes the aim of polishing primarily with reaching high quality

Such a surface is ideal for the application of a white sub-layer of gypsum, lime or kaolin. By rubbing the surface with a certain applied pressure, the whole compound, i.e. wall construction and plaster, is compressed, which is one of the reasons for the strong compound, applied several hundreds of years ago, observed at the temples of Nyarma. Another effect of the use of this burnishing-method is the smoothening and not necessary levelling of the upper surface. A reason for remaining unevenness may be changing pressure with the stone onto the wall, which causes a not exactly levelled application of the plaster material below. By burnishing, such irregularities are partially equated.[12] At finished surfaces we are able to observe these still existing uneven wall portions by their changing light refraction. Another result of this method is that within some wall areas we find just a few smaller spallings. When burnishing with a certain pressure, the plaster at the breaking line still provides good adherence to the adobe bricks below.

In a state of decay in which we find the surfaces today, there is no light reflection of such a burnished surface visible since the upper surface is missing due to weathering. But still the remaining surface appears more homogenous, as we observe at much younger plasters, which are not pressed and smoothed. Due to the fact that this method is still used in Himalayan regions as a result of extreme good adhesion of the plaster and its levelled appearance with very few spallings within a closed wall area, we can hypothetically state that the finishing of a plaster may have been similar to the still known and afore described smoothing-method.

### 1.3.2 Layers of plasters

Due to the strong weathering of the plaster surfaces and the still remaining homogenous compound within the whole plaster, for some plasters it is difficult to argue for a one-layer or two-layer plaster.[13] In several parts of the plaster where samples were taken from, the plaster obviously came off in two layers. At some parts, in contrast, the whole plaster structure was of such homogeneity that it was difficult to identify and separate the layers.[14]

Further evidence for a double layer application is the use of straw in the lower section of the plaster (with a thickness of app. 2 cm to 3 cm on average or less), or no straw in the upper section (with a thickness of app. 1 cm to 2 cm). In the case that more straw could be detected in the lower section of the plaster and less in the upper section, we can assume that the plaster was processed in two steps and two layers since the amount of straw may not vary within one plaster layer. Due to these reasons we can emphasise the hypothesis of the former use of a two-layer plaster, relevant for all the examined temples in Nyarma (I, II, IIIa, IIIb and IV). In view of the leading questions

---

using a polishing-grain (VKI 2003: 90). AN: When using a stone, its grain size and grain structure determine the quality of the finished surface.

[12] Dependent on the time of burnishing and the used polishing-grain, a burnished surface is characterised by smooth areas and throughs (VKI 2003: 90, Fig. 72).

[13] At several historical Himalayan sites a two-layer plaster was detected.

[14] At recent restorations at the monastery of Alchi, for the interior plaster three layers, mixed with straw, were added. Their thickness decreases towards the upper surface. The size of layers was given as: Layer 1 = 5 mm to 8 mm; layer 2 = 3 mm to 4 mm; layer 3 = 1 mm to 2 mm (Interview with Sanjay Dhar, January 2003; Feiglstorfer 2002: 21).

we concentrate our particular research on the ground layer (e.g. content of straw) and the upper layer (e.g. ground for sub-layer for whitewashing or adding colours).

To get an idea of differently used standards in the preparation of a wall plaster, a sample of an exterior plaster along the northern *cella* wall of the main temple was collected. In this case the plaster shows a much higher amount of straw, which detached from the lower part of the wall (sample 15406). This was not the case at any other plaster within this structure.

A further question that arises in relation with plasters, in particular interior plasters, concerns the use of colours. The present research is focused on clay. For technical reasons clay samples were not separated from adjoining layers, in particular sub-layers used for colours. According to the conducted research we may mention different possibilities for the preparation of a white layer as sub-layer for the addition of colours. At some parts of the Nyarma temples, e.g. in the *cella* of the main temple, remains of wall paintings are still visible.[15] Many surface areas do not show any painting remains visible to the naked eye. Such occurrences potentially have different reasons.

A practical reason would be that these seemingly uncoloured portions of the temple have been exposed to natural weathering due to a missing roof. Today, for example the *cella of the main temple* is covered with a roof. We have no evidence of when this portion of the main temple was covered with a roof. Due to the rough fabrication of the subconstruction of the existing roof within such a representative structure and a second storey added at a later phase, we can assume that this roof was a later addition to the original structure. This means that weathering over the last centuries is most likely a reason for a deterioration of the colours and also their sub-layers.

Another reason may be that there was a difference in a particular use of temple spaces for the decision to use colours as a monochrome surface or as a polychrome painting. From an art historical approach, this question is of interest since according to one hypothesis, in a very early state, instead of wall paintings, mobile pictures – probably *thanka*s – covered the walls of the main temple (cf. Feiglstorfer 2011: 117). For the deterioration of colour pigments we have to search beyond the mineral analytic methods, which are the core of the whole study.

In the whole temple area the aureoles (*halo*s) in the assembly hall and in the *cella* are the only clay-modelled ornaments. The sizes of the two types of aureoles in the assembly hall show the following dimensions (cf. Feiglstorfer, forthcoming b).

---

[15] From reports on wall conservations we know about the use of white layers made of kaolin, gypsum or calcite as sub-layer for paintings. For the original paintings at Nako Monastery in Upper Kinnaur, reaching back to the 12th century, gypsum was used (cf. Bayerová 2014). At recent restorations at the monastery of Alchi, for the interior plaster, upon the third layer of plaster a white colour was applied, which was either prepared of kaolin or lime. This white colour was stabilised with a glue prepared of yak skin (Interview with Sanjay Dhar, January 2003; Feiglstorfer 2002: 21). The choice between gypsum and a carbonatic ground is mainly dependent on the local availabilty of the particular raw material. In the side valley of the Spiti River towards Giu, for example, gypsum is available, which is used in Spiti and Upper Kinnaur. For the white wash of village houses like in Tabo villagers quarry gypsum in this valley.

- Aureole on the west wall: 65/65 cm (width/height) at the upper portion and of about 110/82 cm at the lower portion. Dimension of the profile of the aureole: 12/2 cm (width/height).
- Aureole on the east wall: 74/87 cm (width/height) at the upper portion and of about 160/206 cm at the lower portion. Dimension of the profile of the aureole: 10/8 cm (width/height) at the upper portion and about 15.5/5 cm at the lower portion. They are attached to the adobe brick wall with a relatively strong binding. Some parts are already missing and others are in a rather deteriorated state.

Concerning the constructive and material aspect, we find such clay modelled aureoles in particular in the early temples in the Western Himalayas, such as Nyarma, Tabo or Ropa. In later periods aureoles were painted onto the wall and no longer modelled. To adjust ornaments, such as the ring of flames on the already modelled aureole, methods such as additional modelling or painting were applied. In the case of Nyarma, the aureoles were plastered onto the wall. Since these examples are in general still intact, it is not possible to say at this point whether this was the same at other early sites, like Tabo, or if these aureoles were additionally fixed with wooden components (e.g. sticks).

In Nyarma the method of attaching aureoles to the wall must have been similar to attaching a plaster since no sticks for holes at places of missing parts of the aureoles could be found. Comparing the basic material of the plaster with the one used for an aureole might strengthen this hypothesis. Since the aureole in the *cella* also shows remains of colours, we encounter the question of whether the aureol's surface was treated in the same manner as the plaster (e.g. by burnishing). As we will see in the following, different treatment of these surfaces may have been a reason for the choice of different qualities of clay.

According to a today's Western categorisation, the craft for modelling such an aureole is close to the craft of modelling religious sculptures of clay in general but is still related to a mason's understanding of the behaviour of a plaster in relation to the adobe wall below. The size of the profiling is set in proportion to the profile of the whole aureole, and the size of the aureoles is related to their position in the whole assembly hall. The two aureoles flanking the eastern gate of the assembly hall, which is walled today, are much bigger and accordingly modelled with a bigger profile. The remaining aureoles along the west wall are much smaller, closer to each other and modelled with a smaller profile. The profile of each of these two types of profiles is similar as far as one may state after a long period of weathering. The profile of the aureole on the rear wall inside the *cella* of the main temple is widely damaged. Similar to the application of plaster, the modelling of these aureoles may have taken place in situ in a still not dried state using a template by prefabricating single parts and attaching them.

### 1.4 The method of desludging

Desludging can be used for separating different grain size fractions within one type of clay – i.e. changing the grain size fractions of a clay without adding a second type of clay. It is commonly used in pottery. Historical evidence for the production of plasters in the Himalayan cultural zone is not known.[16] On the other hand we do not know much about the building practices about 1,000 years ago in the Himalayas in general and can not exclude the use of this technique. For the builders of the main temple of the first West Tibetan monastery we may expect that the latest technical developments were used to achieve the highest material quality.

As stated with the following observation, the use of raw material without any further material addition can not be excluded, in particular for the production of bricks and ground layers of plasters. On the other hand, for processing the upper layer of plasters, the raw material was manipulated in such a way that mixing was just partially conducted, though this does not completely explain the given material results of this study. Since historical evidence from the Himalayas on the use of the method of desludging is missing, comparative historical examples of desludging from other countries will be given in the following. For conducting the method of desludging, the vicinity to water, which is needed in a large amount, is necessary. In the Himalayas water is scarce at higher altitudes except in close vicinity to rivers. Regarding the position of early monastery foundations in the Western Himalayas, the building site was chosen close to water resources as mentioned before. In Nyarma, for instance, a lake is adjacent to the monastery structures.

The material was mixed with water in a pit and, according to the Stokes' Law, the bigger grains sank faster than the smaller ones. The latter were skimmed off after a particular amount of time of setting, which must have been estimated by feeling since measuring tools in today's technical understanding can be excluded. The naturally resulting time blur may be the reason for slight differences in the grain size distributions, as we will see at later samples of interior plasters. But in general their basic features remain constant.

In summary, the latter hypothesis of using the method of desludging can be emphasised by several aspects and further examinations:

1) A comparison of the grain size distribution curve of sample 6073 of the upper most layer of the plaster with samples from a full plaster compound, coarse and fine layer, e.g. sample 11745.
2) The essentially easy and efficient approach using the same material for two different purposes, i.e. coarse and fine layer, which is less labour intensive than sieving and mixing.

From a practical point of view the workers must have been very competent in preparing this finer upper plaster regarding factors like separating the material at the right time or plastering in dark rooms. Plastering in the interior (i.e. dark rooms lit by candles) where the difference in temperature between day and night is lower than outside the building compared to exterior plasters enables a homogenous surface without cracks, despite a relatively high content of clay.

---

[16] According to Maïni Satprem the use of a sieve is widely common in India, but he does not give any historical data (Conversation Maïni Satprem 2015). He also mentions that separation by using basins of different levels is traditionally not known to produce building materials.

The separation of coarse material so as to extract the finer fractions for building purposes, such as plasters, aureoles or sculptures, is based on one raw material in its pure and unmanipulated form; on the one hand for adobe bricks and in its extracted form for finer purposes like the plaster (or at least for the upper and finer layer of a plaster). On the other hand desludging enables the extraction of a continuous relatively fine and homogenous fraction (Noll 1991: 75). A too fine sludge (i.e. with a too high amount of clay and not enough sand) caused by too fine desludging would increase the risk of cracks when shrinking, particularly when the clay minerals are swellable. This is the case in samples with a content of smectite.

The method of desludging to reduce the amount of grains of coarse fractions – in particular gravel and sand – has a historically long tradition, in particular in advanced civilisations. For ancient times, desludging is known to separate the clay from coarse impurities in big water basins. Heavy and coarse minerals are deposited on the bottom, and light components are used as slurry with a preference for the medium coarse deposits as the base material to be used in further steps (Rösch et al. 2010: 8). The Old Romans differentiated between the *tegularius,* who produced roof tiles (*tegula*) and the *laterarius,* who produced adobe bricks (*later crudis*) and fired bricks (*later coctus*), and they (Rupp, Günther 1993: 5) knew about the finishing of the surface with engobe for the *terra sigillata*. Most probably the clay, which was used by the Attic potters, was desludged before the next steps of processing – setting the proper moisture level, beating or stepping on it and kneading (Hofmann 1966: 32). To avoid the fabrication of metal sieves, the use of reed and cane, as known from south Italy, is an option for an early method of constructing a sieve. The simplest but also most time consuming method is the repeated decomposition of the watered clay in smaller pieces and picking out of the coarse pieces by hand (Noll 1991: 75). Noll also mentions the early use of such techniques in Mesopotamia, Crete and very early examples in the Neolithic era where the whole body of the ceramics was made of such finely prepared clay (ibid. 75). The simplest form is to dig up the clay, leave it in the pit, add water and stir it intensely before letting it set. Most of the coarse grains find themselves on the ground, and by feeling one can skim off as much material as needed – the deeper one skims, the coarser the clay. The skimmed clay can be collected in ceramic pots or baskets. Instead of skimming the fine fraction in a still wet state, the desludged clay can be dried and cut out as blocks for a further use.

A more advanced technique is the building of several basins beside each other. Noll (1991: 77) refers to Hangst (1979)[17] who mentions such basins for potters in historic times in the Fayum Oasis in Egypt. They were dug into the ground, and by this show a simple form of this technique. In Ancient Egypt and still today, clay from the Nile was and is used for preparing bricks without sieving or desludging of the raw material. Building structures made of this material are in the span of about one generation relatively short living (Rupp, Günther 1993: 8) but on the other hand the effort and costs for transport are rather low.

In the German language we know the term *Schlammziegel* (Ger. *Schlamm* = “mud” or “sludge”, Ger. *Ziegel* = “brick”), which is a handmade brick unfired as well as fired and made of the alluvial raw material found along rivers. This refers to the afore mentioned desludged material along the shore of the Nile, the so called *Schlammziegel*. In several civilisations, rivers are the source of

---

[17] This publication, which was searched by the interlibrary loan of the TUW could not be found. Also a search at the University of Cologne remained without result.

the production of a big amount of *Schlammziegel*, especially the Nile, the Euphrates and Tigris or the Indus (Bender 1995: 242). In this regard we should not exclude the possibility that the lake in Nyarma – whose size at the time of the foundation of the temple in 996 CE is not known – was used in connection with a desludging process. Rivers may also have been the source of raw material or may at least have been involved in a desludging process. With the lake the builders benefitted from close accessibility to water, which is indeed an important factor in the preparation of adobe bricks.

The fineness of the raw material needed for preparing an engobe[18] (but not necessarily its relatively high moisture content) is comparable with the material needed for processing a proper base material for an interior plaster. The traditional method of desludging for gaining the proper material is relatively similar. In the 19th century the method of desludging – with a steadily increasing technological effort – is still widely used for cleaning and preparing raw material for fired bricks, in particular for facing stones or clay tubes (Heusinger von Waldegg 1867: 74). Heusinger describes a simple version by making a hole in the ground, and filling it with water of app. double the height of the clay. With harrows and knives the clay is stirred till it has dispersed completely. Within one minute after stirring the bigger grains sink to the ground and the clay has to be desludged into a basin (ibid. 76). There are different ways to desludge. Sax mentions the method of soaking clay in containers, stirring it up and adding as much water as possible until liquefaction occurs (Sax 1814: 29, §55). Thereafter the suspension is put into another container with a hole in its bottom and a sink below (ibid.). Another method is desludging in a pot of water with a rubbing stone on its ground. When turning the stone, several particles are ground. The finest sink to the ground and will be decanted with the uppermost part of the suspension (Schmitts 1826: 365). The easiest way to increase the content of clay is to use a powdery and dry or a crumbly and semi-dry (Ger. *erdfeucht*) base material, which is put in containers filled with water and stirred with stirring tools. Oblong troughs and rake-like tools are suitable (Minke 1995: 69).[19]

The more often the desludging process is conducted, the longer the whole process lasts. Further, when the sludge skimming process occurs at a less deep level, the material is of a finer and better quality (Mohr 1875: 197). Skimming off and leaving it to overflow into another container may conduct the process of desludging. Containers and particularly pits made for desludging can be used for further steps in processing the clay, like stepping on it and also mixing it with other types of clay and additives, such as sand or straw. Processing clay by stomping was already conducted in Ancient Egypt, as we know from paintings (Rupp, Günther 1993: 12). Also the former use of animals must be regarded.

---

[18] Engobe is used in a possibly fluid constitution while on the contrary the raw material for the plaster has to be applied with a much less amount of moisture. For this reason, for the use as engobe the sludge is skimmed off, while for the use as plaster it has to be pre-dried under the sun or mixed with dry material. According to Kienow, engobes are relatively fine desludged grain fractions of early sintering, mostly of illite and kaolinite clay and he mentions as examples the Roman Terra Sigillata and paintings on Greek vases (Kienow 1970: 308). Complementary to the statement given by Kienow the author wants to add in the following way: The early sintering depends on the content of flow agents like ferro oxides or feldspar. It may be expected that during the desludging process flow agents are transported into the desludged portion and become part of the engobe. Just the content of illite and kaolinite does not cause an early sintering.

[19] Minke mentions the method of (Ger.) *Aufschlämmen,* which in this contribution is mentioned as desludging. This would correlate with *Abschlämmen* in a German translation.

All the mentioned methods do not have a direct relation with the methods used in the Himalayas but give an overview about wide spread historical use of this method. As long as we have no direct evidence of such methods from the Himalayan sites, a kind of experimental archaeology seems to be a helpful approach.

## 2. Research questions

The generally posed research questions as given in the Introduction are adjusted to the research topic of Chapter II in the following way:

- Research question 1: Are there any material qualities to categorise clay used at the Nyarma Monastery?
- Research question 2: Are the particular material qualities related to specific components of the Nyarma Monastery structures?
- Research question 3: What are the material qualities that support the use of commonly used clay in Nyarma for particular building purposes?
- Research question 4: Which relations are given between the single temple structures regarding their mineral compositions?
- Research question 5: What are the geological parameters of the material used at the Nyarma Monastery?

## 3. Origin of the samples

The author collected the samples at different clay pits and from new bricks as well as from debris lying on the ground at various spots along the structures of the Nyarma Monastery and whose original place within the structure was evident (Table 1.2). The samples are categorised in the following way.

- Clay pits
- New adobe bricks
- Historical adobe bricks
- Interior wall plasters
- Exterior wall plasters

Table 1.2 List of the samples.

| **Sample** | **Use** | **Use in detail** | **Location** | **Local name** |
|---|---|---|---|---|
| **Clay pits** | | | | |
| 11754 | raw material | used for bricks | Nyarma | *zhing sa* |
| 11956 | raw material | used for bricks | Nyarma | *zhing sa* |
| **New adobe bricks** | | | | |
| 8505 | brick | --- | Nyarma | *zhing sa* |
| 11947 | brick | --- | Thikse | *zhing sa* |

| **Sample** | **Use** | **Use in detail** | **Sttructure** | **Position in detail** |
|---|---|---|---|---|
| **Historical adobe bricks** | | | | |
| 11767 | adobe brick | --- | Temple I | assembly hall; reveal towards inner ambulatory |
| 8509 | adobe brick | --- | Temple II | assembly hall; door reveal |
| 11750 | adobe brick | --- | Temple II | assembly hall; door reveal |
| 11926 | adobe brick | --- | Temple IIIa | door reveal |
| 11744 | adobe brick | --- | Temple IIIb | door reveal |
| 8533 | adobe brick | --- | Temple IIIb | door reveal |
| 15407 | adobe brick | --- | Temple IV | assembly hall; door reveal |
| 11917 | adobe brick | --- | Temple IV | assembly hall; door reveal |
| 11765 | adobe brick | --- | Temple VIa | door reveal next to assembly hall |
| 11760 | adobe brick | --- | Temple VIb | door reveal next to assembly hall |
| 11766 | adobe brick | --- | Enclosure wall | east side; final part towards north |
| **Interior wall plasters** | | | | |
| 6073 | int. plaster | upper layer | Temple I | cella |
| 11745 | int. plaster | ground + upper layer | Temple I | cella |
| 11753 | int. plaster | ground + upper layer | Temple I | cella |
| 11925 | int. plaster | ground + upper layer | Temple I | cella |
| 11918 | int. plaster | ground + upper layer | Temple I | assembly hall; beside aureole east gate |
| 8531 | int. plaster | ground + upper layer | Temple I | assembly hall; beside aureole |
| 8514 | int. plaster | ground + upper layer | Temple IIIa | left hand wall when entering |
| 15406 | int. plaster | upper layer | Temple IV | assembly hall |
| 8517 | int. plaster | ground layer | Temple IV | assembly hall |
| 11761 | int. plaster | ground + upper layer | Temple V | south temple attached to Temple I |
| 8532 | int. plaster | ground layer | Stupa | |
| 8520 | int. plaster | upper layer | Stupa | |
| 15405 | wall frieze | | Stupa | |
| 8522 | aureole | ground layer | Temple I | assembly hall |
| 8516 | aureole | upper layer | Temple I | assembly hall |
| **Exterior wall plasters** | | | | |
| 11914 | ext. plaster | | Temple I | cella; north wall |
| 11762 | ext. plaster | Ground + upper layer | Temple I | ambulatorium; south wall |
| 15408 | ext. plaster | Ground + upper layer | Temple IIIb | exterior wall; entrance left hand |
| 8519 | ext. plaster | Ground + upper layer | Temple IV | exterior wall; entrance left hand |

## 4. MINERAL ANALYSIS

### 4.1 Clay pits

### CLAY PIT. SAMPLE 11754

Sampling point

Clay used in the village from a still used clay pit along the road linking the Nyarma temple site and the main road to Leh. Sample number in the field: 38 (Fig. 8.2, clay pit see Fig. 3.2 and Fig. 4.2). Constructive use: A*dobe brick*. Sample colour: This sample shows no red colour, contrary to most of the samples from Nyarma.

Fig. 8.2 Nyarma. Sample 11754.
Sample colour (after Munsell):
Dry 5YR 5/2 olive grey.
Semi-dry 5YR 3/2 dark olive grey.

Grain size distribution

The material is relatively coarse. Biggest fraction: fine gravel. The median is located at app.180 µm; the <2 µm fraction contains app. 11% of the whole sample. The coarse fractions >63 µm (sand + gravel) are together about 73% of the whole material with a relatively high content in all of the three sand fractions and a relatively low content of silt and clay. The grain size distribution curve shows a sharp break from fine sand to coarse silt, which is a possible indication for a material mixture.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 11754 | 6.5 | 65.9 | 17.0 | 10.6 |

Grain shapes

The grain shapes measured in the fractions >2,000 µm, >630 µm and >200 µm have a dominance of "angular shaped". There is no evidence pointing towards a mixture. The grain shapes also show the slightly less rounding of bigger grains (e.g. quartz and feldspar) and a slightly more rounding of the smaller grains (e.g. mica) (Fig. 9.2).

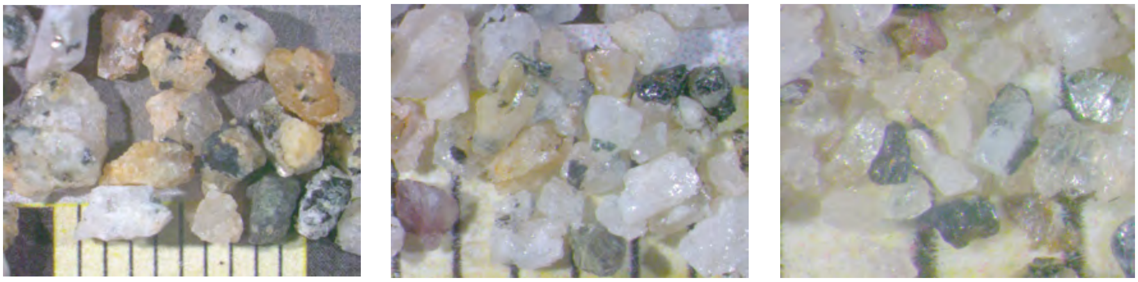


Fig. 9.2 Shapes of grains in sample 11754. Scaled in millimetre.
Shape of fraction >2,000 µm (Left), 630–2,000 µm (Centre), 200–630 µm (Right).

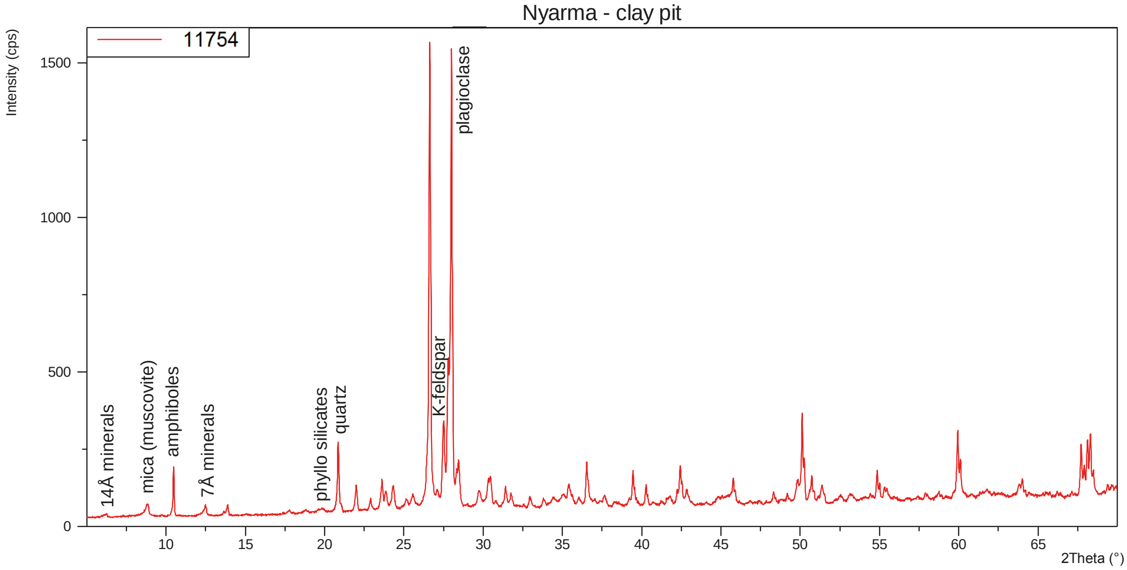


Fig. 10. 2 Nyarma. BMA. Clay pit. Sample 11754.

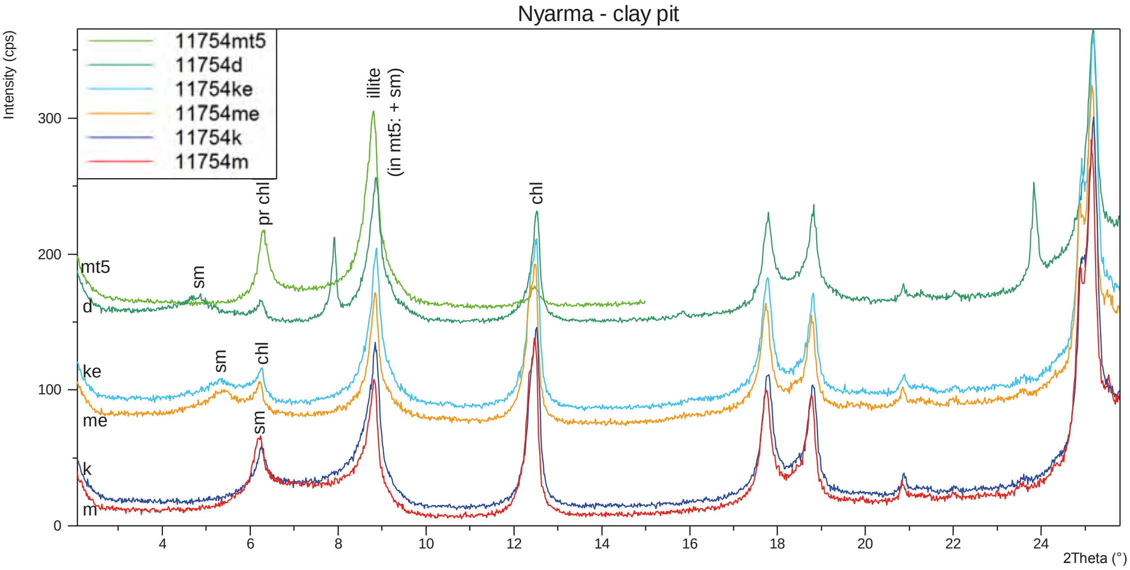


Fig. 11.2 Nyarma. CMA. Clay pit. Sample 11754.

### Bulk and clay mineral analysis

The BMA follows the average values of the Nyarma series (Fig. 10.2): 14Å minerals, mica, 7Å minerals and phyllo silicates are available as traces; amphiboles, quartz, and K-feldspar are found in a small amount (in the Table 4.2 marked with (*)), and plagioclase is present in a high amount (marked in Table 4.2 with (***)). No calcite or gypsum is available.

The CMA shows a small content of swellable minerals, a small content of kaolinite, a medium content of chlorite and a high content of illite. This clay mineral content follows an average amount within the Nyarma samples as given in brackets (Fig. 11.2).

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 11754 | 5 | 65 | 8 | 22 |
| Sample average | (2–10) | (59–69) | (5–12) | (18–30) |

## CLAY PIT. SAMPLE 11956

### Sampling point

Clay used in the village from an active clay pit in a private garden along the road linking the Nyarma temple site and the main road to Leh; the clay pit is not identical to sample 11754. Sample number in the field: 10 (Fig. 12.2). Constructive use: Adobe brick. Compared with samples 11754 (clay pit) and 8505 (new adobe brick), it is the only finding of a small piece of coal.

Fig. 12.2 Nyarma. Sample 11956.
Sample colour (after Munsell):
Dry 10YR 6/1 grey.
Semi-dry 10YR 3/1 very dark grey.

### Grain size distribution

The material is relatively coarse. Biggest fraction: fine gravel. The distribution is similar to sample 11754. The median is located at app. 95.0 µm which is finer than sample 11754 due to a higher amount of fine material, i.e. silt and clay; the <2 µm fraction contains app. 15% of the whole sample. The fractions >63 µm are together about 58% of the whole material. It shows a relatively high amount in all three sand fractions, similar to sample 11754, and also a relatively low content of silt and clay. The grain size distribution curve shows a sharp break from fine sand to coarse silt. The sharp break can be an indication of a material mixture, similar to sample 11754. The list below shows comparison with sample 11754. The grain shapes were determined according to Tucker (1985) with a dominance of “angular shaped”. No evidence for a material mixture with sand or another type of clay is given.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 11956 | 6.4 | 51.6 | 27.1 | 14.9 |
| 11754 | 6.5 | 65.9 | 17.0 | 10.6 |

### Bulk and clay mineral analysis

The BMA shows a strong similarity to the clay pit afore (sample 11754). Only plagioclase appears in a medium amount (**), smaller than for sample 11754, and traces of haematite are available. No calcite and gypsum could be traced. The colour compared to sample 11754 this sample 11956 leans towards grey with a less amount of olive and a slight red colouring due to traces of haematite. Small pieces of coal were found in this sample. The CMA shows similarities to the clay pit afore (sample 11754), as given in the list below. An average amount within the Nyarma samples is given in brackets.

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 11956 | 5 | 65 | 8 | 22 |
| 11754 | 3 | 62 | 10 | 25 |
| Samples average | (2–10) | (59–69) | (5–12) | (18–30) |

## 4.2 New adobe bricks

### NEW ADOBE BRICK. SAMPLE 8505

### Sampling point

Adobe brick from clay pit along the road linking the Nyarma temple site and the main road to Leh. Sample number in the field: 57 NY/LZ. Constructive use: Material used for recent adobe bricks. Sample colour (according to Munsell colour chart): Dry 5YR 6/2 light olive brown. Semi-dry 5YR 4/2 olive grey. Compared with samples 11754 and 11956, the olive and grey content remains significant. Similar to the clay pit-sample (11754), no red colour could be traced. No additives are available.

### Grain size distribution

The material is relatively coarse. Biggest fraction: fine gravel. The median is located at app. 98 µm; the <2 µm fraction contains app. 12% of the whole sample with a relatively high content of coarse and medium sand and a high amount of silt and clay. The fractions >630 µm (>coarse silt) are together 58.2% of the whole material. The grain size distribution curve shows a break from medium sand to fine sand; no features for a possible indication for a material mixture with sand or another type of clay are visible. The list below shows similarities with sample 11956 which originates from a clay pit.

|  | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 8505 | 3.9 | 54.3 | 28.7 | 13.1 |
| 11956 | 6.4 | 51.6 | 27.1 | 14.9 |

### Grain shapes

The grain shapes >200 µm show a dominance of "angular". This fact goes hand-in-hand with the grain size distribution. Since the valley in the grain size distribution (i.e. a bimodal distribution) is below 200 µm, a further statement concerning a potential mixture with sand or another type of clay can not be given by observing the grain shapes. The similarity between brick sample 8505 and the samples of the clay bricks emphasises the hypothesis that the used brick material was directly taken from the pit (Fig. 13.2).

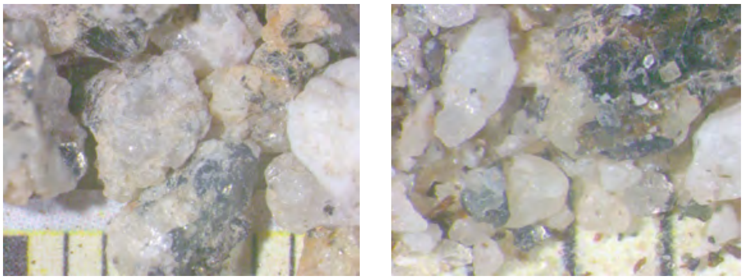


Fig. 13.2 Shapes of grains in sample 8505.
Scaled in millimetre.
Shape of fraction >2,000 µm (Left), 40–2,000 µm (Right).

### Bulk and clay mineral analysis

Compared with samples 11754 and 11956 the content of bulk minerals is rather similar. Also the CMA shows similarities to the clay pits afore (samples 11754 and 11956) as shown in the list below. An average amount within the Nyarma samples is given in brackets.

|  | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 8505 | 8 | 59 | 8 | 25 |
| 11754 | 3 | 62 | 10 | 25 |
| 11956 | 5 | 65 | 8 | 22 |
| Samples average | (2–10) | (59–69) | (5–12) | (18–30) |

## New adobe brick. Sample 11947

### Sampling point

Adobe brick from Thikse prepared from *field clay* (*shingsa*), given to the author by Deldan Angmo in Mangyu. At that time of research, Deldan Angmo was a Senior Conservation Architect at INTACH (Indian National Trust for Art and Cultural Heritage). Sample number in the field: 58 Thikse (Fig. 14.2). Constructive use: Recently prepared adobe bricks. No additives are available. Within the sample a several centimetres long piece of wood remained. There are no further traces of any organic additive.

Fig. 14.2 Nyarma. Sample 11947.
Sample colour (after Munsell):
Dry 10YR 6/2 light brownish grey.
Semi-dry 10YR 3/2 very dark greyish brown.

## Grain size distribution

The material is relatively coarse. Biggest fraction: fine gravel. The median is located at app. 110 µm; the <2 µm fraction contains app. 12% of the whole sample with a relatively high amount of fine gravel and sand, similar to clay pit sample 119576 (see list below). The fractions >63 µm are together about 60% of the whole material. The grain size distribution is similar to clay pit-sample 11754 and particularly similar to sample 11956. With this sample we can state that the recently made adobe brick equals the material directly taken from the clay pit. Since it is processed *field clay*, we can also state that this raw material was taken out of the pit and processed either without further mixing or with a relatively similar addition of coarse material >63 µm. This would also explain the break in the grain size distribution for sample 8505 in the 63 to 200 µm-fraction. In sample 11956 and present sample 11947, a small amount of medium gravel is present.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 11947 | 9.3 | 50.9 | 28.4 | 11.4 |
| 11754 | 6.5 | 65.9 | 17.0 | 10.6 |
| 11956 | 6.4 | 51.6 | 27.1 | 14.9 |

## Grain shapes

The grain shapes show a dominance of “angular”. This fact goes hand-in-hand with the afore mentioned evaluations of samples 11754, 11956 and 8505. This means that within the sand and gravel fractions, adding of a coarse material would not have occurred.

## Bulk and clay mineral analysis

Except for showing traces of calcite, the bulk mineral analysis is very similar to clay pit-sample 11754, and aside from this amount of calcite, it is also very similar to pit sample 11956. Compared with samples 11754 and 11956, the olive and grey content remains significant. The red appearance due to the content of traces of haematite is also similar to clay pit sample 11956. The CMA shows similarities to the previous clay pits (samples 11754 and 11956) and also to brick sample 8505, as given in the list below. An average amount within the Nyarma samples is given in brackets.

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 11947 | 2 | 62 | 10 | 26 |
| 11754 | 3 | 62 | 10 | 25 |
| Samples average | (2–10) | (59–69) | (5–12) | (18–30) |

### 4.3 Historical adobe bricks

For the study of adobe bricks, which were used in the monastery of Nyarma, the following samples were collected mainly along the reveal of the entrance to the single structures.

#### Origin of the samples

- Temple I – Sample 11767: Assembly hall, wall between assembly hall and inner ambulatory. Sample number in the field: 13.
- Temple II – Sample 8509: Sample from along the entrance. Sample number in the field: 58 NY-RZ/LZ.
- Temple II – Sample 11750: Sample from along the entrance. Sample number in the field: 8.
- Temple IIIa – Sample 11926: Sample from the reveal of the entrance. Sample number in the field: 36.
- Temple IIIb – Sample 11744: Sample from the reveal of the entrance. Sample number in the field: 37.
- Temple IIIb – Sample 8533: Sample from the reveal of the entrance. Sample number in the field: 64 NY-RZ/LZ.
- Temple IV – Sample 15407: Sample from the reveal of the entrance. Sample number in the field: 61 NY-RZ/LZ.
- Temple IV – Sample 11917: Sample from the reveal of the entrance. Sample number in the field: 18.
- Temple VIa – Sample 11765: Sample from the reveal of the entrance, left hand side with view from outside towards the temple. Sample number in the field: 7.
- Temple VIb – Sample 11760: Sample from the reveal of the entrance, left hand side with view from outside towards the temple. Sample number in the field: 17.
- Enclosure wall of the temple compound – Sample 11766: Sample from the eastern end of the wall pointing north. Sample number in the field: 14.

#### Grain size distribution

Compared to the average values of examined original adobe bricks, the material follows a clear pattern. All samples contain a small amount of gravel, ranging between 1.3% and 12.2%. The strongest fraction is sand, ranging between 40.6% and 64.5%, with app. 54% as the average value. Silt is the second strongest fraction, ranging between 19.4% and 37.7%, with app. 25% as the average value. The clay fraction ranges between 10% and 20.8%, with app. 15% as the average value. The material is relatively coarse. Biggest fraction: fine/medium gravel. The medians are located between app. 28 µm and 180 µm, on average app. 108 µm; the <2 µm fraction contains between app. 10% and 21%, on average app. 15%. The grain size distribution curves show in most cases a sharp break from the sand to the silt fraction which points towards a possible addition of coarse material. Comparing the grain size distribution of single bricks with each other shows the following result:

- Brick sample 11767 from the main temple shows clear similarity to the sample from Temple VIa (sample 11765) and the samples of Temples IIIa and IIIb (samples 8533, 11744 and 11926). The sample from the main temple is slightly coarser. The mineral content below 2 µm ranges between 15% and 21%, their content of clay between 14.9% and 20.8%, their content of silt between 22.9% and 37.7%. The content of sand ranges between 40.6% and 55.9%.

- The material used at Temple VIb, which also belongs to the main temple, does not match with the result of the main temple. With a median of 130 µm it is much coarser than the material of the main temple with 55 µm. The mineral content below 2 µm of the material from Temple VIb shows a value of 10%, contrary to 18% at the main temple. At the main temple the content of sand is around 45.4% while at Temple VIb it is around 60.4%. The material from Temple VIb contains not only fine but also medium gravel.

- The sample from Temple II shows slight differences to the material from the main temple. In particular, at 35.1% the content of silt for the sample from the main temple is higher than at Temple IV with 19.4% and 21.9%. On the other hand the rates for the content of clay are close to each other. Their mineral content below 2 µm ranges from 18% for the sample from the main temple to 13% and 14% for the samples from Temple IV.

- A clear difference is stated between the sample of the main temple and the brick sample of Temple II. Primarily the content of clay at 10.8% and 11.5% for the sample of Temple II is clearly below 16.7% of the main temple, and at 56.3% and 57.3% the content of sand is clearly higher than at the main temple with 45.4%.

- A similarity is stated between the samples of the main temple and the sample of Temple IIIa, in particular between Temple IIIa (sample 11926) and Temple IIIb (samples 11744 and 8533). Their content of sand ranges between 50.2% and 55.9%, their content of silt ranges between 22.9% and 25.7%, and their content of clay is between 14.9% and 20.8%. Their mineral content below 2 µm ranges between 15% and 21%.

- Comparing Temple II and Temple III, their rates are relatively close to those of Temple IIIa, closer than to Temple IIIb. Their content of sand ranges between 55.9% and 57.3%, silt ranges between 20.4% and 25.5%, and clay ranges between 10.8% and 14.9%. Their mineral content below 2 µm ranges between 11% and 15%.

- Also the brick samples of Temple II and of Temple IV show a close relation. Their content of sand ranges between 49.9% and 59.7%, silt ranges between 19.4% and 25.5% and clay ranges between 10.8% and 13.6%. Their mineral content below 2 µm ranges between 11% and 14%.

- The brick material of Temples IIIa and IIIb and the material of Temple IV are also close to each other. Their content of sand ranges between 49.9% and 59.7%, silt ranges between 19.4% and 25.7% and clay ranges between 13.3% and 20.8%. Their mineral content below 2 µm ranges between 13% and 21%.

- With a median at 180 µm, the enclosure wall shows the coarsest sample. At 64.5%, the content of sand has the highest value for sand. Nevertheless it shows some similarities to all the temples excluding the main temple and the related Temple VIa.

In Table 2.2 the two clay pit samples are included. This juxtaposition of grain size distributions makes clear that all the samples – except samples 11767 from the main temple and 11765 from the Temple VIa, which is attached to the main temple – use the raw material directly from the clay pit, possibly without or with minimal manipulation. The samples from the main temple and from Temple VIa show a reduced content of sand and an increased content of silt and clay. Grain sizes of up to 18 mm, as in samples 11750 and 11926, are available.

Table 2.2 Grain size distribution of historical adobe bricks compared with clay pits.

| Sample | Gravel | Sand | Silt | Clay |
|---|---|---|---|---|
| 11754 | 6.5 | 65.9 | 17.0 | 10.6 |
| 11956 | 6.4 | 51.6 | 27.1 | 14.9 |
| 11767 | 2.8 | 45.4 | 35.1 | 16.7 |
| 8509 | 5.7 | 57.3 | 25.5 | 11.5 |
| 11750 | 12.2 | 56.6 | 20.4 | 10.8 |
| 11926 | 6.3 | 55.9 | 22.9 | 14.9 |
| 11744 | 2.1 | 51.9 | 25.2 | 20.8 |
| 8533 | 7.2 | 50.2 | 25.7 | 16.9 |
| 15407 | 5.1 | 59.7 | 21.9 | 13.3 |
| 11917 | 7.1 | 49.9 | 19.4 | 13.6 |
| 11765 | 1.3 | 40.6 | 37.7 | 20.4 |
| 11760 | 5.9 | 60.4 | 23.7 | 10 |
| 11766 | 3.5 | 64.5 | 19.5 | 12.7 |

After comparison with samples from clay pits, it can be be determined if there is any relation between the mineral composition of the recently used material and the material used at the monastery. Samples 8505 and 11947, which originate from recent adobe bricks, are again rather similar to all samples except the sample from the main temple and the sample from Temple VIa. This may indicate that knowledge in using particular raw material is today still kept in the way as it was existent already at the time of erecting the monastery.

### Grain shapes

From the adobe brick-samples the grain shapes of seven samples were examined. These include samples 8509, 11744, 11750, 11760, 11766, 11767 and 11926. All these samples show a dominance of "angular" without any considerable deviation.

### Bulk mineral analysis

The results of the BMA show strong similarities to the mineralogical composition of the samples of Nyarma in general. 14Å minerals appear generally as traces, mica appears as traces or in a small amount, amphiboles range between traces and a medium amount, 7Å minerals are found between traces and a small amount, phyllo silicates are generally found in trace amounts with one exception, quartz is generally found in a small amount, K-feldspar on average is noted in a small amount, and plagioclase appears with a rather high content in a medium or high amount. All samples except sample 11926 show traces of calcite, which may be part of the raw material or added as a small amount to the samples when mixing. The latter is a method that no longer has a tradition for preparing adobe bricks, as far as could be observed.

### Clay mineral analysis

A comparison of the interior wall plasters from the *cella* (‘Group-1’ (6073, 11745, 11753, 11925)), the interior wall plasters from the assembly hall (‘Group-2’ (11918, 8531, 11762)) and the clay mineral average data from clay pits (11754, 11956) shows close similarities. With ‘Group-3’ the average of CMA-data for all measured historical bricks is given. Similar to the BMA-results, the CMA-results are also too close to each other to trace clear differences. This similarity in the data clearly states that the raw material was used from within close vicinity or even from the same clay pit, and that its qualities have rather well been known already 1,000 years ago.

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| Ø Group-1 | 3–5 | 66–69 | 4–9 | 22–26 |
| Ø Group-2 | 4–9 | 66–67 | 6–7 | 19–23 |
| Ø Clay pits | 3–5 | 62–65 | 8–10 | 22–25 |
| Ø Group-3 | 2–5 | 59–68 | 6–8 | 21–30 |

### Sample colours (according to Munsell colour chart)

The colour of the different samples ranges between brownish grey, pale brown, light grey, pinkish grey in a dry state and between (dark) greyish brown and brown in a semi-dry state. Just a few samples show a slight reddish colour due to a content of haematite, especially sample 11744.

| | | | | |
|---|---|---|---|---|
| Temple I | 11767 | Dry | 2.5YR 6/2 | light brownish grey |
| | | Semi-dry | 2.5YR 4/2 | dark greyish brown |
| Temple II | 8509 | Dry | 2.5YR 6/2 | light brownish grey |
| | | Semi-dry | 2.5YR 3/2 | very dark greyish brown |
| Temple II | 11750 | Dry | 10YR 6/2 | light brownish grey |
| | | Semi-dry | 10YR 4/2 | dark greyish brown |
| Temple IIIa | 11926 | Dry | 10YR 6/2 | light brownish grey |
| | | Semi-dry | 10YR 5/3 | brown |
| Temple IIIb | 11744 | Dry | 10YR 6/3 | pale brown |
| | | Semi-dry | 10YR 4/3 | brown |
| Temple IIIb | 8533 | Dry | 10YR 7/2 | light grey |
| | | Semi-dry | 10YR 5/2 | greyish brown |
| Temple IV | 11917 | Dry | 7.5YR 6/2 | pinkish grey |
| | | Semi-dry | 7.5YR 4/2 | brown |
| Temple VIa | 11765 | Dry | 10YR 7/2 | light grey |
| | | Semi-dry | 10YR 5/2 | greyish brown |
| Temple VIb | 11760 | Dry | 2.5YR 6/2 | light brownish grey |
| | | Semi-dry | 2.5YR 4/2 | dark greyish brown |
| Enclosure wall of the temple compound 11766 | | | | |
| | | Dry | 10YR 6/2 | light brownish grey |
| | | Semi-dry | 10YR 4/2 | dark greyish brown |

### Additives

In general adding straw or any other organic additives was only found with one piece of straw of 2 cm length in sample 11767. For samples 11760 (Temple VIb) and 11766 (enclosure wall), very few pieces of straw with a length of up to app. 1 cm were found. These seem to be an exception.

## 4.4 Interior wall plasters

### 4.4.1 Wall plasters in the *cella* of the main temple

### *CELLA*. INTERIOR PLASTER. SAMPLE 6073

Sampling point

Temple I (Fig. 15.2, Fig. 16.2). Constructive use: Interior plaster, upper layer of the wall plaster. In the sample no additives are available (Fig. 17.2).[20] This points towards strengthening of the fine upper layer of the plaster not being necessary, probably also due to the extreme low difference in temperature between day and night inside the dark temple room resulting in reduced tensile stress in the plaster.

Fig. 15.2 Nyarma. Main temple. *Cella*. East elevation.

Grain size distribution

The material is relatively fine. Biggest fractions: medium and coarse sand. The median is located at app. 2.9 µm; the <2 µm fraction contains app. 38% of the whole sample, with a relatively high amount of fine silt and coarse clay. These two fractions contain together about 67% of the whole sample.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 6073 | 0 | 5.7 | 56.9 | 37.4 |
| 11745 | 0.9 | 19.7 | 39.2 | 40.2 |

---

[20] The sample was given to the author by Gerald Kozicz, an Austrian researcher, with a focus on architecture in Ladakh.

Fig. 16.2 (Left) Nyarma. Main temple. *Cella*. Remains of the aureole and wall paintings on the west wall (not identical with the sample origin).
Fig. 17.2 (Right) Nyarma. Sample 6073. Sample colour (after Munsell): Dry 2.5 Y 7/2 light grey. Semi-dry 2.5 Y 4/3 olive brown.

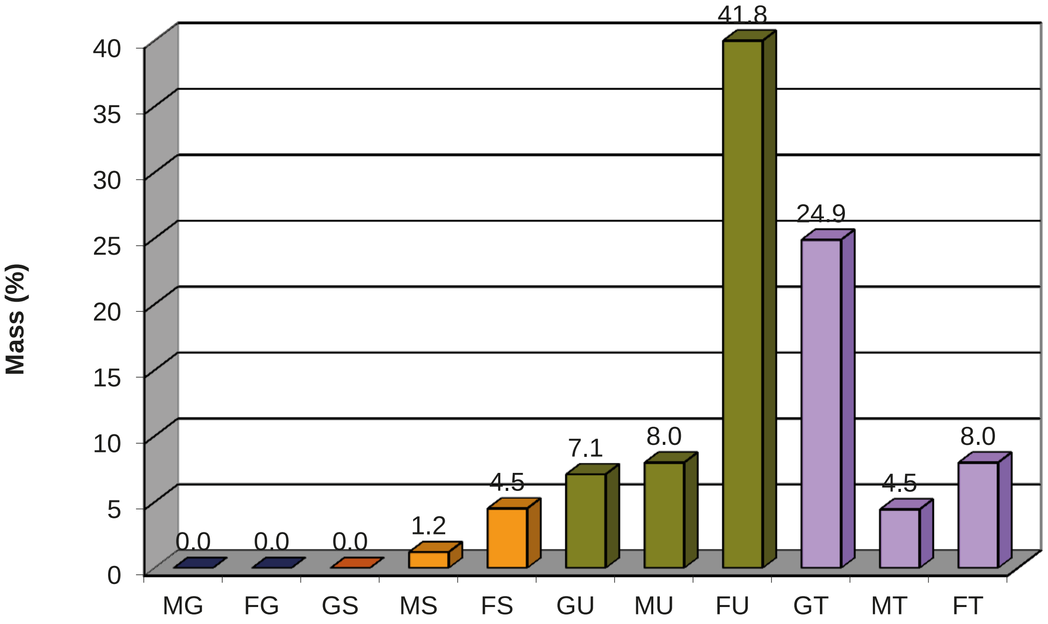
The grain size distribution curve shows a sharp break from medium silt to fine silt and a bimodal distribution marked by a valley between coarse and fine clay. The high amount of fine material and just traces of medium and fine sand, and the lack of coarse material might be evidence for manipulation of the raw material. The grain size distribution curve points towards a sieved raw material regarding further samples of the whole plaster (not only the upper layer). These samples in contrast show a further peak in the grain size distribution curve in the sand-fraction (Fig. 18.2 and Fig. 19.2).

The grain size distribution of further interior plaster samples, which show a clear peak in the coarse material, could also point towards a mixture of a very fine base material as used for sample 6073 with coarse fractions. This is the case for example at sample 11745 where the whole plaster (coarse and fine layer) was analysed.

These two versions can also be relativised by the high amount of phyllo silicates and the low amount of feldspar in sample 6073,[21] compared with, e.g. sample 11745. This indicates a separation of the fine fractions from the coarse (sandy) material. There are two ways to conduct this separation. One is by sieving. Up until now there is no evidence of the existence of sieves in the years around 1000 CE in the Himalayan region, in particular with a grain size of about 63 µm.

---

[21] Comparison on the basis of differences in the content of phyllo silicates and feldspar is only of relevance in the case that the raw material is more or less the same. Otherwise the difference can already be stated by different raw material sources. As we can see within this study, for the whole building site, the used raw material originates from the building site itself or within close vicinity.



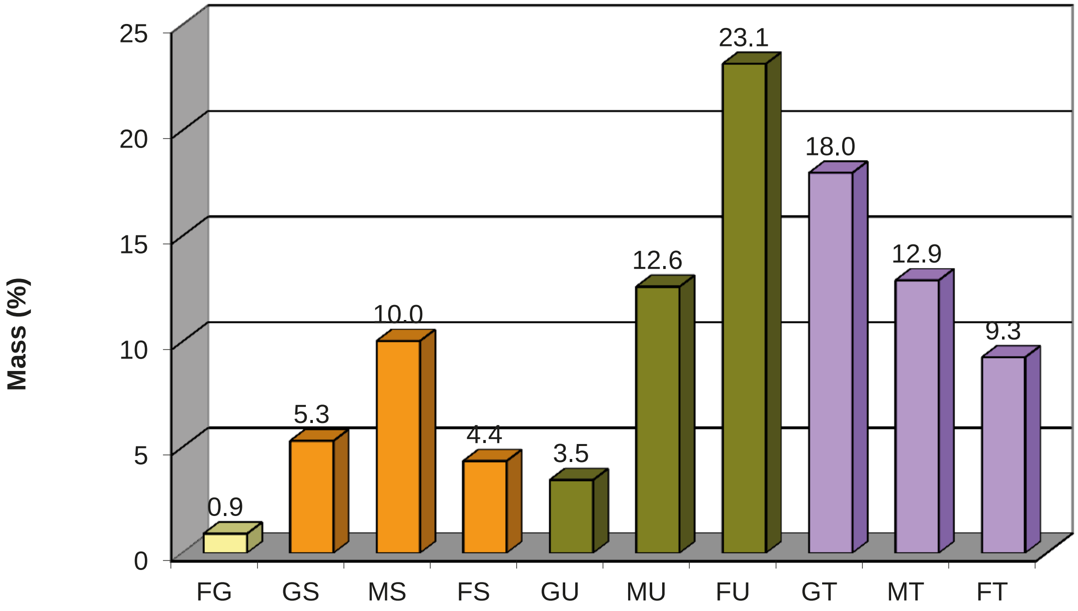


Fig. 18.2 (Top) Nyarma. GSD. Sample 6073.

Fig. 19.2 (Bottom) Nyarma. GSD. Sample 11745.

The existence of sieves made of wood or hair can not be excluded.[22] Therefore another practical method seems to be more likely, i.e. the method of desludging.

### Grain shapes

The biggest available fraction in this sample is medium sand which is "angular shaped". This result matches with most of the clay pit samples and also with the grain shapes of the medium sand-fraction of interior plasters in the *cella* (observed in the following). Due to the analysis of the grain size distribution (above), a mixture of different materials is unlikely.

### Bulk mineral analysis

In a small amount, the content of 14Å minerals is slightly increased in comparison to the whole Nyarma series (marked in the Table 4.2 with (*)). In a medium amount (**), the content of mica is slightly increased in comparison to the whole Nyarma series. In trace amounts (**), the content of amphiboles is slightly decreased in comparison to the whole Nyarma series. In a medium amount, the content of 7Å minerals is slightly increased in comparison to the whole Nyarma series, and phyllo silicates in a high amount (***) are strongly increased. K-feldspar, which occurs in traces, is slightly decreased. Gypsum is not available. The content of calcite was measured at 1.5%, in the Table 4.2 given with 2%.

### Clay mineral analysis

The CMA shows, strongly similar to other Nyarma samples, a small content of smectite and kaolinite, a medium content of chlorite and a high content of illite. The list below shows a juxtaposition of interior wall plasters from the *cella* ('Group-1' (6073, 11745, 11753, 11925)) and the clay mineral average data from clay pits (11754, 11956). Compared to an average of the Nyarma samples, the amount of smectite in this sample is at the lower end.

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 6073 | 3 | 66 | 9 | 22 |
| Ø Group-1 | 3–5 | 66–69 | 4–9 | 22–26 |
| Ø Clay pits | 3–5 | 62–65 | 8–10 | 22–25 |

---

[22] In Asia the use of a sieve has a historical relation to the production of paper. In Europe the use of metal mesh sieves followed construction with bamboo and reed in the Middle Ages (Tschudin 1996: 424ff). In Ancient Egypt, preparation of flour sieves made of hair or fine vines was known; this was also the case later on in the Greek and the Roman Empires (Lynch, Rowland 2005: 27). Brandon et al. (2014: 32) mention the use of sieves for rubble during Roman times. These facts give an impression of the relation of the development of sieves for particular processes, such as making of paper or bread, and do not completely exclude a possible presence of sieves for building purposes in the Himalayas. Nevertheless, empirically no evidence supports this hypothesis. In the Tibetan cultural zone, potters give indices for the use of scarves as sieves (cf. Feiglstorfer, forthcoming a).

## *CELLA*. INTERIOR PLASTER. SAMPLE 11745

### Sampling point

Temple I, *cella* in the main temple. Sample number in the field: 9. Constructive use: Interior plaster, ground and upper layer. Additives: Straw fibres with a length of 2 mm to 20 mm available in a relatively high amount. Pieces of straw with a length of up to 3 cm were found. Sample colour (after Munsell): dry 2.5 7/2 light grey; semi-dry 2.5 4/2 dark greyish brown.

### Grain size distribution

Samples 11754 and 11956 from two clay pits and also sample 6073 (a very fine upper layer of a plaster) are listed for comparison.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 11745 *Cella* | 0.9 | 19.7 | 39.2 | 40.2 |

The material is relatively fine with a small coarse content. Biggest fraction: fine gravel. The grain size distribution shows two peaks which is distinctive for most of the observed interior plasters used at the Nyarma temple site. With a median of 3.1 µm, the grain size distribution compared to the upper layer plaster sample 6073 shows a similarity to the upper layer plaster sample 6073 with 2.9 µm; the <2 µm fraction contains app. 40% (i.e. relatively fine) of the whole sample. The distribution in the silt and clay fractions is similar while the amount of sand is much higher resulting in the coarse content which is necessary for the coarse ground (=levelling) layer of the plaster. This means that for the ground layer a higher amount of sand was preferred. We find these characteristics in most of the interior plasters of the Nyarma temples and question the use of the desludging method.

### With this result we provide a first hypothesis

The base material of clay pit samples, which is presently still used for the production of adobe bricks, was used to prepare two different fractions: one for the coarse plaster and one for the fine plaster. In a first step after desludging, in order to obtain the coarse (ground) plaster (sample 11745), the amount of sand was just slightly reduced. In a second step after desludging, so as to receive the ground plaster, the amount of sand was reduced to traces (see “The method of desludging” in this chapter).

If the material was sieved, the net must have been relatively fine (as will be described in the following). Using the method of desludging out of a pit would mean that after stirring, the watered base material (relation between base material and water is app. 1:3) would have sunk towards the ground for about one minute. When skimming off the slurry, upper parts of the sand fraction were also skimmed, the time period of sinking after stirring was reduced to increase the amount of sand in the slurry, or – due to less time precision in 996 CE – both approaches were applied by feeling, i.e. the time of sinking and setting down of the sand fraction, and skimming off parts of the sand fraction was reduced. This approach is practicable but takes time and needs experience to gain a homogenous mixture.

### Grain shapes

The grain shapes show a dominance of "angular" and others with "beginning rounding". A mixture with sand or another type of clay can not be excluded (Fig. 20.2).

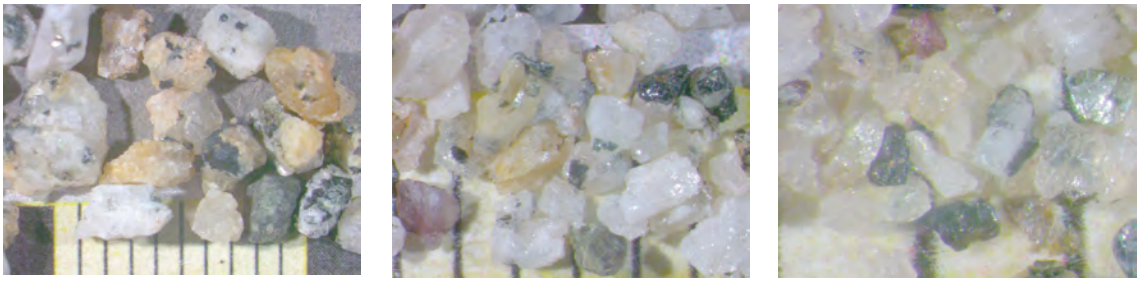


Fig. 20.2 Shapes of grains in sample 11745. Scaled in millimetre.
Shape of fraction >2,000 µm (Left), 630–2,000 µm (Centre), 200–630 µm (Right).

### Bulk mineral analysis

The results of the BMA are in general similar to the samples of Nyarma (Fig. 21.2). This sample shows traces of calcite and gypsum. Since the appearance of these two minerals points towards possible remains of a ground layer for a wall painting, the content of calcite and gypsum seems to be of relevance for this building material. In raw material samples 11754 and 11956, no calcite was traced. This was also the case in new brick sample 8505 and in new brick sample 11947, where just traces were detected. This fact emphasises that calcite was added after digging up of the raw material. It further indicates that its availability has an anthropogenic reason. At 4% the content of gypsum is rather high being that it is available in just one further interior plaster sample. Since no natural origin could be traced for the samples of Nyarma, its addition becomes evident. In no other samples from Nyarma except sample 8520 (an interior plaster in a stupa) gypsum was traced, which does not allow the general hypothesis of its addition for the preparation of a sub-layer for wall paintings. The amount of calcite was measured at 5%. The STA shows an endothermic peak at 136° pointing towards a content of gypsum, calculated at 5%. The light reddish colour is caused by a content of haematite.

### Clay mineral analysis

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 11745 | 4 | 69 | 5 | 22 |

## *CELLA*. INTERIOR PLASTER. SAMPLE 11753

### Sampling point

Temple I, main temple, *cella*. Sample number in the field: 15. Constructive use: Interior plaster, ground and upper layer. Additives: Straw fibres with sizes <2 mm to more than 20mm are available in a relatively high amount – similar to sample 11745, the afore treated sample of an interior plaster in the *cella*. Pieces of straw with a length of up to 3 cm were found. Sample colour (after Munsell): dry 2.5 7/2 light grey; semi-dry 2.5 4/2 dark greyish brown.

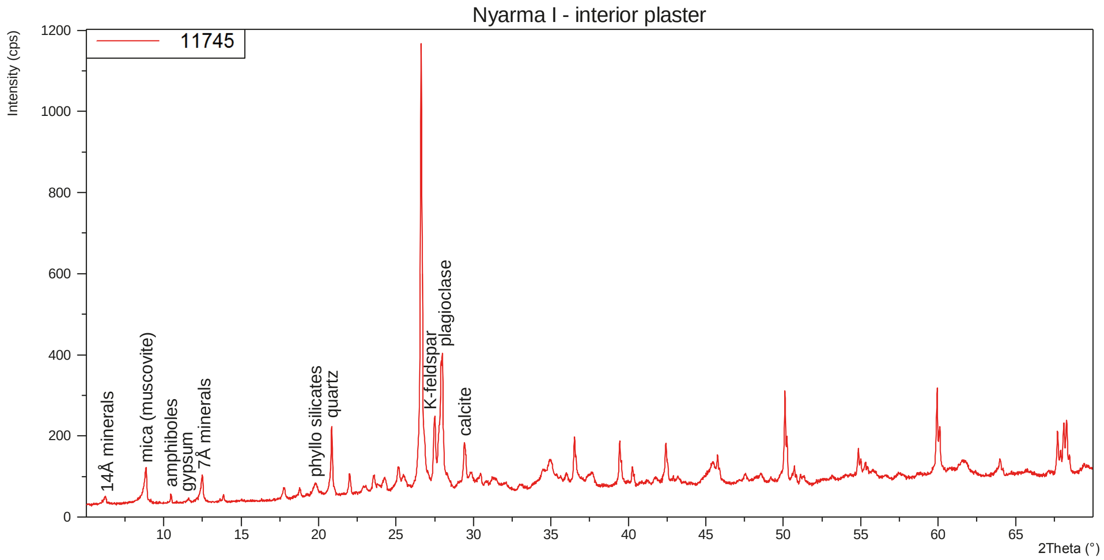


Fig. 21.2 Nyarma. BMA. Sample 11745.

### Grain size distribution

The material is relatively fine with a slight coarse content. Biggest fraction: fine gravel. The grain size distribution shows two peaks which is distinctive for most of the observed interior plasters used at the Nyarma temple site, as described previously. This is a possible marker for adding coarse material after desludging. The median is located at app. 5 µm; the <2 µm fraction contains app. 33% (relatively fine) of the whole sample and a relatively high amount of sand, particularly medium sand – very similar to sample 11745 as shown in the following juxtaposition.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 11753 *Cella* | 0.7 | 27.0 | 39.6 | 32.7 |
| 11745 *Cella* | 0.9 | 19.7 | 39.2 | 40.2 |

In general, samples 11753 and 11745 (containing ground and upper layer of the plaster) are relatively similar and give a homogenous appearance with other interior plasters in the *cella*. The slight differences in the grain size distribution indicates on the one hand that the used material is not exactly the same but from the same raw material and on the other hand emphasises the hypothesis of small variations due to irregularities during desludging or mixing.

### Grain shapes

The grain shape shows a dominance of "angular" with "beginning rounding" >630 µm but no evidence for the addition of another type of clay.

### Bulk and clay mineral analysis

The bulk mineral analysis matches with those of sample 11745, i.e. the afore treated sample of an interior plaster in the *cella*. A comparison between interior wall plasters from the *cella* ('Group-1' (6073, 11745, 11753, 11925)) and the clay mineral average data from clay pits (11754, 11956) is given below. The clay mineral analysis matches with those of sample 11745, i.e. the previously treated sample of an interior plaster in the *cella*. A comparison with other interior plasters and samples from clay pits shows similarities in clay mineral composition. The colour is similar to sample 11745. In the diffractogram, the content of haematite is not clear. The lack of a reddish colour in the sample itself contradicts such content.

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 11753 | 5 | 68 | 5 | 22 |
| 11745 | 4 | 69 | 5 | 22 |
| Ø Group-1 | 3–5 | 66–69 | 4–9 | 22–26 |
| Ø Clay pits | 3–5 | 62–65 | 8–10 | 22–25 |

### *CELLA*. INTERIOR PLASTER. SAMPLE 11925

#### Sampling point

Temple I, main temple, *cella*. Sample number in the field: 12. Constructive use: Interior plaster, ground and upper layer. Additives: Straw fibres with a length between <2 mm and more than 20 mm are available in a relatively high amount – also similar to samples 11745 and 11753, i.e. the afore treated samples of interior plasters in the *cella*. Additives: Pieces of straw with a length of up to 2 cm were found. Sample colour (after Munsell): dry 2.5 7/2 light grey; semi-dry 2.5 5/3 dark greyish brown.

#### Grain size distribution

The material is relatively fine with a content of coarse material. Biggest fraction: fine gravel. The grain size distribution shows two peaks. The median is located at app. 3.7 µm; the <2 µm fraction contains app. 40% (relatively fine) of the whole sample and a relatively high amount of sand, particularly medium sand – again similar to sample 11745. The results confirm the findings from samples 11753 and 11745, both interior plasters in the *cella,* as shown in the following juxtaposition.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 11925 *Cella* | 1.2 | 20.7 | 38.9 | 39.2 |
| 6073 *Cella* | 0 | 5.7 | 56.9 | 37.4 |
| 11745 *Cella* | 0.9 | 19.7 | 39.2 | 40.2 |
| 11753 *Cella* | 0.7 | 27.0 | 39.6 | 32.7 |
| 11754 Clay pit | 6.5 | 65.9 | 17 | 10.6 |
| 11956 Clay pit | 6.4 | 51.6 | 27.1 | 14.9 |

#### Grain shapes

Compared to sample 11745, this sample also shows a slight change of the grain shape between "angular" and "beginning rounding", similar to samples 11745 and 11753, both of which are from interior plasters within the *cella*. The grain shapes between the fractions medium sand and fine gravel of samples 11754 and 11956 show primarily a dominance of "angular shaped". These samples were from clay, which is the raw material (samples 11754 and 11956), and were recently used to produce adobe bricks (samples 8505 and 11947).

It is only with the interior plasters in the *cella* that for all the three examined samples – 11745, 11753 and 11925 – the fractions >200 µm (i.e. coarse sand and fine gravel) become slightly more rounded. This is in comparison to the material that was found in the clay pit and new adobe bricks. These fractions – coarse sand and fine gravel – are easy to handle when the material is made slightly more sandy (process in German language known as *abmagern*).

Continuing with the afore mentioned hypothesis of using the method of desludging for receiving the finer material for the upper layer of the plaster, the sludge was then mixed with coarse sand and fine gravel by adding sand (Ger. *abmagern*) or to raise the amount of fine material (silt and clay) by desludging.

The sand may also have originated from any other pit. From Likir (cf. Feiglstorfer, forthcoming a) we have evidence of local knowledge about sand pits for digging particular mixing material for potteries. The sand pits are located only about a dozen metres away and still used today. Members of a local pottery family showed the author these pits, which would be difficult to detect on one's own without a local guide or if the use of particular pits is more than 1,000 years ago, as is the case in Nyarma. Also the knowledge of locals in Nyarma about using clay for wall plaster is not helpful regarding this historical question since the process of desludging is rather time consuming, and if necessary today, nets for sieving are used.

### Bulk and clay mineral analysis

The bulk mineral analysis matches with those of 11745 and 11753, the previously treated samples of interior plasters in the *cella*. For sample 11925, the values for mica, amphiboles, 7Å minerals and phyllo silicates are slightly less. The light reddish colour results from a content of haematite.

Comparison between interior wall plasters from the *cella* ('Group-1' (6073, 11745, 11753, 11925)) and the clay mineral average data from clay pits (11754, 11956): Similarities are shown in the following list. The clay mineral analysis matches with those of samples 11745 and 11753, the afore treated samples of interior plasters in the *cella*.

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 11925 | 3 | 67 | 4 | 26 |
| 11753 | 5 | 68 | 5 | 22 |
| 11745 | 4 | 69 | 5 | 22 |
| Ø Group-1 | 3–5 | 66–69 | 4–9 | 22–26 |
| Ø Clay pits | 3–5 | 62–65 | 8–10 | 22–25 |

### 4.4.2 Wall plasters in the assembly hall

### ASSEMBLY HALL. INTERIOR PLASTER. SAMPLE 11918

#### Sampling point

Temple I, main temple, assembly hall (Fig. 22.2, Fig. 23.2), beside the aureole right of the east gate (view from the interior towards east) (see Fig. 1.2). Sample number in the field: 16 (Fig. 24.2). Similar to the other samples of the plaster within the assembly hall, no wall paintings could be observed. Constructive use: Interior plaster, ground and upper layer. Additives: Straw fibres with a length between <2mm and more than 20 mm are available in a relatively high amount – also similar to the afore treated samples of interior plasters in the *cella*. Pieces of straw with a length of up to 2 cm were found.

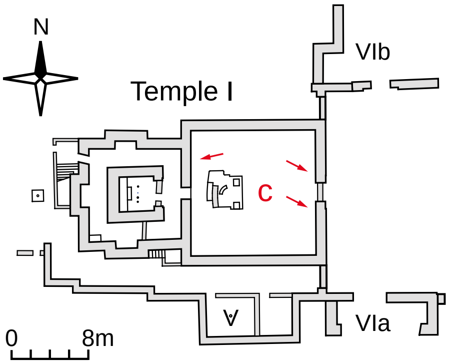


Fig. 22.2 (Left) Nyarma. Main temple. View onto the second storey on top of the *cella* (white) and the assembly hall to its right.
Fig. 23.2 (Right) Nyarma. Ground plan of Temple I (Detail of ground plan of the whole Nyarma temple site shown in Fig. 1.2). C = Assembly hall. The red arrows in the assembly hall show the position of aureoles along the east and west wall.

Fig. 24.2 Nyarma. Sample 11918.
Sample colour (after Munsell):
Dry 7.5YR 7/1 light grey.
Semi-dry 7.5YR 5/2 brown.

### Grain size distribution

The material is relatively fine with a coarse amount. Biggest fraction: fine gravel. The median is located at app. 10 µm; that is considerably higher than the comparable values of the interior plasters in the *cella*. The <2 µm fraction contains app. 26% of the whole sample. The grain size distribution shows two peaks. It also shows a relatively high amount of sand, particularly medium sand – very similar to the samples in the *cella*. Results confirm findings from the samples of the *cella* with a slightly higher amount of sand and a slightly lower amount of clay, as shown in the following juxtaposition.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 11918 Assembly hall | 2.2 | 33.2 | 39.4 | 25.2 |

### Grain shapes

This result shows an obvious change in the grain size between medium sand and the coarser fractions of coarse sand and fine gravel, similar to what was observed at the plasters in the *cella* which also showed two shapes, i.e. "angular" and "beginning rounding" (Fig. 25.2).

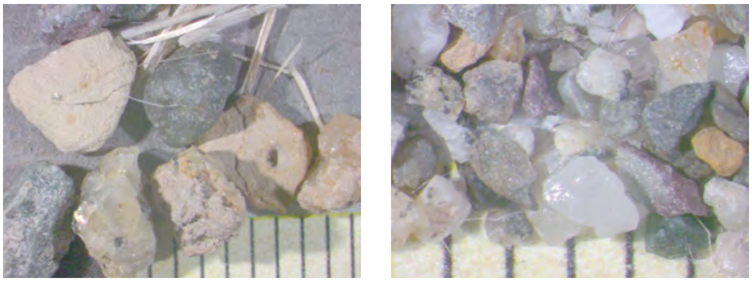


Fig. 25.2 Shapes of grains in sample 11918. Scaled in millimetre.
Shape of fraction >2,000 µm (Left), 630–2,000 µm (Right).

### Bulk mineral analysis

The bulk mineral analysis matches in general with those of interior wall plasters, very similar to sample 11925 (interior plaster in the *cella*). Calcite is available in small traces; no gypsum. The light reddish colour results from a content of haematite.

### Clay mineral analysis

Comparison between interior wall plasters from the *cella* ('Group-1' (6073, 11745, 11753, 11925)), the interior wall plasters from the assembly hall ('Group-2' (11918, 8531, 11762)) and the clay mineral average data from clay pits (11754, 11956). In general Group-2 (interior plasters in the assembly hall) matches the clay mineral data of Group-1 and the clay pit-data. For sample 11918, at 3% the amount of smectite is at the lower end; the same can be stated for the content of kaolinite at 4%.

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 11918 | 3 | 67 | 4 | 26 |
| Ø Group-1 | 3–5 | 66–69 | 4–9 | 22–26 |
| Ø Group-2 | 4–9 | 66–67 | 6–7 | 19–23 |
| Ø Clay pits | 3–5 | 62–65 | 8–10 | 22–25 |

## ASSEMBLY HALL. INTERIOR PLASTER. SAMPLE 8531

### Sampling point

Temple I, main temple, assembly hall, left beside the most right located aureole, located to the right of the gateway towards the *cella* (view from the interior of the assembly hall towards the west). Sample number in the field: 66 NY-RZ/IP. Similar to the other samples of the plaster within the assembly hall, no wall paintings were observed. Additives: Straw fibres with a length between 10 mm and more than 20 mm are available in a relatively high amount – similar to the afore treated samples of interior plasters in the *cella* but the fibres are not cut as short. Pieces of straw with a length of up to 2 cm were found. Constructive use: Interior plaster, ground and upper layer. Sample colour (after Munsell): dry 7.5YR 7/2 pinkish grey; semi-dry 7.5YR 4/4 brown.

### Grain size distribution

The material is relatively fine with a coarse amount. Biggest fraction: fine gravel. The median is located at app. 21 µm; this is considerably higher than the comparable values of the interior plasters in the *cella*. The <2 µm fraction contains app. 23% of the whole sample. The grain size distribution shows two peaks. The relatively high amount of sand, particularly fine sand, is similar to the samples in the *cella*. Results confirm findings from the samples of the *cella* with a higher amount of sand and a lower amount of clay, and show a relatively higher similarity with sample 11918, an interior plaster of the assembly hall, as shown in the following juxtaposition.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 8531 Assembly hall | 2.3 | 40.0 | 33.9 | 23.8 |
| 11918 Assembly hall | 2.2 | 33.2 | 39.4 | 25.2 |

### Grain shapes

This result does not show an obvious change in the grain size between medium sand and the coarser fractions coarse sand and fine gravel, as seen in sample 11918. Thus, the possible use of a sand supplement can not be regarded as continuity within the assembly hall as found in the *cella*.

### Bulk mineral analysis

The bulk mineral analysis matches in general with those of interior wall plasters of the *cella* (samples 11745 and 11753), but varies from both samples of plasters in the assembly hall (samples 11918 and 11762) in that it shows a slightly higher content of mica, amphiboles and 7Å minerals. The content of feldspar and plagioclase, in relation to the samples from Nyarma, are in general relatively high. Calcite is available in small amounts (marked in Table 4.2 with (*)); no gypsum could be traced. The light reddish colour results from a content of haematite.

### Clay mineral analysis

A comparison between interior wall plasters from the *cella* ('Group-1' (6073, 11745, 11753, 11925)), the interior wall plasters from the assembly hall ('Group-2' (11918, 8531, 11762)) and the clay mineral average data from clay pits (11754, 11956) shows close similarities. For sample 8531, at 3% the amount of smectite is small; at 7% kaolinite is at an average level compared to all the examined samples, and at the upper end within Group-2.

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 8531 | 3 | 67 | 4 | 26 |
| Ø Group-1 | 3–5 | 66–69 | 4–9 | 22–26 |
| Ø Group-2 | 4–9 | 66–67 | 6–7 | 19–23 |
| Ø Clay pits | 3–5 | 62–65 | 8–10 | 22–25 |

### 4.4.3 Wall plaster in Temple IIIa

### Temple IIIa. Interior plaster. Sample 8514

#### Sampling point

Temple IIIa, interior side of the wall (left hand when entering the temple) (Fig. 26.2, Fig. 27.2). Sample number in the field: 65 NY-RZ/IP. Constructive use: Interior plaster. Additives: Straw fibres with a length between <2 mm and 10 mm are available in a relatively high amount – also similar to the afore treated samples of interior plasters in the *cella* and assembly hall. The straw is much finer with an average length up to app. 5 mm.

#### Grain size distribution

The material is relatively fine. Biggest fraction: fine gravel. The median is located at app. 3.5 µm; the <2 µm fraction contains app. 43% of the whole sample with a relatively high mineral content in the fractions between medium silt and fine clay. The grain size distribution curve shows a soft break from coarse silt to medium silt and a bimodal distribution marked by a soft valley between fine sand and medium silt, which are both features of a possible indication for a material mixture. The high amount of clay matches with plaster used in the *cella* (e.g. sample 11745). The same can be said for the median which is also much more related to the plasters of the *cella*. In general these sample features are related to the *cella* in quality, and not to the assembly hall, as shown in the following juxtaposition.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 8514 Temple IIIa | 0.4 | 19.9 | 37.3 | 42.4 |
| 11745 *Cella* | 0.9 | 19.7 | 39.2 | 40.2 |

Fig. 26.2 (Left) Nyarma. Temple IIIa on the left side of the picture and Temple IIIb on the right side.
Fig. 27.2 (Right) Nyarma. Inside Temple IIIa with a view towards Temple IIIb.

### Grain shapes

The grain shapes show a dominance of “angular” and “slightly rounded”. This indicates a possible addition of sand. Thus for sample 8514 evidence of a mixture with sand or another type of clay can not be excluded, similar to afore mentioned plasters (Fig. 28.2).

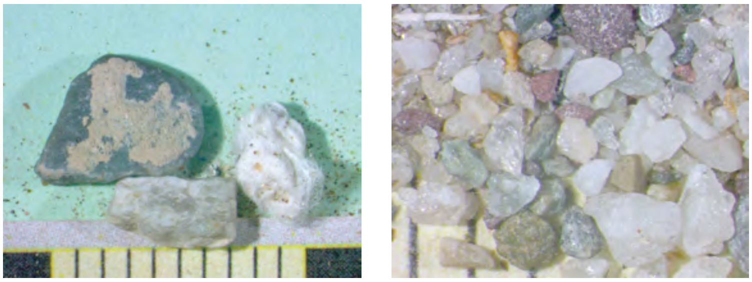


Fig. 28.2 Shapes of grains in sample 8514. Scaled in millimetre.
Shape of fraction >2,000 μm (Left), 630–2,000 μm (Right).

### Bulk and clay mineral analysis

The content of K-feldspar, which appears as traces, in comparison to the whole Nyarma series, is slightly decreased. Calcite is available as traces; gypsum is not available. The light reddish colour results from a content of haematite. A comparison between interior wall plasters from the *cella* (‘Group-1’ (6073, 11745, 11753, 11925)), the interior wall plasters from the assembly hall (‘Group-2’ (11918, 8531, 11762)) and the clay mineral average data from clay pits (11754, 11956) shows close similarities. For sample 8514, at 7% the amount of smectite is of a medium amount; at 7% kaolinite is at an average level compared to all the examined samples, and at the upper end within Group-2.

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 8514 | 7 | 62 | 7 | 24 |
| Ø Group-1 | 3–5 | 66–69 | 4–9 | 22–26 |
| Ø Group-2 | 4–9 | 66–67 | 6–7 | 19–23 |
| Ø Clay pits | 3–5 | 62–65 | 8–10 | 22–25 |

## 4.4.4 Wall plaster in Temple IV

## Temple IV. Interior plaster. Sample 15406

### Sampling point

Temple IV, plaster upper layer (Fig. 29.2, Fig. 30.2, Fig. 31.2). Sample number in the field: 59 NY-RZ/IP. In some areas of the wall, the upper and ground layer of the interior plaster are easily detached from each other. Constructive use: Interior plaster, upper layer. Additives: Straw fibres with a length between <2 mm and 10 mm are available in a relatively high amount – also similar to the afore treated samples of interior plasters in the *cella* and assembly hall. The straw is much finer with an average length up to app. 5 mm. Sample colour (after Munsell): dry 10YR 7/3 very pale brown; semi-dry 10YR 5/3 brown.

### Grain size distribution

The material is relatively fine. Biggest fraction: coarse sand. The median is located at app. 4 µm; the <2 µm fraction contains app. 39% of the whole sample with a relatively high mineral content in the fractions between medium silt and fine clay. The grain size distribution curve shows a peak in the fine sand fraction, a possible indication of a material mixture. The high amount of clay matches with the plaster used in Temple IIIa (sample 8514) and also with the plasters used in the *cella* (samples 6073, 11745, 11753 and 11925). The wall plasters in the assembly hall are not of such a high content of clay although the content of silt is similar between all these interior wall plasters. But the sand fraction is again similar to the interior wall plasters used in the *cella* and not to those used in the assembly hall. This becomes evident in a similar median ranging around 3 µm to 4 µm on average. In general these samples' features and also those of the sample of Temple IIIa (sample 8514) are, in their mineral composition, related to the *cella* and not to the assembly hall, as shown in the following juxtaposition. The grain shape "angular" does not show any evidence of a mixture with sand or another type of clay.

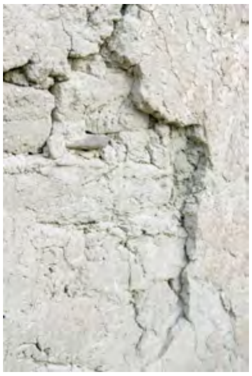


Fig. 29.2 (Left) Nyarma. Temple IV. East elevation.
Fig. 30.2 (Centre) Nyarma. Inside Temple IV. View into the south west corner.
Fig. 31.2 (Right) Nyarma. Parts of a detaching plaster.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 15406 | 0 | 21.8 | 39.8 | 38.4 |
| 8514 Temple IIIa | 0.4 | 19.9 | 37.3 | 42.4 |
| 11745 *Cella* | 0.9 | 19.7 | 39.2 | 40.2 |

### Bulk and clay mineral analysis

The results of the BMA show strong similarities to the mineralogical composition of the samples of Nyarma in general. Calcite is available as traces measured according to Scheibler at 2%; gypsum is not available. The light reddish colour results from a content of haematite.

A comparison between interior wall plasters from the *cella* ('Group-1' (6073, 11745, 11753, 11925)), the interior wall plasters from the assembly hall ('Group-2' (11918, 8531, 11762)) and the clay mineral average data from clay pits (11754, 11956) shows close similarities. For sample 15406, at 2% the amount of smectite is a rather small amount; at 5% kaolinite is at an average level.

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 15406 | 2 | 63 | 5 | 30 |
| Ø Group-1 | 3–5 | 66–69 | 4–9 | 22–26 |
| Ø Group-2 | 4–9 | 66–67 | 6–7 | 19–23 |
| Ø Clay pits | 3–5 | 62–65 | 8–10 | 22–25 |

## Temple IV. Interior plaster. Sample 8517

### Sampling point

Temple IV, plaster ground layer. Sample number in the field: 60 NY-RZ/IP. In some areas of the wall, the upper and ground layer of the interior plaster may be easily detached from each other. This sample is related to sample 15406 regarding the composition of the ground layer. At some parts of the wall, the two layers (ground and upper layer) were easily detached. A fine grey tissue possibly woven by invading insects was visible. This damage could be detected at several other sites. One example was observed in Ne located north of Basgo in Ladakh (cf. Feiglstorfer, forthcoming a) (Fig. 32.2). Constructive use: Interior plaster, ground layer. Additives: Straw of the length between <2 mm and 10 mm is available in a relatively high amount – also similar to the afore treated samples of interior plasters in the *cella* and assembly hall. The straw is much finer with an average length up to app. 5 mm. Sample colour (after Munsell): dry 10YR 7/3 very pale brown; semi-dry 10YR 5/3 brown.

### Grain size distribution

The material, compared to its upper layer in sample 15406, is relatively coarse. Biggest fraction: medium gravel. The median is located at app. 135 µm; the <2 µm fraction contains app. 14% of the whole sample with a relatively high mineral content in the fractions between medium silt and medium clay. But the maximum peaks are in the sand fractions, with medium sand at 24.6% and fine sand at 19.8%. The grain size distribution curve shows a bimodal distribution marked by a valley between fine sand and medium silt, a possible indication of a material mixture.

At 14% the small content of clay is rather close to the raw material found in the pits (samples 11754 and 11956) and also the material used for bricks in sample 11947. With this important result we state that the coarse layer in this temple is rather similar to the base material, possibly coarsened with some sand, and shows no indication of a fine mixture as used for upper plaster layers or plasters found in the *cella* or the assembly hall of Temple I. The following juxtaposition shows the differences. Grain sizes are available up to a diameter of 28 mm.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 8517 Temple IV coarse layer | 8.2 | 54 | 23.8 | 14 |
| 11754 Clay pit | 6.5 | 65.9 | 17.0 | 10.6 |
| 11745 *Cella* | 0.9 | 19.7 | 39.2 | 40.2 |

### Grain shapes

The grain shape shows a dominance in “angular” mixed with “beginning rounding” (Fig. 33.2).

Fig. 32.2 Ne. Ladakh. Wall of a temple with missing roof. Nest of insects.

### Bulk mineral analysis

The results of the BMA show strong similarities to the mineralogical composition of the samples of Nyarma in general. Calcite is available between traces and a medium amount of 6%; gypsum is not available. Since this sample is related to the ground layer, which was not covered with any type of painted layer, the question arises for the origin of a content of calcite of 6%. This result indicates the addition of lime to the plaster in general since in the clay pits no content of calcite was available. This can be a sign that at the time when this plaster was added, the addition of lime for strengthening was conducted or that the ground layer was once used as a whitewashed upper layer. Regarding analysis of sample 8532 (in the following), which shows close similarity in grain size distribution but as a coarse layer, we can state that the plaster sample collected in Temple V may be the remains of a coarse layer. The light reddish colour results from a content of haematite.

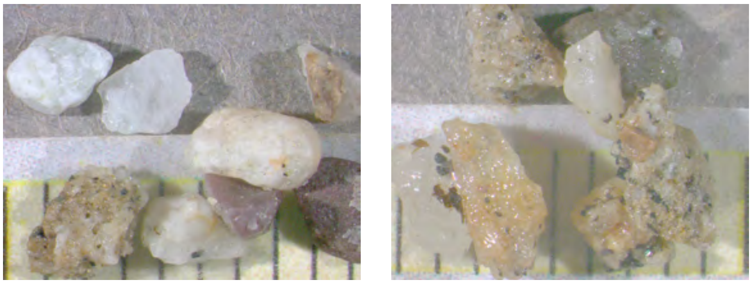


Fig. 33.2 Shapes of grains in sample 8517. Scaled in millimetre.
Shape of fraction >2,000 µm (Left and right).

### Clay mineral analysis

A comparison between interior wall plasters from the *cella* ('Group-1' (6073, 11745, 11753, 11925)), the interior wall plasters from the assembly hall ('Group-2' (11918, 8531, 11762)) and the clay mineral average data from clay pits (11754, 11956) shows close similarities. For sample 8517, at 3% the amount of smectite is a rather small amount; at 5% kaolinite is at an average level. Both rates are similar to sample 15406, the upper plaster layer.

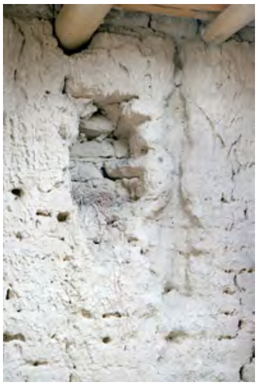
| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 8517 | 3 | 69 | 5 | 23 |
| Ø Group-1 | 3–5 | 66–69 | 4–9 | 22–26 |
| Ø Group-2 | 4–9 | 66–67 | 6–7 | 19–23 |
| Ø Clay pits | 3–5 | 62–65 | 8–10 | 22–25 |

## 4.4.5 Wall plaster in the side Temple V south of the assembly hall

### Temple V. Interior plaster. Sample 11761

#### Sampling point

Temple V is part of the main temple and a side temple annex located along the south side of the outer ambulatory (Fig. 34.2, Fig. 35.2). This sample was partially relatively loose and detached from the wall (Fig. 36.2). Sample number in the field: 34 (Fig. 37.2). Constructive use: Interior plaster ground and upper layer. Additives: Straw fibres with a length between <2 mm and 20 mm available in a small amount. One piece of wood was found with a length of app. 11 cm. The pieces of straw are rather fine, on average with a length up to about 5 mm.



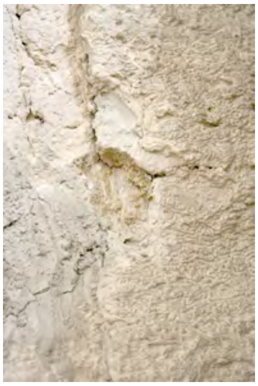


Fig. 34.2 (Left) Nyarma. Inside Temple V. View towards east.
Fig. 35.2 (Centre) Nyarma. Inside Temple V. View towards east.
Fig. 36.2 (Right) Nyarma. Parts of a detaching plaster.

Fig. 37.2 Nyarma. Sample 11761.
Sample colour (after Munsell):
Dry 2.5YR 6/2 very light brownish grey.
Semi-dry 2.5YR 4/2 dark greyish brown.

#### Grain size distribution

Compared to the average values of examined interior plasters, the material is relatively coarse but also with a high amount of fine fractions. Biggest fraction: fine gravel. The median is located at app. 40 µm which is high in relation to the average values of examined interior plasters. The <2 µm fraction contains app. 22% of the whole sample. Already when collecting this sample the high amount of sand was evident. The grain size distribution also shows two peaks and a bimodal distribution marked by a valley between the fine sand and the medium silt fractions. With this feature it matches with the plasters of the site. The amount of sand is rather high and comparable to the plasters used in the assembly hall, just slightly coarser. Accordingly, the content of clay is rather small.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 11761 Temple V | 0.4 | 45.9 | 32.3 | 21.5 |

### Grain shapes

The grain shapes show a dominance in “angular” and “angular with beginning rounding”. The grain shapes show the same continuity in the appearance of two different shapes matching with sample 11762 (plaster in the ambulatory). This feature is also similar to afore mentioned samples of interior plasters in the assembly hall, showing a continuity in the applied knowledge of similar mixtures and related raw materials (Fig. 38.2).

Fig. 38.2 Shapes of grains in sample 11761. Scaled in millimetre.
Shape of fraction >2,000 µm (Left), 630–2,000 µm (Centre), 200–630 µm (Right).

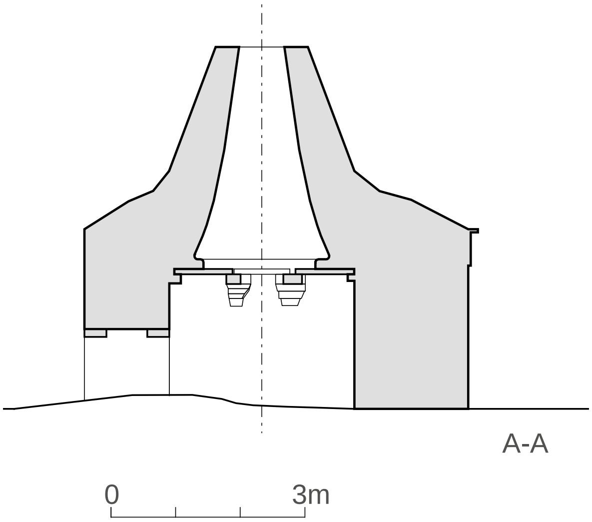
### Bulk and clay mineral analysis

The results of the BMA show strong similarities to the mineralogical composition of the samples of Nyarma in general. Calcite is available in traces; gypsum is not available. The light reddish colour results from a content of haematite.

A comparison between interior wall plasters from the *cella* (‘Group-1’ (6073, 11745, 11753, 11925)), the interior wall plasters from the assembly hall (‘Group-2’ (11918, 8531, 11762)) and the clay mineral average data from clay pits (11754, 11956) shows close similarities. For sample 11761, at 3% the amount of smectite is rather small; at 7% kaolinite is at an average level, and at 26% the amount of chlorite is relatively high. The given values show a strong similarity with the material used in the assembly hall (sample 11918).

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 11761 | 3 | 64 | 7 | 26 |
| Ø Group-1 | 3–5 | 66–69 | 4–9 | 22–26 |
| Ø Group-2 | 4–9 | 66–67 | 6–7 | 19–23 |
| Ø Clay pits | 3–5 | 62–65 | 8–10 | 22–25 |

### 4.4.6 Wall plasters in an accessible stupa in the monastery compound



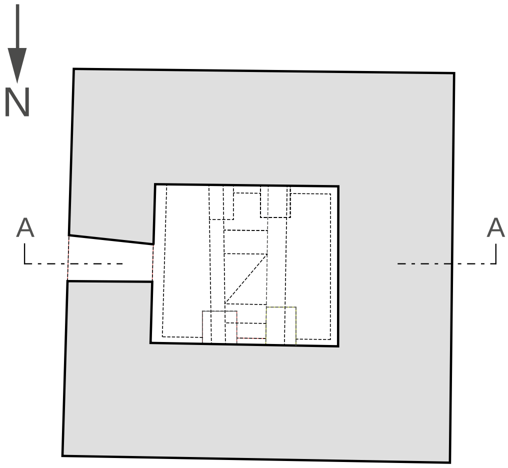


Fig. 39.2 (Top, left) Nyarma. Stupa. Section A-A.
Fig. 40.2 (Top, right) Nyarma. Stupa. Ground plan.
Fig. 41.2 (Bottom, left) Nyarma. East elevation.
Fig. 42.2 (Bottom, right) Nyarma. Inside the stupa.

## Stupa. Interior plaster. Sample 8532

### Sampling point

Accessible stupa, located south of the main temple (Figs. 39.2 to 42.2). Ground layer of the plaster. Sample number in the field: 54 NY-RZ/IP. Constructive use: Ground layer of plaster. Additives: Straw fibres with a length between <2 mm and 20 mm available in a small amount. One piece of wood was found with a length of app. 11 cm. The pieces of straw are rather fine, on average up to about 5 mm. Sample colour (after Munsell): dry 5YR 7/2 light grey; semi-dry 5YR 5/2 olive grey.

### Grain size distribution

Compared to the average values of examined interior plasters, the material is relatively coarse but also with a high amount of fine fractions. Biggest fraction: fine gravel. The median is located at app. 65 µm which is high in relation to the average values of examined interior plasters; the <2 µm fraction contains app. 20% of the whole sample. Already when taking this sample the high amount of sand was evident. The grain size distribution shows also two peaks and a bimodal distribution marked by a valley between the fine sand and the medium silt fractions. With this feature it matches with the plasters of the site. The amount of sand is rather high and comparable to the plasters used in the assembly hall. Accordingly the content of clay is rather small. The mineral composition shows close similarities to sample 11761 from Temple V.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 8532 Stupa | 4.2 | 46.9 | 29.2 | 19.7 |
| 11761 Temple V | 0.4 | 45.9 | 32.3 | 21.5 |

## Grain shapes

The sample shows grains which are “angular shaped” and others with “beginning rounding”. A mixture with sand or another type of clay can not be excluded (Fig. 43.2).

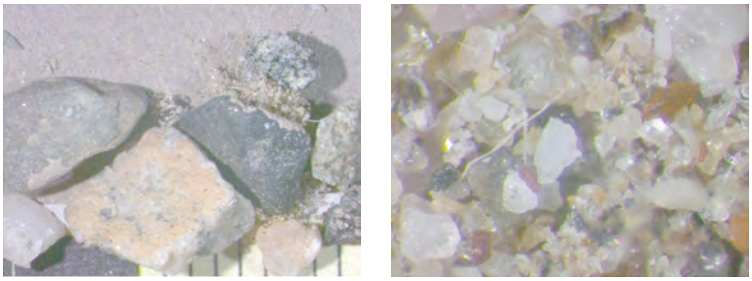


Fig. 43.2 Shapes of grains in sample 8532. Scaled in millimetre.
Shape of fraction >2,000 µm (Left), 40–2,000 µm (Right).

## Bulk and clay mineral analysis

The results of the BMA show strong similarities to the mineralogical composition of the samples of Nyarma in general. Calcite is available at 3%; gypsum is not available. The light reddish colour results from a content of haematite.

A comparison between interior wall plasters from the *cella* (‘Group-1’ (6073, 11745, 11753, 11925)), the interior wall plasters from the assembly hall (‘Group-2’ (11918, 8531, 11762)) and the clay mineral average data from clay pits (11754, 11956) shows close similarities. For sample 8520, at 10% the amount of smectite is with 10% rather high; at 7% kaolinite is at an average level, and the amount of chlorite at 20% is relatively low. The given values show strong similarity with the material used for the upper layer of this plaster (sample 8520). The following list shows relations between these samples.

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 8532 | 9 | 64 | 7 | 20 |
| Ø Group-1 | 3–5 | 66–69 | 4–9 | 22–26 |
| Ø Group-2 | 4–9 | 66–67 | 6–7 | 19–23 |
| Ø Clay pits | 3–5 | 62–65 | 8–10 | 22–25 |

## STUPA. INTERIOR PLASTER. SAMPLE 8520

### Sampling point

Accessible stupa, located south of the main temple. Upper layer of the plaster already detached from the wall. Sample number in the field: 55 NY-RZ/IP. Constructive use: Upper layer of plaster. Additives: Straw fibres with a length between <2 mm and 20 mm available in a small amount. The pieces of straw are rather fine, on average up to about 5 mm. Sample colour (after Munsell): dry 10YR 7/2 light grey; semi-dry 10YR 4/2 dark greyish brown.

### Grain size distribution

Compared to the average values of examined interior plasters the material is relatively sandy but also has a peak of 39% at the medium sand fraction. It further also contains fine material (silt and clay) at 36.7%. Biggest fraction: coarse sand. The median is located at app. 150 µm which is high in relation to the average values of examined interior plasters; the <2 µm fraction contains app. 20% of the whole sample. The grain size distribution also shows two peaks and a bimodal distribution marked by a valley between the fine sand and the medium silt fractions. With this feature it matches with the plasters of the site. The amount of sand is rather high and also exceeds the average content of the values used in the assembly hall. Accordingly, the content of clay is rather small. The mineral composition shows close similarity to sample 8532, i.e. the ground layer of this plaster. Contrary to the ground layer, no gravel is available and the content of clay is rather similar but the content of sand much higher while the content of silt is smaller. This sample, which is the upper layer, due to its coarse appearance, is atypical for plasters, and particularly atypical for upper plaster layers in Nyarma. Differences and similarities are shown in the following juxtaposition.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 8520 Stupa upper layer | 0 | 63.3 | 17.4 | 19.3 |
| 8532 Stupa ground layer | 4.2 | 46.9 | 29.2 | 19.7 |

### Grain shapes

Similar to sample 8532, this sample shows grains, which are “angular shaped” and others with a “beginning rounding”. A mixture with sand or another type of clay can not be excluded but is not obvious.

### Bulk mineral analysis

The results of the BMA show strong similarities to the mineralogical composition of the samples of Nyarma in general. The content of K-feldspar and plagioclase is high and at 3% the amount of calcite ranges in an average field compared with other Nyarma plaster samples. Fig. 44.2 shows a content of calcite and gypsum. For this sample in the STA, a content of 3% gypsum was measured, which is a possible remain of the sub-layer of a wall painting. This sample shows remains of colours for which gypsum may have been used as a sub-layer. The STA shows endothermic peaks at 122° pointing towards a content of gypsum (calculated at 5%). The light reddish colour results from a content of haematite.

## Clay mineral analysis

A comparison between interior wall plasters from the *cella* ('Group-1' (6073, 11745, 11753, 11925)), the interior wall plasters from the assembly hall ('Group-2' (11918, 8531, 11762)) and the clay mineral average data from clay pits (11754, 11956) shows close similarities. For sample 8532, at 9% the amount of smectite is rather high; at 6% kaolinite is at an average level, and the amount of chlorite at 23% is relatively low. The given values show a strong similarity to the material used for the ground layer of this plaster (sample 8532). The high amount of smectite points towards a raw material different to the clay used for the other interior plasters in Nyarma (Fig. 45.2).

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 8520 | 10 | 61 | 6 | 23 |

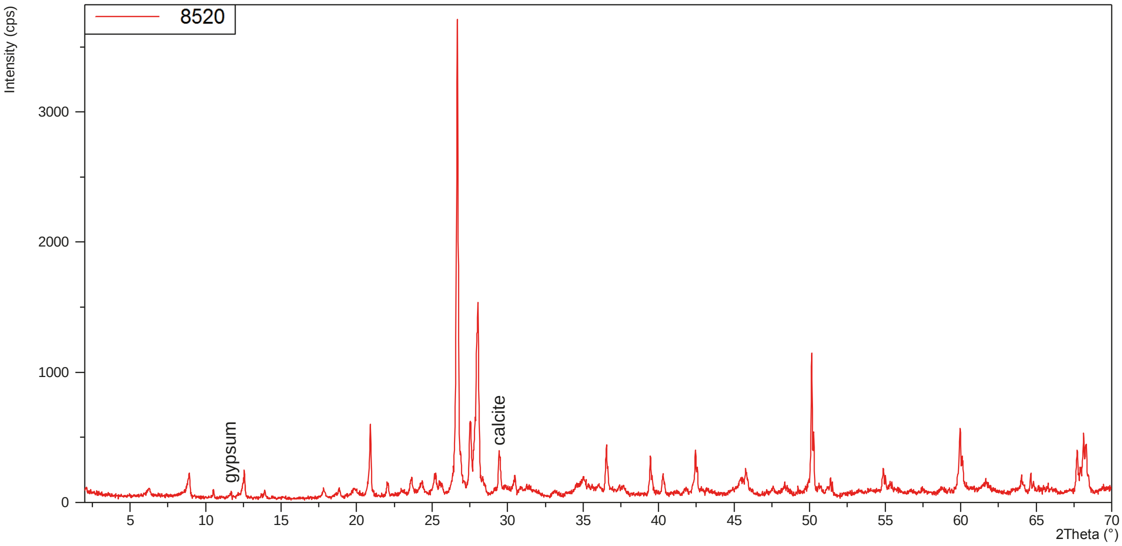


Fig. 44.2 Nyarma. BMA. Sample 8520.

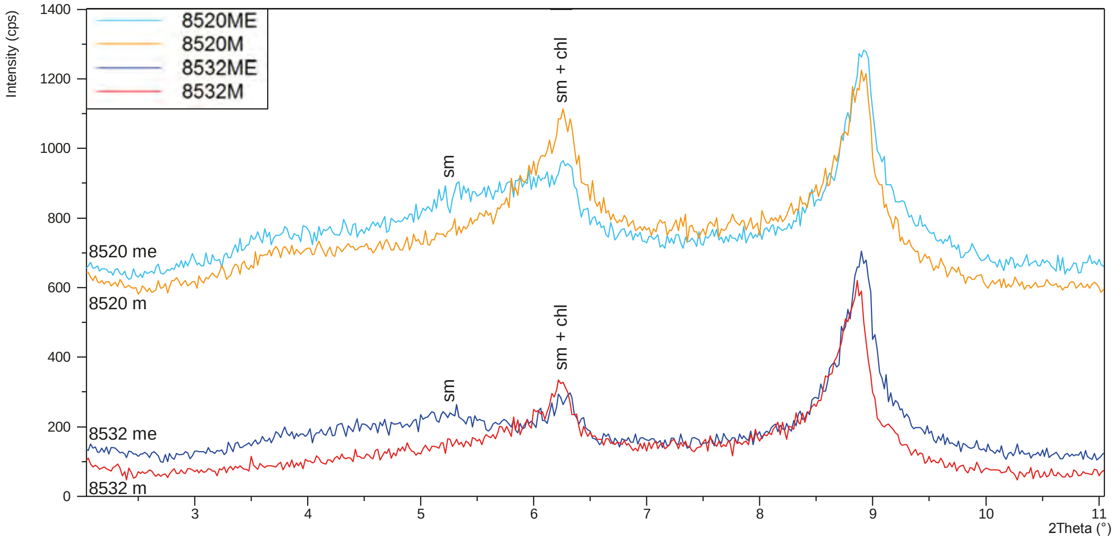


Fig. 45.2 Nyarma. CMA. Samples 8520 and 8532 juxtaposed.

### 4.4.7 Modelled wall frieze in an accessible stupa

### STUPA. MODELLED WALL FRIEZE. SAMPLE 15405

#### Sampling point

Piece of a clay sculpture found in the accessible stupa (described before), located south of the main temple. Sample number in the field: 56 NY-RZ/IP. This cylindrically shaped piece was found lying on the floor in the stupa. Its exact position in the wall could not be exactly traced; regarding form, colour and in accordance to the mineral composition of the wall plaster of this stupa, it is most probably an upper completion of the wall as a frieze. Constructive use: Wall frieze. Additives: Straw fibres with a length between <2 mm and 20 mm are available in a small amount, similar to the ground layer 8532. The pieces of straw are rather fine, on average up to about 5 mm. Sample colour (after Munsell): dry 10YR 7/2 light grey; semi-dry 10YR 5/3 brown.

#### Grain size distribution

Compared to the average values of examined interior plasters, the material is relatively coarse with a high content of fine fractions (silt and clay) equalling 35.3%. Biggest fraction: coarse sand. The median is located at app. 125 µm; the <2 µm fraction contains app. 17%. The grain size distribution also shows two peaks with clear maxima for medium sand at 26.4% and fine sand at 27.1%, and a bimodal distribution marked by a valley between the fine sand and the silt fractions. With this feature it matches with the plasters of the site. The high content of silt does not conform to the average values of wall plasters in Nyarma. It is of interest that the material used for this frieze is – regarding grain size composition – rather similar to the upper plaster layer of the stupa where it was found. It is important to state that the use of 64.7% sand with a content of 15.7% of clay creates a mixture with high strength. This was evident when trying to break pieces of the sample for further analysis. The grain shape is “angular” and does not show any evidence for a mixture with sand or another type of clay.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 15405 Stupa wall frieze | 0 | 64.7 | 19.6 | 15.7 |
| 8550 Stupa upper layer | 0 | 63.3 | 17.4 | 19.3 |

#### Bulk mineral analysis

The results of the BMA show strong similarities to the mineralogical composition of the samples of Nyarma in general. At 6% an amount of calcite ranges in an average field compared with other Nyarma plaster samples. Close similarity between the samples of the aureoles (sample 8516) and the samples of the plaster in the stupa (sample 8532) can be stated. The light reddish colour results from a content of haematite.

Aureoles in the assemply hall (opposite page)

Fig. 46.2 (Top, left) Nyarma. Assembly hall. West wall with aureoles.

Fig. 47.2 (Top, centre), Fig. 48.2 (Top, right) Nyarma. Assembly hall. Aureole on the west wall.

Fig. 49.2 (Centre, left) Nyarma. Assembly hall. East wall with aureoles.

Fig. 50.2 (Centre, centre), Fig. 51.2 (Centre, right) Nyarma. Assembly hall. Aureole on the east wall.

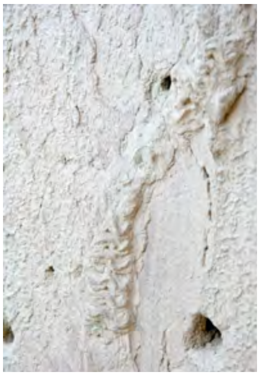
Fig. 52.2 (Bottom, left) Nyarma. Sections of different types of aureoles (Feiglstorfer, forthcoming b). a = east wall, head aureole; b = east wall, torso-aureole; c = west wall.

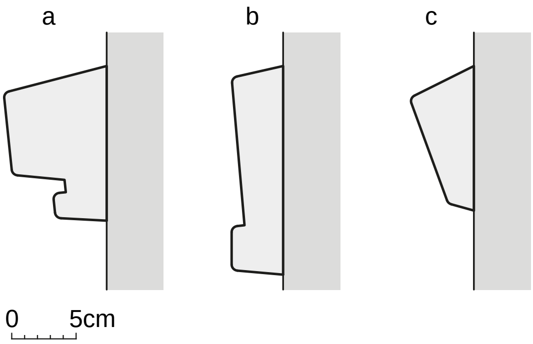
### 4.4.8 Clay modelled aureoles

### ASSEMBLY HALL. AUREOLE. SAMPLE 8522

#### Sampling point

Temple I, main temple, assembly hall. Aureole right to the east gate (view from the interior towards east) (Figs. 46.2 to 52.2). Ground layer of the aureole without ornaments. Sample number in the field: 68 NY-RZ/SK. Additives: Straw fibres with a length between <2 mm and 20 mm available in a small amount, similar to ground layer 8532. The pieces of straw are rather fine, on average up to about 5 mm. Constructive use: Aureole, ground layer. Sample colour (after Munsell): dry 10YR 7/2 light grey; semi-dry 10YR 4/2 dark greyish brown.





### Grain size distribution

Compared to the average values of examined interior plasters, the material is relatively fine with a high content of the sand fraction. Biggest fraction: fine gravel. The median is located at app. 9 µm; the <2 µm fraction contains app. 27% of the whole sample. The grain size distribution also shows two peaks and a bimodal distribution marked by a valley between the medium sand and the medium silt fractions. With this feature it matches with the plasters of the site. The amount of sand is rather high and is compensated by a high content of fine material between medium silt and medium clay. Comparison with other samples of Nyarma wall plasters shows clear similarities to the plaster samples of the assembly hall. The analysis shows that the material used for the ground layer of the aureole is similar to the material used as plaster and that no difference was made regarding these kinds of use.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 8522 Aureole ground layer | 1.4 | 34.1 | 38.6 | 25.9 |
| 11918 Assembly hall | 2.2 | 33.2 | 39.4 | 25.2 |

### Grain shapes

The shape of the grains shows a change from the fraction gravel >2,000 µm with a "beginning rounding" to smaller fractions which are "angular shaped". A change in sand fractions is not evident (Fig. 53.2), which is possible evidence for the addition of gravel.

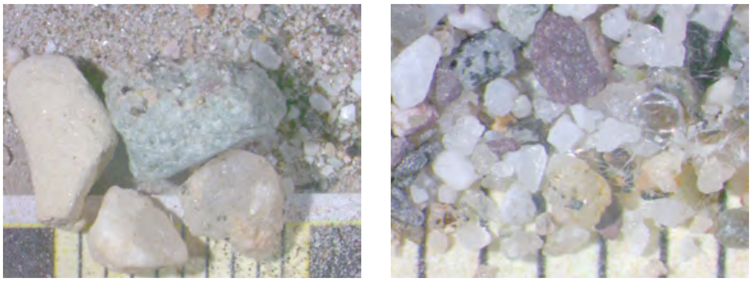


Fig. 53.2 Shapes of grains in sample 8522. Scaled in millimetre.
Shape of fraction >2,000 µm (Left), 40–2,000 µm (Right).

### Bulk mineral analysis

The results of the BMA show strong similarities to the mineralogical composition of the samples of Nyarma in general. An amount of calcite of 4% was measured. This ranges in an average field compared with other Nyarma plaster samples. Close similarity to the upper layer of the aureole (sample 8516) is given. Comparing with samples 8531 and 11918, the wall plasters within the assembly hall show differences in the content of K-feldspar and plagioclase. The light reddish colour results from a content of haematite.

### Clay mineral analysis

A comparison with interior wall plasters from the *cella* ('Group-1' (6073, 11745, 11753, 11925)), the interior wall plasters from the assembly hall ('Group-2' (11918, 8531, 11762)) and the clay mineral average data from clay pits (11754, 11956) shows close similarities. For sample 8532, at 10% the amount of smectite is rather high; at 7% kaolinite is at an average level, and the amount of chlorite at 18% is relatively low. The content of swellable clay minerals is slightly higher than in the upper layer.

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 8522 | 10 | 65 | 7 | 18 |
| Ø Group-1 | 3–5 | 66–69 | 4–9 | 22–26 |
| Ø Group-2 | 4–9 | 66–67 | 6–7 | 19–23 |
| Ø Clay pits | 3–5 | 62–65 | 8–10 | 22–25 |

## ASSEMBLY HALL. AUREOLE. SAMPLE 8516

### Sampling point

Temple I, main temple, assembly hall. Aureole to the right of the east gate (view from the interior towards east). Upper layer of the aureole with ornaments. Sample number in the field: 67 NY-RZ/SK. Constructive use: Aureole, upper layer with modelled ornament. Additives: Straw fibres with a length between <2 mm and 20 mm are available in a small amount, similar to ground layer 8532. The pieces of straw are rather fine, on average up to about 5 mm. Sample colour (after Munsell): dry 10YR 7/2 light grey; semi-dry 10YR 5/3 brown.

### Grain size distribution

Compared to the average values of examined interior plasters, the material is relatively fine with a high content of fine fractions (silt and clay) equalling 77.4%. Biggest fraction: fine gravel. The median is located at app. 8.5 µm; the <2 µm fraction contains app. 31% of the whole sample, in general slightly finer than the lower layer of the aureole. The grain size distribution also shows two peaks and a bimodal distribution marked by a valley between the fine sand and the medium silt fractions. With this feature it matches with the plasters of the site. The amount of sand is rather high and is compensated by a high content of fine material. The comparison with other samples of Nyarma wall plasters shows clear similarities with the plaster samples of the assembly hall. The material used for the upper layer of the aureole is similar to the material used as plaster and shows that no difference was made regarding these kinds of use. A closer look shows that the builders were aware of the need for a slightly finer upper layer of the aureole, probably related to the modelling of ornaments along its surface.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 8516 Aureole upper layer | 1.9 | 30.7 | 36.2 | 31.2 |
| 8522 Aureole ground layer | 1.4 | 34.1 | 38.6 | 25.9 |
| 11918 Assembly hall | 2.2 | 33.2 | 39.4 | 25.2 |

### Grain shapes

The shape of the grains shows a dominance of “angular” and unlike sample 8522, no change in the fraction >2,000 µm. A change in the sand fractions is not evident.

### Bulk mineral analysis

The results of the BMA show strong similarities to the mineralogical composition of the samples of Nyarma in general. At 3% an amount of calcite ranges in an average field compared with other Nyarma plaster samples. Close similarity to the ground layer of the aureole (sample 8522) can be stated. Comparing with samples 8531 and 11918, the wall plasters within the assembly hall show differences in the content of K-feldspar and plagioclase.

### Clay mineral analysis

A comparison between interior wall plasters from the *cella* (‘Group-1’ (6073, 11745, 11753, 11925)), the interior wall plasters from the assembly hall (‘Group-2’ (11918, 8531, 11762)) and the clay mineral average data from clay pits (11754, 11956) shows close similarities. For sample 8532, at 7% the amount of smectite is rather high; at 7% kaolinite is at an average level, and the amount of chlorite at 22% is relatively low. The content of swellable clay minerals is slightly smaller than in the ground layer.

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 8516 | 7 | 64 | 7 | 22 |
| Ø Group-1 | 3–5 | 66–69 | 4–9 | 22–26 |
| Ø Group-2 | 4–9 | 66–67 | 6–7 | 19–23 |
| Ø Clay pits | 3–5 | 62–65 | 8–10 | 22–25 |

## 4.5 Exterior wall plasters

### 4.5.1 Wall plaster in the inner ambulatory

### MAIN TEMPLE. INNER AMBULATORY. WALL PLASTER. SAMPLE 11914

### Sampling point

Temple I, north wall of the *cella*. Exterior plaster located in the inner ambulatory (Fig. 54.2, Fig. 55.2). Sample number in the field: 11. Constructive use: Exterior plaster of the *cella* building. Today, the ambulation corridor is partially without a roof. It is not clear if it was originally closed with a roof. Additives: The content of straw is rather high and the used pieces are big and up to a length of 3 cm. Sample colour (after Munsell): dry 2.5YR 7/2 light grey; semi-dry 2.5YR 4/2 greyish brown.

### Grain size distribution

Fig. 54.2 (Left) Nyarma. Main temple. Inner ambulatory.
Fig. 55.2 (Right) Nyarma. Main temple. Wall plaster along the inner ambulatory.

Compared to the average values of examined interior plasters, the material is relatively fine with a high content in the fine fractions (silt and clay) of 65.7%. Biggest fraction: coarse sand. The median is located at app. 7.5 µm; the <2 µm fraction contains app. 32%. The grain size distribution also shows two peaks at medium sand and fine silt, and coarse clay and a bimodal distribution marked by a valley between the fine sand and the fine silt fractions. Compared with most of the other plaster samples from Nyarma, the grain size distribution according to the course of the curve can be described as poorly sorted. Close similarity to sample 11753, an interior plaster in the *cella,* and to sample 8516, the upper part of the aureole in the assembly hall, can be stated. Despite the relatively coarse appearance, this plaster conforms to the grain size distributions of two of the finest plasters of the monastery. Gravel was found with a diameter of up to 12 mm.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 11914 *Cella* ext. plaster | 3.1 | 31.2 | 34.5 | 31.2 |
| 11753 *Cella* | 0.7 | 27.0 | 39.6 | 32.7 |
| 8516 Aureole upper layer | 1.9 | 30.7 | 36.2 | 31.2 |

### Bulk mineral analysis

The results of the BMA show strong similarities to the mineralogical composition of the samples of Nyarma in general. An amount of calcite, which was found as traces, ranges in a lower average field compared with other Nyarma plaster samples. Close similarity to sample 11753, an interior plaster in the *cella*, and sample 8516, the upper part of the aureole in the assembly hall, is given regarding grain size distribution.

### Grain shapes

The shape of the grains can be described as “angular” and with a “beginning rounding” in the >2,000 µm fraction; as “angular” but less with a “beginning rounding” in the >630 µm fraction; and as primarily “angular” in the >200 µm fraction. A mixture with sand or another type of clay can not be excluded (Fig. 56.2).

Fig. 56.2 Shapes of grains in sample 11914. Scaled in millimetre.
Shape of fraction >2,000 µm (Left), 630–2,000 µm (Centre), 200–630 µm (Right).

### Clay mineral analysis

A comparison to interior wall plasters from the *cella* (‘Group-1’ (6073, 11745, 11753, 11925)), the interior wall plasters from the assembly hall (‘Group-2’ (11918, 8531, 11762)) and the clay mineral average data from clay pits (11754, 11956) shows close similarities. For sample 11914, at 3% the amount of smectite is rather small; at 5% kaolinite is at an average level, and the amount of chlorite at 23% is relatively low.

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 11914 | 3 | 69 | 5 | 23 |
| Ø Group-1 | 3–5 | 66–69 | 4–9 | 22–26 |
| Ø Group-2 | 4–9 | 66–67 | 6–7 | 19–23 |
| Ø Clay pits | 3–5 | 62–65 | 8–10 | 22–25 |

## 4.5.2 Wall plaster in the outer ambulatory

## MAIN TEMPLE. OUTER AMBULATORY. WALL PLASTER. SAMPLE 11762

### Sampling point

Temple I, main temple, outer ambulatory at the southside of the assembly hall (Fig. 57.2, Fig. 58.2). Sample number in the field: 19. Constructive use: Plaster, ground and upper layer. Similar to sample 11914, the exterior plaster at the north wall of the *cella,* the content of straw is rather high and the used pieces are considered big and up to a length of app. 2 cm.

Fig. 57.2 (Left) Nyarma. Main temple. Outer ambulatory.
Fig. 58.2 (Right) Nyarma. Main temple. Wall of the assembly hall along the outer ambulatory.

### Grain size distribution

Compared to the average values of examined interior plasters, the material is relatively fine. Biggest fraction: fine gravel. The median is located at app. 7 µm; the <2 µm fraction contains app. 28%. The grain size distribution also shows two peaks at medium sand and fine silt, and coarse clay and a bimodal distribution marked by a valley between the medium sand and the fine silt fractions. The grain size distribution shows strong similarities to the exterior plaster (sample 11914) used along the north facade of the *cella*.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 11762 Assembly hall ext. plaster | 3.3 | 27.8 | 41.5 | 27.4 |
| 11914 *Cella* ext. plaster | 3.1 | 31.2 | 34.5 | 31.2 |

### Grain shapes

Similar to plaster 11914 the >2,000 µm fraction shows two shapes, a dominance in "angular", and a "beginning rounding". In the fractions <2,000 µm, a dominance of "angular" is evident.

### Bulk mineral analysis

The results of the BMA show strong similarities to the mineralogical composition of the samples of Nyarma in general. The bulk mineral analysis matches with the interior wall plaster of the *cella* (sample 11925) and with the interior wall plaster of the assembly hall (sample 11918) but varies from the other examined wall plasters inside the *cella* and assembly hall due to a slightly lower amount of mica, 7Å minerals and phyllo silicates. At 15% the amount of calcite is the highest detected within the Nyarma samples (Fig. 59.2). No gypsum is available.

Some features, particularly along the central temple (*cella* and inner circumambulation path), show evidence of a former covering of the outer ambulation corridor (cf. Feiglstorfer, forthcoming b). Regarding the mineral components, calcite appears in a relatively high amount, a hint that this wall may have been covered with a calcite ground layer or that it was whitewashed in earlier days. The amount of 15% indicates the existence of a rather thick layer of whitewash or the addition of lime to the plaster. The layer of whitewash points towards its former use as an exterior wall.

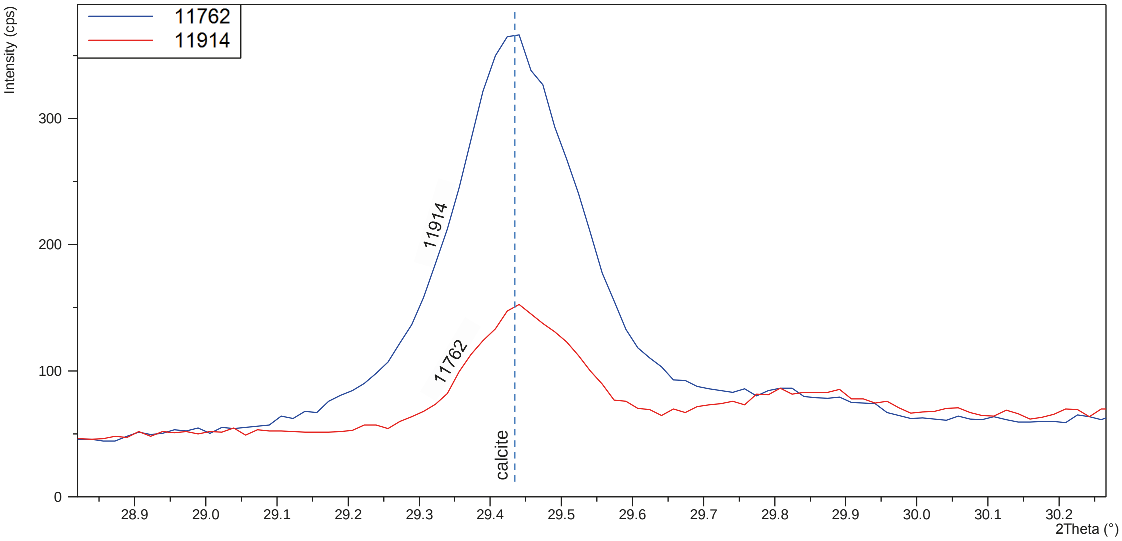


Fig. 59.2 Nyarma. BMA. Content of calcite. Samples 11762 and 11914 juxtaposed.

### Clay mineral analysis

A comparison to interior wall plasters from the *cella* (‘Group-1’ (6073, 11745, 11753, 11925)), the interior wall plasters from the assembly hall (‘Group-2’ (11918, 8531, 11762)) and the clay mineral average data from clay pits (11754, 11956) shows close similarities. For sample 11762, at 6% the amount of smectite is average; at 7% kaolinite is at an average level, and the amount of chlorite at 21% is relatively low. The CMA-data of this sample matches with the data of 11918, i.e. the interior plaster in the assembly hall. There is no doubt that it was the same base material.

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 11762 | 6 | 67 | 7 | 21 |
| Ø Group-1 | 3–5 | 66–69 | 4–9 | 22–26 |
| Ø Group-2 | 4–9 | 66–67 | 6–7 | 19–23 |
| Ø Clay pits | 3–5 | 62–65 | 8–10 | 22–25 |

## TEMPLE IIIB. EXTERIOR PLASTER. SAMPLE 15408

### Sampling point

Temple IIIb (Fig. 60.2, Fig. 61.2). Sample number in the field: 63 NY-RZ/AP. Constructive use: Exterior plaster, ground and upper layer. Similar to sample 11914, i.e. the exterior plaster at the north wall of the *cella,* the content of straw is rather high and the used pieces are of a size up to a length of 2 cm. Sample colour (after Munsell): dry 2.5YR 7/2 light grey; semi-dry 2.5YR 4/2 dark greyish brown.

Fig. 60.2 (Left) Nyarma. Main temple. Outer ambulatory.
Fig. 61.2 (Right) Nyarma. Main temple. Wall of the assembly hall along the outer ambulatory.

### Grain size distribution

Compared to the average values of examined interior plasters, the material is relatively coarse. Biggest fraction: fine gravel. The median is located at app. 280 µm; the <2 µm fraction contains app. 12%. The grain size distribution also shows two peaks: the maximum peak at the coarse and medium sand fraction and a much smaller peak at the fine silt fraction. There is further a bimodal distribution marked by a valley between the medium sand and the fine silt fractions. The grain size distribution, due to its coarse composition, shows the strongest similarity to clay pit sample 11754. It becomes obvious that the raw material was directly used for the whole exterior plaster. A juxtaposition of the samples shows the relation of this sample to other Nyarma samples. The grain shapes show a dominance of "angular" and no evidence of a mixture with sand or another type of clay.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 15408 Temple IIIb | 0.2 | 65.3 | 22 | 12.5 |
| 11754 Clay pit | 6.5 | 65.9 | 17.0 | 10.6 |

### Bulk mineral analysis

The results of the BMA show strong similarities to the mineralogical composition of the samples of Nyarma in general. An amount of calcite measured at 5% ranges in an average field compared with other Nyarma plaster samples.

### Clay mineral analysis

A comparison to interior wall plasters from the *cella* ('Group-1' (6073, 11745, 11753, 11925)), the interior wall plasters from the assembly hall ('Group-2' (11918, 8531, 11762)) and the clay mineral average data from clay pits (11754, 11956) shows close similarities. For sample 15408, at 3% the amount of smectite is rather low; at 5% kaolinite is at an average level, and the amount of chlorite at 23% is relatively low (shown in the following list).

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 15408 | 3 | 69 | 5 | 23 |
| Ø Group-1 | 3–5 | 66–69 | 4–9 | 22–26 |
| Ø Group-2 | 4–9 | 66–67 | 6–7 | 19–23 |
| Ø Clay pits | 3–5 | 62–65 | 8–10 | 22–25 |

## Temple IV. Exterior plaster. Sample 8519

### Sampling point

Temple IV. Exterior plaster along the wall left of the entrance. Sample number in the field: 62 NY-RZ/AP. Constructive use: Exterior plaster, ground and upper layer. Similar to sample 11914 – i.e. the exterior plaster at the north wall of the *cella* – the content of straw is rather high and the used pieces are considered big with a length of 2 cm. Sample colour (after Munsell): dry 5YR 7/2 olive grey; semi-dry 5YR 5/2 olive grey.

### Grain size distribution

Compared to the average values of examined interior plasters, the material is relatively coarse. Biggest fraction: fine gravel. The median is located at app. 90 µm; the <2 µm fraction contains app. 13%. The grain size distribution also shows only one peak at 31.3% for the fine sand fraction. No bimodal distribution is available as shown at most of the other Nyarma plaster samples which points towards an unmixed sample.

The grain size distribution shows strong similarity to the exterior plaster sample from Temple IIIa (sample 15408). The examinations state that for the exterior plasters of Temples IIIa and IVa, a similar coarse material was used. A juxtaposition of the samples shows the relation of this sample to other Nyarma samples. The size of gravel found in this sample is of a diameter of up to 10 mm.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 8519 Temple IV | 3.2 | 56.2 | 28 | 12.6 |
| 15408 Temple IIIb | 0.2 | 65.3 | 22 | 12.5 |

### Grain shapes

In the <2,000 µm fraction, "angular" is the dominant shape, while in the fraction >2,000 µm, "beginning rounding" and "rounded" grains are additionally available. This emphasises the addition of coarse material.

### Bulk and clay mineral analysis

The results of the BMA show strong similarities to the mineralogical composition of the samples of Nyarma in general, specifically regarding the amount of quartz (due to the high content of sand) and also of plagioclase and K-feldspar. At 3% the amount of measured calcite ranges in an average field compared with other Nyarma plaster samples.

A comparison to interior wall plasters from the *cella* ('Group-1' (6073, 11745, 11753, 11925)), the interior wall plasters from the assembly hall ('Group-2' (11918, 8531, 11762)) and the clay mineral average data from clay pits (11754, 11956) shows close similarities. For sample 8519, at 3% the amount of smectite is rather low; at 7% kaolinite is at an average level, and the amount of chlorite at 20% is relatively low (shown in the following list).

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 8519 | 3 | 67 | 7 | 20 |
| Ø Group-1 | 3–5 | 66–69 | 4–9 | 22–26 |
| Ø Group-2 | 4–9 | 66–67 | 6–7 | 19–23 |
| Ø Clay pits | 3–5 | 62–65 | 8–10 | 22–25 |

## 4.6 Results of mineral analysis given in tables

| Sample | Gravel [%] | Sand [%] | Silt [%] | Clay [%] | Median [µm at 50%] | <2µm [%] |
|---|---|---|---|---|---|---|
| Clay pits and new bricks | | | | | | |
| 11754 | 6.5 | 65.9 | 17.0 | 10.6 | 180 | 11 |
| 11956 | 6.4 | 51.6 | 27.1 | 14.9 | 95 | 15 |
| 8505 | 3.9 | 54.3 | 28.7 | 13.1 | 98 | 12 |
| 11947 | 9.3 | 50.9 | 28.4 | 11.4 | 110 | 12 |
| Interior wall plasters in Temple I / *cella* | | | | | | |
| 6073 | 0 | 5.7 | 56.9 | 37.4 | 2.9 | 38 |
| 11745 | 0.9 | 19.7 | 39.2 | 40.2 | 3.1 | 40 |
| 11753 | 0.7 | 27 | 39.6 | 32.7 | 5 | 33 |
| 11925 | 1.2 | 20.7 | 38.9 | 39.2 | 3.7 | 40 |
| Interior wall plasters in Temple I / assembly hall | | | | | | |
| 11918 | 2.2 | 33.2 | 39.4 | 25.2 | 10 | 26 |
| 8531 | 2.3 | 40 | 33.9 | 23.8 | 21 | 23 |
| Interior wall plaster in Temple III | | | | | | |
| 8514 | 0.4 | 19.9 | 37.3 | 42.4 | 3.5 | 43 |
| Interior wall plasters in Temple IV | | | | | | |
| 15406 | 0 | 21.8 | 39.8 | 38.4 | 4 | 39 |
| 8517 | 8.2 | 54 | 23.8 | 14 | 135 | 14 |
| Interior wall plaster in Temple V | | | | | | |
| 11761 | 0.4 | 45.9 | 32.3 | 21.5 | 40 | 22 |
| Interior wall plasters in a stupa | | | | | | |
| 8532 | 4.2 | 46.9 | 29.2 | 19.7 | 65 | 20 |
| 8520 | 0 | 63.3 | 17.4 | 19.3 | 150 | 20 |
| 15405 | 0 | 64.7 | 19.6 | 15.7 | 125 | 17 |
| Aureoles | | | | | | |
| 8522 | 1.4 | 34.1 | 38.6 | 25.9 | 9 | 27 |
| 8516 | 1.9 | 30.7 | 36.2 | 31.2 | 8.5 | 31 |
| Exterior wall plasters | | | | | | |
| 11914 | 3.1 | 31.2 | 34.5 | 31.2 | 7.5 | 32 |
| 11762 | 3.3 | 27.8 | 41.5 | 27.4 | 7 | 28 |
| 15408 | 0.2 | 65.3 | 22 | 12.5 | 280 | 12 |
| 8519 | 3.2 | 56.2 | 28 | 12.6 | 90 | 13 |

Table 3.2. (Previous page) Part 1. Grain size classes.

Table 3.2. (On this page) Part 2. Grain size classes.

| **Sample** | **Gravel** [%] | **Sand** [%] | **Silt** [%] | **Clay** [%] | **Median** [µm at 50%] | **<2µm** [%] |
|---|---|---|---|---|---|---|
| Brick Temple I | | | | | | |
| 11767 | 2.8 | 45.4 | 35.1 | 16.7 | 55 | 18 |
| Bricks Temple II | | | | | | |
| 8509 | 5.7 | 57.3 | 25.5 | 11.5 | 125 | 12 |
| 11750 | 12.2 | 56.6 | 20.4 | 10.8 | 170 | 11 |
| Brick Temple IIIa | | | | | | |
| 11926 | 6.3 | 55.9 | 22.9 | 14.9 | 110 | 15 |
| Bricks Temple IIIb | | | | | | |
| 11744 | 2.1 | 51.9 | 25.2 | 20.8 | 75 | 21 |
| 8533 | 7.2 | 50.2 | 25.7 | 16.9 | 95 | 18 |
| Bricks Temple IV | | | | | | |
| 15407 | 5.1 | 59.7 | 21.9 | 13.3 | 135 | 13 |
| 11917 | 7.1 | 49.9 | 19.4 | 13.6 | 90 | 14 |
| Brick Temple VIa | | | | | | |
| 11765 | 1.3 | 40.6 | 37.7 | 20.4 | 28 | 20 |
| Brick Temple VIb | | | | | | |
| 11760 | 5.9 | 60.4 | 23.7 | 10 | 130 | 10 |
| Enclosure wall of the temple compound | | | | | | |
| 11766 | 3.5 | 64.5 | 19.5 | 12.7 | 180 | 13 |

Table 4.2. Part 1. Bulk mineral analysis.

| Sample | 14Å | Mica | Amph | 7Å | Phy sil | Quar | K-fsp | Plagio | Calc | Haem | Gyps | Pyr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Clay pits and new bricks | | | | | | | | | | | | |
| 11754 | . | . | * | . | . | * | * | *** | --- | --- | --- | --- |
| 11956 | . | . | * | . | . | * | * | ** | 0% | . | --- | --- |
| 8505 | * | * | ** | * | * | ** | * | ** | --- | --- | --- | --- |
| 11947 | . | · | * | . | . | * | * | ** | . | . | --- | --- |
| Interior wall plasters in Temple I / *cella* | | | | | | | | | | | | |
| 6073 | * | ** | . | ** | *** | ** | . | ** | 2% | . | --- | ? |
| 11745 | . | * | . | * | * | * | . | * | 5% | . | 4% | --- |
| 11753 | . | * | . | * | * | * | . | * | . | --- | --- | --- |
| 11925 | . | . | . | . | . | * | . | * | . | . | --- | ? |
| Interior wall plasters in Temple I / assembly hall | | | | | | | | | | | | |
| 11918 | . | . | . | . | * | * | * | * | . | . | --- | ? |
| 8531 | . | * | * | * | * | * | ** | *** | . | --- | --- | ? |
| Interior wall plaster in Temple III | | | | | | | | | | | | |
| 8514 | . | * | . | * | * | * | . | ** | . | . | --- | ? |
| Interior wall plasters in Temple IV | | | | | | | | | | | | |
| 15406 | . | * | . | * | * | * | . | * | 2% | . | --- | . |
| 8517 | . | . | . | * | . | * | * | ** | 6% | . | --- | --- |
| Interior wall plaster in Temple V | | | | | | | | | | | | |
| 11761 | . | . | . | . | . | * | . | ** | . | . | --- | ? |
| Interior wall plaster in a stupa | | | | | | | | | | | | |
| 8532 | . | * | * | * | * | * | ** | *** | 3% | . | --- | --- |
| 8520 | . | * | . | * | * | ** | ** | *** | 4% | . | 3% | ? |
| 15405 | . | * | * | * | . | * | * | ** | 6% | . | --- | --- |
| Aureoles | | | | | | | | | | | | |
| 8522 | . | * | . | * | * | ** | * | ** | 4% | . | --- | ? |
| 8516 | . | * | * | * | * | * | * | ** | 3% | . | --- | ? |
| Exterior wall plasters | | | | | | | | | | | | |
| 11914 | . | * | . | * | . | * | . | ** | . | . | --- | ? |
| 11762 | . | . | . | . | . | * | . | * | 15% | . | --- | ? |
| 15408 | . | * | . | * | . | * | * | ** | 5% | . | --- | --- |
| 8519 | . | * | * | * | * | ** | *** | *** | 3% | . | --- | |

Table 4.2. Part 2. Bulk mineral analysis.

| Sample | 14Å | Mica | Amph | 7Å | Phy sil | Quar | K-fsp | Plagio | Calc | Haem | Gyps | Pyr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Historical adobe bricks | | | | | | | | | | | | |
| 11767 | . | . | . | . | . | * | . | ** | . | --- | --- | ? |
| 8509 | . | * | ** | * | . | * | ** | *** | . | --- | --- | ? |
| 11750 | . | * | * | . | . | * | * | *** | . | --- | --- | --- |
| 11926 | . | . | * | . | . | * | * | *** | --- | --- | --- | --- |
| 11744 | . | . | * | * | . | * | * | ** | . | . | --- | --- |
| 8533 | . | * | ** | * | * | * | ** | *** | 2% | --- | --- | --- |
| 15407 | . | * | ** | * | . | * | ** | *** | 3% | --- | --- | ? |
| 11917 | . | . | * | . | . | * | * | *** | . | --- | --- | --- |
| 11765 | . | . | * | . | . | * | * | ** | . | --- | --- | ? |
| 11760 | . | * | * | . | . | * | * | *** | . | --- | --- | --- |
| 11766 | . | . | . | . | . | * | * | ** | . | --- | --- | ? |

Table 5.2. Part 1. Clay mineral analysis.

| Sample | Origin of the samples | Smectite | Illite | Kaolinite | Chlorite |
|---|---|---|---|---|---|
| Clay pits and new bricks | | | | | |
| 11754 | clay pit, used for bricks | 5 | 65 | 8 | 22 |
| 11956 | clay pit, used for bricks | 3 | 62 | 10 | 25 |
| 8505 | brick | 8 | 59 | 8 | 25 |
| 11947 | brick | 2 | 62 | 10 | 26 |
| Interior wall plasters in Temple I / *cella* | | | | | |
| 6073 | Temple I, upper layer | 3 | 66 | 9 | 22 |
| 11745 | Temple I, bottom + upper layer | 4 | 69 | 5 | 22 |
| 11753 | Temple I, bottom + upper layer | 5 | 68 | 5 | 22 |
| 11925 | Temple I, bottom + upper layer | 3 | 67 | 4 | 26 |
| Interior wall plasters in Temple I / assembly hall | | | | | |
| 11918 | Temple I, bottom + upper layer | 4 | 66 | 7 | 23 |
| 8531 | Temple I, bottom + upper layer | 9 | 66 | 6 | 19 |
| Interior wall plaster in Temple III | | | | | |
| 8514 | Temple IIIa, bottom + upper layer | 7 | 62 | 7 | 24 |
| Interior wall plasters in Temple IV | | | | | |
| 15406 | Temple IV, upper layer | 2 | 63 | 5 | 30 |
| 8517 | Temple IV, bottom layer | 3 | 69 | 5 | 23 |
| Interior wall plaster in Temple V | | | | | |
| 11761 | Temple V, bottom + upper layer | 3 | 64 | 7 | 26 |
| Interior wall plasters in a stupa | | | | | |
| 8532 | Stupa, bottom layer | 9 | 64 | 7 | 20 |
| 8520 | Stupa, upper layer | 10 | 61 | 6 | 23 |
| 15405 | Stupa, wall frieze | 22 | 35 | 5 | 18 |
| Aureoles | | | | | |
| 8522 | Temple I, bottom layer | 10 | 65 | 7 | 18 |
| 8516 | Temple I, upper layer | 7 | 64 | 7 | 22 |
| Exterior wall plasters | | | | | |
| 11914 | Temple I, bottom + upper layer | 3 | 69 | 5 | 23 |
| 11762 | Temple I, bottom + upper layer | 6 | 67 | 7 | 21 |
| 15408 | Temple IIIb, bottom + upper layer | 3 | 69 | 5 | 23 |
| 8519 | Temple IV, upper layer | 3 | 67 | 7 | 20 |

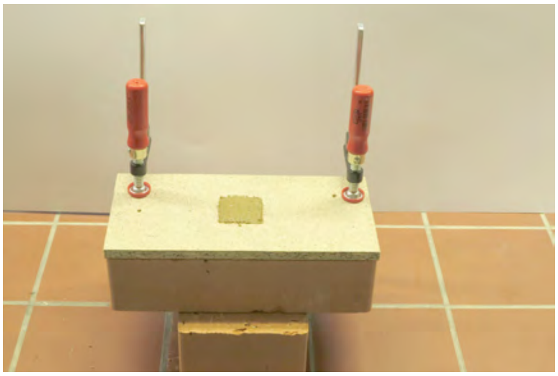
Table 5.2. Part 2. Clay mineral analysis.

| Sample | Origin of the samples | Smectite | Illite | Kaolinite | Chlorite |
|---|---|---|---|---|---|
| Historical adobe bricks | | | | | |
| 11767 | Temple I | 2 | 62 | 6 | 30 |
| 8509 | Temple II | 5 | 68 | 6 | 21 |
| 11750 | Temple II | 2 | 67 | 7 | 24 |
| 11926 | Temple IIIa | 4 | 62 | 8 | 26 |
| 11744 | Temple IIIb | 2 | 65 | 7 | 26 |
| 8533 | Temple IIIb | 4 | 65 | 7 | 24 |
| 15407 | Temple IV | 2 | 63 | 8 | 27 |
| 11917 | Temple IV | 3 | 66 | 6 | 25 |
| 11765 | Temple VIa | 2 | 65 | 6 | 27 |
| 11766 | Temple VIb | 3 | 59 | 8 | 30 |
| 11760 | enclosure wall | 2 | 64 | 7 | 27 |

# 5. FURTHER MATERIAL ANALYSES

## 5.1 Plasters

To get closer to a practical recipe for burnishing a plaster, a series of tests was conducted at the IAG / BOKU. For this reason, original plaster material from the main temple of Nyarma (year of foundation 996 CE) was used, and samples with a size of 40 x 40 x 10 mm were prepared (Fig. 62.2, Fig. 63.2). Of each mixture two specimens were prepared: one to observe its surface in an untreated state, and another to compare it to the second with a burnished surface. In the following the different mixtures, their treatment, the burnishing and their final appearance will be analysed and compared. With the Vickers needle test, possible changes of the surfaces' hardness will be examined.



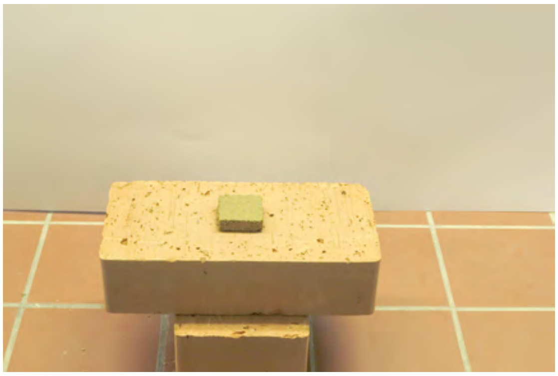


Fig. 62.2 Mould for the preparation of specimens.
Fig. 63.2 Specimen, which is ready for further examinations.

### 5.1.1 Quality of surfaces

Different tools were used for burnishing, like porcelain, a metal spoon or fingernails.[23] Important was the smoothness, hardness and a certain rounding of the particular tool. In general, the best time for burnishing was at a leather-hard state up until the surface turned into a white-dry state. The examined surfaces range between 'unburnishable', and 'smooth and shiny'. At small troughs, burnishing is difficult and needs a stronger pressure to level the protruding portions or the application of a new slurry and continuing burnishing. If burnished for a too long period, the shining surface tarnishes. Grains from the sand fraction may be loosened by burnishing and scratch adjoining and already burnished surface portions.

---

[23] Further results of burnishing tests of *arga* roof material are given in Chapter III.

### 15614 (unburnished)

For this sample an industrially prefabricated plaster was used, i.e. the “Universallehmputz”[24] developed by Roland Meingast. This material is primarily used as wall plaster. It soaks up water relatively fast and too much water quickly turns it into slurry. But as soon as it hardens, it becomes a strong and difficult to damage plaster. Due to the content of coarse material from the sand fraction, its surface remains too rough to be burnished. The content of fine material was not enough, so that when burnishing, grains are breaking from the surface (Fig. 64.2). This material is too coarse for a Vickers test.

### 15614 (base) + 15615 (surface) (smectite powder; unburnished)

For this sample, the afore described specimen (15614) was covered with a smectite powder and layered as slurry. Due to a high content of swellable clay, the surface cracks become a wavy surface and detach from the core below (Fig. 65.2). This material is improper for a Vickers test.

Fig. 64.2 (Top, left) Sample 15614. Unburnished.
Fig. 65.2 (Top, right) Sample 15614 (base) +15615 (surface). Unburnished.
Fig. 66.2 (Bottom) Sample 15614 (base) +11947 (surface). Unburnished.

---

[24] The author is grateful to Roland Meingast, an Austrian expert on earth architecture, for providing testing material of “Universallehmputz UNI 1.8” (former Biofaserlehmputz BFH02; a clay mixed with organic fibres) produced by „Levita Lehm“ of the company Egginger. Roland Meingast also provided a smectite clay powder used for tests.

Fig. 67.2 (Left) Sample 11947. Coarse material after desludging. Unburnished
Fig. 68.2 (Right) Sample 11947. Coarse material after desludging. Burnished.

### 15614 (base) + 11947 (surface) (1 min desludged; fine; unburnished)

For this sample, the afore described specimen (15614) was covered with raw material from Nyarma. This material was used for making bricks. To receive the fine content and avoid sieving, the material was desludged in a 1-min course. The used method of desludging is described in another part of this chapter. The slurry of the fine portion after desludging was added in fine layers, more similar to the act of painting than to plastering. The surface shows some cracks which the addition of finer material can fill. For this specimen slurry is already too fine to be burnished (Fig. 66.2). During the Vickers test, at a load of 10 kg, this sample broke and the load was reduced to 3 kg. This material is too uneven for a hardness test according to Vickers.

### 11947 (unburnished and burnished)

Results of tests for the burnished surface of sample 11947 in a pure and not desludged state see Fig. 59.3 and Fig. 60.3 in Chapter III.

### 11947 (1 min desludged; coarse)

For this sample, the afore mentioned cover material from Nyarma was used as core – just as in the previous specimen (sample 11947) without any further covering but the sample was desludged and the coarse remains were used (Fig. 67.2). After burnishing the surface remains too sandy and crumbly (Fig. 68.2). A smooth surface can not be achieved but it appears smoother than sample 11947 when desludged and not burnished. This material is too coarse for a Vickers test.

### 11918 (unburnished)

For this sample, an original plaster from Nyarma was used without desludging, meaning it contained the coarse fraction. In an unburnished state, the sample's surface remains relatively fine and smooth (Fig. 69.2).

Fig. 69.2 (Left) Sample 11918. Unburnished.
Fig. 70.2 (Right) Sample 11918. Burnished.

Test of the hardness of the surface according to Vickers:

11918-1 unburnished (Vick 1.1, see Appendix Chapter II)

- applied force 2 kgf;
- diagonals: 976 µm and 977 µm;
- 3.89 HD 2 (3.89 kg/mm²).

11918-2 unburnished (Vick 2.1, see Appendix Chapter II)

- applied force 2 kgf;
- diagonals: 980 µm and 982 µm;
- 3.85 HD 2 (3.85 kg/mm²).

### 5.1.2 Burnishing of plasters

11918 (burnished)

Burnishing was conducted in a state of a still humid surface with a thickness of about 1 mm to 2 mm. The core remains stable when adding water for burnishing. After burnishing, the surface was not closed completely for app. five minutes. Still some unevenness remained, which could be removed by burnishing for another five minutes after again adding water and letting it soak for about one minute. After drying for another five minutes, water remains on the surface for a longer period. Burnishing was continued after about one hour with another 20 minutes break and thereafter finishing with burnishing for another 10 minutes. Compared to the burnished *arga* samples 11947 and 11947 + 15370 (ground *arga*; see Chapter III), the surface is not as shiny but much smoother and easier to process and burnish. Fine fibres of straw appear on the surface.

After burnishing of the surface it becomes very smooth and is ready for attachment of a sub-layer, e.g. lime or gypsum, before adding colours. The corners remain stable without breaking. This sample can be mentioned as the only one whose surface is of such a brilliant and high quality in a burnished state (Fig. 70.2). A juxtaposition of this sample in an unburnished state with a sample in a burnished state under the REM[25] (scanning electron microscope) shows the following result: In the unburnished state the single phyllo silicate sheets are ordered in a seemingly 'chaotic' manner while in the burnished state the sheets are laid in a horizontal position, by that closing the most upper surface.

Test of the hardness of the surface according to Vickers:

11918 burnished (Vick 3.1, see Appendix Chapter II)

- applied force 2 kgf;
- diagonals: 943 µm and 948 µm;
- 4.15 HD 2 (4.15 kg/mm²).

11918 (base) + 11947 (surface) (fine sludge after 1 min sinking; unburnished)
For this sample the original plaster sample (11918) from Nyarma was used as the core and was covered by sample 11947 after desludging of the fine content. This method was already used for a sample previously described. For this sample (11947; 1 min desludged; fine), the result of the surface shows small cracks and it was too fine for burnishing. For the sample (11918 + 11947), the same cover is tested on a different core, which is the material used in Nyarma for bricks. During application the cover was pressed into thin layers. Nearly no cracks remained and at one corner the cover detached slightly. The remaining surface is the finest of the unburnished surfaces. Sample 11918 from Nyarma is much finer than for example the "Universallehmputz"-sample 15614 (see Fig. 64.2 before), and by that the moisture is kept on the surface for a longer period than for the "Universallehmputz" which soaks up moisture quickly. By keeping the water on the surface for a longer period, the cover does not dry so quickly. This can be a reason for the reduction of cracks after drying despite using a very fine material (Fig. 71.2). This specimen (11918 + 11947) shows the influence of the core material (in practical use on a wall of the ground layer) on the behaviour of the upper plaster layer.

Test of the hardness of the surface according to Vickers:

11918 (base) + 11947 (surface) unburnished (Vick 4.2, see Appendix Chapter II)

- applied force 1 kgf;
- diagonals: 1284 µm and 1285 µm;
- 1.12 HD 1 (1.12 kg/mm²).

11918 (base) + 11947 (surface) (sludge after 1 min sinking; burnished)
For this sample the specimen from before was burnished. The effect is the shifting of the fine

---

[25] REM examination was conducted at the IPM / BOKU (Institute of Physics and Materials Science). The author is very grateful to Walter Klug for support in conducting the REM observation. Fig. 80.2 shows the burnished surface and Fig. 81.2 shows the surface in an unburnished state. With increased temperatures the phyllo silicate sheets again change into an upright position.

Fig. 71.2 Sample 11947 as upper layer on top of sample 11918 as core. Unburnished.
Fig. 72.2 Sample 11947 as upper layer on top of sample 11918 as core. Burnished.

phyllo silicate sheets of clay over each other. This makes the surface too instable for such a treatment (Fig. 72.2). Under the REM, the unburnishable surface shows the single sheets without adhesion to the surface below (Fig. 73.2, Fig. 74.2). An air blast would result in quick erosion of this loose surface.

The high content of clay makes it difficult to burnish. Coarse material or fibres are missing. Trying to improve the surface by again adding water and burnishing material is displaced and the surface remains inhomogenous. When burnishing with less pressure, not much changes. New material is to be added in the form of fine layers of slurry. The surface bleeds when touched, which is unfavourable for its use without a further coating. For comparison, Fig. 75.2 and Fig. 76.2 show the layering of phyllo silicate sheets not on the surface but inside the compressed sample 11918 after breaking.

Test of the hardness of the surface according to Vickers:

11918 (base) + 11947 (surface) burnished (Vick 5.2, see Appendix Chapter II)
- applied force 1 kgf;
- diagonals: 1111 µm and 1108 µm;
- 1.51 HD 1 (1.51 kg/mm²).

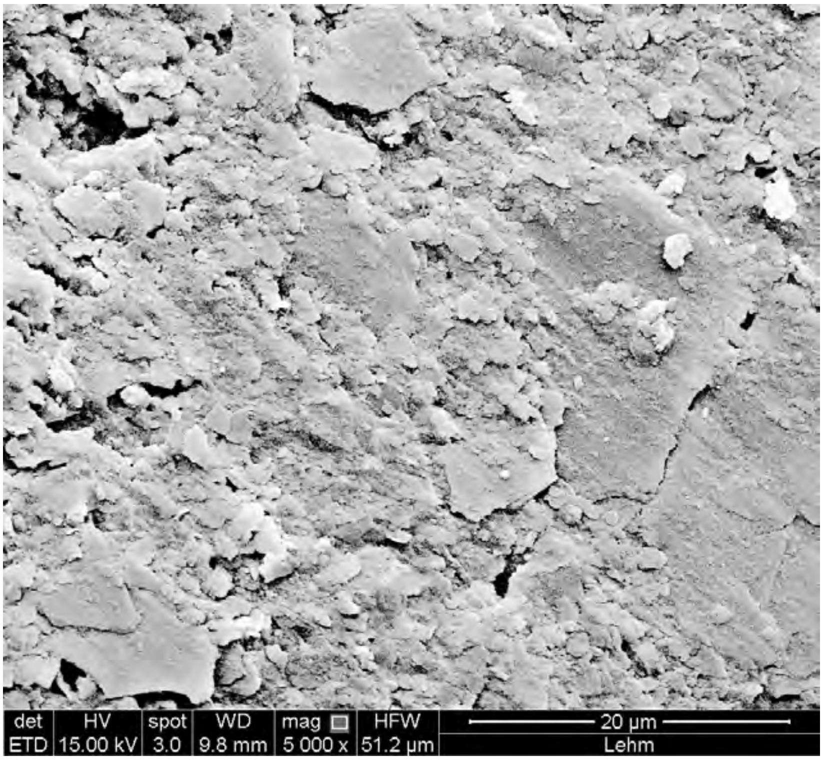
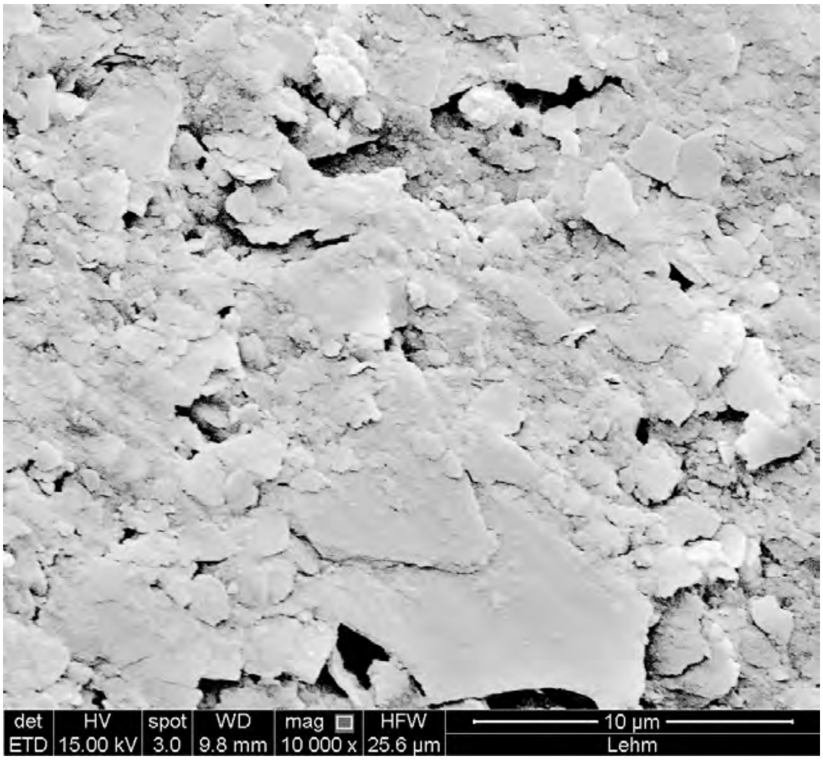


Fig. 73.2 REM observation (Top) and Fig. 74.2 (Below) show with different magnifications the surface of sample 11947 after burnishing. The surface layer is too fine and instabile for a successful burnishing and the phyllo silicate sheets are shifted above each other. Observation at BOKU / Vienna.



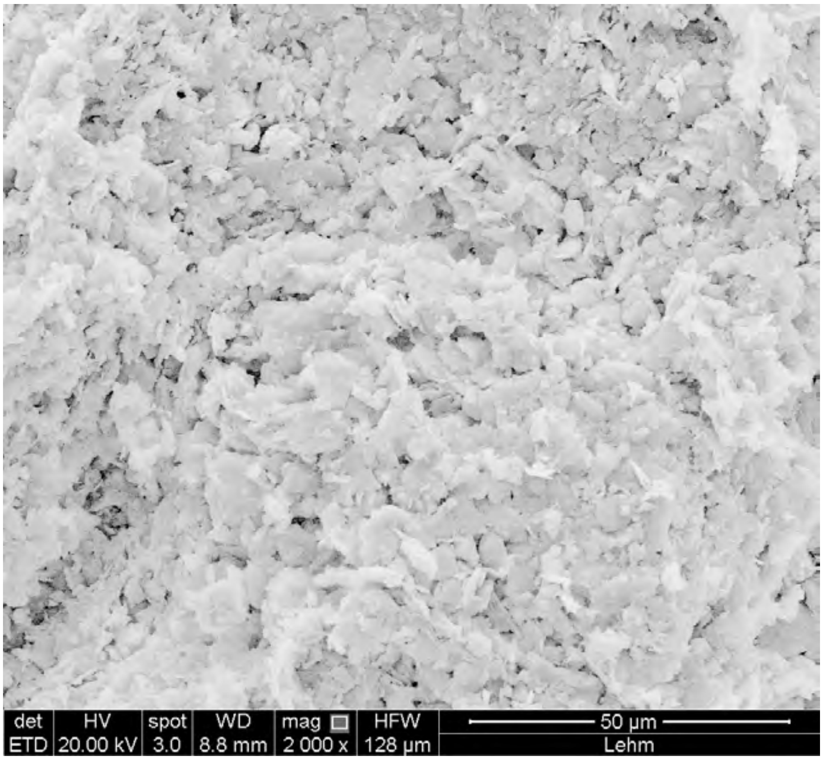
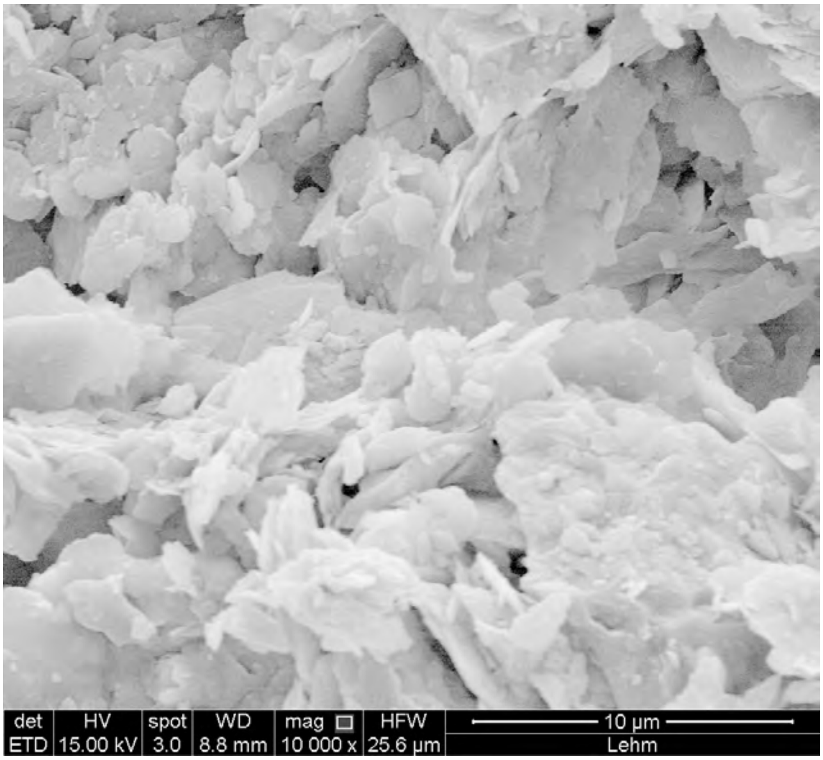


Fig. 75.2 REM observation (Top) and Fig. 76.2 (Below) show with different magnifications the surface of the breakage of sample 11918. It is an example for the layering of the phyllo silicate sheets inside the sample after breaking. Observation at BOKU / Vienna.



### 5.1.3 REM investigation of burnished surfaces

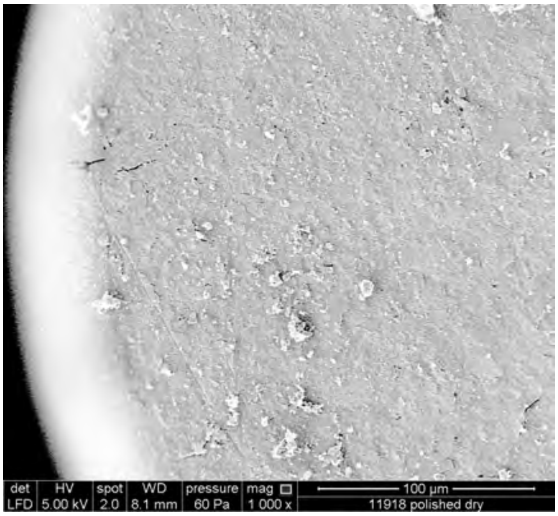
In the following REM-photos (Figs. 77.2 to 88.2) different stages of a burnished surface in dry, and moistened state are shown: The formerly compressed structure in a dry state, with equally and often horizontally orientated silicates, moves into a chaotically orientated order and small channels between the phyllo silicate sheets open for the capillary transport of the water.

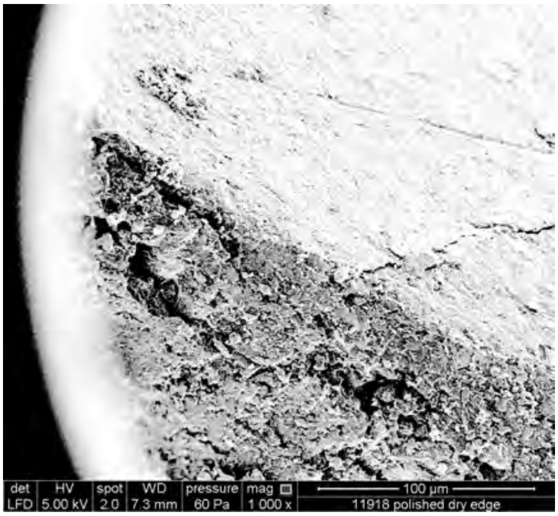
#### Dry state (Fig. 77.2 to Fig. 82.2)

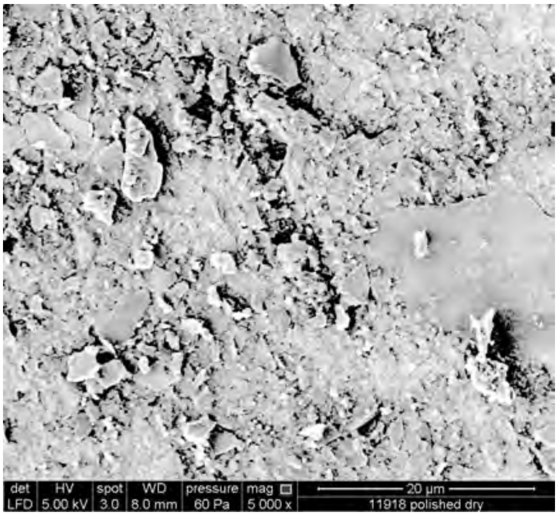
- Fig. 77.2, Fig. 78.2 and Fig. 79.2 show different magnification levels of a burnished surface, and are juxtaposed in the same magnification levels in Fig. 80.2, Fig. 81.2 and Fig. 82.2.
- Fig. 80.2, Fig. 81.2 and Fig. 82.2 show the behaviour of the upper and side surfaces along the edge of the sample.
- Fig. 77.2 shows the burnished surface at a 1,000 times magnification. Small cracks are visible in the surface structure, which in general appears homogenous.
- Fig. 78.2 and Fig. 79.2 show the burnished surface at a 5,000 times and 15,000 times magnification. Pieces of phyllo silicate sheets are scattered. In some areas a kind of compressed sheets with a closed surface appears as an ideal case for a closed surface structure by compressing and burnishing.
- Fig. 80.2 shows the edge of the sample where the burnished upper surface and the unburnished lateral surface meet. At a 1,000 times magnification, the lateral unburnished but compressed structure appears more chaotic as is the case along the upper surface.
- Fig. 81.2 and Fig. 82.2 show this edge (of Fig. 80.2) at a 5,000 times and 15,000 times magnification. The compression is visible in layers, with a most upper layer of about 4 µm thickness.

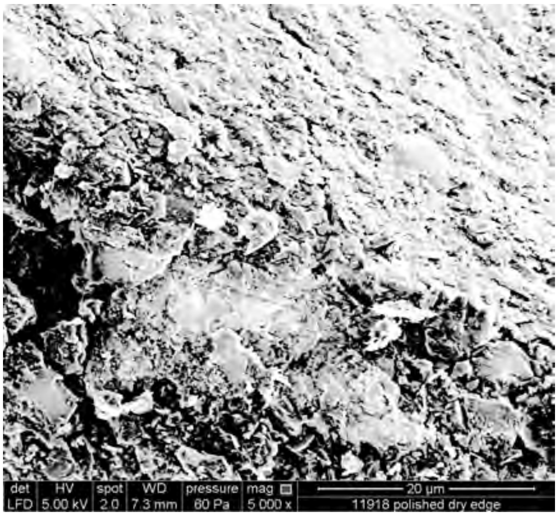
#### Moistened state (Figs. 83.2 to 88.2)

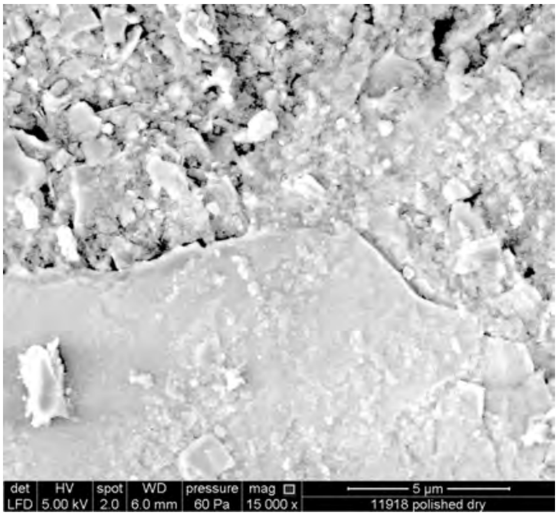
- Fig. 83.2, Fig. 84.2 and Fig. 85.2 show the sample in a slightly moistened / semi-dry stage
- Fig. 86.2, Fig. 87.2 and Fig. 88.2 show the sample in a fully with water saturated stage.
- Fig. 83.2 shows the semi-dry surface at a 1,000 times magnification. The surface still appears homogenous.
- Fig. 84.2 and Fig. 85.2 show the semi-dry surface at a 5,000 times and 15,000 times magnification. On top of the surface scattered phyllo silicate sheets are still visible but below the structure is also not as homogenous as in the dry state.
- Fig. 86.2 shows the saturated surface at a 1,000 times magnification. The surface is no longer closed but becomes porous.
- Fig. 87.2 and Fig. 88.2 show a chaotic organisation of the sheets which are not organised in the former horizontal manner. Channels for the capillary transport are formed. The whole structure becomes less dense.

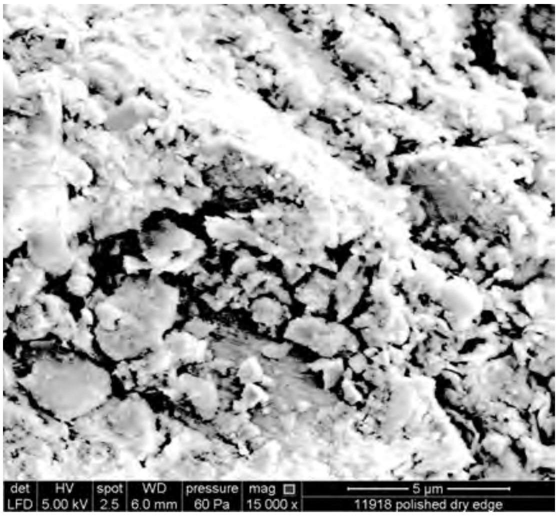








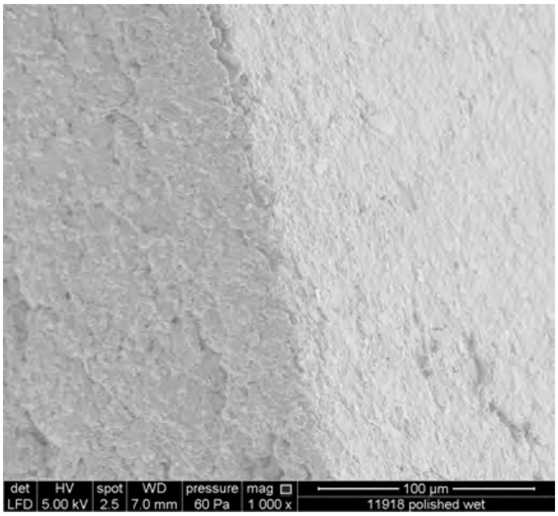


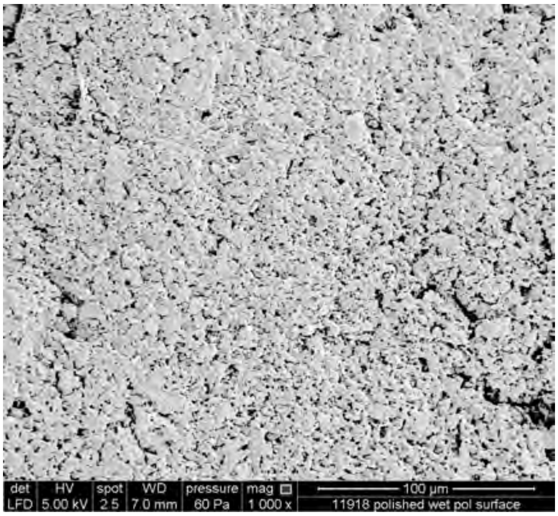


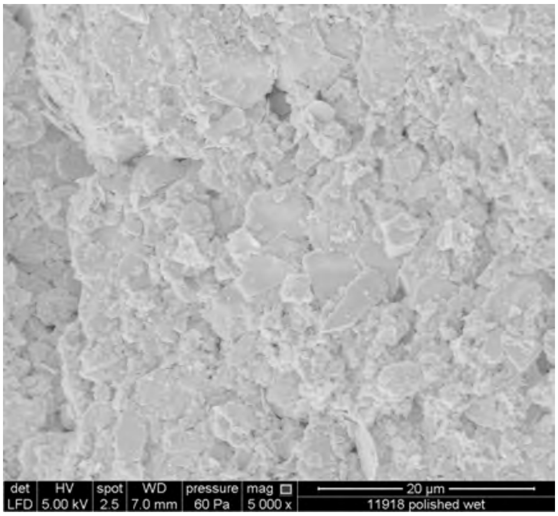
Figs. 77.2 to 82.2 show different REM magnifications of a burnished surface. Observation at BOKU / Vienna.

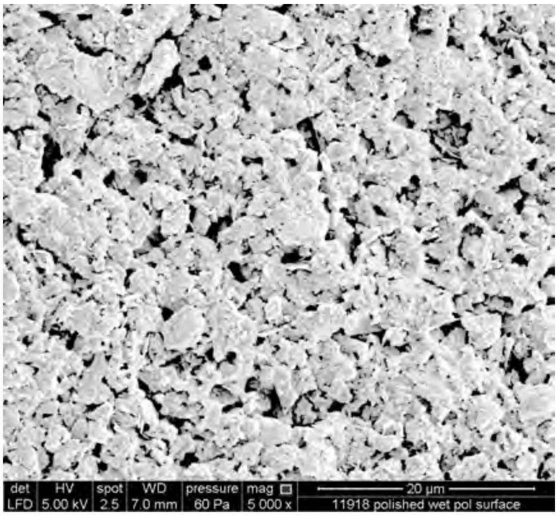
Fig. 77.2 (Top, left)
Fig. 78.2 (Centre, left)
Fig. 79.2 (Bottom, left)

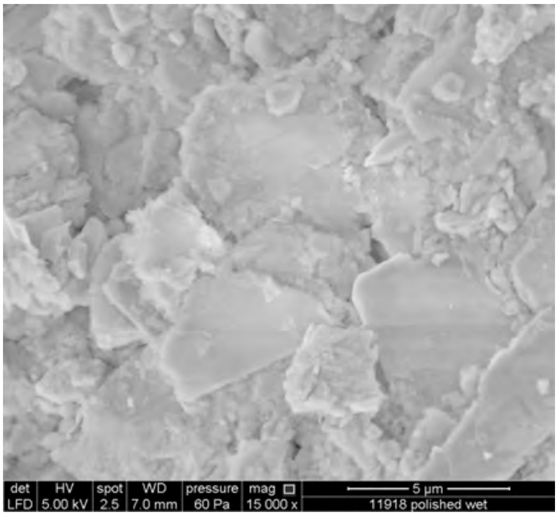
Fig. 80.2 (Top, right)
Fig. 81.2 (Centre, right)
Fig. 82.2 (Bottom, right)











Figs. 83.2 to 88.2 show different REM magnifications of a moistened surface. Observation at BOKU / Vienna.

Fig. 83.2 (Top, left)
Fig. 84.2 (Centre, left)
Fig. 85.2 (Bottom, left)

Fig. 86.2 (Top, right)
Fig. 87.2 (Centre, right)
Fig. 88.2 (Bottom, right)

Based on previous examinations in Fig. 89.2 various effects during the process of burnishing are shown.

1 In a dry state the phyllo silicate sheets are partially of a similar orientation.

2 In a moistened state the spaces between the sheets open up as a kind of channels.

3 In the state of drying from moistened to semi-dry the channels close.

4 During burnishing the phyllo silicate sheets are layered more parallel and the compression is optimised.

5 In case of a too high content of clay, the phyllo silicate sheets start slipping over each other and remain loose and not integrated in the compound below.

6 In case of a too high content of swellable minerals the horizontal compound is lost, according to the stress distribution within the sample.

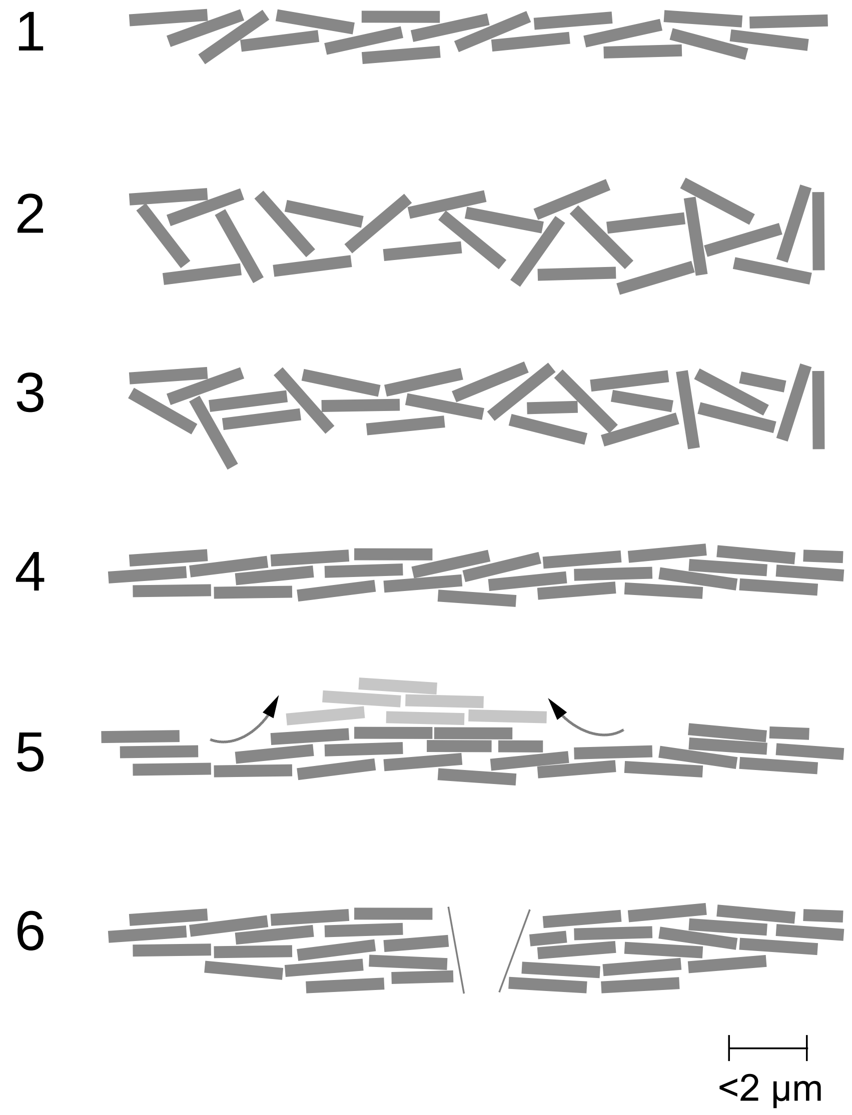


Fig. 89.2 System sketch of effects of burnishing on the layering of phyllo silicate sheets along the surface of a sample. The depiction of the sheets with the same size is a simplification of different sizes <2 µm.

## 5.2 Method of desludging

### 5.2.1 Reconstruction on the site

Since thus far no written evidence about the existence of a historical method of desludging in the Himalayas has been uncovered, we can not be sure of the exact applied method. According to historical evidence from other countries, as mentioned before, several possible steps for desludging can hypothetically be given:

Step 1: Digging a hole and collecting raw material on site

The simplest form would be the digging of a hole from which the raw material would be collected, and the easiest way would be not to dig for the raw material but to find it already in the desludging-pit. This scenario seems more realistic for the Himalayas than cutting trees and using wooden planks, as such planks would have had to be processed properly for making troughs above terrain, or for carrying raw material to the desludging-pit.

Step 2: Watering the raw material

In a next step the raw material has to be watered. According to current research, early West Tibetan monasteries, which were built in the plane, were erected near water sources, such as rivers or lakes. Tabo (996 CE), Khorchag (996 CE), and Alchi Dukhang (11th cent. CE; Luczanits, Neuwirth 2009: 79, 84) were all built near a river, and Nyarma (996 CE) and Nako (Lotsāba Lhakhang, 12th cent. CE; Luczanits 2004: 84) were constructed near a lake. In all these instances water is available in close vicinity, which is probably also a reason for the choice of a particular building site. Building a monastery of bricks requires a large amount of water simply for preparing bricks and, if conducted, also for desludging. For the preparation of adobe bricks at a later phase, a reduced amount of water would be needed since the desludged raw material would have already been soaked with water.

Step 3: Stirring the watered raw material

As a next step the watered raw material needs to be stirred continuously to disperse as much as possible. The intensity and depth of stirring influences the quality of the stirring process. The easiest way is to stir with wooden sticks but also the use of animals can not be excluded. A circular walk of yaks around a central stick on which the animals are fastened – a method still used today for threshing – is a hypothetical approach to the reconstruction of a possible desludging process.[26] In this case the yaks might not have rotated to pound corn but to pull a wooden board or a braided mat (hypothesis). According to Bender (2004: Fig. 7.92) the method of desludging with horses was documented at the beginning of the 19th century. Bender mentions a sketch by G. Paape showing so called (Ger.) *Tonwäscher* (transl. “people employed for washing clay”) mixing the watered clay by hand with metal and timber tools (see Bender 2004: Fig. 7.91).

Step 4: Sinking of the coarse fractions

The period of sinking determines the grain size distribution in the desludged portion. According to the Stokes’ Law coarse fractions are sinking faster.

---

[26] This method can also be used for the labour intense mixing of big amounts of clay with straw.

### Step 5: Skimming off the fraction with a reduced amount of sand

After a certain amount of time for sinking and setting of the heavier grains, the desludged material has to be skimmed off. This process may have been conducted by using containers – possibly of wood or leather. To receive a relatively equal grain size distribution this process would have had to be conducted quickly; and for a bigger amount, several helpers would have been needed, or material would have been dispensed into smaller pits. What we also know from European desludging procedures is the preparation of several pits beside each other, and leaving the sludge in deeper located and perhaps smaller pits. The easiest method would have been just to let the material set within the pit and dry until a semi-dry and workable state had been reached.

### Step 6: Thickening and mixing of the sludge

For easy thickening of the sludge, the sludge itself is mixed with only as much water as necessary. Alternatively, it has to be dried or again mixed with dry raw material. With this method the amount of grains within a smaller volume would have been increased. The finer the surface, the more sludge needed. Since the whole process is just hypothetical and partially based on known European methods, further tests should bring us closer to the quality of the single steps of desludging. For this reason the following experimental arrangement is set.

## 5.2.2 Laboratory analysis

### Step 1: Digging a hole and collecting raw material

The material used for this experiment is from sample 8505 which originates from a recently prepared adobe brick from Nyarma. It was made out of the raw material from a local clay pit without any further mixing (see explanations in detail under mineral analysis of sample 8505). This sample was divided into three equal parts, each with an amount of approximately 100 grams and collected in a 1-litre glass.

### Step 2: Watering the raw material

The raw material in each glass was mixed with water three times its volume, at a proportion of app. 1:3. Heusinger (1867: 76) describes the amount of water as about two times the volume of the clay, though this turned out to be not enough for the laboratory tests and an increased height of water at a proportion of 1:3 proved favourable.

### Step 3: Stirring the watered raw material

The 1:3-mixture is stirred with a magnetic stirrer at a speed level of 6.5 (of 10 speed levels). This was the necessary speed needed to keep the mixture in motion and not have the stirrer get stuck in the sandy ground (Fig. 90.2).

### Step 4: Period of sinking of the coarse fractions

The period of sinking defines the time between stirring and skimming off. For the present study three periods of sinking are observed, 60 minutes, 1 minute and an immediate skimming off after stirring, in the text mentioned as 60 min-, 1 min- and 0 min- (or immediate) sinking.

Fig. 90.2 (Left) Magnetic stirrer.
Fig. 91.2 (Middle) Coarse material left in the bucket, fine material caught in the ceramic bowl.
Fig. 92.2 (Right) Openings of different size and height.

Period of sinking: Heusinger (1867: 76) describes 1 minute as an ideal period of sinking. The longer the period of sinking, the finer the slurry will be with a proportionally continuous increasing content of clay minerals.

### Step 5: Skimming off (desludging) the fraction with a reduced amount of sand

After a particular time of sinking as described in Step 4, the fine slurry was skimmed off. The three different portions differ primarily in their different periods of sinking after stirring (60-minutes, 1-minute and immediately).

For skimming, two different methods were used. For the first method from the upper portion, which is about the upper third, a vacuum sucker was used for the 60-minutes portion.[27] An amount of 200 ml was vacuumed from the upper third of the suspension. This was about the maximum amount before risking vacuuming of too coarse grains. The vacuuming-process of this amount lasts about 1 minute.

For the second method, openings in the container were used to regulate the amount and the fineness of desludged grains, used for the 1-minute and 0-minute portions (Fig. 91.2). For this purpose, in a round plastic container, round holes with a diameter of app. 1.2 cm were drilled at the bottom end of the container and closed with plugs made of rubber. The suspension in the container was stirred (see Step 3) and after a particular period of time (see Step 4) the plugs were removed and the desludging process (which lasted about 30 seconds) started. By this the following regulations were possible:

Amount of water: It regulates the sedimentation height and the speed of the leaving sludge; more water carries away more coarse material, while less water carries away less coarse material.

---

[27] It turned out that the vacuum sucker removes fine material in a different manner, as is the case with desludging from one container into the other. In the following, the latter method (above mentioned as the second method) was applied.

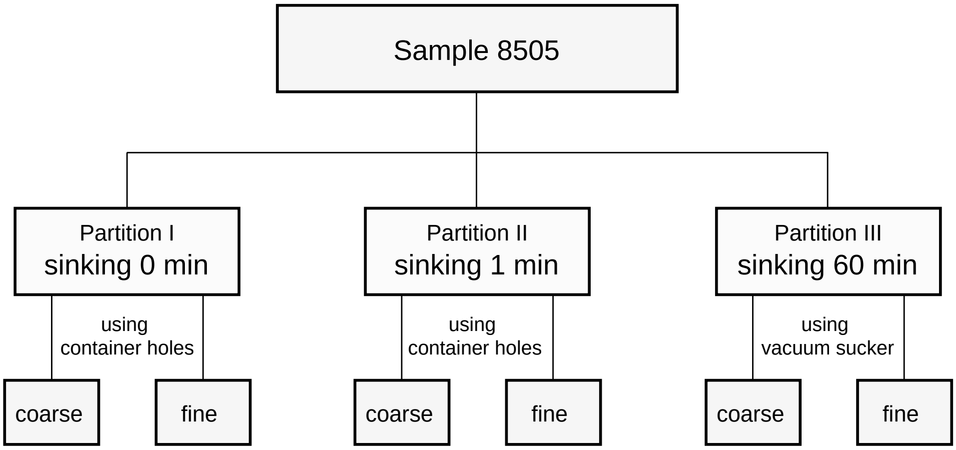


Fig. 93.2 Scheme of the experimental arrangement of desludging.

Size and height of the holes for removing the sludge: The bigger the holes and the more holes opened, the more coarse material is carried away and the less fine the slurry will be. Different heights of the holes above the container's bottom allow for regulation of the amount of coarse material that is carried away (Fig. 92.2). The whole process of desludging within this study is schematically shown in Fig. 93.2.
A first result after comparing the grain size distribution of the vacuumed 60-minutes portion and the 1-minute and 0-minutes portions, which result by using the holes of the container shows the distribution curve of the 60-minutes fine portion very close to the curve of the 1-minute fine portion (Fig. 94.2). This result questions the equality of the two methods and in a further decision the focus was laid on the observation of portions resulting of the use of the holes of the container (the 1-minute and 0-minutes portions), and not of the vacuum sucker (60-minutes portion) (Fig. 95.2). A reason for this similarity may be the depth of the vacuum sucker in the initial solution and the amount of sucked out material. A comparison of these methods should be part of future studies.

For the following study from each 1:3-mixture a slurry was desludged (not vacuumed) through holes after a certain period of time with differing periods:

Test A: desludged after 1-minute sinking
Test B: desludged after 0-minutes sinking (immediate desludging)

### Step 6: Testing and comparing of the desludged material

Testing of the grain size distribution and the content of clay within the desludged portion of a new clay brick sample. In the following, various desludged samples are compared and juxtaposed to an original plaster from the Nyarma Monastery. For this purpose the fine and also coarse 1-min-desludged[28] remains of sample 11947 from the Nyarma Monastery were tested by preparing specimens for further observations as plaster in a

---

[28] The desludging period of 1-minute was chosen for this plaster since this period turned out as the ideal time for desludging of sample 8505. The certification with "ideal" follows the observation that with a 1-minute period the result of the grain size distribution was rather close to the original material used for the fine plaster at sample 6073.

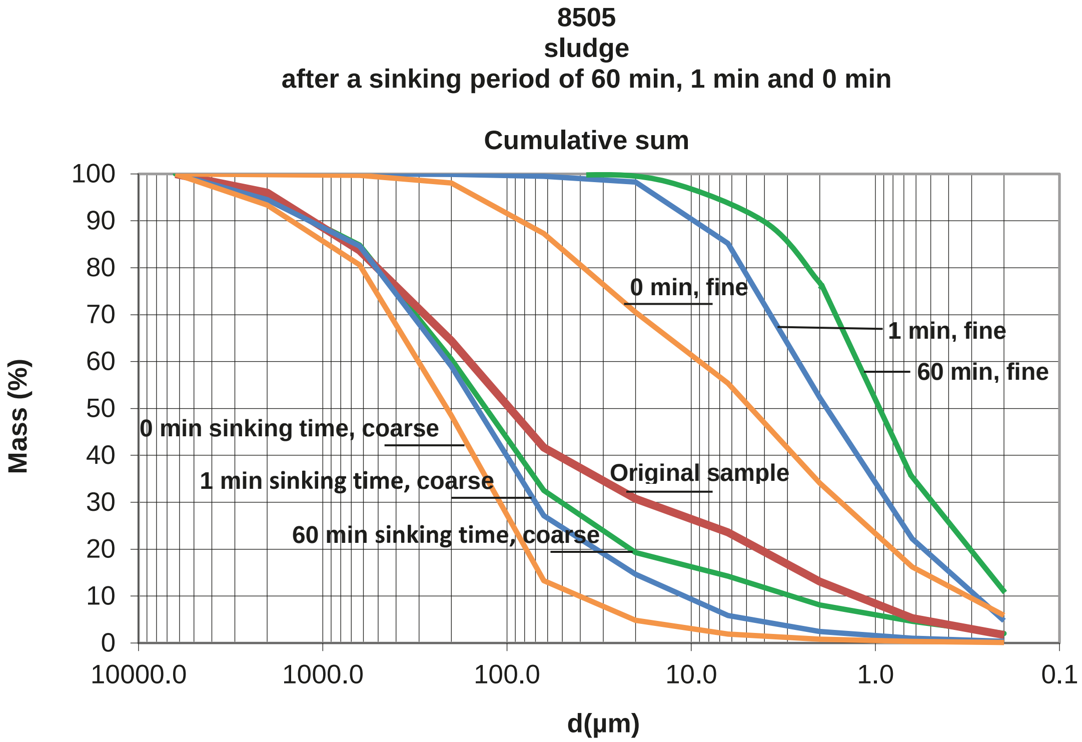


Fig. 94.2 Nyarma. GSD. Sample 8505. Coarse and fine remains. Desludging after a period of sinking of 60 minutes, 1 minute and 0 minutes.

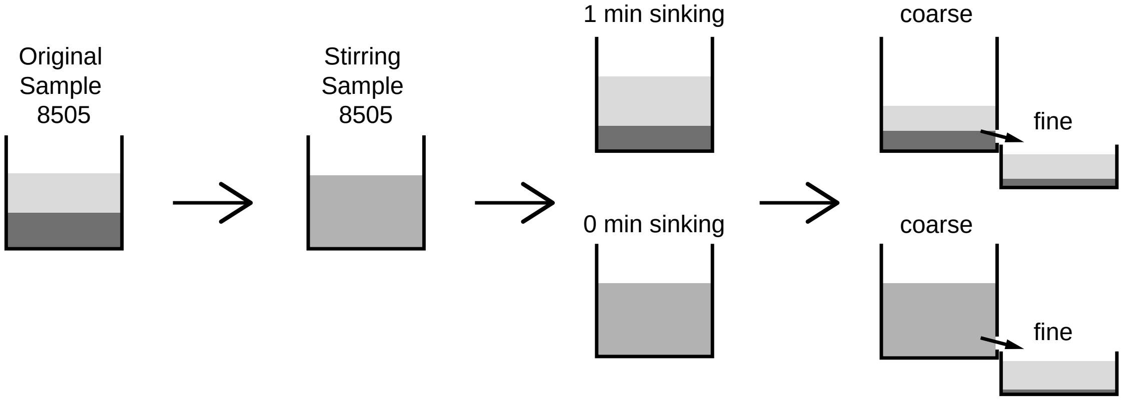


Fig. 95.2 Scheme of the experimental arrangement of desludging, focussing on a method using the holes of the container. Finally we receive a coarse and a fine portion of the 1 min (period of sinking) sample and a coarse and a fine portion of the 0 min (period of sinking) sample – in total four different portions and the original sample for further comparison.

burnished and unburnished state. For a detailed description and analysis of these samples, see "Burnishing of plasters" in this chapter. Fig. 96.2 and Fig. 97.2 show the results for the two different times of sinking, each compared with the original sample.

The coarse portions in comparison (setting time: immediate [0'], 1 minute [1'], and original):

The setting down of coarse particles happens rather quickly. For medium and fine sand it takes longer. The median of the coarse portion is at the 0'-sample with 210 µm higher than at the 1'-sample with 150 µm. At 98 µm the median at the original sample is finer. The 2 µm fraction at the 0'-sample is 2%, and at the 1'-sample 9%, with the latter being close to the original sample with 12%. The content of silt at the 0'-sample is 12.4% and at the 1'-sample 20.1%, which is clearly less compared to 28.7% measured at the original sample (Fig. 98.2).

The fine portions in comparison (setting time: immediate [0'], 1-minute [1'], and original):

At 4.8 µm the median of the fine portion for the 0'-sample is higher than for the 1'-sample with 2 µm. For comparison, the median at the original sample is 95 µm. The 2 µm fraction at the 0'-sample is 34%, and at the 1'-sample 50% (Fig. 99.2). An explanation for this result (and not for a higher amount of clay in the 0'-sample) is that at the 1'-sample the fine material was able to settle on the ground and was closer to the holes in the container which allowed for transport outside into the next container. This effect may influence the result compared to desludging by sinking within just one container. At 98 µm the median at the original sample is much coarser. The content of silt at the 0'-sample is 53.4%, close to 1'-sample with 50.2%, with both clearly higher compared to 28.7% measured at the original sample. In the 0'-sample, 12.5% sand (medium + fine fractions) remains while in the 1'-sample no sand is left. The sand is too heavy to be transported (= washed away) from the first container into the second after setting for one minute. That means that as long as grains from the sand fraction did not set on the ground, they were more easily transported through the hole into the second container.

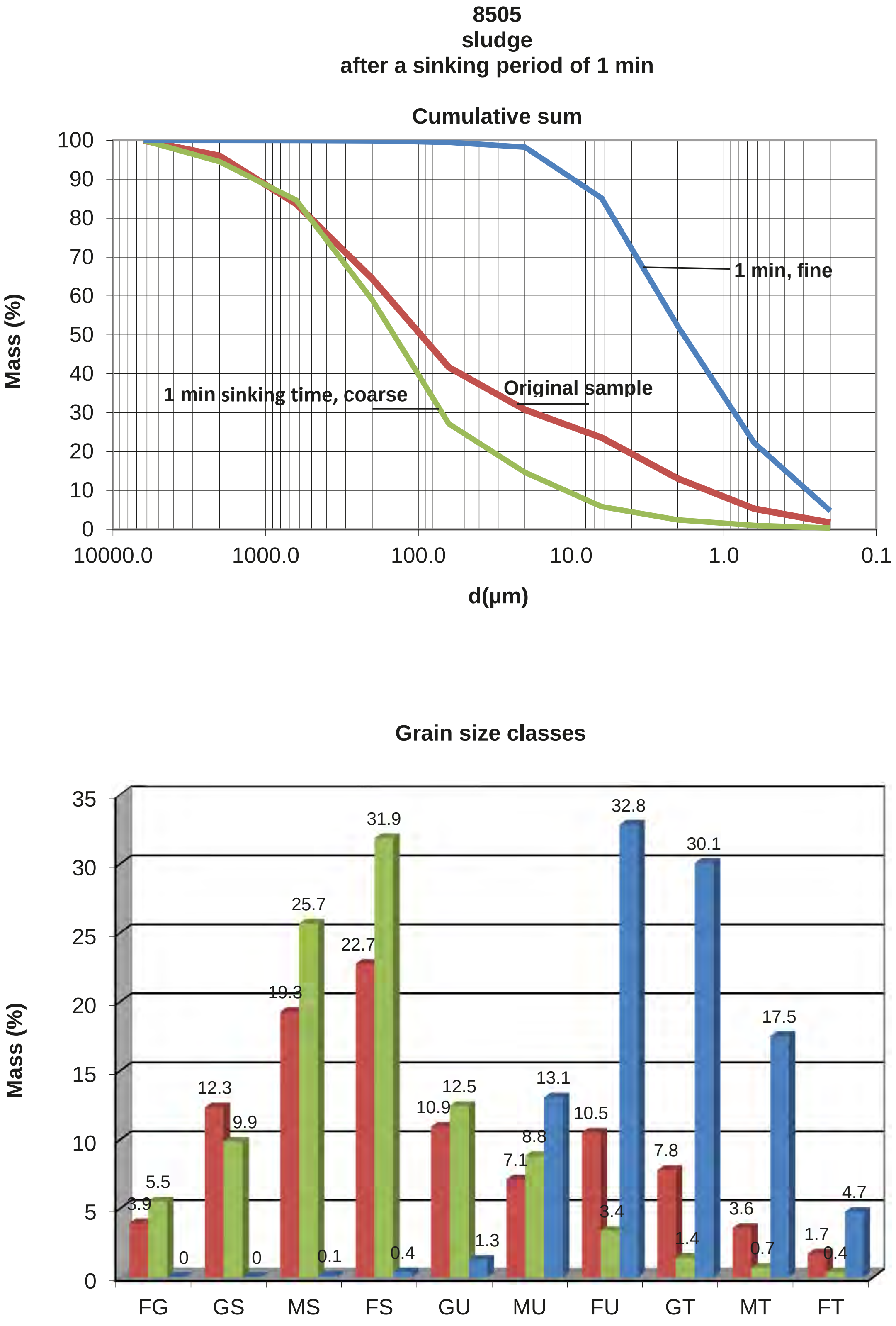


Fig. 96.2 Nyarma. GSD. Sample 8505. Desludging after a sinking period of 1 minute in comparison with the original sample.

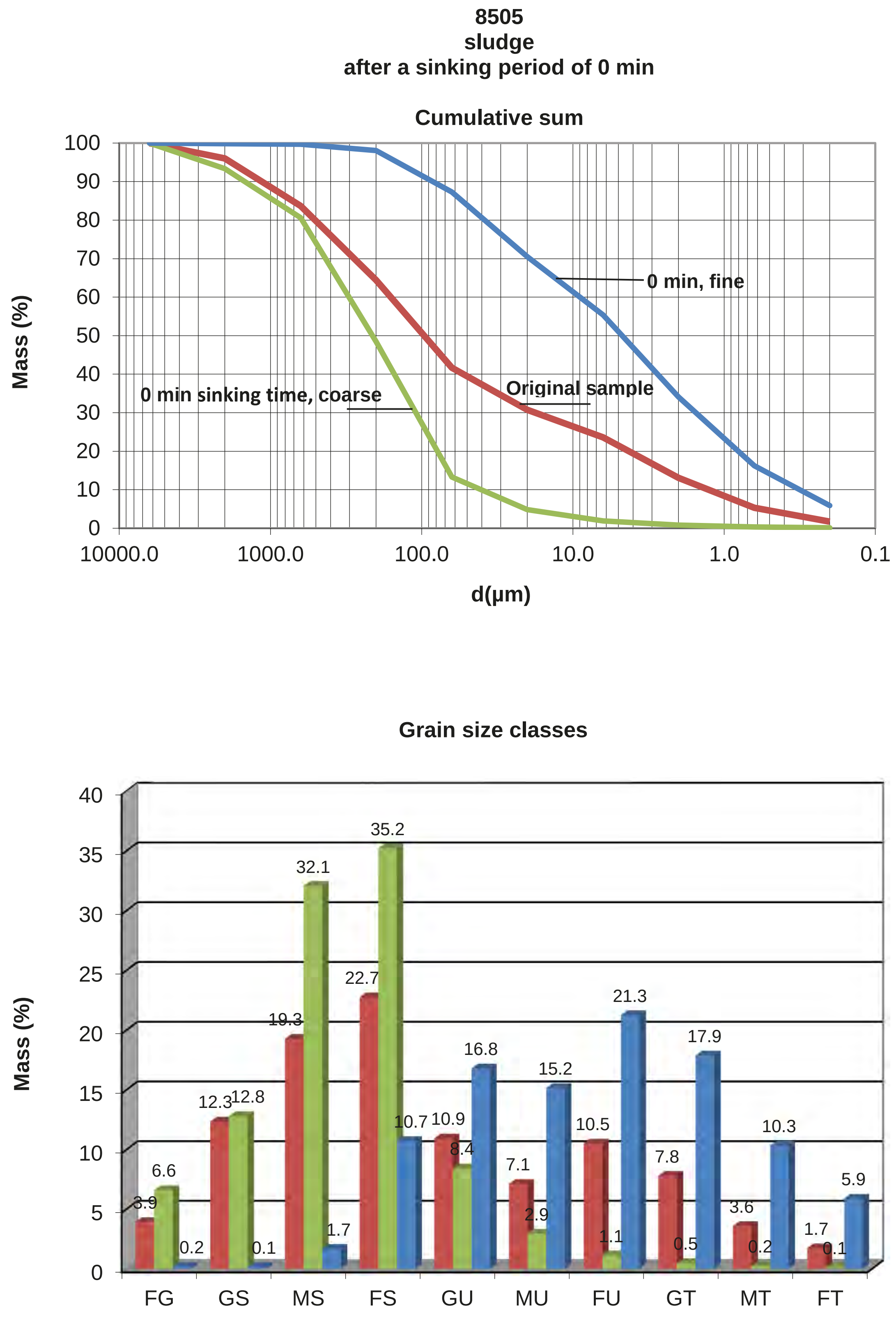


Fig. 97.2 Nyarma. GSD. Sample 8505. Desludging after a sinking period of 0 minute in comparison with the original sample.

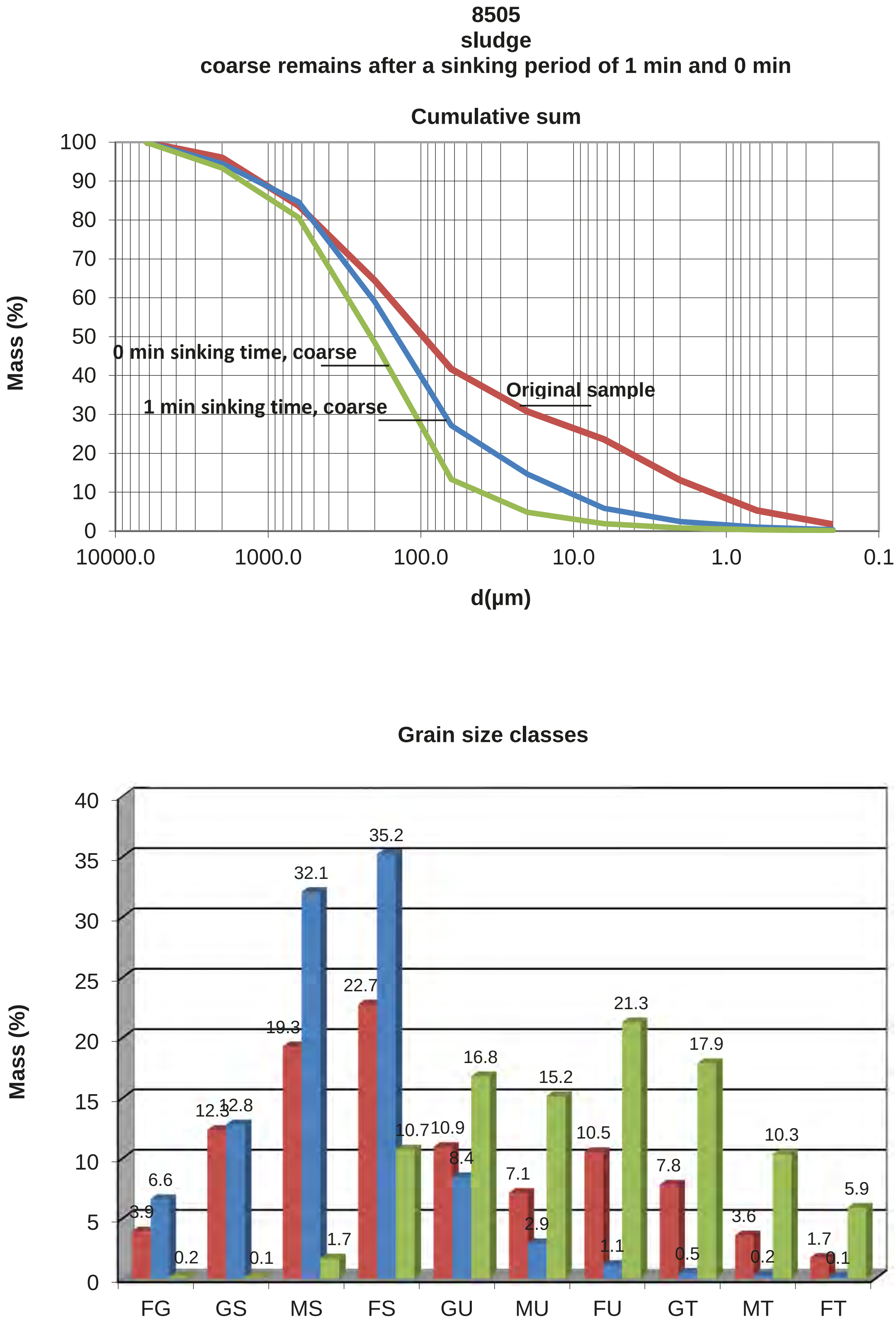


Fig. 98.2 Nyarma. GSD. Sample 8505. Coarse remains. Desludging after a sinking period of 1 minute and 0 minutes, in comparison with the original sample.

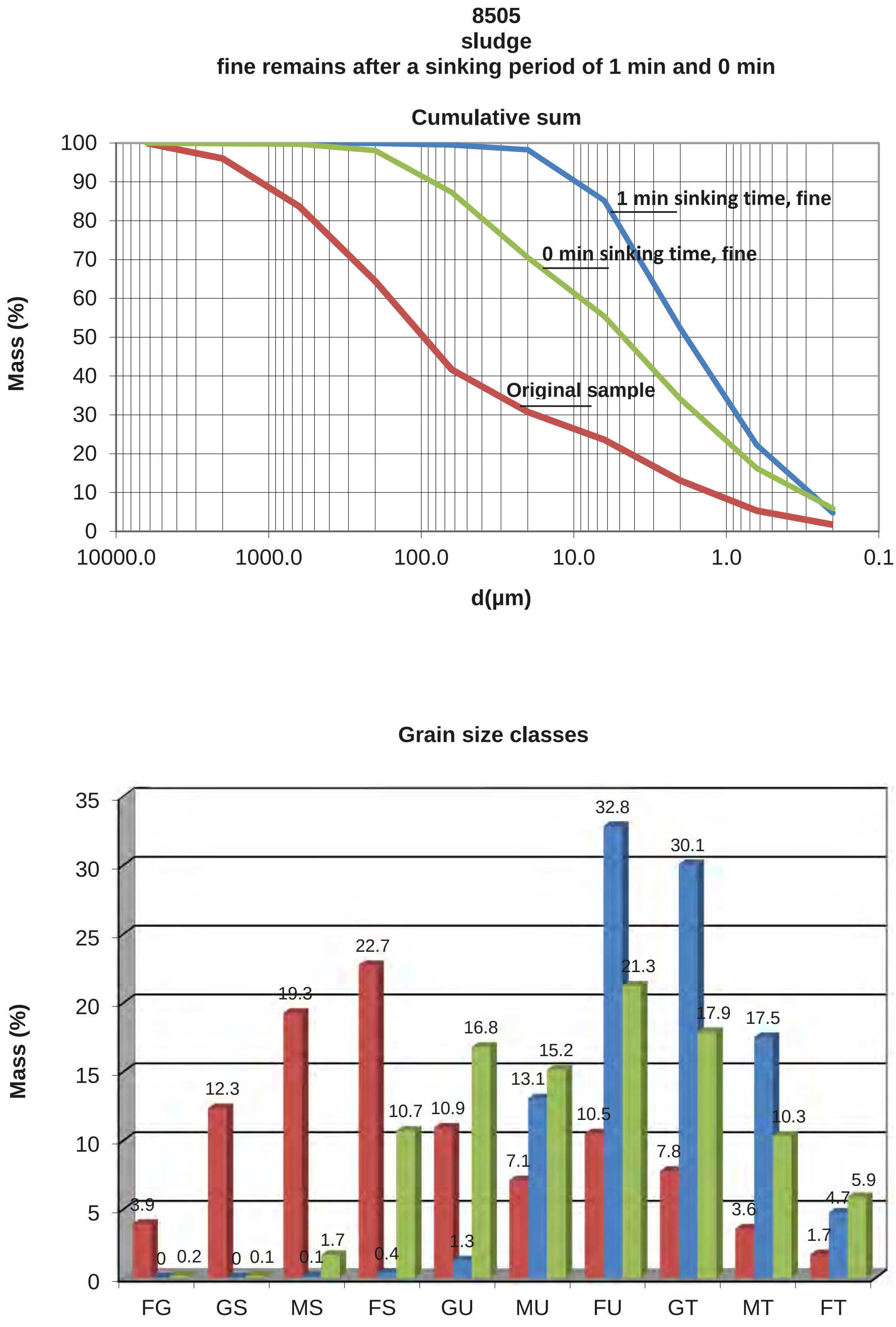


Fig. 99.2 Nyarma. GSD. Sample 8505. Fine remains. Desludging after a sinking period of 60 minutes and 1 minute, in comparison with the original sample.

Table 6.2 Juxtaposition of the detailed grain size distribution (GSD) of the different portions resulting from desludging and of the original sample.

| | FG | GS | MS | FS | GU | MU | FU | GT | MT | FT |
|---|---|---|---|---|---|---|---|---|---|---|
| 8505 original | 3.9 | 12.3 | 19.3 | 22.7 | 11.1 | 7.1 | 10.5 | 7.8 | 3.6 | 1.7 |
| 8505 1-min/coarse | 5 | 10.1 | 26.4 | 30.3 | 12.3 | 3 | 4.8 | 4 | 2.6 | 1.5 |
| 8505 0-min/coarse | 6.6 | 12.8 | 32.1 | 35.3 | 8.4 | 2.9 | 1.1 | 0.5 | 0.2 | 0.1 |
| 8505 1-min/fine | 0 | 0 | 0 | 0.4 | 3.9 | 17.2 | 29 | 23.6 | 16.3 | 9.5 |
| 8505 0-min/fine | 0.2 | 0.1 | 1.7 | 10.7 | 16.9 | 15.2 | 21.3 | 17.9 | 10.3 | 5.9 |

Table 7.2 Juxtaposition of the grain size distribution (GSD) of the different portions including the median and the 2 µm fraction.

| | Gravel | Sand | Silt | Clay | Median (µm) | 2 µm (%) |
|---|---|---|---|---|---|---|
| 8505 original | 3.9 | 54.3 | 28.7 | 13.1 | 98 | 12 |
| 8505 1-min/coarse | 5 | 66.8 | 20.1 | 8.1 | 150 | 9 |
| 8505 0-min/coarse | 6.6 | 80.2 | 12.4* | 0.8* | 210 | 2 |
| 8505 1-min/fine | 0 | 0.4 | 50.2 | 49.4 | 2 | 50 |
| 8505 0-min/fine | 0.2 | 12.5 | 53.4 | 34.1 | 4.8 | 34 |

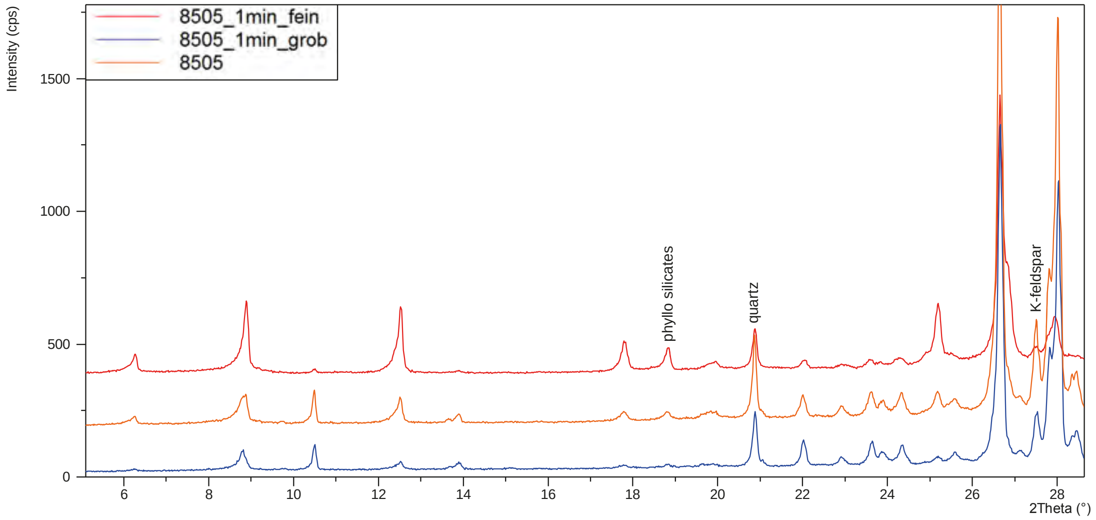
Table 6.2 and Table 7.2 show a juxtaposition of the single portions. Values marked with (*) appear rather low for the content of clay and silt and high for the content of sand. The results are subject to fluctuations due to the handling of the container during desludging. Future investigations will specify the given results. Finally, the mentioned possible fluctuations have no impact on the general given message.

### Influences of the desludging on the BMA of the 1 min-samples

The BMA of the different portions shows a diverse result (Table 8.2, Fig. 100.2, Fig. 101.2). The fine portion of the 1 minute sample shows a concentration of mica, also of quartz and 7Å and 14Å minerals, and a diminishing of hornblende and of feldspar. The BMA of the original sample is similar to the coarse portion, except mica which remains floating while the other minerals sink faster.

Table 8.2 Nyarma. Method of desludging tested at brick-sample 8505 with a juxtaposition between coarse and fine fractions after a sinking period of 1 minute and the original sample.

| Sample | 14Å | Mica | Amph | 7Å | Phy sil | Quar | K-fsp | Plagio | |
|---|---|---|---|---|---|---|---|---|---|
| Original | * | * | ** | * | * | ** | * | ** | Sample unmanipulated |
| | | | | | | | | | |
| 1 mi/f | ** | *** | * | ** | * | ** | . | * | Fine sludge after 1 min sinking |
| | | | | | | | | | |
| 1 mi/c | . | * | . | . | . | ** | * | ** | Coarse sludge after 1 min sinking |



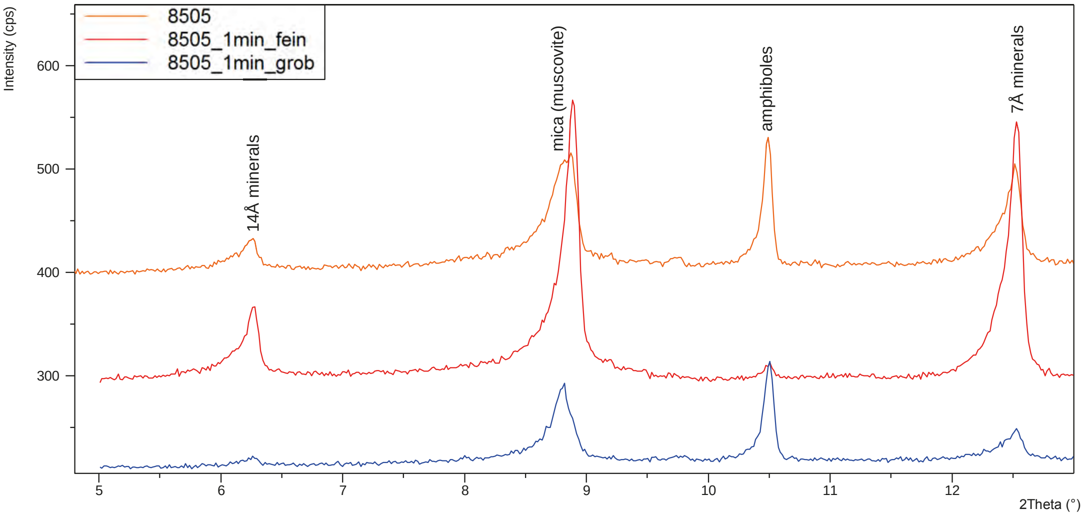


Fig. 100.2 (Bottom) Nyarma. BMA. Sample 8505. Fine and coarse remains juxtaposed.
Fig. 101.2 (Top) Nyarma. BMA. Sample 8505. Fine and coarse remains juxtaposed in detail.

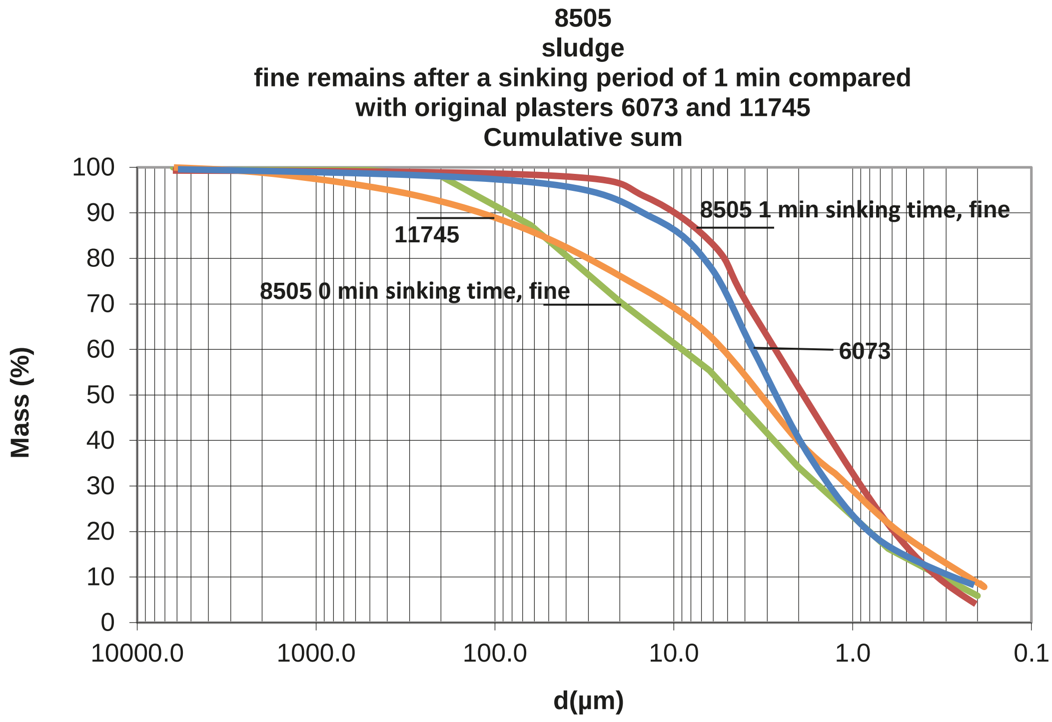
### 5.2.3 Comparison with original plaster samples

A comparison of the fine portions after desludging with two rather fine plaster samples of the main temple (samples 11745 and 6073) shows the following results. The comparative list of grain size distributions shows that the content of gravel is 0 or at least <1. At 5.7% sample 6073 shows a small content of sand, compared to plaster sample 11745 with 19.7% and the 0'/fine sample with 12.5%. In the desludged samples, nearly no sand is evident (see examination afore). Regarding the silt fraction, sample 6073 is 56.9%, which is rather close to the 1'/fine sample with 50.2% and to the 0'/fine sample with 53.4%, while at 39.2% plaster sample 11745 shows a smaller content. Regarding the clay fraction, the two plaster samples (6073 with 37.4% and 11745 with 40.2%) are similar to the 1'/fine sample with 49.4% and the 0'/fine sample with 34.1%. This shows a general similarity with an average of about 40%. Regarding the median of the 1'/fine sample with 2 µm and its <2 µm content of 50%, it is slightly coarser than plaster samples 11745 and 6073. On the other hand the 0'/fine sample with a median at 2 µm and a <2 µm content of 34% is slightly coarser.

| | Gravel | Sand | Silt | Clay | Median | 2 µm |
|---|---|---|---|---|---|---|
| 8505 1-min/fine | 0 | 0.4 | 50.2 | 49.4 | 2 | 50 |
| 8505 0-min/fine | 0.2 | 12.5 | 53.4 | 34.1 | 4.8 | 34 |
| 11745 | 0.9 | 19.7 | 39.2 | 40.2 | 2.9 | 40 |
| 6073 | 0 | 5.7 | 56.9 | 37.4 | 2.9 | 38 |

The graphics (Fig. 102.2) makes the differences and similarities clear according to the given analysis. The portion 8505 1'/fine follows closely the curve of the fine plaster 6073 but still seems to have been set for slightly a too long period of time for becoming coarser but not as coarse as the 0-min/fine portion. On the other hand the portion 0'/fine follows the sand fraction very closely by being slightly too silty and not coarse enough.

With this result we can assume that original samples 6073 and 11745 are close enough to the results of the produced sludge to be most probable results of a historical desludging process. The sludge must have been taken away after the material settled after stirring for a period between an estimated 15 and 45 seconds, which is a rather short time and one that would not noticeably interrupt the building process for a longer period.



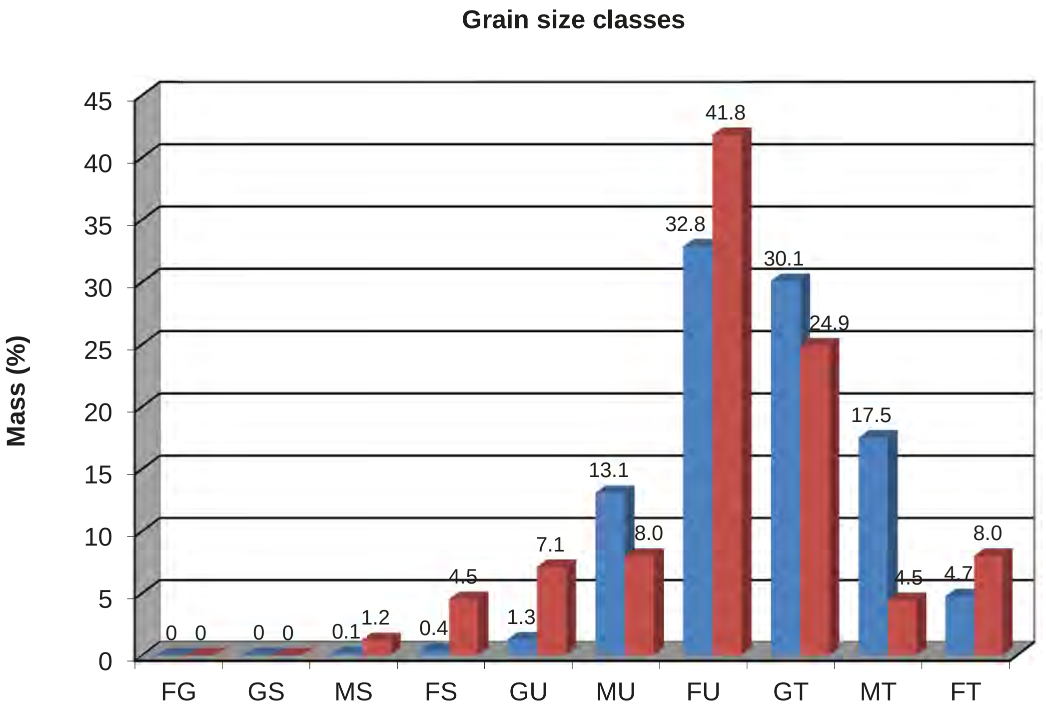


Fig. 102.2 Nyarma. GSD. Sample 8505. Fine remains. Desludging after a sinking period of 1 minute and 0 minute compared with original plaster samples 11745 and 6073.

## 6. CONCLUSION

### Research question 1: Are there any material qualities to categorise clay used at the Nyarma Monastery?

“Field clay” within close vicinity was used to build the Nyarma temples. The available grain shapes according to Tucker (1985) are 1 (“very angular”), 2 (“angular”) and 3 (“beginning rounding”) – with a majority being “angular”. The grain shape “beginning rounding” appears in several cases as a mixing additive. According to the conducted examinations, the added and more rounded material belongs to the sand-fraction. The GSD of the raw material shows a content of gravel of app. 6.5%, of sand between 51.6% and 65.9%, of silt between 17% and 27.1% and of clay between 10.6% and 14.9%. In the BMA, amphiboles, quartz and K-feldspar appear in a small amount while plagioclase is available in a high amount. In the raw material no calcite is available. Noticeable is a content of hornblende (amphibole) as a basic characteristic of all samples. Regarding samples 11754 and 11956 – both from clay pits in Nyarma – no calcite is available. This would explain that at least traces of calcite have been added to the raw material. The CMA of the raw material shows a high content of illite between 62% and 65%, kaolinite between 8% and 10% and chlorite between 22% and 25%. The content of smectite ranges between 3% and 5%.

For the Nyarma series, the colours vary between grey (in a dry state) and brown (in a semi-dry state) with a range of (6–7 / 3–5). Further chromatic values towards red could be traced in most of the samples due to a slight content of haematite.

### Research question 2: Are the particular material qualities related to specific components of the Nyarma Monastery structures?

Regarding the quality of plasters, we generally speak of “good binding” and a high quality product for construction purpose. Touching and observing the samples with the naked eye at the original site already gives this impression. Grain size distribution following a continuous recipe throughout the whole temple site, and organic additives and layering of the plasters give evidence of the quality of the single structural components and of the universal applicable quality of the raw material. The differences between adobe bricks, ground plaster, upper plaster or hand-modelled aureoles are available in nuances and show a careful regulation of the working steps related to each component. After observing a big variety of samples within one temple site, we can state that the quality and composition of clay of the single components were well adjusted to each other. This is only possible with the possession of good knowledge about the processing of the raw material. Knowledge of the use of the same raw material similar to 1,000 years ago is still evident. Today the processing of the material, in particular of plasters, regarding their long lasting quality, seems to have changed. In general, bricks have a much lower amount of fine grains and a higher median regarding grain size distribution.

A differentiation between the qualities of exterior plaster can also be recognised. Exterior plaster sample 11762 applied to the outside of the wall of the assembly hall is relatively fine and was processed with the addition of general interior plasters – in other words, the seemingly exterior wall was treated as an interior wall and probably was an interior wall which is contradicted by the fact of the high amount of calcite, possibly pointing towards its treatment as an exterior wall by extensive whitewashing. For all temples, the applied techniques of processing the plaster seem to have changed, partially by keeping the raw material unchanged, and partially by mixing and changing the raw material.

### Research question 3: What are the material qualities that support the use of clay commonly used in Nyarma for particular building purposes?

Within this study it was proven that the raw material of all the structural components originates from the site itself or at least from within close vicinity. In the following, results are given from examinations of the single structural components:

#### Raw material and brick

- Clay pits and new bricks: According to the given examinations, the material used for recently processed bricks was an unmixed raw material without additives.

- Adobe bricks: The material used in the Nyarma temples to produce adobe bricks can in general be described as material still used today and which originates directly from the clay pit, most probably without any further manipulation of the raw material by sieving or adding sand. Since the grain shapes of the bricks are continuously evident as “angular”, we can deduce that for several other samples in Nyarma, which do not show such a clear continuity in “angular shaped”, mixtures of two different species of clay or an addition of coarse material took place.

#### Plasters

Contrary to the adobe bricks, some of the wall plasters show changes in the grain shapes, which points towards an addition of further material – due to the unchanging values regarding BMA and CMA, most probably sand and not clay. This concerns the following interior plaster samples: 11745, 11918, 8514, 8517, 11761, 8522 and possibly also 8532 and 8520, though this is not as evident at the two latter mentioned samples. Also all of the exterior plaster samples – 11914, 11762 and 8519 – show a changing grain shape. An important result regarding the understanding of processing aureoles is the most probable addition of sand at the ground layer but no changes of grain shapes in the upper layer.

Regarding organic additives, which are not evident as intentional additions in adobe bricks, nearly all the plaster samples (ground and upper layer) contain straw, partially of a rather high amount. Besides straw, in most of the samples (including adobe bricks) we find pieces of ears or seeds of crop. Some of the seeds are early species no longer common today. These results give new insight on a botanical level and are being examined by colleagues from the archaeo-botanical discipline. Results will be published separate from this contribution. The same applies to $C^{14}$ analysis, which has been conducted for small organic ingredients of nearly all the temple structural components. In a few samples wooden pieces and anorganic material like coal are available.

- Wall plasters in the *cella*: Generally speaking, the average values between the interior plasters in the *cella* are relatively similar to the values of the raw material in the clay pits. The values 'fit together' in such a way that we can speak of the interior plaster material being based on clay from the site in close vicinity of the temples. The occurrence of swellable smectite in all samples (also in the base material) guaranties a homogeneity of the surface and also a proper ground layer for later treatment of the upper surface of the plaster, like rubbing and smoothing with stones, coating with, e.g. lime or gypsum, and painting. The content of smectite shifts the limit between plastic and liquid limit and supports the plasticity of the plaster. However we can not exclude the possibility of adding slightly more rounded material in the sand fraction, possibly originating from another pit.

- Wall plasters in the assembly hall: The content of sand in the assembly hall-plasters is slightly higher and the content of clay slightly less, as is the case in the *cella*-plasters. Regarding the grain shapes of the assembly hall-samples, a mixture with sand or another type of clay can not be excluded due to the occurrence of an additional shape of "beginning rounding". Regarding the grain shape, the samples of the assembly hall do not show such continuity as found in the *cella*. This points towards a slightly different composition for the assembly hall samples, possibly by desludging or adding of a slightly more rounded material. Similar to the aureoles we can state that for the ground layer of the plaster, sand was most probable, though this can not be stated for the upper layer. The used clay contains swellable mineral components that are also similar to the plaster used in the *cella*. If the process of desludging was used for the plasters of the assembly hall and the *cella,* than in the case of the assembly hall, the setting of the slurry was conducted in a different manner to obtain a slightly coarser material.

- Wall plaster in Temple IIIa: The content of sand in the Temple IIIa-plaster is less than in the assembly hall of the main temple. It shows close similarities to the plaster used in the *cella*. Regarding the grain shapes of the assembly hall-samples, a mixture with sand or another type of clay can not be excluded and shows similarity to the rounding in the *cella*. This points towards a slightly different composition compared to the assembly hall-samples.

- Wall plaster in Temple IV: The content of sand used in the ground layer is much higher than used in the finer upper layer and is similar to material taken from the clay pits. Coarse material with a size of up to 28 mm shows a tendency of having rather coarse material. This implies that for the ground plaster layer, the used raw material is directly taken from the pit without any further addition. Contrary to the ground layer, for the upper layer the grain size composition is closely related to the material processed in the *cella*. Regarding grain shape, particularly in the finer upper layer, a mixture with coarse minerals can be excluded which may point towards the use of desludged clay.

- Wall plaster in Temple V: Regarding grain size distribution, the fractions sand, silt and clay are related to the raw material found in the clay pit but are not as coarse. It seems as that a different pit was used. The gravel fraction shows a rather low content which possibly points towards a sieved material. The two different shapes point towards a mixture with sand or another type of clay.

- Wall plasters in an accessible stupa in the monastery compound: Regarding the grain size distribution of the ground layer, the fractions sand, silt and clay are related to the raw material found in the clay, which is similar to the plaster examined in Temple V, i.e. a side temple of the main temple. But at the ground layer of the plaster in the stupa, the coarse fraction also shows a higher content than the plaster in Temple V. Similar to the ground layer used in Temple IV, we can state that no addition or other manipulation of the material from the clay pit is available.

It seems as if a further pit was used. The gravel fraction shows a rather low content which points towards a sieved material. The two different shapes point towards a mixture. The upper layer shows a difference to other upper layers from Nyarma: It indicates the highest content of sand within the Nyarma plasters, and regarding its amount of sand, this sample is also similar to material from clay pit 11754. However the content of clay is slightly higher and the gravel reduced to zero. This material seems to be sieved in the gravel fraction, and desludging was not conducted. An addition of material is not obvious.

- Modelled wall frieze in the accessible stupa: Regarding grain size distribution and shape of the grains, the material is rather close to the material used in the upper layer of the plaster in this stupa. The reinforcement of the plaster is conducted with a dense implantation of long fibres of straw whose length is atypical for plasters found in Nyarma. Results of mineralogical examination emphasize the hypothesis that this sample once was part of the wall frieze.

- Clay modelled aureoles: Regarding the grain size distribution of the ground layer and the upper layer, a strong similarity to the plasters used in the assembly hall can be stated. The two layers themselves are similar and do not differentiate between fine and coarse layers. Also the shape of the grains is similar to the samples examined in the assembly hall. This leads to the following hypotheses:

  - The aureoles were made in situ at the same time as the wall plaster.
  - The aureoles were modelled out of the wall plaster without changing the material composition.

A closer look shows that the builders were aware of the need for a slightly finer upper layer of the aureole, probably related to the evident modelling of ornaments along its surface.

- Wall plaster in the outer and inner ambulatory: Regarding the grain size distribution and shape of the grains of the plaster used in the inner ambulatory (sample 11914), the used material shows a close relation to the material used in the assembly hall, in particular for the aureoles. The used gravel with a diameter of up to 12 mm is rather coarse compared to other interior plasters.
The material used for the plaster in the outer ambulatory (sample 11762) contains slightly less sand and slightly more silt and clay and a similar amount of gravel, and shows an even stronger relation to the material which was used as interior plaster for the assembly hall. Comparing the composition of these interior plasters with exterior plasters (samples

15408 and 8519), it is evident that exterior plasters were processed with a much coarser material. This aspect implies that the plaster used in the inner ambulatory was treated as interior plaster and that this inner ambulatory was treated as interior and not as an exterior part of the building (today partially without a roof). This emphasises the hypothesis that this part of the temple was in its former use covered with a roof. A thick layer of whitewash therefore may relate to the period after the roof went missing (cf. Feiglstorfer, forthcoming b).

In contrast, for the samples of exterior plasters within the main temple (samples 11914 and 11762), we can state that they were treated like interior plasters and may have never been processed as exterior plasters. This result brings us closer to an answer to the question of whether the inner ambulatory and outer ambulatory of the main temple were covered. Since their plasters were prepared like interior plasters and not as exterior plasters – a different approach in their preparation was clearly stated in this study – the hypothesis is emphasised that these circumambulation paths were covered in an early period and the whole structure was planned as one whole composition and not as a continuous addition of single parts.

- Exterior wall plasters: Regarding grain size distribution, the used material for exterior plasters is close to the material in the examined clay pit. This emphasises the hypothesis that the material found in the pit was directly used for processing exterior plasters.

### Burnishing of wall plasters

This technique follows a common tradition in the Tibetan cultural zone. As a conclusion, we can state that only particular mixtures allow for the processing of a high quality unburnished surface. For practical use, sample 11918 (burnished) shows a usable result for further processing of wall paintings as one can still find in Himalayan regions. A useful property is that the surface is smooth and shiny and does not soak up moisture immediately. It can easily be covered with another layer of lime, gypsum or kaolin; it is even and relatively hard. As shown with Vickers tests, burnishing may, but not necessarily, increase hardness. Whether hardness increases depends on the grain size distribution. With sample 11918, an original plaster from Nyarma, the best quality was achieved. This material still contains 2.2% of gravel and 33.2% of sand, besides 39.4% of silt and 25.2% of clay. The content of smectite is 4%. This material shows a rather smooth and soft surface in an unburnished state and becomes hard and shiny when burnished. When using the fine desludged material, which was available in the *cella* with slightly less gravel and sand, the behaviour of the surface correlates with what was examined for sample 11918 (base) + 11947 (surface). This result leads to the hypothesis that the fineness of the material as used in the *cella* was not provided by being burnished and that this surface remained unburnished but painted, possibly as a part of the aureole. Contrary, the material used for all the other wall plasters would be ideal for burnishing.

### The method of desludging

No records of the use of a desludging technique in Tibet were found so far, and examination of this method is a hypothetical approach since we can also not exclude its historical application. Several methods of desludging may have been used, as we know from European history – either desludging from one pit into another pit or just within one pit. The examinations lead to the result that the ideal time given for setting of the clay is within one minute. The results of desludging are two portions: one fine and one coarse. Both are known for different applications – the fine portion, e.g. as engobe or slip (in pottery), and the coarse portion as a burnishable upper plaster layer.

In general for the fine portion, the content of fine components is increased in the clay fraction from the 0’-sample to the 1’-sample. This behaviour starts to change within the silt fraction. The analysis gives first insight into changes when desludging for different periods. The method of desludging influences the result. Desludging just by setting the first container (or pit) on the ground without allowing the material flow into another container makes a difference compared to desludging from one into another container. The latter method is shown in the examination of this study.

The base material of this experiment is a recently prepared adobe brick from a Nyarma clay pit. A question within this study is the relation between raw material (= the examined brick) and fine Nyarma plasters (samples 6073 and 11745). With the result of this examination, we can state that the original samples, i.e. 6073 and 11745, show such a strong similarity to the results of the produced sludge that we can assume they are most probably results of a historical desludging process. The sludge must have been taken away after the material could settle and after stirring for a period between an estimated 15 and 45 seconds, which is a rather short time that does not noticeably interrupt the building process.

Since the grain size distribution curve of plaster 11745 is of a high similarity in the clay and silt fractions, but becomes slightly coarser in the sand fraction, it can not be excluded that a small amount of the desludged coarse material was again added to the fine sludge to make it slightly coarser. This would also explain the bimodal distribution marked by a valley in the grain size classes between medium sand and medium silt. At a first glance this gives the impression of a material mixture with sand or another type of clay but is actually a mixture of portions of the same material. Due to the desludging process it is possible to remove the coarse parts.

With this study a previously given hypothesis can be partially stated. The base material of clay pit samples, which is presently still used for the production of adobe bricks, was historically used for the preparation of bricks but not as suspected for two different fractions. The raw material was kept unchanged for making bricks. In contrast, for several plasters (see above) the raw material was manipulated, either by sieving, adding coarse material (sand) or by desludging.

## The content of gypsum and calcite

Most of the samples are without gypsum, with only a few showing a very small content.[29] Gypsum is a mineral that is softer and not as alkaline as lime. The solubility of gypsum is reached with about two grams of gypsum in one litre of water.

The use of gypsum is known as one possibility for preparing the sub-layer for wall paintings. The finding of gypsum in a single sample may lead us to assume its appearance within all the wall plaster samples taken from this particular structure. The fact that this is not the case leaves several questions open, which would be good content for future research on this matter:

> - Restoration(s): In the case of restoration of a temple wall, we can not exclude that parts of the wall have been treated in another way using, e.g. gypsum as sub-layer.
> - Weathering: Since gypsum as a sub-layer for wall paintings is applied as a thin coating onto the smoothened clay wall, it can easily – at least partially – be washed out when the roof is missing. In the case of a missing roof (i.e. a total exposure of the walls), the complete dilution of a gypsum-coating after a short period of time (several years) may be given due to solution decomposition. It is different with lime; its dilution lasts longer[30] than is the case for gypsum.

As examples, the accessible stupa (as described before) and the *cella* of the main temple are given. The stupa roof seems to be original and the wall paintings partially still exist. In the case of the *cella* of the main temple, in contrast, we know that it was overbuilt by a second storey in a later phase. Several parameters (simple roof construction, strong weathering of the walls and of the mural paintings) emphasise the hypothesis that the roof is not original but we can not determine whether it was removed at the time of addition of another storey to the temple or much earlier which would probably also extend the time of rooflessness and by that exposure of the walls to damaging influences like precipitation or UV-rays. The lack of roof protection may be a reason for partial missing of the gypsum layer due to weathering. At the first glimpse this argumentation could be an answer but regarding the existence of remains of colours, this argumentation must be withdrawn since in the case of a still existing most upper layer containing colours, the gypsum-layer below must have been protected and not washed out (not considering that the remaining colours could be later additions). Of the four samples of interior plasters within the *cella* (6073, 11745, 11753, 11925), only sample 11745 shows about 4% of gypsum, similar to the 3% of gypsum found in the stupa.

Since all the samples of plasters of the Nyarma temples contain a certain low amount of calcite (up to app. 5%), this amount could point towards the use of lime as a sub-layer.

---

[29] Schumann (2007: 62, 70) mentions the following hardness according to Mohs scale: Gypsum ($CaSO_4$ x $2H_2O$): hardness 1.5 to 2; Calcite ($CaCO_3$): hardness 3.

[30] Compared with loess the process of decalcification of an about 0.5 m thick layer takes about 20,000 years in areas with an average precipitation of about 1,000 ml/year (Personal communication with Franz Ottner / BOKU in March 2014).

Also this hypothesis is weakened with the existence of calcite not only within plasters but also in a small amount within the bricks.

Only a few samples show a higher amount of calcite within the bulk mineral analysis which would lead to another approach: This concerns samples 8532 (stupa / upper layer of plaster), 8519 (main temple / exterior plaster) 11762 (plaster within the ambulatory south of the assembly hall), 8516 and 8522 (the latter two being samples from an aureole). These results emphasise the following hypotheses:

In sample 8532, 3% of calcite is available in the ground layer while in the raw material no calcite and in the bricks just traces of calcite are available. This points towards the use of lime in the stupa plaster for additional strengthening. Being that sample 8520, which originates from the same stupa from an upper plaster layer, shows 3% of gypsum in addition to calcite points towards its use as a sub-layer for mural painting.

According to sample 8519 with 3% of calcite and sample 11762 with 15% of calcite, the exterior plasters were covered with a higher amount of calcite – probably a result of whitewashing. This is certain for sample 11762 where the amount of calcite is much higher. Such an amount is due to either a former covering of the exterior face of the wall of the assembly hall located along the outer ambulation corridor or due to a much younger and recently applied whitewash. This result is important for the reconstruction of the exterior surface of the adobe bricks, which were plastered and whitewashed. The whitewash was applied with such a high amount of lime that still today a rather high amount of calcite is available.

For sample 8516 (upper layer of an aureole) a content of 3% of calcite and for sample 8522 (ground layer of the mentioned aureole) a content of 4% of calcite was measured. Since calcite is available in the ground layer in the same amount as in the upper layer, we can deduce that the calcite was used for strengthening the aureole in combination with the use of organic fibres. The same procedure can be stated for processing the frieze in the stupa when using 6% calcite.

### Research question 4: Which relations are given between the single temple structures regarding their mineral compositions?

After examining the mineral properties of the single components of the Nyarma temple structures (bricks and plaster), the question arises if there is a relation between the single structures on a mineral basis. Constructive features, such as adobe brick sizes, brick bonds and static features, are not part of this material study.[31] Nevertheless, the mineral properties of single structures can be a first step in their analysis and a basis for future studies. To start with the plaster, we are facing – in contrast to the adobe bricks – the uncertainty of whether a particular plaster was part of the original structure or the result of a renovation. The study of the plasters primarily gives an overview

---

[31] This topic was treated by the author in a presentation at the Terra Conference in 2016, published in Feiglstorfer (2018). Absolute dating of the single structures is not part of the present contribution.

as well as detailed insight into material properties and particular historical methods of processing. As described before, we can not talk of one specific method in processing the plaster but of a variety of methods, applied according to raw material features in connection with constructive needs.

Much more evidence in regard to a further comparison between the single temple structures is given with adobe bricks which are most probably part of the original structure. As this study has proven that the material for the bricks originates from the site or within close vicinity, the results of the bulk and clay mineral analysis are rather close to each other. Differences occur in the grain size distribution and point towards the use of different clay pits. Thus different methods of processing at a different period of time can not be excluded. The following results of similarities or dissimilarities can be stated.

Similarities:

| | |
|---|---|
| Temples I, IIIb, VIa | showing a small content of gravel and a high content of clay |
| Temples I, VIa | showing a small content of sand |

Dissimilarities:

Temples I and VIb
Temples I and II
Temples I and enclosure wall

### Research question 5: What are the geological parameters of the material used at the Nyarma Monastery?

Transport of the sediments: Due to their primarily “angular” shape (just a few with a “beginning rounding”) a short geological transport can be stated. For those with “beginning rounding” longer or more intense transport (by water and glaciers) may have taken place, possibly related to the nearness of the Indus River. In the course of flooding of meandering riverbeds within the last 13,000 years, minerals were shaped and colluvium created – possibly a mixture of rivers and colluvium. The maximum shaping found was “beginning rounding”.

Interpretations based on results of the BMA and CMA: A content of gypsum is evidence for the drying up of a former sea. The “field clay” used for all components of the shell structure shows consistent appearance within the Nyarma temple site structures, and this consistency can be found within close vicinity to the temple site, at least up to the north to the village of Thikse. For this type of clay we can state a content of illite and chlorite together with more than 90% of the <2 µm fraction, which points towards strong physical weathering. The change of mica into illite is a result of weathering during the glacial period.

# III. *ARGA* STONE ROOF CONSTRUCTION

This chapter deals with a specific type of stone, which is traditionally known over the Tibetan cultural zone as base material for a particular roof construction of a water resistant and durable quality. This labour intensive method of making roofs, ceilings and floors is rather unique within the Himalayas. It mirrors a Himalayan specific traditional approach on a technical and socio-economic level.

This chapter is divided in a construction based first part and an analytical second part. The first part, which is titled "Himalayan flat roof constructions", deals with the technical features of an *arga* roof and its relation to flat earth roofs.[1] The second part, which is titled as "Material analysis", deals with material properties of the *arga* stone in general and of specific examples in detail.

## 1. Himalayan flat roof constructions

The examined region stretches over about 1,600 km (Map 1.3). The eastern most part of the area of this research topic is Lhasa and its surrounding of Central Tibet. In Lhasa the roofs of two monasteries and the used material were observed. *Arga* restoration work was accompanied and documented on the roof of the Jokhang Temple and of the Gyüme Dratsang, both religious buildings in the heart of the city. The Jokhang is the central and most sacred of the Tibetan monasteries for Tibetan people. The Gyüme Dratsang (Tib. Rgyud smad grwa tshang) is an institute for tantric studies founded in 1433 CE (Alexander 2005: 157ff.). The author conducted research at the Jokhang[2] in 2010, 2014 and 2015, and at the Gyüme Dratsang in 2014 and 2015.

In Ngari, the place of research is the monastery of Khorchag and its surrounding, which are close to the Nepalese border in the south and the province Purang and the Kailas Range in the north. The most western area of research, located about 500 km north-west of Khorchag, is subdivided into Ladakh and Zangskar. Several buildings with *arga*[3] roofs and floors in Ladakh were observed and raw material was collected at one specific site in Ladakh close to the monastery of Mangyu not far from Alchi along the Indus River. The sample from Zangskar was taken from a site close to the Phugtal Monastery, which at the time of research was a four-day journey by bus, jeep and horse from Leh. The distance between Phugtal and Mangyu is about 100 km.[4] Besides these three regions – Central Tibet, West Tibet and Ladakh-Zangskar – from where the observed

---

[1] Sections of this first part of the current chapter were used as textual and pictorial basis for the film "The making of an *arga* roof" which the author presented at the IATS (International Association for Tibetan Studies) conference in June 2016 in Bergen and which is available on YouTube (Feiglstorfer 2016).

[2] The collection of samples and the related field research was undertaken at the Lhasa Jokhang, the Khorchag Monastery and at Mangyu within the FWF Project P 21806; at the Gyüme Dratsang and also at the Jokhang in Lhasa within the FWF Project P 25066.

[3] The first syllable *ar-* of the term *arga* points towards the term's relation to a building process.

[4] Interview with Anurada Chaturvedi, January 2003: Besides a quarry in Phugtal, further quarries are known in Stok and Leh, both in Ladakh (Feiglstorfer 2002: 16).

https://doi.org/10.1515/9783110591330-005

Map 1.3 Western and Central Himalayas. Sites related to *arga*. GIS data based map: Jakob Gredler. Final graphics: author. Map based on data from VD and BM.

raw material originates, archival research was undertaken at the Library of Tibetan Works and Archives at McLeod Ganj, and interviews were conducted, inter alia at the Norbulingka Institute near Dharamsala.[5]

## 1.1 General aspects of Himalayan flat roofs

In the Himalayas at altitudes of more than about 2,800 m, flat roof construction is the predominant roof form (Fig. 1.3, Fig. 2.3). Most of the flat roofs are still built with clay as the upper layer and the water disposal surface. Similar forms of earth roofs with different variations can be found all over the globe. There is a particular type of flat roof, which varies from the common type of clay used since it is mainly not made with clay but with a specific stone, i.e. the *arga* (Tib. *'ar ka*).

---

[5] Interviews were conducted with Choe Phuntsog from Dharamsala, Lama Ishay Jamyang from Saspol, with the head Lama in 2011 from the Shanti-stupa in Leh, Lama Konchok Tharchin in Lamayuru, Nawang Tsering from Mangyu, Mr. Angchuk an engineer from Basgo, with Tsering Norbu from Ne, Sonam Wangchuk from SECMOL in Phey, with Thobgye from Phenpo, who guided the works at the Gyüme Dratsang, and Nyema Tashi and Tashi Tsering from Lhasa. The most essential parts of the interviews will be reproduced within this research.

This stone is still known in Central Tibet and western Tibet as well as in Ladakh and Zangskar. Mr. Mani from the ASI (Archaeological Survey of India) mentioned another stone used for roof construction in Ladakh as *karevan*[6] that reminded the author of *arga*. According to local knowledge, an *arga* roof guarantees a long lasting and waterproof surface, a strong homogenous core and a surface of high aesthetic quality. Currently the high physical quality of traditional constructions is being rediscovered. From an economic point of view the higher investment for the making of a traditional *arga* roof subsequently guarantees less damage and less follow-up costs, less effort in maintenance and a higher quality of life for the users. Undoubtedly such technologically advanced traditions – which were developed and improved over generations – can be a sustainable answer to recent architectural challenges. (cf. Feiglstorfer 2016)

In Tibet, *arga* was used as base material for floors and roof constructions for representative religious and residential buildings. *Arga* roofs are known from Central Tibet, Lhoka, Phenpo and also Amdo. Floors, ceilings and roofs are erected in the same manner with a particularly adjusted subconstruction. A difference between floors and roofs is in the daily treatment of the surface. The floor is kept shiny by regularly polishing the surface.[7] As reported by Christiane Kalantari (Interview Kalantari 2011), in the monastery of Shalu, which is located in Central Tibet, a heavy bag made of sheep skin that has been filled with barley is pulled with ceremonial scarves (Tib. *kha btags*) across the floor as a part of a daily *puja* to polish the *arga* floor (Fig. 3.3, Fig. 4.3).[8] At the very least, walking on an *arga* floor keeps it durable for a longer period. Today, we still find well-maintained examples of *arga* floors in Central Tibet, e.g. in the Jokhang of Lhasa, or in Ngari, e.g. at the monastery of Khorchag, or in Amdo, e.g. at the book printing house in Derge. Due to a lack of monks and perhaps also due to loss of awareness, this technique has become rare.

Fig. 1.3 Labrang. Kinnaur. India. Flat roof constructions.
Fig. 2.3 Lamayuru. Ladakh. India. Wooden subconstruction of a flat roof.

---

[6] B.R. Mani mentions the use of a stone locally called *karevan* for the floor in the monastery of Likir in Ladakh. Before processing it was mixed with clay (Interview with B.R. Mani, December 2002; Feiglstorfer 2002: 38).

[7] Interview with Deldan Angmo, December 2002: *Arga* floors are described as black and shiny.

[8] At other places, polishing is also conducted by hand with textiles, as could be observed, for example, at the Dorje Chenmo Lhakhang in Nyarma. Here the soot floor is polished till it reaches a shiny black surface. Similarily, terrazzo is also known to gain a shining surface by its use.

Fig. 3.3 (Left) Monk at Shalu Monastery in Tibet polishing the floor. Photo: Christiane Kalantari, 2010 (FWF P 21806).
Fig. 4.3 (Right) Gyüme Dratsang. Lhasa. Woolen bag made of sheep skin filled with barley for polishing the floor.

Today, in many cases, *arga* floors are covered with synthetic floor material. An example would be the assembly hall in Spituk in Ladakh or the *zimchung* (Tib. *gzim chung*) in Lamayuru in Ladakh (Fig. 5.3, Fig. 6.3). Others are covered with wooden floors, e.g. using tongue and groove joints (e.g. at the Serzang Lhakhang in Basgo in Ladakh), which were built in the 16th century. Today at the Serzang Lhakhang, the surface of the *arga* roof is partly chipping off, especially areas more exposed to precipitation, similar to what the author observed in Purang on the roof of the Lhakhang Chenmo in Khorchag in West Tibet. For a restoration of this kind of damaged roof, the removal of the whole damaged *arga* layer is recommended. In the case of cracks in the *arga* surface, the *arga* is scratched out in stripes along the crack and refilled with fresh *arga*. At the Serzang Lhakhang in Basgo, we find stones as the subconstruction below the *arga* layer.

In Ladakh, an *arga* floor construction can also be found in the *zimchung* in the upper most storey of the monastery in Lamayuru.[9] This part of the monastery is highly representative and used for accommodating personalities of high social and religious rank, such as H.H. the Dalai Lama. A former Lama of Lamayuru, who has already passed away, constructed this floor about 70 to 90 years ago. Today, a loosely laid PVC-floor covers this great work and unfortunately makes it invisible to guests and visitors. Lama Konchok Tarchin helped the author to partially remove the PVC-floor and to examine the quality of the *arga*. After having washed away a thick layer of dust, the shining wet floor showed its colourful appearance, similar to the high quality of *arga* floors found in the Jokhang in Lhasa or in the Jokhang Temple in Khorchag. The palace of Stok is another example of where to find an *arga* roof construction. There are many more examples of *arga* floors than there are for *arga* roofs, for instance, at the monasteries of Stakna and Spituk.[10]

---

[9] Interview with Anurada Chaturvedi, January 2002: She also mentions *arga* floors in the palace of Stok, the monastery in Hemis or the *cella* niche in the Alchi Dukhang (Feiglstorfer 2002: 16).

[10] Interview with Deldan Angmo, December 2002: With thanks to Deldan Angmo who gave information about the *arga* floor in Spituk.

Fig. 5.3 Spituk. Ladakh. Assembly hall. *Arga* partially coverd with PVC.

Fig. 6.3 Lamayuru. Ladakh. *Zimchung*. *Arga* after removing the covering PVC floor.

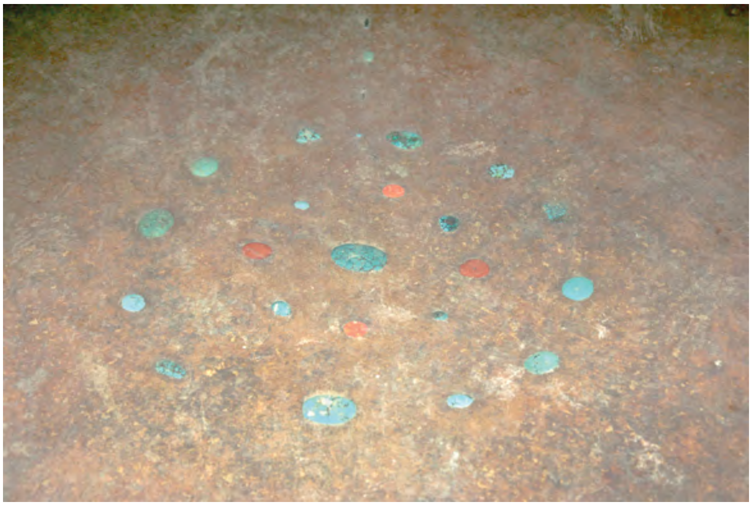


Fig. 7.3 Khorchag. West Tibet. *Arga* floor in the *Jokhang* at the entrance to the assembly hall.

In Tabo, which is located in Spiti in Himachal Pradesh, *arga* as raw material could be traced within a field research in 2018 and its former use at least as flooring material in the main temple, according to local saying seems to obvious.

There are several indices for *arga* construction having been well known in Tibet in earlier days, at least until the Cultural Revolution. For example, the ground floor in the whole Khorchag Jokhang, exclusively the area of the inner circumambulation path (Tib. *nang skor*), was paved with *arga* with a polished surface refined with oil. In the area of the entrance in the assembly hall (Tib. *'du khang*), inlays of colourful stones were created in a circular disposal in the *arga* floor (Fig. 7.3).

Another constructive fact indicates the *arga* roof having been the traditional roof construction at the temples of Khorchag. It is the subconstruction below the *arga* which can be seen in several parts of these temples. For instance, a damaged part of the ceiling construction in the storage room for wooden logs, located to the right of the entrance chamber of the Lhakhang Chenmo, gives insight into the subconstruction of the ceiling made of stones. This kind of construction resembles *arga* roofs from the whole Tibetan cultural zone from Ladakh to East Tibet.

### 1.1.1 Subconstruction of flat earth roofs

A basic difference between an *arga* roof and a traditional flat earth roof − which is the most common roof construction over the Himalayas − is the used materials, i.e. *arga* stone on a clay sublayer or simply clay, respectively. Contrary to *arga* roofs, earth roofs also exist as sloping roofs as found in Kashmir. Sloping roofs require a much more complicated wooden subconstruction, necessitating a higher need of wood which is not available at higher Himalayan altitudes.

The ramming of the *arga* causes vibrations during the working process. This affords a subconstruction of an adjusted strength. For this purpose, Choe Phuntsog (cf. Interview 2002) describes in a Central Tibetan context the use of flat stone slabs of an approximate size of 10 x 10 x 3 cm laid on wooden planks[11] or on beams, which the author observed in the monastery of Khorchag in West Tibet. For a traditional earth roof in the Western Himalayas, the use of heavy stones as a subconstruction on the wooden beams is rather uncommon. A constructive difference between two types of flat roofs is the subconstruction with or without the use of stone. In the Central Himalayas the use of a stone-based subconstruction – for *arga* roofs as well as for flat earth roofs – seems to be more common than in the Western Himalayas, in particular the Indian Himalayas. The solid stone-subconstruction probably results in the need of a strong subconstruction which resists the many vibrations caused by the continuous ramming of the *arga* stones on the roof. The Central Tibetan technique of an *arga* roof construction resembles observed *arga* subconstructions found in Ladakh, e.g. at the Serzang Lhakhang in Basgo.

---

[11] The content of the interview with Choe Phuntsog emphasises the understanding of the basic procedure for the preparation of an *arga* roof (Interview with Choe Phuntsog in 2002; Feiglstorfer 2002: 7). Also compare the drawing of a section of an *arga* roof given in Feiglstorfer (2012).

Lama Gyatsho (1979), in his description of Tibetan monastic customs, mentions the wooden subconstruction followed by a multi-layered stone construction.[12] This description reminds us of the idea of the 'Fuller parable' through the use of different sizes of stones to minimise the spaces between the grains and to reach a better compaction. His description of the smoothening of the upper of these stone layers, up to this level of the construction, shows similarities to an *arga* roof (for details, see below) but does not mention a layer of clay below the *arga* layer, as the author found at different examples in Lhasa. But since he describes the making of a two layered and rammed earth roof above this stone construction, it becomes clear that he is describing an earth roof, and not an *arga* roof. Specifically, this earth roof is being treated like an *arga* roof by ramming on a massive and very strong subconstruction made of stones. This type of construction is rare in the Western Himalayas and is probably related to a heavier Central Tibetan building technique.

This description of Lama Gyatsho also explains the use of a heavy subconstruction made of stone for a flat earth roof and not just for an *arga* roof. His description resembles a modern description given by Penba Tashi (Interview 2014; cf. Feiglstorfer, forthcoming a). The latter describes the same method of a heavy subconstruction using stone for a flat earth roof as well as for an *arga* roof. Just the most upper layer differs between these two techniques, i.e. clay or *arga,* respectively. The following offers a better understanding of the difference between an *arga* flat roof and a flat earth roof.

## 1.2 Flat earth roofs

The common earth roof construction is similar to roofs found in other parts of the world that have a wooden subconstruction resting on branches or wooden planks[13] and an organic layer below which is open to vapour diffusion. In the Himalayas this organic layer can be a specific grass, bush or bark of a tree. Dependent on particular local resources of suitable fibres, local traditions are identifiable.[14] The technical quality of the whole roof depends on the quality of the used organic layer, which may have to do with the fact that earlier roofs show much higher longevity (Interview Chaturvedi 2002; Feiglstorfer 2002: 13). Further examples of organic material used for roof insulation are given below under 1.2.1 "Insulation layer". For plasters as well as for clay used for flat roofs with a demand for a certain high quality, several layers of clay are applied.

---

[12] "When the rafters have been arranged at evenly-spaced intervals, short ceiling planks should then be laid above them, alternating back and forth in herring-bone fashion from rafter to rafter. Atop them a layer of alluvial stones called *ceiling-plank stones* is laid, and between them smaller stones are placed. Any remaining gaps are filled up with gravel, and finally the surface is smoothened over with small pebbles. Then, the foregoing surface is completely covered over with a layer of thinned clay of good quality, which must be stamped down energetically with the feet. Next, it is covered with a layer of dry clay and again packed down thoroughly. Only after the edges of the completed roof, where the tips of the rafters rest, have been packed down with stones great and elaborate, […]" (Thubten Legshay Gyatsho, 1979, pages 36 and 38).

[13] Subconstructions of Himalayan flat roofs were described in detail in Feiglstorfer (2012: 5, 6).

[14] The influence of organic layers as subconstructions of flat roofs and their impact on the physical behaviour were treated in Feiglstorfer (2012: 7). Also several locally available types of organic material were mentioned as being used as a kind of insolation layer between the clay as the adjoining upper and the wooden subconstruction as the adjoining lower layer. For the sake of completeness and better recognition of the single plants, a compilation is given.

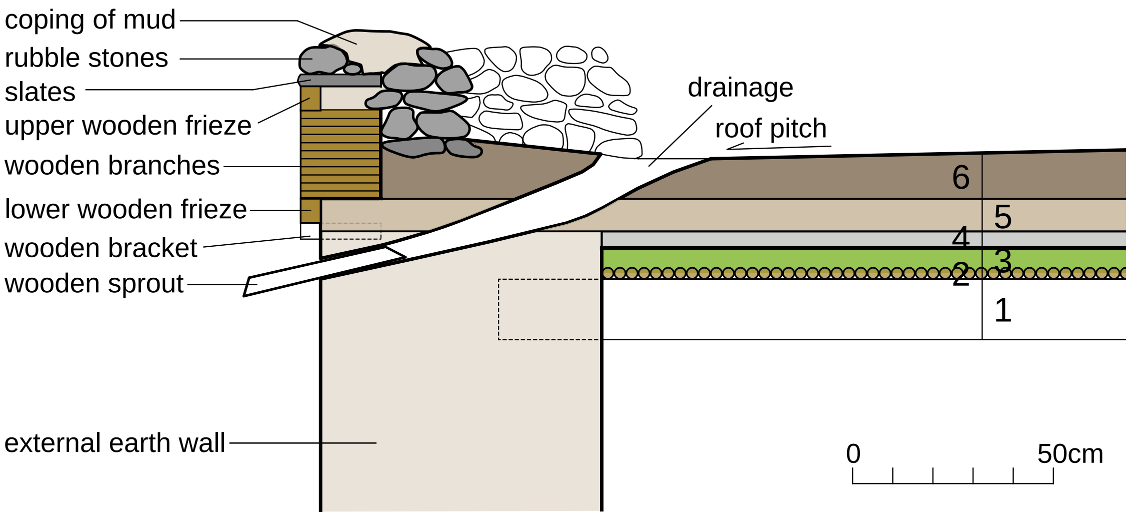


Fig. 8.3 Section of a traditional flat earth roof construction.
CT = Central Tibet; WT = Western Himalayas (cf. Feiglstorfer, forthcoming a).

1 = *cham* (Tib. *lcam*, secondary beam), often placed on the *dungma* (Tib. *gdung ma*, main beam), the latter resting on one ore more *kawa* (Tib. *ka ba*, pillar).
2 = *delma* (Tib. *dral ma*, small pieces of wood of a tree or bush), e.g. willow branches are commonly used in WT.
3 = organic layer; specific types of grass like *yakses* used in WT; the use of an organic layer is commonly known in WT, but not everywhere in CT.
4 (ground layer) = *yamba* (Tib. *gyam pa*, flat stones); often used in combination with an *arga* roof; often used in CT or Purang; rarely used in WT.
4 (upper layer) = *dorug* (Tib. *rdo hrug*, small stones); used in combination with the *yamba* below to fill gaps between the bigger stones.
5 = thogdag (Tib. *thog 'dag*); is the first layer of clay.
6 = *thigsa* (Tib. *thig sa*); upper and fine layer of clay, which is in some areas traditionally exchanged or simply added every year and maintained before rain falls.

In the plaster, similar to that used in European technologies, the coarse sub-layer works as an undercoat while the upper and final layer consists of fine material with less organic additives, and in certain cases it is also used as an undercoat for wall paintings. In the case of flat roofs, the lower layers are usually of a coarse material and the upper layer of a fine clay, such as the *markalak* clay. If the roof is not continuously maintained, the finer upper layer is washed out and a coarse sub-layer remains. In general, this sub-layer appears as a hard layer from which it is difficult to remove a piece without cracking, as it is conglomerated with the fine material from above. Such a sequence from the lower and coarse layer with decreasing sizes of grains in the upper layers was followed in a proposal given by Maïni Satprem for the Nako preservation project (Interview Maïni Satprem 2006). His idea introduced six different layers for a new earth roof construction. Further variations of layers of clay you find in section 1.2.2 “Layers of clay” in this chapter.

Fig. 9.3 (Left) Purthi. Chamba. India. Birch bark as organic layer below the clay.

Fig. 10.3 (Right) Purthi. Layer of clay covering the birch bark.

### 1.2.1 Insulation layer

Apart from the quality and mixture of the layers of clay, the insulation layer below plays an important role in keeping humidity out of the wooden parts of the construction. This is especially important because humidity is the main reason for rotting.[15] Fig. 8.3 shows a flat earth roof construction. In the Jokhang in Khorchag as well as in the Maitreya Lhakhang in Basgo, birch bark was already used in earlier days as a material for this layer. Results of field research in Purthi in Chamba (Himachal Pradesh / North India) give good insight into still living traditions (Fig. 9.3, Fig. 10.3). This type of birch, the *betula utilis* (Hindi *bojpatar,* Tib. *shing stag ma*)*,* can be found at higher altitudes, for example, in the village of Piukar (or Pekar) along the slopes in Lahaul in North India. The birch often grows in a grove, which gives the impression of having been planted at a certain place, possibly for easy access to a bigger group of birches. Such groves can be found in altitudes far above 3,000 m.

We can still find the use of the birch bark at various places, such as in the roof construction of the Jokhang in Khorchag, which is located in Purang in West Tibet.[16] The birch bark is cut off of the trees in strips, which are then laid onto the wooden subconstruction of the roof (Fig. 9.3). Afterwards, the bark is covered with layers of clay, which in a following course, are compressed by stamping (Fig. 10.3).

Aside from the birch bark, the *yakses* is also known in Ladakh as material used for an insulation layer (Fig. 11.3 and Fig. 12.3; also see figures titled “Plant 1.3” to “Plant 4.3”. There are particular areas in Ladakh locally known for the availability of *yakses*, especially in the area of the

---

[15] In the Western Himalayas, the author could observe the use of an insulation layer both, at elite structures like monastery buildings and at common farm buildings. In Central Tibet the use of such an insulation layer is known at several places but could not be observed as a (still) living commonly known tradition.

[16] According to local tradition, in former days in Purang a bigger variety of timber was locally available. Today, different species of structural timber, which are commonly known in Tibet for their high quality, like the *shugpa* (Tib. *shug pa*) or the cedar, are imported from areas in north-western Nepal. This area, bordering Purang, is richer in vegetation.

Fig. 11.3 (Left) and Fig. 12.3 (Right) Lamayuru. Ladakh. *Yakses* is pulled on top of the roof and placed on the wooden subconstruction.

Kardung-la, which is on the way from Leh towards the Nubra Valley. *Yakses* is not dried before placement onto the roof. The use of *yakses* is a traditional technique still used in Ladakh today (Interview Sonam Dawa 2002). Before application, *yakses* is moistened to enable good compression. Several layers of this grass are laid 90° crosswise above each other. This technique avoids trickling of clay through the subconstruction into the building.[17]

In several areas, like in Upper Kinnaur or Ladakh, a bush known as *burze* is used for this insulation layer. It can be found at altitudes of app. 3,500 m up to 4,000 m. When water enters the roof construction, it may rot. The *burze* as a plant is also known in Purang in West Tibet but it is not known as insulation material. In Ladakh it is still known as an organic layering material used for the roof, though this use was not common in Khorchag in Purang.

Other examples of plants used as insulation material (see figures titled "Plant 1.3" to "Plant 4.3" on the following pages) are known locally by different names. One specific plant is known as *jiwa* in Zangskar, as *chipyang* in Ladakh (Interview Wangyal Tsering 2002), and as *jange* in Upper Kinnaur. The *somlata* plant, as it is known in Hindi, is also widely known all over the Western Himalayas but just partially used as insulation material. This plant turned out to be known by different names throughout the Western Himalayas. It can be found in lower areas of Kinnaur up to altitudes of app. 3,000 m, for example, in the village of Labrang in Middle Kinnaur in Himachal Pradesh where the plant is locally described as being used for roof constructions.

In Ladakh the twigs of the *umbo* (spoken Lad.; Tib. *'um bu*) are still used for an insulation layer between the layers of wooden planks below and the clay on top. The author noted this bush to have fine leaves similar to a fern. *Umbo* is found at an altitude of about 3,500 m in the groves of the *Alchi doc*, a pasture at higher altitudes between Alchi and Mangyu in Ladakh. Most of the trees found in this valley at the foot of the Lotsāba Lhakhang at the *Alchi doc* are planted along

---

[17] Observation at the renovation of a roof at the Lamayuru Monastery in 2008 in Ladakh.

irrigation channels. At a similar altitude just a few kilometres further west, the branches of this bush are traditionally used as a roof insulation material. Deldan Angmo, a senior conservation architect from INTACH working at the conservation of the temples of Mangyu, also mentioned this material as being used for the conservation of Mangyu Temple roofs. In Alchi, on the way from Yülkor to Druggyeling, organic material used as an insulation layer was found. It is referred to as *burmar* (Lad.) and it grows in the area west and south of Alchi.

One feature of some of these particular plants used as insulation material, like the *yakses,* is their ability to expand when wet and their capacity to store water which prevents a continuous seepage of water into the wooden construction below. When full saturation of the organic material as storage medium is reached, humidity seeps through. Regarding this concern it has to be mentioned that these organic insulation layers will only work up to a certain amount of precipitation. Another important effect of certain organic materials is their antifungal behaviour, caused by their individual fragrance. This quality, as we know from cedar wood, is also found in materials used as insulation layers, similar to worm wood, whose name refers to its antifungal behaviour.

Each region has its own vegetation and accordingly a related tradition in using particular material for the roof construction. The figures titled “Plant 1.3” to “Plant 4.3” give an overview of the most common organic insolation materials used in particular Himalayan regions, such as Ladakh, Kinnaur or Purang. Similar to earth building materials, these organic materials are locally used or at least locally known.

| | |
|---|---|
| *Asteraceae* | botanical family |
| *Burze* | Chulling and Nako (Upper Kinnaur) |
| *Jurt* | Spillo (Lower Kinnaur) |
| *Nyurtsi* | Keylong (Lahaul) |
| *Sedjesl* | term used by Tsering Dorje (Lahaul) |
| *Yakses* | Ladakh |
| *Wormwood* | English |
| *Wermut* | German |

Plant 1.3 Plant used as organic layer for Himalayan flat roof constructions. Local terms known for *wormwood*.

| | |
|---|---|
| *Jange* | Chulling (Upper Kinnaur) |
| *Nangye* | Lahaul |
| *Jiwa* | Zangskar |
| *Chipyang* | Ladakh |

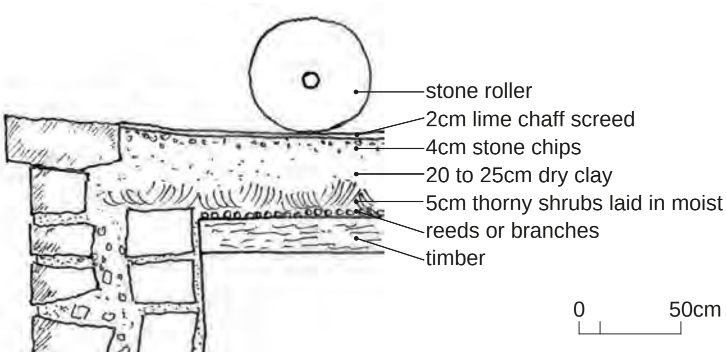
Red fruits are edible.

Plant 2.3 Plant used as organic layer for Himalayan flat roof constructions. Local terms known for *chipyang*.

| | |
|---|---|
| *Equisetaceae* | botanical family |
| *Zebur* | Chulling (Upper Kinnaur);<br>not used for roof constructions |
| *Kanta* | Spillo (Lower Kinnaur)<br>used for roof constructions |
| *Ghin* | Keylong (Lahaul)<br>not used for roof constructions |
| *Somlata* | Hindi |
| *Horse tale* | English |
| *Schachtelhalm* | German |

Plant 3.3 Plant used as organic layer for Himalayan flat roof constructions. Local terms known for *horse tale*.

Plant 4.3 Plant used as organic layer for Himalayan flat roof constructions. In Ladakh known as *umbo*.



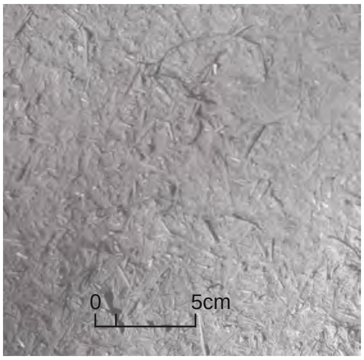


Fig. 13.3 (Left) Lebanon. Metal roller. After Ragette 1974.
Fig. 14.3 (Right) Iran. Bāgh-e Fin. Metal roller compressed straw-clay as upper surface.

### 1.2.2 Layers of clay

In the Himalayas, clay is thrown upon the described organic layers and then compressed by foot and wooden beaters. It is not rolled, a technique we know from the Middle East – Iran,[18] Syria and Turkey. The author observed use of a metal roller (Fig. 13.3) in the Bāgh-e Fin in Iran for compressing the most upper layer of the roof (Fig. 14.3). Due to this method it is possible to add fine pieces of straw even in the most upper layer of clay on the roof, which in a finished state is visible from above. This method of using a stone roller should be mentioned as related to a method which is also known and still practised in Central Tibet for *arga* roofs. In particular the first layer of *arga* is compressed and slightly crushed with a heavy stone roller. Contrary, for earth roofs this method as mentioned above is not traditionally practised in the Western Himalayas. Also, adding capillary active straw material to the most upper layer of clay on the roof is known only in exceptional cases in the Himalayas; it is not common practice.

In southern regions – as we know especially from Turkey and Iran – salt is added to the clay to be used for roofs. In Abyaneh, as the author observed in 2003, village elders explained the method of adding salt to the clay.[19] The reason for the use of salt in a roof construction – from a physical point of view – is still unclear.[20] The addition of salt to an earth roof is – as far as the author could observe – not practised in the Western and Central Himalayas.

---

[18] Interview Azimeh Riahi 2015: She mentions the use of metal rollers in Iran since app. 200 years ago.

[19] Presented by the author at a lecture at the Vienna University of Technology on Nov. 8, 2004, titled *Traditional Architecture in Iran – Building with and under the earth*. The given information is based on field research in Iran in 2003. Azimeh Riahi, who at that time was working as an architect in Abyaneh, Iran, translated the interview conducted in the field. On site it was explained that the salt is washed out after a time and new salt has to be added.

[20] According to a hypothesis given by Christof Ziegert, a German expert on earth constructions, at his lecture at the Vienna University of Technology in autumn 2014, the salt is able to attract humidity at such a level that the clay does not soak too much. As a further result, salt keeps the homogenous mass of clay flexible and by that avoids cracks. One hypothesis given by one of the reviewers of this publication should also be mentioned here: If smectite is present in the clay used for the roof, salt addition could lead to cation exchange and increase the plasticity of the clay.

The clay roof on top of the insulation layer consists of one or several layers of clay, dependent on local traditions and the amount of effort invested for transport of the material and its compression on the roof. The different traditional variations in preparing such layers of clay show a big diversity. The collected examples, which will be described in the following, give an outline of common variations of layer structures of flat earth roofs. Deviations from local traditions, particularly introducing 'modern' materials, can be seen as rather critical, since their composition is connected to particular local qualities of clay.

Leh / Ladakh (India):[21]

Method for the renovation of a temple roof

- 1st layer: Clay added in two layers (moistened), each about 6 cm to 8 cm.
- 2nd layer: Wood chips as insolation layer, about 10 cm to 16 cm.
- 3rd layer: Clay mixed with *markalak* clay, about 8 cm to 11 cm.

Leh / Ladakh (India):[22]

Two methods for making an earth roof. The clay is applied moistened. The upper layer has to be changed frequently.

- Method I:
  - 1st layer: Clay, about 15 cm to 20 cm.
  - 2nd layer: Clay mixed with *markalak* clay, about 10 cm.
- Method II:
  - 1st layer above *yakses*: *Markalak* clay about 5 cm thick, which is slightly moistened before application. Afterwards it is rammed.
  - 2nd layer: Layer, which is slightly sandy, is used to build the slope, about 8 cm. This layer is moistened even more and also rammed.
  - 3rd layer: Fine layer of clay for smoothing. This layer can be mixed with straw (Tib. *sog ma*).

Leh / Ladakh (India):[23]

Roof for a residential building in Ladakh

- Just one layer: *Markalak* clay, about 10 cm to 16 cm.

Pin Valley / Himacha Pradesh (India):[24]

Recently built roof on a residential building in the Pin Valley.

- Just one layer: Clay without stones, about 5 cm.

Different types of clay were used for walls and roofs. At earlier constructions, *takpa* (a type of wood) was mixed with clay. For a traditional roof of a farm house, between two and four workers and a foreman and during finishing the roof between 25 and 30 workers are needed.

---

[21] Interview Ringzen Dorjee (2002); Feiglstorfer (2002: 29).

[22] Interview Wangyal Tsering (2002); Feiglstorfer (2002: 30).

[23] Interview with Sonam Dawa (2002); Feiglstorfer (2002: 37).

[24] Interview Rajkumar Bodh (2002); Feiglstorfer (2002: 31).

Nako in Upper Kinnaur / Himachal Praedsh (India):[25]

At the monastery of Nako, for the restoration of a temple roof, which was conducted by local workers, two different types of earth roofs will be described: one prepared during the renovation, the other as it existed before the renovation. The renovated roof was described as waterproof at the time of this interview.

- I: Construction used traditionally before renovation:
  - Wooden planks, about 4 cm.
  - 1st layer: *Yakses*.
  - 2nd layer: *Tua*, about 15 cm to 20 cm.
  - 3rd layer: *Kalak* = with water mixed *tua* clay, about 2 cm to 3 cm.
- II: Construction used for the renovation:
  - Wooden planks.
  - 1st layer: Plastic sheet.
  - 2nd layer: Clay.
  - 3rd layer: Bituminous felt.
  - 4th layer: Mixture of *yakses*, clay and water.
  - 5th layer: *Kalak* = with water mixed *tua* clay.

Nako in Upper Kinnaur / Himachal Praedsh (India):[26]

- Maïni Satprem (2004: 5) also describes several methods in constructing an earth roof, in particular for the renovation of a temple roof at Nako in Upper Kinnaur. Listed in his report are two types of construction: one as traditionally used before the renovation, and one proposal for the renovation.
- Construction traditionally used at Nako according to Satprem (2004: 5):
  - 1st layer: Several layers of *thawa* clay, about 20 cm; for the absorption of water.
  - 2nd layer: Slurry of *tua* clay.

He also describes the need to remove snow after every snowfall and apply a new layer of *tua* clay every six months. Heavier rainfalls and the damaging of the *tua* clay layer when removing snow are reasons for the development of a new layer composition. Therefore he mentions two types of layering, though only the one recommended by him is described in Table 1.3.

Author's comment: The proposal is a rather complicated but efficient 6-layer composition and starts, according to local tradition, with the coarse layer below (see layer 1 in Table 1.3). Towards layer 4 from below the layers are reduced in height and the proportion of *thawa* clay (coarse material) to *tua* clay (fine material) changes towards a continuously finer mixture (proportionally a higher content of *tua* clay) in layer 4. Layer number 4 no longer contains *thawa clay* and is the finest and by that the water-bearing layer. Above layer number 4, two further layers with a rather high content of *thawa* clay are laid and the content of *thawa* clay increases towards the top. With this solution the two top layers are basically capillarily opening and do not act as water bearing layers but as harder layers mechanically more resistant against rain, snow or impacts from above (compare afore described method in Iran with straw in the upper layer of clay). To increase this

---

[25] Interview Rachana Viswanathan (2002); Feiglstorfer (2002: 30).

[26] Interview Maïni Satprem 2006.

mechanical resistance, the two upper layers are mixed with a relatively high amount of straw and the most upper layer additionally with mule dung, which makes it more resistant against water (as we know this effect from historical exterior plasters (coatings) of solid walls in Europe, which are thick layers of clay mixed with straw and dung).

Table 1.3 Earth roof layering. Recommendation for various types of clay, dimensions and mix ratio for Nako given by Maïni Satprem (2004: 12).

| Roof No. 2 | | | | | | |
|---|---|---|---|---|---|---|
| Coat | Thickness | *Thawa* clay | *Tua* clay | Barley straw | Mule dung | Water |
| 1 (bottom) | 5 cm | 2.5 | – | – | – | 1 |
| 2 | 5 cm | 15 | 1 | – | – | 5 |
| 3 | 1.5 cm | 9 | 1 | – | – | 3 |
| 4 | 0.5 cm | – | 2 | – | – | 1 |
| 5 | 2.5 cm | 9 | 1 | 1 | – | 4 |
| 6 (top) | 2.5 cm | 3 | – | 1 | 1 | 2 |

## 1.3 Arga stone roofs

The clay used for a common earth roof is collected in close vicinity to the building site. The used clay is often mentioned as *shingsa* (Tib. *zhing sa*),[27] which describes a “clay from the field” and a commonly used clay without particular specific properties. Only for the water-repellent upper layer of a flat earth roof clay is collected from locations quite some distance away, like for high quality building material, such as *markalak* clay (see Chapter IV).

The *arga* material, in contrast, is collected at specific sites also a greater distance away from the building site.[28] For Lhasa, for instance, we know quarries with *arga* in Drag Yerpa (Tib. Brag Yer pa), the Dogde (Tib. Dog sde) Valley close to the Sera Monastery, and the village of Serme (Tib. Ser smad) in Chushöl (Tib. Chu zhol) (cf. Feiglstorfer, forthcoming a). The best *arga*, as the author was told at the Gyümed Dratsang in Lhasa, is said to be from Phenpo (Tib. ’Phan po), located about 75 km north of Lhasa. In earlier days the material was carried on the back of yaks. The load capacity of one yak can be calculated to be app. 40 kg to 50 kg and the amount of time, which the animal is able to walk in one day, is up to nine hours (see Map 1.2) (Interview Tsering Drongshar 2015).

The density of rammed earth ranges between 1,700 to 2,200 kg/m$^3$. Calculating with app. 2,000 kg/m$^3$ and a thickness of 14 cm (which is the average thickness between André Alexander’s and the author’s research), the weight of the layer of clay below the *arga* is app. 280 kg/m$^2$.

---

[27] It has to be emphasised that the term *shingsa* does not describe a particular quality of clay. On the contrary each type of *shingsa* shows its own mineral composition.

[28] According to Alexander (2011: 70) only a master can identify the quality of *arga* material by tasting the material. It was believed to “ripen” and the act of quarrying was equal with “harvesting” *arga*. According to Tsering Drongshar (Interview in September 2015), places where *arga* can be found are often covered with clay and in some cases have gravel below.

Fig. 15.3 Lhasa. Gyüme Dratsang. *Arga* roof.

Fig. 16.3 Lhasa. Jokhang. *Arga* roof.

The density of limestone ranges between 2,600 and 2,900 kg/m³. Calculating with 2,800 kg/m³ (including spaces between the stones) and a thickness of 8 cm (on average between André Alexanders and the author's research), the weight of the *arga* layer is app. 224 kg/m². By adding a subconstruction made of ashlars or slates of a thickness of app. 8 cm calculated with 2,900 kg/m³, we can add another 232 kg/m². This calculation would result in a load of app. 740 kg/m² for an *arga* roof with a thickness of app. 30 cm.

In 2014, the *arga* roof of the Gyüme Dratsang in Lhasa − a tantric college of the Gelugpa school − was completely renewed (Fig. 15.3) and the roof of the Jokang in Lhasa partially repaired (Fig. 16.3). Both objects are located in Lhasa and addressed in this documentation. There are different qualities of *arga* primarily depending on the content of different stones, and the needed effort to ram and crush varies from one stone type to the next.[29] For a religious purpose, the sap of a specific kind of a root is used as an additive to achieve a reddish pink colouring.[30]

The *arga* at both building sites was said to be brought from Chushöl. The material itself is of a greyish-brown colour. The mineral analyses show a high content of calcite and a small proportion of quartz and feldspar, similar but not identical at both sites (see the mineral alalysis).

For the renewing of the roughly 700 m² roof of the Gyüme Dratsang (Fig. 17.3), 80 to 100 workers were necessary and continuously worked from 8 am till 5 pm for about four weeks. Since the material is heavier in a compressed condition and due to the vibrations resulting from several days of the ramming process, the common subconstruction known from earth roofs is not sufficient. Stone slabs (Tib. *gyam pa*) resting – from top to bottom – on 1) wooden boards or branches (Tib. *dral ma*), 2) secondary beams (Tib. *lcam*), 3) primary beams (Tib. *gdung ma*) and 4) pillars

---

[29] Similar to Western terrazzo the colourful surface depends on the colour of the stones on the one hand and on the binder on the other hand.

[30] Interview Nyema Tashi (2013); also Alexander (2011: 71): Red *arga* is known as having the best quality and was used for monasteries and governmental purposes. The white *arga* was for common use. A further differentiation was made between "female" and "male" *arga* which were mixed to receive the best result. Tsering Drongshar (Interview September 2015) mentions the red *arga* as the better quality. Red and white *arga* can be mixed.

(Tib. *ka ba*) assume the required static role.[31] The amount of layers of *arga* depends on the required quality. As reported by locals in the case of the buckling of a pillar from below, the roof does not collapse due to the homogenous and elastic quality of the rammed *arga*.

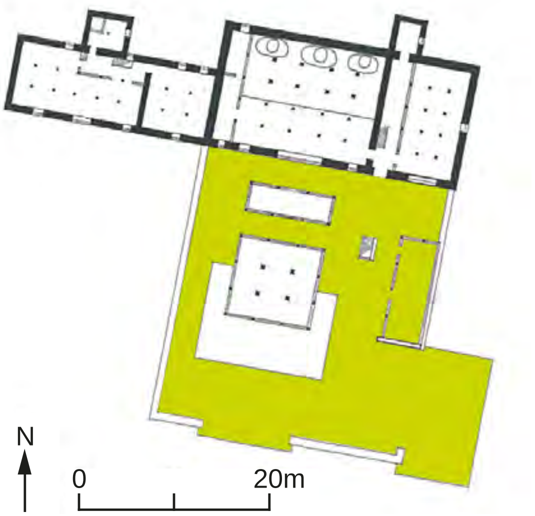


Fig. 17.3 Lhasa. Gyüme Dratsang. Area of the new roof. Groundplan by Alexander (2005: 161), with additions by the author.

As the technique of constructing an *arga* floor or an *arga* roof is no longer practised in Ladakh by tradition, it is difficult to find someone who can explain its construction process. Several local people, who had contact to Central Tibetan monks, or monks themselves, who have been to Central Tibet, have knowledge about this technique. Lama Ishay Jamyang was able to give a very detailed description of how to use *arga* (Interview Ishay Jamyang 2011): The raw material can be found inside the so-called *moonland* at Lamayuru on the right side of the road when moving from Lamayuru towards Leh (not to be mixed up with the *markalak* clay on the left side of the road). The material is described as brown and hollow.

In Mangyu in Ladakh the author was shown an *arga* stone at the backside of the monastery of Mangyu by Nawang Tsering. This *arga* stone was relatively hard and could only be broken with the force of another stone (see sample 11953) (Interview Nawang Tsering 2011). Its colour, spotted black and white grey, was different to the colour as was described by Lama Jamyang.

Lama Ishay Jamyang describes the making of an *arga* floor in the following way: "The making of an *arga* floor is reminiscent of making a terrazzo flooring. The raw material is crushed without adding water by using a piece of iron which is fixed to a stick until the *arga* pieces reach a size of about the thickness of one finger. The thickness of the layer itself should be about three inches (app. 7.5 cm). The weight of the iron piece is approximately 750 grams and should not be too heavy. In former days, a round and flat stone was used instead. The dust which is produced during ramming is kept aside for a later use. With about six to seven workers, this layer is continuously compacted but not crushed anymore. The workers move in a line through the room. This process takes around two to three days. If during this compacting process any hole remains in the floor, it will be filled up with the dust which was collected before. After about two to three days water is added. After that the members do not step on the floor but they slip with their feet over it and continue compacting the floor till the water disappears completely. This process should take around

---

[31] Tsering Drongshar mentions the *thogdag* (Tib. *thog 'dag*) as a Tibetan term for the most upper part of an earth roof, *thog* meaning roof and *'dag* meaning earth. Contrary to the *thigsa*, the *thogdag* does not just functionally describe a layer of clay or a particular quality of the clay but in an anthropological context the final process of a roof construction. When making the *thogdag,* a ritual ceremony is held.

Fig. 18.3 Lhasa. Jokhang. Clay (in front) as sub-layer.

Fig. 19.3 Gyüme Dratsang. Stone roller for compression.

six to seven hours. Then further water is added and the surface of the floor gets burnished with a round stone and remaining water is sopped with a textile. By this process the multi-coloured marbled surface of the floor becomes visible. Before continuing, the water has to be dried up completely." Lama Ishay Jamyang states no difference between the construction of a floor and a roof.

Nawang Tsering describes the construction of the *arga* floor similarly but in a reduced form in the following manner: "The *arga* stones are strewn over the floor, mixed with water and rammed for about one day if there are enough people available for this work. After ramming, a lot of oil is added onto the surface till it is soaked into the floor. On the surface remaining oil is sopped with a textile."

In the following, in addition to the historical description of the *arga* technique, the presently observed process of making an *arga* roof will be described in detail. This process is essential for further understanding of the material properties in the working process.[32]

### 1.3.1 Ramming

As a first step, a layer of clay that has been mostly collected from the fields – the so-called *shingsa* − is rammed to a thickness of about 10 cm (Fig. 18.3).[33] At Khorchag, the particular clay used for the *arga* roof originates from within close vicinity of the monastery. After, the *arga* is thrown on the layer of clay with a layer-thickness of about 10 cm to 14 cm[34] and crushed by heavy

---

[32] As a common ritual, Sonam Anchuk (Interview 2011) mentions the first *chang* (Tibetan beer) to be added to the *arga* material before processing.

[33] Feiglstorfer (2002: 7) and Feiglstorfer (2012): Choe Phuntsog mentions a height of the layer of clay of about 5 cm to 8 cm. Ishay Jamyang also mentions a thickness of app. 8 cm.

[34] Different recipes are known for preparation and it should not be stated that there is a "one and only method" but instead a variety of methods differing in details. The thickness of the *arga* layer, which the author observed, matches with Alexander's (2011: 71) thickness of 10 cm to 20 cm while the thickness of the clay as subconstruction, including pebbles he reports as 35 cm.

rollers made of stone (Fig. 19.3).[35] The *arga* stones with an app. size between 2 cm and 4 cm[36] are crushed while pouring water over them. The water makes crushing easier but a liquefied consistency is not reached.[37]

The quality of the water is known as being important and said to be best during Karma Döpa (Tib. *skar ma dod pa*) or Karma Rishi (referring to a Sanskrit term: *skar ma ri shi*), which is the name of a star. According to the Tibetan calendar, this star appears in the month of August (Ponda 8, Tib. *bod zla*). The Tibetan people consider this month's water to be clean and pure, and good for taking a bath. According to the Tibetan calendar, this star is visible between about the 30th of July and the 2nd of August (Interview Tsering Drongshar 2015).[38] At this time Tibetans take a bath outside in a river. Low water quality reduces the adherence of the crushed stone material. Particular minerals can be washed out or transported due to the level of snowmelt water or rainwater, dependent on the season. This factor needs to be examined in a further study.

After rough crushing with the roller, which lasts about one to two days, the ramming (Tib. *'bog tho*) process starts. For flat surfaces, the so-called *bogdo* (Tib. *'bog rdo*) (Fig. 20.3) is used.[39] This is a flat stone with an average diameter of 15 cm fastened at the bottom end of a stick. For smaller surfaces, like cracks, and also for round surfaces, like parapet walls, a wooden beater made of hard wood – the *bärdo* (Tib. *ber rdo*) – is used (Fig. 21.3, Fig. 22.3 and Fig. 23.3). Grothmann (2011: 19) also uses the expression *lakchak* (Tib. *lag bcag*).[40] With these tools the *arga* is crushed

---

[35] The use of rollers is also known for the preparation of European terrazzo, in particular for grain sizes between 1.5 cm and 2.5 cm (Eltgen 2004: 450).

[36] Choe Phuntsog mentions that pieces of *arga* of a size of about 5 cm are thrown onto the layer of clay after it has dried out. This statement contradicts the author's observation at the Jokhang in Lhasa where the *arga* was thrown onto a still humid and flattened layer of clay. Further, according to Phuntsog, the stones are crushed into pieces of a size of about 3 cm (Feiglstorfer 2002: 7; Feiglstorfer 2012: 17).

[37] Today, the water flows through a pipe and can be poured onto the roof at any time in big amounts. Watering starts already during the first steps as soon as the *arga* stones cover the roof. Contrary to this procedure, the explanation of Choe Phuntsog refers to earlier days when water was not that easily available. In his description (Feiglstorfer 2002: 7; Feiglstorfer 2012: 17), water is poured onto the roof after three days of ramming and crushing from about 5 cm in diameter to about 3 cm, which in today's working process is the starting size. This may also be the reason for why he explains the start of the ramming with the drying of the first layer of clay, which makes the process of crushing more efficient. During this process fine filling material is produced.

Observations conducted by the author are in contrast to this description: This subconstruction of clay becomes wet and soft, and is thus easily mixed with the *arga* stones from above. Alexander (2011: 71) also describes the pounding of the first layer of *arga* into a wet pulp by constantly adding water. In this regard, for an *arga* construction, we also have to emphasise the availability of a large amount of water, which makes being in close vicinity to a water source − river or spring – necessary.

[38] Dates are given according to the Tibetan calendar.

[39] Wiebeking (1826: 217) mentions for the compression of a *terrazzo* (in Venice known as *composto terrazzo marmorino*, in Naples known as *Lastrico*) the use of an iron tool, the so-called *Eisenschlägel*.

[40] Either *arga* was laid in areas or cracks are stitched by replacing the loose material with fresh *arga* and combining it by ramming with the old surface. Alexander (2011: 71) describes the ramming of new layers of *arga* upon older layers, resulting in a thickness of roof constructions of more than one metre.

Fig. 20.3 Lhasa. Gyüme Dratsang. *Bogdo* left during a working break.

Fig. 21.3 Gyüme Dratsang. Preparing the attics with a *lakchak* and smoothing with stones.

into smaller pieces until the surface is compact and smooth. During this process water is continuously poured onto the stones until the roof is fully saturated. At this point the water starts to be pressed above the upper surface of the smoothened roof level. This process lasts approximately ten days and sometimes even longer. The last steps involve ramming along corners, channellings and drainage holes (Fig. 24.3). So as not to dry too fast and thus to avoid cracks due to shrinkage, the surface is either covered directly before each working-break or parts of the whole roof are covered with a tent construction (see Fig. 25.3). Keeping the roof humid makes the continuation of the working process less labour intense.

At religious sites in earlier days, monks were involved in the whole construction process. The workers at the Gyüme Dratsang had their origin in Phenpo. Working on the *arga* team means an additional income besides other activities, primarily farming. The time it takes to construct the roof depends on their naturally determined working periods. The making of an *arga* roof requires

Fig. 22.3 Lhasa. Gyüme Dratsang. Preparing the attic with a *lakchak*.

Fig. 23.3 Lhasa. Jokhang. Stitching cracks in the *arga* roof with a *lakchak*.

Fig. 24.3 Lhasa. Gyüme Dratsang. Preparing corners separately with wood block and hammer.

Fig. 25.3 Lhasa. Gyüme Dratsang. Ramming accompanied by *arshe* and the rhytm of the *bogdo*.

a working-collective. In a wider cultural context, these working collectives are the social basis in upholding this kind of building tradition. At this site the head of such a team and finally a keeper of the knowledge is the *zhépön* (Tib. *gzhas dpon*).[41] He is aware of all the steps during the whole building process. He controls the quality, pays the wages to the workers, and knows precisely about the whole time schedule. Every year he works on several such projects, starting in spring till autumn. In 2014 he conducted four monastic *arga* building sites. Due to his overview, the working conditions allow for a stress free procedure, including social conducts and families with children on the site. The ramming process is accompanied by songs, the so called *arshe* (Tib. *ar gzhas*). As an antiphony, two groups of workers alternate singing. After several minutes the workers repeat parts of the song and rotate by 90°. The rhythm is given by the ramming tool, the *bogdo*.[42] Ramming is conducted in two groups by following the rhythm − this division and also the changing of the moves not only support the reduction of the load on the subconstruction below, but also the treatment of each spot on the roof from a different side.

---

[41] According to Alexander (2011: 66) the head carpenter and the master mason worked as a close team for the whole working process, and a third master artisan, the *zhépön,* oversaw the whole working process. AN: Such separation between master mason and *zhépön* was also the case at the Gyüme Dratsang. A master carpenter was not present since the plan of the whole building was already implemented and the aim of this working process was conservation without using any timber work.

[42] *Arshe* can be assigned to the group of working songs (Grothmann 2011: 36) and oral poetry (ibid. 6). Today the texts are reduced to secular topics, also including variations of popular songs. A few texts were related to building construction, and others were influenced by Tibetan theatre and its literary sources; others referred to structures of society and family, and to the living environment and nature in regard to its vertically tripartite structure (ibid. 149, 150). A mentioning in the songs of single parts of the body was mainly related to religious sources and some songs refer to particular religious sites (Grothmann 2011; according to Grothmann mentioned in Feiglstorfer 2016).

Fig. 26.3 Lhasa. Gyüme Dratsang. Smoothening the attics by burnishing with stones.

Fig. 27.3 Lhasa. Gyüme Dratsang. For smoothening each worker has own preferences in size and form of the polishing stone.

### 1.3.2 Smoothing and burnishing

As soon as the ramming process is finished, the smoothing process (Tib. *’phyid brdar*) starts. Uneven spots are evened with trowels and stones (Fig. 26.3, Fig. 27.3).[43] Remaining material is collected and used for filling cracks along the wall and for smoothing the shape of the drainage on the roof leading into the sprout (Tib. *wa kha*) (Fig. 28.3, Fig. 29.3). The ramming of a slope along the roof is important for the drains. In contrast to earth roofs, this slope remains over time and is not diminished by water or wind erosion.

Fig. 28.3 Lhasa. Gyüme Dratsang. Corners and sprouts are rammed and smoothed last.

Fig. 29.3 Lhasa. Gyüme Dratsang. A water proof sprout after finishing the upper surface.

---

[43] As we know from Western artificial methods, the effort to burnish a terrazzo by hand depends on its workability, which relies on its hardness. In Europe this hardness changed with the introduction of burnishing machines at the beginning of the 20th century (Müller 2002: 31). For this reason, limestone or marble was preferred.

Fig. 30.3 Uru Katsel. Polishing stones used for wall plasters.

Fig. 31.3 Lhasa. Gyüme Dratsang. Protecting the moistened attics against the sun.

This work goes hand in hand with another time consuming process: the burnishing of the surface. With stones of different size, shape and roughness, the semi-dry surface is rubbed shiny and smooth (see Fig. 27.3). The stones used for burnishing are called *ürti* (Tib. *dbur ti*), a word deriving from ironing.[44] To keep the humidity on the surface during this process, small water bottles are used – or one spits on the particular spot. This burnishing-method is traditionally also applied for wall plasters, for instance, as a sub-layer for wall paintings. In the Uru Katsel (Tib. Dbu ru Ka rtsal) Temple, which is located close to Medrogonkar, the traditional method of smoothening a plastered wall before the application of a ground layer for wall paintings was conducted (Fig. 30.3). Women were standing in a row along the wall with stones of different sizes in their hands and burnishing the surface of the plaster.

The *arga* method enables a homogenous and seamless surface over the whole roof. It can be described as similar to the traditionally handmade technique of terrazzo, which has been around since ancient times. The striking difference to the Western terrazzo tradition is the reduction of used materials to only stone, clay and water for the *arga* and the clay layer below, and the lack of additionally used binders, like cement or hydraulic lime.[45]

---

[44] Wiebeking (1826: 218) mentions for the burnishing of a Venetian *terrazzo* the use of sandstone and whetstone.

[45] Additionally, early European mentioning of terrazzo techniques are given as juxtaposition to the Tibetan *arga* technique. Vitruvius describes the preparation of the floor of a *triclinium* (“refectory”): “… after the bottom is well rammed, a pavement of rubbish or potsherds is spread over it, with a declivity towards the holes of the drain. A composition of pounded coals, lime, sand, and ashes, is mixed up and spread there over, half a foot in thickness, perfectly smooth and level. The surface being then rubbed with stone, it has the appearance of a black pavement. Thus, at their banquets, the liquor that is spilt, and the expectoration which falls on it, immediately dry up; and the persons who wait on the guests, though barefooted, do not suffer from cold on this sort of pavement.” Markus Vitruvius Pollio: de Architectura, Book VII, chapter 4, paragraph 5, translation and Latin version in: http://penelope.uchicago.edu/Thayer/E/Roman/Texts/Vitruvius/7*.html (access: 2015-09-08).

This method also known as *opus signium* (Ger. *Scherbenestrich*) describes a waterproof screed following a Roman version. It follows the knowledge on *opus cementitium* using stones, sand, limestone and pozzolana. The Greek version is known without the use of pozzolana but calcite as a binder, as described by Plinius (Keber 1865: 46).

Fig. 32.3 Lhasa. Gyüme Dratsang. *Yombog* trees growing in the courtyard of the monastery.

Fig. 33.3 Lhasa. Gyüme Dratsang. The leaves of the *yombog* tree.

Fig. 34.3 Lhasa. Gyüme Dratsang The bark of the *yombog* tree.

Fig. 35.3 Lhasa. Gyüme Dratsang. A sirup-like doughly liquid remains for impregnating the roof.

---

Plinius describes a concrete-like mass of lime, sand and crushed potsherds or gravel (Fink et al. 2007). Eidenbenz et al. (2010: 62) differentiate between the Roman and the Greek version of a cast masonry (Ger. *Gussmauerwerk*) by the advanced Roman method in using pozzolana versus the Greek method in using simple lime as a binder. This Greek technique correlates with the *arga* roof technique in Tibet where also only calcite and no hydraulic additive was used (AN).

Eltgen (2004: 450; according to Müller 2002: 91) differentiates between three kinds of terrazzo according to the grain size of aggregates, the "mosaique" (1.5 to 2.5 cm), the "terrazzo" (0.5 to 1.5 cm) and the "granito" (<0.5 cm), and mentions the most used version being a mixture of two grain sizes. AN: In comparison, we also find the use of different grain sizes for the *arga* method. For the Roman technique, Eltgen (2004: 448) describes a mixture of trass and calcite. A terrazzo is known as a screed made of coloured cement and additives of limestone and marble. In the Encyclopaedic Dictionary of Archaeology (Kipfer 2000), an *opus signium* is described as a kind of waterproof floor (e.g. for bathrooms) and is produced by mixing lime mortar with an aggregate of coarse pieces of broken terracotta, following Vitruvius about 30 BCE.

Fig. 36.3 Lhasa. Gyüme Dratsang. Renewing the old concrete floor with *arga*.

After burnishing, the surface is covered to prevent too quick drying, and made ready for the next step (Fig. 31.3). According to Eltgen (2004: 450) the western terrazzo was historically compressed with a beater (Ger. *Patscher*) and a ramming tool along the corners. Afterwards, the aggregates were sprinkled and rolled into the screed. This method was primarily used for the so called *mosaique-terrazzo* (ibid.).

The bark of the *yombog* (Tib. *yom 'bog*), the elm tree, which is often planted in monasteries (Fig. 32.3, Fig. 33.3, Fig. 34.3), is cut in stripes of a width of about 1 cm to 2 cm. Next it is stired in a pot of water till a syrup-like doughy liquid remains.[46] In former days it was also used for washing hair and carpets. Boiling is not crucial but increases quality, as was explained by the master mason. With brooms the *yombog* is applied over the whole *arga* three times, each time following a semidry stage of the layer before (Fig. 35.3). After the third course, it is again covered with one or two further layers of conventional oil, the *num* (Tib. *snum*).[47]

In Khorchag in West Tibet, mustard (Tib. *yung dkar*)[48] seeds were explained as the basis for the oil used for sealing an *arga* roof. In general, this surface treatment guarantees a smooth and waterproof surface and accentuates the terrazzo-like surface-structure. The longer the working process, the more this structure becomes evident. For Ladakh, Lama Jamyang from Saspol describes a kind of a "shampoo" as being applied to the surface of the floor which afterwards is polished

---

[46] According to Wiebeking (1826: 218) the Venetian *terrazzo* is finally soaked with hot lineseed oil.

[47] In an interview with Choe Phuntsog, he describes the use of oil of the sunflower, which is mixed with *yombok* and cooked in the oil of rapeseed. Sunflower is described as also being used for the floor's treatment in the interior (Feiglstorfer 2002: 7; Feiglstorfer 2012: 17). Instead of the use of oil (Tib. *snum*), Larsen and Sinding-Larsen (2001: 47) describe the use of a resin known as *pökar* (Tib. *spos dkar*), which is added several times. According to Grothmann (2011: 23), it is described as a mixture of *pökar* and *canola* oil (Tib. *spos dkar snum*).

[48] Phuntsog describes the use of this oil as a high quality solution which is mixed with pine resin at the rate of 2/3:1/3 (Feiglstorfer 2002: 7; Feiglstorfer 2012: 17). In a restoration report by the Shalu Association, the following description is given: "[…] and two more coats of mustard oil will be rubbed in over the next couple of months" (Shalu Association, 2002).

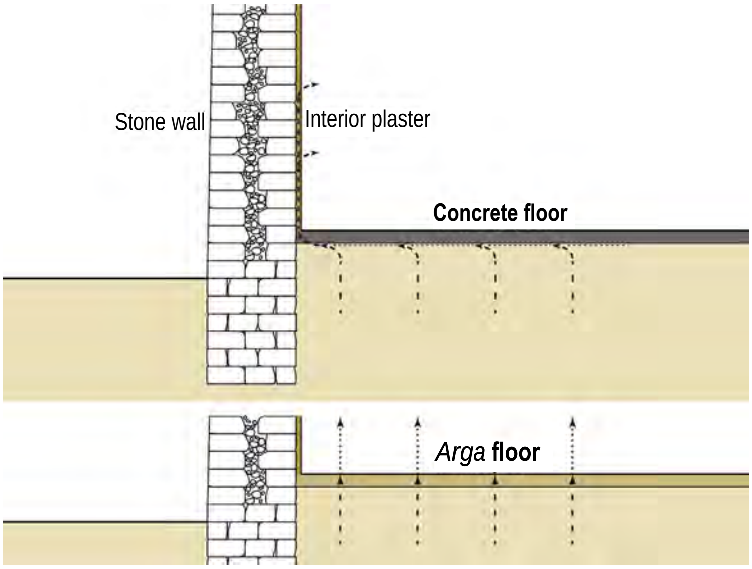


Fig. 37.3 Comparison between *arga* floors and concrete floors regarding the water transport in floors and adjoining walls.
Top: Concrete floor.
Below: *Arga* floor

with a piece of cloth. *Sarzung* oil (Hindi *sarzung tel*) is mixed with *pökar,* which is picked from a tree. *Pökar* is available, for example, in the bazaar of Leh for use during a *puja,* particularly in a *gönkhang* (protector's chapel). It is heated till the mixture is fluent and soft. *Tsalay,*[49] which he describes as looking like glaze for pottery, is heated over a fire, increasing its volume. This substance is crushed with stones and added to the mentioned mixture containing *sarzung* and *pökar*. After the *arga* floor has been dried out, this final mixture is added to the surface using a textile. To make the floor shinier, the wax of candles is applied onto the surface and textiles are used for polishing the floor with the feet.

Returning to the roof of the Gyüme Dratsang in Lhasa, after the drying of the oil, the protecting tent-structure is removed, the roof is cleaned and the prayer flags and victory banners fixed on their original spot. Besides the roof construction, additional maintenance-work is conducted, for example, renewing the *penbey* fries along the eaves.

### 1.3.3 Today's meaning of an *arga* roof

Nowadays, the tradition of making an *arga* roof is primarily kept alive with the need to conserve existing Tibetan floors and roofs. At the time of research in the Gyüme Dratsang, the whole concrete floor in the *tsangkhang* (*cella*) in the ground floor had been removed to be renewed by a traditional *arga* floor, as it had existed in earlier days before being replaced by concrete (Fig. 36.3). Over the last decades, traditional knowledge had been neglected and replaced by modern materials, such as concrete. Concrete floors are not open to vapour diffusion but act as a moisture barrier layer against the humidity below (Fig. 37.3). Over the years humidity finds its way via a capillary transport into the walls along foundations and the ground touching area. This humidity results in continuous damage of the surface and further of the structure of the walls.

---

[49] *Tsalay* has as of yet to be identified and will be a matter for future research.

## 2. RESEARCH QUESTIONS

The generally posed research questions as given in the Introduction are adjusted to the research topic of Chapter II and related to specific material properties and traditions of *arga's* use as a building material in the following way:

- Research question 1: Are there any material qualities to categorise *arga*?
- Research question 2: Are the particular material qualities related to specific regions?
- Research question 3: What are the material qualities that support *arga's* use for particular building purposes?

In the following, the mineral properties of the samples will be tested. Physical qualities will also be tested. Specifically, the hardness of the *arga* stone will be determined using a point load test, and the hardness of the surface according to Vickers will be determined in a wet and in a dry state. At first the collected samples will be analysed according to their origin and local use, their grain size distribution and grain shapes, the related bulk and clay mineralogy, the content of calcite according to Scheibler or based on simultaneous thermal analysis. Results of the analysis will be juxtaposed. Further on, material properties will be examined regarding the hardness of samples using the point load test, and the surface of burnished and unburnished samples will be examined with the Vickers needle test in a dry and also moistened state.

Examination of samples follows a geographic order from east to west (Central Tibet – West Tibet – Ladakh – Zangskar) and contains the following samples:

- Central Tibet: 11078, 14765, 15370 (Lhasa Jokhang); 14766 (Lhasa Gyüme Dratsang)
- West Tibet: 15372 (Khorchag)
- Ladakh: 11953 (Mangyu)
- Zangskar: 8473 (Phugtal)

## 3. ORIGIN OF THE SAMPLES

The samples originate from different sites in Central Tibet (Lhasa) and the Western Himalayas (West Tibet, Ladakh, Zangskar), according to which the following categorisation was defined (see Map 1.3). According to Table 2.3, material from the following sites will be examined:

- Lhasa – Jokhang; from conservation work on the temple's roof
- Lhasa – Gyüme Dratsang; from conservation work on the temple's roof
- Khorchag – Monastery; from *arga* stored in the courtyard and used for conservation
- Mangyu – clay pit
- Phugtal – clay pit

Table 2.3 List of the samples.

| Sample | Country | Province | Valley | Settlement | Location | Local name |
|---|---|---|---|---|---|---|
| **Lhasa – Jokhang** | | | | | | |
| 11078 | China | Lhasa | Tsangpo | Lhasa | raw material | *arga* |
| 14765 | China | Lhasa | Tsangpo | Lhasa | raw material | *arga* |
| 15370 | China | Lhasa | Tsangpo | Lhasa | raw material | *arga* |
| **Lhasa – Gyüme Dratsang** | | | | | | |
| 14766 | China | Lhasa | Tsangpo | Lhasa | raw material | *arga* |
| **Khorchag – Monastery** | | | | | | |
| 15372 | China | Ngari | Peacock | Khorchag | raw material | *arga* |
| **Mangyu – mining pit** | | | | | | |
| 11953 | India | Ladakh | | Mangyu | clay pit | *arga* |
| **Phugtal – mining pit** | | | | | | |
| 8473 | India | Zangskar | Zangskar | Phugtal | clay pit | *arga* |

# 4. MINERAL ANALYSIS

## 4.1 Central Tibet

### LHASA JOKHANG. SAMPLE 11078

#### Sampling point

Lhasa, roof of the Jokhang during renovation, located at app. 29°39’11.02”N, 91°7’55.35”E (Map 2.2).[50] The material was available as loose stones (Fig. 38.3). Constructive use: *Arga* roof construction. This material was used during the renovation of the roof of the Jokhang in 2010 (see Fig. 15.3 and Fig. 16.3).

Map 2.3 Lhasa. Location of the Jokhang and the Gyüme Dratsang.
Source: Google Earth. © 2015 Image Digital Globe.

Fig. 38.3 Lhasa. Sample 11078. Sample colour (after Munsell): 10YR8/1 white with a tendency towards greyish brown as a single piece when not ground.

---

[50] In gratitude to Christiane Kalantari for collecting the material.

### Bulk mineral analysis

Silicates (mica, 7Å minerals, phyllo silicates, quartz, feldspar and plagioclase) are available in small amounts (marked in Table 3.3 with (*)). 14Å minerals and amphiboles are available as traces (marked in Table 3.3 with (.)). K-feldspar is available in a medium amount (marked in Table 3.3 with (**)). A relatively high amount of goethite is available. The content of calcite was measured with 46%.[51] This stone did not carry enough loose material to sieve or result in a representative cumulative curve.

### Results measured with STA

- The content of calcite was measured at 46%.
- The residual mass at 1,000°C is 76.14%.

### Clay mineral analysis

Although the fine material resting on the *arga* stone was not enough to define its grain size distribution, a CMA could be conducted.

On the ceramic plate coated with a <2 µm fraction of magnesium (Mg), the CMA shows several peaks pointing towards the content of smectite + chlorite, illite and chlorite + kaolinite − shown with curve *ke* (Fig. 39.3). On the ceramic plate coated with a <2 µm fraction of potassium (K), the smectite + chlorite peak separates into two peaks: a smectite-peak shifting towards left and a chlorite-peak remaining at the same position as with Mg – shown with curve *k*.

On the ceramic plate coated with a <2 µm fraction accumulated with dimethyl sulfoxide (DMSO), the smectite peak moves further left, while the primary chlorite and the illite peak remain in the same position – shown with curve *d*. A small peak between the chlorite peak and the illite peak points towards the content of a well crystallised kaolinite. The <2 µm fraction annealed at 550°C shows the chlorite and illite peaks in the same position as at the DMSO-plate – shown with curve of *mt5*. Since the peaks were relatively weak, the CMA of the sample was juxtaposed with the CMA of the sample after its treatment with acetate (Fig. 40.3). The CMA shows the magnesium (Mg) peak – with curve *m* juxtaposed to the magnesium curve treated with acetate – with curve *ac-m*. The result shows the peaks at the same position, just with a much higher intensity for the acetate treated sample. The magnesium (Mg) + ethylene ($CH_2$)-peak – shown with curve *me* – was juxtaposed to the magnesium + ethylene-curve treated with acetate – shown with curve *ac-me*. The result shows, similar to the juxtaposition of curves *m* and *ac-m,* the peaks remaining at the same position, just with a much higher intensity at the acetate treated sample.

---

[51] According to Alexander 2011, fn. 135: *Arga* is described as micrite, a sedimentary rock consisting of fossil materials (usually shell fragments) and small particles of other rocks, cemented together with calcite.

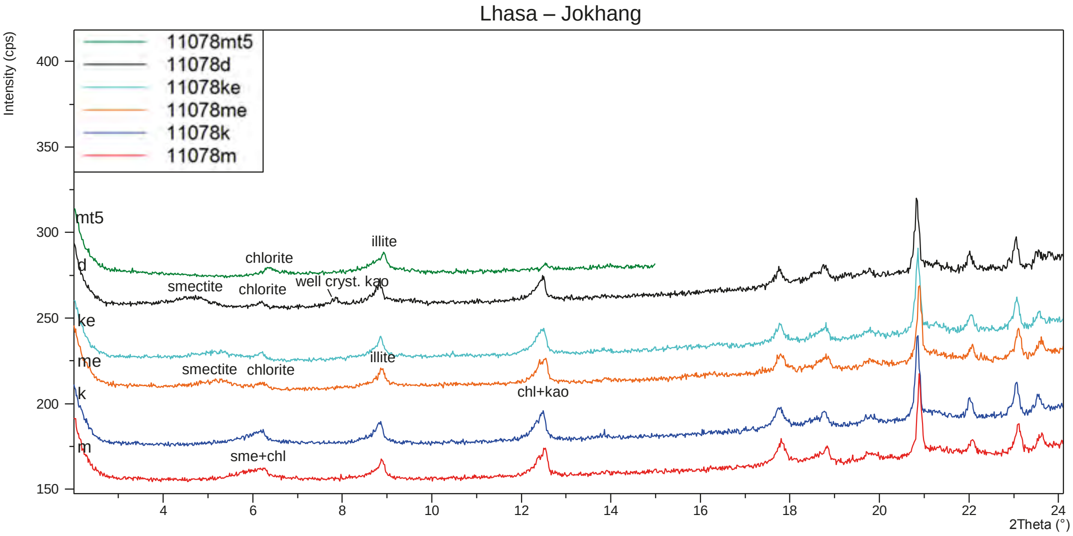


Fig. 39.3 Sample 11078. CMA without using acetate.

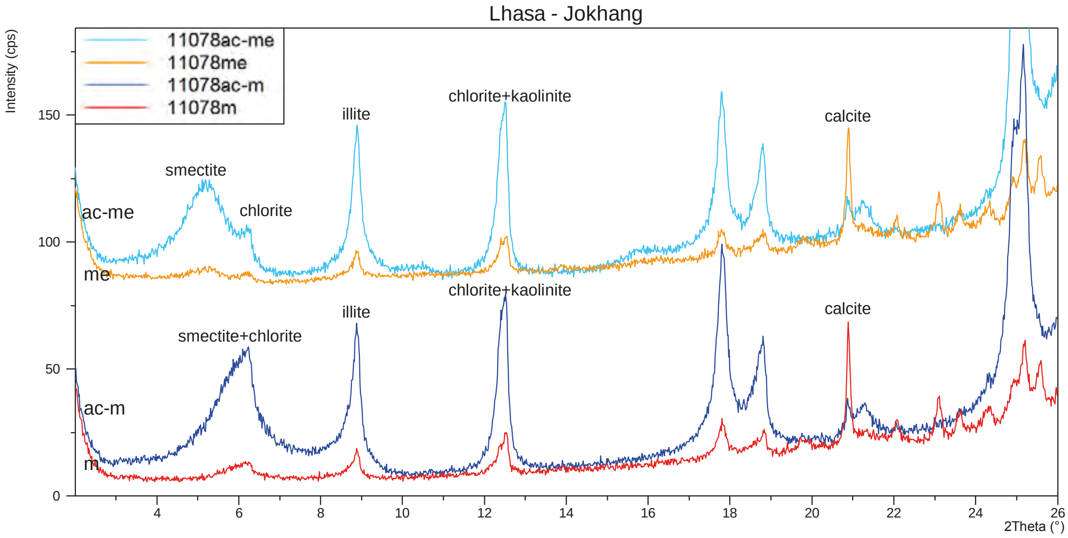


Fig. 40.3 Sample 11078. CMA. Juxtaposition of the sample with and without using acetate.

## Lhasa Jokhang. Sample 15370

### Sampling point

Lhasa, roof of the Jokhang during renovation. The material was available as loose stones. Sample number in the field: 5. Constructive use: A*rga* roof construction. At the time of field research at Lhasa in 2010, this material was used for repairing the rounded top of attics on roofs.

### Bulk and clay mineral analysis

Although the material was collected in the same year from the same roof, the BMA results of these two samples differ much. This points towards different quarries for both materials. In contrast to sample 11078, no mica, amphiboles, 7Å minerals or phyllo silicates could be detected. Quartz and plagioclase appear as traces while for sample 11078 they are available in small amounts. In sample 15370, K-feldspar appears as traces while in sample 11078 it is available in a medium amount. The only minerals which appear in a similar amount – in this case as traces – are the 14Å minerals. The content of calcite was measured at 75%. This stone did not carry enough loose material to sieve and to result in a representative cumulative curve or CMA.

## Lhasa Jokhang. Sample 14765

### Sampling point

Lhasa, roof of the Jokhang during renovation. In 2014, on site workers gave the material, which was stored in plastic bags on an intermediate floor, to the author. The material was available as loose stones. Constructive use: *Arga* roof construction. Used in 2014 during the renovation of the roof, primarily for repairing cracks. The sample colour is in a dry state after grinding light yellowish brown, similar to samples 15370 and 11078 (Fig. 41.3).

Fig. 41.3 Lhasa. Sample 14765. Colour after Munsell: 10YR6/4 light yellowish brown.

### Bulk mineral analysis

This sample shows similarities to sample 11078. 14Å minerals, mica, amphiboles, 7Å minerals, phyllo silicates, quartz, K-feldspar and plagioclase are available similar to sample 11078 but all just in trace amounts. Silicates (mica, 7Å minerals, phyllo silicates, quartz, feldspar and plagioclase) are available in small amounts (marked in Table 3.3 with (*)). 14Å minerals and amphiboles are available as traces (marked in Table 3.3 with (.)). K-feldspar is available in a medium amount (marked in Table 3.3 with (**)). At 50% the content of calcite, along with sample 11078 at 40%, is the smallest rate within the examined *arga* samples. This stone did not carry enough fine material to sieve and result in a representative cumulative curve.

### Results measured with STA

- The content of calcite was measured at 50%.
- The residual mass at 1,000°C is 72.80%.

### Clay mineral analysis

Although the fine material resting on the *arga* stone was not enough to define its grain size distribution, a CMA could be conducted. On the ceramic plate coated with a <2 µm fraction of magnesium (Mg), the CMA (Fig. 42.3) shows several peaks pointing towards the content of chlorite, illite and poorly chrystallised kaolinite − shown with curve *m*. The course of the magnesium (Mg) + ethylene ($CH_2$)-curve – shown with curve *me* – is very similar. Since the peaks were relatively weak, the CMA of the sample was juxtaposed with the CMA of the sample after treatment with acetate. The related magnesium (Mg) curve – shown with *ac-m* – as well as the ethylene ($CH_2$)-curve – shown with *ac-me* – show a similar course to the curves *m* and *me*, just with a stronger intensity of the peaks, similar to sample 1078. The chlorite is available in a secondary form and the kaolinite as poorly crystallised.

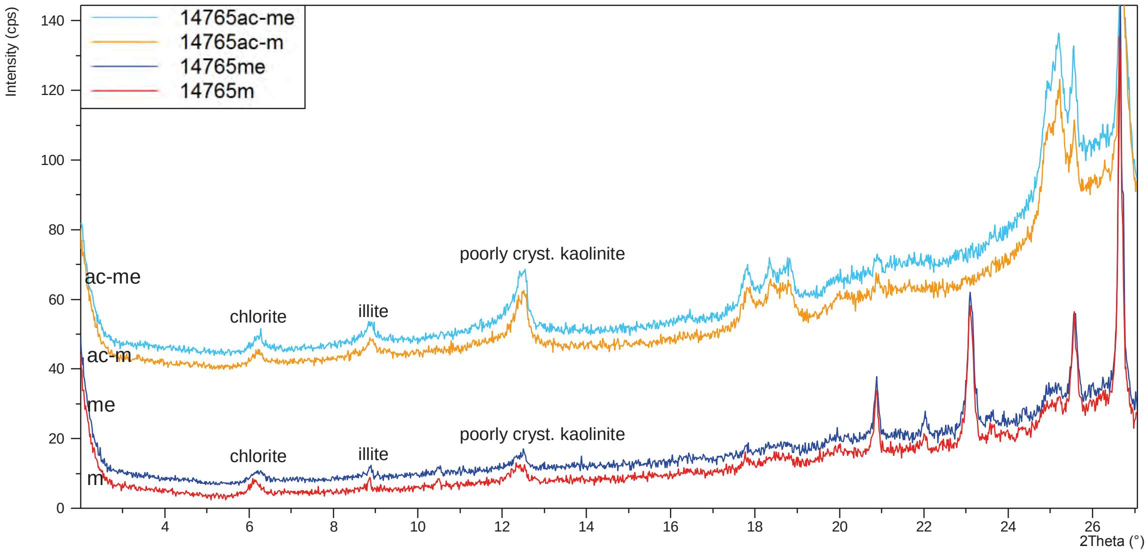


Fig. 42.3 CMA. Sample 14765 compared with the sample treated with acetate.

## LHASA GYÜMED DRATSANG. SAMPLE 14766

### Sampling point

Lhasa, roof of the Gyümed Dratsang during renovation. Workers gave this material to the author, which was stored in big hips in the courtyard (Fig. 43.3). The courtyard was covered by a tarpaulin. Here, the workers collected the material and carried it on wooden back carriers up to the roof. Sieves were used to separate the material from impurities. Constructive use: *Arga* roof construction. The material was used during the renovation of the whole roof in 2014. The sample is light yellowish brown, similar to the samples used at the Lhasa Jokhang: 11078, 15370 and 14765.

Fig. 43.3 Lhasa. Sample 14766. Sample colour (after Munsell): 10YR6/4 light yellowish brown.

### Gran size distribution

The material is coarse and rather easy to break by hand. Biggest fraction: fine gravel. The median is located at app. 108 µm; the <2 µm fraction contains app. 14% of the whole sample. At 62.4% the amount of coarse material (gravel + sand) is relatively high. The maximum peaks lie at the sand fractions. A bimodal distribution is given by a small valley in the grain size distribution curve between coarse silt and fine silt. A mixture with sand or another type of clay can be excluded since this sample was directly taken from a heap of stones.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 14766 | 1.3 | 61.1 | 23.3 | 14.3 |

### Bulk mineral analysis

This sample shows strong similarities to sample 14765 from the roof of the Jokhang collected in spring 2010 but is contrary to samples 11078 and 15370. Its similarity to sample 14765 is given by 14Å minerals, mica, amphiboles, 7Å minerals, phyllo silicates, quartz, K-feldspar and plagioclase, which are available as traces. At 62% the content of calcite is high. The mineral content besides calcite is available in traces and in a poorly crystallised form.

### Results measured with STA

- The content of calcite was measured at 62%.
- The residual mass at 1,000°C is 67.96%.

### Clay mineral analysis

Since the peaks are relatively weak, the CMA of the sample was juxtaposed with the CMA of the sample after treatment with acetate. On the ceramic plate coated with a <2 µm fraction with magnesium (Mg), results of the CMA (Fig. 44.3) show several peaks pointing towards the content of smectite + chlorite, illite and chlorite + kaolinite − shown with curve *ac-m*. The magnesium (Mg) + ethylene (CH$_2$)-peak – shown with curve *ac-me* − was juxtaposed to the pure magnesium (Mg)-curve. The result shows the moving of the smectite-peak to the left and all the other peaks for chlorite, illite and kaolinite remaining in the same position. The <2 µm fraction annealed at 550°C and shows the chlorite peak remaining in the same position – indicated by curve *mt5*. Since the kaolinite-peak is reduced to traces, the chlorite appears as primary. The elevated and softly increasing curve between the chlorite peak and the illite peak points towards the existence of a mixed layer. The clay mineral fraction also contains a small amount of hornblende. Since the calcite peak is rather high, no clear statement can be given regarding swellable clay minerals.

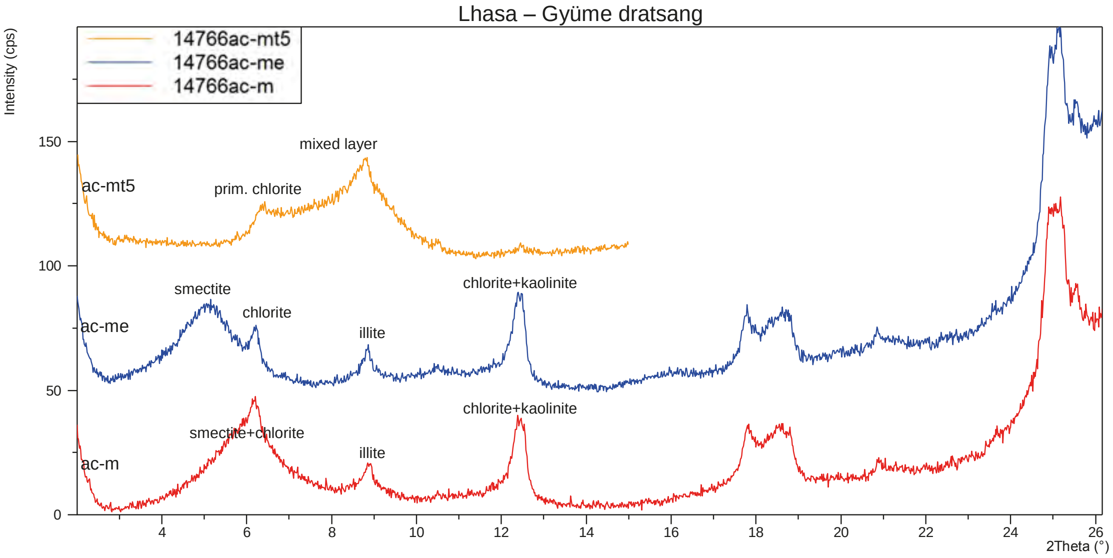


Fig. 44.3 Sample 14766. CMA of the sample treated with acetate.

## 4.2 West Tibet

### KHORCHAG MONASTERY. SAMPLE 15372

#### Sampling point

Khorchag Monastery, stored in the courtyard. At the time of research at the Khorchag Monastery in 2010, the material was prepared for further use as big blocks in the courtyard of the monastery. The roof of the monastery was prepared with this material but was in a rather bad condition. The very fine upper layer had cracked and detached. Samples of mustard seed were given to the author, and they are still used for the preparation of mustard-oil for covering the *arga* surface. The *arga* material was available as a big breccia. The detached layer appeared similar to the damage on the roof of the Serzang Lhakhang in Basgo (Figs. 45.3, 46.3). Fine layers of a thickness of less than 1 mm detached from the roof and opened it to further damage; in particular, humidity seeped into the un-protected *arga* construction, and congelifraction occurred as a further damage scenario. These damages are the result of negligence and a lack of maintenance, both of which are visible by its dull appearance. Furthermore, the protecting layers of oil seem to have been made of an improper quality, and reapplication of this oil in a shorter amount of time would be necessary. In contrast, the *arga* floor which was made in the Jokhang of Khorchag, was well maintained. It

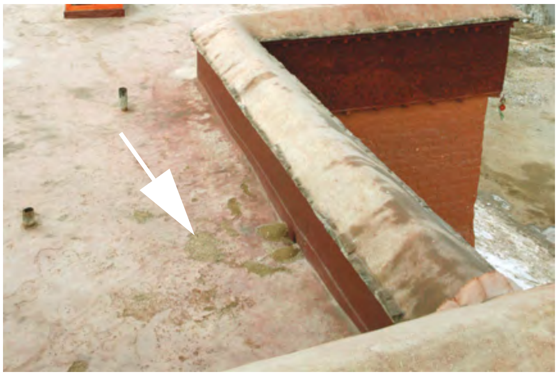


Fig. 45.3 (Top, left) Basgo. Ladakh. Serzang Lhakhang and Fig. 46.3 (Top, right) Khorchag. Ngari. Lhakhang Chenmo. Demage: Both examples showing a detaching of the upper layer of the *arga* surface.
Fig. 47.3 (Bottom, left) Khorchang. Jokhang. Lhakhang on the roof terrace. After oiling the new *arga* floor.
Fig. 48.3 (Bottom, right) Khorchang. Lhakhang Chenmo. Storage room. Ceiling with view into the *arga* subconstruction.

was shiny and in rather good condition. Close to the entrance gate, coloured stones were laid into the *arga* floor. A new glass room on the roof of the Jokhang was erected with a new *arga* floor, and at the time of research, oil was applied onto the new floor in such a large amount that puddles remained for several hours and kept the roof sticky for some days (Fig. 47.3). At some spots inside the Lhakhang Chenmo, which is one of the two temples of the Khorchag Monastery, insight into the ceiling construction from below was possible. For instance, in the storage room located close to the entrance – one could find the bottom of the *arga* roof covered by flat stones, and then again covered with a bamboo mat which was laid on wooden sticks and branches (Fig. 48.3). Sample number in the field: 7. Constructive use: *Arga* roof construction. Collected in 2010. Used for the roof. The brownish colour is similar to what was examined for previously analysed samples (Fig. 49.3). The sample colour in a dry state after grinding is very pale brown.

Fig. 49.3 Khorchag. Sample 15372.
Sample colour (after Munsell): 10YR8/2 very pale brown.

Fig. 50.3 (Left) Mangyu. Mountain slope behind the monastery showing the path towards the *arga* deposit in front left.
Fig. 51.3 (Right) Mangyu. A*rga* deposit.

## 4.3 Ladakh

### Mangyu quarry. Sample 11953

#### Sampling point

Mangyu, uphill several dozen metres behind the monastery, located app. at 34°14'0.34"N, 77° 2'54.64"E (Fig. 50.3, Fig. 51.3). The material was collected by a local worker who was engaged at the temple conservation in 2011. The material is available as breccia (Fig. 52.3). Sample number in the field: 54. Constructive use: Locally known as material for *arga* roof constructions.

#### Bulk and clay mineral analysis

Fig. 52.3 Mangyu. Sample 11953.

The BMA shows similarities to sample 14765 from the Jokhang in Lhasa and to sample 14766 from the Gyüme Dratsang in Lhasa. Mica, 7Å minerals, phyllo silicates, quartz, K-feldspar and plagioclase are available as traces. 14Å minerals and amphiboles are not available. The content of calcite is 64.2%. This stone did not carry enough 'loose' material to be sieved and to give a representative result of a cumulative curve or CMA.[52]

---

[52] For processing as a roofing material, the *arga* stone is crushed on the building site, which may make the fragments appear as smaller fractions. Therefore, it is only apparently 'loose' material. By crushing in the laboratory, the determination of mineralogy was possible.

Fig. 53.3 (Left) Phugtal. Zangskar. The arrow showing the yellowish shining *arga* deposits.
Fig. 54.3 (Right) Pugtal. A*rga* deposit.

## 4.4 Zangskar

### PHUGTAL QUARRY. SAMPLE 8473

### Sampling point

Phugtal in Zangskar, below the monastery, orange-brown and shiny, located at app. 33°16’2.52”N, 77°10’45.29”E. Available as loose stones along the slope of the foot of the mountain below the monastery (Fig. 53.3, Fig. 54.3). During research in 2005, an elder monk who had stayed in Tibet before he left to India, helped to identify the material as *arga*. In Tibet this material was known for its use for making roofs. When mixing with water, the material is described as becoming hard like rubber. In earlier days it was used in the Phugtal Monastery for making floors. At the time of research, examples of *arga* floors still existed. Several *arga* floors exist in Zangskar. Examples include the floor, which is prepared with *arga,* of the assembly hall in the Sani Monastery close to Padum. Sample number in the field: 1 PH/AR. Constructive use: Construction of an *arga* roof. The material is of an orange-brown colour and appears eye-catching and shiny against the landscape (Fig. 55.3).

Fig. 55.3 Phugtal. Sample 8473. Sample colour (after Munsell): 10YR8/6 yellow.

### Gran size distribution

The material is very coarse. Biggest fraction: fine gravel. The median is located at app. 3,000 µm; the <2 µm fraction contains app. 1% of the whole sample. At 87% the amount of coarse material (gravel + sand) is relatively high. The maximum peak lies at the gravel fraction. The distribution between coarse sand and fine silt is relatively steady and decreases in the clay fraction. The sand and silt fractions show a similar amount.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 8473 | 75.7 | 11.3 | 11.7 | 1.3 |

### Bulk mineral analysis

The BMA shows similarities to sample 11953 from Mangyu. 14Å minerals, amphiboles, 7Å minerals and K-feldspar are not available. Phyllo silicates, quartz, goethite and plagioclase are available as traces and mica as a small amount (marked in Table 3.3 with (*)). At 80.2% the content of calcite is high and similar to sample 11953 from Mangyu. A content of goethite is responsible for the yellow colour, which is not relevant for building purposes. The goethite as a bivalent ferric oxide emphasises the evidence of physical weathering. From far away and at dawn, the orange-yellow appearance is distinctive. During the day and when the sun is shining, the luminous appearance changes towards a brownish colour, similar to what was examined for the other samples.

### Results measured with STA

- The residual mass at 1,000°C is 61.68%.

### Clay mineral analysis

In the CMA this material consists of nearly 100% muscovitic illite with traces of kaolinite and no swellable minerals; the calcite peak, also in the 2 µm fraction, is relatively high.

## 4.5 Results of mineral analysis given in tables

Table 3.3 Bulk mineral analysis.

| Sample | 14Å | Mica | Amph | 7Å | Phy sil | Quar | Goeth | K-fsp | Plagio | Calc | Dol | Haem | Gyps | Pyr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lhasa – Jokhang | | | | | | | | | | | | | | |
| 11078 | . | * | . | * | * | * | --- | ** | * | 46% | --- | --- | --- | --- |
| 14765 | . | . | . | . | . | . | --- | . | . | 50% | --- | --- | --- | --- |
| 15370 | . | --- | --- | --- | --- | . | --- | . | . | 75% | --- | --- | --- | --- |
| Lhasa – Gyüme Dratsang | | | | | | | | | | | | | | |
| 14766 | . | . | . | . | . | . | --- | . | . | 62% | --- | --- | --- | --- |
| Khorchag – Monastery | | | | | | | | | | | | | | |
| 15372 | --- | . | --- | . | . | . | --- | . | . | 64% | --- | --- | --- | --- |
| Mangyu – Clay pit | | | | | | | | | | | | | | |
| 11953 | --- | --- | --- | --- | . | . | --- | ----- | ----- | 80% | --- | --- | --- | --- |
| Phugtal – Clay pit | | | | | | | | | | | | | | |
| 8473 | --- | * | --- | --- | . | . | * | ----- | . | 80% | --- | --- | --- | --- |

Table 4.3 Clay mineral analysis.

| Sample | Smectite | Vermiculite 14Å/18Å | | Illite | Kaolinite | Chlorite | Mixed layer |
|---|---|---|---|---|---|---|---|
| Lhasa – Jokhang | | | | | | | |
| 11078 | 25 | --- | --- | 42 | 8 | 25 (prim.) | --- |
| 14765 | --- | --- | --- | 27 | 5 | 58 (sec.) | --- |
| Lhasa – Gyüme Dratsang | | | | | | | |
| 14766 | 47 | --- | --- | 17 | 7 | 29 (sec.) | available |
| Phugtal | | | | | | | |
| 8473 | --- | --- | --- | 100 | --- | --- | --- |

## 5. Material analysis

### 5.1 The effect of crushing and grinding the *arga* on its crystal structure

The effect of ramming on the *arga* should be simulated with several tests.[53] The question arises of whether there are changes in the crystal structure of involved minerals during crushing: The tests were conducted by grinding one *arga* sample (15370 from the Jokhang in Lhasa) for different periods of time, starting with four minutes, and then extending to 30 minutes, 60 minutes and so on at a 30 minutes frequency up to 10 hours. For a BMA, the 4 min-, 360 min-, 480 min- and 600 min ground material were selected (Fig. 56.3). A comparison of a calcite peak at app. 29.4°θ shows the decrease of its intensity and the widening of its base with an increase of the duration of grinding: the crystal structure is breaking continuously.

After 4 hours:
- The peaks for hornblende, mica and amphiboles start decreasing and the calcite peak decreases.

After 6 hours:
- The content of chlorite disappears.

After 10 hours:
- The quartz remains nearly the same even after 10 hours of grinding. The calcite peak is reduced to about the half size, plagioclase is reduced at a high extent, and mica and chlorite are either no longer available or just as traces.

Regarding the quartz-peak compared with the width of the peak at medium height at app. 29.4°θ

| | | |
|---|---|---|
| · Without grinding: | peak at 1287 cps | width: 0.197° |
| · After 4 min grinding: | peak at 1197 cps | width: 0.185° |
| · After 360 min grinding: | peak at 992 cps | width: 0.169° |
| · After 480 min grinding: | peak at 877 cps | width: 0.220° |
| · After 600 min grinding: | peak at 708 cps | width: 0.251° |

Between no grinding and a grinding time of 10 hours, the calcite peak shrinks down to about half its height and widens. A comparison between the 4 minutes and the 10 hours peaks shows the quartz remaining nearly unchanged while feldspar was drastically reduced. Calcite peaks were reduced in height and widened at their base. Chlorite is completely gone and hornblende remains in trace amounts. At 50°θ and also at 60°θ, quartz starts with its amorphisation.

---

[53] At this point the question is raised as to why the tests have not been conducted at a 1:1 model either built new in the laboratory or translocated from an existing Tibetan *arga* roof. The intention is given and also the need for obtaining further information but due to costs and restrictions, we have yet to be satisfied with a smaller amount of sampling material and dealing with a 1:10 model. Nevertheless, at least this approach allows for insight to be obtained and for further research questions to be precisely formulated.

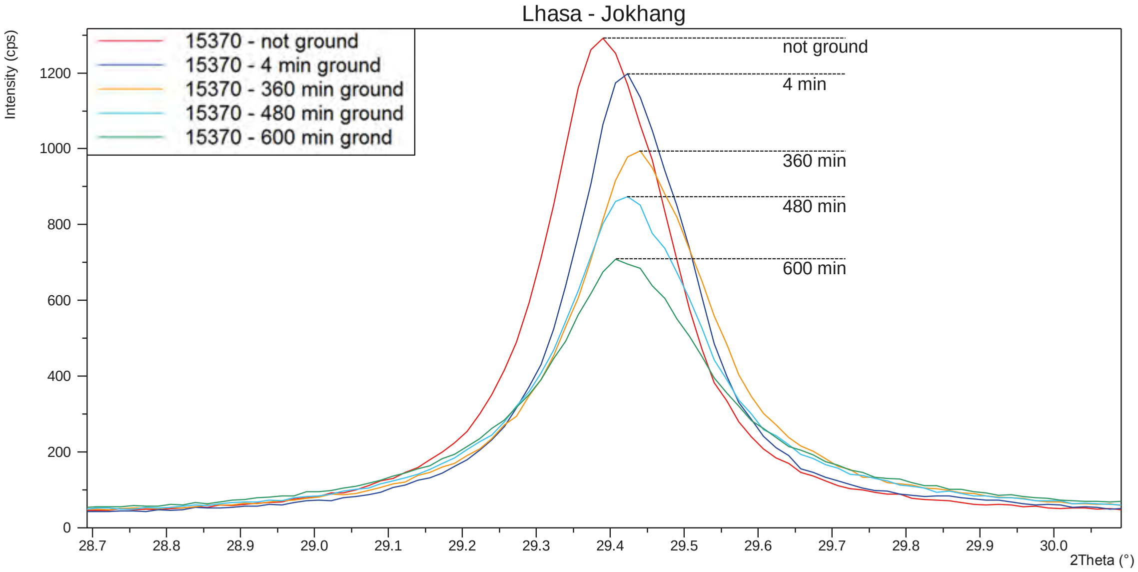


Fig. 56.3 Sample 15370. BMA. Comparison of different periods of grinding.

## 5.2 The *arga* surface

Regarding the matter of the crushing of *arga*, mixing with water and drying at the IAG / BOKU, several test specimens of different mixtures were prepared.[54] To get closer to a practical recipe for treatment and burnishing, a series of tests was conducted. For this reason, original plaster material was also used and samples with a size of 40 x 40 x 10 mm were prepared in a ramming tool, which enabled continuous control by a glass window in the front part (Fig. 57.3).

The first specimen (I) was prepared with pure *arga* (sample 15370) in a ground form (Fig. 58.3). The time of grinding was app. 10 hours. During the drying process, cracks appeared, and in a dry state the sample was broken in several pieces. Polishing was no longer possible. The material is too brittle to test hardness according to Vickers.

The second specimen (II) was prepared using just clay (sample 11947).[55] For the following specimen, this clay was used for the preparation of samples as a carrier of the *arga* surface. In a dry state, the surface was burnished until it started to shine. The material is rather coarse compared to the finely ground powder from specimen (I). It shows a content of 9.3% of fine gravel and 50.9%

---

[54] The size of the test specimens was 40 x 40 x 10 mm (10 mm = height). The size was chosen regarding an efficient preparation of the single samples, and in the following regarding a quick and comparable preparation of the surfaces. Since for the dozens of collected samples, only a limited amount could be transported from the Himalayas to Vienna, the size of the samples had to be chosen with a material-economical aspect. At this point it has to be mentioned that several of the examinations show possibilities for future examinations for which particular raw material will be collected of a necessary and bigger amount.

[55] The used clay was locally described as “clay from the fields” in the surrounding fields without mentioning any further need for specific properties. This approach does not give any evidence for the search for a particular clay, probably with hydraulic properties, especially pozzolanas.

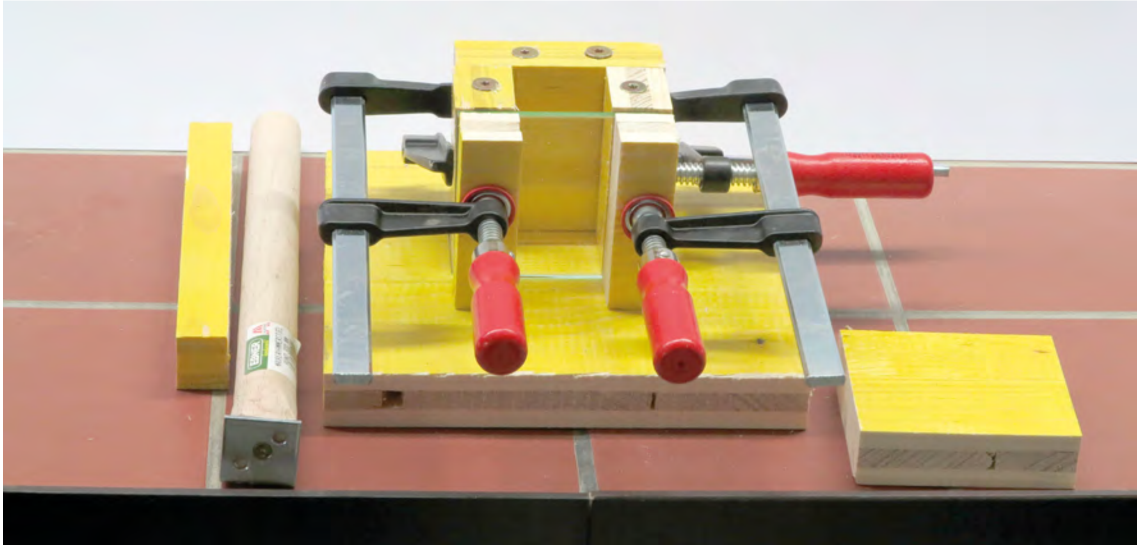


Fig. 57.3 Tool for the compression of samples.

of sand, together equally a content of 60.2% coarse material. The body (except the surface) of the specimen remains soft and can easily change into a fluid consistency when water is added.

Test of the hardness of the surface according to Vickers:

11947 unburnished (Vick 1.3, see Appendix Chapter II)
- applied force 3 kgf;
- diagonals: 1159 µm and 1160 µm;
- 4.14 HD 3 (4.14 kg/mm²); the sample is difficult to measure: the result remains unclear.

For this sample, the previously mentioned fine layer material from Nyarma (Chapter I) was used as the core material for the preparation of the sample. No further covering was necessary (Fig. 59.3). Interestingly the burnishing turned the surface into a brilliant, shining and dark surface (Fig. 60.3).[56] When adding drops of water to the burnished surface, they remained without seeping while when added to the unburnished surface, they seeped away immediately – as we know from loose clay. A first hypothesis is that the content of a particular amount of coarse material – in particular sand – supports the quality of the burnished surface. When burnishing, a certain pressure has to be applied since the specimen breaks easily, in particular along the corners. The hardness of the surface of this sample is by far the highest of all the tested samples, and shows this material mixture as an ideal composition for burnishing.

Test of the hardness of the surface according to Vickers:

11947 burnished (Vick 2.3, see Appendix Chapter II)
- applied force 2.5 kgf;
- diagonals: 504 µm and 458 µm;
- 20.03 HD 2.5 (20.03 kg/mm²); the sample is difficult to measure: the result remains unclear.

---

[56] When burnished, the surface becomes shiny – its appearance becomes comparable to a light greyish sugar icing.

Specimen I:
Fig. 58.3 (Top, left) Sample 15370.
Specimen I. *Arga* powder compressed.

Specimen II:
Fig. 59.3 (Top, right) Sample 11947. Plaster from Nyarma (see Chapter II) unburnished, for comparison.
Fig. 60.3 (Centre) Sample 11947. Plaster from Nyarma (see Chapter II) burnished, for comparison.

Specimen III:
*Arga* ground (15370) and mixed with clay 11947:
Fig. 61.3 (Bottom, left) Sample. Burnished.
Fig. 62.3 (Bottom, right) Sample. Unburnished.

The third specimen (III) was prepared as a mixture of clay (sample 11947) and ground[57] *arga* (used for specimen I). The body of the specimen (III) is relatively hard and by far does not crumble that easily, same as the just-clay specimen. Interestingly, compared with the watered *arga* dust mixture of specimen (I) – which showed strong cracks through the whole body during the process of drying – the specimen (III) did not show any cracks but instead remained a strong block. This mixture already shows that clay and *arga* dust support each other when being mixed. The best time for burnishing turned out to be in a slightly moistened but already leather hard state. When burnished in a too dry state, coarse grains are shifted and the surface scratched; when too wet the surface is too instable and the slurry does not remain in place.

The burnished surface of specimen (III) (Fig. 61.3) appears similar to the one of the burnished specimen (II) compared with the unburnished surface in Fig. 62.3. Compared with specimen (II), higher pressure can be applied without breaking the sample, and the corners remain less broken. During burnishing, the surface is less luting and appears harder. After burnishing it is slightly more reflective than specimen (II). When burnished for a too long period of time, the shining surface tarnishes. This can be repaired by applying a new slurry, filling the small gaps, and repeating burnishing.

Polishing was conducted in several phases:

- 1. Phase for closing unevenness lasted about 45 minutes, where drops of water were continuously added.
- 2. Before finishing, when the surface started to become shiny, it was dried for about five minutes.
- 3. After this treatment, water remained on the surface and did not soak in immediately.

The Vickers needle test will show if there is any difference in the hardness between burnished and unburnished states. For a higher hydrophobic characteristic, this surface is more appropriate for the following addition of oil or other fluids onto the surface. The specimen (II) macerates when adding fluids like oil. With a load of 5 kg, this sample broke, and the load was reduced to 2.5 kg and 1 kg. As the Vickers test shows, the burnishing of the surface increases the hardness of the surface from 1.96 kg/mm² to 3.24 kg/mm².

11947 + 15370 unburnished

- applied force 1 kgf;
- diagonals: 982 µm and 964 µm;
- 1.96 HD 1 (1.96 kg/mm²).

11947 + 15370 burnished (Vick 3.3, see Appendix Chapter II)

- applied force 2.5 kgf;
- diagonals: 1203 µm and 1189 µm;
- 3.24 HD 2.5 (3.24 kg/mm²).

---

[57] The duration of grinding was 10 hours to simulate a long lasting process of a continuous crushing by ramming.

Fig. 63.3 (Left) Sample 15370. Rammed. Specimen II. Bright unburnished part in front.
Fig. 64.3 (Right) Sample 15370. Rammed. Specimen II. Shiny dark burnished parts.

The fourth specimen (IV) was prepared as a 1:10 model of an original *arga* roof compound. This means that a layer of clay with a height of about 1.2 cm was covered with a layer of *arga* of a similar height consisting of different grain sizes (also in a 1:10 scale) – starting with grains of a size of about 3 mm at the bottom decreasing to a size of about 1 mm on top which were both produced by crushing towards dust as the third most upper fraction, produced by grinding (Fig. 63.3). After ramming for several hours, a cross section of the sample (40 x 40 x 10 mm [l/w/h]) shows the meshing compound of the two layers, which would probably become stronger with continued ramming. Since the ingredients of *arga* are too fine (in particular by using the ground powder), it becomes too exhausting to press the layer of clay from the bottom to the top by ramming. We learn that the content of a coarse and also not too fine grain size is important to keep the upper *arga* layer open to the clay being pressed through it from below.

When burnishing, the surface has to be as hard as leather and not soaked with water. The best consistency for burnishing is when the surface colour has already completely changed from an obviously dry and dark state to bright grey. If too wet, the fine layers of the material start to shift and a burnishable homogenous compound is not maintained. On the other hand, when too dry the surface becomes sandy, similar to the explanation given for specimen (III). Due to the fine ground material, burnishing is much more difficult than with a small content of coarse material, as given for specimen (III). The surface does not turn into a shining and homogenous structure; instead, due to the fine ingredients, the shifted material damages the already burnished surface. The dark surface results from the use of a metal spoon as a burnishing tool while in the case of using porcelain, the surface does not darken but is more difficult to burnish (Fig. 64.3). Also in this case a Vickers needle test will be used to determine any difference in the hardness of the surface.

11947 + 15370 burnished (Vick 4.3, Appendix Chapter II)
- applied force 1 kgf;
- diagonals: 917 µm and 920 µm;
- 2.2 HD 1 (2.2 kg/mm²).

Concluding, it can be stated that the use of ground and too fine material for the most upper surface is not ideal in the case of burnishing. It has to be mixed with coarser material, which would be the case if in the course of ramming the clay below were to be pressed to the upper most surface. At a 1:1 model the grain size of the *arga* pieces can not be small enough to leave enough space between the grains for pressing the clay through the holes in between.

### 5.3 Vickers needle tests

To prove the hardness of the surface of the *arga* material, the Vickers needle test is applied.[58] For further comparison the measured scratch hardness for calcite according to Mohs is reported at '3' while the values measured according to Vickers micro hardness range between ~105 and ~172, according to different sources: Stachowiak and Batchelor (2013: 537) give a value between 109 and 172; Epple (2003: 29) gives a value of HV 150; Atkinson (1993: 107) gives a value of 125 kg/mm²; Winkler (1975: 38, Table 7) gives a value ranging between 105 and 136 as a compilation of Taylor (1949: 721), and Winchell (1945), Tertsch (1949) and Ramamurthy (2010: 88) give a value of 1,250 N/mm².

The measured values of the *arga* will be compared with the values given for calcite in literature and also with other materials of which the Vickers microhardness (F <1,961 N) was comparatively also measured at the IPM / BOKU. The samples from the point load test were measured, and in the following, the data of the *arga* (sample 15370) will be given. Since the moistening of the *arga* stone during its processing on the building site is of crucial importance, the Vickers test was conducted in a dry and a moistened state after soaking the stone for about six hours.

For a further comparison, different types of limestone were tested according to Vickers:

Marble, 'Wachauer' fine burnished with a 1,000 µm grain size (Vick 5.3, see Appendix Chapter III)
- · applied force 10 kgf;
- · diagonals: 289 µm and 295 µm;
- · 217 HD 10 (217 kg/mm²).

Marble from Carrara, burnished (Vick 6.3, see Appendix Chapter II)
- · applied force 10 kgf;
- · diagonals: 335 µm and 345 µm;
- · 160 HD 10 (160 kg/mm²).

---

[58] For testing the abrasion resistance with ball mills (Micro-Deval–Los Angeles-Nordic-Ball-Mill), the amount of collected raw material (500g–5,000g–1,000g according to Heibaum, Warnecke 2012: 96) was not enough.

The *arga* stone was cut into several plane-parallel pieces to make them easier to handle under the Vickers machine and further on under the microscope.

*Arga* dry: *Arga* stone (sample 15370), dry (Vick 7.3 and Vick 8.3, see Appendix Chapter III)
· applied force 10 kgf;
· diagonals: 361 µm and 360 µm;
· 143 HD 10 (143 kg/mm²).

· applied force 10 kgf;
· diagonals: 380 µm and 342 µm;
· 142 HD 10 (142 kg/mm²).

With this hardness this *arga* stone ranges in the lower third of comparable hardness data of limestone with a range between HV 105 and HV 170, according to literature sources (see above).

*Arga* moistened: *Arga* stone (sample 15370), (Vick 9.3 and Vick 10.3, see Appendix Chapter III)
· applied force 10 kgf;
· diagonals: 361 µm and 362 µm;
· 142 HD 10 (142 kg/mm²).

· applied force 10 kgf;
· diagonals: 361 µm and 360 µm;
· 143 HD 10 (143 kg/mm²).

Compared to the two marble samples, one from the Wachau in Lower Austria with 217 HD 10 and the other a marble stone from Carrara with 160 HD 10, the *arga* stone with 143 HD 10 – no matter if in a dry or wet state – ranges at the lower end of this series and shows a hardness at its surface approximately comparable with the medium range given in literature for calcite with a hardness between 105 and 170 kg/mm².

## 5.4 Point load tests

Regarding the continuous load onto the *arga* stone during the ramming process, its compressive strength plays an important role – primarily regarding its workability during ramming. This means the harder the stone the more effort for crushing and later for burnishing can be expected. For the present survey, the question of hardness compared to other kinds of stones used for building purposes, specifically for chiselling, is addressed since no comparative data exists on ramming-strengths.

To produce comparative data, the point load of several types of stones was measured to find a range of categorisation:

Granulite, highly metamorphic; rich in feldspar and quartz; very schistose; from the Kata zone

- 282 bar equal to 40.5 kN

Limestone from Gutenstein in Austria

- 92 bar equal to 13.3 kN

Sandstone; fine-grained piece of a millstone; slight discolouration by weathering due to the content of goethite

- 45 bar equal to 6.5 kN

Limestone from Dachstein in Austria

- 37 bar equal to 5.5 kN

Wetterstein limestone from Trias period; bright blue; surface burnished

- 30 bar equal to 4.2 kN

*Arga* stone, sample 15370 from the Jokhang in Lhasa

- 26 bar equal to 3.8 kN
- 29 bar equal to 4.2 kN
- 32 bar equal to 4.5 kN

This result means an average similarity in hardness to the Wetterstein limestone, which ranges in relation to the point load values of the limestones from Dachstein and Gutenstein in the lower segment.

## 6. ANALYSIS OF THE CONSTRUCTION

### 6.1 A materially intermeshing structure and a burnished surface

The thickness of the single described layers of crushed *arga* varies and seems to follow local variations. Nevertheless, striking is the common pattern of the mentioning of consequently the same material layers (from bottom to top):

1. Supporting layer (wooden beams, sticks and stone plates)
2. Clay as a sub-layer
3. *Arga* stones as upper layer
4. Specific oils and fluids as uppermost water repellent coating

The supporting layer (1) is generally related to a static system, i.e. a wooden beam to calculate on two supports. The coating layer (4), in contrast, takes no role in the load bearing context. It is a water repellent layer, which protects the construction below from water, and further gives a shiny appearance. We can also think of this coating as being permeable to air and water vapour. But what exactly gives the roof such a positive reputation regarding durability and plasticity? Even in the case of a buckling pillar below, why is the roof known for sagging but not collapsing? For answers we have to go into the clay and *arga* layers (2, 3).

The *arga* stones themselves are limestone, and the ramming process alone crushes them, but no binding follows. Adding water binds the crushed pieces but – as a test showed – after drying not only the surface but the whole homogenous compressed lime starts to become inelastic and cracks, and subsequently falls apart.[59] Regarding binding the pieces together, joining of the pieces by again ramming provided no positive result.

A further question is raised for the technical functional purpose of the layer of clay below the layer of *arga*. The first aspect was that it is a kind of absorber of the vibrations by ramming the *arga* stones above, a process which lasts several days. But after preparing several *arga* samples in the laboratory,[60] a new aspect for the function of the layer of clay was evident. When ramming and crushing the *arga,* a continuously increasing mixing with the softer clay below takes place. On the one hand, *arga* is crushed; on the other hand, *arga* and crushed pieces of *arga* are pressed into the clay and mixed with it (Fig. 65.3). After a days long ramming process, softer and finer material fills the gap between the coarser particles and finally results in an ideal particle size distribution.[61]

---

[59] Alexander (2011: 71): The behaviour of micrite is compared to a natural cement.

[60] Due to a lack of a larger amount of *arga* in the laboratory, the existing material was enough to prepare a 1:10 model but not a 1:1 model.

[61] The use of different grain sizes, on the one hand, and the crushing and compressing of the whole *arga*-clay mixture, on the other hand, converges in an ideal curve for the grain size distribution, studied by W.B. Fuller and S.E. Thompson and described with the so called *Fuller parable*. Its aim is an ideal distribution with as little space between the grains as possible. By this the homogenous mass of the whole compound is increased. Alexander (2011: 71) mentions that the *arga* material in general is described as being collected in melon-sized pieces, which are crushed on site into three different grain sizes. Starting with the largest, the *arga* was placed evenly all over

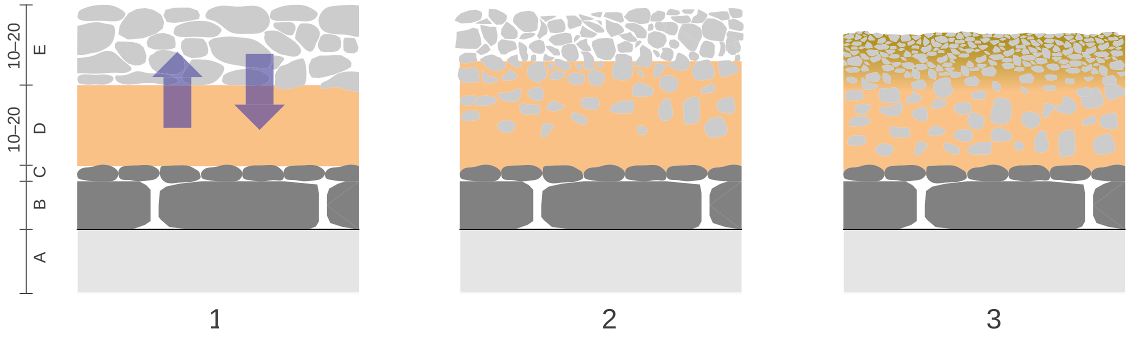


Fig. 65.3 Phases of the process of the compaction of the *arga* roof. Measurements in centimetre.
A = Wooden subconstruction; B = Ashlars; C = Layer of stones; D = Layer of clay; E = *Arga*.
Phase 1: Beginning of the compression.
Phase 2: Addition of water and compression. Soft clay is pressed upwards. *Arga* is crushed and pressed into the clay below.
Phase 3: Further addition of water and compression. Upper most *arga* pieces are crushed at most. *Arga* and clay are mixed up. The finest crushed *arga* pieces are mixed with the clay-*arga* paste in the most upper area. Spaces between are filled up with fine material until no spaces remain and the water is pressed up onto the surface, which is the time when the compression is finished.

Fig. 66.3 shows a section through a parapet wall whose top is partially prepared in *arga*. On top of a homogenously compressed layer of *arga* a thin burnished layer can be seen.

In the beginning of the ramming process, the continuously added water is drained through the coarse upper material towards the clay. During the ramming process the water is pressed upwards into the layers with bigger interspaces between the grains without the water being stored. The longer the ramming process takes, the more clay as water-storing mass is pressed upwards. A further effect is that the whole mixture becomes more and more a homogenous mass – crushed *arga* mixed with clay and water. The ramming process is finished at the stage of full saturation with water – in a practical sense this means that the ramming process is finished when the water is pressed over the upper surface of the floor and remains in position. At this stage the levelling and burnishing process starts for which constant basic moisture is advantageous.

## 6.2 Hydraulic properties

The calcite is strongly impure. Different kinds of residues appearing in different amounts within the calcite seem important for building purposes. Regarding *arga*, future research will address whether the same geological layer is always searched for when quarrying, since a particular geological variability, which distinctly influences the behaviour of the *arga,* may be given and also locally known. A presumption – which could not be stated – was that a finer material content may be the key for particular hydraulic properties, also based on the fact that some of the quarries are close to areas containing volcanic stone deposits.

---

the roof surface. AN: This method of using three different grain sizes enables a continuous reduction of the added grain sizes by getting closer to the surface. On the one hand, this differentiation of sizes of the stones before adding homogenises the whole compound, and on the other hand, decreases its ability to absorb water in a further stage.

Fig. 66.3 Lhasa. Jokhang.
*Arga* parapet.

## 7. CONCLUSION

### **Research question 1: Are there any material qualities to categorise *arga*?**

According to results of the BMA, we state the following evidence:

- Sample 11078 (Jokhang roof 2010) contains a higher amount of quartz, feldspar and clay minerals. In all the samples there are no traces of dolomite.
- All of the samples contain a relatively high amount of calcite ranging between 46% (11078) and 80% (8473 and 11953).
- Sample 14765 shows less content of phyllo silicates.
- Sample 11953 shows a relatively small amount of phyllo silicates.
- Some amorphous contents, e.g. for sample 11953, at 12.5°θ or 9°θ are available.
- Sample 8473 contains some mica and phyllo silicates.

Samples 14765 (Jokhang 2014: 50%), 14766 (Gyüme Dratsang 2014: 62%) and 15370 (Jokhang 2010: 75%) show a relatively similar content of calcite. In particular, the two first mentioned samples (14765 and 14766) – both collected during renovation work in Lhasa in 2014 – originate from the area of Chushül, and possibly are even from the same quarry. The mineral content beside calcite is available in traces, which means in a poorly crystallised form. In general these samples show a high content of calcite with few poorly crystallised ferric oxides.

As a result of laboratory tests, it can be stated that a high amount of calcite when the sample is in a not-ground state negatively affects the cohesion between ground *arga* and the clay. Calcite reduces the water absorption capacity of the clay and moves towards coalgulating and flocculating. Decreasing the content of calcite would reduce this effect. The content of calcite in a crystallised form decreases, by that most likely affecting the cohesion in a less negative way.

Regarding lithological characteristics, *arga* is neither a weathered conglomerate nor a pure limestone, but a limestone-marl. The content of calcite of the examined *arga* samples is between 46% and 80%. This corresponds with lower calcite components a marl or marlstone and with the higher calcite components a calcarous marl or calcarous marlstone.

### Research question 2: Are the particular material qualities related to specific regions?

So far, we know of the Tibetan *arga* technique from Ladakh and Ngari in the Western Himalayas via Central Tibet to East Tibet. This technique is traditionally applied to structures of high social status. In ancient European times, similar techniques were developed, for instance, in Greece, where we find a tradition, which works without hydraulic binders, similar to *arga*. The content of calcite in the *arga* material is shrinking in a west-east direction from Ladakh towards Central-Tibet. Some different *arga* systems with varying layer dimensions were handed down to the author by master masons. The question arises as to why these experienced masons used different dimensions for the construction of these roofs and what these local variations result from? Trial and error is obviously an unsatisfying answer and different qualities of the used clay and *arga* may influence a different thickness of the layer of clay, and by that a changing proportion of the thickness of the layers of clay and *arga* to each other. The following mentioned parameters influencing the quality of the functional interaction can be reasons for adjusting the thickness of the clay- and the *arga* layers to local conditions.

### Research question 3: What are the material qualities that support *arga's* use for particular building purposes?

The content of calcite within the examined samples ranges between 46% and 80%. From this, the content of silicates (i.e. the non-calcitic content) ranges between 54% and 20%. This makes the material a product of calcite and silicates – which can be mentioned as one of their important features relevant for further processing as roofing material.

We then must ask about the content of particular silicates and their impact on construction. The whole construction we can talk of two components, hard components (calcite on top) and soft components (clay below). The soft clay matrix (phyllo silicates) is compacted by pounding of the hard calcite components. Calcite particles are enveloped by the soft portion. Calcite remains the supporting framework and phyllo silicates are the binder.

> *a. The stone roller:* The first step in preparing the *arga* layer was its compaction with a stone-roller. Its calculated weight is app. 100 kg. By continuously drawing this roller over the layer of *arga,* it is uniformly compressed without leaving any valleys – an important step for levelling the *arga* surface. Relatively big and angular shaped stones are broken. Stones are pressed into the layer of clay below.
> Water is poured over the *arga* layer to keep it permanently humid and to make the clay tractable. Effects of this process: Laboratory tests showed that the humid *arga* does not

break more easily when soaked with water. The hardness of the *arga* stone was not reduced in a moistened state after soaking the stone for about six hours. Regarding its use for ramming, soaking with water seems to not influence (or facilitate) the workability within the ramming process. On the other hand, this aspect would mean that the prime reason for adding water might be found in the ability of binding the crushed stone with the soaked clay from below, and not in changing its workability.

The continuous moisture penetration of the layer of clay enables two processes: the pressing of the stones into the clay, and the pressing of the clay between the stones. After finishing this rolling-process, the *arga* surface is levelled but still coarse.

*b. The ramming process:* The upper stone layer – which is rich in calcite – is crushed, and the crushed and smaller pieces are pressed into the holes between the upper and bigger stones. Big stones, which protrude above the floor level, are either pressed down into the soft layer of clay or crushed on the hard layer of stones below. Crushing the stones means a continuous amorphising and enlarging of the surface of the stone. On the other hand, by continuously pressing the stones into the clay, the latter is pressed up between the stones with the finest grains on top. This sludge is divided into the holes between the grains and continuously closes all the spaces in between them. The ramming process is finished when no more water is kept within the roof construction but pressed onto the surface of the floor, meaning saturation of all the pores. Until this happens, the ramming process is also accompanied by pouring water onto the surface. Fig. 67.3 and Fig. 68.3 show the influence of different qualities of treatment on one roof.

This process of ramming the *arga* into layers of clay below enables the distribution of fine clay material into the gaps and possibly results in an ideal distribution of the grain fractions with the result of no shrinking. The absence of cracks between the grains and the filling material after finishing the roof in a dry state is evidence for the ideal distribution of grain fractions since the breccia itself does not shrink. The used clay is nothing specific, just a common *field clay*. The reason for taking this type of coarse clay may again be in the reduction of the risk of shrinking with a certain content of coarse material.

As a result of the examined samples, the content of calcite should be at least 50%. The calcite itself should not exceed a certain hardness. This aspect and the inner cohesion within the calcite may be crucial for the effort in ramming the *arga*. To find a certain modus for measuring this hardness, the single samples were examined according to a point load test and the Vickers needle test, since so far there is no testing method to prove the rammability of stones.

Crucial for a further understanding would be the examination of a 1:1 model of a rammed roof where the clay and the *arga* layer are processed into one homogenous roof structure. Since no such model of the whole compound has been made available up to this point, the current research was carried out examining the grain size distribution within such a sample.

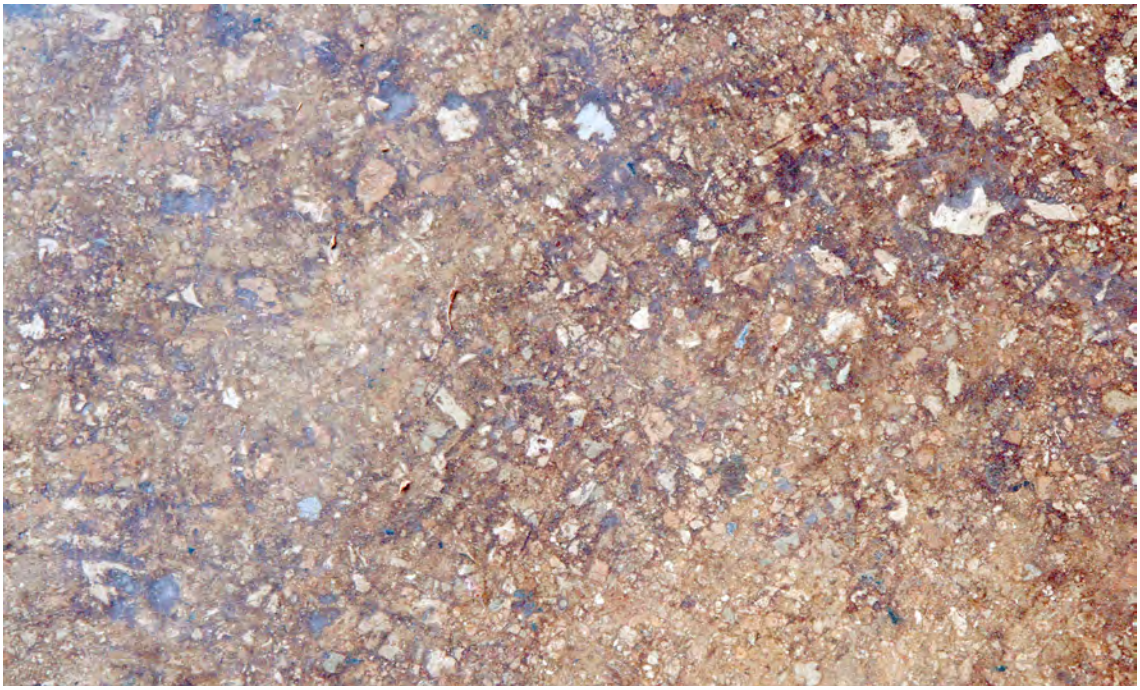
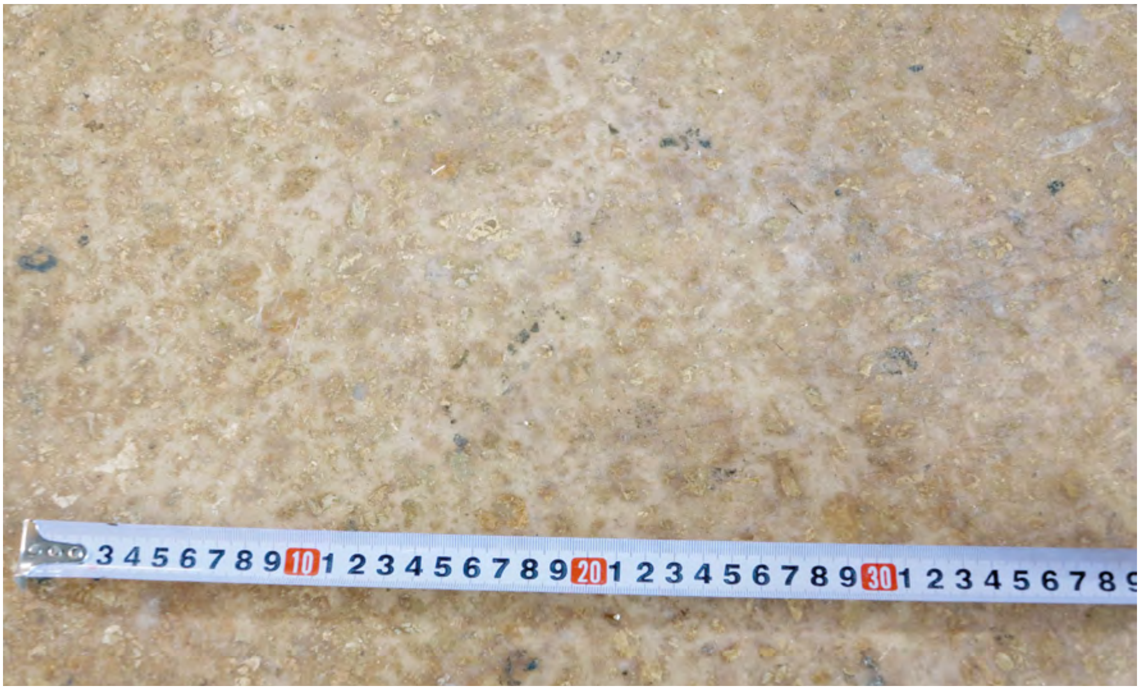


Fig. 67.3 (Top) Lhasa. Jokhang. Not completely finished burnishing. Surface remains coarse and rough.

Fig. 68.3 (Bottom) Lhasa. Jokhang. After finished burnishing the surface becomes smoother compared to the weathered sample shown in Fig. 67.3.



Parameters influencing the behaviour of clay and the choice of a particular layer thickness:

- Sandy or soft clay
- Ratio between the grain fractions
- Existence and amount of swellable minerals
- Content of added water

Parameters influencing the behaviour of *arga* and the choice of a particular layer thickness:

- Content of clay
- Content of calcite
- Particular surface- and ramming hardness of the raw material
- Inclusion of a higher amount of another kind of stones – possibly harder than the *arga*
- Content of silt and clay minerals
- Consistency and quality of the clay
- Duration of the ramming process
- Existence and amount of swellable minerals within the clay
- Amount of added water

### What have we learned from traditions in making a flat earth roof and an *arga* roof for modern applications?

Flat roof constructions follow a long lasting building tradition with particular local characteristics. The introduction of 'modern' materials, such as a bituminous felt, is questionable from a technical and economic point of view, in particular since traditional methods have worked properly for a long period. Particular materials, such as *markalak*-, *tua*- or *thawa*-clay, are part of common flat roof traditions in the Western Himalayas. The preparation of a traditional flat roof means thinking in layers which complement each other from a technical point of view. It is the whole compound and not the single layer which has to be regarded as a working unit. In this regard we find several basic different approaches in arranging the single layers of clay of a flat earth roof on top of the organic layers as listed below. Several of the described methods for earth roofs (e.g. by Thubten Legshay Gyatsho or by Wangyal Tsering) are related to the use of a ramming technique.

1. The water bearing layer is placed as the upper layer of the roof: starting with coarse material below and becoming finer towards the top (most common).
2. The water bearing layer is placed as intermediate layer. The upper layers on top are defined as mechanical resistant and protecting the finer layer below (example from Nako by Maïni Satprem).
3. A stone layer is covered with rammed earth layers (described by Thubten Legshay Gyatsho and Penba Tashi).
4. An *arga* roof which is based on a layer of clay as ground layer below.

For a brief overview regarding subconstructions for flat roofs we can state:

1. Wooden subconstruction and organic layers are existent over the whole Himalayas
2. Mineral layers
    - 2.1. Layers made of clay on top of an organic layer are known over the whole Himalayan region.
    - 2.2. A*rga* roofs are widely known over the Himalayas but just in some regions such as Central Tibet the making of an *arga* roof remained as a living building tradition.
        - 2.2.1. On top of a sub-layer of wood or stone a layer of clay is laid as sub-layer for an upper layer of *arga*.

# IV. *MARKALAK* CLAY

During field research, a particular type of clay appeared at different places along the Western Himalayas. It turned out to be commonly known as having a high quality for building purposes, and further appeared to have a long tradition with hard to understand roots. On the one hand it is presently a popular material used by locals and conservators; on the other hand we have evidence of its historical use. For now the research presented here extends from the very west of Ladakh to the most eastern finding of this material. It further stretches to a local building tradition in Purang located in West Tibet not far south of the Kailas region close to the Nepalese border (Map 1.4).

Partially the names given to this material are changing. In Ladakh it is commonly known as *markalak* clay.[1] In Zangskar, Spiti, Lahaul, Kinnaur and Ngari (see Map 1.4) this term is also known although not necessarily commonly used (Feiglstorfer 2014: 378). For a *markalak* clay the expression "clay" is locally more common than "earth" (Interview Tsering Wangyal 2002; Feiglstorfer 2002: 36). South of Ladakh in the north east of Himachal Pradesh, in Spiti and Upper Kinnaur, it is known as *tua* clay. Moving further east to Purang in western Tibet, it is again known – similar to *markalak* clay– as *narkalak* clay. This obvious similarity of the names over a distance of approximately 700 km indicates a knowledge transfer of clay and invites deeper investigation.

During field research it was determined that places where this type of clay could be found were always related to a particular water transport close to a river, such as the Indus, the Spiti, the Sutlej or the Peacock River. However, these locations were not necessarily immediately adjacent to the water. In this relation it is of importance that vicinity to an aquiferous geological formation seems to be relevant for this type of clay. The author intends to question this relation within this chapter.

Common uses of this type of fine material are primarily for particular structural and decorative objects and building parts. One field of application is flat earth roofs, primarily used for the most upper constructive layer. For the roof, this material is used to fill cracks. In an interview, Mr. Dawa, the former director of LEDeG in Leh / Ladakh, described the method on the roof of the Ladakh Ecological Development Group (LEDeG) in Leh (Interview Sonam Dawa 2002).[2] In the case of cracks, pieces of *markalak* clay of a size of up to one fist are sprinkled onto the roof along cracks. This is conducted during a dry period. As soon as rain falls the hard bricks of *markalak* clay are softened, and by turning into sludge the *markalak* clay fills and closes the cracks. After drying the cracks are filled without leaving any further cracks between the new filling material and the original clay on the roof. The mixture of this material, in particular of swellable and non

---

[1] In the area of Basgo also a *chukalak* (Tib. *chu ka lag*: *chu* meaning water), i.e. clay-like silt on the ground of irrigation ponds and flood plains, is known (Feiglstorfer 2014: 374).

[2] "Mr. Dawa presented some samples of *markalak* clay, which are characterised by a soft chalk fineness. In his youth − about 50 years ago, as he mentioned, he used this clay for writing on blackboards. The method of applying this material is very simple: fist-sized lumps of clay are crumbled into smaller pieces and scattered onto the leaking roof locations. No further addition of water is necessary. Only in the course of the next rain does the sprinkled clay combine with the underlying roof surface to form a homogeneous and moisture-proof layer of clay. Finally, the newly applied layer is about one centimetre thick. This is also a good method of refurbishment of the roof when previously a sufficient amount of clay was applied." (Feiglstorfer 2002: 36, translation from German)

https://doi.org/10.1515/9783110591330-006

Map 1.4 Origin of the samples. GIS data based map: Jakob Gredler. Final graphics: author. Map based on data from VD and BM.

swellable clay minerals, and the amount of silt are ideal for this kind of purpose.[3] For this reason such material is also popular for the restoration of cracks in walls, in particular of plasters and upper layers of plasters. As seen during examination of other kinds of clays in other regions, particularly in Nyarma (Chapter II) or at Basgo and Likir (cf. Feiglstorfer, forthcoming a), *markalak* clay is not a prime material for the preparation of plasters, although these would be areas close to *markalak* clay resources (Map 1.4). In Lamayuru in Ladakh on the other hand the *markalak* clay is mixed with sand for the preparation of plasters (Feiglstorfer 2014: 374).

While cracks in the exterior surface of an exterior wall, which was covered with a clay plaster, can easily be filled by pouring a slurry of clay over the cracks, the treatment of interior walls and of the roof is not particularly easy. After closing cracks on the inner surfaces of walls, their appearance should be even, especially in the case of walls covered by wall paintings, as we find in early Tibetan temples. For this purpose the clay does not have to be too coarse, as in this case it would not stick sufficiently to the surrounding existing material. Otherwise, too high content of clay would cause the filling-material to shrink and further cracks between the filling material and the surrounding existing parts of the wall would result.

---

[3] See Chapter III for a detailed description of flat roof constructions.

For this reason some types of *markalak* clays, which show a high content of silt, are popular for closing cracks. If the material does not have to be so fine, as is the case with the *markalak* clay, it is mixed with coarser clay. If the latter mentioned clay is of good quality according to the particular need, not much *markalak* clay or none at all has to be added. Mr. Wangchuk from the Archaeological Survey of India (ASI) in Leh mentions the former use of dark, black clay as the upper roof layer since this kind of clay stores a larger amount of water[4] (Interview Wangchuk 2005). Interviews along the whole Western Himalayas have confirmed the wide dissemination of the knowledge about using *markalak* clay to fill cracks. In Dhankar in Spiti, for example, the owner of a local building showed his method of pouring a highly aqueous slurry of *markalak* clay with his watering can over the cracks along the facades. This is a method of maintenance which he practices every spring when cracks become visible. Such cracks are caused in the exterior surface of the wall by the freezing of precipitation.

In the case of bigger cracks (not hair cracks), which primarily are the result of static changes in the wall or much likelier in the subfloor or in the basement, these methods for filling cracks are not sufficient. For stitching big cracks, the filling itself has to be stressable by tension. Simply using clay is not enough in such a case. John Hurd explained a method for stitching structural cracks.[5] After cutting a recess, the crack is filled with alternating layers of moistened bricks and a mixture of *yagtsa* (in the following given with the commonly used term *"yakses"*) as well as twigs, branches and Hessian cloth (Interview Hurd 2008).

*Markalak* clay is also mentioned in relation to clay sculptures or as being used on painted surfaces before applying white wash.[6] As seen in Nyarma (see Chapter II) for all ornaments – be it the modelled aureole in the assembly hall of the main temple or the piece of a frieze of the interior of a stupa – the characteristics of *markalak* clay can not be determined throughout the remains of the whole monastery. Also the material – which is used for building up the substructure of clay models, as practised at the CIBS (Central Institute of Buddhist Studies) in Choglamsar / Ladakh – is more related to what is commonly used for adobe bricks and has nothing to do with material qualities representative of *markalak* clays. On the other hand *markalak* clay was locally mentioned in relation to clay sculptures. For that reason, any relation to the *markalak* clay– most probably related to the fine (and most upper) layer of statues, which has yet to be examined – will be a challenge for further research.

---

[4] The use of dark, black clay and the storage of water points towards an organic content. This description does not refer to a *markalak* clay but more to a tradition of using clay with an organic content as we know this from the neighbouring region of Kashmir.

[5] The method of stitching structural cracks in earth walls is mentioned in an unpublished paper, which John Hurd gave to the author at the Terra Conference 2008 in Mali.

[6] Cf. Feiglstorfer (2014: 379), according to Bielmeier et al. (Forthcoming).

The haptic property of *markalak* clays is soft and greasy which may be an influence for the origin of its name (cf. Feiglstorfer 2014). The Tibetan term *mar* meaning "butter" seems well suited for widely understandable terminology to define a particular material property related to its haptic and visual qualities. The very fine types of *markalak* clays have a soft taste with minimal cracking sound between the teeth, and they 'melt' on the tongue but do not stick to it, indicating a particular amount of silt. In Pin Valley in North India the use of the term *"kalak"* for a *tua* clay mixed with water was recorded (see under 1.2.2 "Layers of clay" in Chapter III).

The visual effect is a monochromatic and smoothly broken surface without any clearly visible sand. The material breaks when in block form, and when dry it needs quite a lot of effort to be broken into small pieces by hand. When soaking in water, the water just slowly reaches the material's core – an indication of a dense and fine structure of the material. As soon as it is wet, it becomes sticky and easily malleable – indications for a content of clay minerals. After drying again, it remains without further cracks which makes it interesting for different kinds of building purposes, like filling cracks in wall plasters, flat earth roofs and clay sculptures.

## 1. Origin of the samples

According to Table 1.4, clay from the following sites is examined (see Map 1.4):

- Spituk (Ladakh)
- Alchi (Ladakh)
- Lamayuru − Basgo (Ladakh)
- Shey (Ladakh)
- Nako − Shelkhar (Upper Kinnaur)
- Khorchag (Ngari)

The samples were collected at different sites according to which the following categorisation was defined.[7] The *markalak* clay is an important raw material for conservators and builders. One research area concerns Ladakh where this material is widely known as a building material with good properties for building purposes. Dr. Christine Bläuer was kind enough to provide several samples of *markalak* clay for further research and comparisons with different other kinds of known types of *markalak* clay which were collected by the author. In particular this concerns the following samples:

- Sample 14874 from Lamayuru
- Sample 14875 from Spituk
- Sample 14876 from Alchi

Within discussions on *markalak* clay, which the author conducted with the Ladakh people, the most often mentioned type was the *markalak* clay from Spituk. Over more than ten years the author collected samples from the Spituk clay pit from different points of withdrawal at different

---

[7] Several samples (numbers starting with 119.., 117.., 153.. and 154...) were collected and related field research was undertaken within the FWF Project P 21806 (Society, power and religion in pre-modern Western Tibet).

Table 1.4 List of the samples.

| Sample | Country | Province | Valley | Settlement | Location | Local name |
|---|---|---|---|---|---|---|
| **Spituk** | | | | | | |
| 6052 | India | Ladakh | Indus | Spituk | clay pit | *markalak* |
| 8466 | India | Ladakh | Indus | Spituk | clay pit | *markalak* |
| 8481 | India | Ladakh | Indus | Spituk | clay pit | *markalak* |
| 14875 | India | Ladakh | Indus | Spituk | clay pit | *markalak* |
| **Alchi** | | | | | | |
| 8526 | India | Ladakh | Indus | Alchi | clay pit | *markalak* |
| 11934 | India | Ladakh | Indus | Alchi | clay pit | *markalak* |
| 14876 | India | Ladakh | Indus | Alchi | clay pit | *markalak* |
| **Lamayuru** | | | | | | |
| 11939 | India | Ladakh | Lamayuru | Lamayuru | clay pit | *markalak* |
| 14874 | India | Ladakh | Lamayuru | Lamayuru | clay pit | *markalak* |
| **Basgo** | | | | | | |
| 15518 | India | Ladakh | Indus | Basgo | clay pit | *markalak* |
| **Shey** | | | | | | |
| 11913 | India | Ladakh | Indus | Shey | clay pit | *markalak* |
| 15404 | India | Ladakh | Indus | Shey | clay pit | |
| **Nako** | | | | | | |
| 15516 | India | Kinnaur | Spiti | Nako | building site | *tua* |
| **Shelkhar** | | | | | | |
| 8504 | India | Spiti | Spiti | Shelkhar | clay pit | *tua* |
| **Khorchag** | | | | | | |
| 15377 | China | Purang | Peacock | Khorchag | clay pit | *narkalak* |

heights along the mining wall. Such a collection practice shows the stratigraphic layering very well. This concerns samples 6052, 8466 and 8481. The clay pit itself is protected and digging is prohibited, as written on a big sign along the road. Nevertheless, during the author's visits a couple of people were digging which showed the renown and popularity of this material (Fig. 1.4 and Fig. 2.4). Further research led to Alchi where the author collected different types of clay used for different building purposes with the help of Morup Dorje, a local teacher. This concerns samples 8526 and 11934. Similar to the *markalak* clay from Spituk, the *markalak* clay from Lamayuru is well known within Ladakh. From this site the author collected sample 11939. In other regions of Ladakh, e.g. Basgo and the surrounding area, different species of clay are locally known (cf. Feiglstorfer, forthcoming a), and attributed to particular building purposes. Also a type of *markalak* clay is known. This concerns sample 15518. Also the *markalak* clay from Shey is widely known as a fine material for building purposes. Its location is a desertic area within a field of stupas. 11913 is the *markalak* clay sample from Shey. For comparison of different types of clay besides *markalak* clays, the author collected another clay material from Shey from a clay

Fig. 1.4 (Top) Spituk. Ladakh. The clay is collected in big bags.

Fig. 2.4 (Bottom) Spituk. Remains of a lacustrine palaeolake in front. The Spituk Monastery is visible in the background.

pit which is not a *markalak* clay and which is used for the production of bricks. This concerns sample 15404.

To enable comparison of the *markalak* clay types of Ladakh with *markalak* clay (-like) material from other Western Himalayan regions outside of Ladakh, particular material was collected in Himachal Pradesh at Shelkhar (sample 8504) and at Nako (sample 15516). Also in Tabo, from Nako upstream to Spiti, *tua* clay, which is said to be very similar to *markalak* clay, is still well known for its good material qualities. Further east in Purang in West Tibet (Ngari), moving along the Sutlej and close to the Kailas turning south along the Peacock River, another material as well known as *narkalak* clay was collected by a Lama from the Khorchag Monastery and provided to the author (see sample 15377).

According to present studies, the study on the *markalak* clay in Chapter IV will be subdivided into three geographic parts, i.e. Ladakh in Jammu and Kashmir, Spiti and Upper Kinnaur in Himachal Pradesh, and Purang in West Tibet. Although today the border between India and China is closed for a further understanding in the development of material traditions, these borders are not of striking relevance in the observation of former transport and related knowledge transfer. Much more, the whole research area within the Western Himalayas can be seen as one cultural zone specifically concerning building material traditions.

## 2. RESEARCH QUESTIONS

The generally posed research question as given in the Introduction of Chapter I are adjusted to the research topic of Chapter III and related to specific material properties and building traditions in the following way:

- Research question 1: Are there any particular material qualities to categorise a particular clay as *markalak*?
- Research question 2: Are the particular material qualities related to specific regions?
- Research question 3: What are the material qualities which support the *markalak* clay’s use for the mentioned building purposes?
- Research question 4: Regarding places of finding, are there regional peculiarities for places where to find *markalak* clay?
- Research question 5: In which way can knowledge transfer concerning *markalak* clay be related to specific locally conventional terms?
- Research question 6: What are the geological parameters of *markalak* clays?

First the collected samples will be analysed according to their origin and local use, their grain size distribution and grain shapes, the related bulk and clay mineralogy, the content of calcite according to Scheibler, and based on simultaneous thermal analysis. Results of the analysis will be juxtaposed. Later, material properties will be examined regarding shrinkage according to DIN 18952, the liquid and plasticity limit, and the coefficient for the activity and the hardness of the surface with the Vickers needle test.

# 3. Properties of the studied clay[8]

## 3.1 Spituk

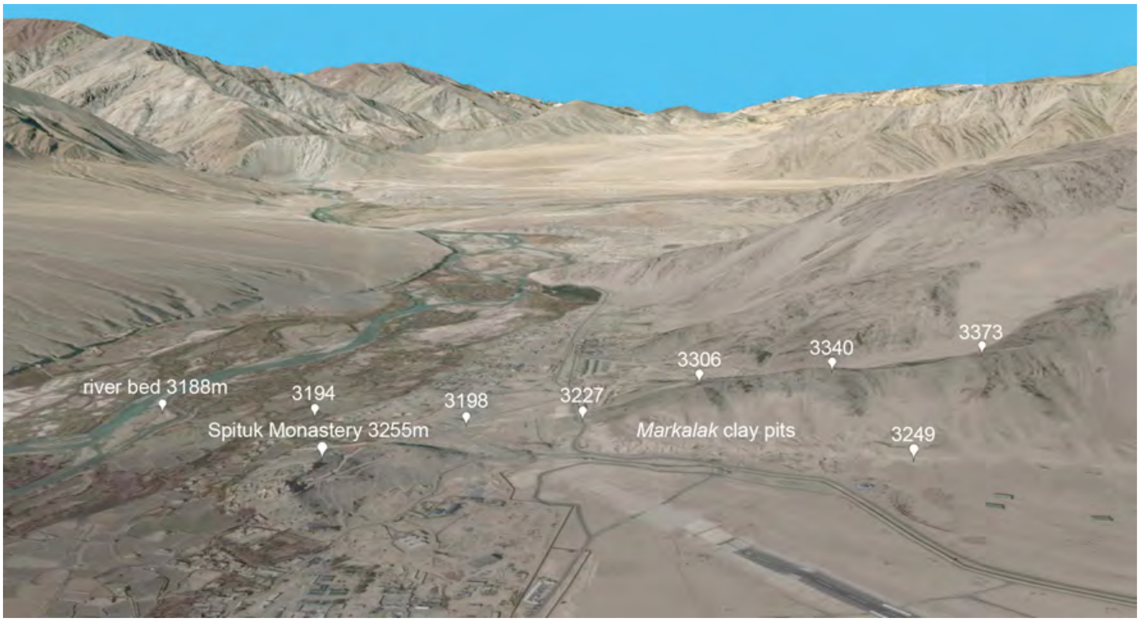


Fig. 3.4 Spituk. The level marks show the incline of the cross-country tread from the riverbed of the Indus on top of the remains of the lacustrine basin.
Source: Google Earth. Image © 2015 CNES / Astrium. Image Landsat. Image © 2015 Digital Globe.

### Spituk. Sample 6052

#### Sampling point

The Spituk clay pits (Fig. 3.4) are located in Ladakh at app. 34°7’51.22”N, 77°31’30.46”E. The area of the clay pits is located with a distance of app. 1 km from the Indus River and 61 m above the riverbed at a crossing with another valley in a northern direction. Fig. 3.4 shows a continuous increase of altitude from the Indus River towards the clay pits which points towards the direction of geological transport. Directly adjoining south to the Indus River, small inflows generate fluviatile forms and small alluvial fans. In a northerly direction along the glacial trough of the Indus River and the inflow, a lake may have resulted in impounding water and continuous piling up of layer by layer of fine alluvial sediments. A continuous repetition of this process caused the layering we find at several *markalak* clay pits. Constructive use: This material is locally reported as material for the most upper layer of earth roofs (Interview with Tsering Wangyal 2002; Feiglstorfer 2002: 36) (Fig. 4.4).

---

[8] The documentation on which this analysis is based is collected as graphics and tables in Appendix IV. This concerns tables, grain size classes, bulk mineral analysis, clay mineral analysis, simultane thermo analysis, infrared spectroscopy and Vickers needle tests. In the appendix these data are collected by method of documentation according to the list of objects.

Fig. 4.4 Spituk. Sample 6052.
Sample colour (after Munsell):
Dry 2.5Y6/2 light brownish grey.
Semi-dry 2.5 Y 6/3 light yellow grey.

### Grain size distribution

The material is very fine. Biggest fraction: coarse silt (not regarding contents of 0.2% in the sand fraction and 0.1% in the gravel fraction). The median is located at app. 7.5 µm; the <2 µm fraction contains app. 16% of the whole sample. At 84.6%, the amount of silt is high. The maximum peak lies at 39.5% for medium silt. In the distribution curve, no bimodal distribution is evident. A mixture of the material with sand or another type of clay is excluded since this sample was directly taken from the pit. The cumulative curve shows a soft break from fine silt to coarse clay and emphasises the clear dominance of silt. The high amount of silt is responsible for counteracting against too strong shrinkage and avoiding cracks.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 6052 | 0.1 | 0.2 | 84.6 | 15.1 |

### Grain shapes

An average shape can be given as “angular” (Fig. 5.4).

Fig. 5.4 Shapes of grains in sample 6052. Same scale (see upper left corner of the left picture).
Shape of fraction >2,000 µm (Left), 630–2,000 µm (Centre), 200–630 µm (Right).

### Bulk mineral analysis

This material matches with the main features of the Spituk samples: Mica, phyllosilicates, quartz and plagioclase are available in small amounts; 14Å minerals, 7Å minerals and K-feldspar are found as traces. Amphiboles could not be traced. At 69% the content of calcite reaches its maximum within the *markalak* clay samples. At 5% the content of dolomite is similar to the value compared with samples containing dolomite, in particular sample 14875 from Spituk; the other samples from Spituk, i.e. 8466 and 8481, do not show any dolomite. The sample appears as rather bright. A small amount of goethite explains the soft changing of the colour towards brownish/yellowish.

Anticipating the analysis of the further *markalak* clay samples, a content of calcite starting with traces up to about 42% seems to be a kind of marker for *markalak* clay.[9] In this sample a goethite in the X-ray diffraction is not clearly traceable but would explain the partially yellowish colouring. A small amount of mica, quartz and on average also a small amount of plagioclase – in some samples also a medium or high amount but at least a small amount (marked with (*) in Table 3.4) – are markers for a *markalak* clay. A potash feldspar (here mentioned as K-feldspar) also occurs at least as a trace in each *markalak* clay sample.

### Results measured with STA

- The content of calcite was measured at 69%, the content of dolomite at 5%.
- The residual mass at 1,000°C is 65.69%.

### Clay mineral analysis

The CMA shows a small amount of 6% of swellable clay minerals, and in particular no vermiculite, only smectite. The content of illite at 70% is rather high. The amount of kaolinite at 6% is rather low. A cracking of the material during the drying process after its application is avoided by the high and non swellable content of silt and the low content of swellable clay minerals. Values below are given in % of the clay fraction.

| | Smectite | Illite | Kaolinite | Chlorite |
|---|---|---|---|---|
| 6052 | 6 | 70 | 6 | 18 |

## SPITUK. SAMPLE 8466

### Sampling point

Ladakh, Spituk, clay pit. Like sample 6052, this sample was also taken from the bright layers within the bright and dark layered wall of the clay pit. Sample number in the field: 14 SP/MARK. Constructive use: Today this material is known as being used for the most upper layer of earth roofs. Sample colour: The sample appears as rather bright but without a yellowish content like sample 6052. The picture shows the red colouring of the sample, which emphasises the content of haematite (Fig. 6.4).

---

[9] The sediments from the Indus Valley are locally mentioned as fine grained material like chalk or glacial flour. Their origin is the bedrock ground as a result of glacial erosion (Feiglstorfer 2014: 365).

Fig. 6.4 Spituk. Sample 8466.
Sample colour (after Munsell):
Dry 10YR 7/1 light grey.
Semi-dry 10YR 5/2 greyish brown.

### Grain size distribution

The material is very fine. Biggest fraction: medium sand. The median is located at app. 0.9 µm; the <2 µm fraction contains app. 80% of the whole sample. Compared to the previous sample, i.e. sample 6052, this sample contains less silt and has a much higher content of clay (vs. sample 6052 with 15.1%) but also a very small content of medium and fine sand. The maximum peaks lie at 43.9% for coarse clay and at 24.1% for medium clay. In the distribution curve, no bimodal distribution is evident. A mixture of the material with sand or another type of clay is excluded since this sample was directly taken from the clay pit. The cumulative curve shows a break from fine silt to coarse clay but contrary to sample 6052, this break goes in the other direction, and emphasises a clear dominance of clay.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 8466 | 0 | 0.3 | 20 | 79.7 |
| 6052 | 0.1 | 0.2 | 84.6 | 15.1 |

Conversely to sample 6052, sample 8466 shows a high amount of clay and not of silt. Interestingly, the tests of this material showed that the small amount of silt and sand can be enough to keep the material crack free during drying. Shrinkage tests with this material showed a drying process without any cracks. The rounding can be mentioned as “angular shaped”.

### Bulk mineral analysis

This material matches with the main features of the Spituk samples: Mica, quartz and plagioclase, in this case also 14Å minerals and 7Å minerals, are available in small amounts; just amphiboles and K-feldspar occur as traces. In this sample a goethite in the diffractogram is not clearly identified but can not be excluded. Contrary, traces of haematite are visible in the X-ray diffraction and also for the sample colour itself. This explains the partially reddish colouring. At 5% the content of calcite ranges below the average of the measured *markalak* clay samples. No dolomite is available.

### Clay mineral analysis

In general, the clay mineral distribution accords with the other examined samples from Spituk. The CMA shows a small amount of 8% of swellable clay minerals of the clay fraction; in particular, no vermiculite but only smectite. The small amount of smectite must be important for the strong cohesiveness of this type of fine *markalak* clays so as to make it hard in a dry state. The content of illite at 65% is smaller than for sample 6052 but still rather high. The amount of kaolinite is rather low. Cracking during the drying process seems to also be avoided by the high and non swellable content of silt. In the following list, juxtaposition with sample 6052 is given.

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 8466 | 8 | 65 | 4 | 23 |
| 6052 | 6 | 70 | 6 | 18 |

## SPITUK. SAMPLE 8481

### Sampling point

Ladakh, Spituk, clay pit. Contrary to samples 6052 and 8466, sample 8481 (Fig. 7.4) was not taken from the bright layers within the bright and dark layered wall of the clay pit but from one of the dark layers, in close vicinity to the layer of sample 8466. Constructive use: Today this material is locally mentioned as used for the most upper layer of the earth roofs, and in general used for building structures. Sample number in the field: 16 SP/MARK II.

Fig. 7.4 Spituk. Sample 8481.
Sample colour (after Munsell):
Dry 10YR 6/1 grey.
Semi-dry 10YR 4/2–5/2 dark greyish brown to greyish brown.

### Grain size distribution

Generally speaking the grain size distribution of this sample shows a similarity to bright sample 8466. The material is very fine. Biggest fraction: fine sand. The median is located at app. 0.6 µm (same as sample 8466); the <2 µm fraction contains app. 82% of the whole sample (vs. sample 8466 with app. 80%) and can be described as extremely high. Compared to sample 8466 this sample contains a similar small amount of silt and only traces of sand. The maximum peaks lie at 29.1% for coarse clay and at 29% for medium clay. In the distribution curve, no bimodal distribution is evident. A mixture of the material with sand or another type of clay is excluded since this sample was directly taken from the pit. The cumulative curve shows a break from fine silt to coarse clay but contrary to sample 6052, it goes in the other direction and emphasises a clear dominance of clay. This material – similar to sample 8466 – can be mentioned as close to pure clay and as an extremely fine material. Compared to sample 6052 with a dominance of silt, this dichotomy is striking. Conversely to sample 6052 but similar to sample 8466, sample 8481 shows a high amount of clay and not of silt.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 8481 | 0 | 1 | 17.5 | 81.5 |
| 6052 | 0.1 | 0.2 | 84.6 | 15.1 |
| 8466 | 0 | 0.3 | 20 | 79.7 |

### Bulk mineral analysis

This material matches with the main features of the Spituk samples, most in regard to the brighter layer of sample 8481: Mica, quartz and plagioclase, and in this case also 7Å minerals, are available in small amounts; only 14Å minerals, amphiboles and K-feldspar occur as traces as well as the content of some haematite. At 3% the content of calcite ranges below the average of the measured *markalak* clay samples. No dolomite is available – this also matches with sample 8466. Yellowish, red and blue stripes point towards a content of goethite, respectively haematite representing a reduced iron compound. In the dry state the difference between samples 8466 (10YR 7/1 – light grey) and 8481 (10YR 6/1 – grey) become slightly evident. In the field within the in-situ conditions the stripes become more evident than on small pieces in the laboratory. Fig. 7.4 shows the striped layering in which this sample is embedded.

### Clay mineral analysis

In general the clay mineral distribution accords with the other examined samples from Spituk, again with a high accordance to the brighter layer shown by sample 8466. The CMA shows a small amount of 12% of swellable clay minerals of the clay fraction, in particular no vermiculite but only smectite, although this rate is the highest within the samples collected at the Spituk clay pit. At 64% the content of illite of the clay fraction is smaller than for sample 6052 but nearly identical to sample 8466. With 65% of the clay fraction, the content is still rather high. The amount of kaolinite is again rather low.

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 8481 | 12 | 64 | 5 | 19 |
| 6052 | 6 | 70 | 6 | 18 |
| 8466 | 0 | 0.3 | 20 | 79.7 |

## SPITUK. SAMPLE 14875

### Sampling point

Sample (Fig. 8.4) was also taken from the Spituk clay pit and provided to the author by Dr. Christine Bläuer.[10] Dr. Martina Oeter[11] explained its origin and use. Both work as professional conservators in Ladakh related to the ACHI association. Sample number in the field: Collected on behalf of Achi Association.[12] Constructive use: According to Martina Oeter this material's use is described in various forms. For conservation work, which goes deeper into the wall, the *markalak* clay is mixed with fine river sand with a grain size of up to about 2 mm. The proportion of mixing is about 2:1. For finer corrections up to the painting level, the *markalak* clay is used purely without being mixed with sand. Martina Oeter also explains that for the un-mixed (pure) application, the oatmeal material is best suited since the yellowish and grey materials shrink and crack after compression.[13]

These statements would mean that sample 6052 with a light brownish grey colour (2.5Y 6/2) shows a much higher content of silt and would give a much better result concerning less shrinkage than the light grey and grey samples, e.g. sample 8466, which shows a much higher content of clay than of silt. However, despite the shrinkage behaviour of sample 8466 – which can be classified as light grey – showing no cracks, the proportion of clay to silt is still not ideal due to a rather high content of clay. In this regard sample 6052, which shows the mentioned oatmeal colour, has a controversial proportion of clay to silt due to a much higher content of silt. Sample 14875 is somewhere in between. On the one hand it still has a relatively high amount of clay, but on the other hand it still has a relatively high amount of silt which seems to be the prime reason for its proper use, according to Martina Oeter.

### Grain size distribution

Generally speaking the grain size distribution of this sample shows similar features to samples 8466 and 8481. In detail, this sample shows a kind of merging of the features of samples 6052 (with a higher content of silt) and 8466 or 8481 (both with a higher content of clay). In the case of sample 14875, the amount of silt is much higher than for samples 8466 or 8481 but still less than for sample 6052. Further the amount of clay is still relatively high and versus sample 6052 the dominant fraction. The material is very fine. Biggest fraction: fine sand. The median is located at app. 0.8 µm (vs. 7.5 µm for sample 6052 and similar to samples 8466 and 8481 both with 0.9 µm and 0.55 µm, respectively); the <2 µm fraction contains app. 70% of the whole sample (vs. sample 6052 with 16%, sample 8466 with 80% and sample 8481 with 82%). The maximum peaks lie at 23%, 23.5% and 21.3%, respectively, for coarse, medium and fine clay. In the distribution curve, no bimodal distribution is evident. The grain size distribution curve does not show a break from fine silt to coarse clay as found for samples 6052, 8466 and 8481.

---

[10] Dr. Christine Bläuer is a conservation scientist at Conservation Science Consulting Sàrl BIO.

[11] Dr. Martina Oeter works as a freelance conservator and head conservator of the Achi Association, and teaches at Regensburg Technical University in the Faculty of Architecture.

[12] "The Achi Association is a NGO based in Europe which has been working in Ladakh since 1999 on earthen architectural heritage endangered through climate change related effects" (cf. Bertagnin et al. 2015: 43).

[13] E-Mail message by Martina Oeter on October 11 in 2014.

Fig. 8.4 Spituk. Sample 14875. Sample colour (after Munsell): Dry 10YR 8/1–10YR 7/1 partially white – light grey – yellowish. Semi-dry 10YR 6/2 light brownish grey.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 14875 | 0 | 0.9 | 31.3 | 67.8 |
| 6052 | 0.1 | 0.2 | 84.6 | 15.1 |
| 8466 | 0 | 0.3 | 20 | 79.7 |
| 8481 | 0 | 1 | 17.5 | 81.5 |

With a proportion of app. 1:2.1, this sample shows a more balanced proportion between silt and clay than sample 6052 with a proportion of app. 1:0.18 (or 5.6:1), sample 8466 with a proportion of 1:4 and sample 8481 with a proportion of 1:4.7.

### Bulk mineral analysis

This material matches with the main features of the Spituk samples, though mostly with sample 6052 which shows a high content of silt: Mica, 7Å minerals, phyllo silicates, quartz and plagioclase are available in small amounts; just 14Å minerals, amphiboles and K-feldspar occur as traces. Traces of haematite are visible in the X-ray diffraction. The content of calcite at 42% again shows similarities to sample 6052 at 69% and exceeds the average content of calcite within the *markalak* clay samples. Dolomite being available at 4% is also similar to sample 6052. In comparing the colours of the Spituk samples, they are obviously marked by some reddish content due to traces of haematite. In samples 6052, 8466 and 8481, this is probably also due to possible traces of goethite. Compared to the other samples collected in Spituk (6052, 8466 and 8481), sample 14875 appears as relatively bright giving the following comparison:

| | | | |
|---|---|---|---|
| 14875 | Dry | 10YR 8/1–10YR 7/1 | partially white – light grey – yellowish |
| | Semi-dry | 10YR 6/2 | light brownish grey |
| 6052 | Dry | 2.5 Y 6/2 | light brownish grey |
| | Semi-dry | 2.5 Y 6/3 | light yellowish grey |
| 8466 | Dry | 10YR 7/1 | light grey |
| | Semi-dry | 10YR 5/2 | greyish brown |
| 8481 | Dry | 10YR 6/1 | grey |
| | Semi-dry | 10YR 4/2–5/2 | dark greyish brown–greyish brown |

Results measured with STA

- The content of calcite was measured at 69%, the content of dolomite at 5%.
- The residual mass at 1,000°C is 75.65%.

Clay mineral analysis

In general the clay mineral distribution accords with the other examined samples from Spituk, again with a high accordance to sample 6052. At 3% of the clay fraction, the CMA shows – compared to the other samples of Spituk – the smallest amount of swellable clay minerals, again containing no vermiculite but only smectite. The content of illite at 64% of the clay fraction is within an average range of the samples from Spituk. The amount of kaolinite at 6% is also the same for the clay fraction. The content of chlorite is the highest within the samples of Spituk.

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 14875 | 3 | 64 | 6 | 27 |
| 6052 | 6 | 70 | 6 | 18 |
| 8466 | 8 | 65 | 4 | 23 |
| 8481 | 12 | 64 | 5 | 19 |

## 3.2 Analyses of Spituk samples

Sample 8466 from Spituk, which the author collected himself, was one of the brighter striped layers within this locally well-known varve clay pit and was locally recommended as “the best quality clay” (see Fig. 6.4). For its characteristics as building material and also in particular for very fine and detailed work, tests were conducted at the IAG / BOKU to determine its material properties related to standardised values.

### 3.2.1 Shrinkage tests and determining the drying shrinkage according to DIN 18952

Three samples of the same size from same sample 8466 were tested (Fig. 9.4 and Fig. 10.4).

Shrinkage during drying: Final length after drying in the oven (70C°)
18.65 cm at Sample I
18.65 cm at Sample II
18.60 cm at Sample III

Within this period in the oven, no further shrinkage could be observed, i.e. the shrinkage process was already finished after four days drying at room temperature. Finally, shrinkage during drying could be stated at about 7%. According to DIN 18952, Bl. 2, four types of clay are categorised by their behaviour during their shrinkage process: “Loose clay”, “Nearly loose clay”, “Soft clay” and “Very soft clay”. *Markalak* clay sample 8466 ranges in the category of “Very soft clay”.

Fig. 9.4 (Left) Sample 8466 from Spituk.
Sample used for shrinkage test.

Fig. 10.4 (Top) Sample 8466 from Spituk. Fine surface after the shrinkage test showing just one hair crack.

| Type of clay | shrinkage in % | [in mm] |
|---|---|---|
| Loose clay (Ger. *Magerer Lehm*) | 1 to 2.5 | [2 to 5] |
| Nearly loose clay (Ger. *Fast fetter Lehm*) | 2 to 2.5 | [4 to 7] |
| Soft clay (Ger. *Fetter Lehm*) | 3 to 5 | [6 to 10] |
| Very soft clay (Ger. *Sehr fetter Lehm*) | 4 to 10 | [8 to 20] |

Result of the Shrinkage tests and determining the drying shrinkage: According to DIN 18952, the standard stiffness of *markalak* clay sample 8466 had a water content of 121% (giving the geotechnical value for humidity).

### 3.2.2 Testing the plasticity according to DIN 18122, part 1: (a) Determination of the liquid limit ($W_L$); (b) the plasticity limit ($W_P$) (‘Atterberg limits’); (c) number for plasticity ($I_P$).

The liquid limit ($W_L$) marks the transformation point from liquid to plastic; the plasticity limit ($W_P$) marks the transformation point from plastic to semi-hard (Fig. 11.4).

(a) Determination of the liquid limit ($W_L$) according to A. Casagrande (Calculation, see Appendix of Chapter IV). According to DIN 18122, the liquid limit ($W_L$) for *markalak* clay sample 8466 shows a water content of 133.7% on a scale of 25 beats (giving the geotechnical value for humidity; see Fig. 11.4).

(b) Determination of the plasticity limit ($W_P$) (Calculation, see Appendix of Chapter IV). Result: According to DIN 18122, the plasticity limit ($W_P$) had a water content of 121% on average (giving the geotechnical value for humidity).

(c) Classification number for the plasticity ($I_P$) of clays according to Voth 1978 (Minke 1995: 43).

$I_P$ [%] = $W_L$ [%] – $W_P$ [%]
$I_P$ [%] = 133.75% – 121% = 12.75%

The values for the water content are given according to geotechnical standards (versus geological standards):

| Type of clay | $W_L$ [%] | $W_P$ [%] | $I_P$ [%] |
|---|---|---|---|
| Very sandy | 110–123 | 105–120 | <5 |
| Very silty | 115–135 | 110–125 | 5–15 |
| Very clayey | 128–250 | 120–150 | 15–95 |
| Bentonite | 140 | 108 | 32 |

Regarding the result for liquid limit ($W_L$) and plasticity limit ($W_P$), the plasticity number $I_P$ is given as 12.75%. With the measured liquid limit ($W_L$), the plasticity limit ($W_P$) and number for the plasticity ($I_P$) of this sample can be classified as "very clayey" with a tendency towards "very silty".

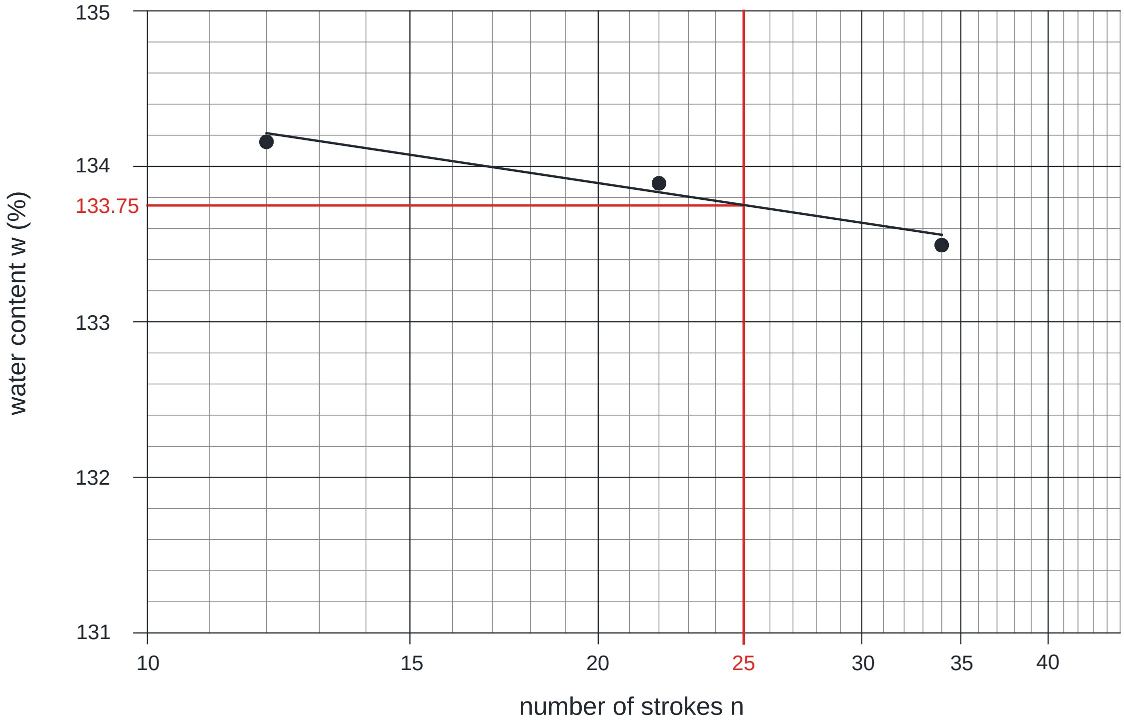


Fig. 11.4 Sample 8466 from Spituk. Atterberg limits.

### 3.2.3 Coefficient for the activity

$$I_A = \frac{W_L - W_P \text{ [percent by mass]}}{\text{Content of clay [percent by mass]}}$$

$I_A = (133.75\% - 121\%) / 84.7 = 12.75 / 84.7 = 0.15$
$I_A < 0.75$ points towards a very little activity
$I_A > 0.75$ and $< 1.25$ points towards a normal activity
$I_A > 0.75$ points towards a high activity

The coefficient for the activity $I_A$ with 0.15 is below 0.75, and according to Houben and Guillaud (1984: 59), regarding content of clay, it compares with the plasticity ($I_P$) according to Voth 1978. Despite a relatively high content of clay, a determined $I_A$ value of 0.15 points towards 'very little activity'.

### 3.2.4 Hardness of the sample according to Vickers

$$\text{HV [kg/mm}^2\text{]} = \frac{F * 1.854}{d^2} \qquad d = \frac{d_1 + d_2}{2}$$

The hardness of several plasters was examined in Chapter II (5.1.1 "Quality of surfaces"). For comparison, this test shows the relation between the hardness of those samples particularly chosen as plasters and a type of *markalak* clay, which appears as relatively hard when dry (Fig. 12.4). The result matches with the result after scratching the surface of the sample with a fingernail. The surface is easily scratched, and with a hardness of 1.39 kg/mm$^2$.

Result of the hardness test according to Vickers:
Tested sample: 8466 unburnished
Applied force 0.5 kgf;
Diagonals: 848 µm and 783 µm;
1.39 HD 0.5 (1.39 kg/mm$^2$).

Fig. 12.4 Sample 8466 from Spituk. Specimen used for the hardness test according to Vickers.

## 3.3 Alchi

### ALCHI. SAMPLE 8526

#### Sampling point

This sample was collected along the road leaving the village of Alchi towards the bridge crossing the Indus (Fig. 13.4). It was collected by Morup Dorje, a teacher from Alchi. Sample number in the field: 70 AL/LG. Constructive use: Today this material is known for making earth roofs. It is used without any further additives and without sieving. It is known to be of similar consistency as the mentioned *markalak* clay from Spituk (Interview Morup Dorjay 2002; Feiglstorfer 2002: 11).

Fig. 13.4 Alchi. Sample 8526.
Sample colour (after Munsell):
Dry 2.5YR 7/2 light grey.
Semi-dry 2.5YR 6/3 light yellowish brown.

#### Grain size distribution

Generally speaking the grain size distribution of this sample shows no similarity to the samples from Spituk. It appears as much coarser with a very different course of the grain size distribution curve. Biggest fractions: coarse, medium and fine gravel. The median is located at app. 95 µm; the <2 µm fraction contains app. 13% of the whole sample. The maximum peak lies at 32.6% for fine sand. In the distribution curve a bimodal distribution with a soft valley between coarse silt and fine silt is evident. The grain size distribution curve shows a break on both sides of the fine sand fraction. The distribution of the single fractions is relatively linear. The sample was handed over right after its collection, a mixture with sand or another type of clay is excluded. Compared with any of the Spituk samples, a main difference is certainly the large amount of coarse material.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 8526 (Alchi) | 8.1 | 53.7 | 24.4 | 13.8 |
| 14875 (Spituk) | 0 | 0.9 | 31.3 | 67.8 |

Evidence of not having been mixed with sand or another type of clay is supported by the result given by the examination of the grain shapes, which show no difference between the single fractions. Also within the *markalak* clay samples the examined shape follows for evident continuity when comparing to other *markalak* clay samples such as 8466 or 6052. The grain shape is given according to Tucker (1985: 17f.).

| >6,300 µm | >2,000 µm | >630 µm | >200 µm | >63 µm | on average |
|---|---|---|---|---|---|
| nonexistent | 0 (1) | 1 | 1 | not measured | 1 |

### Bulk mineral analysis

The BMA shows great similarity to samples from Spituk. Mica, 7Å minerals, phyllo silicates, and K-feldspar are available in small amounts; just 14Å minerals and amphiboles occur as traces while quartz and plagioclase occur in a medium amount (in the Table 3.4 marked with (**)). Similar to samples 6052 and 14875, a small amount of dolomite at 3% is also available. The content of calcite at 15% is about the average amount for the samples from Spituk but below the average amount of the samples of Spituk. The sample shows no evidence of the content of ferric oxides.

### Clay mineral analysis

In general the clay mineral distribution is also similar with the samples from Spituk, in particular with sample 6052. The following list shows a comparison with sample 6052 from Spituk.

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 8526 | 6 | 63 | 5 | 26 |
| 6052 | 6 | 70 | 6 | 18 |

Primarily regarding the grain size distribution, this sample's properties do not follow the properties of the *markalak* clay samples, which were examined in Spituk, and also not the other samples, which were collected at Alchi, i.e. samples 14876 and 8526. Morup Dorje knew about the *markalak* clay's approximate location close to the bridge and mentions this material as suitable for making roofs, bringing it in relation with the term *"markalak"*.

In this case a hypothesis for using the term *"markalak"* for this material is its relation to its general use for construction of a roof (which *markalak* clays is general known to be used for). In this context we can not exclude that Morup Dorje took a coarse material from near the site where *markalak* clay is found in regard to his knowledge about the material's use. In this relation the *markalak* clay is not necessarily a highly fine material, as was examined for the samples from Spituk, but related to a particular use, place and commonly known properties.

Use and place are clear in this context while the common traditionally accepted properties are not that clearly defined. Since this material still shows the same content of swellable material as the fine *markalak* clay, this may be one of the prime properties of this material. The grain size distribution shows the availability of all the fine fractions (silt and clay), still with an amount of 38.2%. Morup Dorje mentions that this type of *markalak* clay is not needed to be mixed with sand but that it is used in a kind of already 'mixed' natural state.

## ALCHI. SAMPLE 11934

### Sampling point

This sample was collected along the road leaving the village of Alchi towards the bridge crossing the Indus. Deldan Angmo, who at the time was working at INTACH,[14] collected the sample (Fig. 14.4). Sample number in the field: 49. Constructive use: Today this material is known for making earth roofs. It is used without any further additives and without sieving. Further use was not reported but refers to the description given under sample 14875.

Fig. 14.4 Alchi. Sample 11934. Sample colour (after Munsell): Dry 10YR 8/2 very pale brown. Semi-dry 10YR 5/3 brown.

### Grain size distribution

Generally speaking the grain size distribution of this sample shows a difference (i.e. less clay and more silt) to samples from Spituk, in particular samples 8466 and 8481 or sample 14875 collected by ACHI Association in Spituk. The material is very fine. Biggest fraction: fine sand. The median is located at app. 2.6 µm (vs. 0.9 µm at sample 8466 and 0.6 µm at sample 8481; 0.8 µm at sample 14875); the <2 µm fraction contains app. 43% of the whole sample (vs. sample 8481 with 82% and sample 8466 with 80%; sample 14875 with 70%) and can be described as high. Contrary to samples 8466 and 8481, which contain just between 17.5% and 20% of silt, this sample contains a higher amount of silt than clay. A mixture of the material with sand or another type of clay is excluded since this sample was directly taken from the pit. The depositional environment is similar to the samples from Spituk. For comparison, samples 8466, 8481 and 14875 from Spituk are listed below:

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 11934 (Alchi) | 0 | 1.3 | 56.2 | 42.5 |
| 8466 (Spituk) | 0 | 0.3 | 20 | 79.7 |
| 8481 (Spituk) | 0 | 1 | 17.5 | 81.5 |
| 14875 (Spituk) | 0 | 0.9 | 31.3 | 67.8 |

---

[14] INTACH: Indian National Trust for Art and Cultural Heritage; www.intach.org: In 1984, the Indian National Trust for Art and Cultural Heritage (INTACH) was registered as a society and founded with the vision to create a membership organisation to stimulate and spearhead heritage awareness and conservation in India.

### Bulk mineral analysis

The BMA shows great similarity to samples from Spituk and also within the whole range of *markalak* clay samples collected in Alchi. 14Å minerals, mica, 7Å minerals, phyllo silicates, quartz, and plagioclase are available in small amounts; only amphiboles and K-feldspar occur as traces. Dolomite is not available in this sample. The content of calcite at 14% is about the average amount for the samples from Alchi but below the average amount of the samples of Spituk. The sample shows no evidence of the content of ferric oxides. Similarities are given with the greyish/brown layers of sample 8466 from Spituk or the brown portion of sample 14785 but not with the more greyish portions of these samples or sample 8526, also from Alchi.

### Clay mineral analysis

In general the clay mineral distribution is also similar with the samples from Spituk. The following list shows comparison with samples 6052 and 14875 from Spituk.

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 11934 (Alchi) | 7 | 55 | 4 | 33 |
| 6052 (Spituk) | 6 | 70 | 6 | 18 |
| 14875 (Spituk) | 3 | 64 | 6 | 27 |

## ALCHI. SAMPLE 14876

### Sampling point

This sample was collected in Alchi by members of the ACHI Association and handed over by Dr. Christine Bläuer (Fig. 15.4). Constructive use: As reported by conservators, it is used as filling material for cracks. For a detailed description, refer to the remarks given for the use of sample 14875.

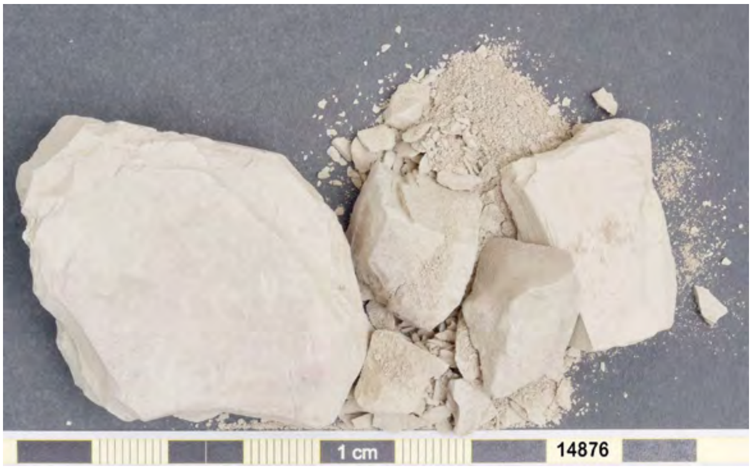


Fig. 15.4 Alchi. Sample 14876.
Sample colour (after Munsell):
Dry 7.5YR 6/3 light brown.
Semi-dry 7.5YR 5/3 brown.

### Grain size distribution

Generally speaking the grain size distribution of this sample shows strong similarity with sample 11934, which is also from Alchi and collected by Deldan Angmo. The material is very fine. Biggest fraction: fine sand. The median is located at app. 1.2 µm (slightly less as at sample 11934); the <2 µm fraction contains app. 77% of the whole sample (higher than for sample 11934 with 43%) and can be described as high. The content of silt and the distribution within the silt and clay fractions is also slightly different to sample 11934. In the distribution curve, no bimodal distribution is evident. A mixture of the material with other substances is excluded since this sample was directly taken from the pit. The grain size distribution curve shows a soft break from fine silt to medium silt and emphasises a clear dominance of clay. A strong similarity to sample 14875 is given.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 14876 (Alchi) | 0 | 0.4 | 23.3 | 76.3 |
| 11934 (Alchi) | 0 | 1.3 | 56.2 | 42.5 |
| 14875 (Spituk) | 0 | 0.9 | 31.3 | 67.8 |

### Bulk mineral analysis

The BMA shows great similarity to sample 11934 from Alchi and also within the whole range of *markalak* clay samples collected in Alchi. 14Å minerals, mica, 7Å minerals, phyllo silicates, quartz and plagioclase are available in small amounts; only amphiboles and K-feldspar occur as traces. Traces of haematite are visible in the sample colour itself. Dolomite is not available in this sample. The content of calcite at 4% is below the rate shown for sample 11934 with 14% but similar to an average available in samples 6052, 8466 and 8481 collected in Spituk. The sample shows evidence of the content of ferric oxides referring to a content of haematite. Similarities are given with samples 8466, 8481 and 14875 (all from Spituk) but not with the colours of samples 8526 and 11934 from Alchi.

### Clay mineral analysis

In general the clay mineral distribution is also similar to sample 11934 and the samples collected in Spituk. The following list shows a comparison with samples 6052 and 14875 from Spituk and the examined samples from Alchi. From the first to the fourth chlorite peak, they are continuously increasing which raises the question for the existence of an aluminium chlorite (similar to material to be found e.g. in Waldviertel in Austria) and not ferric magnesium-chlorites.

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 14876 (Alchi) | 7 | 62 | 5 | 26 |
| 11934 (Alchi) | 7 | 55 | 4 | 33 |
| 6052 (Spituk) | 6 | 70 | 6 | 18 |
| 14875 (Spituk) | 3 | 64 | 6 | 27 |
| 8526 (Spituk) | 6 | 63 | 5 | 26 |

Regarding the data of this sample, we can state that samples 11934 and 14876 must have been collected in close vicinity to each other. They are not completely identical but equal each other in most parameters.

## 3.4 Lamayuru

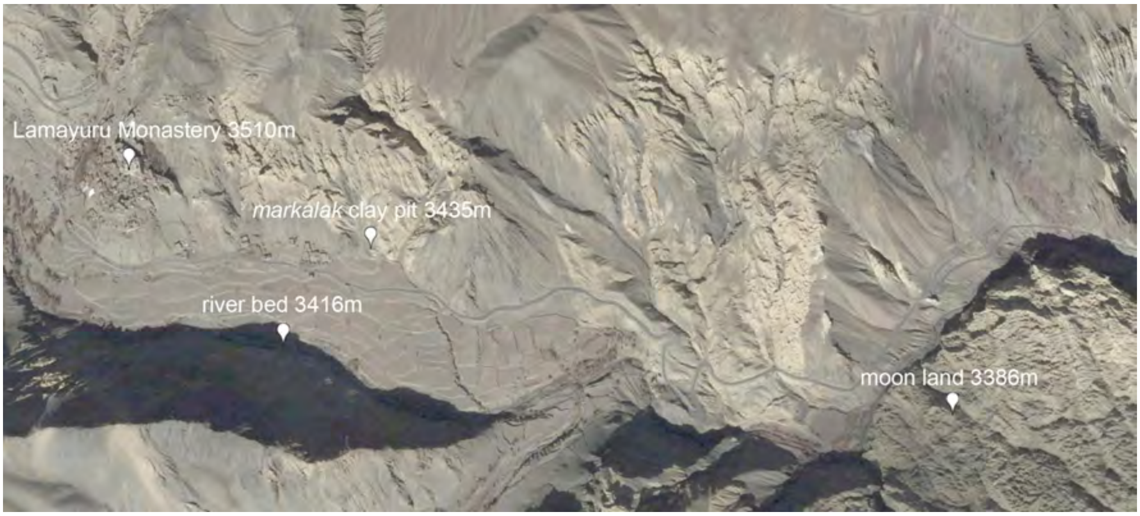


Fig. 16.4 Lamayuru. Ladakh. The level marks show the incline of the cross-country tread from the riverbed to the remains of the lacustrine basin. Source: Google Earth. Image © 2015 Digital Globe. Image NASA.

### LAMAYURU. SAMPLE 11939

#### Sampling point

Lamayuru is located on a former quaternary palaeolake (Fig. 16.4 and Fig. 17.4). Different layers of sedimentation are visible, in particular in the structure of varve clays (Fig. 18.4). This sample was collected in Lamayuru at the eastern entrance to the village, located at app. 34°16’59.22”N, 76°46’45.08”E (Fig. 19.4). The clay pit is located along the road to the right when moving towards Lamayuru and opposite the well-known “moon land”. The location of digging for this kind of *markalak* clay is also locally well known. The area of the clay pits is located at a distance of app. 300 m from the Lamayuru River and 30 m above its riverbed at a crossing with another small valley in a northern direction. Along the glacial trough of the river and as a result of the inflow from the north, a lake may have resulted in pounding water and continuous piling up of layer by layer of fine alluvial sediments, similar to the situation at Spituk. Sample number in the field: 65. Constructive use: Today this material is known for making the upper layer of earth roofs and used for building purposes such as additive for upper plaster layers. It is known for being mixed with sand for the preparation of plasters.

#### Grain size distribution

Generally speaking the grain size distribution of this sample shows a similarity with the *markalak* clay samples that contain a relatively high amount of silt with a maximum peak at the coarse silt fraction. In this relation, sample 6052 from Spituk is comparable. The material is relatively fine. Biggest fraction: fine sand (not counting extremely low contents of fine gravel with 0.5%, coarse sand with 0.5% and medium sand with 0.4%). The median is located at app. 2.3 µm; the <2 µm fraction contains app. 48% of the whole sample which can be described as high. Contrary to the

Fig. 17.4 (Top) Lamayuru. Area of clay pits.

Fig. 18.4 (Below) Lamayuru. Striped *markalak* clay.

Fig. 19.4 Lamayuru.Sample 11939.
Sample colour (after Munsell):
Dry 10YR 7/1 light grey.
Semi-dry 10YR 6/2 light brownish grey.

other afore examined samples of *markalak* clay– except for samples 6052 and 11934 – the highest peak is silt and not of clay fraction. The silt and clay fractions show a similar proportional content within the whole sample. For most of the samples, there is a dominance of the silt fraction. In the distribution curve, no bimodal distribution is evident. A mixture of the material with sand or another type of clay is excluded since this sample was directly taken from the pit. The grain size distribution curve shows no break but a smooth course. For comparison, samples 8466, 8481, 14875 from Spituk and samples 11934 and 14876 from Alchi are listed below:

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 11939 (Lamayuru) | 0 | 2.1 | 49.7 | 48.2 |
| 6052 (Spituk) | 0.1 | 0.2 | 84.6 | 15.1 |
| 11934 (Alchi) | 0 | 1.3 | 56.2 | 42.5 |

### Bulk mineral analysis

In general, the BMA shows great similarity to the other examined *markalak* clay samples. Mica, quartz and plagioclase are available in small amounts (marked in Table 3.4 with (*)); 14Å minerals, amphiboles, 7Å minerals and K-feldspar occur as traces. Traces of haematite are visible in the X-ray diffractogram and also in regard to the sample colour itself. The amount of phyllo silicates is available in a medium amount (marked in the Table 3.4 with (**)). Dolomite is not available in this sample. The content of calcite at 16% is similar to samples 8526, 11934 and 14874, and ranges slightly above an average content of calcite within the *markalak* clay samples. The sample shows evidence of ferric oxides pointing towards a content of haematite. Similarities are given to samples 8466, 8481 and 14875 (all from Spituk), and 14876 from Alchi. A varve structure on the sample is not clearly evident.

### Clay mineral analysis

In general the clay mineral distribution shows similarities with sample 14876 from Alchi and the samples collected in Spituk. Compared to the examined samples of Spituk and Alchi, no smectite is available while the content of illite is clearly higher. Further, this sample contains a mixed layer (illite-smectite; in the list below mentioned in short as ML).

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 11939 (Lamayuru) | 0 (ML) | 77 | 7 | 16 |
| 14876 (Alchi) | 7 | 62 | 5 | 26 |

## LAMAYURU. SAMPLE 14874

### Sampling point

This sample was collected at Lamayuru by members of the ACHI Association and handed over by Dr. Christine Bläuer (Fig. 20.4). Constructive use: Used as filling material for cracks, as reported by conservators. For a detailed description, refer to the remarks given for the use of sample 14875.

Fig. 20.4 Lamayuru. Sample 14874.
Sample colour (after Munsell):
Dry 10YR 7/2 light grey.
Semi-dry 10YR 5/3 brown.

### Grain size distribution

Generally speaking the grain size distribution of this sample shows strong similarity with *markalak* clay sample 11939. The material is relatively fine. Biggest fraction: coarse gravel (not counting an extremely low content of fine gravel with 0.2%). The median is located at app. 2.9 µm (vs. 2.3 µm at sample 11939); the <2 µm fraction contains app. 40% of the whole sample (vs. 48% for sample 11939 and 43% for sample 11934) and can be described as high. Similar to sample 11939 from Lamayuru, the silt and clay fractions show a similar proportional content within the whole sample; for sample 14874 the silt content is slightly higher while sample 11939 shows a slightly higher content of fine sand. A mixture of the material with sand or another type of clay is excluded since this sample was directly taken from the pit. The grain size distribution curve shows no break but a smooth course, which is very close to the course shown at sample 11939. Dark coloured samples are extremely fine regarding the high content of clay.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 14874 (Lamayuru) | 0 | 0.1 | 58.8 | 41.1 |
| 11939 (Lamayuru) | 0 | 2.1 | 49.7 | 48.2 |
| 11934 (Alchi) | 0 | 1.3 | 56.2 | 42.5 |

Bulk mineral analysis

With small differences the BMA shows a similar result to that of sample 11939. Mica, 7Å minerals, phyllo silicates, quartz and plagioclase are available in small amounts (marked in Table 3.4 with (*)); 14Å minerals and K-feldspar occur as traces while amphiboles are not available. Dolomite is not available in this sample. Similar to samples 6052, 8466, and 8481, possible traces of goethite may exist but can not be stated with certainty. The content of calcite at 11% is slightly smaller than for sample 11939 and slightly below the average range of the *markalak* clay samples. The sample shows a linear varve structure, which is not similar to sample 11939 from Lamayuru. A possible content of goethite, following traces in the X-ray diffraction, may explain the yellowish coloured stripes.

Clay mineral analysis

In general, the clay mineral distribution is also very similar with sample 11939. The amount of smectite is also rather low and the content of illite clearly higher than for the other previously tested samples in Spituk and Alchi.

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 14874 (Lamayuru) | 2 | 73 | 7 | 18 |
| 11939 (Lamayuru) | 0 | 77 | 7 | 16 |

## 3.5 Basgo

Fig. 21.4 Basgo. The level marks show the incline of the cross-country tread from the riverbed of the Indus to the remains of the lacustrine basin. Source: Google Earth. Image © 2015 CNES / Astrium.

Fig. 22.4 (Top) Basgo. Clay pit.

Fig. 23.4 (Below) Basgo. *Markalak* clay.

## BASGO. SAMPLE 15518

### Sampling point

This sample was collected in Basgo along a hill not far from the main road. The location of the clay pit is on the left side of the main road in a westerly direction after reaching the high plateau above Basgo when leaving the village along the serpentine road, located at app. 34°13'20.36"N, 77°16'3.47"E (Fig. 21.4, Fig. 22.4 and Fig. 23.4) (cf. Feiglstorfer 2014: 383). The site can be seen from further away due to its bright and white shiny appearance. The area of the clay pit is located at a distance of app. 2.7 km from the Indus River and app. 250 m higher than the riverbed. The next river to the clay pit is embedded in an inflow side valley to the Indus River with a distance of app. 600 m from the clay pit and app. 70 m higher than the riverbed. Along the glacial trough of the Basgo River following the high plateau towards the west, pounding water may have resulted in a continuous piling up of layer by layer of fine alluvial sediments, similar to the situation at Spituk. Sample number in the field: 84 BA/MARK. Constructive use: Today this material is known for being used to make the upper layer of earth roofs and for building purposes such as an additive for upper plaster layers (Fig. 24.4).

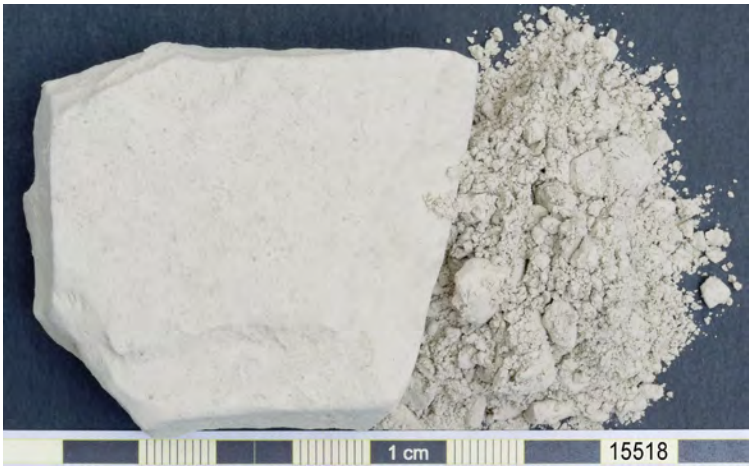


Fig. 24.4 Basgo. Sample 15518.
Sample colour (after Munsell):
Dry 10YR (8/1 to 7/1) light grey.
Semi-dry 10YR 5/4 yellowish brown.

### Grain size distribution

Generally speaking the grain size distribution of this sample shows strong similarity with the *markalak* clay samples from Lamayuru. The material is relatively fine. Biggest fraction (not counting the small amount at 0.4% of the fine sand fraction): coarse silt. The median is located at app. 3.6 µm (vs. 2.9 µm for sample 14874 and 2.3 µm for sample 11939); the <2 µm fraction contains app. 32% of the whole sample (vs. 40% for sample 14874 and 48% for sample 11939, both from Lamayuru) and can be described as high but slightly lower than mentioned samples 14874 and 11939 from Lamayuru. The amount of silt at 68.5% is clearly higher than the case for the Lamayuru samples 14874 and 11939. A mixture of the material is excluded since this sample was directly taken from the pit. The grain size distribution curve shows a soft break between medium silt and coarse silt, and fine silt and coarse clay. At 35.9% the maximum peak is fine silt.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 15518 (Basgo) | 0 | 0.1 | 68.5 | 31.4 |
| 11939 (Lamayuru) | 0 | 2.1 | 49.7 | 48.2 |
| 14874 (Lamayuru) | 0 | 0.1 | 58.8 | 41.1 |

### Bulk mineral analysis

With small differences the BMA shows a similar result to the BMA of the *markalak* clay samples. Differences are the phyllo silicates which are available only as traces and the amphiboles which are not available as traces but in small amounts. Mica, amphiboles, 7Å minerals, quartz and K-feldspar are available in small amounts (marked in Table 3.4 with (*)); besides the phyllo silicates, the 14Å minerals also occur as traces. Plagioclase occurs in a medium amount. Dolomite is not available in this sample. At 1% the content of calcite (measured according to Scheibler) is very small and much below the average rate for calcite within the *markalak* clay samples. This also seems to be a kind of marker of difference to samples 11939 and 14874, both from Lamayuru. When comparing the colour to the samples from Lamayuru, the similarity is strong, with tendencies of grey towards a yellowish colour; similar to sample 119389, but contrary to sample 14874, the sample shows no varve structure.

Samples from Lamayuru for comparison of the colour (according to Munsell colour chart):

| | | | |
|---|---|---|---|
| 14874 | Dry | 10YR 7/2 | light grey |
| | Semi-dry | 10YR 5/3 | brown |
| 11939 | Dry | 10YR 7/1 | light grey |
| | Semi-dry | 10YR 6/2 | light brownish grey |

### Clay mineral analysis

The following list shows comparison of samples 6052 and 14875 from Spituk, and the examined samples from Alchi and from Lamayuru. The similarity of sample 15518 from Basgo to sample 14874 is striking. Besides the samples from Shey (see below), the Lamayuru-Basgo samples show the highest amount of illite while samples from the latter group show a very small content of smectite and a lower content of chlorite.

| | Smectite | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|
| 15518 (Basgo) | 3 | 76 | 6 | 15 |
| 6052 (Spituk) | 6 | 70 | 6 | 18 |
| 14875 (Spituk) | 3 | 64 | 6 | 27 |
| 14874 (Lamayuru) | 2 | 73 | 7 | 18 |

## 3.6 Shey

Fig. 25.4 Shey. The level marks show the incline of the cross-country tread from the riverbed of the Indus to the remains of the lacustrine basin.
Source: Google Earth. Image © 2015 CNES / Astrium.

### SHEY. SAMPLE 11913

#### Sampling point

This sample was collected in Shey in the area of the big field of stupas along the road on the right side when moving towards Leh, located at app. 34°4’27.89”N, 77°38’21.98”E. The area of the clay pits is located with a distance of app. 1.3 km from the Indus and just 10 m to 15 m above its riverbed within a wide plain of lateral offsets of the Indus (Fig. 25.4). Towards the west and north, a small mountain belt encompasses the area of the *markalak* clay pit. Along the glacial trough of the Indus, this small river belt points towards a former naturally formed basin for keeping water that allowed for a continuous piling up of layer by layer of fine alluvial sediments, similar to the situation given at Spituk or Lamayuru (Fig. 26.4 and Fig. 27.4). Sample number in the field: 72. Constructive use: Today this material (Fig. 28.4) is known for making the upper layer of roofs and used for building purposes such as additives for upper plaster layers.

#### Grain size distribution

Generally speaking, the grain size distribution of this sample shows a strong similarity with the *markalak* clay samples from Lamayuru and Basgo. The material is relatively fine with a slightly higher content of fine sand than found for samples 15518 (Basgo) and 14874 (Lamayuru), though it is similar to sample 11939 (Lamayuru). Biggest fraction: medium sand with 0.5%.

Fig. 26.4 (Top) Shey. Area of clay pits.

Fig. 27.4 (Below) Shey. *Markalak* clay.

Fig. 28.4 Shey. Sample 11913.
Sample colour (after Munsell):
Dry 5YR 7/1 light grey.
Semi-dry 5YR 5/1 grey.

The median is located at app. 2.8 µm (vs. 3.6 µm for sample 15518 (Basgo), 2.9 µm for sample 14874 and 2.3 µm for sample 11939 (both from Lamayuru)); the <2 µm fraction contains app. 43% of the whole sample (vs. 32% for sample 15518 (Basgo), 40% for sample 14874 and 48% for sample 11939 (both from Lamayuru), and 43% for sample 11934 (Alchi)) and can be described as high. At 54% the amount of silt is slightly higher than the amount of clay at 43.7%. Together with samples 15518 from Basgo, 6052 from Spituk and 11934 from Alchi, it is one of the samples in which the amount of silt is higher than the amount of clay. A mixture of the material is excluded since this sample was directly taken from the pit. The grain size distribution curve shows a soft break between medium silt and coarse silt. At 23.4% the maximum peaks are medium and fine silt. A juxtaposition of the single grain size classes is given in the following list.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 11913 (Shey) | 0 | 2.3 | 54 | 43.7 |
| 6052 (Spituk) | 0.1 | 0.2 | 84.6 | 15.1 |
| 11934 (Alchi) | 0 | 1.3 | 56.2 | 42.5 |
| 11939 (Lamayuru) | 0 | 2.1 | 49.7 | 48.2 |
| 14874 (Lamayuru) | 0 | 0.2 | 58.8 | 41.1 |
| 15518 (Basgo) | 0 | 0.1 | 68.5 | 31.4 |

### Bulk mineral analysis

With small differences the BMA of this sample shows a similar result to the BMA of the *markalak* clay samples in general. 14Å minerals, mica, 7Å minerals, phyllo silicates, quartz and plagioclase are available in small amounts (marked in Table 3.4 with (*)); amphiboles and K-feldspar occur as traces. Dolomite is not available in this sample. The content of calcite at 5% is small and below the average rate for calcite within the *markalak* clay samples. The grey colour is dominant. No ferric oxides can be traced.

### Clay mineral analysis

The CMA shows differences to most of the previously analysed samples from Spituk, Alchi, Lamayuru and Basgo. Together with samples 11939 and 14874 from Lamayuru, the content of smectite is very small but sample 11913 shows a content of 5% 14Å vermiculite. Together with 1% smectite, it has an average range of content of swellable clay minerals. The following list shows comparison with samples 6052 and 14875 from Spituk and the examined samples from Alchi, Lamayuru and Basgo. This sample from Shey reaches the highest content of illite within the *markalak* clay samples. In general it differs in several parameters from the average *markalak* clay samples. The amount of kaolinite is within an average range but the content of chlorite is comparably low and is the only *markalak* clay sample containing vermiculite. A hornblende appears in the 2 µm-fraction. Also a mixed layer was detected, keeping two variations of mixtures open: 1. chlorite and vermiculite; 2. chlorite and smectite.

| | Smectite | Vermic | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|---|
| 11913 (Shey) | 1 | 5 | 85 | 7 | 2 |
| 6052 (Spituk) | 6 | 0 | 70 | 6 | 18 |
| 14875 (Spituk) | 3 | 0 | 64 | 6 | 27 |
| 11939 (Lamayuru) | 0 | 0 | 77 | 7 | 15 |

## SHEY. SAMPLE 15404

### Sampling point

This sample was collected in Shey from a clay pit (Fig. 29.4). The reason for taking this material into consideration although it has nothing to do with a *markalak* clay is to make its difference clear to another locally used and well known *markalak* clay. In doing so we can question the unique characters of *markalak* clay material. Sample number in the field: 78 SH/ZI. Constructive use: The material is well known as a raw material for adobe bricks. At the CIBS (Central Institute of Buddhist Studies) in Choglamsar in Leh in Ladakh, this material is used to build the first form for clay statues around which the model is later sculptured.

Fig. 29.4 Shey. Sample 15404.
Sample colour (after Munsell):
Dry 10YR 5/3 brown.
Semi-dry 10YR 3/3 dark brown.

### Grain size distribution

Generally speaking the grain size distribution of this sample shows a strong difference to all the afore compared *markalak* clay samples, except sample 8526 from Alchi which was called *markalak* clay by Morup Dorje, a local teacher. In this relation we move closer to another kind of *markalak* clay which bears several specific characteristics, in particular fine fractions of silt and clay. It furthermore has a rather coarse component as a natural mixture. The material is relatively coarse. Biggest fractions: fine gravel. The median is located at app. 180 µm (vs. 95 µm at sample 8526 from Alchi); the <2 µm fraction contains app. 13% of the whole sample (same as for sample 8526 from Alchi). The peak lies at the sand fraction with a maximum of 23.4% of medium sand (vs. a maximum of 32.6% of fine sand for sample 8526 from Alchi). In the distribution curve, a bimodal distribution with a soft valley between coarse and fine silt is evident. The sample was reported to the author as pure and unmixed. A comparison with the coarse *markalak* clay of sample 8526 from Alchi, located about 46 km away, shows its close similarity, while a comparison with the fine *markalak* clay of sample 14876, also from Alchi, shows its difference. A comparison between these samples shows close similarities with the coarse building material from Alchi given with sample 8526.

| | Gravel | Sand | Silt | Clay [in %] |
|---|---|---|---|---|
| 15404 (Shey, coarse building material) | 8 | 57.9 | 21 | 13.1 |
| 14876 (Alchi, fine *markalak* clay) | 0 | 0.4 | 23.3 | 76.3 |
| 8526 (Alchi, coarse *markalak* clay) | 8.1 | 53.7 | 24.4 | 13.8 |

### Bulk mineral analysis

With small differences the BMA shows a similar result to the BMA of the *markalak* clay samples in general. The medium amount of amphiboles is the highest available rate within the *markalak* clay samples (marked in Table 3.4 with (**)). K-feldspar, mica, 7Å minerals and quartz are also available in small amounts (marked in Table 3.4 with (*)); 14Å minerals and phyllo silicates occur as traces. The content of plagioclase is relatively high (marked in Table 3.4 with (***)). Dolomite is not available. The content of calcite at 1% is very small and below the average rate for calcite within the *markalak* clay samples. This samples range within the greyish colours with a slight tendency towards yellowish. Neither in the X-ray diffraction nor with the naked eye could ferric oxides be traced.

### Clay mineral analysis

A comparison of the CMA samples 8526 (Alchi, coarse *markalak* clay), 14876 (Alchi, fine *markalak* clay) and 11913 (Shey, fine *markalak* clay) shows strong similarities to the CMA of the samples of Alchi but not to sample 11913 which also has its origin in Shey. The following list shows a comparison with samples 8526 from Alchi (a coarse *markalak* clay) and 14876 from Alchi (a fine *markalak* clay).

| | Smectite | Vermic | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|---|
| 15404 (Shey) | 4 | 0 | 71 | 5 | 20 |
| 11913 (Shey) | 1 | 5 | 85 | 7 | 2 |
| 14876 (Alchi) | 7 | 0 | 62 | 5 | 26 |
| 8526 (Alchi) | 6 | 0 | 63 | 5 | 26 |

## 3.7 Nako

### NAKO. SAMPLE 15516

#### Sampling point

This sample was collected at the Nako temple building site during renovation work in 2006. The exact source was a heap of clay which was collected about 2 km to the west of Nako, located at Kirsi at app. 78°36'31.32"E, 31°52'42.96"N (Gruber 2011: 139). The material is commonly known as *tua*[15] clay instead of as *markalak* clay (Fig. 30.4). Nako is located in Upper Kinnaur in the Indian state Himachal Pradesh south of Ladakh close to Spiti in the west and the Chinese border in the east. The inclusion of this sample into the *markalak* clay analysis was due to its commonly known fine character and locally mentioned similarity to *markalak* clay. This material is locally mentioned to be similar to the *tua* clay from Shelkhar (compared to the following sample 8504) and was handed over by locals at the building site. The *markalak* clay pit is located along a valley which passes Nako to its west leading into the Spiti River. The area of the clay pit is located with a distance of app. 1 km from the Spiti River and is app. 250 m higher than the riverbed. Along the glacial trough of this side valley, in the form of an inflow into Spiti Valley, one can find deposits along the trough valley. Such deposits may have resulted from a continuous piling up of layer by layer of fine alluvial sediments. Sample number in the field: 82 NAK/*Tua*. The fibres shown in the picture may not be part of the original sample but show remains of building material used during the conservation work. Constructive use: Today this material is known for making the upper layer of earth roofs. Additionally Maria Gruber describes its use as binder in mortars (Gruber 2011: 141).

Fig. 30.4 Nako. Sample 15516.
Sample colour (after Munsell):
Dry 10YR 7/2 light grey.
Semi-dry 10YR 5/4 yellowish brown.

---

[15] Besides *thawa* and *sassa* the *tua* clay is another locally available earth building material. Compare Gruber 2011: 115. The *tua* clay can be classified as clay-silt (Gruber 2011: 139).

### Grain size distribution

Generally speaking, the grain size distribution of this sample shows a strong similarity to fine Ladakh *markalak* clays. The median is located at app. 4.5 µm (vs. 11934 from Alchi with a median at app. 2.6 µm, 11939 from Lamayuru with a median at app. 2.3 µm, and 11913 from Shey with a median at app. 2.8 µm). It is relatively close to sample 15518, a *markalak* clay from Basgo, with a median at app. 3.6 µm; the <2 µm fraction contains app. 29% of the whole sample (vs. 11934 from Alchi with an amount of <2 µm of app. 43%, 11939 from Lamayuru with an amount of 2 µm of app. 48%, and 11913 from Shey with an amount of 2 µm of app. 43%). At app. 32% and 2 µm, sample 15518 from Basgo is again very close to sample 15516. In the distribution curve no bimodal distribution is evident. The grain size distribution curve shows no break with a smooth course. The maximum peak is 30% fine silt. The proportional relation between silt and clay (silt:clay) is also very similar between these two samples: Sample 15518 (*markalak* clay from Basgo) with 68.5:31.4 and sample 15516 (*tua* clay from Nako) with 61.9:29.4. All other fine *markalak* clay samples show a slightly higher content of fine and medium clay, again with an exception being sample 15518 (*markalak* clay from Basgo), which shows similar rates. The sample was locally reported to the author as pure and unmixed.

A comparison with other *markalak* clays shows average rates – except for the slightly increased rates for the content of gravel and sand. The samples *Tua** and *Tua*** have been examined by Maria Gruber (Gruber 2011: 139) and are listed for further comparison. Sample *Tua** also shows similarities to sample 15516 from Nako regarding a slightly higher content of sand and a small amount of gravel. In contrast, sample *Tua*** – in Gruber 2011 referred to as *Tua* (T3) – shows strong similarities to *markalak* clay samples, such as sample 15518 from Basgo.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 15516 (Nako) | 2.8 | 5.9 | 61.9 | 29.4 |
| *Tua** (Nako) | 0.2 | 2.6 | 71.4 | 25.9 |
| *Tua*** (Nako) | 0 | 0.1 | 63.5 | 36.4 |
| 15518 (Basgo) | 0 | 0.1 | 68.5 | 31.4 |
| 11934 (Alchi) | 0 | 1.3 | 56.2 | 42.5 |
| 11939 (Lamayuru) | 0 | 2.1 | 49.7 | 48.2 |

### Bulk mineral analysis

With small differences, the BMA shows a similar result to the BMA of the *markalak* clay samples. Mica, 7Å minerals, phyllo silicates, quartz, plagioclase and K-feldspar are available in small amounts (marked in the Table 3.4 with (*)); 14Å minerals and amphiboles occur as traces. Dolomite is available at 4%. At 36% the content of calcite ranges within the highest rates of the *markalak* clay samples – with this high amount we certainly find a main difference to other *markalak* clay samples whose average contents of calcite are generally lower. It is similar to 38.4% (Gruber 2011: 140), i.e. the result given by Maria Gruber measured with STA. *Tua* clay sample 15516 from Nako ranges within the greyish colours with a slight tendency towards yellowish colouring. Neither in the X-ray diffraction nor with the naked eye is there evidence of ferric oxides. The material appears monochromatic without any varve texture. A comparison of the colour with sample 15518 from Basgo shows similarities with a tendency into yellowish.

| | | | |
|---|---|---|---|
| 15516 | Dry | 10YR 7/2 | light grey |
| | Semi-dry | 10YR 5/4 | yellowish brown |
| 15518 | Dry | 10YR (8/1)–7/1 | light grey |
| | Semi-dry | 10YR 5/4 | yellowish brown |

### Clay mineral analysis

The following list shows a comparison with *markalak* clay samples 14875 from Spituk and 14876 from Alchi, both of which show a close similarity to *markalak* clay sample 15516 from Nako. Sample 15518 from Basgo differs slightly from this pattern.

| | Smectite | Vermic | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|---|
| 15516 (Nako) | 4 | 0 | 69 | 3 | 27 |
| 15518 (Basgo) | 3 | 0 | 76 | 6 | 15 |
| 14875 (Spituk) | 3 | 0 | 64 | 6 | 27 |
| 14876 (Alchi) | 7 | 0 | 62 | 5 | 26 |

## 3.8 Shelkhar

### SHELKHAR. SAMPLE 8504

### Sampling point

This sample was collected at Shelkhar which is about 15 km to the north-west of Nako located at app. 32°0'32.81"N, 78°34'14.04"E (Fig. 31.4, Fig. 32.4 and Fig. 33.4). Same as with sample 15516, it is commonly known as *tua* clay instead of *markalak* clay. The area of the clay pit is located a distance of app. 250 m from the Spiti River and is app. 70 m higher than the riverbed. Several small valleys from the west lead towards Shelkhar. Deposits are found along the glacial trough of these side valleys in the form of an inflow into the Spiti River. Specifically located along the trough valley, these deposits may have resulted from continuous piling up of layer by layer of fine alluvial clay, similar to the situation given at the *tua* clay pit at Kirsi, which is located close to Nako.

In Tabo, for example, this material is also well known as a building material of high quality. In Dhankar, also located in the Spiti Valley, a material called *tala* is commonly known to be of high quality (Interview Tendup Giacho 2002; Feiglstorfer 2002: 12). Whether this material is similar to a *tua* or *markalak* clay is examined in future research. The author took part in digging up the material, thus a mixture of the sample-material with sand or other types of clay is excluded. The location of the relatively small clay pit is along a village road between several hamlets at the upper end of the village and appears as a several metres wide hole in the terrain on the level of the road. Shelkhar is a commonly known place for high quality *tua* clay.[16] The material itself becomes relatively hard after drying, similar to other fine *markalak* clay samples. Sample number in

---

[16] In addition to the statements of Maria Gruber (Gruber 2011: 139) the *tua* clay is not only available at Kirsi near Nako but the name "*tua*" indicates a species of a particular quality of clay belonging to the *markalak* clay type as stated by these tests.

Fig. 31.4 (Top) Shelkhar. The level marks show the incline of the cross-country tread from the riverbed of the Spiti River to the remains of the lacustrine basin. Source: Google Earth. Image © 2015 CNES / Astrium.

Fig. 32.4 (Below) Shelkhar. Area of the clay pit.

Fig. 33.4 Shelkhar. *Tua* clay pit.

the field: 51 SH/LG (Fig. 34.4). Constructive use: Today this material is known for making the upper layer of earth roofs. This material is locally also reported for making clay statues. After digging, the material is relatively hard and has to be crushed with a specific tool.[17]

## Grain size distribution

Generally speaking the grain size distribution of this sample shows strong similarity to fine Ladakh *markalak* clays, in particular to sample 15516. The material is relatively fine. Biggest fraction: coarse silt. Contrary to sample 15516 from Nako, no coarse material, i.e. gravel or sand, was determined. The median is located at app. 4.3 µm, similar to 4.5 µm for sample 15516 at Nako (vs. 11934 from Alchi with a median of app. 2.6 µm, 11939 from Lamayuru with a median of app. 2.3 µm and 11913 from Shey with of median at app. 2.8 µm). With a median of app. 3.6 µm, it is relatively close to sample 15518 from Basgo. The <2 µm fraction contains app. 28% of the whole sample, similar to 29% for sample 15516 from Nako (vs. 11934 from Alchi with an amount of <2 µm of app. 43%, 11939 from Lamayuru with an amount of <2 µm of app. 48%, and 11913 from Shey with an amount of 2 µm of app. 43%). At app. 32% with <2 µm, sample 15518 from Basgo is again very close to *tua* clay sample 15516. In the distribution curve no bimodal distribution is evident. The grain size distribution curve shows a soft break between medium silt and coarse silt, and coarse clay and medium clay. At 36.7% the maximum peak of fine silt is also similar to sample 15516 from Nako. The proportional relation between silt and clay (silt:clay) is also very similar between sample 15518 (*markalak* clay from Basgo) with 73.3:26.6, and sample 15516 (*tua* clay from Nako) with 61.9:29.4. All other fine *markalak* clay samples show a slightly higher content of fine and medium clay, again with an exception being sample 15518 (*markalak* clay from Basgo) which shows very similar rates. Since the author took part in digging, mixture of this material with sand or another type of clay can be excluded. A comparison to grain size classes of other *markalak* clay samples shows the close relation of sample 8504 from Shelkhar, primarily to samples 15516 from Nako and 15518 from Basgo.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 8504 (Shelkhar) | 0 | 0.1 | 73.3 | 26.6 |
| 15516 (Nako) | 2.8 | 5.9 | 61.9 | 29.4 |
| 15518 (Basgo) | 0 | 0.1 | 68.5 | 31.4 |
| 11934 (Alchi) | 0 | 1.3 | 56.2 | 42.5 |
| 11939 (Lamayuru) | 0 | 2.1 | 49.7 | 48.2 |
| 11913 (Shey) | 0 | 2.3 | 54 | 43.7 |

---

[17] Maria Gruber (2011: 141) describes such a tool as a wooden hammer with a surface of about 10 x 10 cm for crushing the material in smaller pieces and thereafter using it as a mortar for grinding into powder.

Fig. 34.4 Shelkhar. Sample 8504.
Sample colour (after Munsell):
Dry 10YR 7/2 light grey.
Semi-dry 10YR 6/4 light yellowish brown.

### Bulk mineral analysis

With small differences, the BMA shows a similar result to the BMA of the *markalak* clay samples in general and a strong similarity to sample 15516 from Nako. Mica, 7Å minerals, phyllo silicates, quartz and plagioclase are available in small amounts (marked in the Table 3.4 with (*)); 14Å minerals, amphiboles and K-feldspar occur as traces. Dolomite is available at 3%. The content of calcite at 27% is in average range under all *markalak* clay samples and fits well to the 36% of calcite for sample 15516 from Nako. The colour is similar to sample 15518 from Basgo.

| | | | |
|---|---|---|---|
| 15516 (Nako) | Dry | 10YR 7/2 | light grey |
| | Semi-dry | 10YR 5/4 | yellowish brown |
| 15518 (Basgo) | Dry | 10YR (8/1)–7/1 | light grey |
| | Semi-dry | 10YR 5/4 | yellowish brown |

### Clay mineral analysis

The following list shows a comparison with *markalak* clay sample 14875 from Spituk and 14876 from Alchi. Both are closely similar to *markalak* clay sample 15516 from Nako. At just 1% the rate for the content of smectite is comparably low. A comparison with samples 15516 from Nako and 15518 from Basgo shows close similarities.

| | Smectite | Vermic | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|---|
| 8504 (Shelkhar) | 1 | 0 | 69 | 3 | 27 |
| 15516 (Nako) | 4 | 0 | 69 | 3 | 15 |
| 14875 (Spituk) | 3 | 0 | 64 | 6 | 27 |
| 14876 (Alchi) | 7 | 0 | 62 | 5 | 27 |

## 3.9 Khorchag

Fig. 35.4 Khorchag Monastery located along the Peacock River.
Source: Google Earth. Image © 2015 Digital Globe.

### KHORCHAG. SAMPLE 15377

#### Sampling point

This sample was collected at Khorchag in West Tibet (Ngari) and is commonly known as *narkalak* clay, not as *markalak* clay as in Ladakh (Fig. 35.4). The sample was collected by a Lama close to the Khorchag-Purang main road in close vicinity to the monastery and the Peacock River. Khorchag itself is located close to the village of Purang about 100 km south of Mount Kailas and about 20 km from the border crossing to Nepal, which is in a southern direction at app. 30°11’45.04”N, 81°16’4.23”E. Khorchag is located both on an alluvial fan, generated by several side valleys, and also opposite of an alluvial fan on the other side of the river. Along the glacial trough of these side valleys, in the form of an inflow into the Peacock River, deposits along the trough valley must have resulted following continuous piling up of layer by layer of fine alluvial clay. Such piling must have specifically occurred in areas of slow flow velocity, like beside rivers such as the Peacock, which transports coarser material due to a higher flow velocity. Sample number in the field: 12 (Fig. 36.4). Constructive use: Today this material is known as a building material of high quality, in particular as ground for wall paintings.

#### Grain size distribution

Generally speaking, the grain size distribution of this sample shows a strong similarity to fine *markalak* clays with a relatively high content of silt and a small amount of coarse material. Despite a still small amount of coarse material, the material is still relatively fine due to a high content of

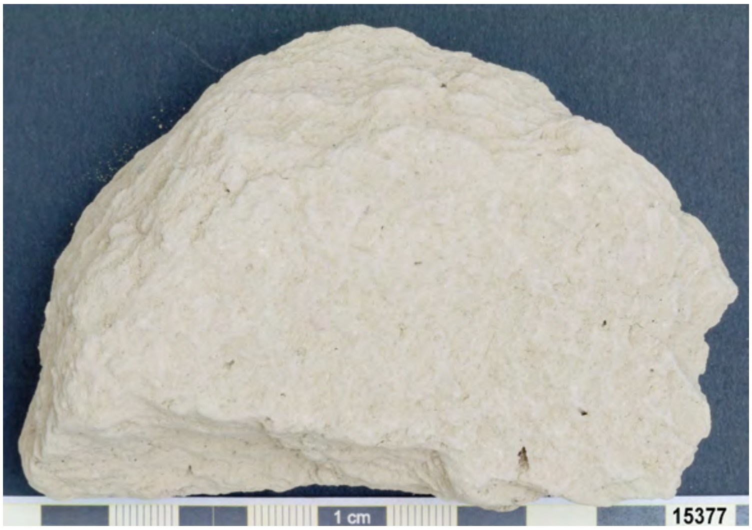


Fig. 36.4 Khorchag. Sample 15377.
Sample colour (after Munsell):
Dry 10YR 6/3 pale brown.
Semi-dry10YR 4/3 brown.

silt. Biggest fraction: medium gravel. Similar to sample 15516 from Nako, coarse material, i.e. gravel or sand, is available in a small amount. The median is located at app. 8.5 µm, (vs. sample 8504 from Shelkhar with a median of app. 4.3 µm, sample 15516 from Nako with a median of app. 4.5 µm, 11934 from Alchi with a median of app. 2.6 µm, 11939 from Lamayuru with a median of app. 2.3 µm, and 11913 from Shey with a median of app. 2.8 µm). It is relatively close to sample 15518 from Basgo with a median of app. 3.6 µm. The <2 µm fraction contains app. 28% of the whole sample, same as for sample 8504, i.e. the *tua* clay from Shelkhar, and similar to 29% of sample 15516 at Nako (vs. 11934 from Alchi with an amount of <2 µm of app. 43%, 11939 from Lamayuru with an amount of <2 µm of app. 48%, and 11913 from Shey with an amount of 2 µm of app. 43%). With app. 32% at 2 µm, sample 15518 from Basgo is again very close to sample 15516. In the distribution curve, no bimodal distribution is evident. The grain size distribution curve shows a soft break between coarse silt and fine sand and also between fine sand and medium sand. The maximum peaks are close to each other in the silt fraction (coarse silt 21.2%, medium silt 18.4%, and fine silt 17.3%).

The proportional relation between silt and clay (silt:clay) is also very similar between sample 15377 with 56.9: 28 and samples 15518 (*markalak* clay from Basgo) with 73.3:26.6, and in particular with sample 15518 (*markalak* clay from Basgo) with 61.9:29.4. All the other fine *markalak* clay samples show a slightly higher content of fine and medium clay. Since this sample has its origin with the longest distance from the other examined samples, the most relevant samples will be juxtaposed in the following list.

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 15377 (Khorchag) | 1.3 | 13.8 | 56.9 | 28 |
| 8504 (Shelkhar) | 0 | 0.1 | 73.3 | 26.6 |
| 15516 (Nako) | 2.8 | 5.9 | 61.9 | 29.4 |
| 15518 (Basgo) | 0 | 0.1 | 68.5 | 31.4 |
| 11934 (Alchi) | 0 | 1.3 | 56.2 | 42.5 |
| 11913 (Shey) | 0 | 2.3 | 54 | 43.7 |

### Bulk mineral analysis

With small differences to the BMA of sample 15377 from Khorchag, the BMA of this sample shows a similar result to the BMA of the *markalak* clay samples, in particular to samples 15516 (Nako) and 8504 (Shelkhar). Mica, 7Å minerals, phyllo silicates, quartz, K-feldspar and plagioclase are available in small amounts (marked in Table 3.4 with (*)); 14Å minerals and amphiboles are not available. At 1% dolomite is available in a very small amount. The content of calcite at 1% is very small and differs from the average amount within the *markalak* clay samples. Compared to samples 15518 from Basgo and 15516 from Nako, the sample 15377 has a tendency towards brown colouring.

| | | | |
|---|---|---|---|
| 15518 (Basgo) | Dry | 10YR (8/1)–7/1 | light grey |
| | Semi-dry | 10YR 5/4 | yellowish brown |
| 15516 (Nako) | Dry | 10YR 7/2 | light grey |
| | Semi-dry | 10YR 5/4 | yellowish brown |

### Clay mineral analysis

The following list shows a comparison with *markalak* clay sample 15518 from Basgo and *tua* clay sample 15516 from Nako. The grain size distribution and also BMA show similarities. At 3% of the clay fraction, the content of smectite is similarly low, and the content of illite is less. The striking difference is the absence of chlorite which was available in all the other examined samples.

| | Smectite | Vermic | Illite | Kaolinite | Chlorite [%] |
|---|---|---|---|---|---|
| 15377 (Khorchag) | 3 | 0 | 53 | 44 | 0 |
| 15518 (Basgo) | 3 | 0 | 76 | 6 | 15 |
| 15516 (Nako) | 4 | 0 | 69 | 3 | 15 |

## 3.10 Results of mineral analysis given in tables

Table 2.4 Grain size classes.

| **Sample** | **Gravel** [%] | **Sand** [%] | **Silt** [%] | **Clay** [%] | **Median** [µm at 50%] | **<2µm** [%] |
|---|---|---|---|---|---|---|
| Spituk | | | | | | |
| 6052 | 0.1 | 0.2 | 84.6 | 15.1 | 7.5 | 16 |
| 8466 | 0 | 0.3 | 20 | 79.7 | 0.9 | 80 |
| 8481 | 0 | 1 | 17.5 | 81.5 | 0.6 | 82 |
| 14875 | 0 | 0.9 | 31.3 | 67.8 | 0.8 | 70 |
| Alchi | | | | | | |
| 8526 | 8.1 | 53.7 | 24.4 | 13.8 | 95 | 13 |
| 11934 | 0 | 1.3 | 56.2 | 42.5 | 2.6 | 43 |
| 14876 | 0 | 0.4 | 23.3 | 76.3 | 1.2 | 77 |
| Lamayuru – Basgo | | | | | | |
| 11939 | 0 | 2.1 | 49.7 | 48.2 | 2.3 | 48 |
| 14874 | 0 | 0.1 | 58.8 | 41.1 | 2.9 | 40 |
| 15518 | 0 | 0.1 | 68.5 | 31.4 | 3.6 | 32 |
| Shey | | | | | | |
| 11913 | 0 | 2.3 | 54 | 43.7 | 2.8 | 43 |
| 15404 | 8 | 57.9 | 21 | 13.1 | 180 | 13 |
| Nako – Shelkhar | | | | | | |
| 15516 | 2.8 | 5.9 | 61.9 | 29.4 | 4.5 | 29 |
| 8504 | 0 | 0.1 | 73.3 | 26.6 | 4.3 | 28 |
| Khorchag | | | | | | |
| 15377 | 1.3 | 13.8 | 56.9 | 28 | 8.5 | 28 |

Table 3.4 Bulk mineral analysis.

| Sample | 14Å | Mica | Amph | 7Å | Phy sil | Quar | Goeth | K-fsp | Plagio | Calc | Dol | Haem | Gyps | Pyr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spituk | | | | | | | | | | | | | | |
| 6052 | . | * | --- | . | * | * | . ? | . | * | 69% | 5% | --- | --- | --- |
| 8466 | * | * | . | * | ** | * | . ? | . | * | 5% | --- | . | --- | . |
| 8481 | . | * | . | * | ** | * | . ? | . | * | 3% | --- | . | --- | --- |
| 14875 | . | * | . | * | * | * | --- | . | * | 42% | 6% | . | --- | --- |
| Alchi | | | | | | | | | | | | | | |
| 8526 | . | * | . | * | * | ** | --- | * | ** | 15% | 3% | --- | --- | --- |
| 11934 | * | * | . | * | * | * | --- | . | * | 14% | . | --- | --- | --- |
| 14876 | * | * | . | * | * | * | --- | . | * | 4% | --- | . | --- | . |
| Lamayuru – Basgo | | | | | | | | | | | | | | |
| 11939 | . | * | . | . | ** | * | --- | . | * | 16% | --- | . | --- | --- |
| 14874 | . | * | --- | * | * | * | . ? | . | * | 11% | --- | --- | --- | --- |
| 15518 | . | * | * | * | . | * | --- | * | ** | 1% | --- | --- | --- | --- |
| Shey | | | | | | | | | | | | | | |
| 11913 | * | * | . | * | * | * | --- | . | * | 5% | --- | --- | --- | . |
| 15404 | . | * | ** | * | . | * | --- | ** | *** | 1% | . | --- | --- | . |
| Nako – Shelkhar | | | | | | | | | | | | | | |
| 15516 | . | * | . | * | * | * | --- | * | * | 36% | 4% | --- | --- | . |
| 8504 | . | * | . | * | * | * | --- | . | * | 27% | 3% | | --- | |
| Khorchag | | | | | | | | | | | | | | |
| 15377 | --- | * | --- | * | * | * | --- | * | * | 1% | 1% | --- | --- | --- |

Table 4.4 Clay mineral analysis.

| Sample | Smectite | Vermiculite 14Å/18Å | | Illite | Kaolinite | Chlorite | Mixed layer |
|---|---|---|---|---|---|---|---|
| Spituk | | | | | | | |
| 6052 | 6 | | | 70 | 6 | 18 | |
| 8466 | 8 | | | 65 | 4 | 23 | |
| 8481 | 12 | | | 64 | 5 | 19 | |
| 14875 | 3 | | | 64 | 6 | 27 | |
| Alchi | | | | | | | |
| 8526 | 6 | | | 63 | 5 | 26 | |
| 11934 | 7 | | | 55 | 4 | 33 | |
| 14876 | 7 | | | 62 | 5 | 26 | |
| Lamayuru – Basgo | | | | | | | |
| 11939 | | | | 77 | 7 | 16 | ML Illit+Smect |
| 14874 | 2 | | | 73 | 7 | 18 | |
| 15518 | 3 | | | 76 | 6 | 15 | |
| Shey | | | | | | | |
| 11913* | 1 | 5 | | 85 | 7 | 2 | ML |
| 15404 | 4 | | | 71 | 5 | 20 | |
| Nako – Shelkhar | | | | | | | |
| 15516 | 4 | | | 67 | 3 | 26 | |
| 8504 | 1 | | | 69 | 3 | 27 | |
| Khorchag | | | | | | | |
| 15377 | 3 | | | 53 | 44 | | |

*Hornblende available in the 2µ-fraction. Chlorite-mixed layer: var. 1: chlorite – vermiculite; var. 2: chlorite – smectite.

## 4. *Markalak* clays and marine clays

The stratigraphic layer sequence of *markalak* clay pits at Lamayuru or Spituk shows a continuous change between bright and dark layers (Fig. 37.4 and Fig. 38.4) (cf. Feiglstorfer 2014: picture 16.5). The layer thickness within the samples varies between app. 5 mm and 20 mm for small stripes. This variation was measured in sample 8481 while *markalak* clay sample 6052 shows no stripes at all. Further, the *markalak* clay sample 8466 shows a layering of app. 15 mm of the reddish dark part and 15 mm of the greyish part. The dimension of the layers is not continuously the same but changing. Samples that appear without stripes from Spituk were part of higher stripes measuring roughly up to one metre. Their colours vary due to different mineral deposits.

*Markalak* clays can be mentioned as marine clays – marine clays in general have glaciolimnic or glacilacustrine sediments (Wimmer-Frey, Schwaighofer 2002: 264). In the case of marine clays, the stratification results from material transport either by flooding or by a continuous inlet, possibly a mixture of both. The coarser and heavier particles are deposited closer to the water stream in the areas of a more rapid flow while the finer material, in particular clay and silt, are deposited in areas of slower water movement (Brady, Weil 2000: 38). Dependent on the speed and amount of the water, the content of coarse as well as fine material varies along the layers of the floodplain.

The change between bright and dark layers within one pit can be explained – comparable to annual rings of trees but in this case semiannual – by a different water seasonal transport. Due to a higher amount of water during snowmelt, more and slightly coarser material is transported than in the dry season. By this the colour and the content proportion between different grain fractions

Fig. 37.4 Spituk clay pit.

Fig. 38.4 Spituk. Lacustrine sedimentation.

Fig. 39.4 Spituk clay pit. Sandy upper layer.

changes – in this case between the layers with a dominance of silt and of clay. After snowmelt, the water content decreases and transport is reduced to smaller particles (that means: more water – increasing speed of transport – transport of coarser grains; see Introduction 6.3.4 “Palaeolakes”). For practical use as a building material, these changes are marginal, but regarding the content proportion of silt:clay, this can be enough to change the colour slightly and cause it to appear brighter or darker. One bright and one dark layer together would mark the course of one year regarding the changes of the amount of water transport, including strong and less strong seasons of transport. The slight and layer wise continuous change in colour is shown by the result of the colour analysis. This observation is valid within the sequence of layers at one particular geological profile, which may change between different profiles as shown in the comparison of samples 8466 and 8481. Both samples show a similar high content of clay but according to the Munsell colour chart, sample 8466 appears as grey (10YR 5/1) while sample 8481 appears as greyish brown (10YR 5/2).

At Spituk the horizontal distance between the Indus River (altitude app. 3190 m) and the *markalak* clay pit (altitude app. 3226 m) is app. 960 m and the difference in altitude is app. 36 m (see Fig. 3.4). The pit is located at the foot of a side valley which runs in a northern direction. Possibilities for the influx of fine material is either from this valley – from here the fine material is desludged (washed out) – or from the side of the Indus River – where the water level allowed for debris, possibly at a narrower passage of the river. The difference in altitude of app. 36 m between the river and the pit is minimal regarding Himalayan situations and allows for such a scenario. A kind of narrowing and/or detaching of parts of the river and the formation of a lake – possibly covering the area of today’s clay pit and at this location depositing the fine desludged material – is reasonable. Also a mixture of both scenarios can be an option for the explanation of the development of this *markalak* clay pit. As a consequence of continuous depositing of desludged material in dependence of seasonal differences in the amount of seasonally flowing water, the striped colouring of the layers within the clay pit can be explained. The upper most layer of *markalak* clay in Spituk is covered by relative sandy sediments (Fig. 39.4).

The striped appearance of the *markalak* clay pits at Spituk or Lamayuru corresponds to what we know from varves (Ger. *Bändertone*) which are dependent on a cold climate with proglacial lakes or small lakes along the ice. One varve is a pair of two layers which change from a coarse and bright lower layer to a darker and finer layer (Press, Siever 1995: 582). In the warmer season at the time when the lakes are free of ice, sediments transported by melt water are brighter and coarser with a higher content of silt, while in the cold season when the lakes are frozen and the water stands still, clay appears in the form of brighter suspended solid sediments (Press, Siever 1995: 343; see Introduction 6.3.4 “Palaeolakes”). Varve clays are commonly known as raw material suitable for ceramics and various uses as building material.

As comparison, in Austria’s western states of Tyrol, Vorarlberg, Salzburg and parts of Carinthia, they are the prime source of raw material for the brick industry. According to Winkler’s (1954) “triangle for the limits of use”, exceeding a maximum of 50% of silt (in particular fine and medium silt) makes the raw material improper for its use for thin-walled hollow fired material. (Wimmer-Frey, Schwaighofer 2002: 264) This approach will not be further treated in the present research since firing of brick or ceramics is a secondary issue within the Himalayas. Concerning building material in this wide mountainous and relatively arid region, fuel for firing is sparse and we are primarily dealing with air-dried and not fired earth building material.

Primarily their content of silt and clay varies and the prime material can be classified as silts, silt-clays (or clay-silts) with a small amount of sand. For the production of bricks the used marine clays have to be improved with further clay materials (Wimmer-Frey, Schwaighofer 2002: 264). This fact again emphasises its extremely fine material characteristic, which is also a reason why even in unfired use in the Himalayas their usage for building purposes in a primary-statically stressed manner (e.g. adobe bricks) and also for subconstructions for plasters is not of importance.

## 4.1 Comparative material

On the basis of results from the Himalayas, a question is raised for the comparability to local Austrian clay. In Wollanig in Carinthia, for example, we know of the existence of marine clays which were deposited during the ice ages. This smooth material with high plasticity is still used for the production of bricks. Another Austrian material, sample 7880 from Stierschweiffeld in Lower Austria, which can in a simplified form be defined as marl (Ger. *Tegel*) with a high content of silt, will be compared with sample 8466 from Spituk, which is a varve clay containing a relatively high amount of silt.

Sample 7697 from Wollanig contains 39.1% of clay with no swellable clay minerals and a linear shrinkage of 5.6% (Kruzik 2008: 96). Sample 7880 from Stierschweiffeld shows a content of clay of 15% with 34% swellable material and a linear shrinkage of 1.6% (Ottner 2006: 7, 15). In comparison, at 84.7% the content of clay in sample 8466 from Spituk is much higher with a content of swellable clay minerals of 8%. The measured linear shrinkage with a value of 7% in sample 8466 from Spituk also exceeds the values of sample 7697 from Wollanig and sample 7880 from Stierschweiffeld. The values of sample 7697 from Wollanig are very similar to those of sample 8466 from Spituk. On the contrary, the values of sample 7880 from Stierschweiffeld differ widely.

Sample 7697 from Wollanig shows a liquid limit ($W_L$) of 31.2%, a plasticity limit ($W_P$) of 18.5% and plasticity ($I_P$) of 12.6%; sample 7880 from Stierschweiffeld shows a liquid limit ($W_L$) of 28.7%, a plasticity limit ($W_P$) of 21.9% and plasticity ($I_P$) of 6.7% (Kruzik 2008: 80). Sample 7880 from Stierschweiffeld in comparison contains 34% of smectite (Ottner 2006: 15). In comparison, sample 8466 from Spituk shows a liquid limit ($W_L$) of 33.2%, a plasticity limit ($W_P$) of 21% and plasticity ($I_P$) of 12.75% which is relatively close to the values of sample 7697 from Wollanig and also of sample 7880 from Stierschweiffeld. The sample from Wollanig shows a grain size distribution (Kruzik 2008: 47) of 1% gravel, 4% sand, 56% silt and 39% clay. Sample 7880 from Stierschweiffeld shows a grain size distribution (Ottner 2006: 7) with 0% gravel, 28% sand, 57.3% silt and 14.7% clay. Sample 8466 from Spituk shows the following grain size distribution: 0% gravel, 0.3% sand, 20% silt and 79.7% clay.

A comparison of these samples shows for the sample from Spituk a higher content of clay containing 8% swellable material (versus 0% for the material from Wollanig and 5% for the material from Stierschweiffeld) and otherwise a much smaller content of silt which is relatively similar for samples 7697 from Wollanig and 7880 from Stierschweiffeld. The content of calcite was measured at 28% for sample 7697 from Wollanig, and 7% for sample 7880 from Stierschweiffeld (Kruzik 2008: 71). On the other hand, at 8% sample 8466 from Spituk shows a much lower content than sample 7697 from Wollanig but a similar value to sample 7880 from Stierschweiffeld. For the *markalak* clay samples from the Himalayas, characteristically their content is of calcite.

## 5. Conclusion

### Research question 1: Are there any particular material qualities to categorise a particular clay as *markalak*?

Starting with haptic qualities, a *markalak* clay can be described as fine. When touching a dry sample, it bleeds and fine layers remain on one's fingers. The core of the samples appears hard and difficult to break. The period of moisture penetration takes longer, as is the case with coarse material, which soaks up water much quicker. As soon as the humidity reaches the core of the sample, it turns into a sticky slurry. The oral test states fineness when the material 'melts' on one‘s tongue and does not create significant noise when chewing. As soon as some content of sand is available, the sound changes into a cracking between the teeth.

At first glance, small *markalak* clay samples appear as monochromatic but already the pit itself is layered in stripes of different colours and intensities, pointing towards its natural origin as varve clay. The large-scale layering at the pit is also visible for the small samples on a smaller scale. Reddish and yellowish colours give evidence of the content of ferric oxides. Following a distinction according to Munsell, in a dry state the colours show tendencies towards brownish, grey and yellowish, and are primarily bright. In a semi-dry state they appear as brown, yellowish and grey, are partially bright with some turning dark.

A further aspect in defining the material's properties is mineral composition. The shape of the grains can be described as "angular" which points towards a short distance of transport and further towards a relatively young material. An analysis of the grain size classes shows no gravel in most samples, or just a small amount. An exception is the sample found in Alchi (sample 8526) which turned out to be basically similar to the fine properties of *markalak* clays in general but already naturally contained some coarse material. Similar is the appearance of samples 15377 from Khorchag and 15516 from Nako, while for the latter an anthropogenic addition of coarse material can not be excluded. The content of sand ranges for the fine samples between 0.1% and 2.3%. Exceptions can again be mentioned and include samples 8526 from Alchi, 15516 from Nako and 15377 from Khorchag. Excluding coarse sample 8526 from Alchi, a median can be stated between 0.6 μm and 8.5 μm and a content of minerals <2 μm was available up to 82%.

Regarding the content of silt, the samples can be divided in two categories. Those with a low content range between app. 18% and 31%, and those with a high content range between app. 50% and 85%. In contrast to the content of silt, we find the content of clay, meaning, in the case of a high amount of silt, the amount of clay is low, and vice versa. Dependent on use, one has to choose between the silt or clay dominated material. Regarding local terminology, no further differentiation regarding this difference in content of clay or silt could be observed.

The bulk mineral analysis showed similarities over all the samples, with only a few variances. The average content of 14Å minerals ranges between traces and a small amount, the content of mica in general occurs in a small amount, the content of amphiboles on average occurs as traces, the content of 7Å minerals in general is seen in a small amount, the content of phyllo silicates is on average a small amount, the content of quartz in general is a small amount, the content of K-feldspar on average occurs in traces and small amount, and the content of plagioclase occurs in a small amount. Partially dolomite could be observed in traces or small amount. Seemingly specific for most of the *markalak* clay samples is a content of calcite varying between a very small amount and 69%. In several samples, traces of haematite were found.

Distinctive for the *markalak* clay samples from all examined regions is their high content of illite, ranging between 53% and 85% of the clay fraction. Also kaolinite, with a content of 3% to 7%, is similar and rather small, though there is one exception: Sample 15377 from Khorchag shows a content of 44% of kaolinite. Also the content of chlorite at 15% to 33% has a similar range, with two exceptions: Sample 11913 from Shey at just 2% and sample 15377 which show no content of chlorite. For *markalak* clays, their small content of swellable clay minerals – which turns out to range between 1% and 12% with an average 4.8% – is important for the behaviour of minimal shrinkage after moistening. In general this is a result of the smectite with only one exception, i.e. in the case of sample 11913 from Shey, the swellable mineral is also vermiculite with a content of 5%.

Observing material properties of sample 8466 from Spituk – which has a content of 80% of clay, median grain size classes at 0.9 µm and a content of 8% of smectite – the water content to reach a standard stiffness was measured at 121%. The liquid limit ($W_L$) was measured according to Casagrande with a water content of 133.75%, a plasticity limit ($W_P$) according to DIN 18122-1 with a water content of 121%, and a plasticity coefficient ($I_P$) according to Voth of 12.75%, which again ranges around "very clayey" with a tendency towards "very silty". According to the result of the shrinkage test according to DIN 18952, this sample can be classified as a "very soft clay" with a shrinkage of 7%. The coefficient for the activity according to Houben and Guillaud (1984) was measured at 0.15% which points towards a classification of "very little activity". The hardness of the surface was measured according to Vickers at 1.39 kg/mm² which is not to compare with the compressive strength.

## Research question 2: Are the particular material qualities related to specific regions?

As specified for the answer to research question 1, we can state distinct material properties for *markalak* clays. In this aspect, a further differentiation between the different regions – i.e. Ladakh, Upper Kinnaur and Khorchag with a maximum distance between Ladakh and Upper Kinnaur of app. 260 km and between Upper Kinnaur and Khorchag again app. 310 km, in total app. 570 km – is of interest.

A comparison between the colours of the samples of the different regions shows the following result. One range of *markalak* clay colours includes those with a light grey appearance in a dry state and brown/yellowish brown colour in a semi-dry state. Of course, we have to consider that the final colour depends on the content of particular minerals which are relatively similar over all the examined samples. A crucial result of this research is that over this distance one particular feature of the *markalak* clay is its colour, if not changed by certain local mineral influences. This given colour (light grey/pale brown in a dry state and brown/yellowish brown in a semi-dry state) can be stated for the sample from Khorchag (sample 15377) in the far east in the west of Tibet, for the samples from Nako (sample 15516) and Shelkhar (sample 8504) in Upper Kinnaur and also for the samples from Ladakh, for example from Basgo (sample 15518).

The different mineral compositions related to these three regions were also examined. Regarding the different grain size classes in Khorchag (sample 15377), we find a *markalak* clay with a relatively high content of silt at 56.9% and a content of clay reaching 28%. This proportion is similar to what we find in Upper Kinnaur for sample 15516 from Nako, which has a content of silt of 61.9% and a content of clay of 29.4%. This is also the case for sample 8504 from Shelkhar, which has a content of silt of 73.3% and a content of clay of 26.6%. These two grain size fractions seem to be decisive for the grain size relation of *markalak* clays. Also in Ladakh various samples, for example from Basgo and Lamayuru (samples 11939, 14874 and 15518), are very close to the mentioned proportion. A slightly higher or lower content of sand does not seem to disturb its basic determination as a *markalak* clay but influences the particular use as building material. In Spituk and Alchi we find varieties of *markalak* clays which deviate from this pattern of a high content of silt and a lower content of clay by changing this proportion into a lower content of silt and a higher content of clay. Locally, they still range as *markalak* clays and can generally be described as extremely fine clays. Dependant on the particular needs, the choice is for one of these variations. Interestingly, it is again not the “one specific type of clay” but a particular variety traditionally known as *markalak* clay.

Regarding the bulk mineral analysis (BMA), we can state that all samples show at least traces of calcite but even within the single regions of examination, the content varies. The content of calcite of the samples of Spituk ranges between 3% and 5% and also between 42% and 69%, at Alchi the range is between 4% and 15%, at Lamayuru between 11% and 16%, at Basgo at 1%, at Shey at 5%, in Upper Kinnaur between 27% and 36% and at Khorchag 1%. All the other bulk mineral components show no abnormalities.

Regarding the clay mineral content, the content of smectite is relatively balanced between the single regions. The content of illite is on average at 68%, and at Khorchag drops to the lowest rate at 53%. At Shey it reaches the highest rate at 85%. The content of kaolinite ranges on average between 3% and 7% but increases up to 44% for the sample from Khorchag. All samples show a content of chlorite with an average of app. 15% to 33%. Just as for sample 11913 from Shey, this value drops to 2%, and at Khorchag no chlorite could be traced.

Concerning the *tua* clays from Nako, data of different types from TARA and Maria Gruber (2011) were juxtaposed. For the restoration at the monastery in Nako, the company TARA tested various samples of local clay to determine its physical properties as building material (Interview Khosla

2002; Feiglstorfer 2002: 12). Chemical observations have been in preparation. Sujoy Chaudhury (TARA) explained the consistency of different kinds of clay and handed a list of results of analysis over to the author. The analysis included a sample of *tua*$^{A}$, explained as a fine material used for the thinner and most upper layer of the earth roof with a sealing aspect. Also included was locally available clay$^{B}$, which is in general used for roofing, and an adobe brick$^{C}$, which is used for the construction of walls (Interview with Sujoy Chaudhury 2002; Feiglstorfer 2002: 12). The data on the list of TARA (see Table 5.4 in Appendix of Chapter IV) were summarised and given below.

List of TARA. Summarised by the author:

| | *Tua*$^{A}$ | Clay$^{B}$ | Adobe brick$^{C}$ [%] |
|---|---|---|---|
| Gravel | 1.20 | 4.44 | 8.43 |
| Sand | 27.80 | 63.56 | 46.57 |
| Silt | 43.00 | 17.00 | 26.00 |
| Clay | 28.00 | 15.00 | 19.00 |

| | Gravel | Sand | Silt | Clay [%] |
|---|---|---|---|---|
| 15516 | 2.8 | 5.9 | 61.9 | 29.4 |
| *Tua* (TARA) | 1.2 | 27.8 | 43 | 28 |
| *Tua** (M. Gruber) | 0.2 | 2.6 | 71.4 | 25.9 |
| *Tua*** (M. Gruber) | 0 | 0.1 | 63.5 | 36.4 |

In general the *tua* clay sample examined by TARA shows, similar to the *tua* clay sample 15516 from Nako, a very small content of gravel, which appears only in these two samples. Compared to the other *tua* clay sampes, the content of sand is very high, the content of silt slightly lower than the average of all the examined *markalak* clay samples, and the content of clay ranges in the lower area. Concerning the content of clay in particular, a similarity to sample 15516 is given. The examined clay sample is rather coarse and the adobe sample appears as a mixture of the *tua*$^{A}$- and the clay$^{B}$ sample.

## Research question 3: What are the material qualities which support the *markalak* clay's use for the mentioned building purposes?

Stitching of cracks on roofs and walls, on the fine upper layer of a plaster or on a sculpture has specific requirements such as

- a proper binding within the material itself
- a proper adhesion to the adjoining layer of clay
- a reduced shrinkage
- an appropriate smoothness

Binding within the *markalak* clay is achieved by a certain amount of clay minerals, in particular of swellable material. Generally speaking, the mixture of this material, in particular of swellable and non swellable clay minerals and the amount of silt, are ideal for the mentioned purpose.

In this regard we have to divide the results of research into two categories: those with a high content of clay (up to app. 82%) and those with a high content of silt (up to app. 85%). Both species find their appropriate practical use. Regarding the first group with a high content of clay, they are certainly rather smooth with a high inner binding and higher tendency to crack than is the case for the second group. Adhesion to adjoining layers of clay depends on the grain size classes, the binding of the adjoining material and the proper content of water for processing the *markalak* clay. With a too dry consistency, adhesion is too low, and with a too wet consistency, shrinkage increases and the duration of drying is extended for a rather long time.

Additionally, the thicker the layer of a *markalak* clay is, the higher the absolute shrinkage of the infill and the higher the risk of a reduced adhesion. In a further course, this results in cracks, primarily between the *markalak* clay infill and the adjoining portions of clay but also in hair cracks within the *markalak* clay itself. These are reasons that may explain Martina Oeter's description of the *markalak* clay's mixture with sand containing grains of up to 2 mm in the case of stitching deeper cracks (see sample 14875).

The higher the content of clay and the thicker the layers of *markalak* clay, the more importance the application of coarse material. The small content of swellable clay minerals (in average 6%) and the slight content of calcite still mean reduced shrinkage and no cracks or just fine hair cracks within the *markalak* clay (see shrinkage tests), even when the content of clay is high. In this regard the treatment of *markalak* clay with a high content of clay with a possible need for mixing with coarse material may be different to the treatment of *markalak* clay with a high content of silt. Its shrinkage is smaller and the content of clay is still enough for proper binding – an ideal material for stitching cracks in walls.

Martina Oeter also mentions that for the un-mixed application, the oatmeal material is well suitable and the yellowish and greyish materials show a tendency to shrink and crack after compression. Particularly in Spituk and also in Alchi, we find varieties of *markalak* clay with a relatively high content of clay. For samples from Lamayuru, Basgo, Shey, Nako, Shelkhar or Khorchag, we can not state such a high content of clay since their content of silt was always higher than for clay. Their colour has a primary tendency towards light greyish in a dry state. Due to a slightly different mineral composition at Spituk, this assignability to colours changes where the grey colours point towards a rather high content of clay (app. 80% for sample 8466 and 82% for sample 8481). On the other hand, the yellowish sample 6052 shows an extremely high content of silt at 84.6%, while the oatmeal (brownish grey in a dry state) *markalak* clay (sample 14875) seems proper with a content of 31.3% of silt and 67.8% of clay. Martina Oeter's description answers the question of the greyish material with a high content of clay, which shows improper behaviour when shrinking.

Due to the high content of clay minerals and the low content of silt – which does not show an internal relocatability of the molecules due to the behaviour of phyllo silicates – it is more difficult to compress which may also result in cracks. This effect can also be seen when burnishing a surface of *markalak* clay with a high content of clay minerals. It continuously loses its internal adhesion and when it is compressed the silicate layers move aside and do not remain stable. We see a similar effect for the behaviour of too fine plasters (shown in Chapter II). With increasing pressure, phyllo silicates detach from the layers below.

When stitching cracks in a roof following the explained method of Mr. Dawa – which involved just scattering pieces of *markalak* clay onto the cracks in the upper layer of the earth roof – the drying process is not of much relevance since this method works with a full saturation of the clay by making it fluid.

### 6.4 Research question 4: Regarding places of finding, are there regional peculiarities for places where to find *markalak* clay?

The places of finding are directly connected to the genesis of the raw material. Most of the samples show a relatively high content of fine and in particular silt material, which may have been transported by wind and water. The material settled in lakes cut off from a main stream of water, thus layer wise segments were deposited. This consideration emphasises the finding that the *markalak* clay material was in all cases in a particular local manner related to the occurrence of water transport and in that relation to a specific geomorphology. The Indus River flows close to the clay pits in Spituk, and the trough of a valley passes from the north; the Indus with the Basgo River as its side arm flows close to the clay pit in Basgo, which is located just below a plateau; the Indus River passes Achi village; Lamayuru is flanked by a water transporting valley; Shey is also flanked by the Indus River; the clay pit in Nako is located along a trough leading into the Spiti River; Shelkhar is also located along the Spiti River; and Khorchag is flanked by the Peacock River. These troughs may have been channels for the transport of material during the ice age, and fine clay was deposited along its sides. A thick layer of ice may also be the reason why the place of deposit is much higher than today's level of the mentioned riverbeds, for example at Basgo or at Nako. This kind of evolution can be seen as not necessarily dependent on Himalayan regions, but just as the individual geomorphology of each trough having a local particularity. Regarding these kinds of precondition, we can not exclude that in the examined regions (Ladakh, Spiti, Kinnaur and Ngari) it is possible to find many more pits with *markalak*-like clay, and thus a great number of variations within the range given in this chapter could be possible.

### 6.5 Research question 5: In which way can knowledge transfer concerning *markalak* clay be related to specific locally conventional terms?

Within this study a knowledge transfer over a wide region over a distance of about 600 km, in particular between Ladakh, Upper Kinnaur and Purang in West Tibet was traced. This transfer was certainly related to both specific local terms and particular properties of the clay. The term *"markalak"* (Tib. *mar ka lag*) is well known over a wide area, particularly in Ladakh, and describes a fine butter like clay. Regarding the results of this research, we can state that, over this wide area from Ladakh to Purang, particular material qualities and usage are clearly defined with the terms *"markalak"*, *"tua"* and *"narkalak"*. When talking about a terminological transfer, the material component is the basis to understand the context. That is to say that during the use of one of these terms in the course of a conversation with locals, traders, workers, et alii, it must have been clear what one was talking about when using terms like *"markalak"*, *"narkalak"* or *"tua"*, particularly over such a wide distance. The key for this understanding must have been given by the knowledge about specific properties of the material, including colour, haptic and visual appearance, and possibly also its taste and also characteristics of the places where the material can be found. Further, also technical features like the behaviour of a particular clay during precipitation (contact with water), wind, pressure, etc. may have been characteristics for the identification and description of particular types of clay. These matters were treated afore in a scientific approach on a material research level. An important factor for communicating on various types of clays seems to be knowledge about the particular clay's use, for example as an upper plaster layer, as proper material for stitching cracks in roofs and walls, or as the upper layer of sculptures etc. The interest of the local user may primarily be the material quality for a particular usage in a complete practical and empirical approach.

In this context, a hypothesis – which has to be treated in an anthropological discourse – is that an essential basis for creating knowledge is *experience*. It is *experience* which covers the knowledge on material and cultural aspects. The regional terms of materials cover these aspects and can be seen as vehicles being necessary for an efficient knowledge transfer. Examining the essence of experience lies beyond this study and the given results offer valuable data for further examinations on this topic.

### 6.6 Research question 6: What are the geological parametres of *markalak* clays?

*Markalak* clays can be identified as lacustrine sediments, in particular as varve clays. The formation of lakes along water run offs seems to have been responsible for the deposit of this rather fine material. The bright layers point towards a higher content of silt, which was deposited during the warmer season, while the darker layers show a higher content of clay, which were deposited during the colder season. Several Austrian examples were given as comparison. Lacustrine sediments play an important role as raw material for the production of fired bricks. The mineral composition of the given Austrian examples show close similarities to some of the Himalayan samples with the following basic features: small content of swellable minerals, in particular smectite, a rather high content of silt and less clay, a dominance of illite, some metamorphic chlorite as the second strongest clay mineral, and some kaolinite. Both dominant minerals, i.e. illite and chlorite, can be traced back to grinding due to activities of glaciers and moraines. Smectite and kaolinite originate from young weathering and can be described as relatively fresh and post-glacial. Smectite originates from light weathering, while kaolinite is the result of strong weathering. Illite also originates from light glacial weathering, e.g. of mica – starting with a mechanical/physical weathering, followed by chemical weathering.

We can partially find a content of vermiculite, which is a "weak" product of weathering. Mixed layers can be traced back to the interglacial period, but are available in the amount of 1%, as found in sample 11939, which is from a building technical point of view negligible. Vermiculite 14Å found in sample 11913 is less swellable than vermiculite 18Å. From a constructive point of view, the high amount of non-swellable clay minerals, i.e. illite, chlorite and kaolinite, can be seen as positive. The small content of smectite indicates only minor weathering and heredity. A content of mica throughout indicates physical weathering during the ice age. Weathered chlorite and mica are products of friction from a physical weathering process with – in the Himalayan samples – a varying and always available content of calcite. The amount of feldspar is low and the rock of the catchment area is metamorphic, which is shown by its content of hornblende and mica.

The high content of clay at app. 80% in sample 8466 and app. 82% in sample 8481 is a result of lacustrine sedimentation in the winter season, when fine sediments sink to the ground. The fineness of the sediments leaves an open question concerning genesis. A reason could be a mechanical crushing of fine sediments (incl. illite and chlorite), e.g. by weathering related to a glacier and glacial milk. Lacustrine chalk built up by nanoplankton can be excluded as an explanation due to a too small content of calcite. The content of smectite is also too small to be useful as an explanation.

# V. SUMMARY AND FUTURE PERSPECTIVES

## 1. Summary

A central aim of this study is identifying the interdisciplinary connection of research on traditional earthen building materials, methods of processing and building techniques. One aspect of the building material research is the analysis of a large selection of mineral based materials. Another aspect is the research on building constructions which focuses on the processing and assemblage of certain building materials in a building engineering context. The Himalayas were chosen as research area with the intention of developing a general methodological approach that is also applicable to other regions with adjusted research questions. From this point of view, a fundamental classification of this complex subject was applied by examining

(1) a historical architectural site,
(2) particular flat roof building techniques and
(3) a specific and widely known type of clay used as raw material.

### Chapter I: Introduction

In this chapter the geological and tectonic setting of the Western Himalayas was examined. It gives the geological basis for a further understanding of the locally available raw material and for particular methods of processing.

### Chapter II: Mineral traditions at the Nyarma Monastery in Ladakh

In this chapter traditional and historical techniques of processing clay within the village of Nyarma were explored and juxtaposed, including a comparative study of various methods of processing.

### Chapter III: *Arga* stone roof construction

In this chapter we are concerned with the investigation of particular flat roof building techniques, which is not exclusively related to a single site but relates to particular Himalayan building traditions. Of specific interest are comparisons between variations of various building techniques.

### Chapter IV: *Markalak* clay

In this chapter research has its focus on the properties of a particular over the Western Himalayas widely known type of clay. Its origin and methods of processing were examined and the question for the dissemination of traditional knowledge over long distanced was discussed.

Many Himalayan building sites are characterised by the use of locally specific types of clay. In vernacular architecture, variations in using different techniques and designs are caused by different local ecological, economic and social characteristics. Particularly regarding vernacular building research, this aspect determines a variety of local material properties and methods of processing. In addition to locally specific processing methods, materials are used in a cultural context by using certain locally rooted terms. The dissemination of specific terms used for particular building materials allows research on the dissemination of knowledge on particular types of clay and methods of processing.

https://doi.org/10.1515/9783110591330-007

Examination methods for the single research topics were developed and applied by the author and can be adapted to respective further research needs according to an adjustment of the respective research question. The above described research topics are to be regarded as mutually supportive. The single chapters describe particular methods of research and are in a general context interrelated with each other: The investigation of particular local material resources as treated in Chapter I is the basis for the study of the raw material's properties and proccessing methods at a historical architectural site as treated in Chapter II, which is again connected to particular types of constructions as treated in Chapter III, which in a further discourse gives insight in building traditions and their relation to specific types of raw material and their renownedness over a wide region as treated in Chapter IV.

The investigation of the given topics raises different research questions, which inspired to set up the respective research methods. These are not limited to a specific region, but can be adapted worldwide on a regional or local level. For research on building materials and building techniques, in a building historical and vernacular context the present basic research takes an important step into an interdisciplinary research including scientific disciplines like mineralogy, archaeology, or material and building technical engineering. This provides opportunities for focussed research. The vernacular aspect, which has hitherto been minimally considered in previous Himalayan building research is of crucial importance in the field of comprehensive architectural research and gives a broad understanding of building traditions.

For a detailed summary of the single chapters, at each chapter's end chapter-related research questions are answered in detail. As a general summary, the examinations show a deep awareness of the local people about properties of their local material resources and the optimisation of processing methods.

Building traditions leave a sustainable foot print behind. This was demonstrated in this research with the building methods used at Nyarma Monastery showing a high technical standard in selecting and processing local clay. It also shows that knowledge on elite and vernacular building techniques match with each other and some materials as used about 1,000 years ago are still processed today in a similar manner but not with the same effort and precision as it was the case for such historical elite structures.

The often discussed separation of vernacular and elite architecture are in terms of local building techniques and a related presumable involvement of local craftsmen not clearly evident. The quality of such elite building structures as we find this at the ruins of the Nyarma Monastery was most probably implemented with a participation of local craftsmen. Certainly the quality of the Nyarma Monastery earth buildings shows a highly optimised standard of clay techniques, which is by far not requested for simple farm houses, of which we unfortunately do not have any archaeological evidence for a further comparison. Nevertheless, for erecting an elite building like the Nyarma Monastery, the knowledge of semi-professional and professional craftsmen is needed. As a hypothesis, the structure of an elite building like the Nyarma Monastery can be erected under guidance of a few professional masons and a predominance of semi-professionals and lay persons. A further research on this hypothesis is to be placed in the discipline of anthropology.

## 2. FUTURE PERSPECTIVES

Both the interdisciplinary and practical relevance of this study open up opportunities for future research and applied implementation. With the underlying methods, which are close to the fields of of archaeology, architecture, building material and building construction research, material qualities of certain components can be determined. These qualities in turn provide information about material origin, material degradation and related transport routes. The quality of local building material is related to methods of processing and the local knowledge of craftsmen. As a result of this study it could be proven that local knowledge is disseminated over long distances, most probably along routes of traders and nomads.

In order to ensure certain processing qualities of building materials (e.g. surface hardness, hydrophobic effect), specific material conditions must be met. The composition of mineral raw materials is linked to a respective site and can differ regionally. In a vernacular context, certain material qualities are widely known, as the study of the *markalak* clay has shown. In particular traditional elite structures show a high awareness of optimising methods for processing raw materials. These properties can be recognised by means of certain sensitively perceptible characteristics, which explains a wide-ranging memorability of certain types of building materials. In this context there exists widespread local knowledge on the processing of mineral raw materials for building purposes, for example, through the addition of straw or lime in a quantitative and qualitative fine-tuning with a particular type of clay‘s properties. Juxtaposing historical and present building methods in the Western Himalayas, a continuity of traditions lasting for more than 1,000 years becomes evident. As further investigations on this subject illustrate, local craft traditions in their material context are overlapping and mutually complementary (cf. Feiglstorfer, forthcoming a). This circumstance is characteristic of a vernacular structure and allows for exploration of a material cultural aspect in a holistic context of craft traditions which are bound to mineral resources.

With this background, material relationships between crafts techniques can be established – for example, between flat roofing techniques based on stone and clay, between wall techniques based on adobe bricks and clay plaster, or between different layers of clay plaster. These techniques are consecutively linked to locally available knowledge about certain material qualities as shown with the examination of *markalak* clay. With further research results in Feiglstorfer (Forthcoming a), a building-technical context can be proven between locally established ctaft techniques, not just related to building crafts but also to crafts such as the production of clay stoves, pottery or clay sculptures. Using knowledge of such relations between different crafts, construction-related methodological interrelations can be explained – for example, the method of desludging, which is applied both in pottery and in production of a clay plaster. A consequent use of this technique in the Himalayas is demonstrated in the present contribution. With this technical approach properties of clay-based structures can be changed without adding other building materials. Another example of an interrelation of local crafts is the method of burnishing. This technique, which is based in pottery, has also been traced in construction technology, for example, in the Himalayas in the production of wall plasters or flat roofs (cf. Feiglstorfer, forthcoming a). The method of investigation used in this study at an historical site in Nyarma shows possibilities for the investigation of constructions and processing techniques with regard to their mineralogical components.

The conclusions drawn from this study can be put into an anthropological context, for example, with regard to raw material production, material transport, material processing, or a related knowledge transfer. The sensual identification of material qualities of mineral building materials without modern technical tools is an important requirement for the existence of building traditions. Important markers for the development and placement of building traditions can be found in names of building materials that have been disseminated over a wide region over hundreds of kilometres, referring to specific qualities and to the origin of materials (see s*markalak* clay).

In addition to a historical reference, building traditions are in close relation to their present and future application for 'modern' building purposes. This can be summarised in the question, "What can we learn from tradition?" We still find traditional knowledge in local methods of preservation of houses similar to methods as used at historical structures. The knowledge of processing is connected to knowledge about clay deposits and quarrying facilities. Knowledge on traditional names of clay types contributes to the identification of certain material properties. For conservation purposes, a distinction is made between structural measures and such just concerning the architectural surface. This differentiation is expressed in the processing and application of building materials (see adobe brick and plaster in Nyarma Monastery in Chapter II). Sensitive perceptible features of traditionally used raw materials support the search for new or already forgotten deposits.

Another very little explored topic is on the transfer of knowledge which leads towards new or transformed applications of traditional techniques. One example is the use of *arga* technology for modern flat roof or floor constructions (see Chapter III). *Arga* material and its corresponding processing allow for the production of a watertight upper surface for roofs and floors using locally available raw materials. A further example is the treatment of clay by means of desludging in order to separate a fine portion of clay, which can in a further step be used, for example, for fine plastering or as engobe. In addition to lower material costs compared to the use of an additional material as a supplement, this method reduces distances of transport. The technique of burnishing in purely manual processing, as another example, is connected to high man power – but could be used under mechanical support for the production of hard, burnished and water-repellent surfaces with a high optical and haptic quality.

Modern application and traditional knowledge are intertwined. Given the fact that vernacular craftsmanship is subject to a high degree of ecological, economic and social factors, it can be translated into modern use while preserving technical characteristics. A decentralised raw material supply based on a vernacular model of sustainability might shorten transport routes and support the revival of the local building trade. A public information on local clay pits might support the access to locally available raw material and shorten routes of transoport. Raising awareness of the quality of traditional crafts might strengthen the appreciation of traditions in a non-historical but innovative contemporary form – in an environmentally-friendly and resource-saving context.

As shown with this study, the topic of materiality on which craftsmanship is based has to be observed interdisciplinarily by examining tangible and intangible aspects and assembling scientific research of technical and humanistic disciplines. The research on the sustainability of traditional craftsmanship which is based on the awareness of optimising methods of processing in an ecological, economic and social context is an essential topic for further interdisciplinary research.

# VI. APPENDIX CHAPTER II

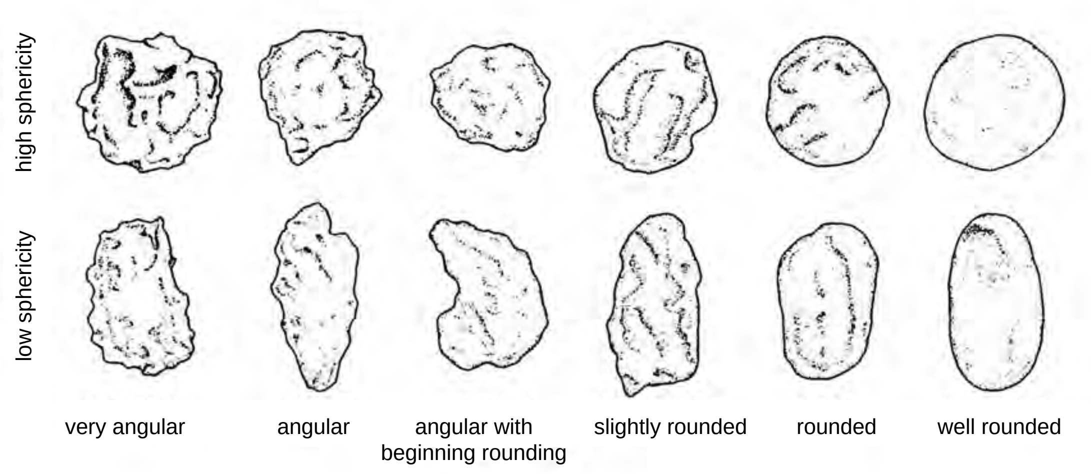
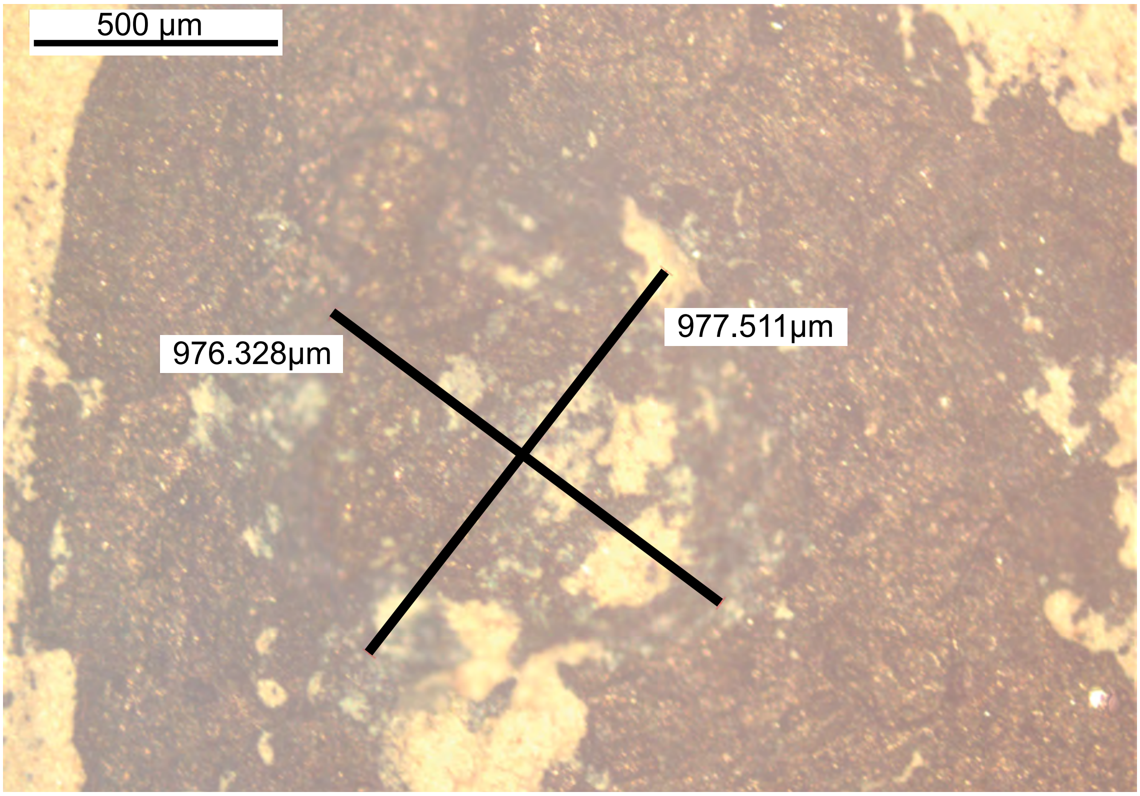
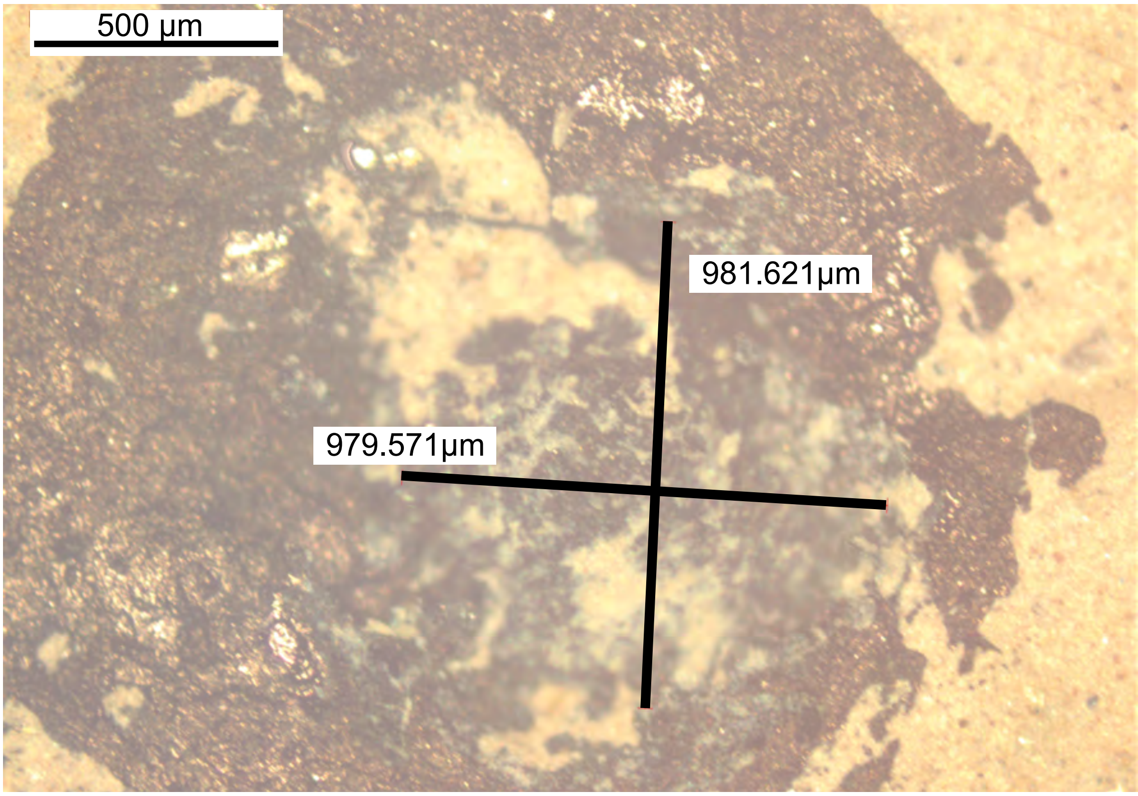


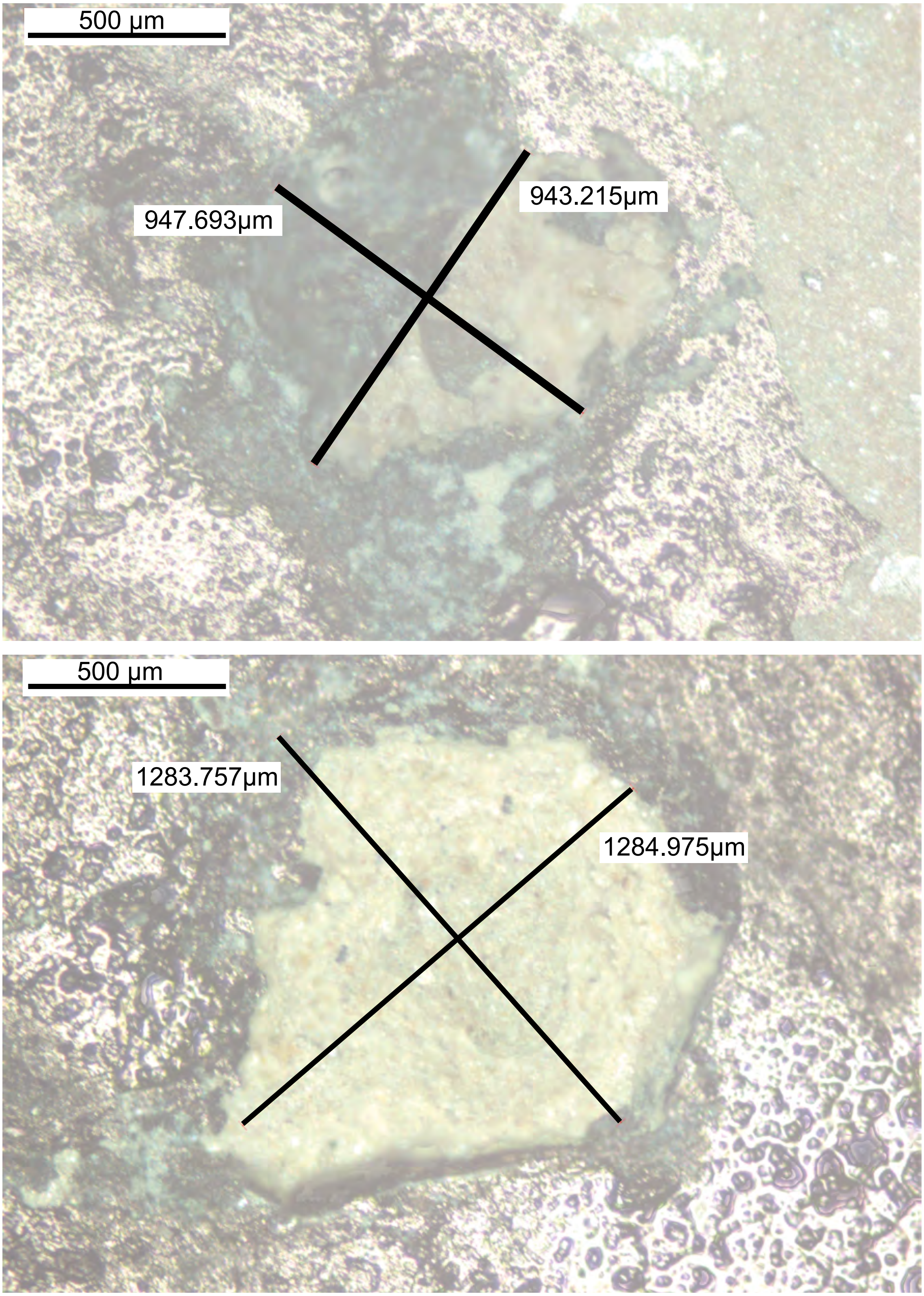
Fig. 103.2 Grain shapes after Tucker 1985: 18.

https://doi.org/10.1515/9783110591330-008

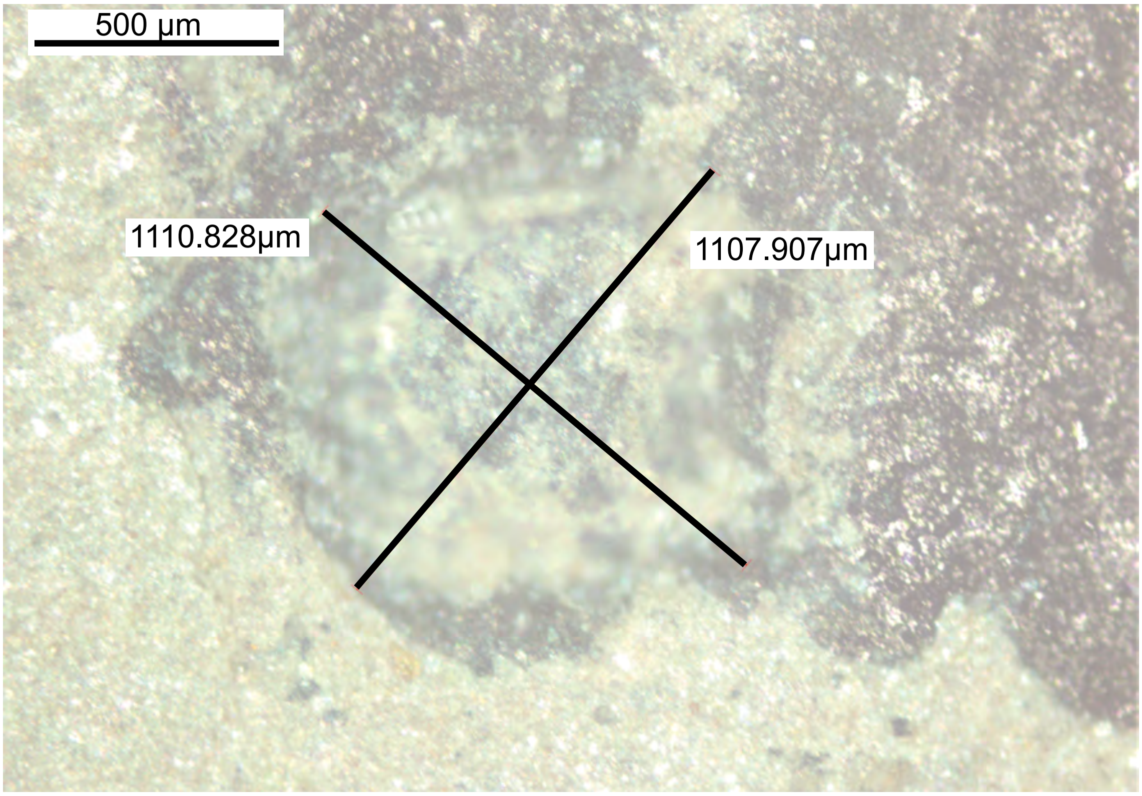




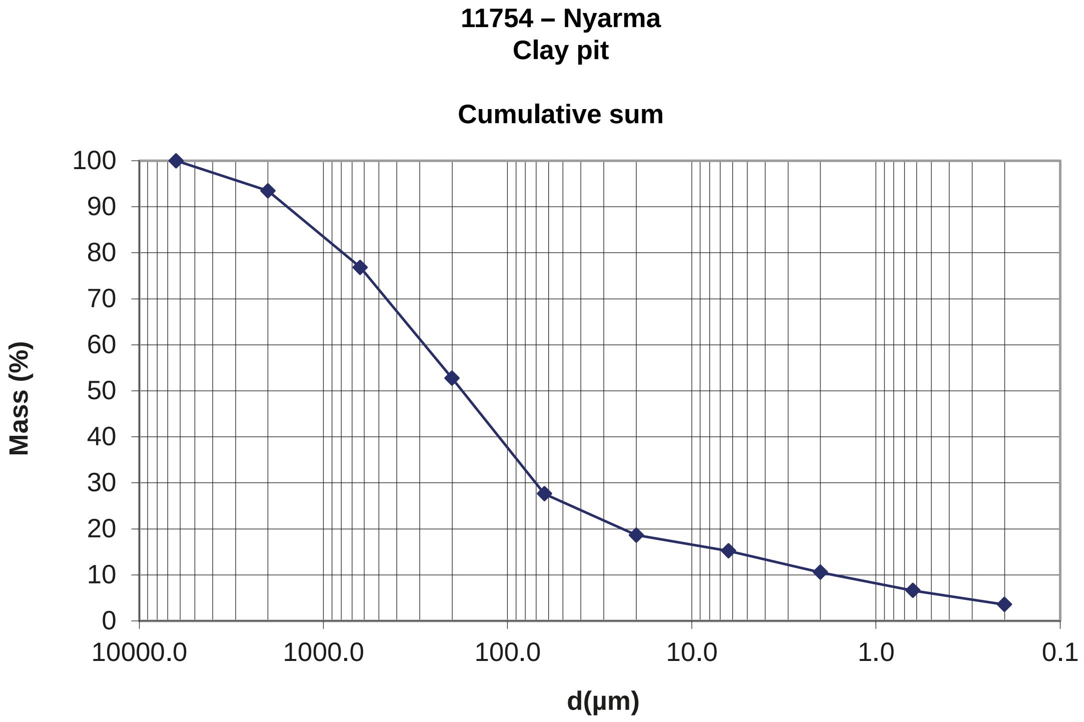
Vick 1.2 (Top) and Vick 2.2 (Bottom). Pictures of the Vickers test.

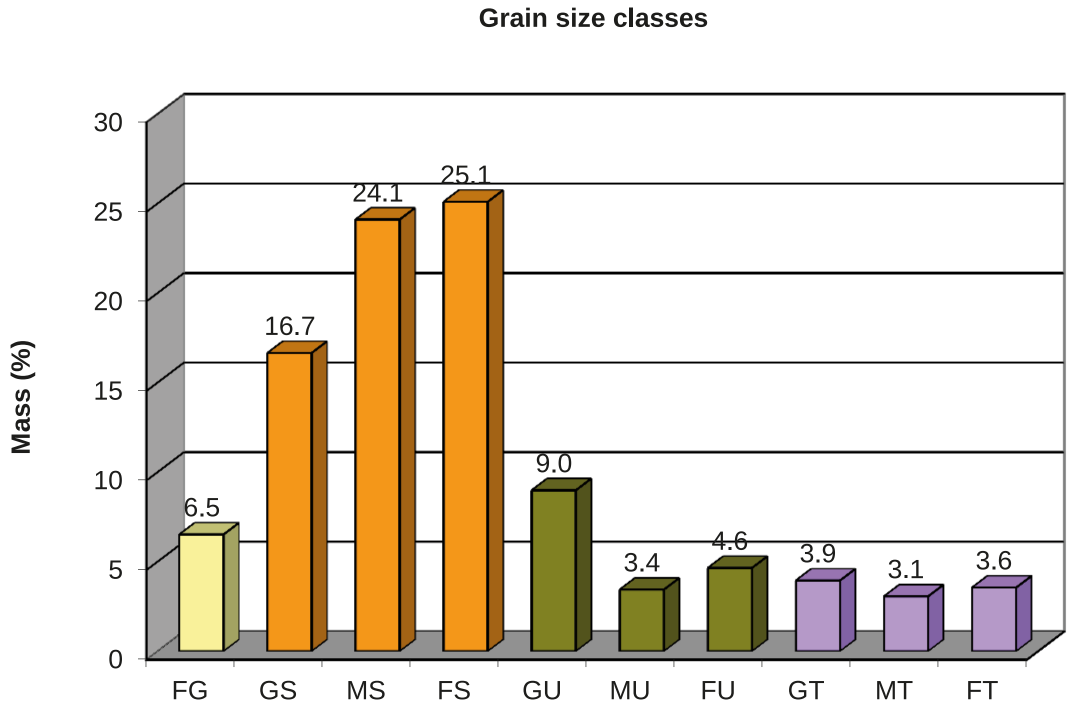


Vick 3.2 (Top) and Vick 4.2 (Bottom). Pictures of the Vickers test.



Vick 5.2 Picture of the Vickers test.

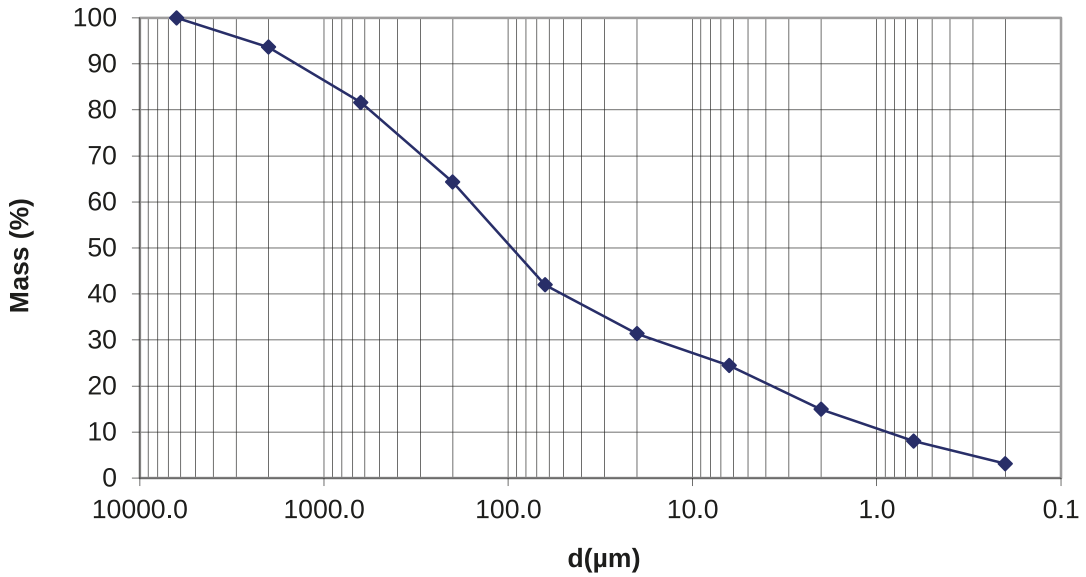




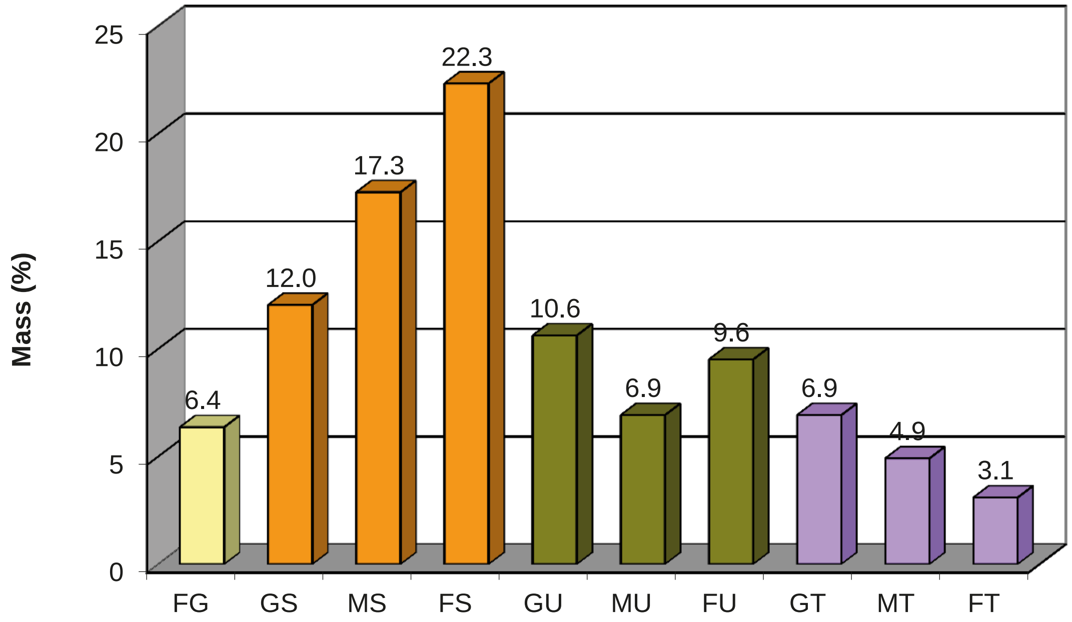
GSD 1.2 Nyarma. Sample 11754. Clay pit.
Top: Cumulative sum. Bottom: Grain size classes.

## 11956 – Nyarma
## Clay pit

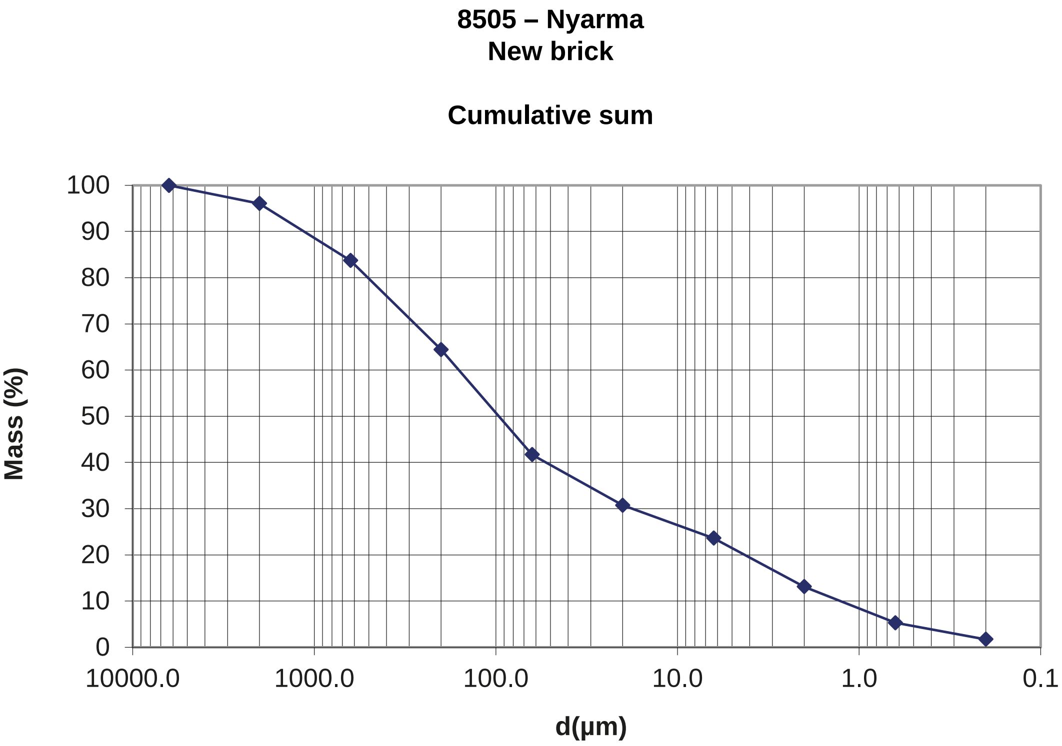
**Cumulative sum**

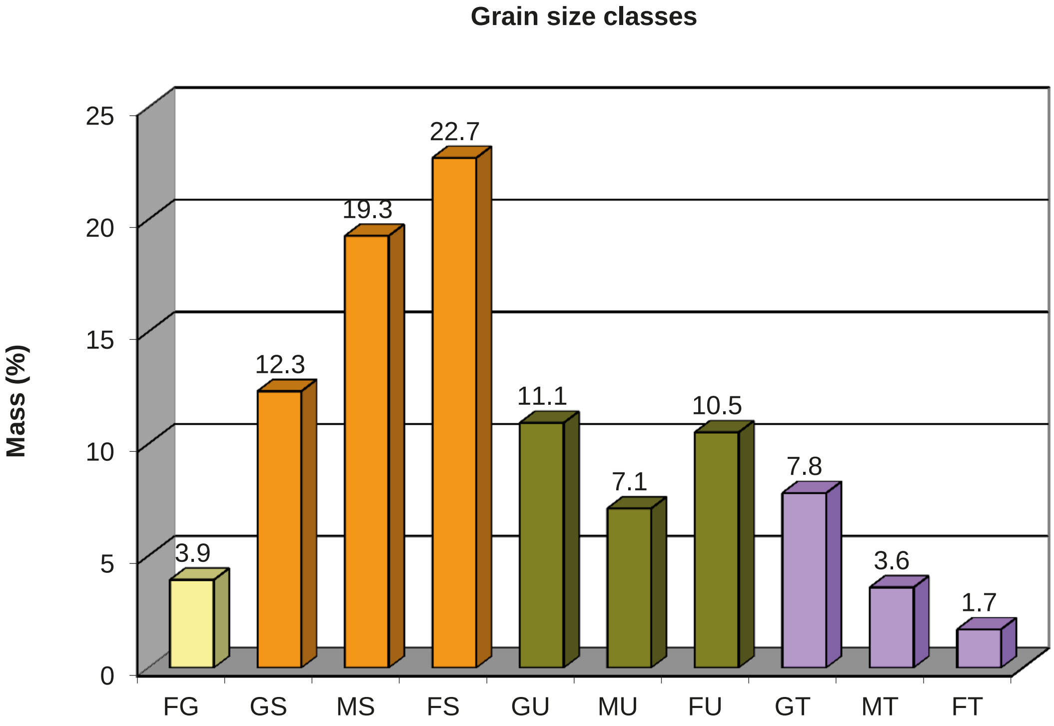


**Grain size classes**



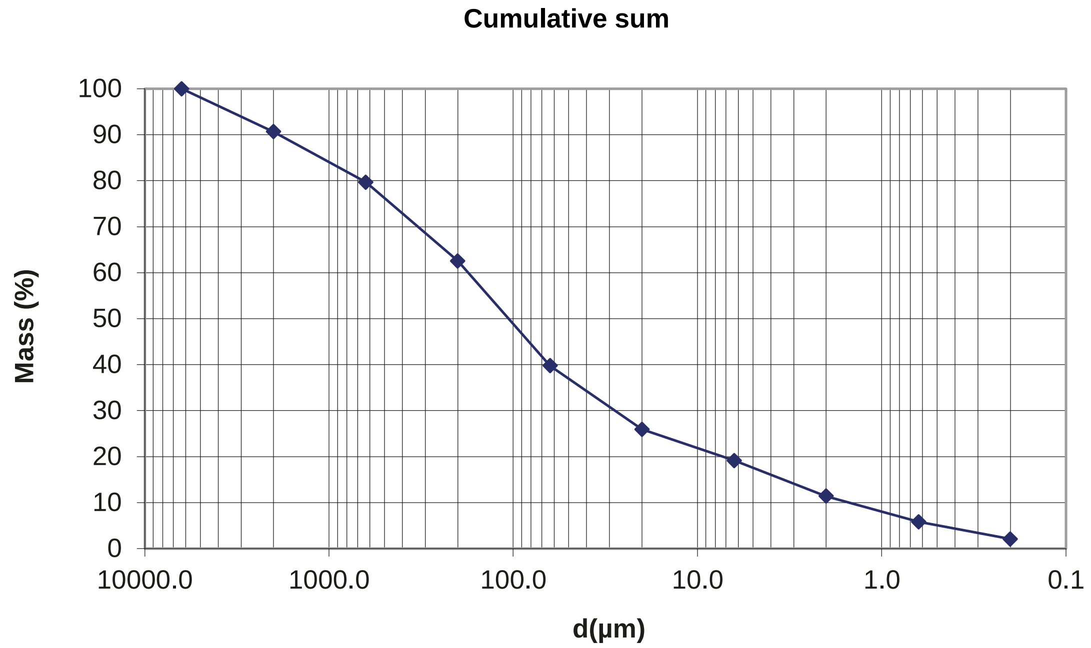
GSD 2.2 Nyarma. Sample 11956. Clay pit.
Top: Cumulative sum. Bottom: Grain size classes.

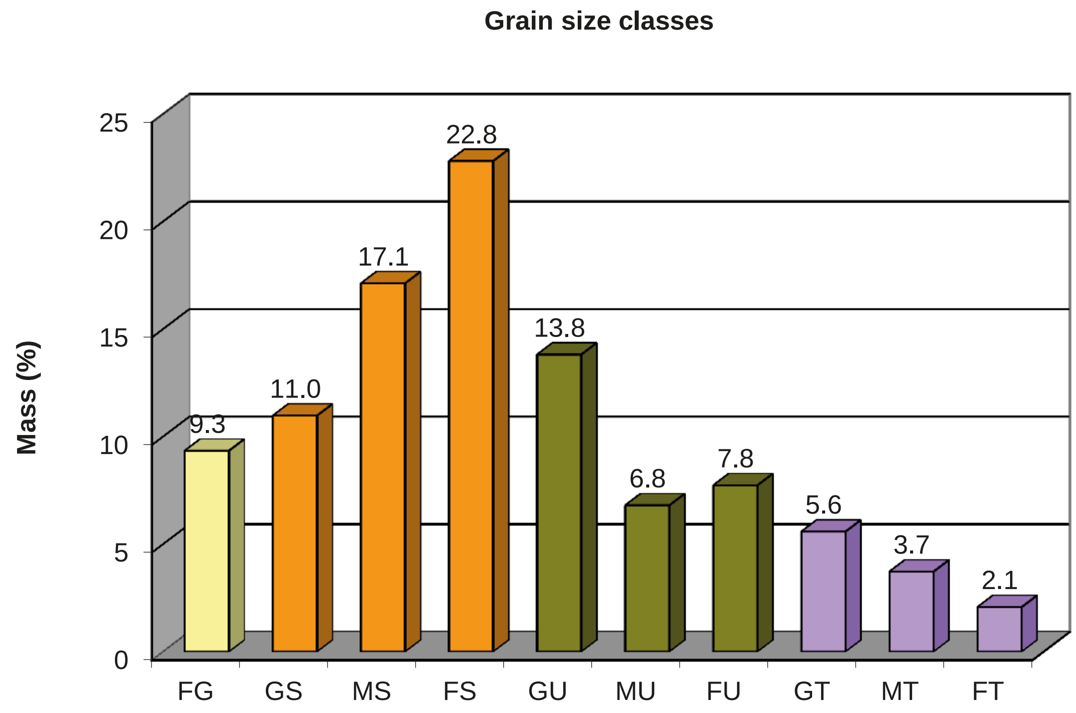




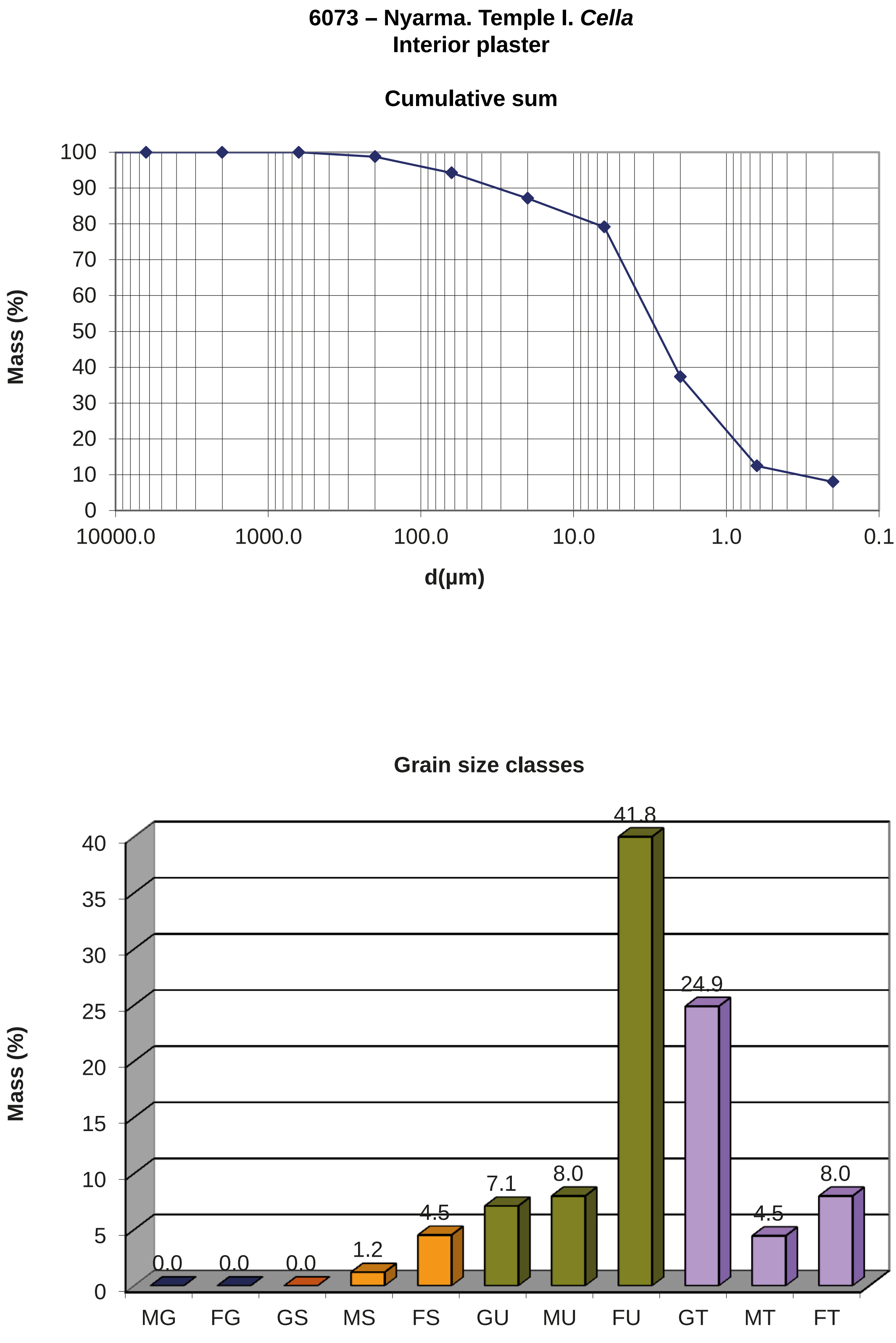
GSD 3.2 Nyarma. Sample 8505. Clay pit.
Top: Cumulative sum. Bottom: Grain size classes.

## 11947 – Thikse
## New brick





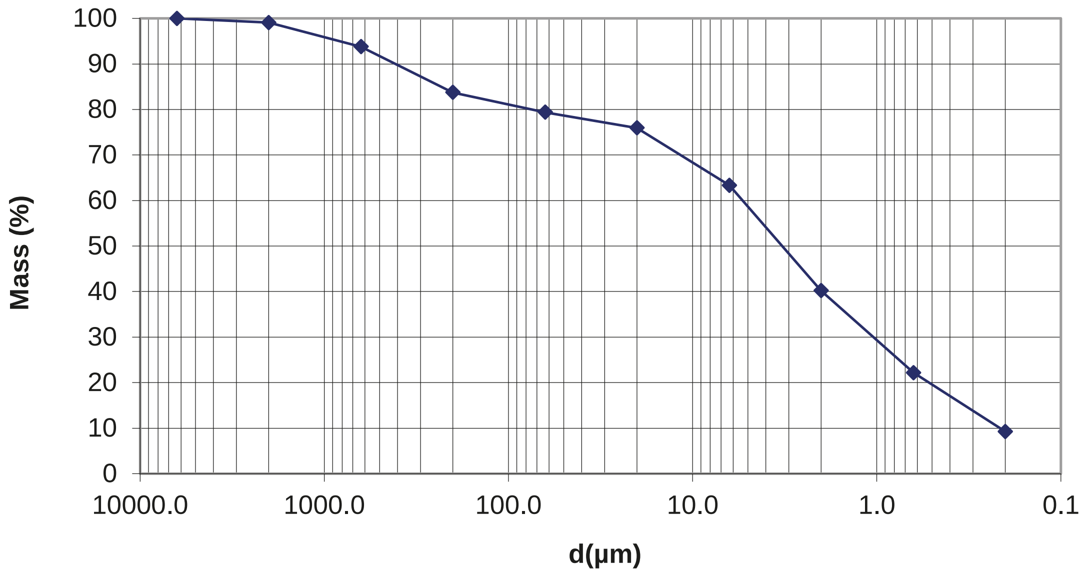
GSD 4.2 Nyarma. Sample 11947. Clay pit.
Top: Cumulative sum. Bottom: Grain size classes.



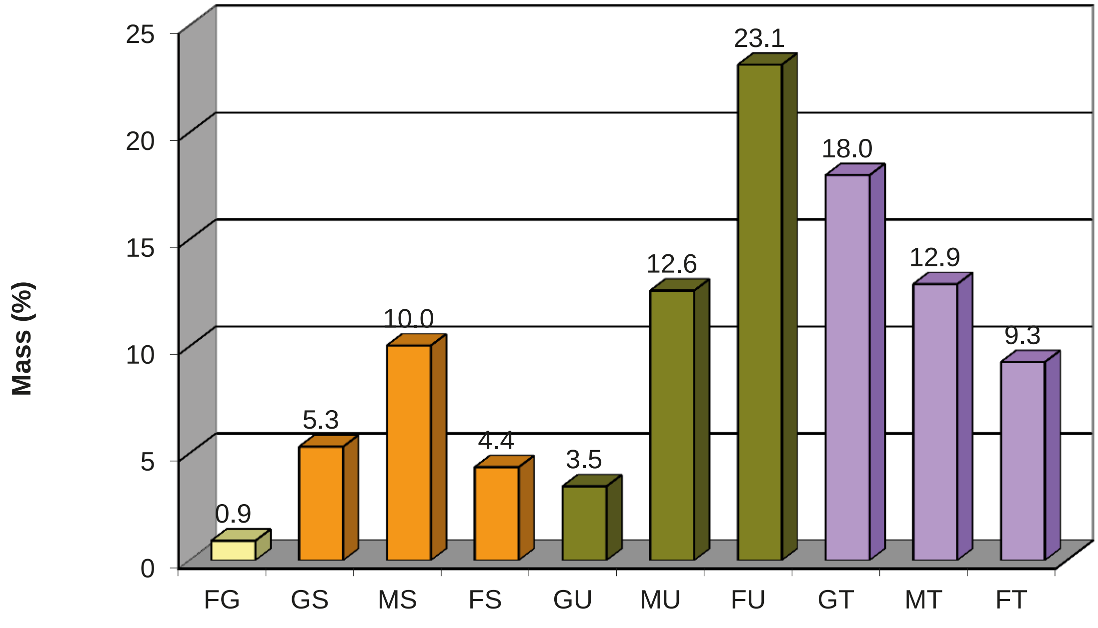
GSD 5.2 Nyarma. Sample 6073. Temple I. Main temple. *Cella*. Interior wall plaster.
Top: Cumulative sum. Bottom: Grain size classes.

## 11745 – Nyarma. Temple I. *Cella*
## Interior wall plaster

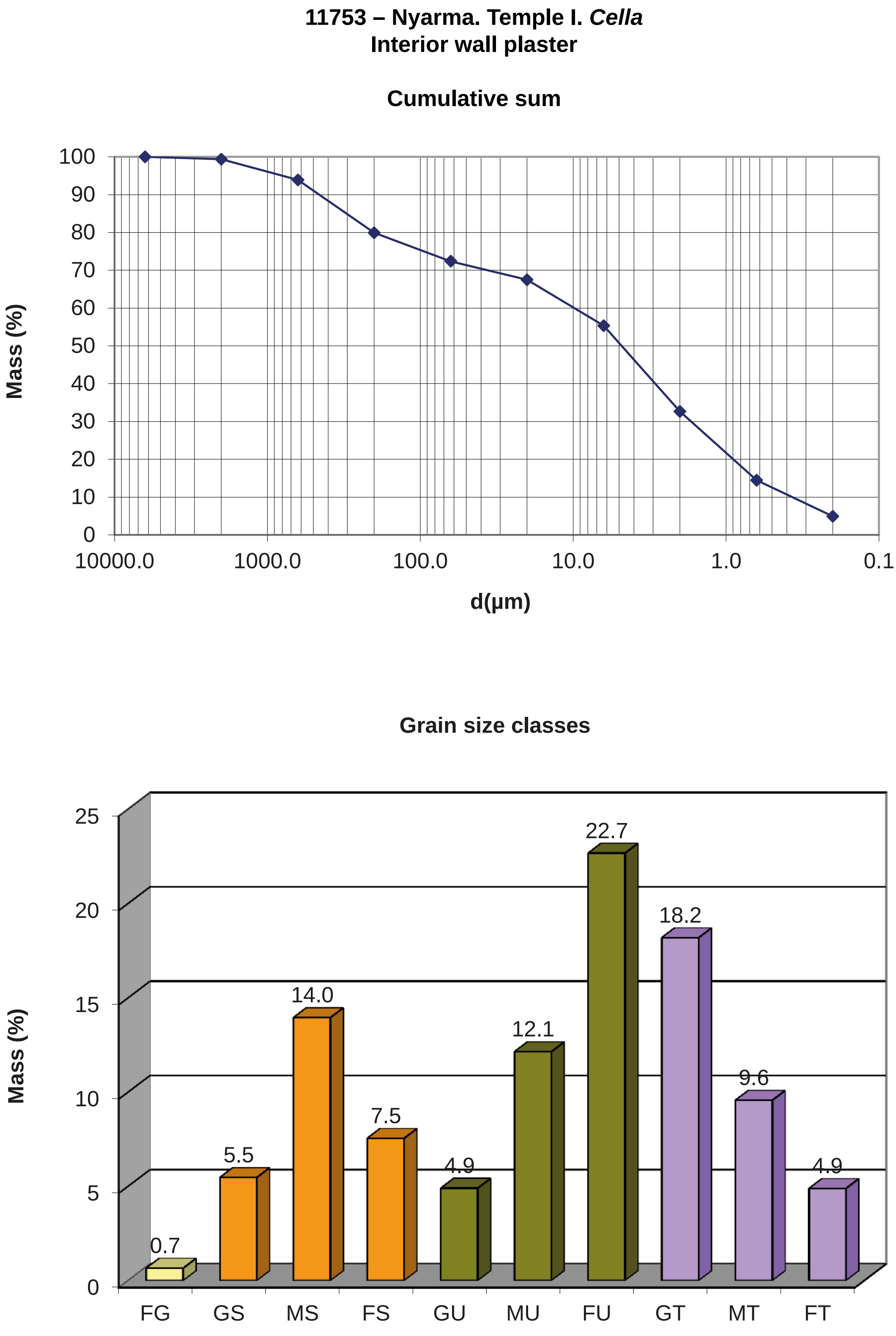
### Cumulative sum



### Grain size classes



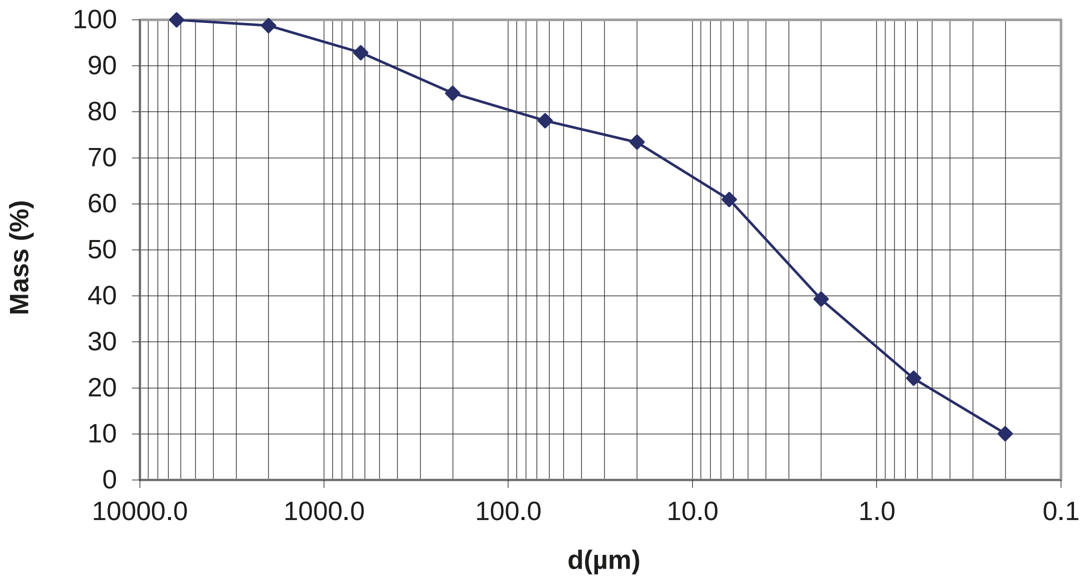
GSD 6.2 Nyarma. Sample 11745. Temple I. *Cella*. Interior wall plaster.
Top: Cumulative sum. Bottom: Grain size classes.



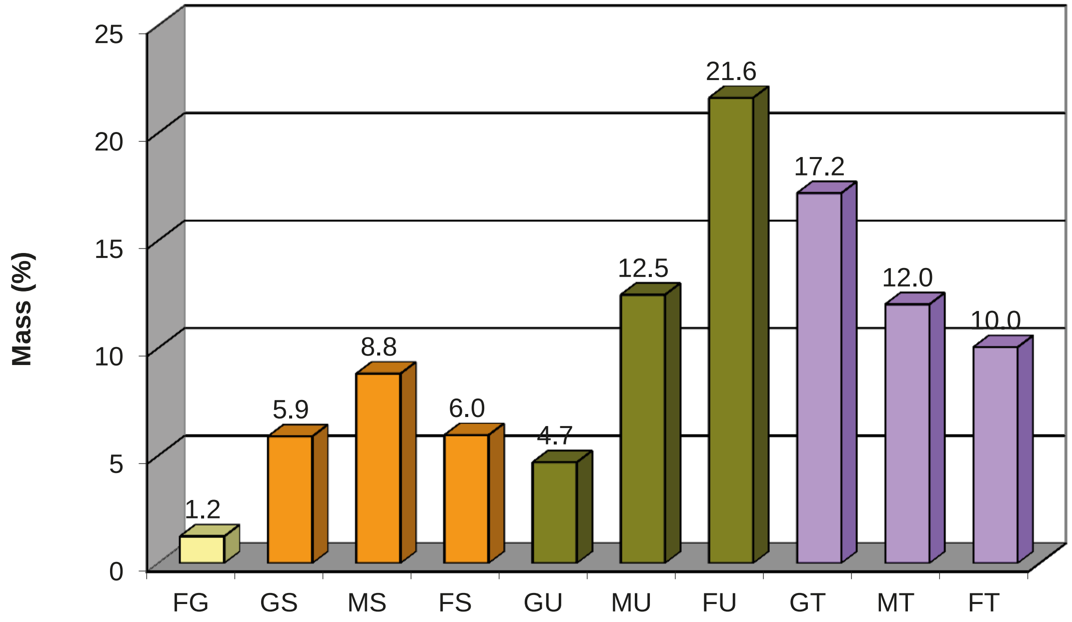
GSD 7.2 Nyarma. Sample 11753. Temple I. *Cella*. Interior wall plaster.
Top: Cumulative sum. Bottom: Grain size classes.

## 11925 – Nyarma. Temple I. *Cella*
## Interior wall plaster

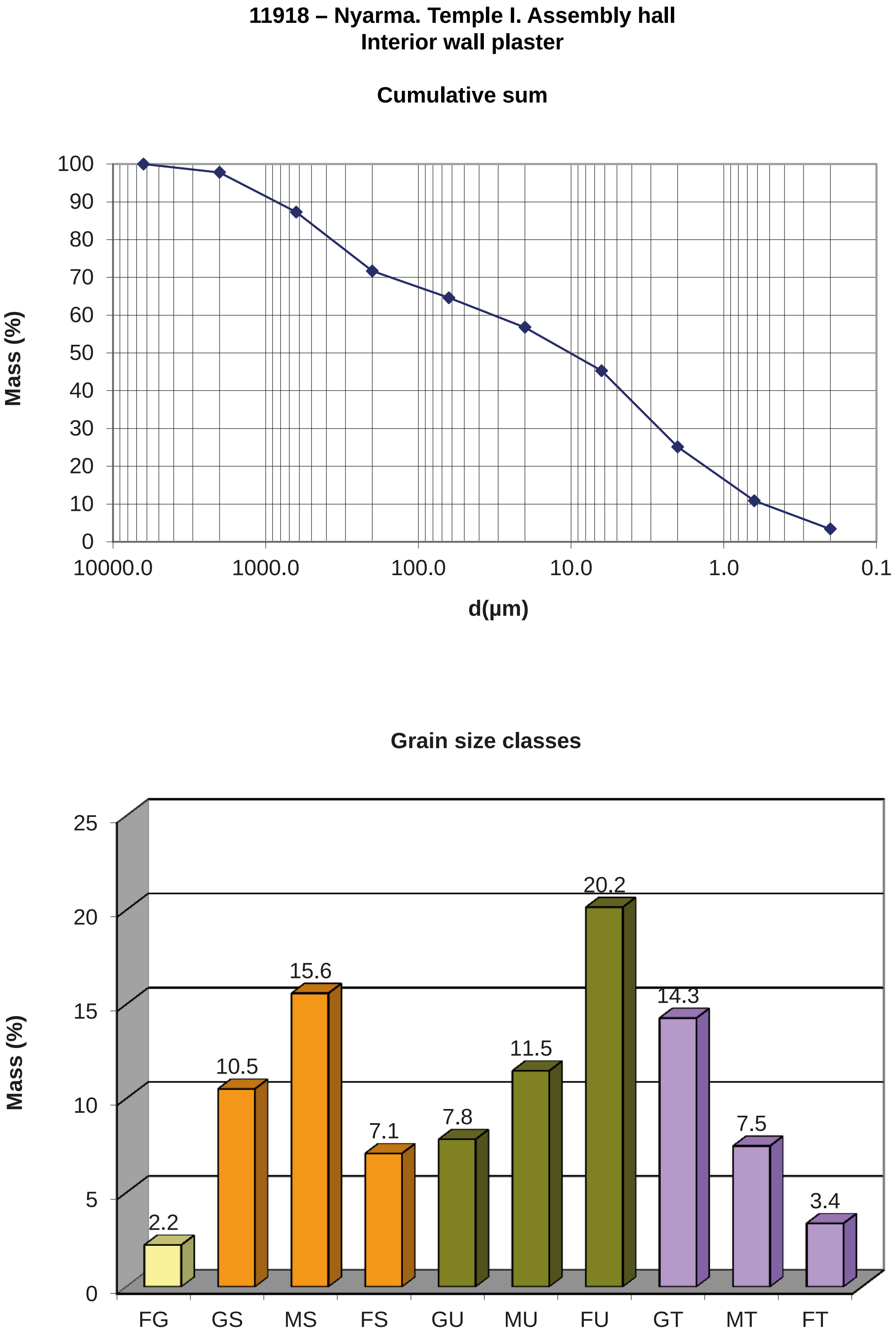
### Cumulative sum



### Grain size classes



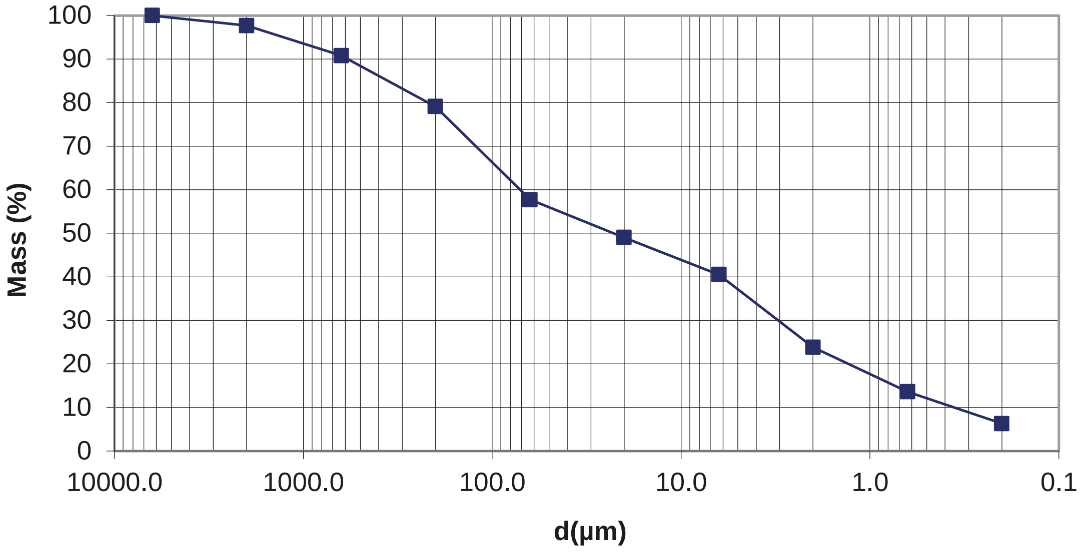
GSD 8.2 Nyarma. Sample 11925. Temple I. *Cella*. Interior wall plaster.
Top: Cumulative sum. Bottom: Grain size classes.



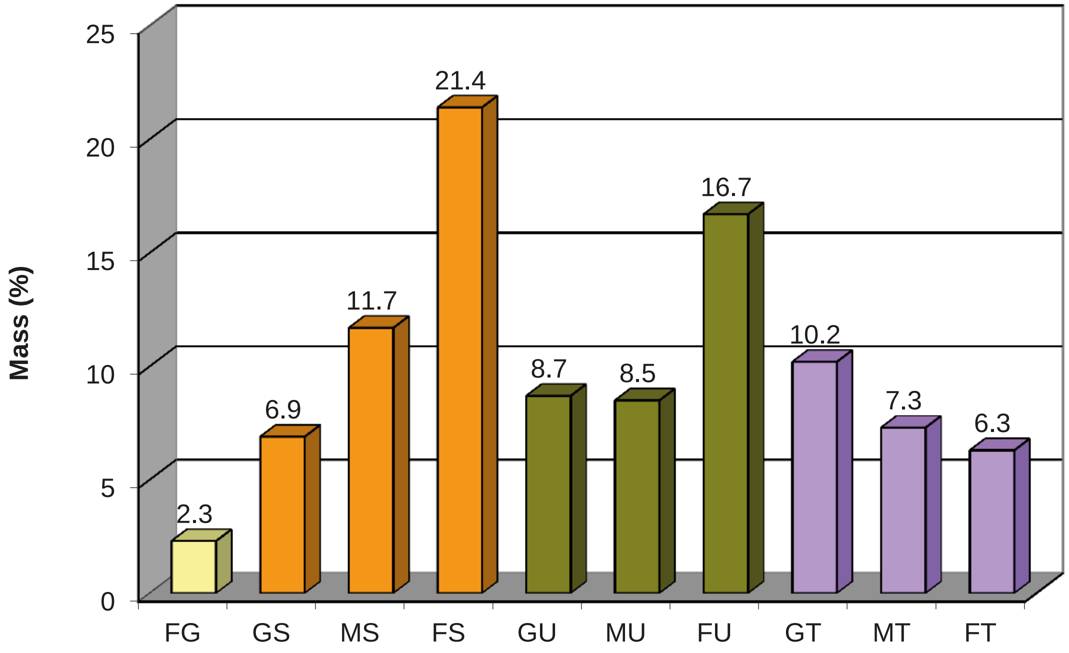
GSD 9.2 Nyarma. Sample 11918. Temple I. Assembly hall. Interior wall plaster.
Top: Cumulative sum. Bottom: Grain size classes.

## 8531 – Nyarma. Temple I. Assembly hall
## Interior wall plaster

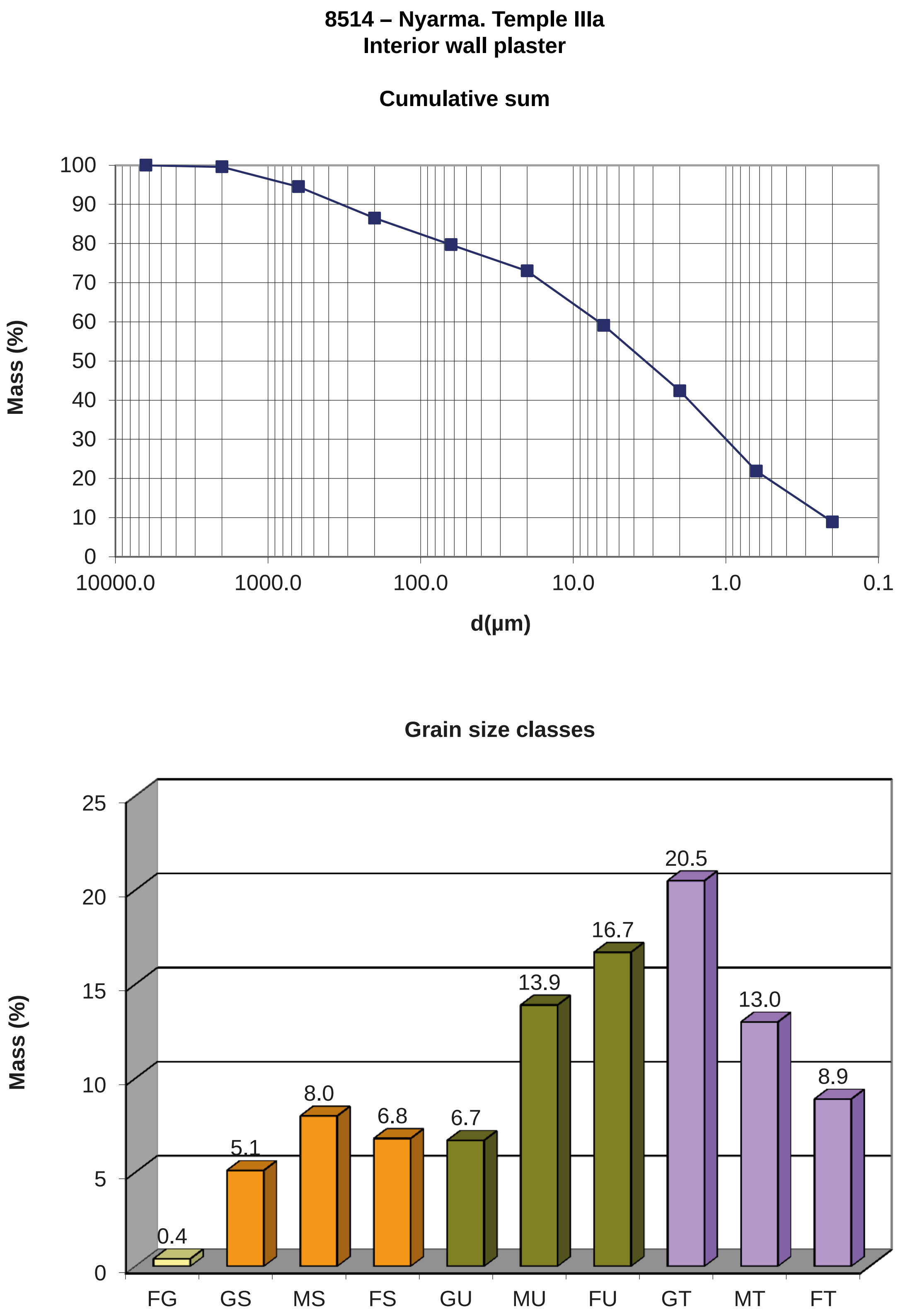
**Cumulative sum**



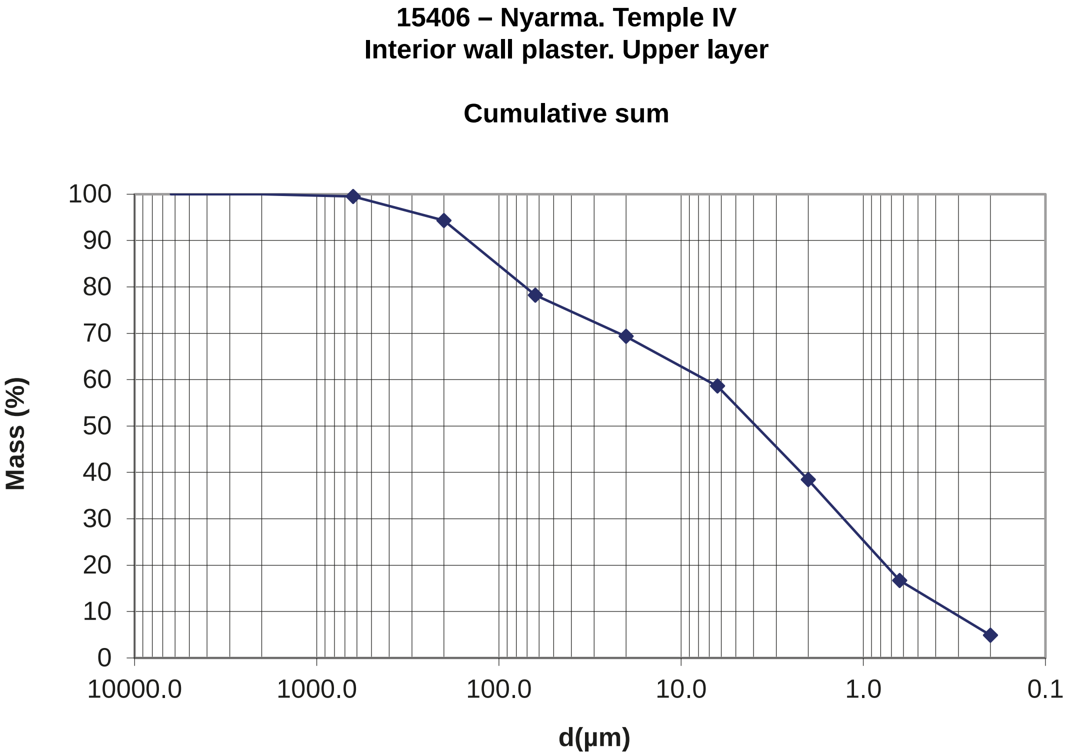
**Grain size classes**

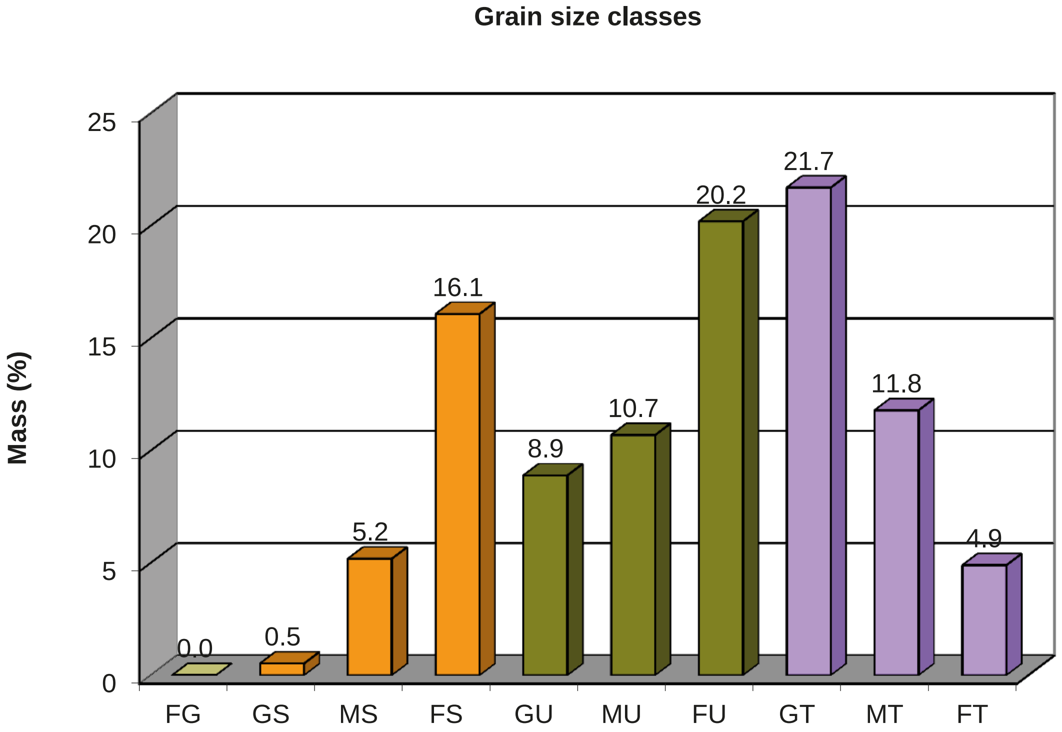


GSD 10.2 Nyarma. Sample 8531. Temple I. Assembly hall. Interior wall plaster.
Top: Cumulative sum. Bottom: Grain size classes.

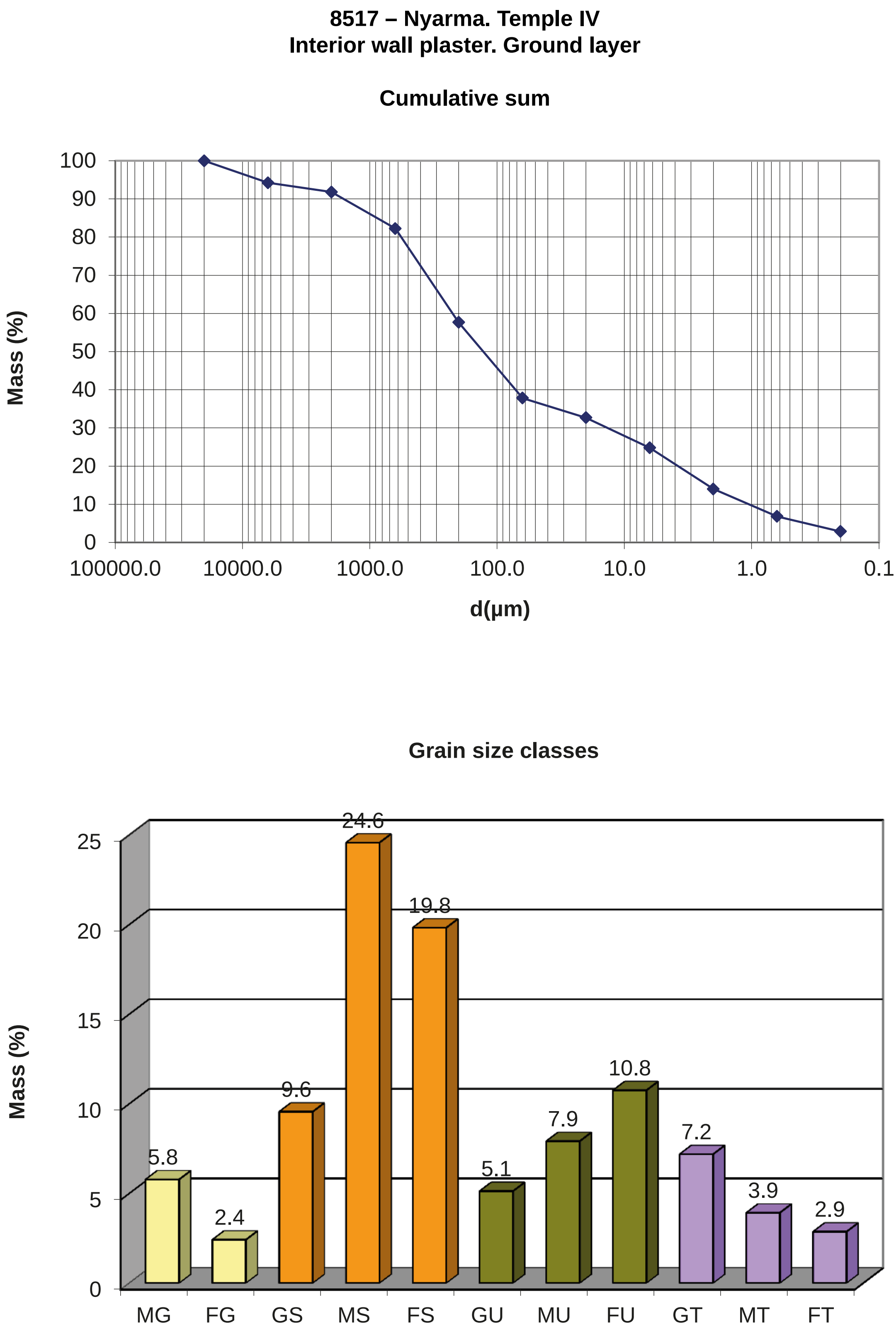


GSD 11.2 Nyarma. Sample 8514. Temple IIIa. Interior wall plaster.
Top: Cumulative sum. Bottom: Grain size classes.



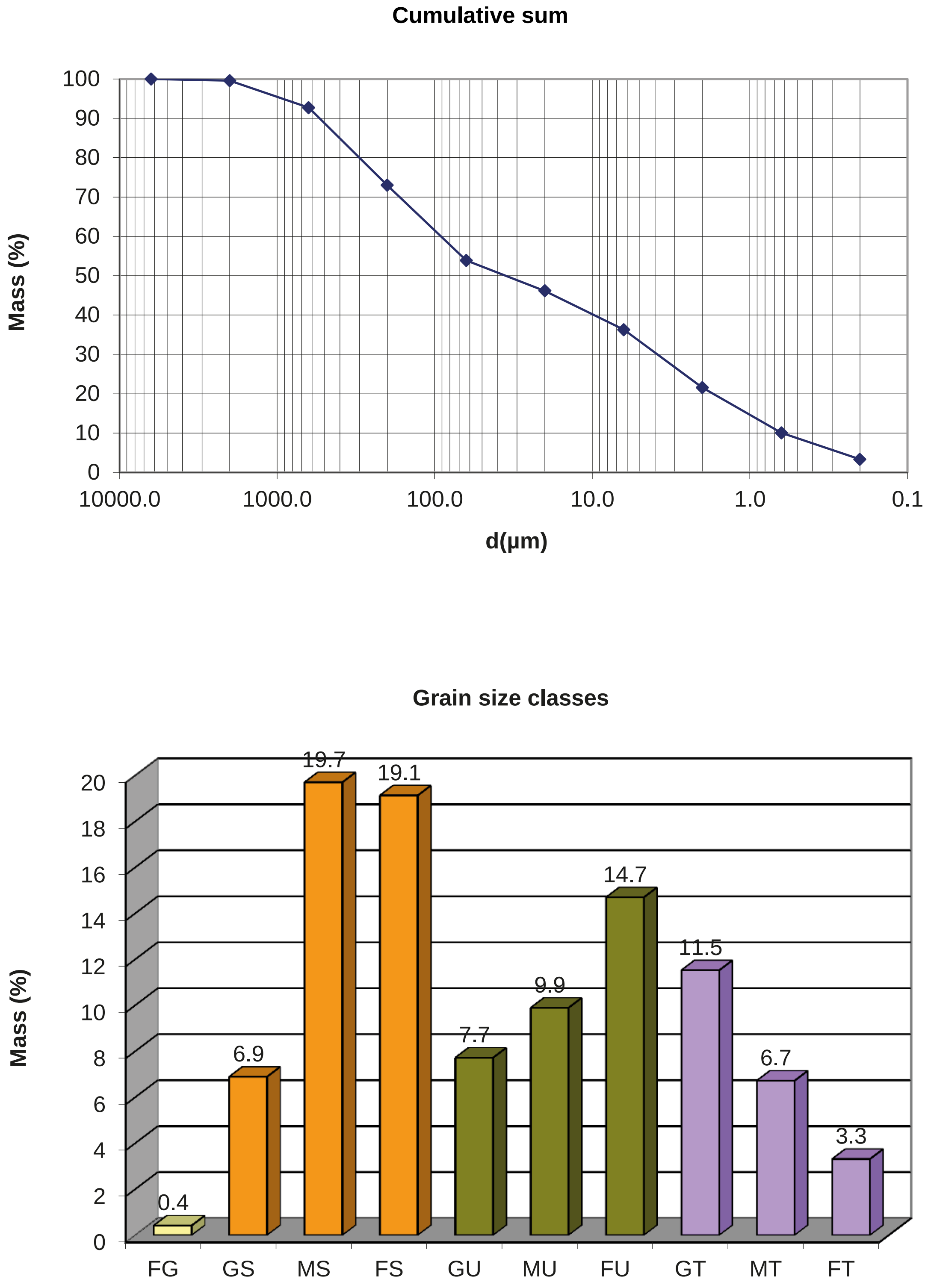


GSD 12.2 Nyarma. Sample 15406. Temple IV. Interior wall plaster. Upper layer.
Top: Cumulative sum. Bottom: Grain size classes.

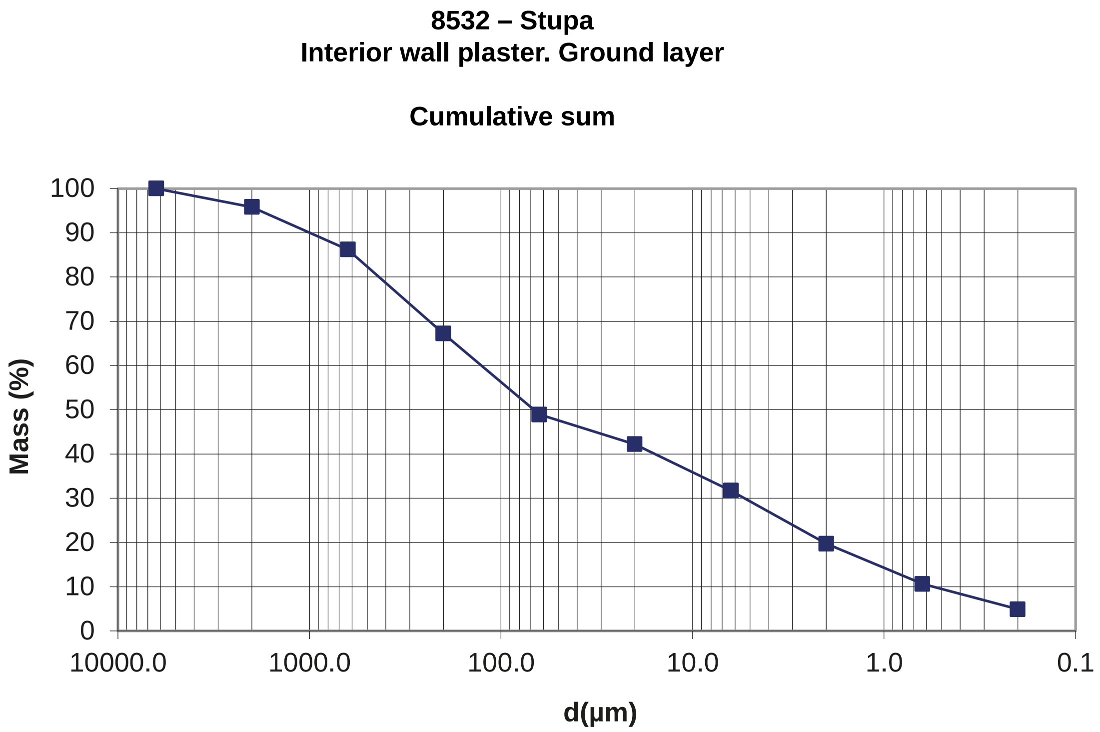


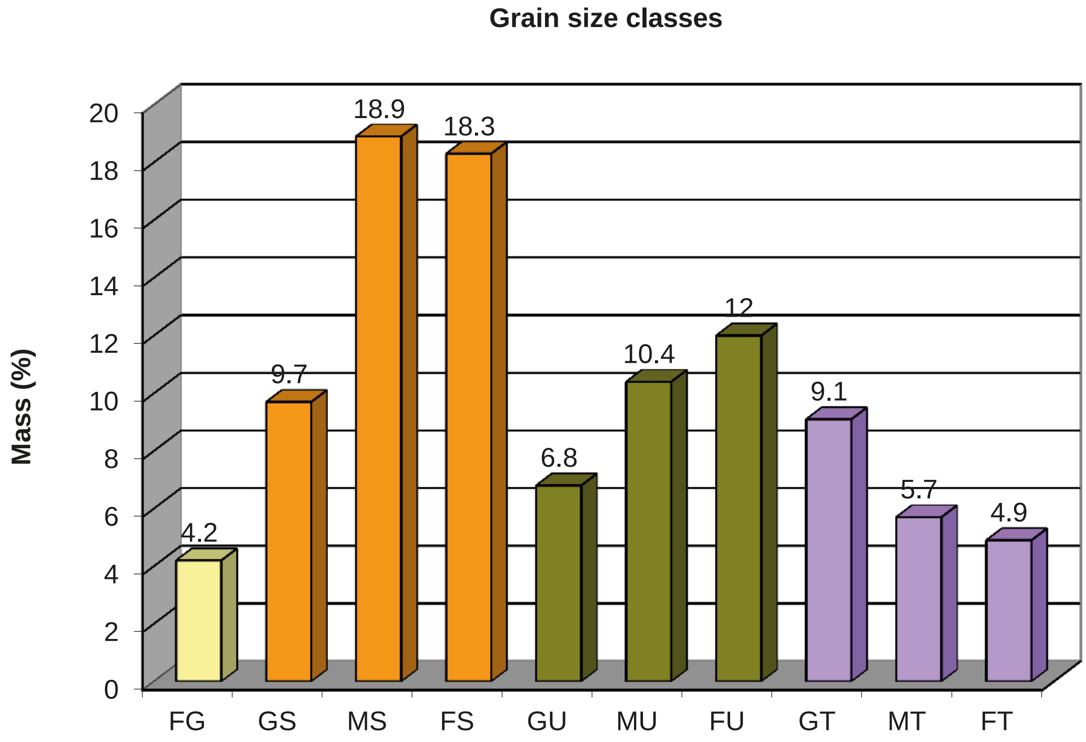
GSD 13.2 Nyarma. Sample 8517. Temple IV. Interior wall plaster. Ground layer.
Top: Cumulative sum. Bottom: Grain size classes.

### 11761 – Nyarma. Temple V
### Interior wall plaster



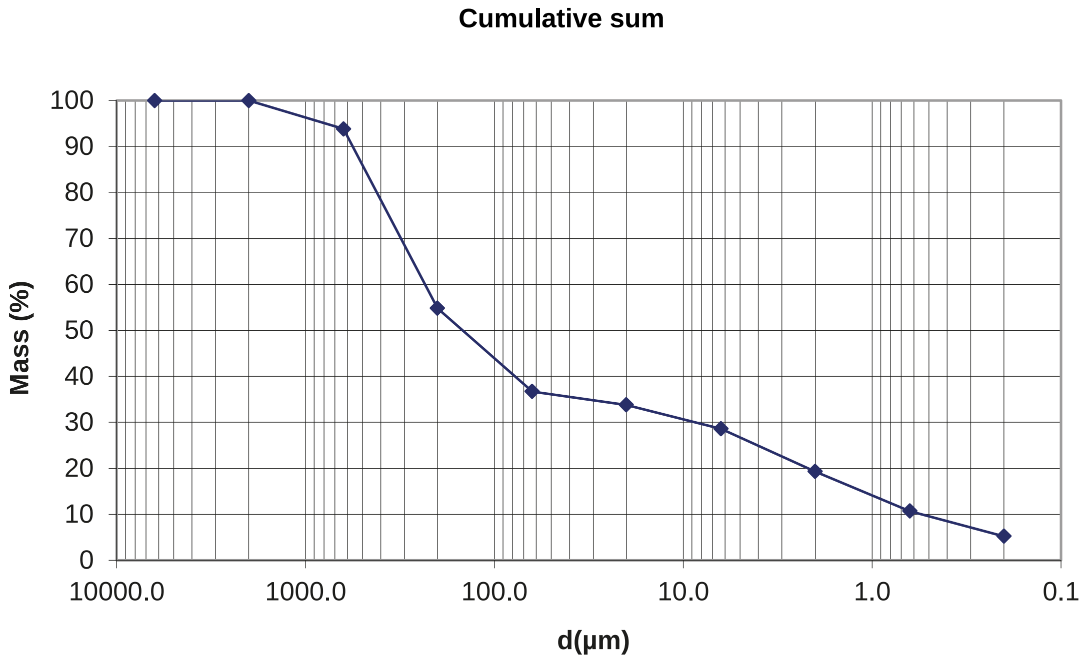
GSD 14.2 Nyarma. Sample 11761. Temple V. Interior wall plaster.
Top: Cumulative sum. Bottom: Grain size classes.

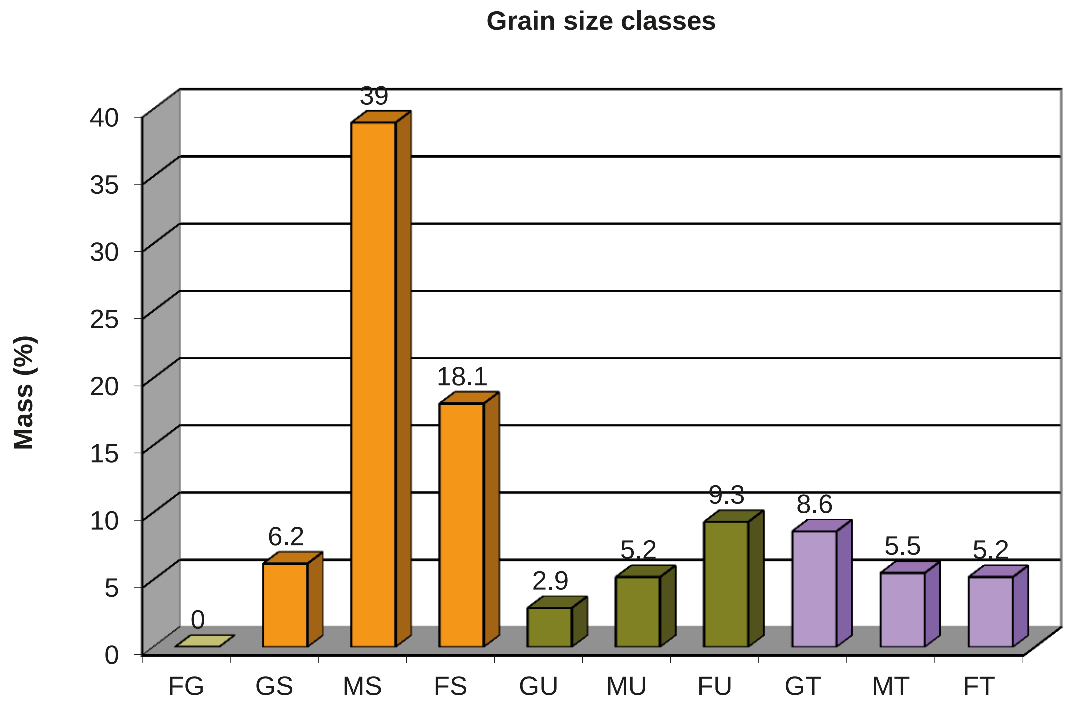




GSD 15.2 Nyarma. Sample 8532. Stupa. Interior wall plaster. Ground layer.
Top: Cumulative sum. Bottom: Grain size classes.

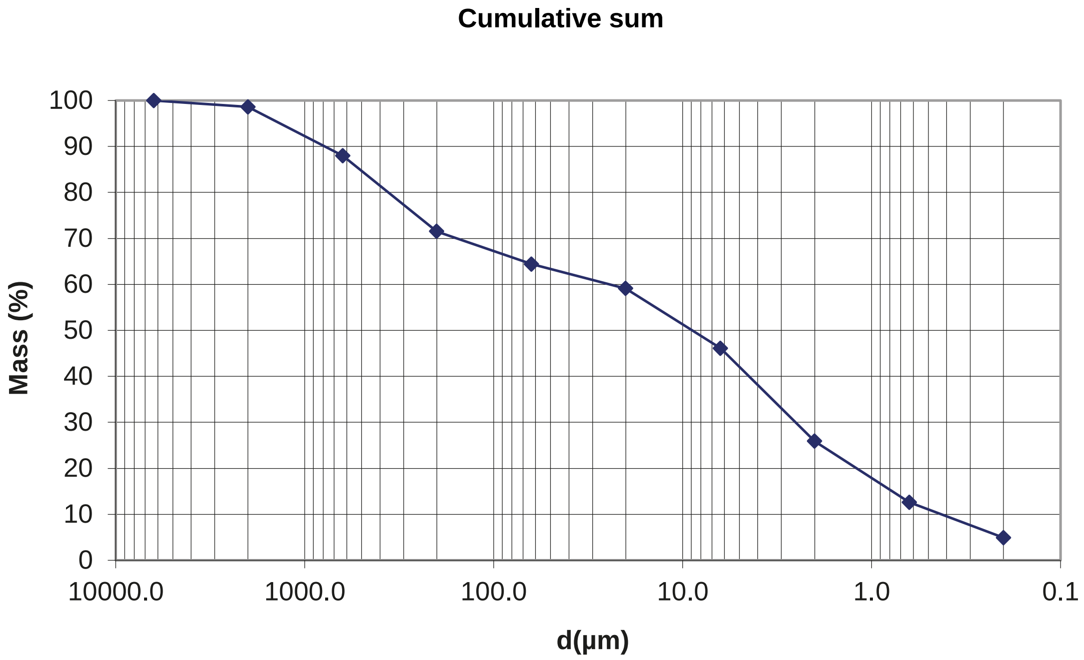
## 8520 – Nyarma. Stupa
## Interior wall plaster. Upper layer

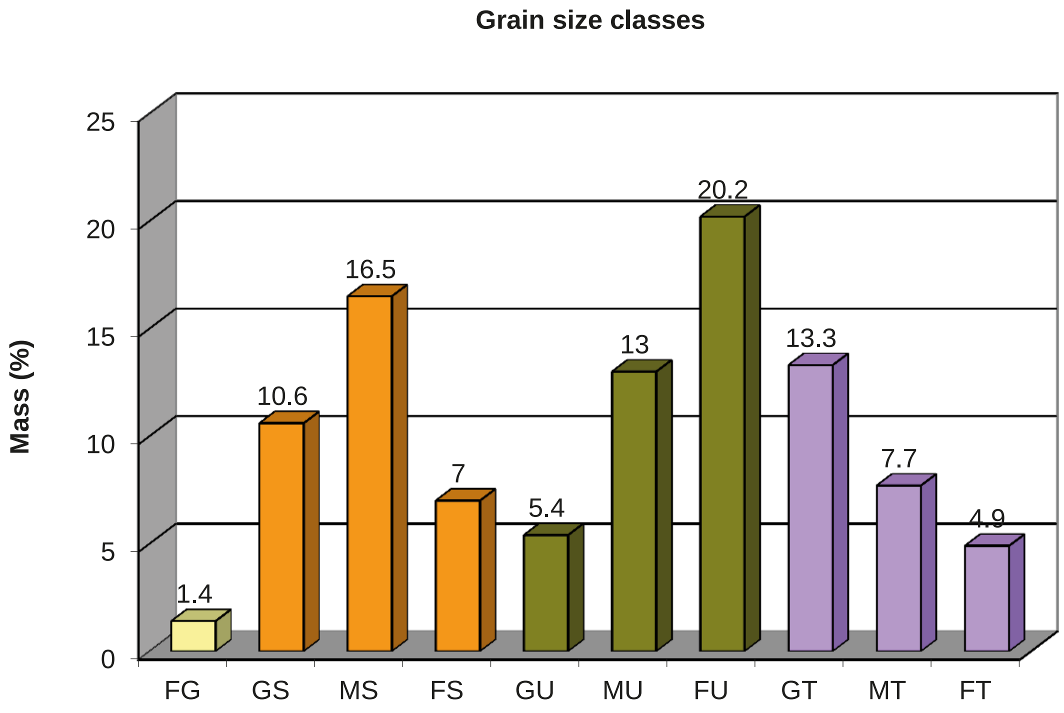




GSD 16.2 Nyarma. Sample 8520. Stupa. Interior wall plaster.
Top: Cumulative sum. Bottom: Grain size classes.

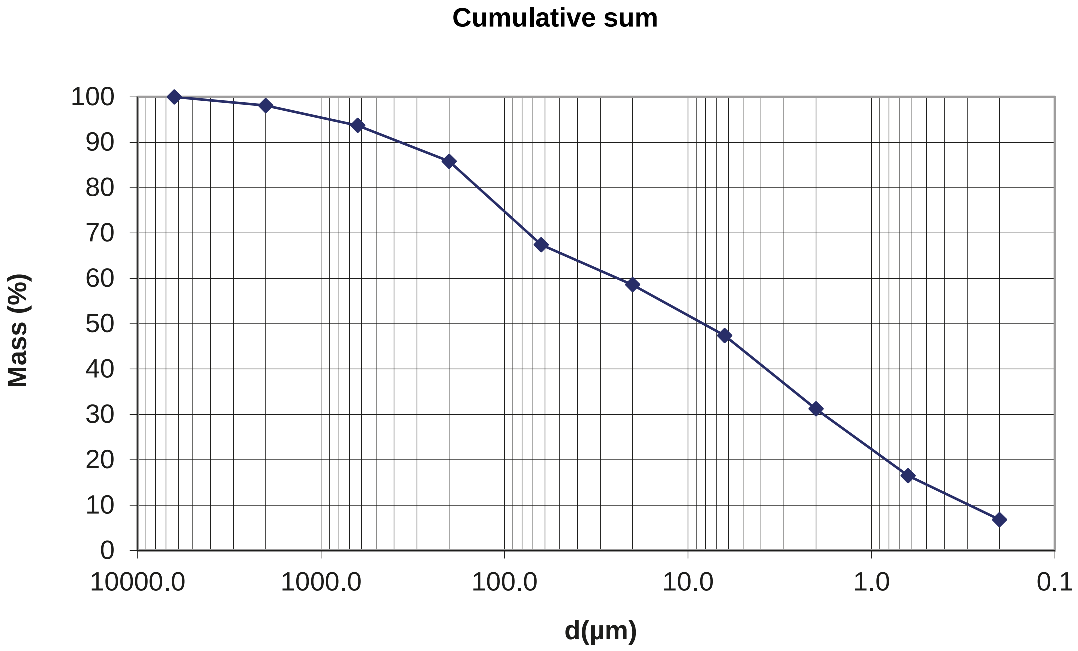
**8522 – Nyarma. Temple I. Aureole**
**Ground layer**

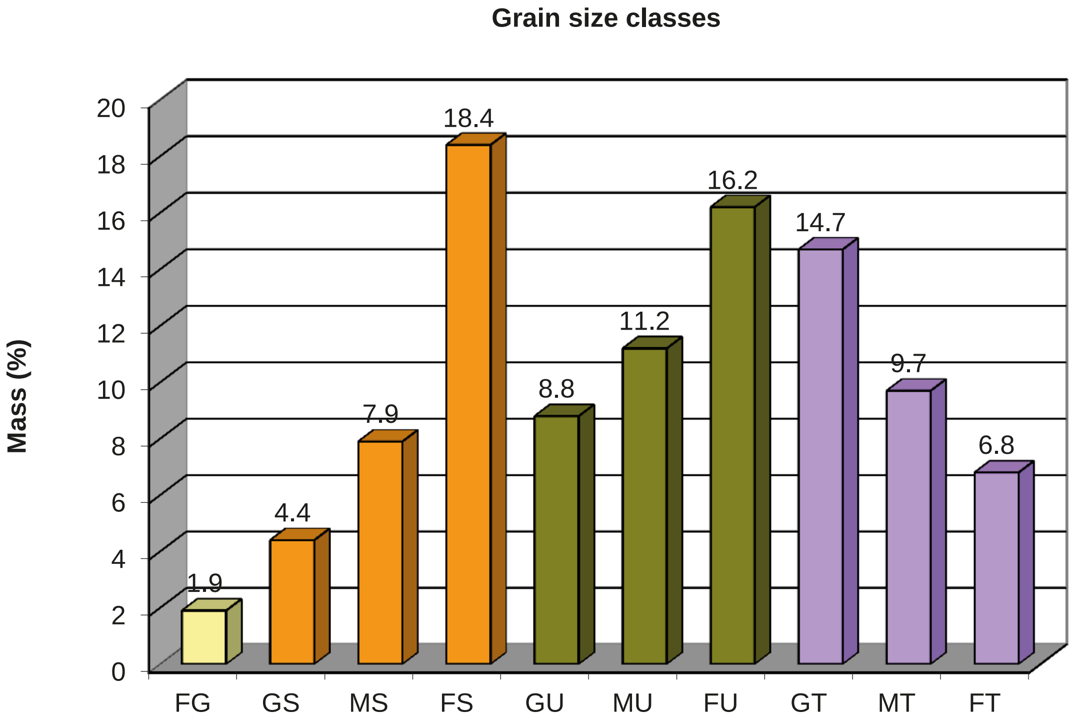




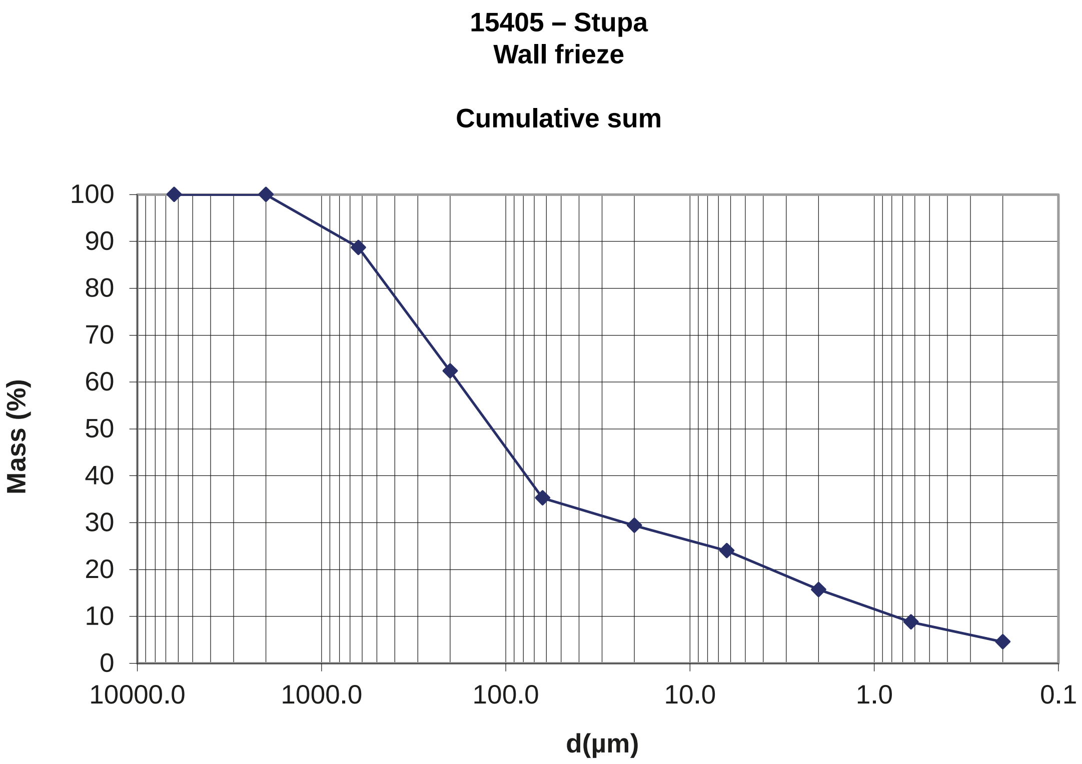
GSD 17.2 Nyarma. Temple I. Sample 8522. Aureole. Ground layer.
Top: Cumulative sum. Bottom: Grain size classes.

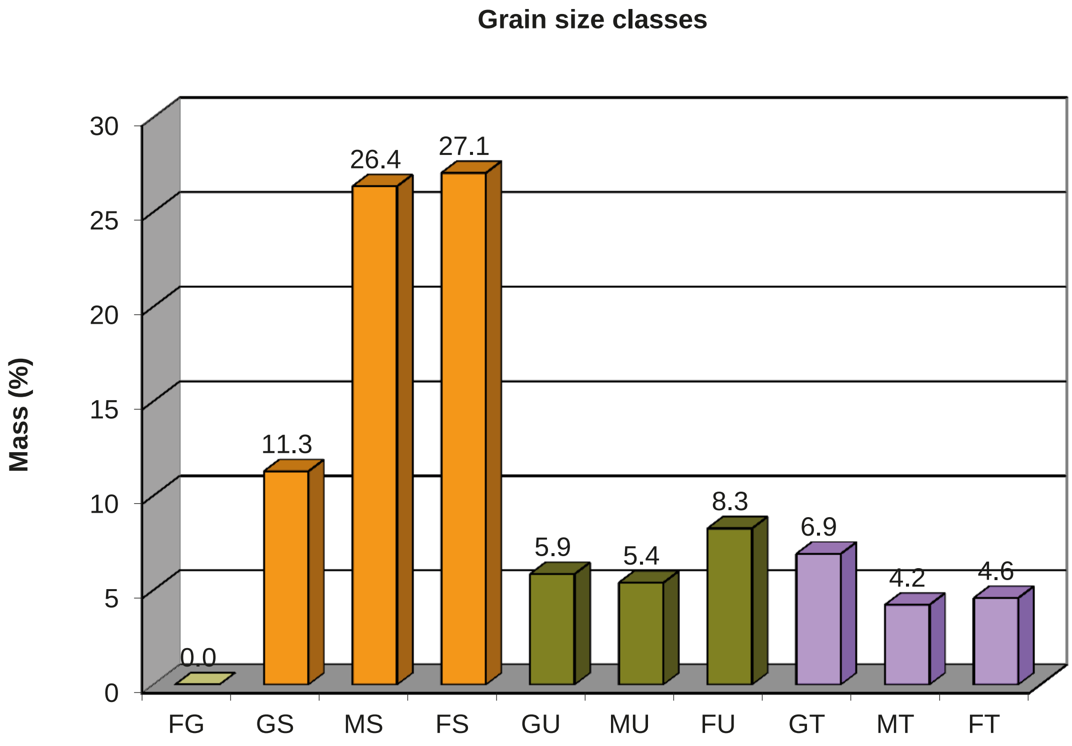
**8516 – Nyarma. Temple I. Aureole**
**Upper layer**





GSD 18.2 Nyarma. Sample 8516. Temple I. Aureole. Upper layer.
Top: Cumulative sum. Bottom: Grain size classes.

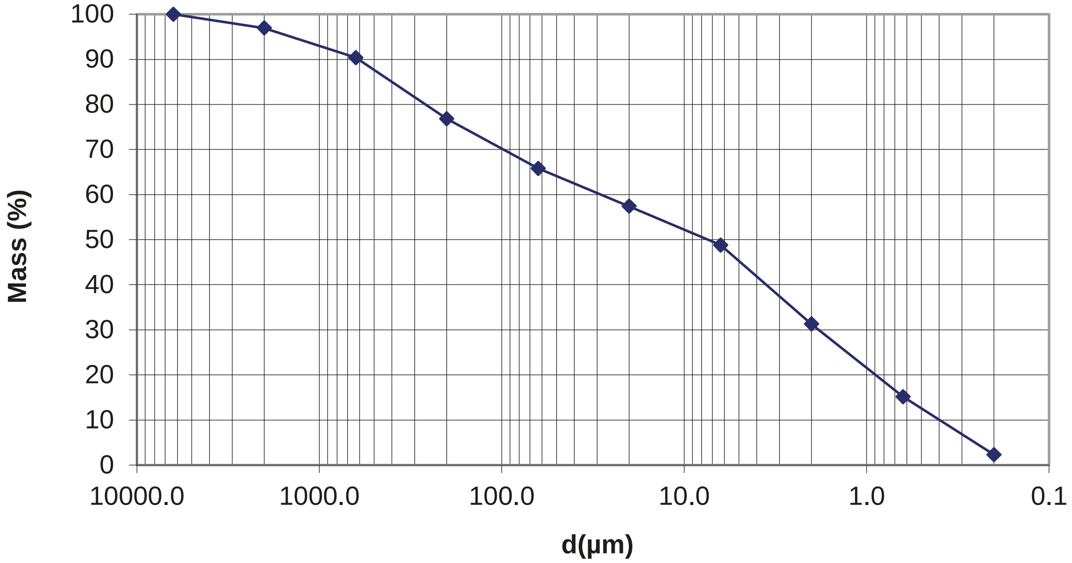




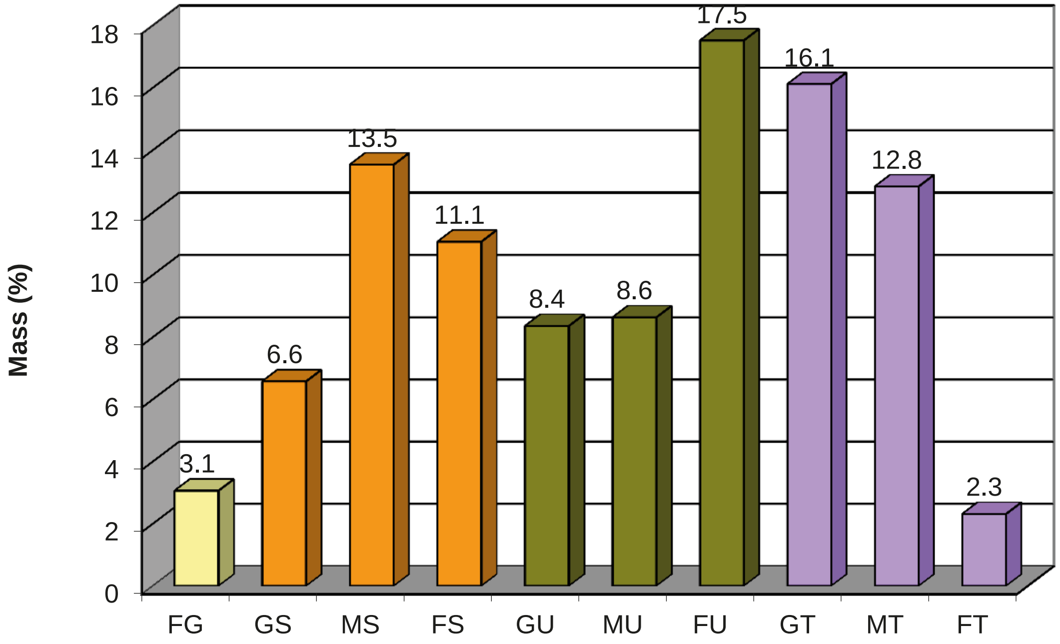
GSD 19.2 Nyarma. Sample 15405. Stupa. Broken piece of a wall frieze.
Top: Cumulative sum. Bottom: Grain size classes.

## 11914 – Nyarma. Temple I. *Cella* north wall
## Exterior plaster

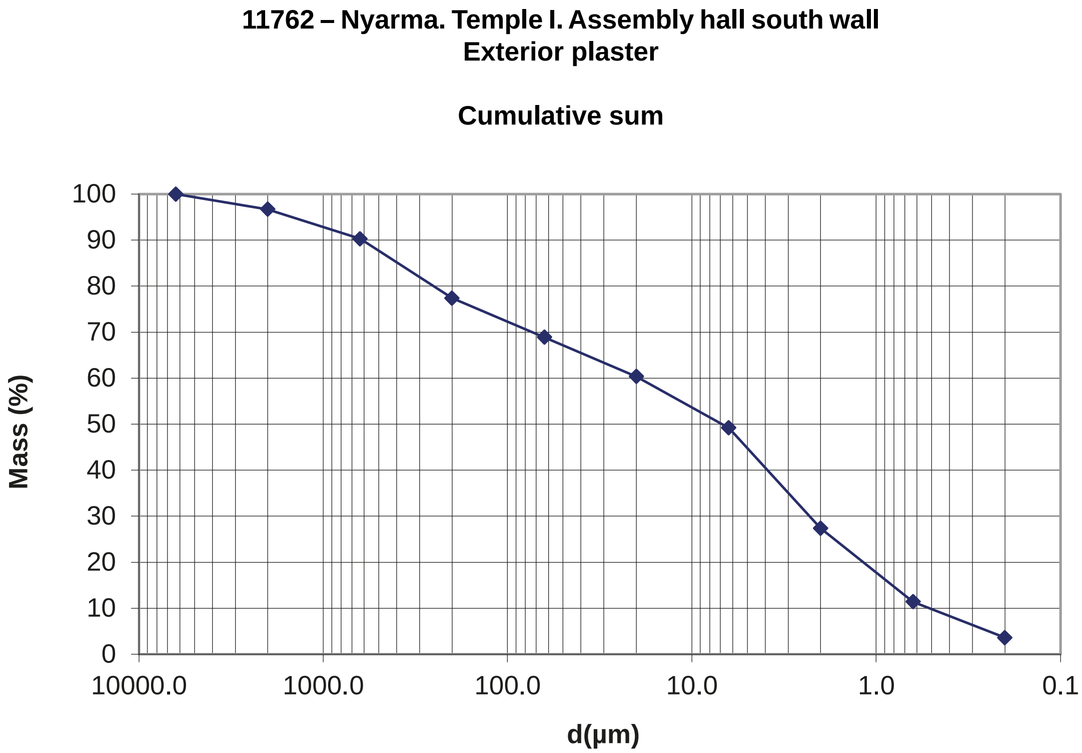
**Cumulative sum**

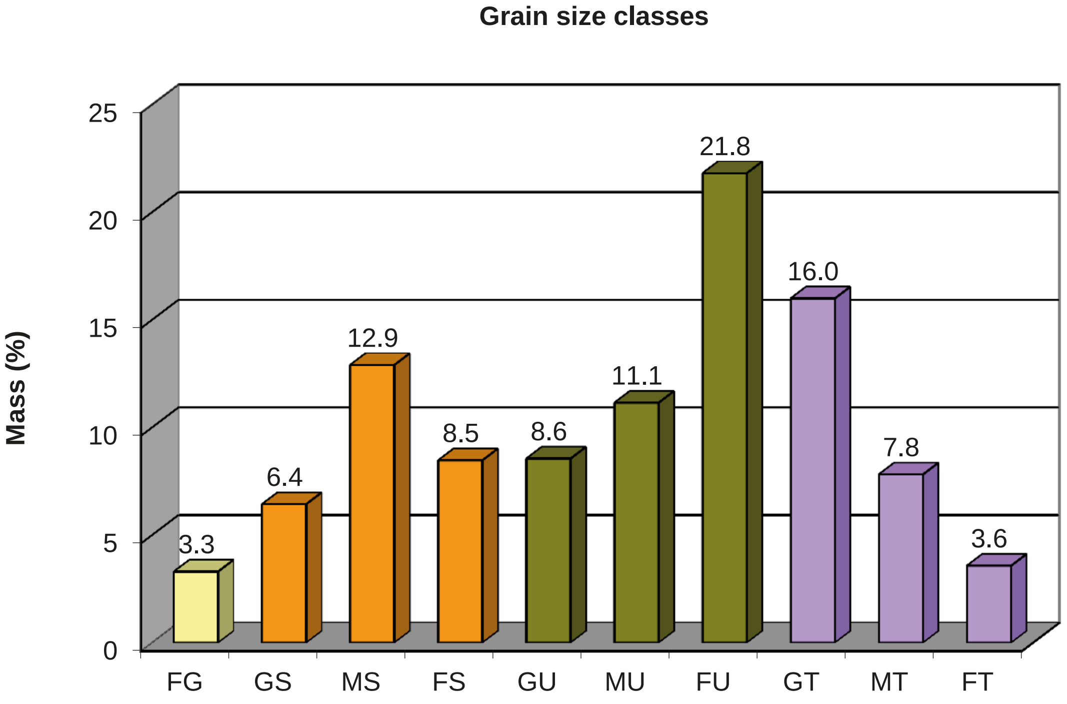


**Grain size classes**



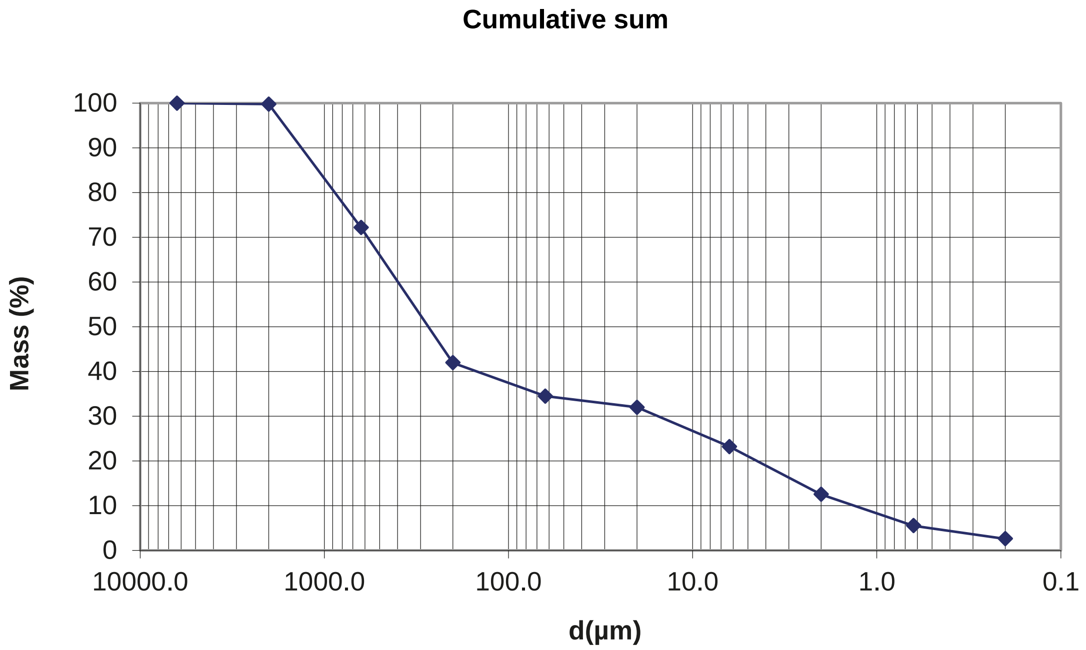
GSD 20.2 Nyarma. Sample 11914. Temple I. *Cella* north wall. Exterior wall plaster.
Top: Cumulative sum. Bottom: Grain size classes.

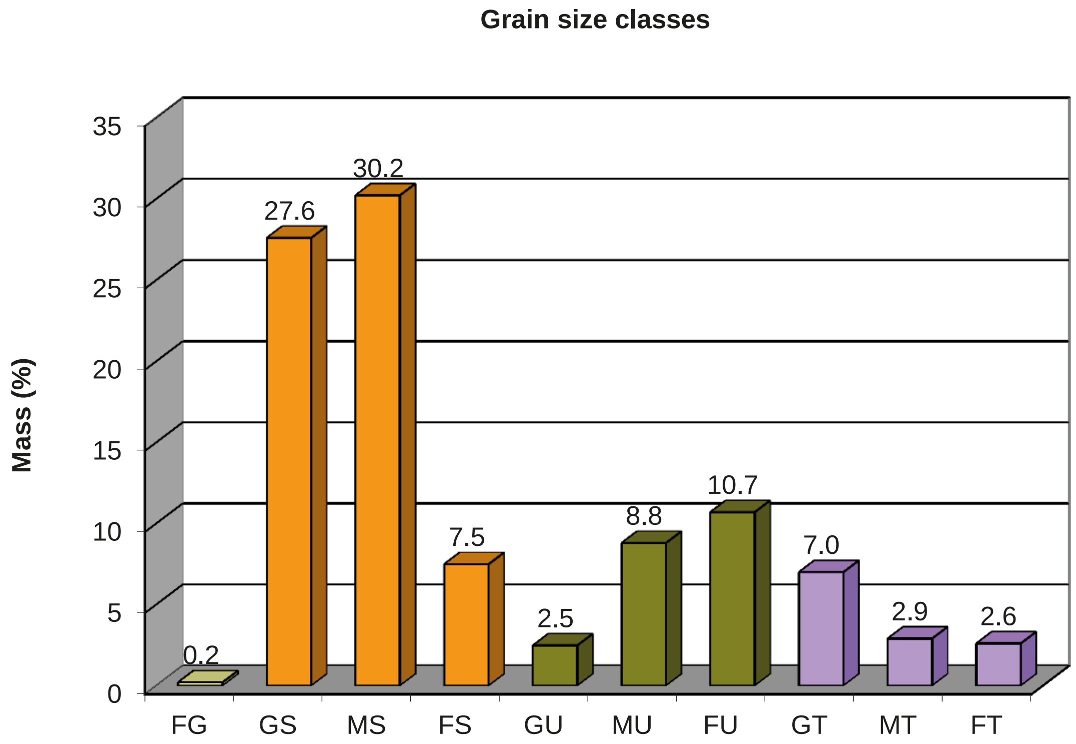




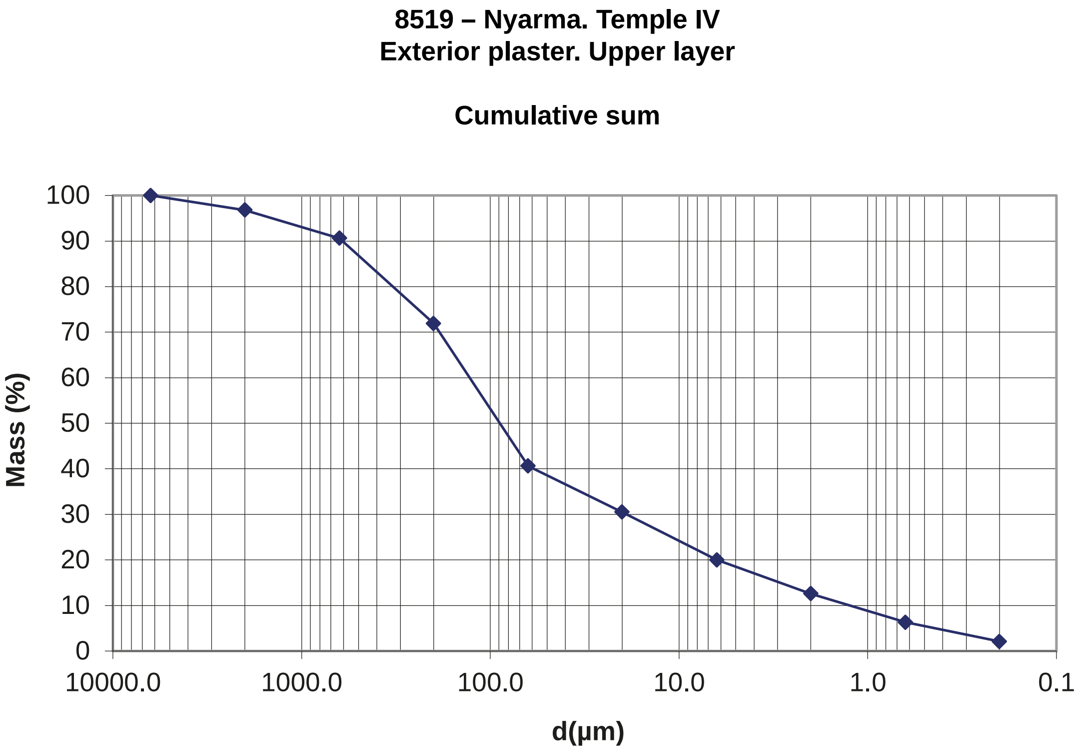
GSD 21.2 Nyarma. Sample 11762. Temple I. Assembly hall south wall. Exterior wall plaster.
Top: Cumulative sum. Bottom: Grain size classes.

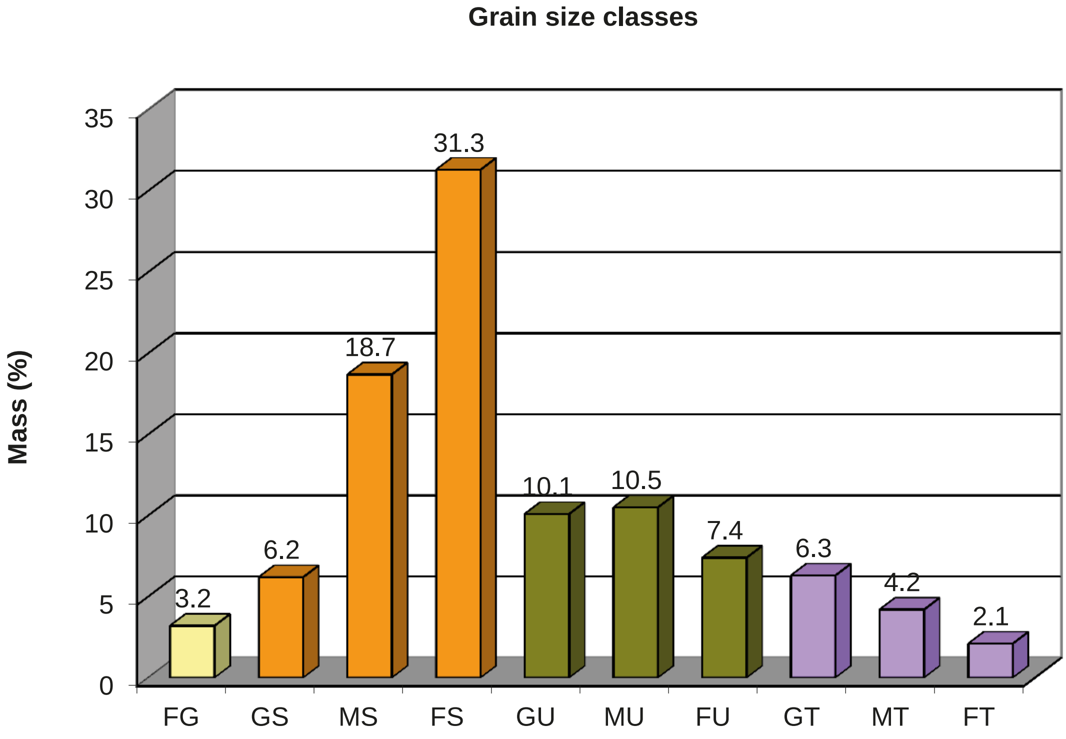
**15408 – Nyarma. Temple IIIb**
**Exterior plaster**





GSD 22.2 Nyarma. Sample 15408. Temple IIIb. Exterior wall plaster.
Top: Cumulative sum. Bottom: Grain size classes.

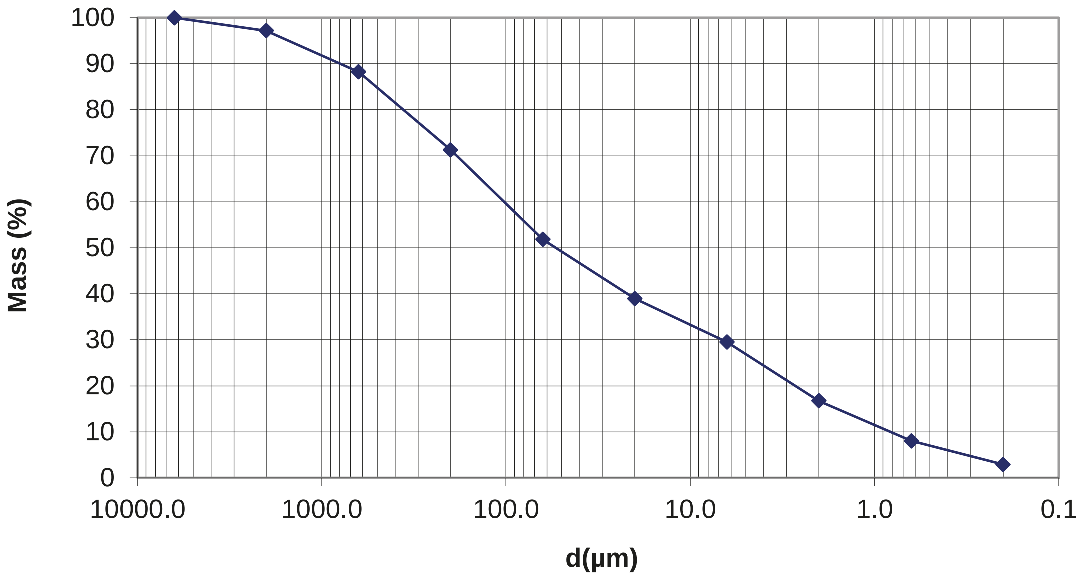




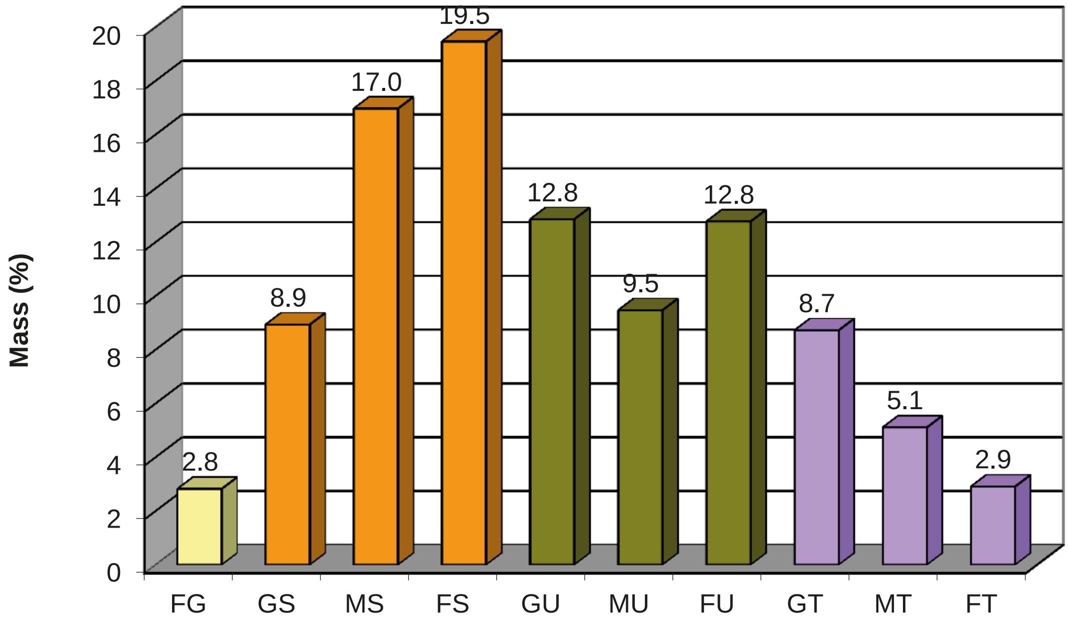
GSD 23.2 Nyarma. Sample 8519. Temple IV. Exterior wall plaster. Upper layer.
Top: Cumulative sum. Bottom: Grain size classes.

## 11767 – Nyarma. Temple I. Assembly hall
## Adobe brick

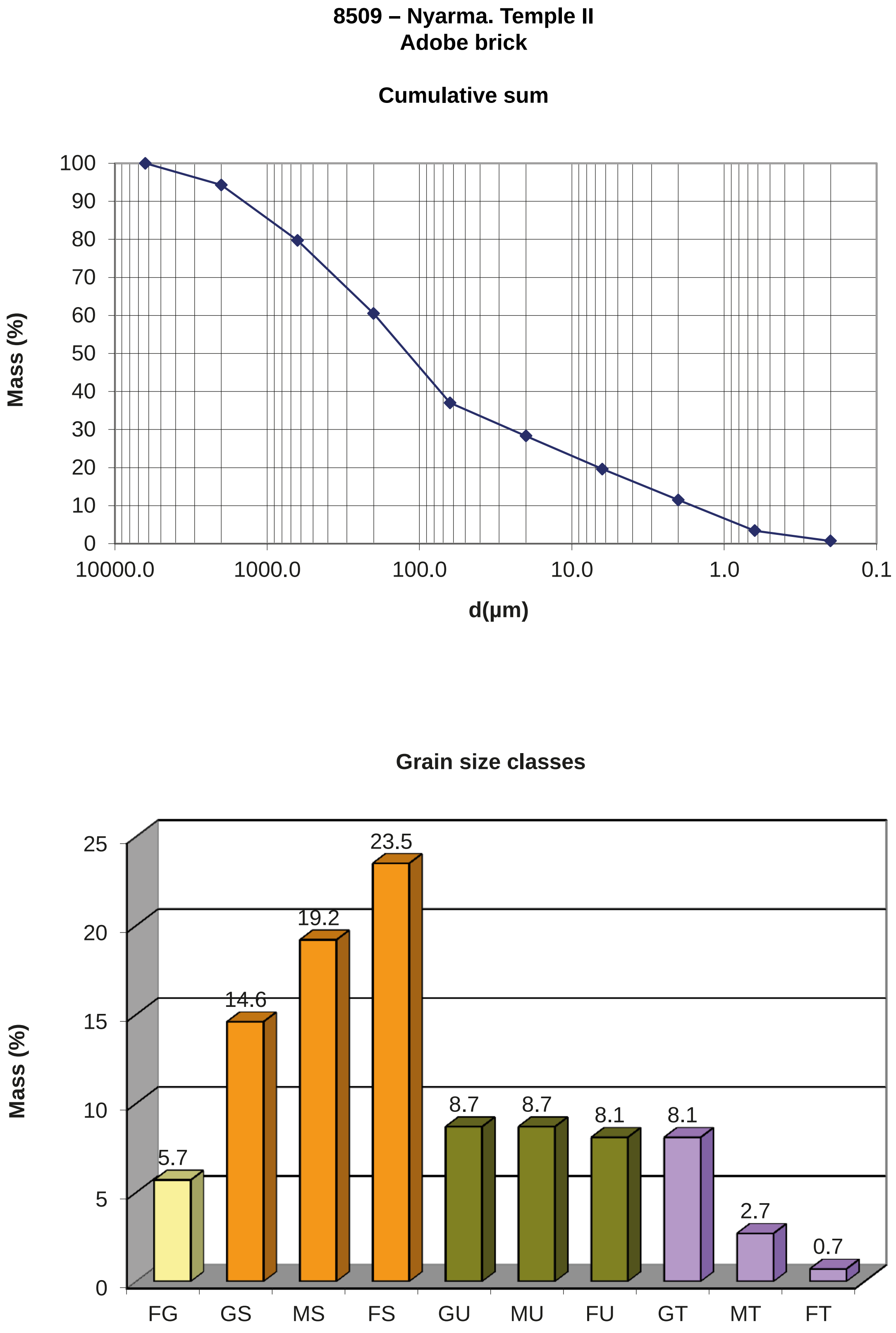
### Cumulative sum



### Grain size classes

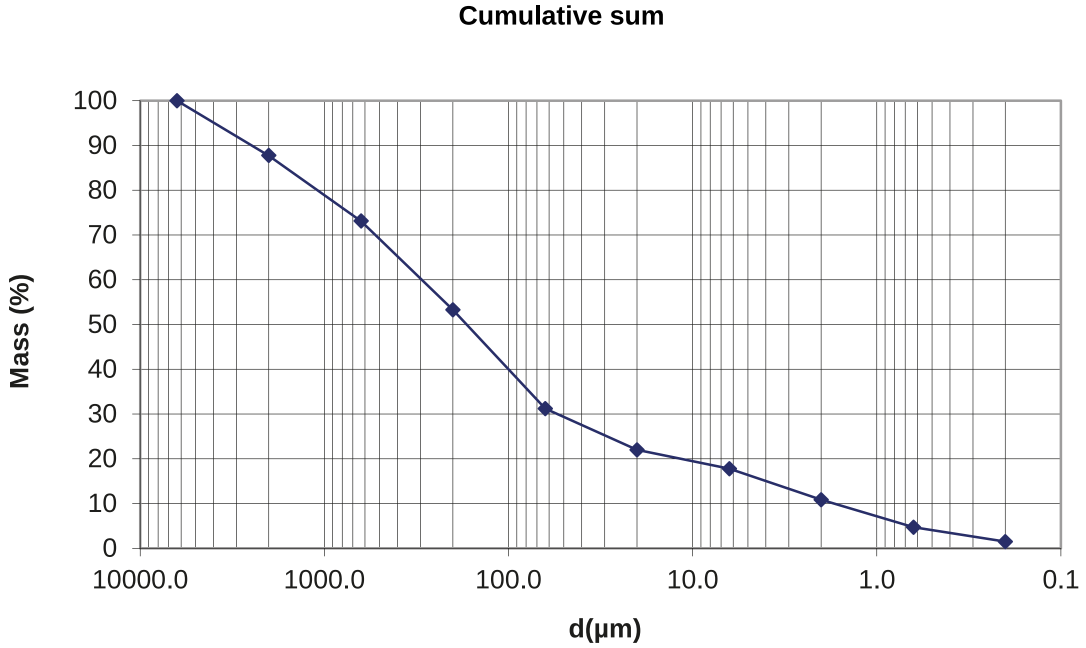


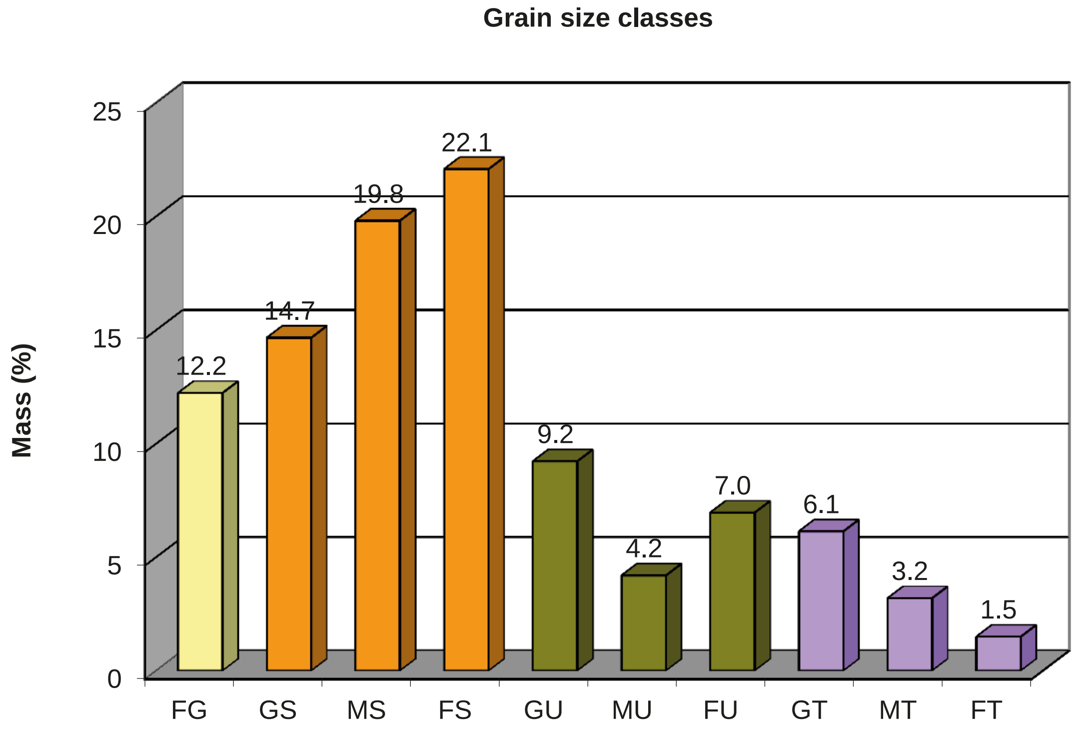
GSD 24.2 Nyarma. Sample 11767. Temple I. Assembly hall. Adobe brick.
Top: Cumulative sum. Bottom: Grain size classes.



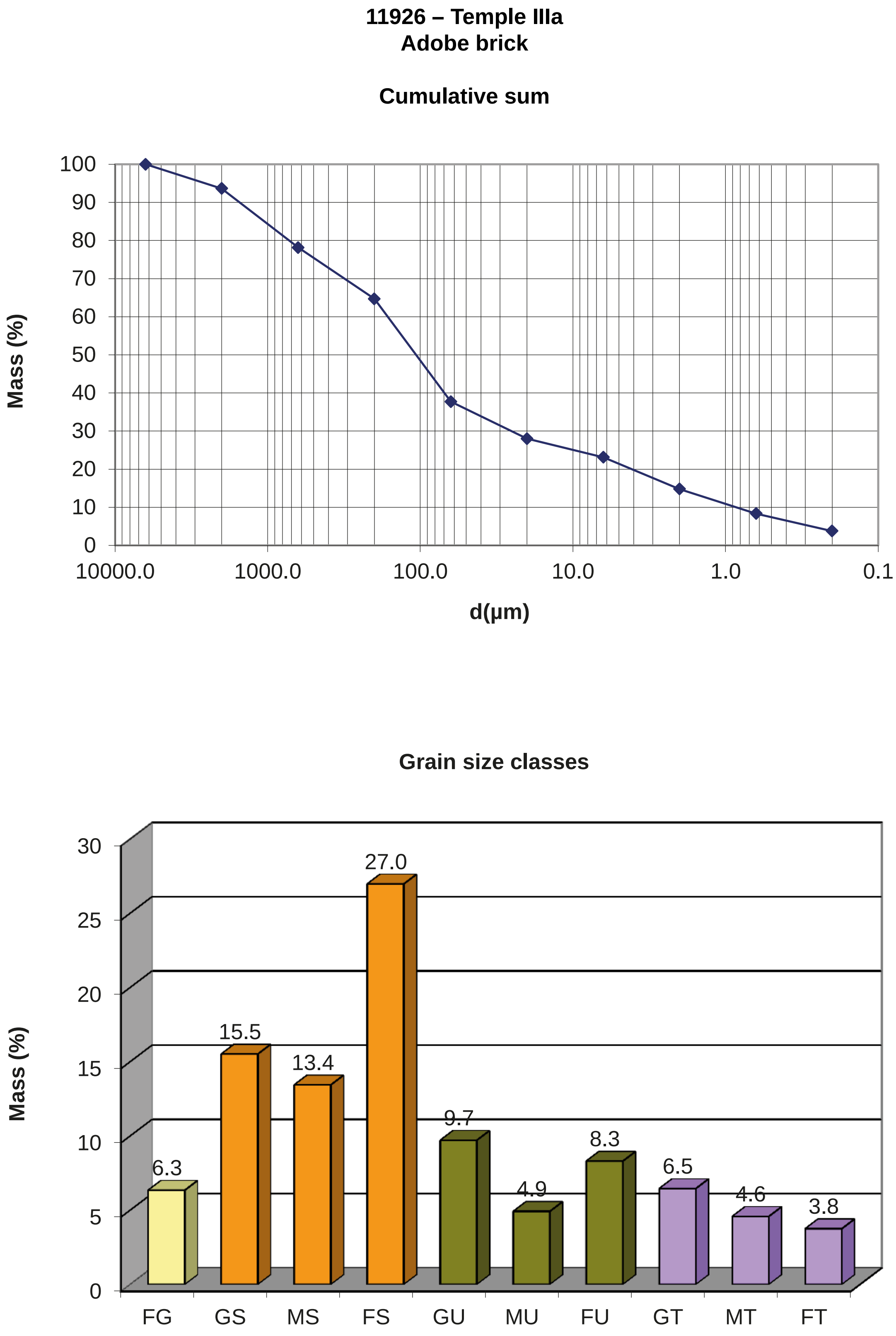
GSD 25.2 Nyarma. Sample 8509. Temple II. Adobe brick.
Top: Cumulative sum. Bottom: Grain size classes.

## 11750 – Nyarma. Temple II
## Adobe brick



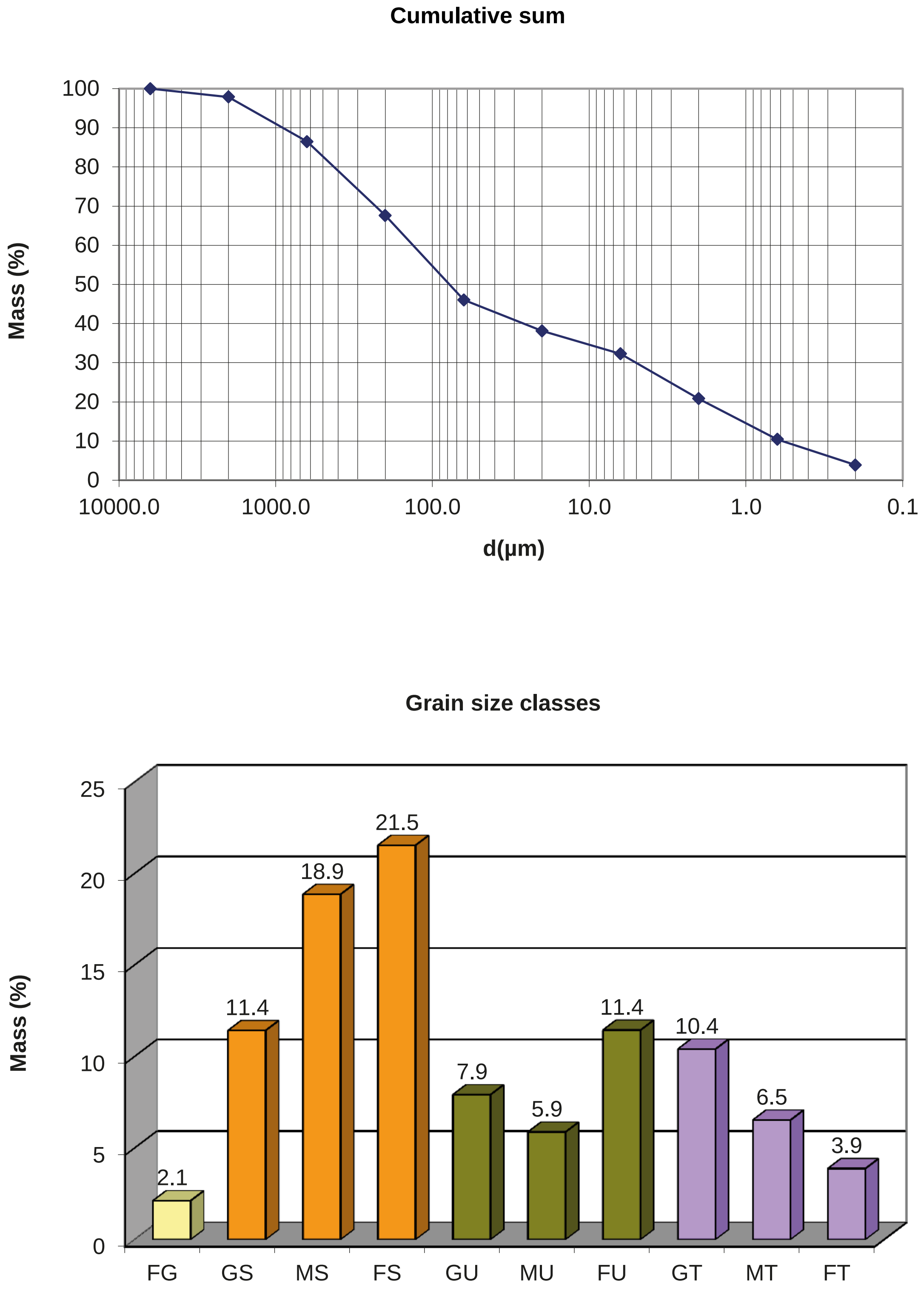


GSD 26.2 Nyarma. Sample 11750. Temple II. Adobe brick.
Top: Cumulative sum. Bottom: Grain size classes.



GSD 27.2 Nyarma. Sample 11926. Temple IIIa. Adobe brick.
Top: Cumulative sum. Bottom: Grain size classes.

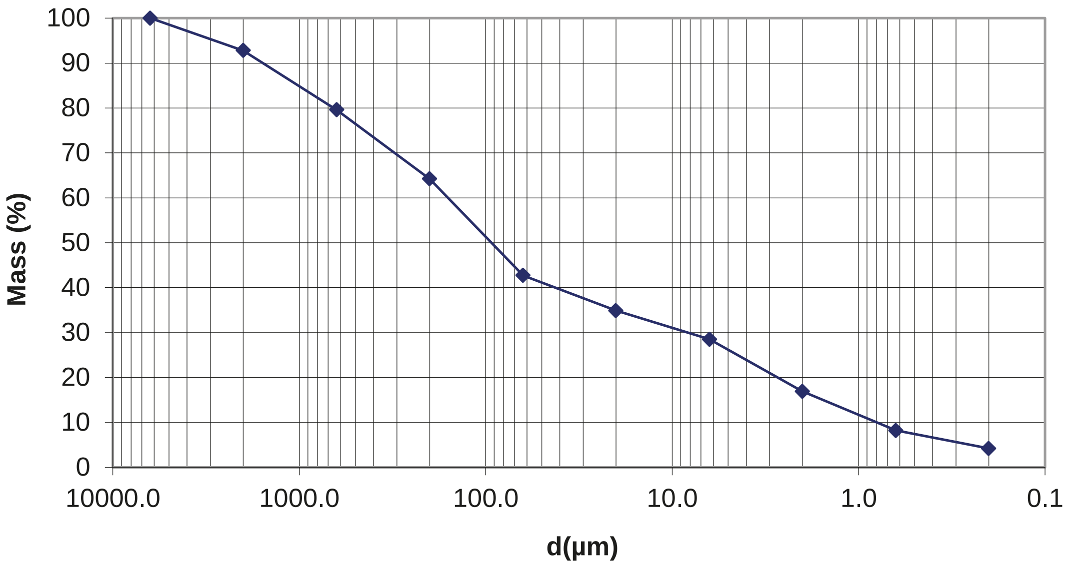
## 11744 – Nyarma. Temple IIIb
## Adobe brick



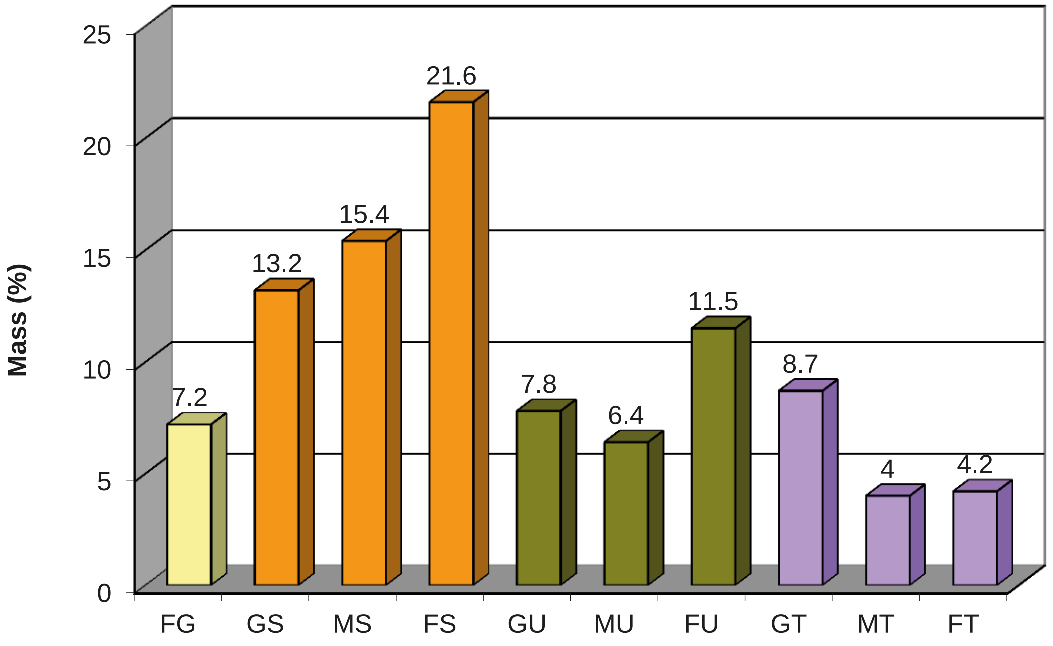
GSD 28.2 Nyarma. Sample 11744. Temple IIIb. Adobe brick.
Top: Cumulative sum. Bottom: Grain size classes.

**8533 – Nyarma. Temple IIIb**
**Adobe brick**

**Cumulative sum**

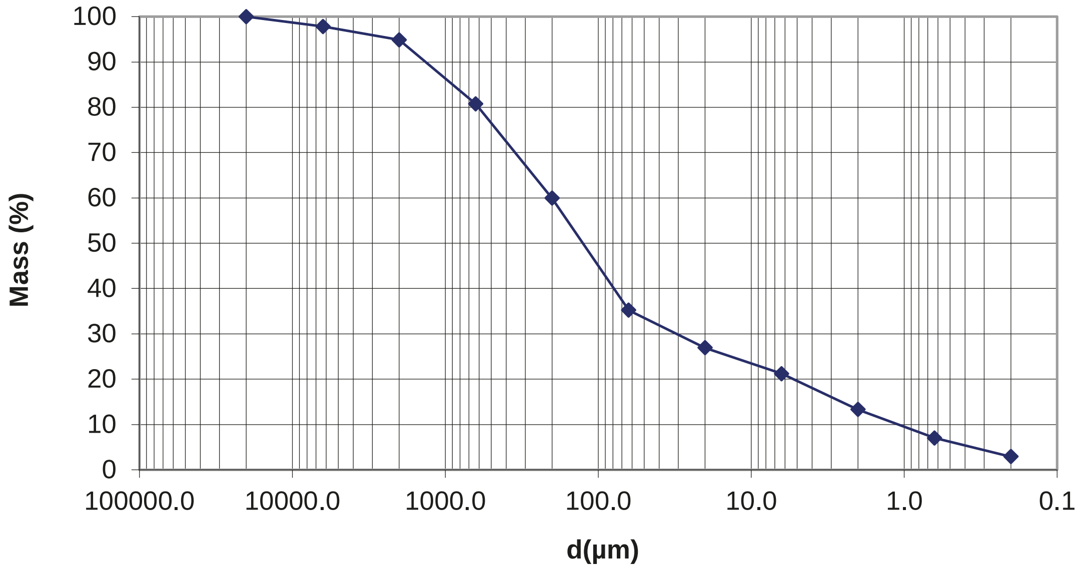


**Grain size classes**

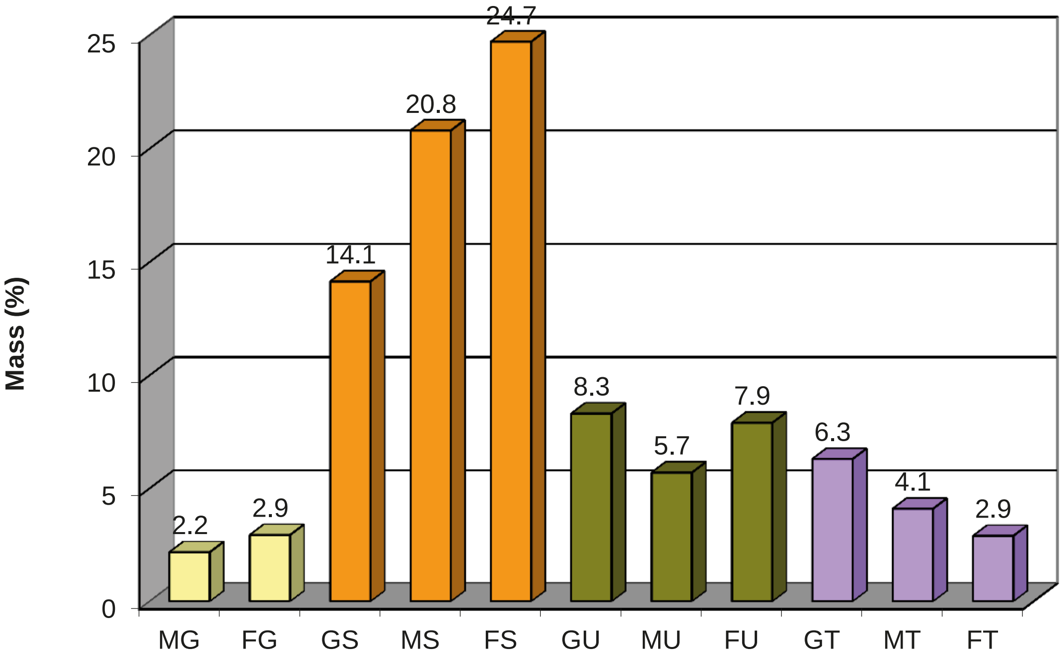


GSD 29.2 Nyarma. Sample 8533. Temple IIIb. Adobe brick.
Top: Cumulative sum. Bottom: Grain size classes.

**15407 – Nyarma. Temple IV**
**Adobe brick**

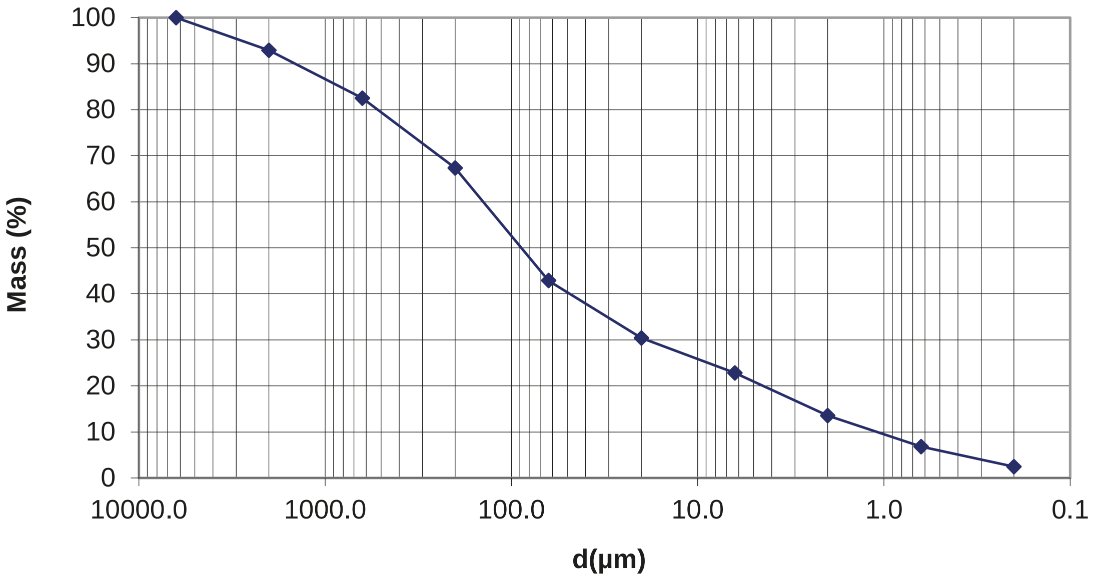


Cumulative sum

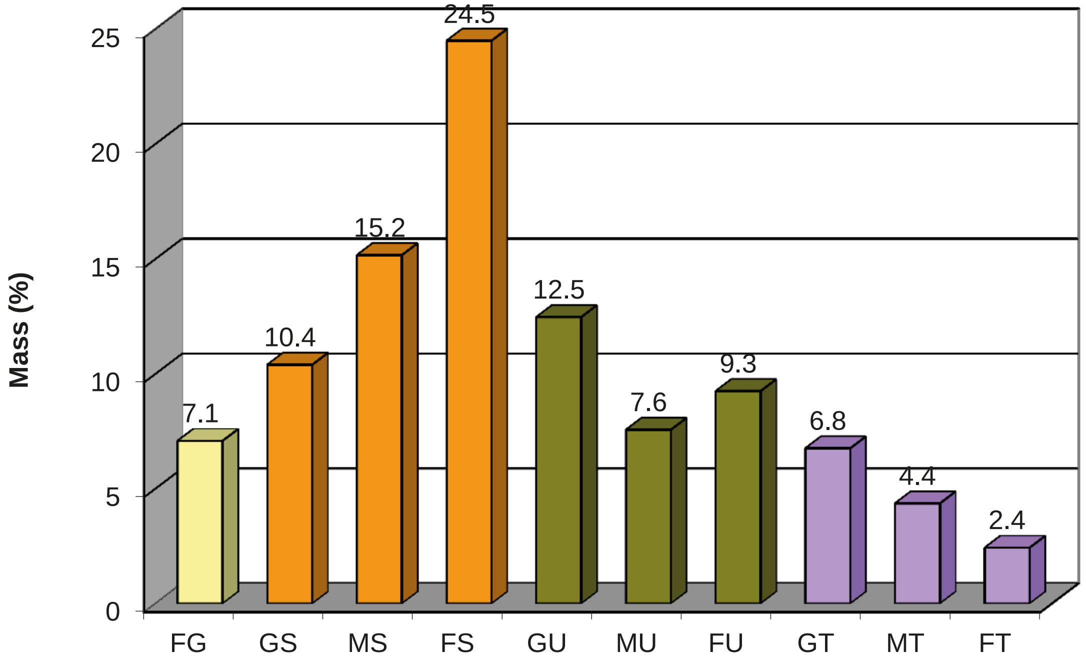


Grain size classes

GSD 30.2 Nyarma. Sample 15407. Temple IV. Adobe brick.
Top: Cumulative sum. Bottom: Grain size classes.

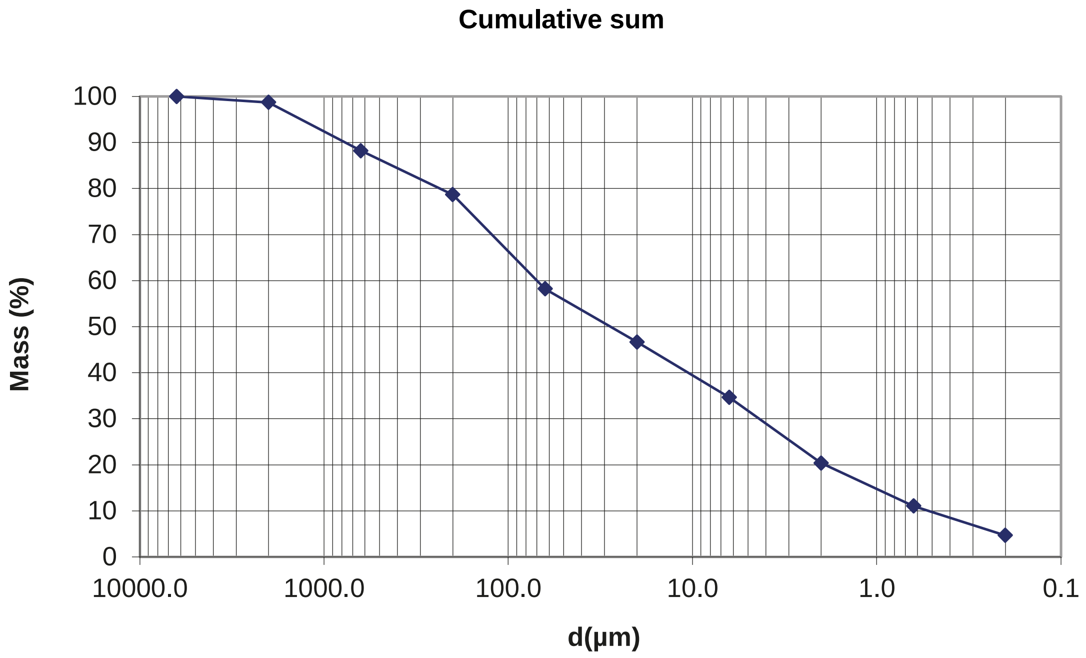

**11917 – Nyarma. Temple IV**
**Adobe brick**

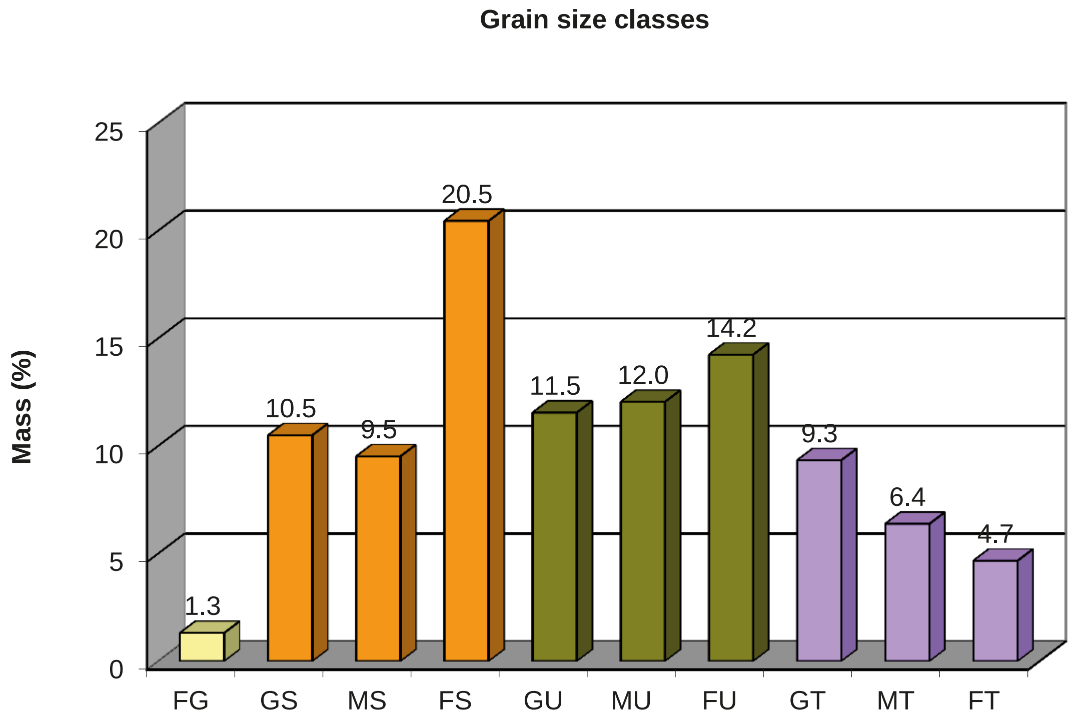
**Cumulative sum**


**Grain size classes**

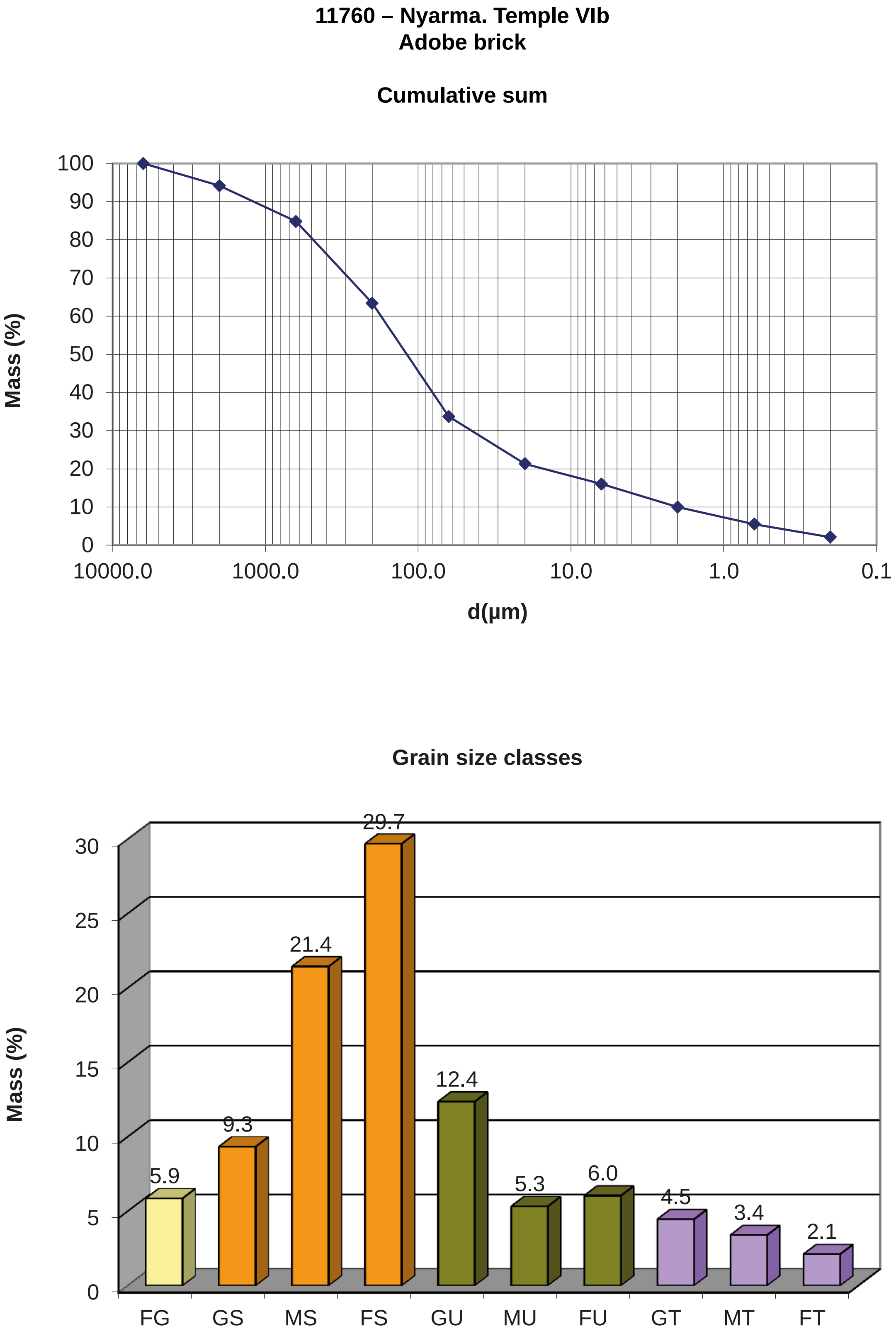
GSD 31.2 Nyarma. Sample 11917. Temple IV. Adobe brick.
Top: Cumulative sum. Bottom: Grain size classes.

## 11765 – Nyarma. Temple VIa
## Adobe brick



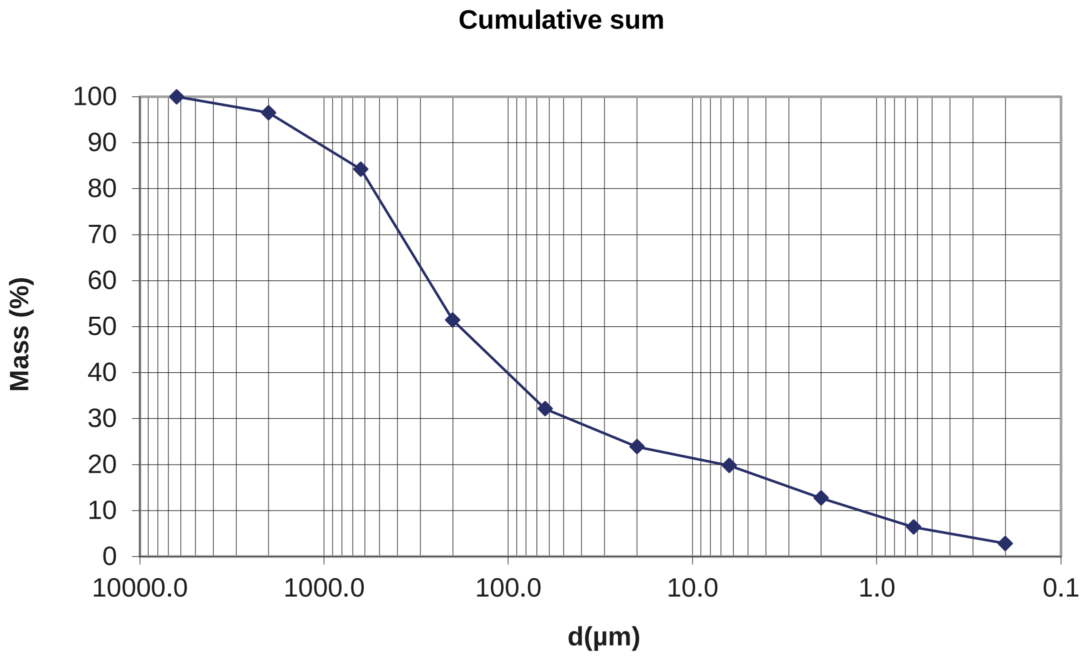


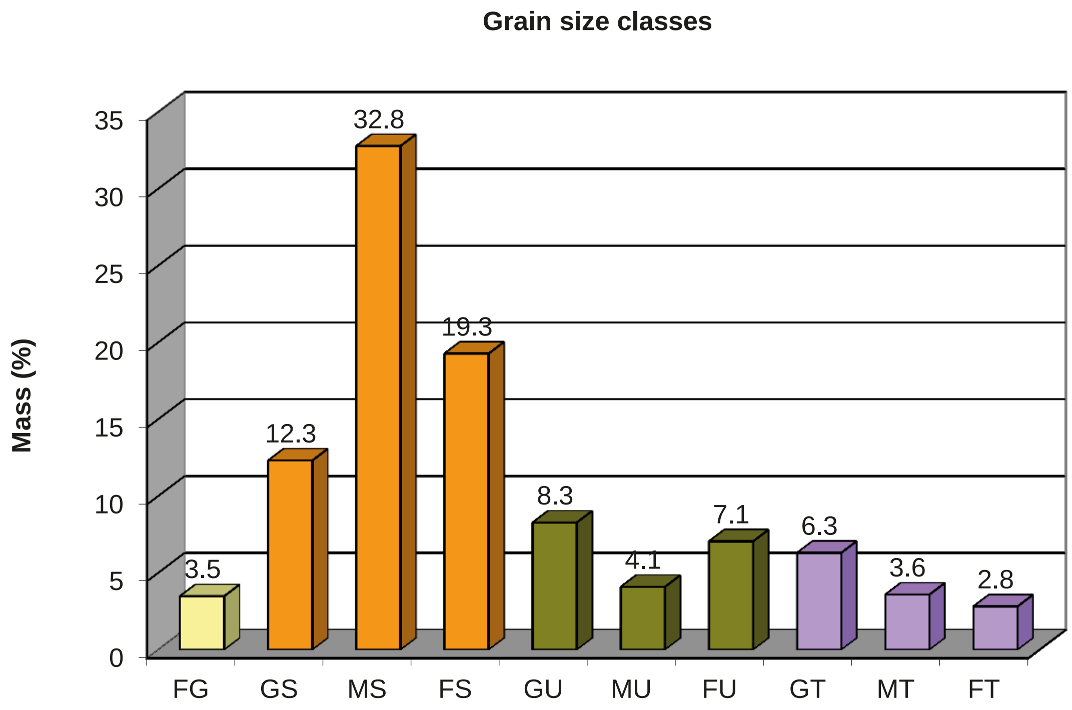
GSD 32.2 Nyarma. Sample 11765. Temple VIa. Adobe brick.
Top: Cumulative sum. Bottom: Grain size classes.



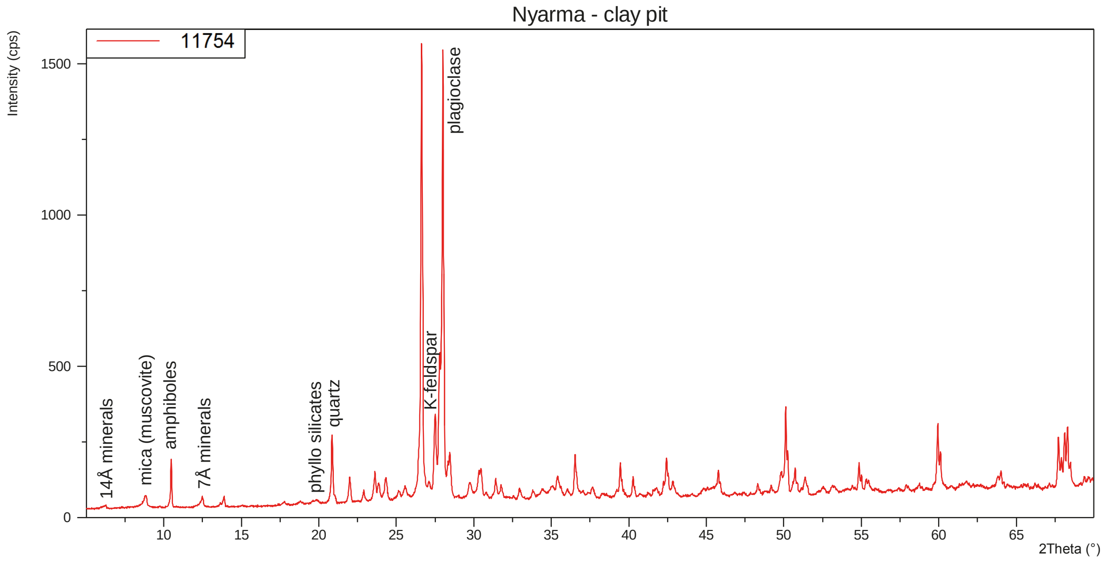
GSD 33.2 Nyarma. Sample 11760. Temple VIb. Adobe brick.
Top: Cumulative sum. Bottom: Grain size classes.

## 11766 – Nyarma. Enclosure wall
## Adobe brick

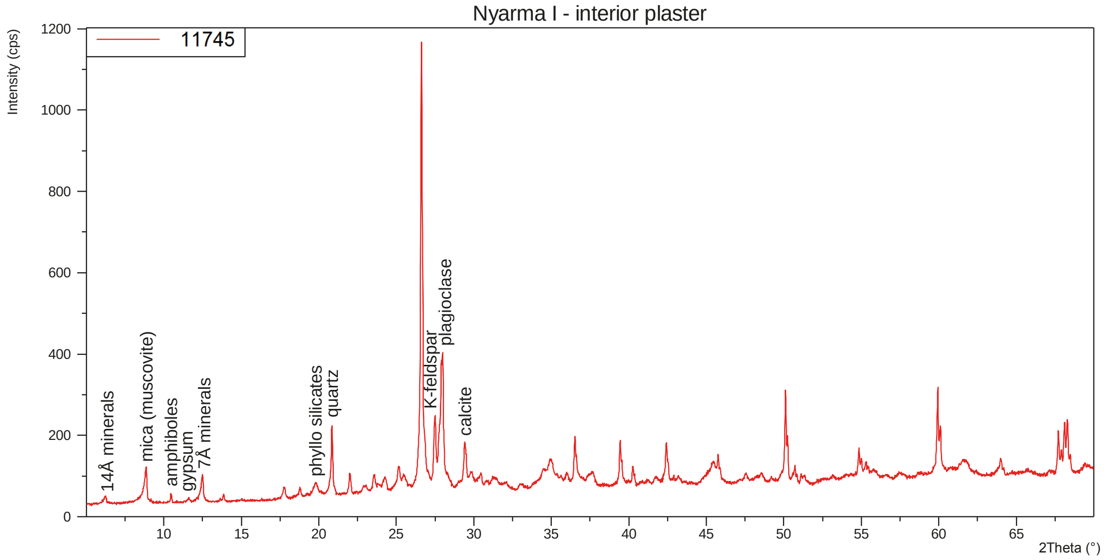




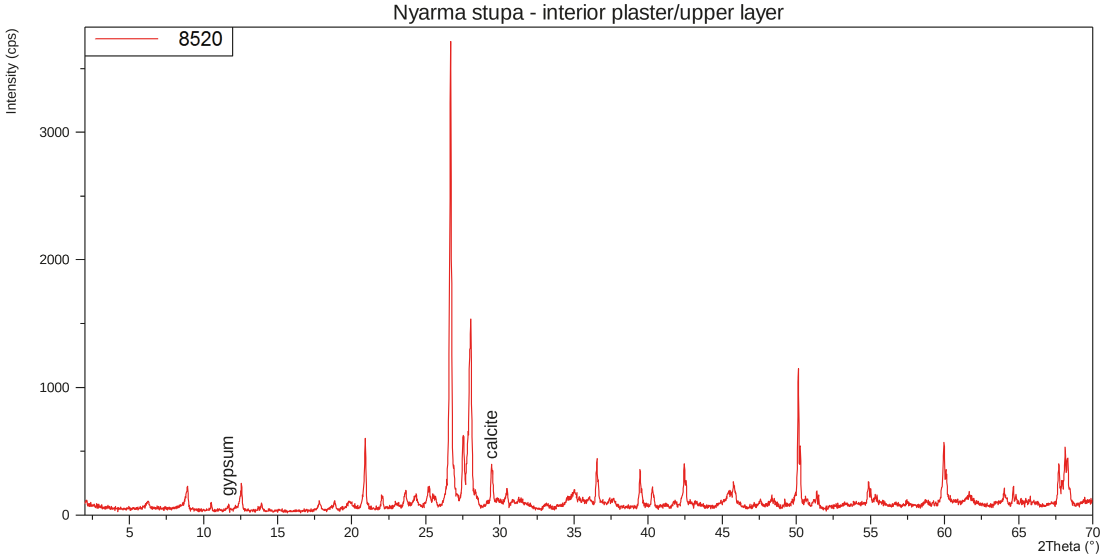
GSD 34.2 Nyarma. Sample 11766. Enclosure wall. Adobe brick.
Top: Cumulative sum. Bottom: Grain size classes.



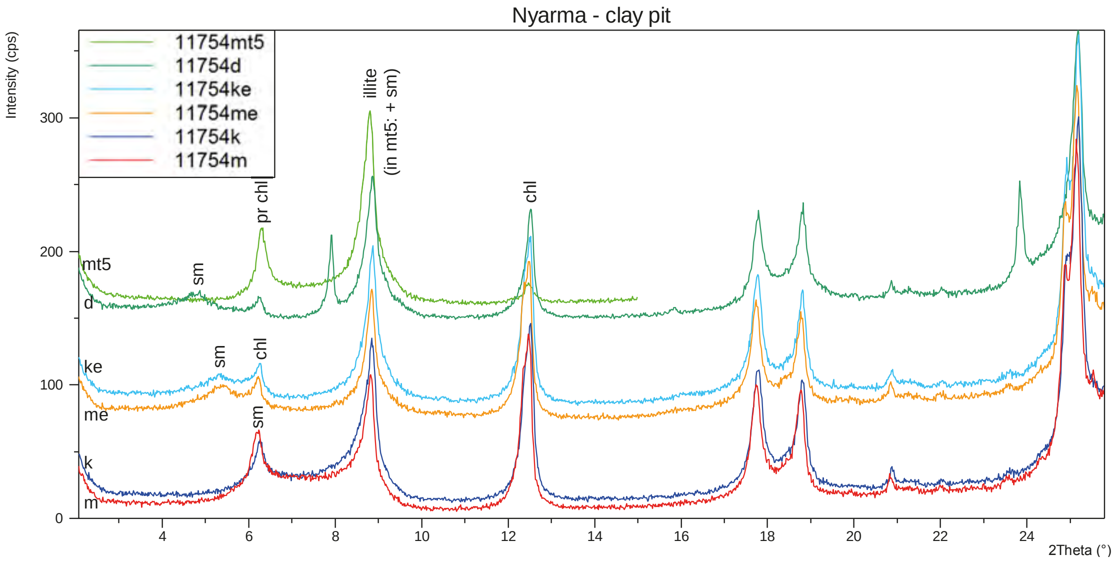
BMA 1.2 Nyarma. Sample 11754. Clay pit.



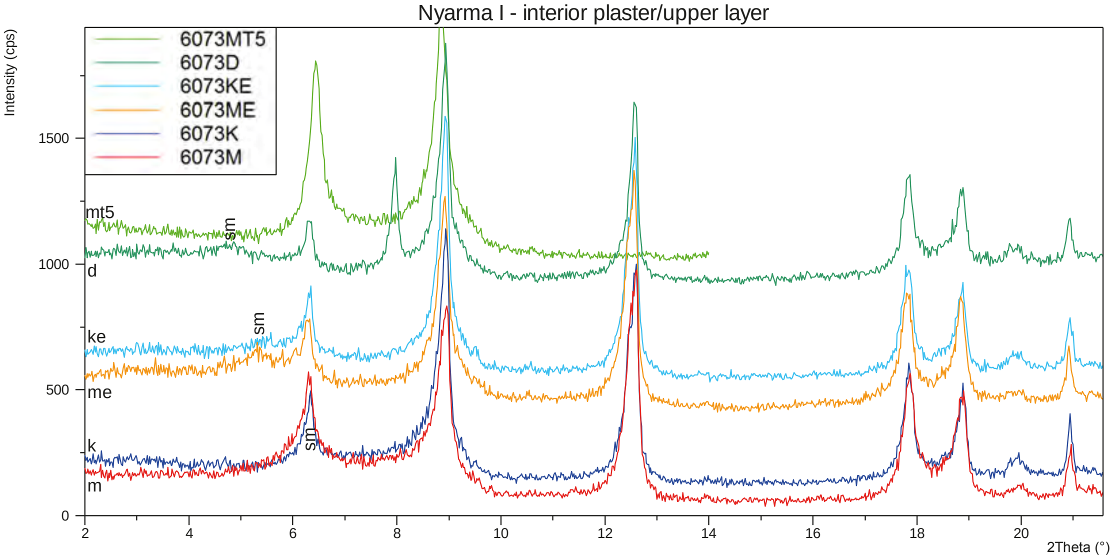
BMA 2.2 Nyarma. Sample 11745. Temple I. Interior plaster.



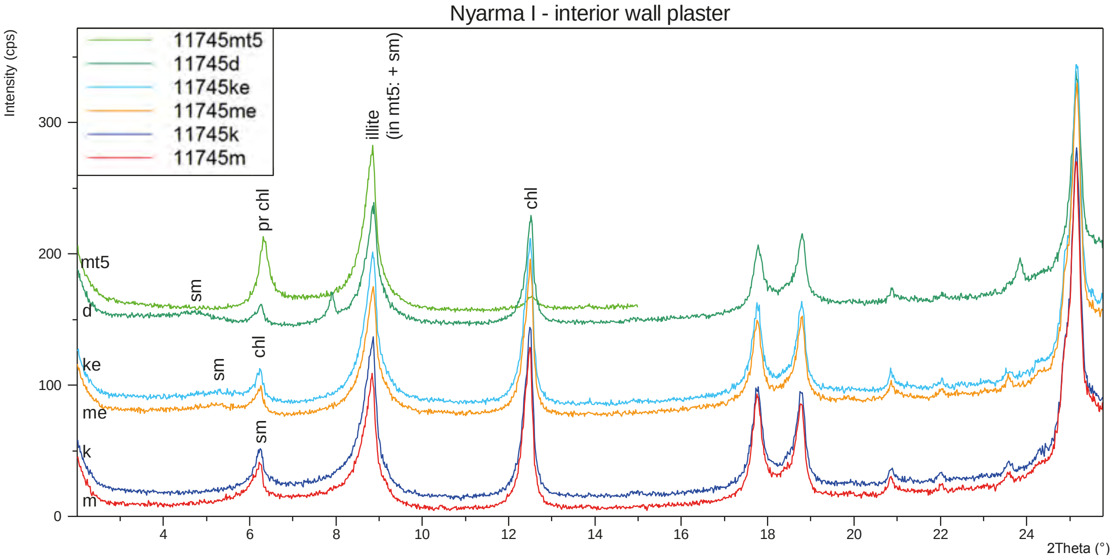
BMA 3.2 Nyarma. Stupa. Sample 8520. Interior plaster. Upper layer.



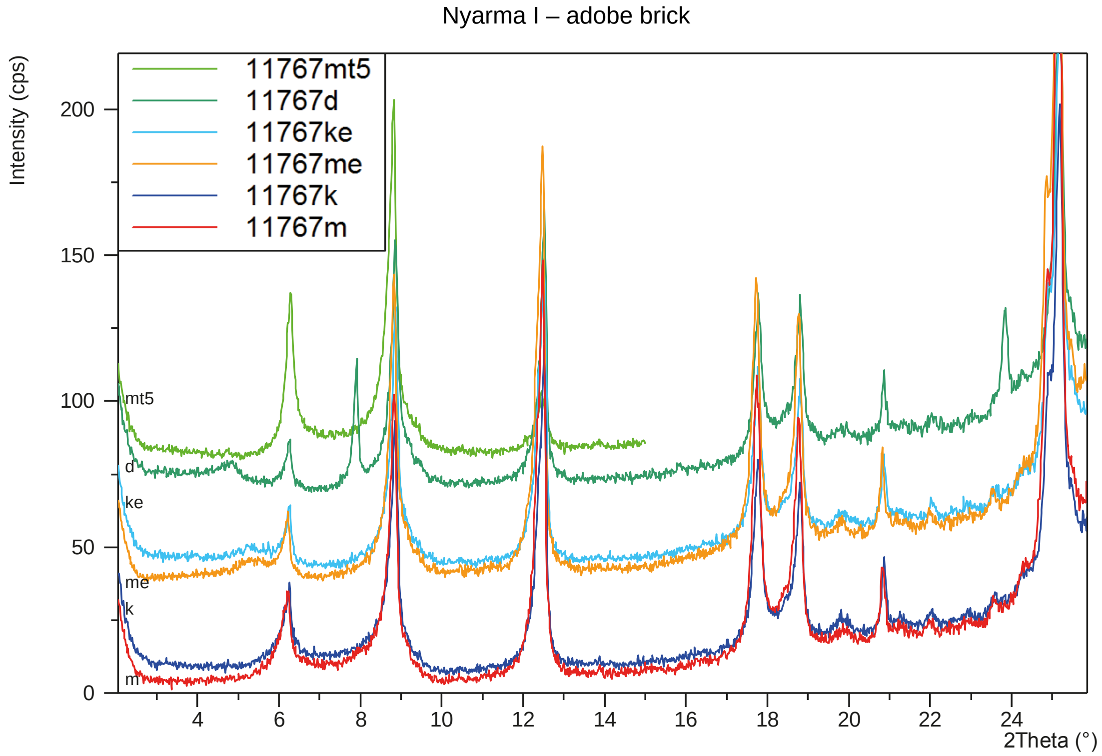
CMA 1.2 Nyarma. Sample 11754. Clay pit.



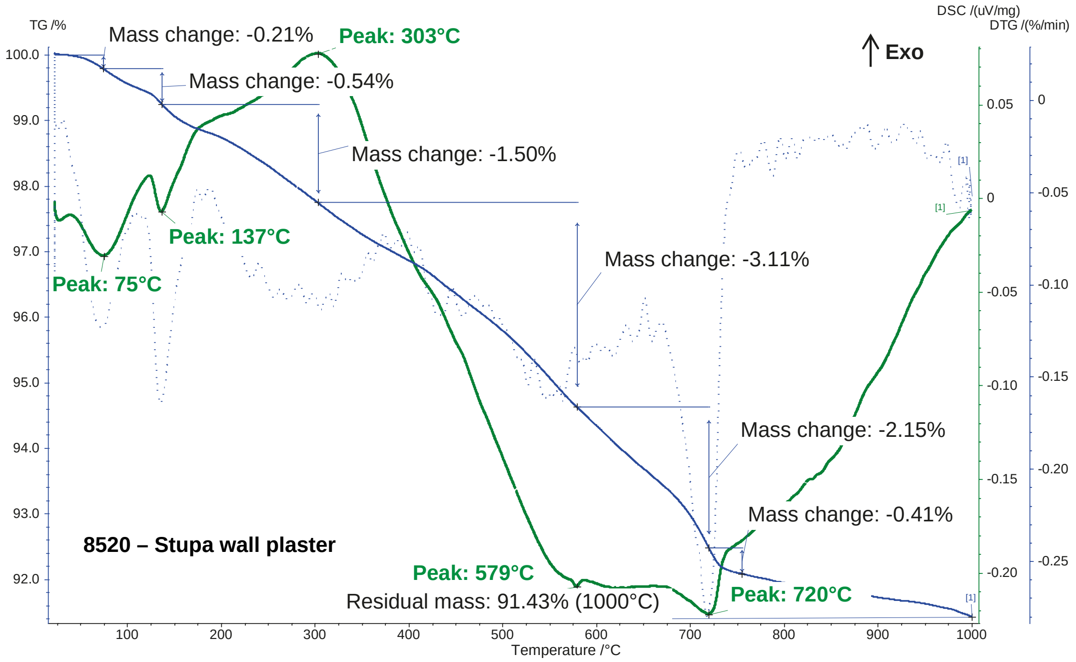
CMA 2.2 Nyarma I. Main temple. Sample 6073. Interior plaster. Upper layer.



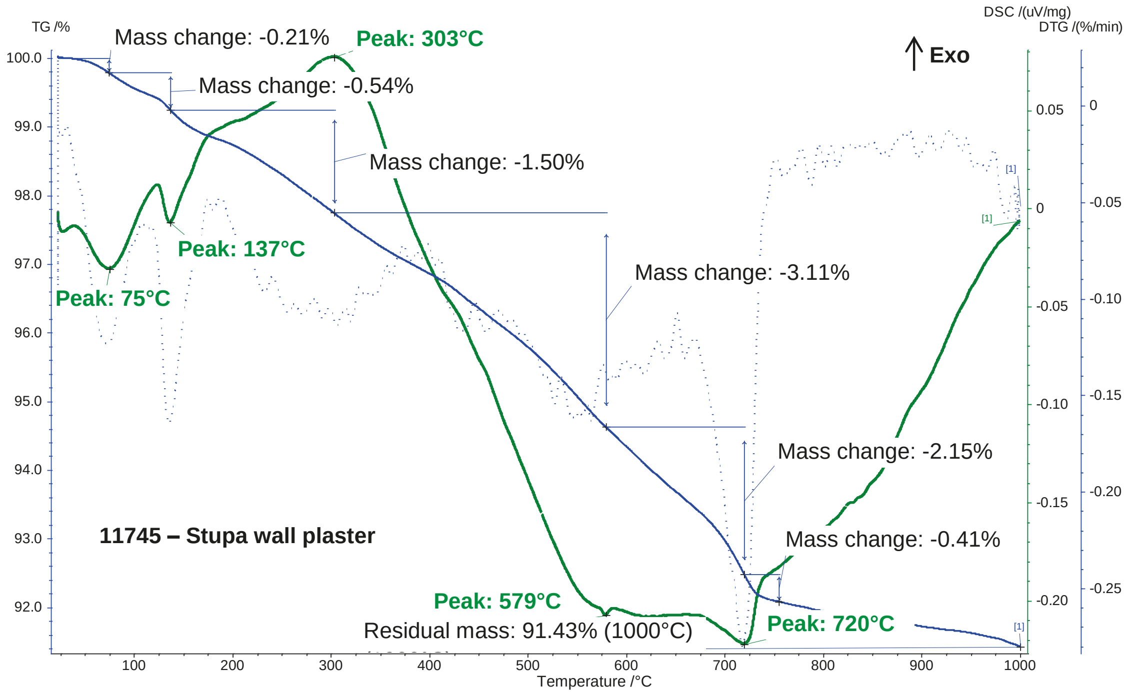
CMA 3.2 Nyarma. Sample 11745. Temple I. Interior plaster.



CMA 4.2 Nyarma. Sample 11767. Temple I. Adobe brick.



STA 1.2 Nyarma. Sample 8520. Stupa. Wall plaster.



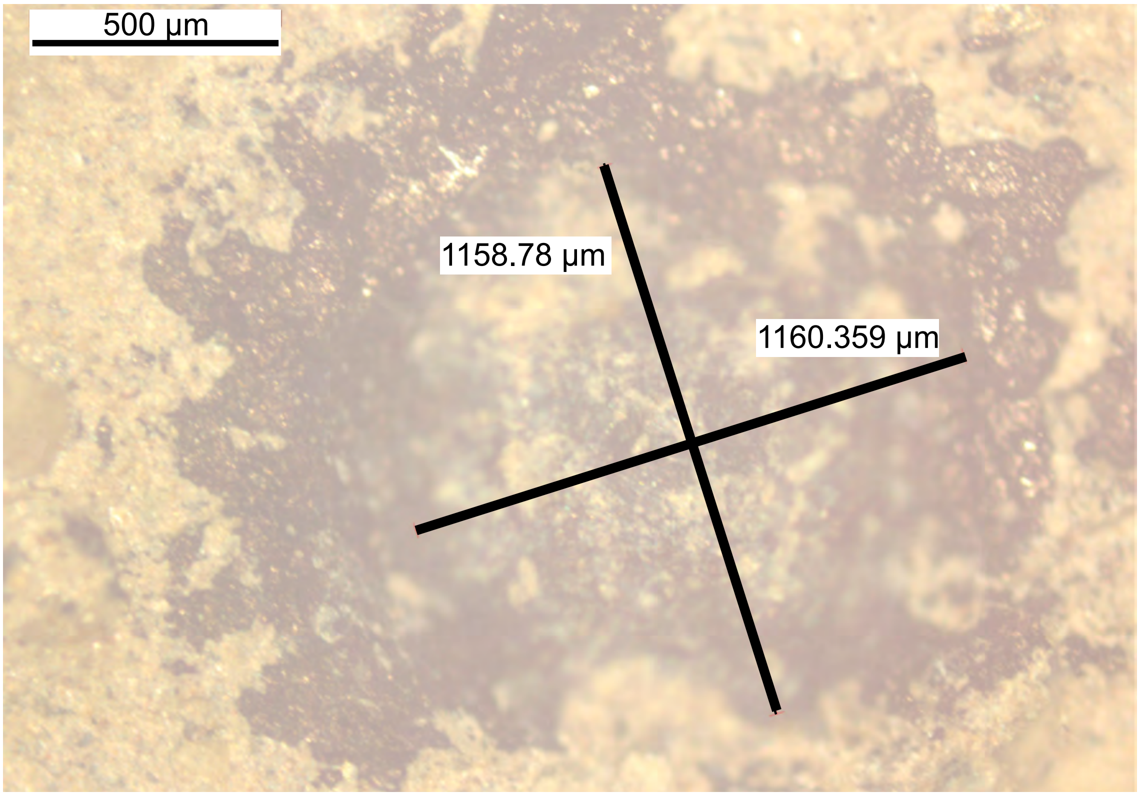
STA 2.2 Nyarma. Sample 11745. Stupa. Wall plaster.

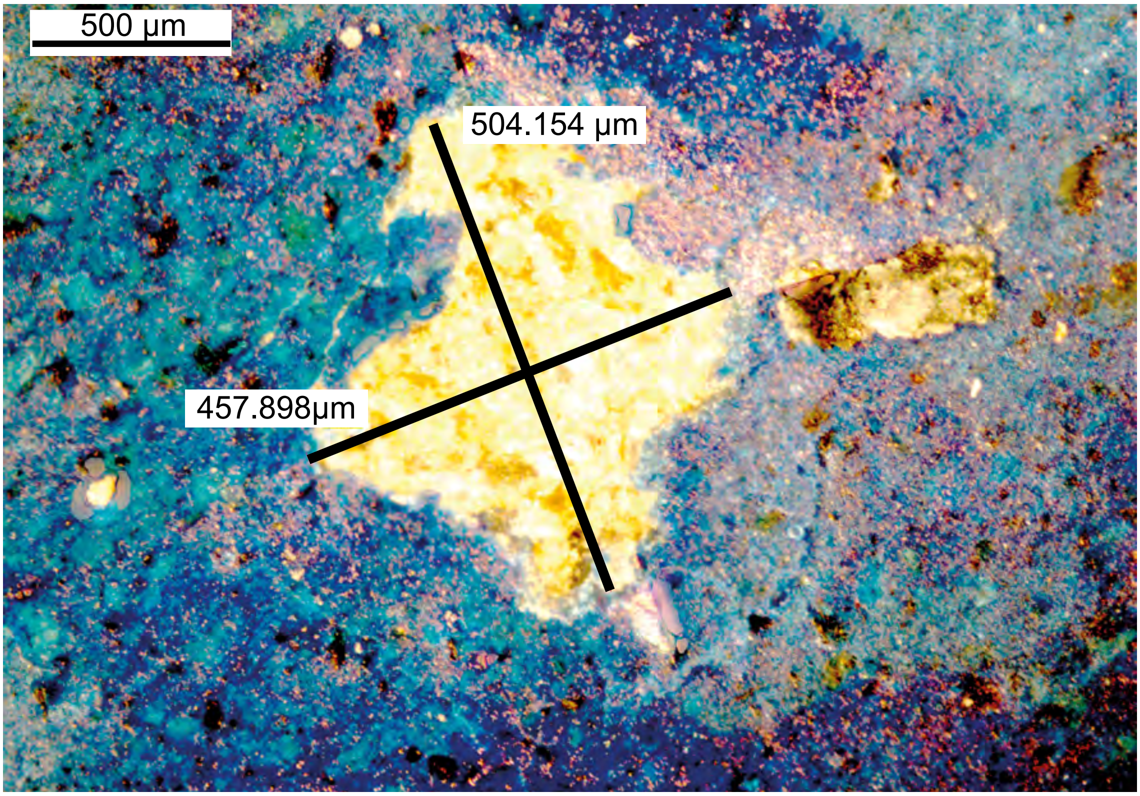
# VII. APPENDIX CHAPTER III

Photographs

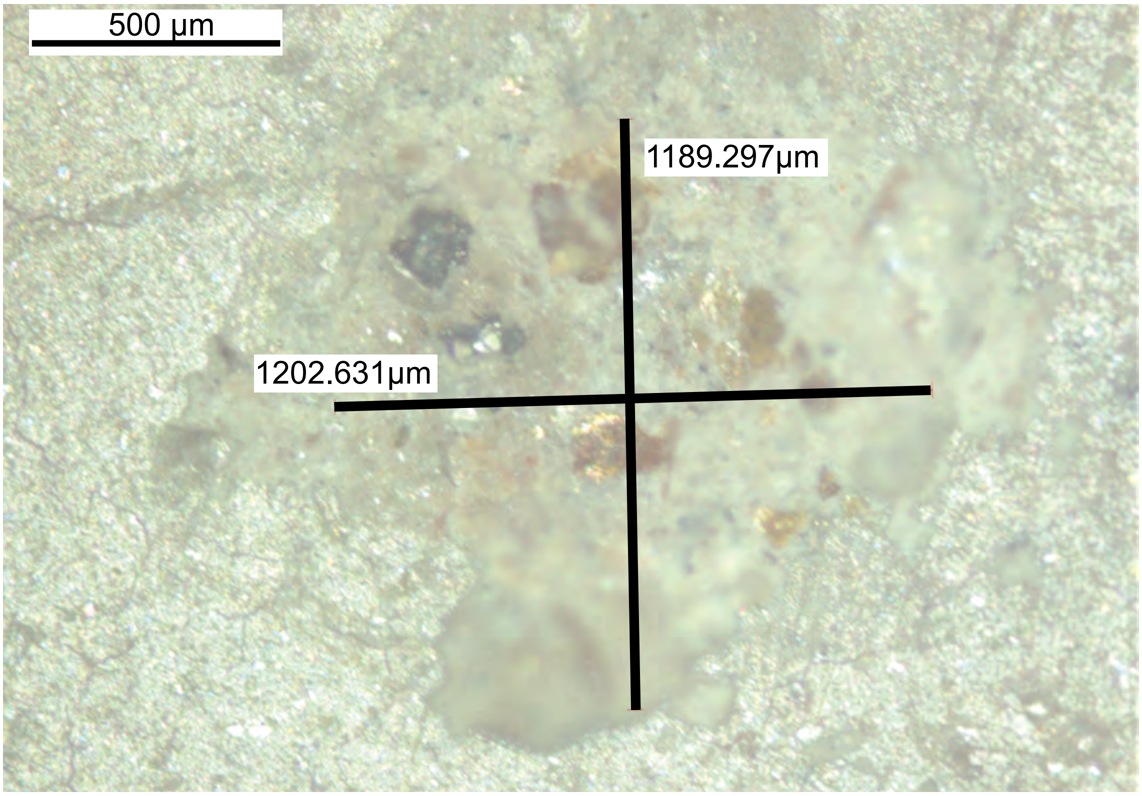
Graphics

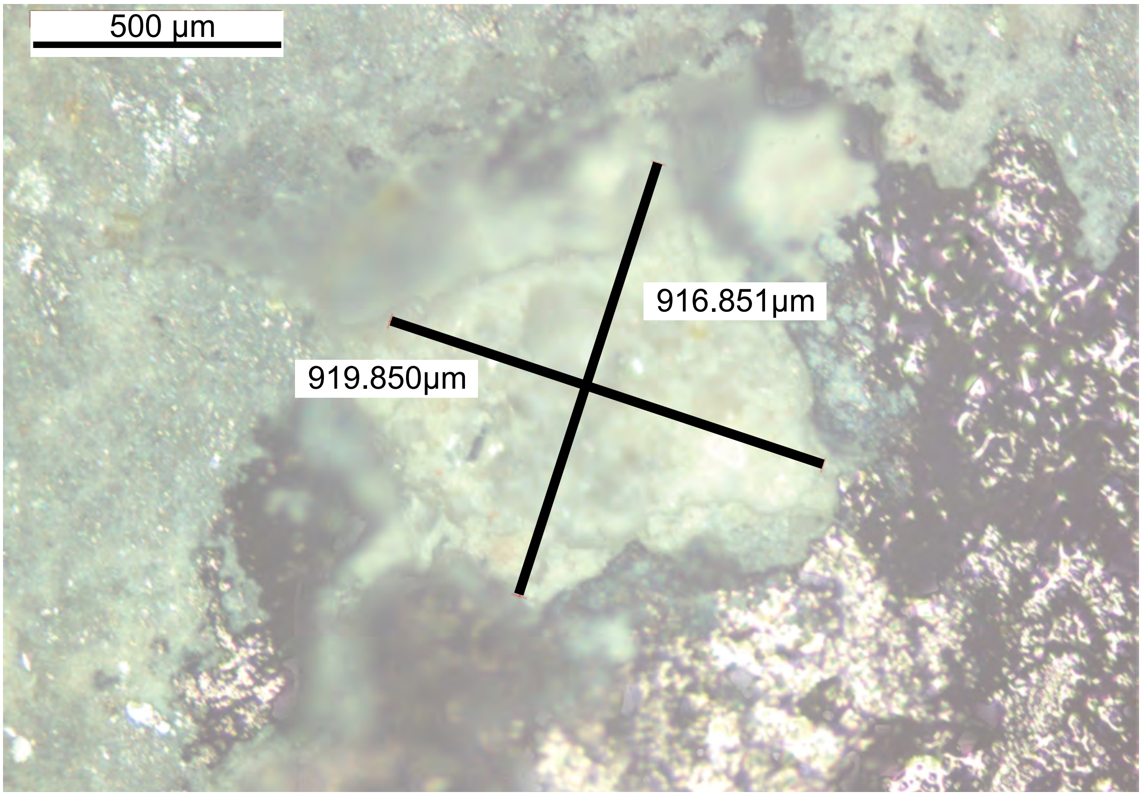
https://doi.org/10.1515/9783110591330-009



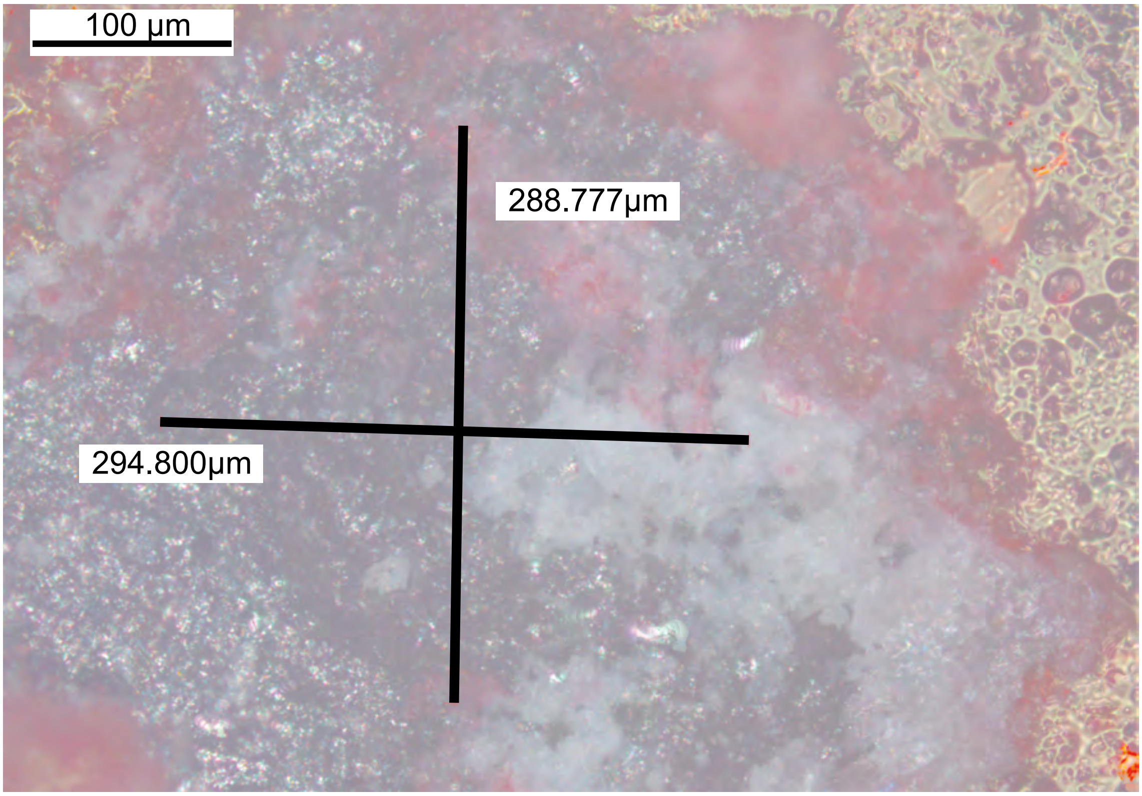


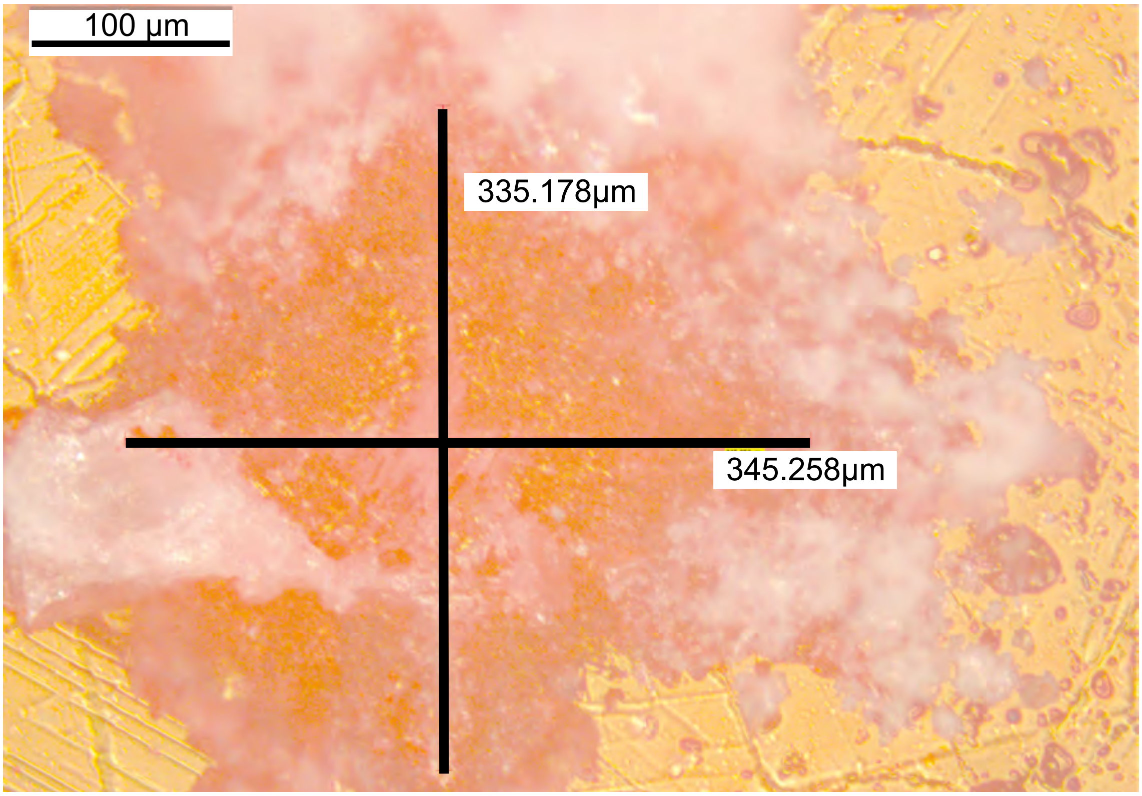
Vick 1.3 (Top) and Vick 2.3 (Bottom). Pictures of the Vickers test.



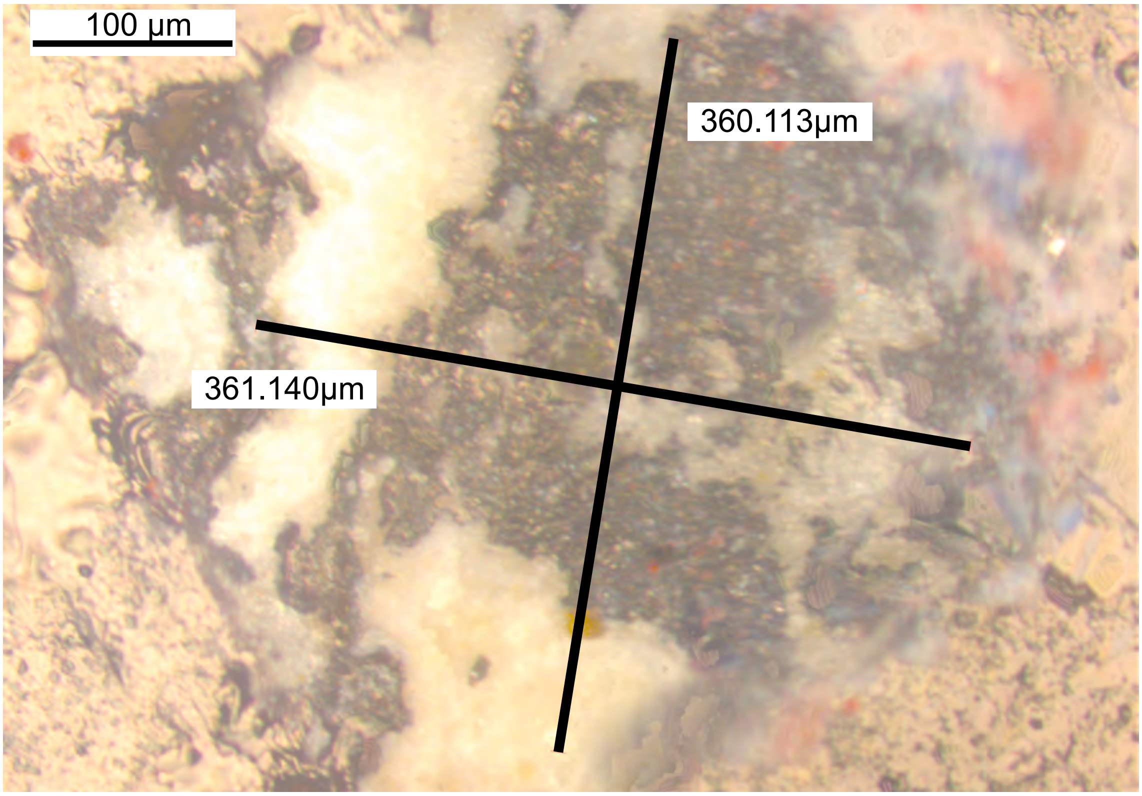


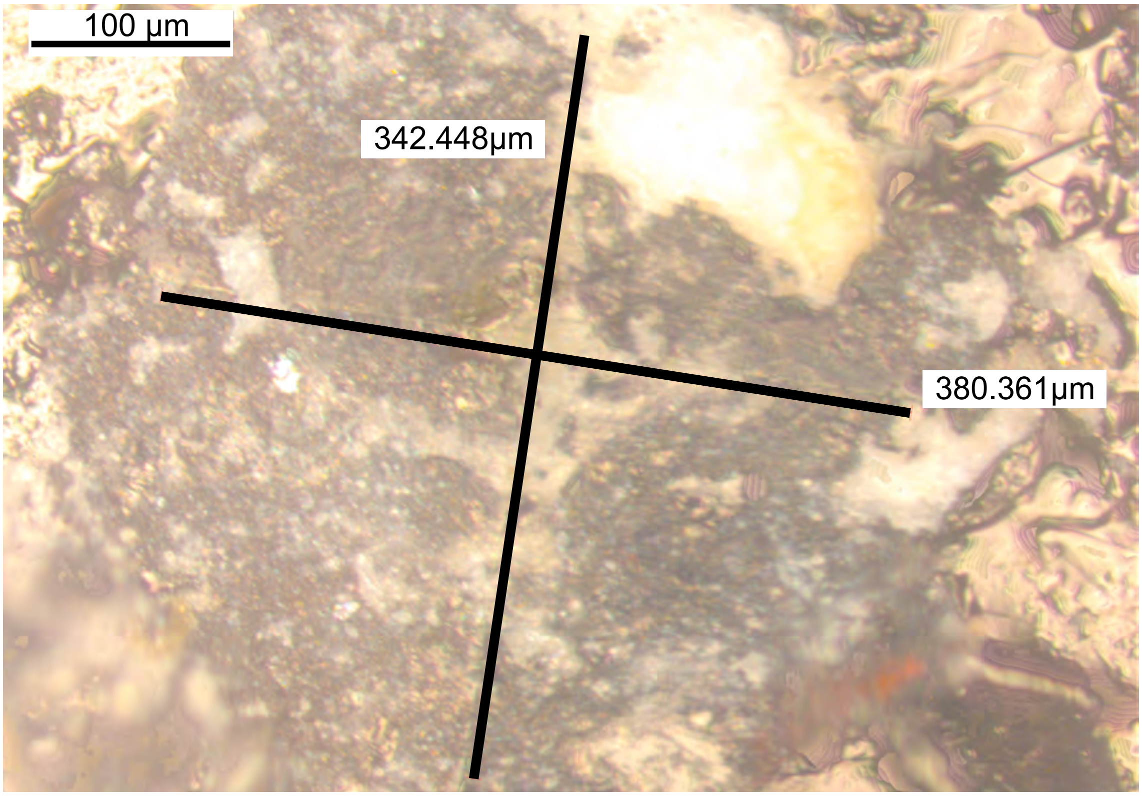
Vick 3.3 (Top) and Vick 4.3 (Bottom). Pictures of the Vickers test.



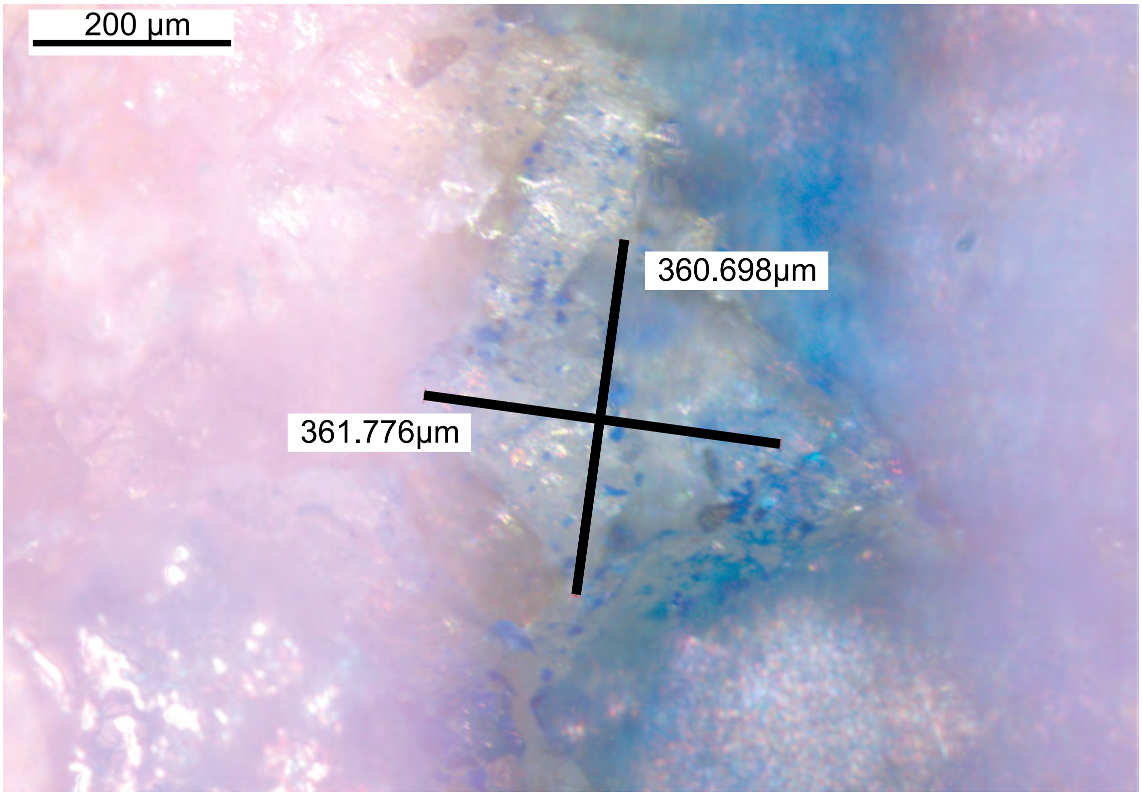


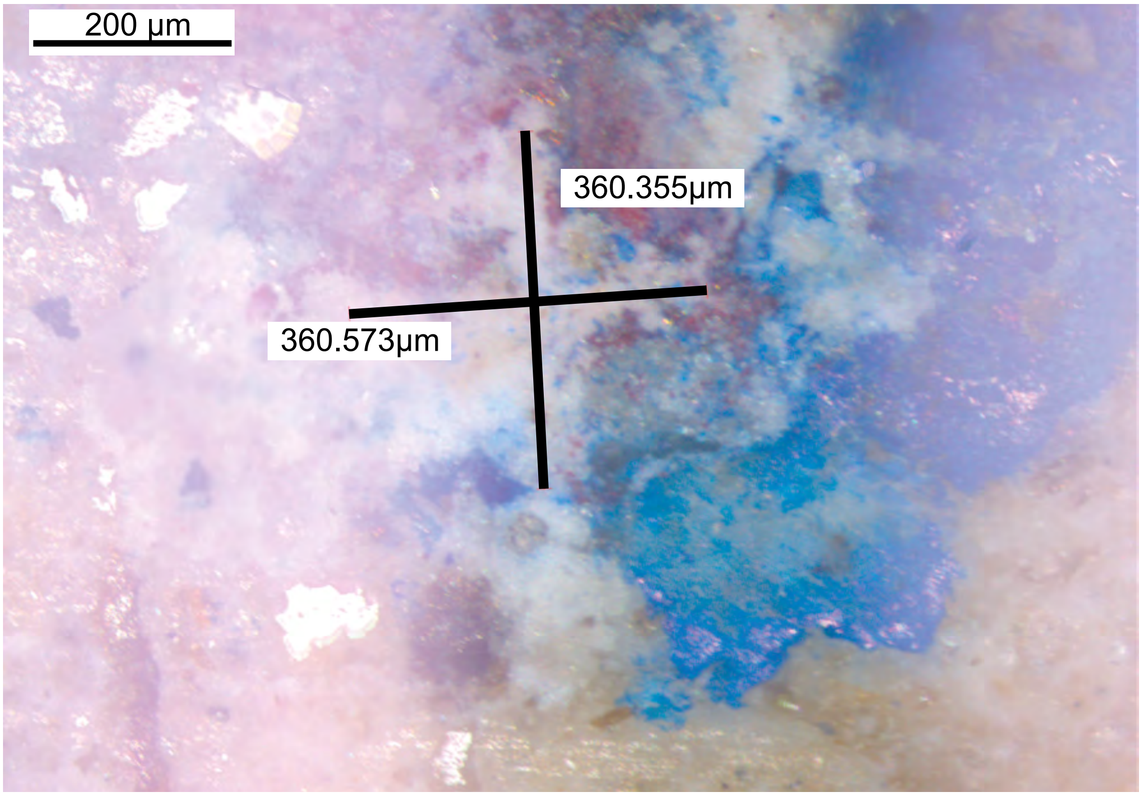
Vick 5.3 (Top) and Vick 6.3 (Bottom). Pictures of the Vickers test.



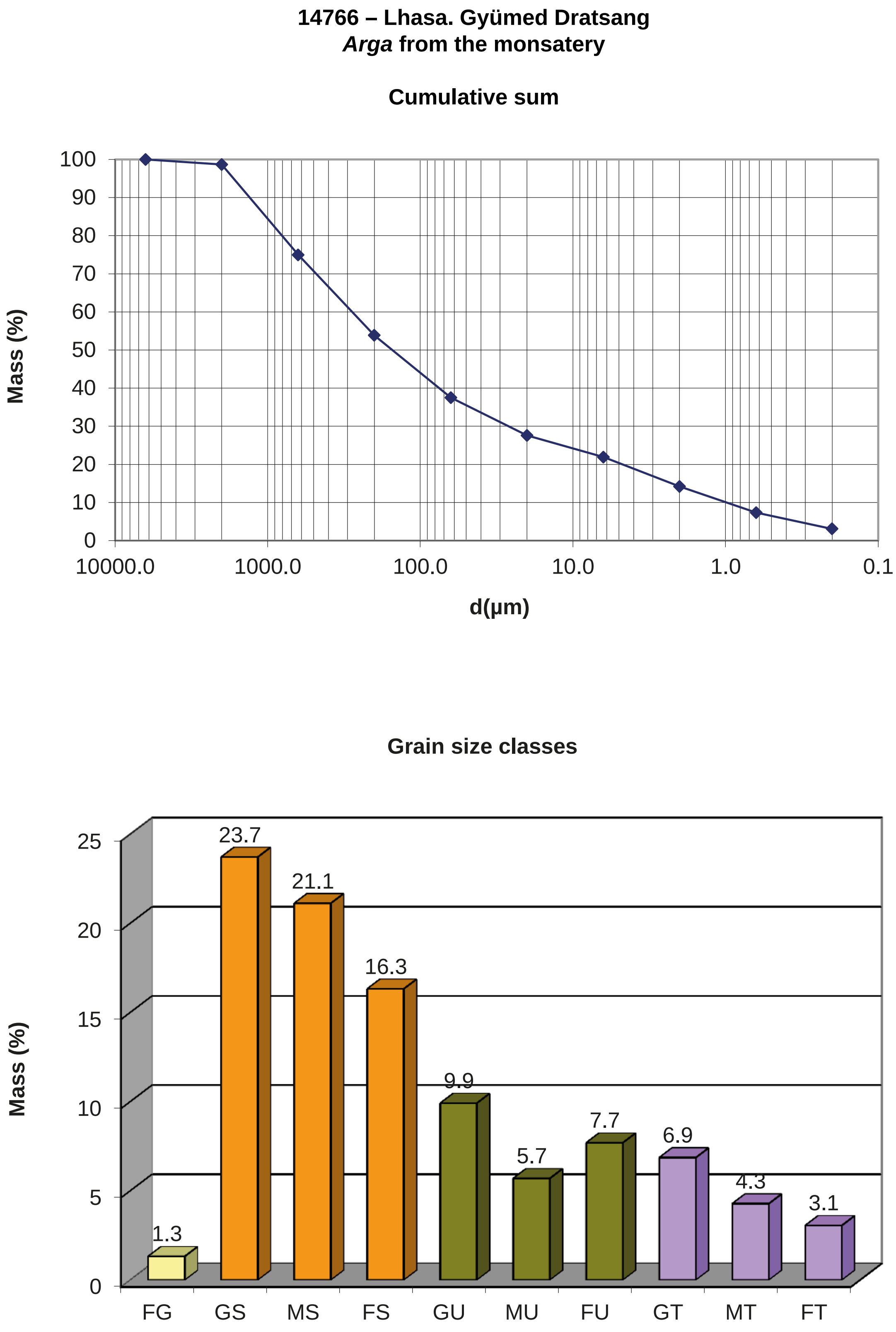


Vick 7.3 (Top) and Vick 8.3 (Bottom). Pictures of the Vickers test.



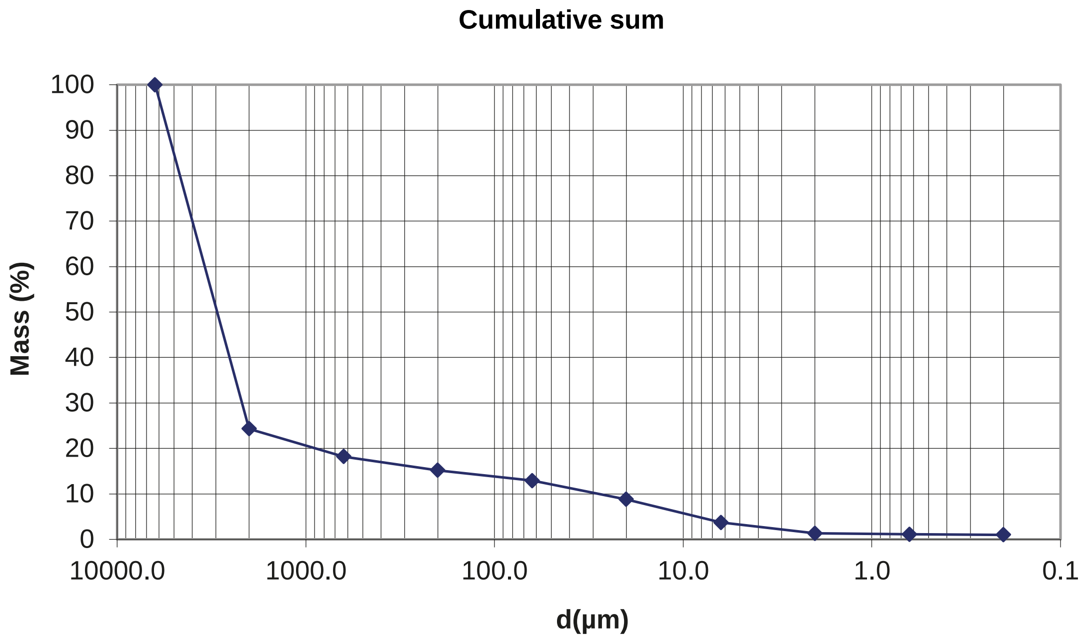


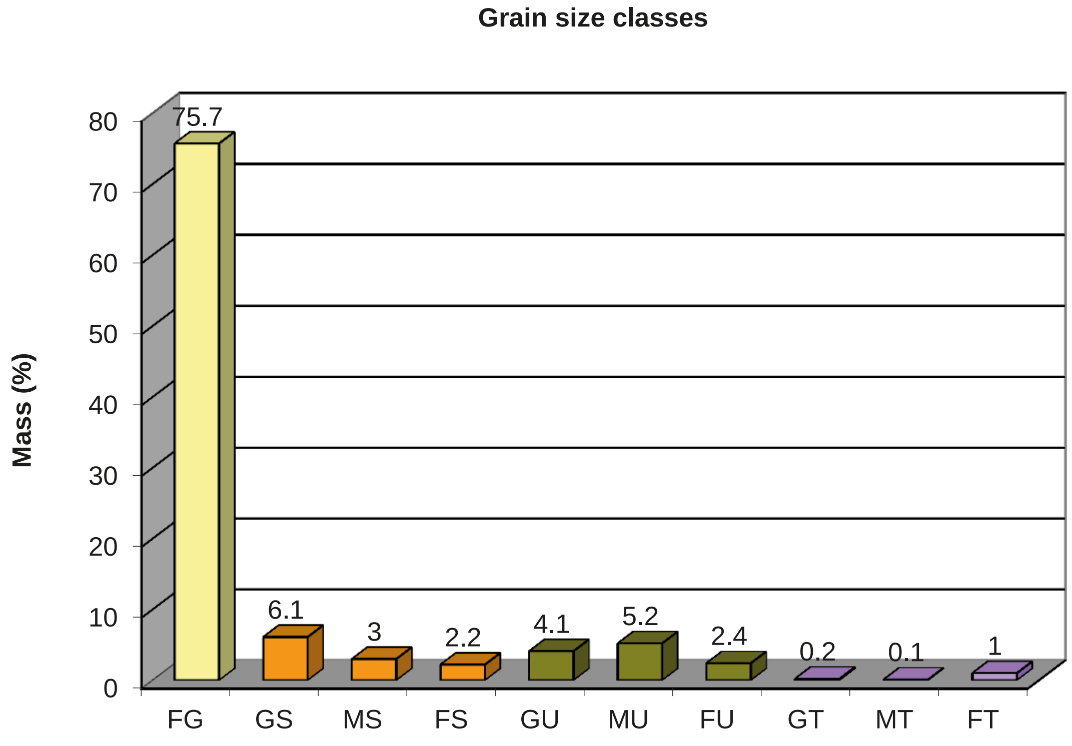
Vick 9.3 (Top) and Vick 10.3 (Bottom). Pictures of the Vickers test.



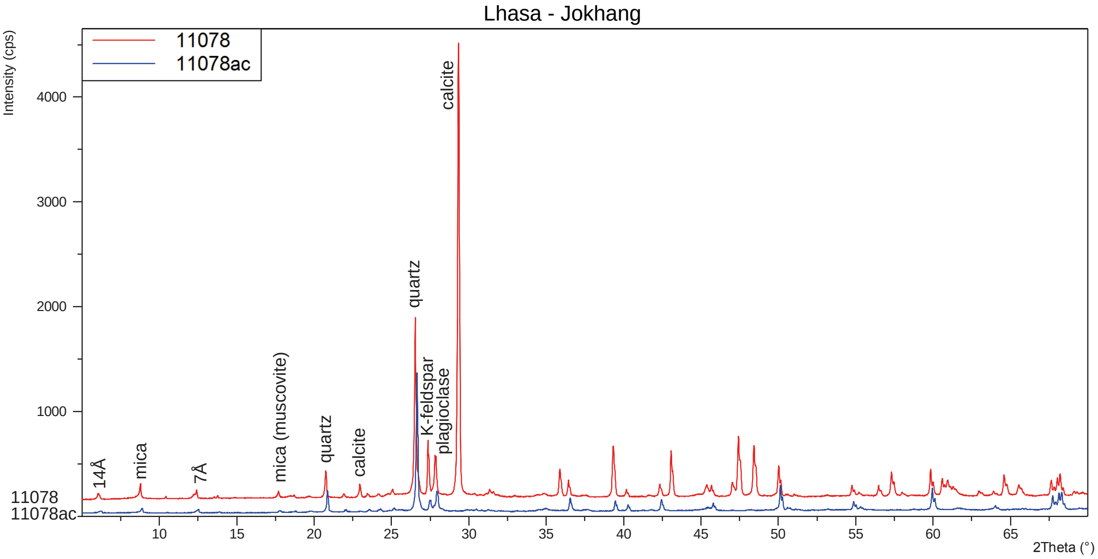
GSD 1.3 Lhasa. Gyüme Dratsang. Sample 14766. *Arga* raw material. Top: Cumulative sum. Bottom: Grain size classes.

## 8473 – Zangskar. Phugtal
## *Arga* from a quarry

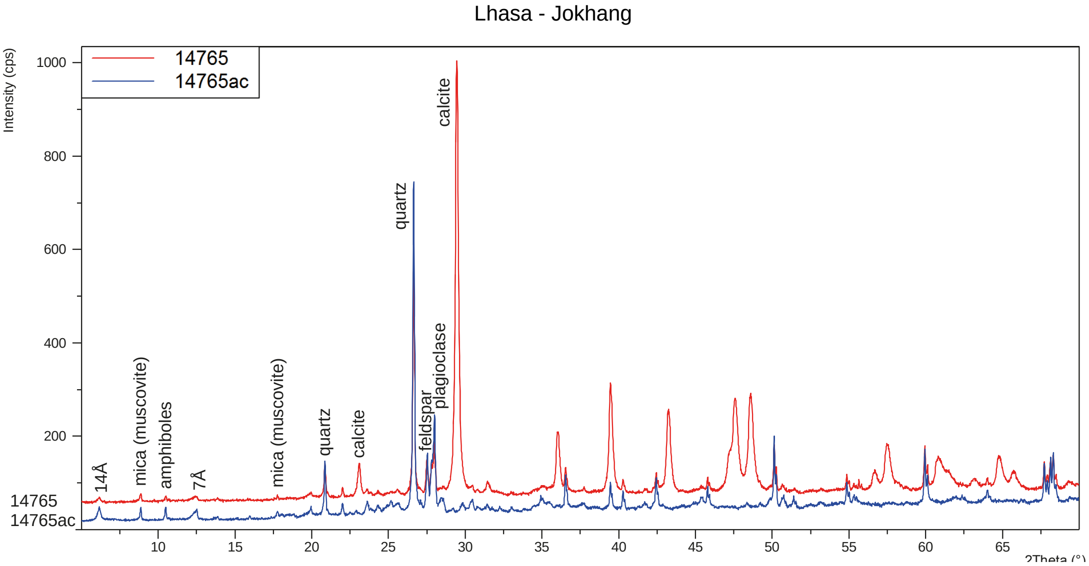




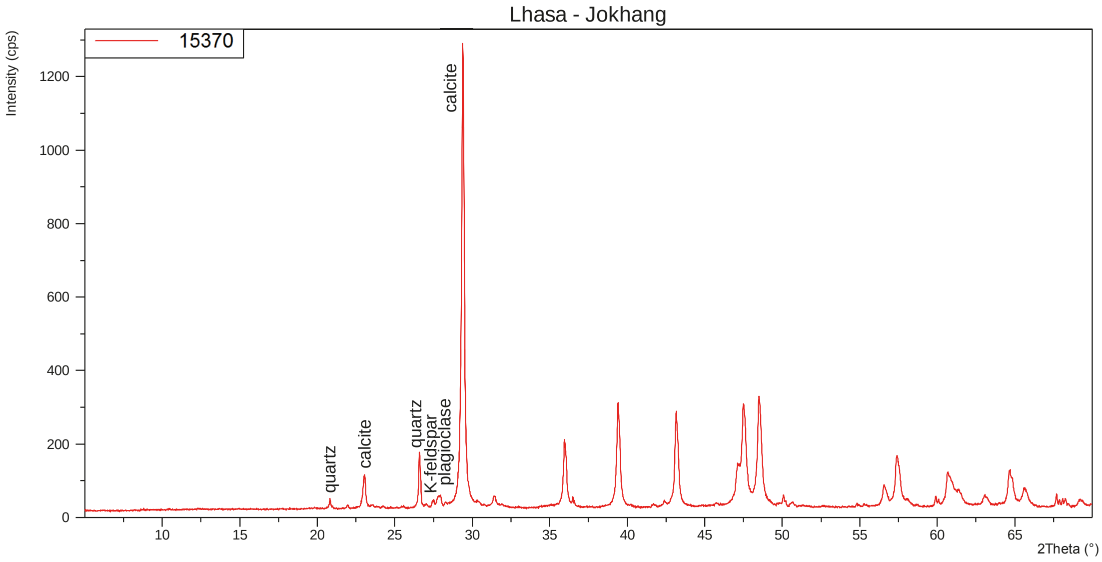
GSD 2.3 Zangskar. Phugtal. Sample 8473. *Arga* raw material taken from a quarry.
Top: Cumulative sum. Bottom: Grain size classes.



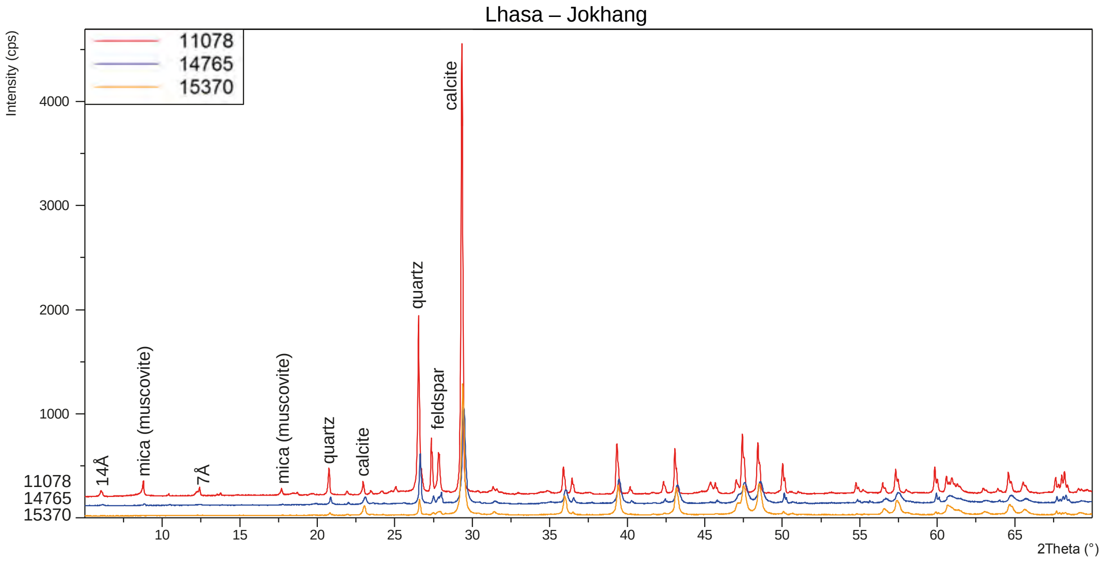
BMA 1.3 Lhasa. Jokhang. Sample 11078. Bulk mineral analysis. 11078ac was treated with an acetate buffer.



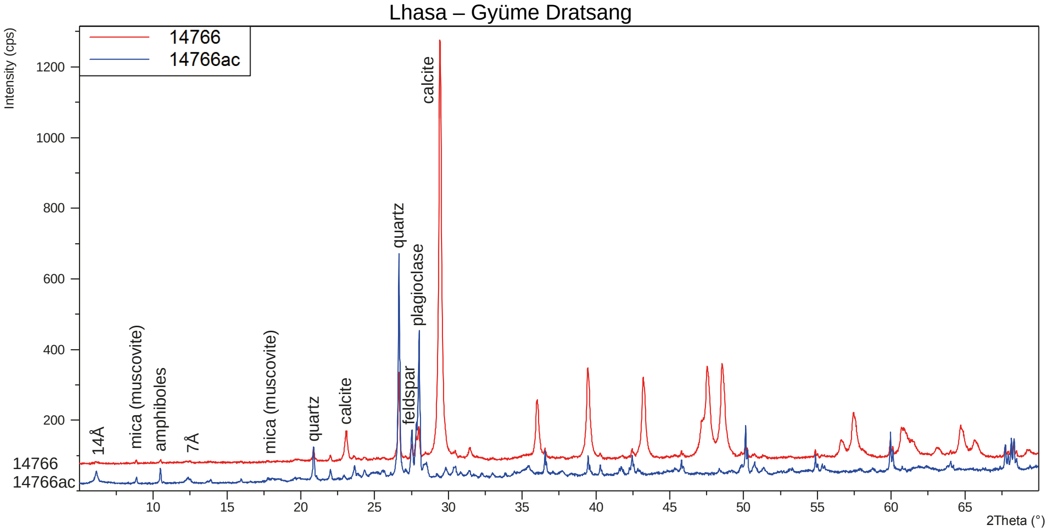
BMA 2.3 Lhasa. Jokhang. Sample 14765. Bulk mineral analysis. 14765ac was treated with an acetate buffer.



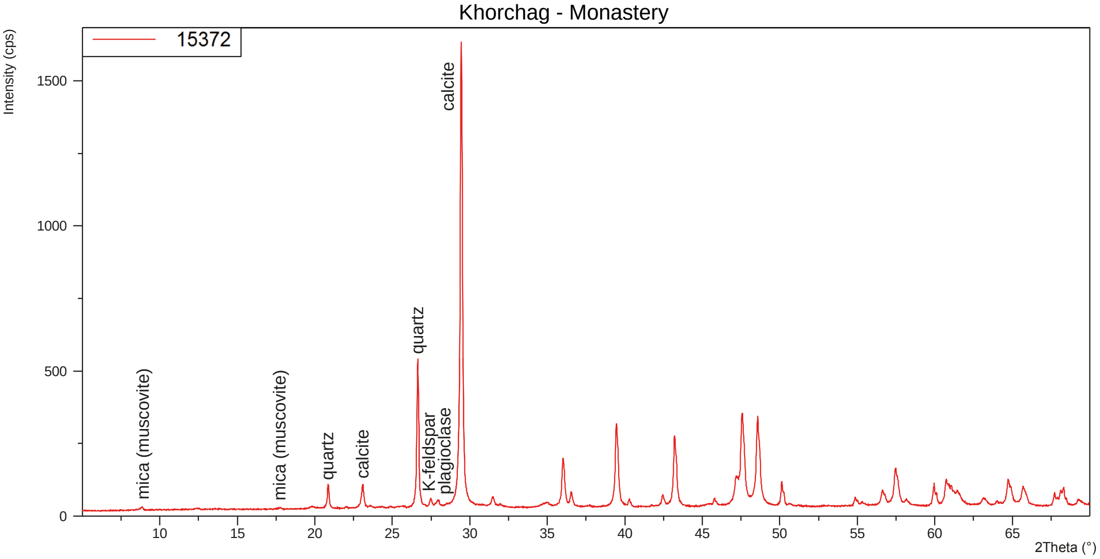
BMA 3.3 Lhasa. Jokhang. Sample 15370. Bulk mineral analysis.



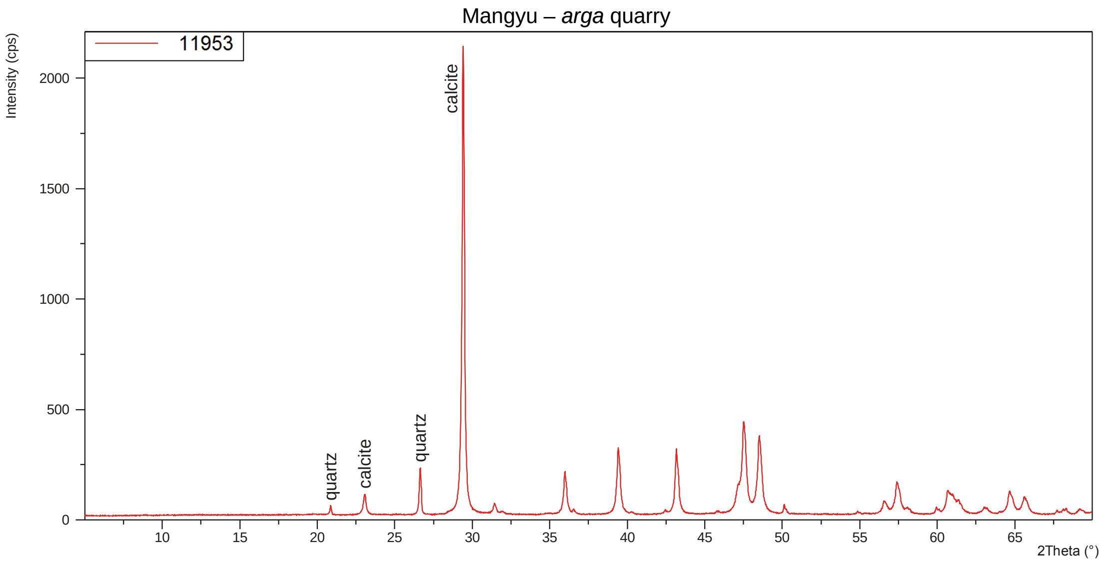
BMA 4.3 Lhasa. Jokhang. Samples 11078, 14765 and 15370. Bulk mineral analysis.



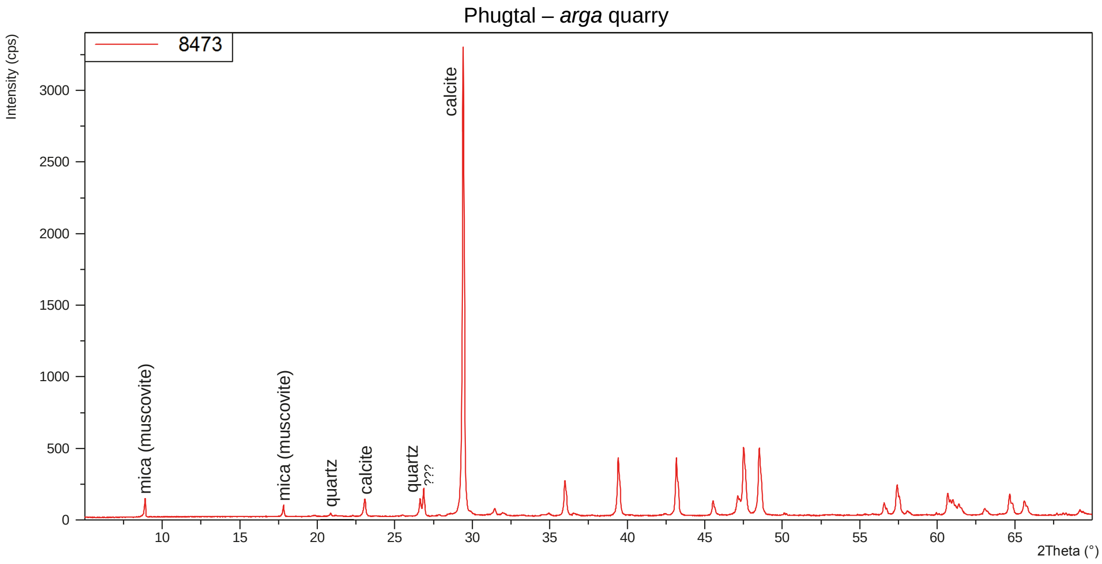
BMA 5.3 Lhasa. Gyüme Dratsang. Sample 14766. Bulk mineral analysis. 14766ac was treated with an acetate buffer.



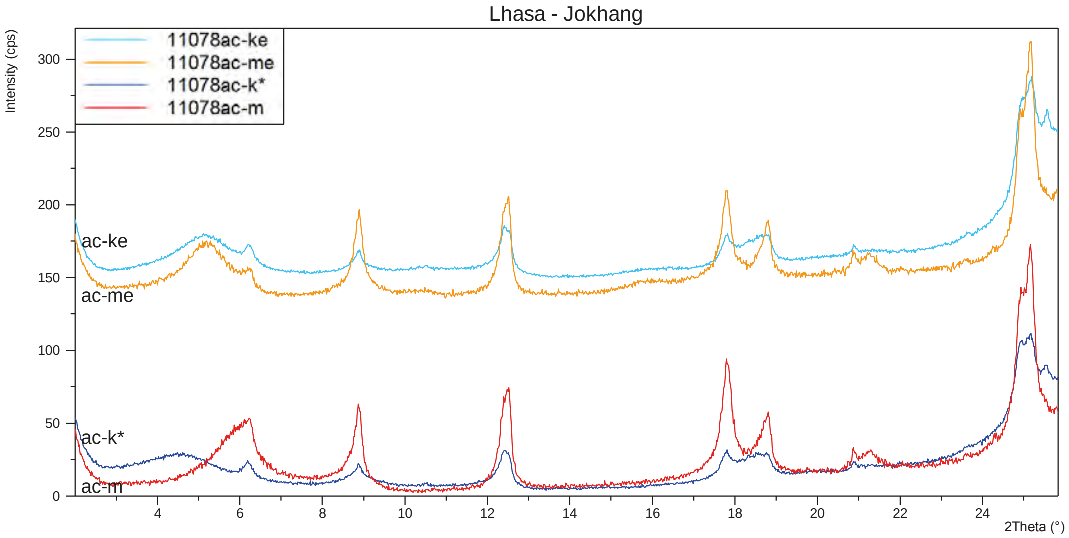
BMA 6.3 Khorchag. Sample 15372. Bulk mineral analysis.



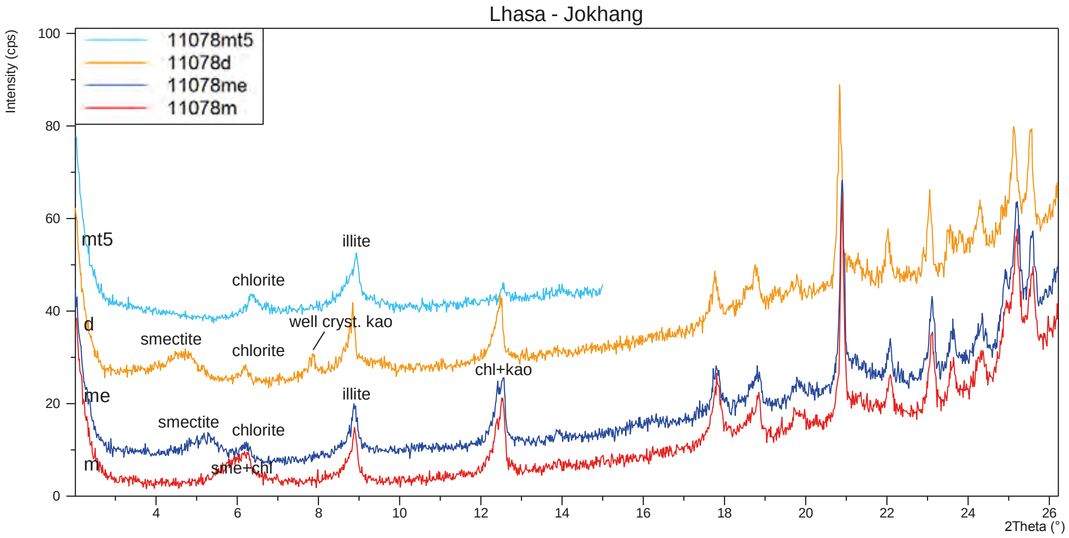
BMA 7.3 Mangyu. *Arga* quarry. Sample 11953. Bulk mineral analysis.



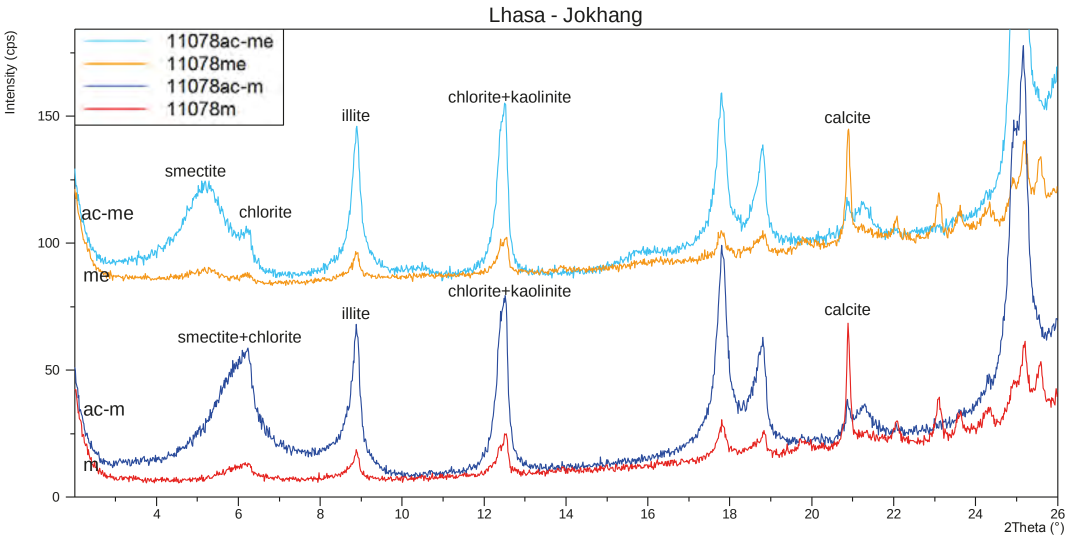
BMA 8.3 Phugtal. *Arga* quarry. Sample 8473. Bulk mineral analysis.



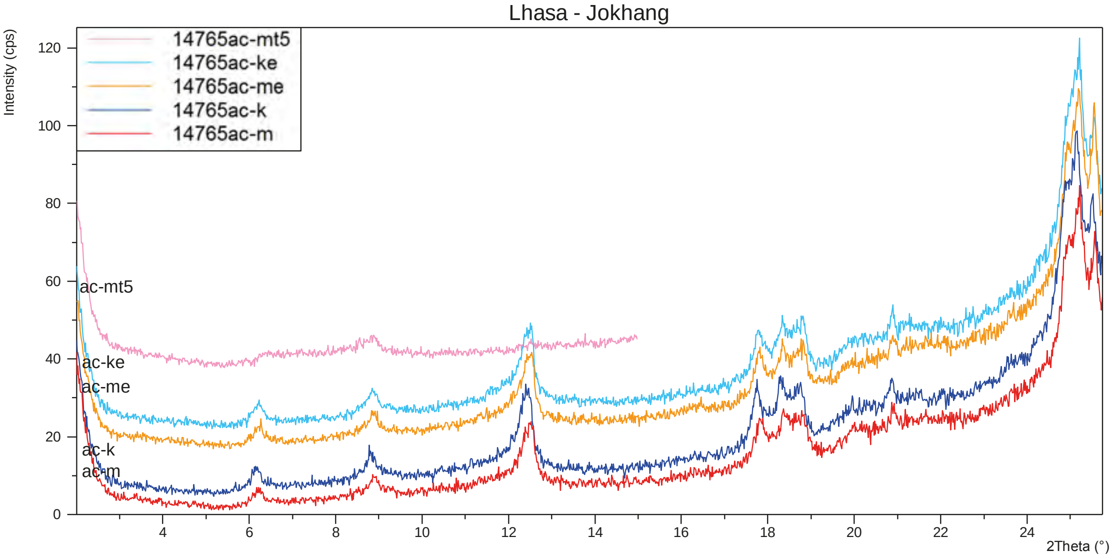
CMA 1.3 Lhasa. Jokhang. Sample 11078ac. Clay mineral analysis. 11078ac was treated with an acetate buffer.



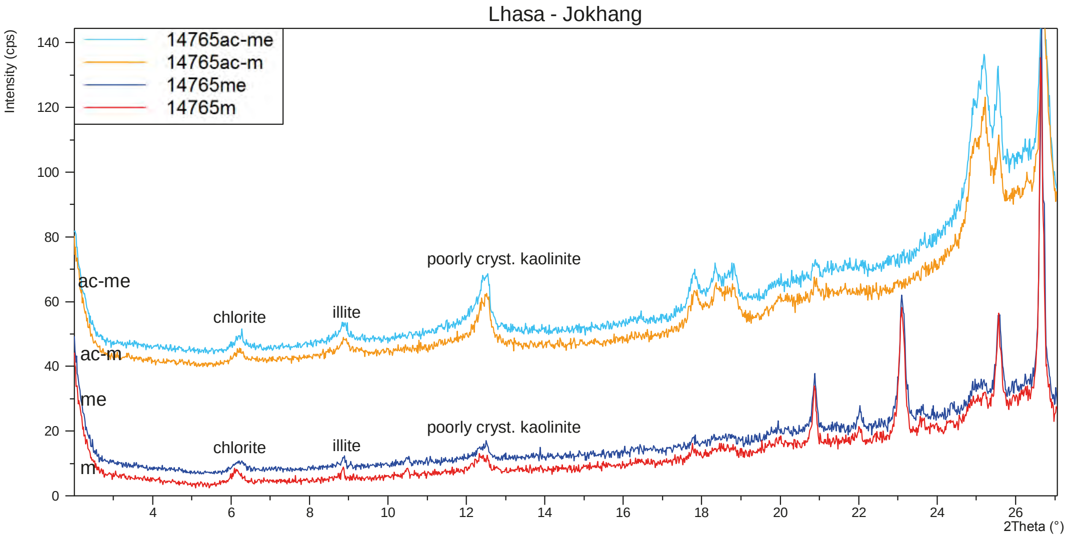
CMA 2.3 Lhasa. Jokhang. Sample 11078. Clay mineral analysis. Detail.



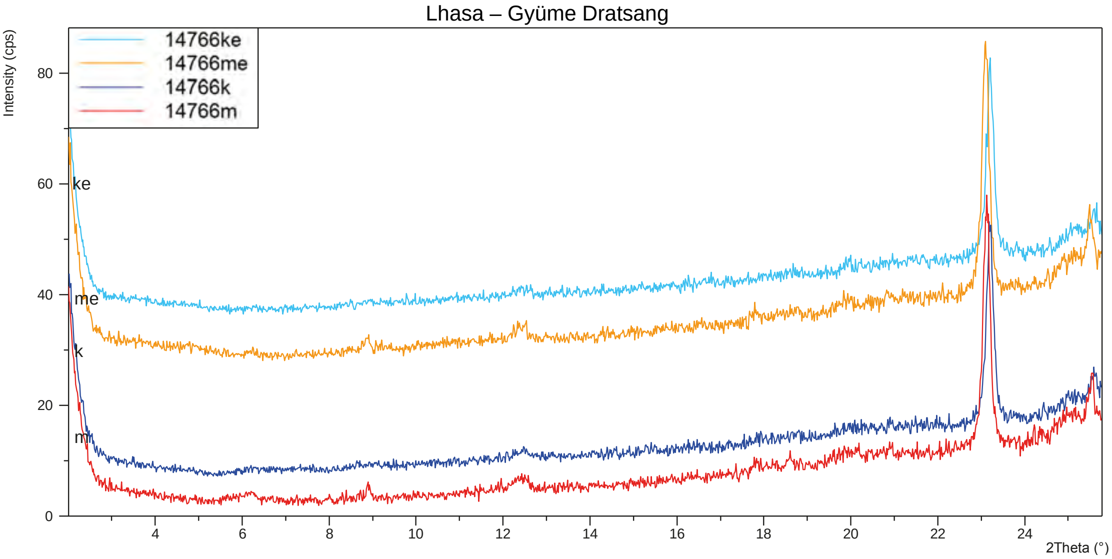
CMA 3.3 Lhasa. Jokhang. Sample 11078 and 11078ac. Clay mineral analysis. Detail.



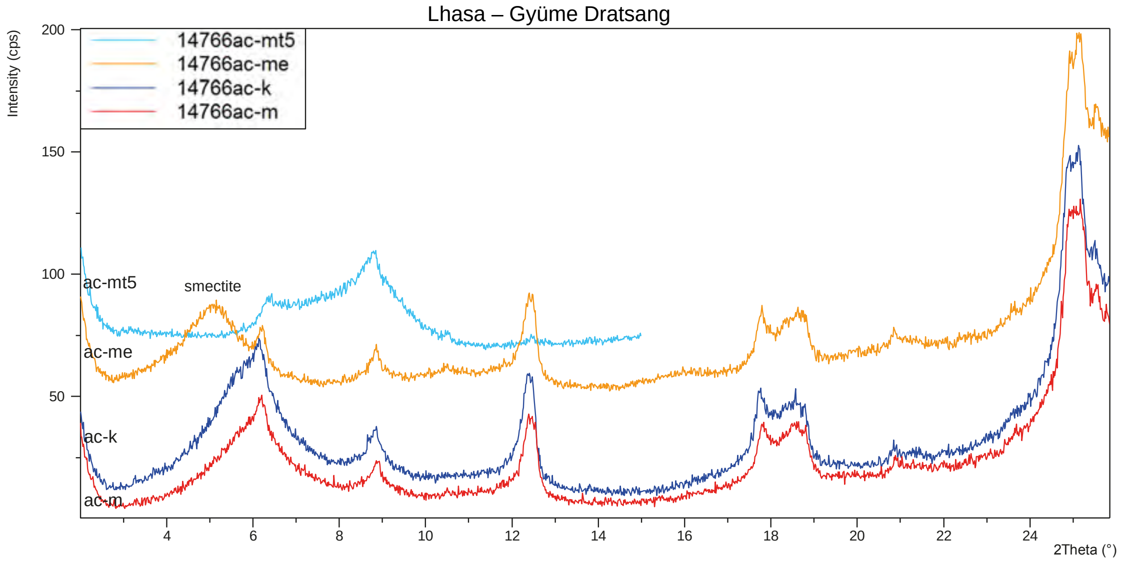
CMA 4.3 Lhasa. Jokhang. Samples 14765ac. Clay mineral analysis. 14765ac was treated with an acetate buffer.



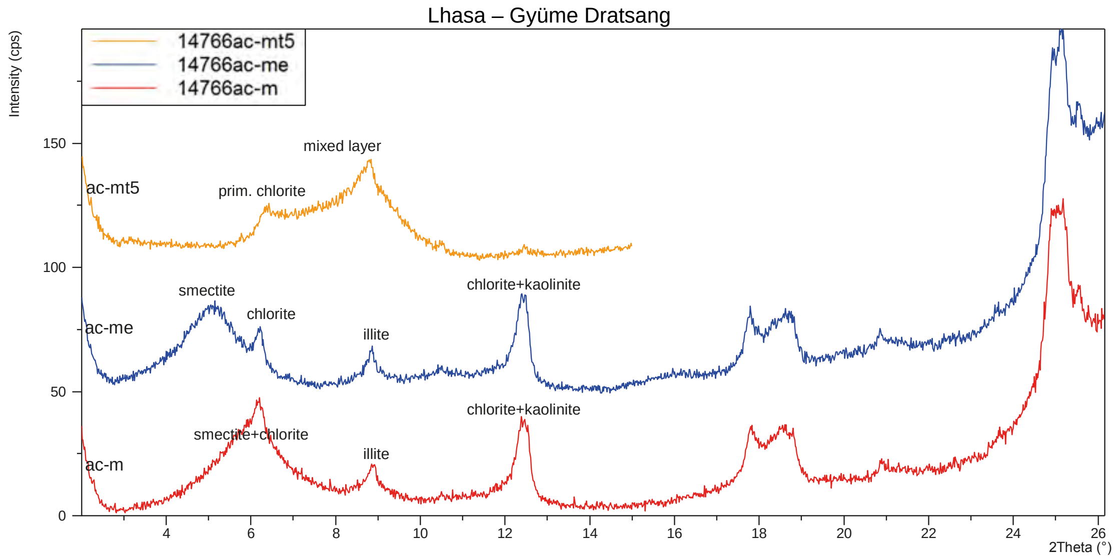
CMA 5.3 Lhasa. Jokhang. Samples 14765 and 14765ac. Clay mineral analysis.



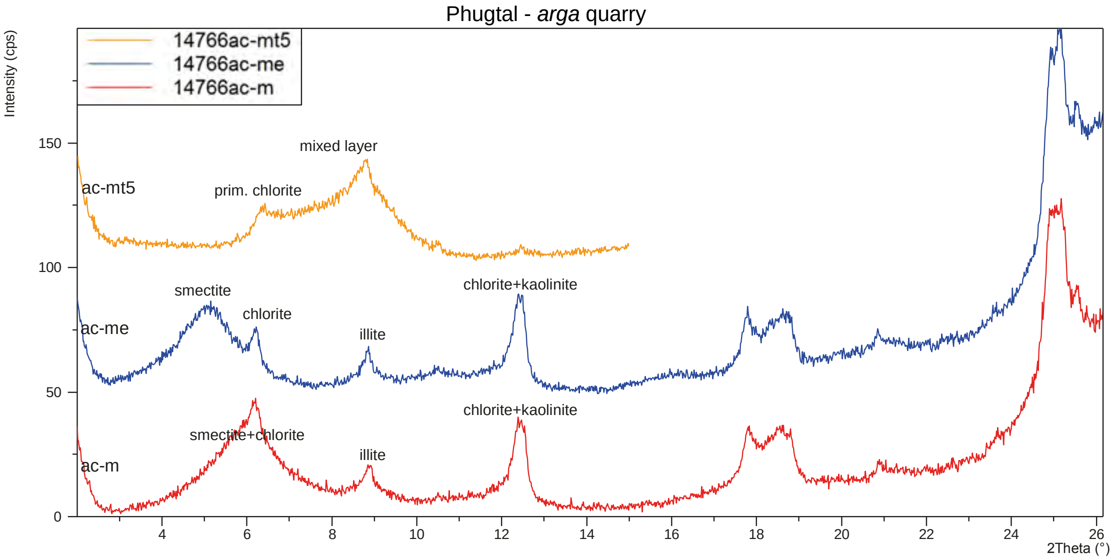
CMA 6.3 Lhasa. Gyüme Dratsang. Sample 14766. Clay mineral analysis.



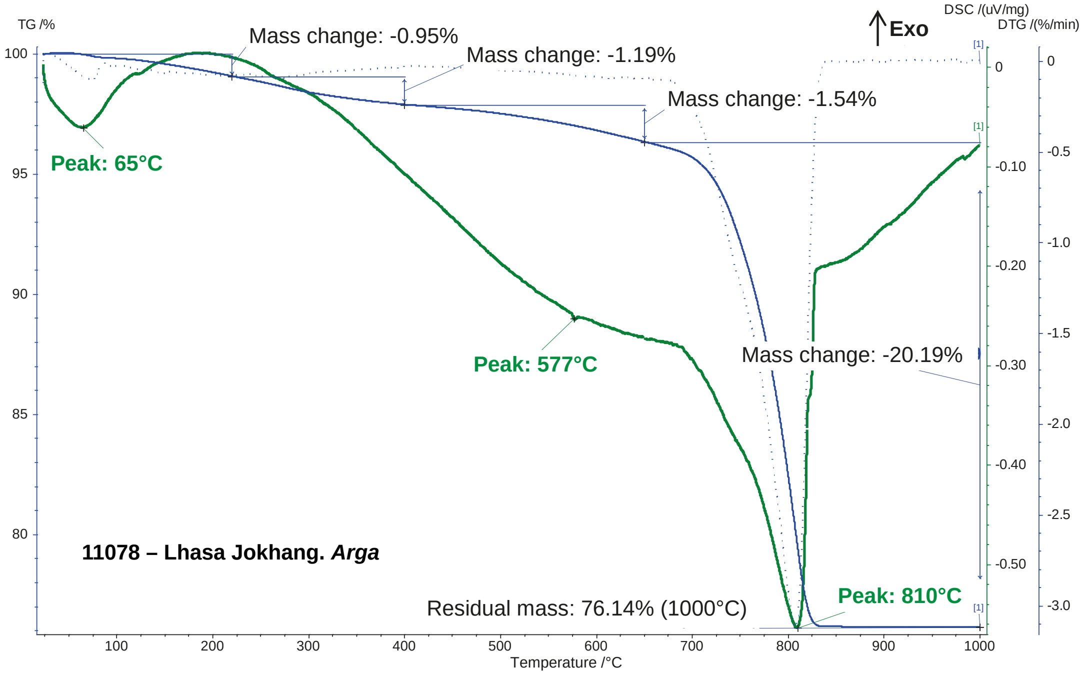
CMA 7.3 Lhasa. Gyüme Dratsang. Sample 14766ac. Clay mineral analysis.



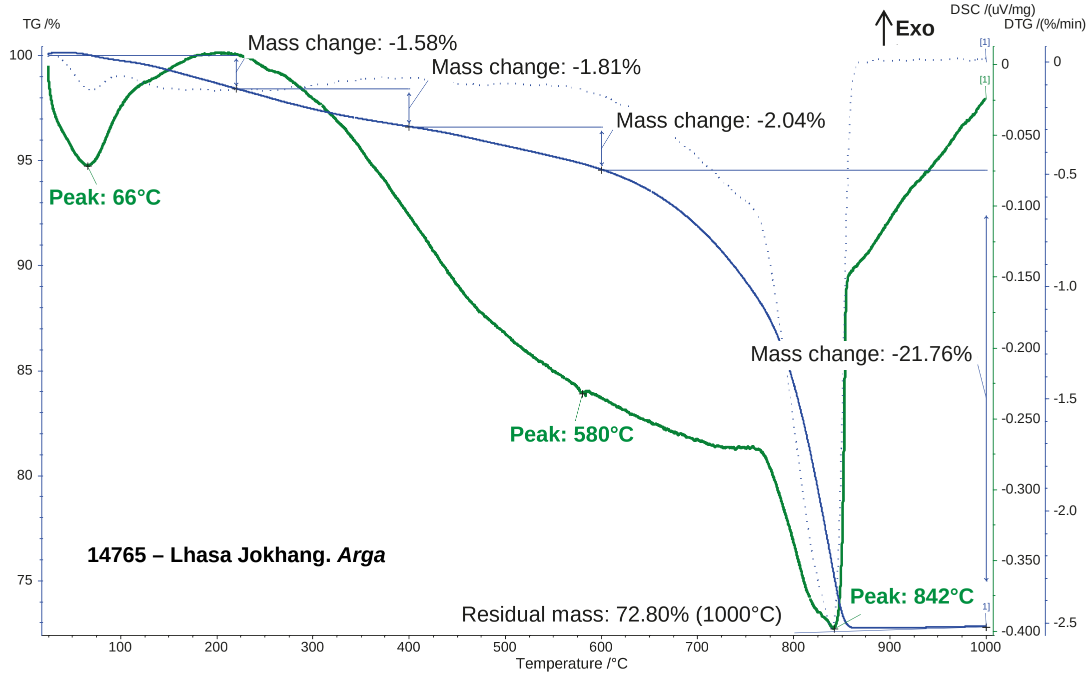
CMA 8.3 Lhasa. Gyüme Dratsang. Sample 14766ac. Clay mineral analysis. Detail.



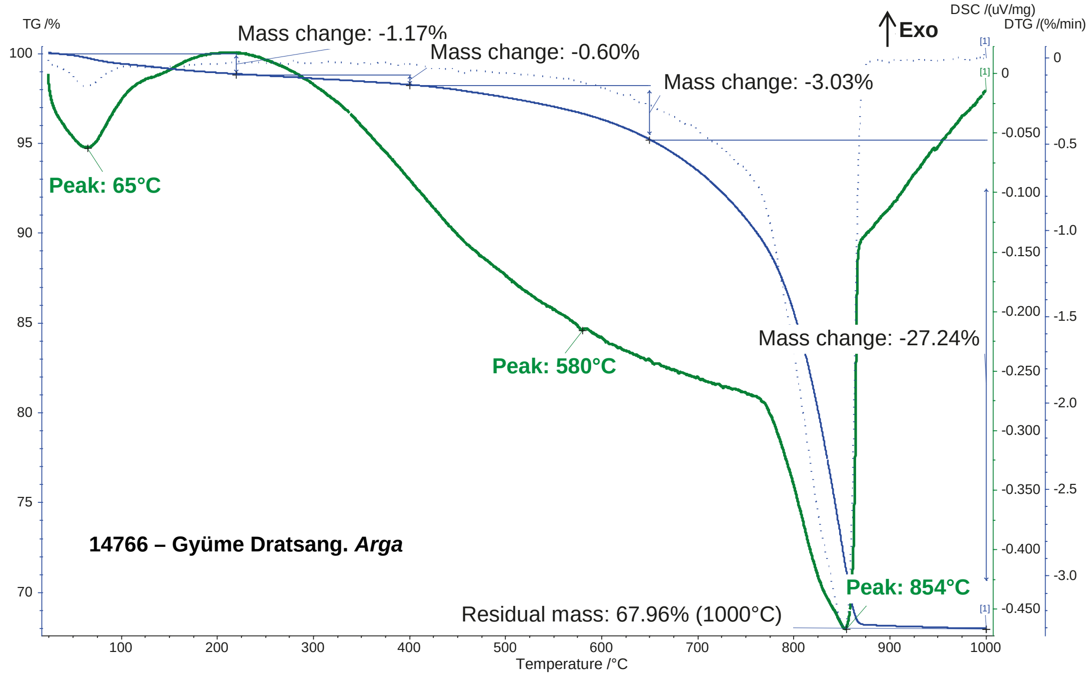
CMA 9.3 Phugtal. Mining pit. Sample 8473. Clay mineral analysis without acetate.



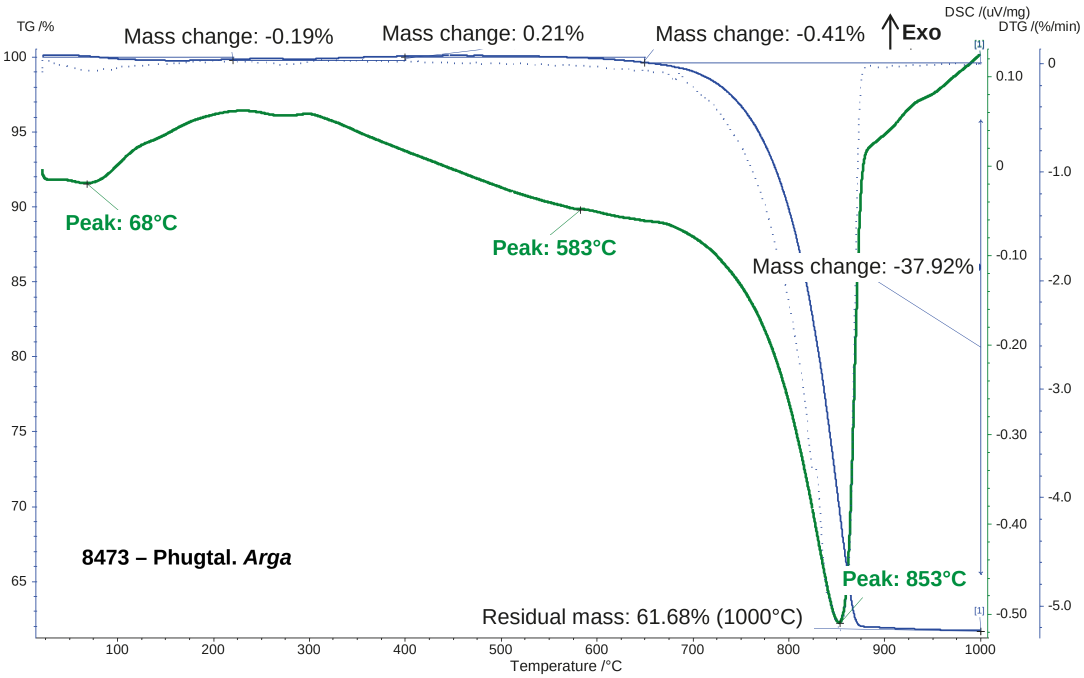
STA 1.3 Lhasa. Jokhang. Sample 11078. Simultaneous thermal analysis.



STA 2.3 Lhasa. Jokhang. Sample 14765. Simultaneous thermal analysis.



STA 3.3 Lhasa. Gyüme Dratsang. Sample 14766. Simultaneous thermal analysis.



STA 4.3 Phugtal. *Arga* quarry. Sample 8473. Simultaneous thermal analysis.

# VIII. APPENDIX CHAPTER IV

## Tables

## Graphics

https://doi.org/10.1515/9783110591330-010

Table 5.4 Grain size distribution of Nako samples. List of TARA company. Handed over to the author during an interview with Sujoy Chaudhury in 2002.

| | *Tua*[A] | Clay[B] | Adobe brick[C] | [%] |
|---|---|---|---|---|
| Coarse gravel | 0.40 | 0.40 | 4.42 | |
| Fine gravel | 0.80 | 4.04 | 4.01 | |
| Coarse sand | 2.41 | 19.75 | 12.05 | |
| Fine sand | 25.39 | 43.81 | 34.52 | |
| Suspendid solids | 43.00 | 17.00 | 26.00 | |
| Clay | 28.00 | 15.00 | 19.00 | |
| Shrinkage | 5.33 | 2.33 | 3.33 | |
| Moisture content | 1.73 | 1.31 | 6.53 | |
| Deformation index | 8.82 | 3.90 | 8.57 | |

Table 6.4 Determination of the liquid limit ($W_L$) according to A. Casagrande.

**12 beats**
Bowl weight: 51.998
Sample moistened with bowl: 79.643
Sample dry with bowl: 70.201
Sample dry: 18.203 = 100%
Sample moistened: 27.645
18.203 / 27.645 = 0.6585 – 1 = 0.3415 x 100 = 34.15 + 100 = 134.15%

**22 beats**
Bowl weight: 47.071
Sample moistened with bowl: 68.009
Sample dry with bowl: 60.911
Sample dry: 13.84 = 100%
Sample moistened: 20.938
13.84 / 20.938 = 0.661 – 1 = 0.339 x 100 = 33.9 + 100 = 133.9%

**34 beats**
Bowl weight: 47.006
Sample moistened with bowl: 62.036
Sample dry with bowl: 57.083
Sample dry: 10.007 = 100%
Sample moistened: 15.03
10.007 / 15.03 = 0.666 – 1 = 0.334 x 100 = 33.42 + 100 = 133.42%

Result: According to DIN 18122 the liquid limit ($W_L$) for the *markalak* clay sample 8466, read on scale at 25 beats (see Fig. 11.4) lies at a water content of 133.75% (giving the geotechnical value).

Table 7.4 Determination of the plasticity limit ($W_P$). Three specimens from sample 8466 (Spituk) were taken for this examination according to DIN 18122-1:1997-07.

**Specimen I**
Bowl weight: 54.735
Sample moistened with bowl: 56.612
Sample dry with bowl: 56.225
Sample dry: 1.49 = 100%
Sample moistened: 1.877
1.49 / 1.877 = 0.794 – 1 = 0.206 x 100 = 20.618 + 100 = 120.618%

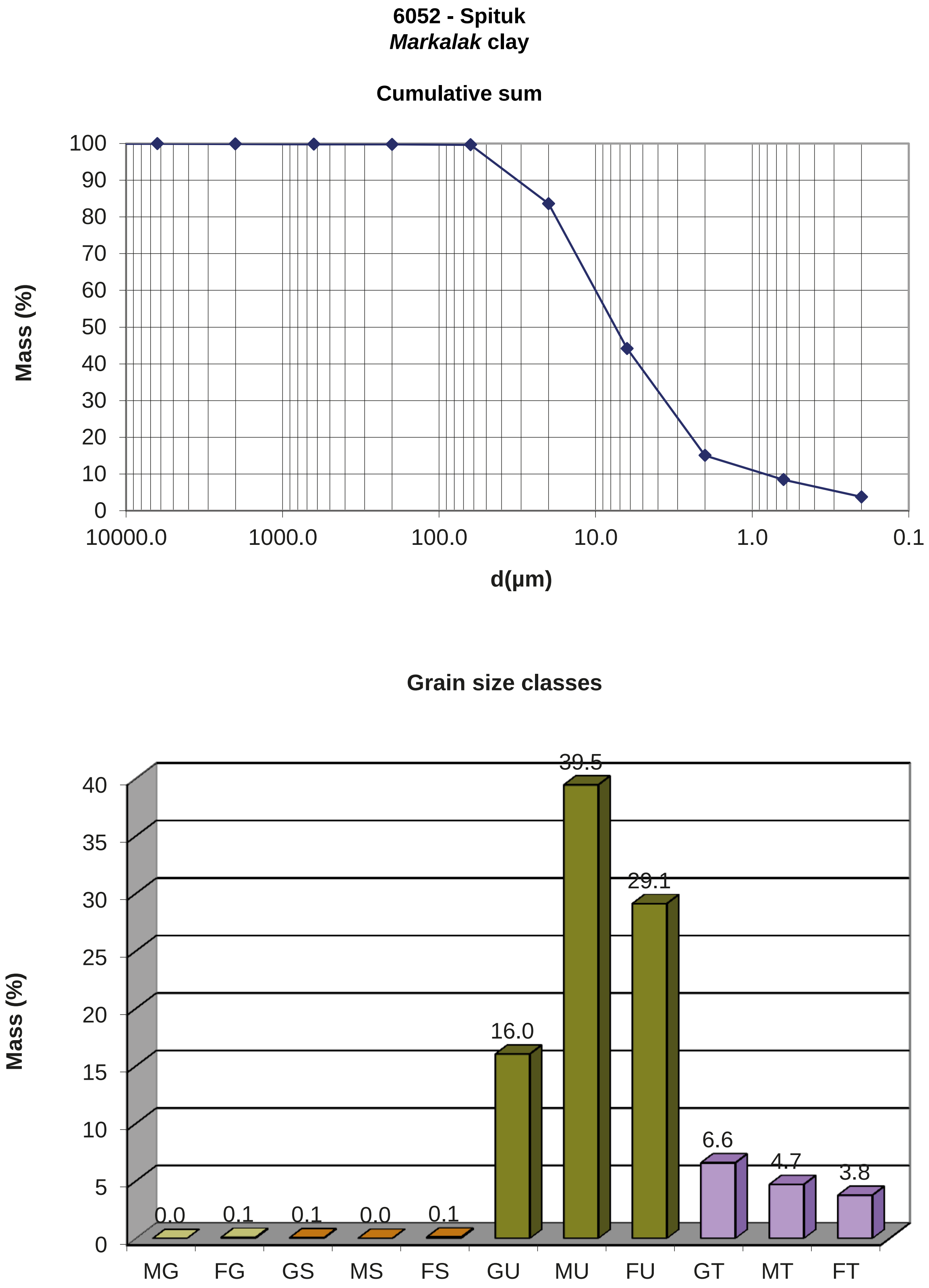
**Specimen II**
Bowl weight: 54.682
Sample moistened with bowl: 57.881
Sample dry with bowl: 57.203
Sample dry: 2.521 = 100%
Sample moistened: 3.199
2.521 / 3.199 = 0.788 – 1 = 0.212 x 100 = 21.194 + 100 = 121.194%

**Specimen III**
Bowl weight: 55.807
Sample moistened with bowl: 59.700
Sample dry with bowl: 58.876
Sample dry: 3.069 = 100%
Sample moistened: 3.893
3.069 / 3.893 = 0.788 – 1 = 0.212 x 100 = 21.166 + 100 = 121.166%

Result: According to DIN 18122 the plasticity limit ($I_P$) lies at water content of 121% on average (giving the geotechnical value for humidity).

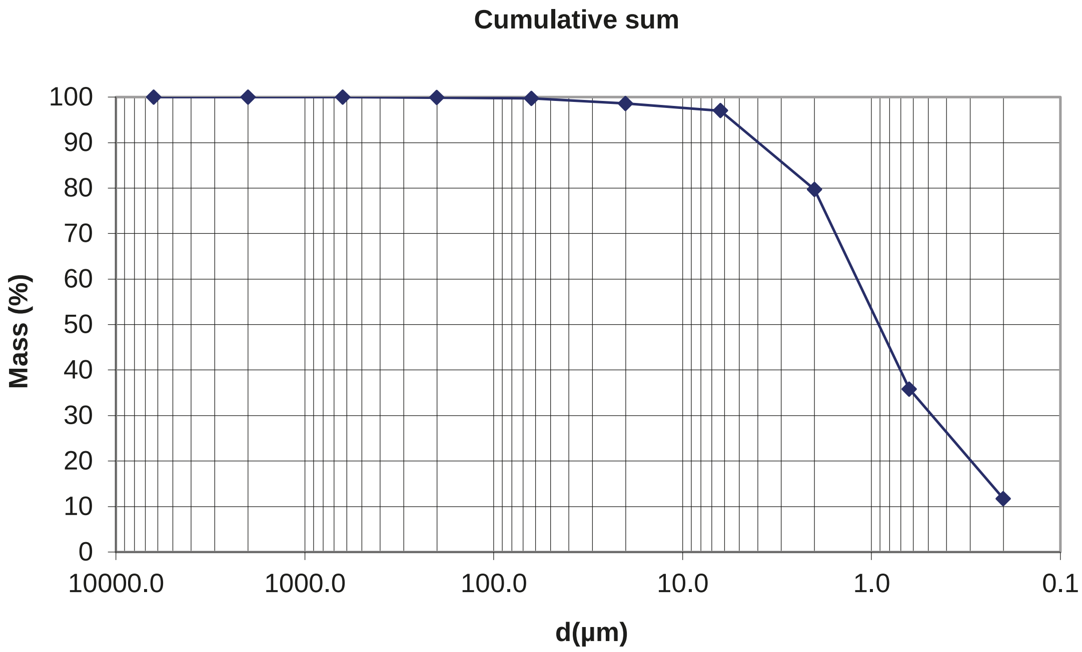
Table 8.3 Classification number for the plasticity ($I_P$) of clays according to Voth 1978 (Minke 1995: 42).

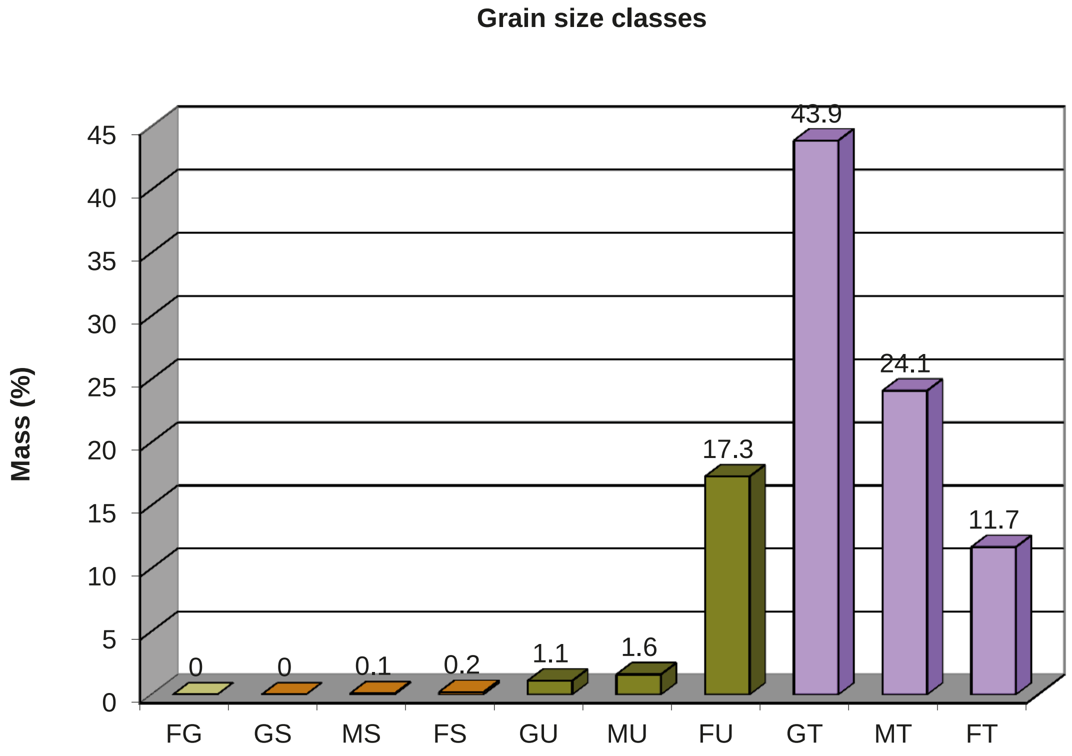
$I_P$ [%] = $W_L$ [%] – $W_P$ [%]
$I_P$ [%] = 133.75% – 121% = 12.75%



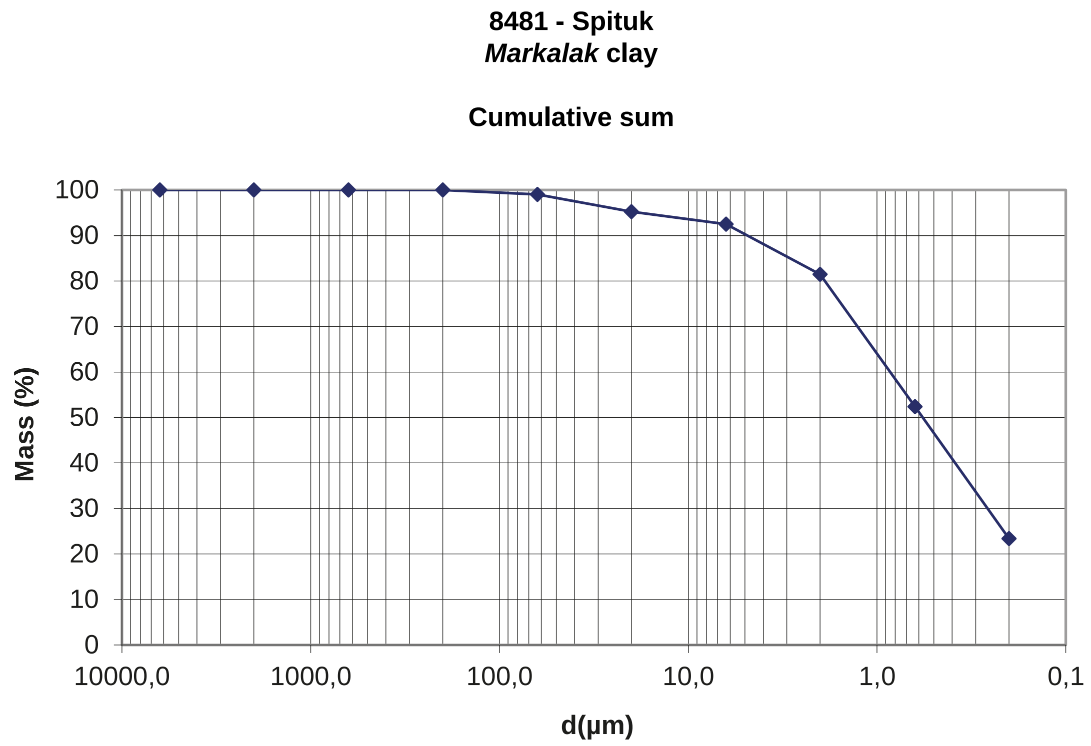
GSD 1.4 Spituk. Sample 6052. *Markalak* clay. Top: Cumulative sum. Bottom: Grain size classes.

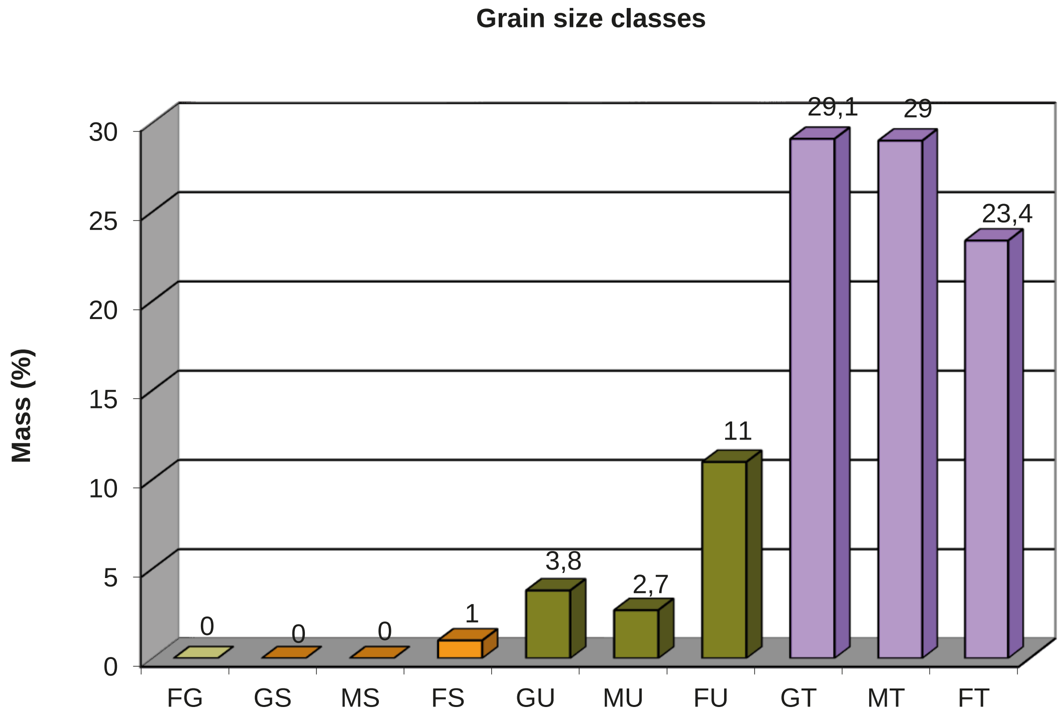
**8466 - Basgo**
**Maitreya Lhakhang - plaster on pillar**



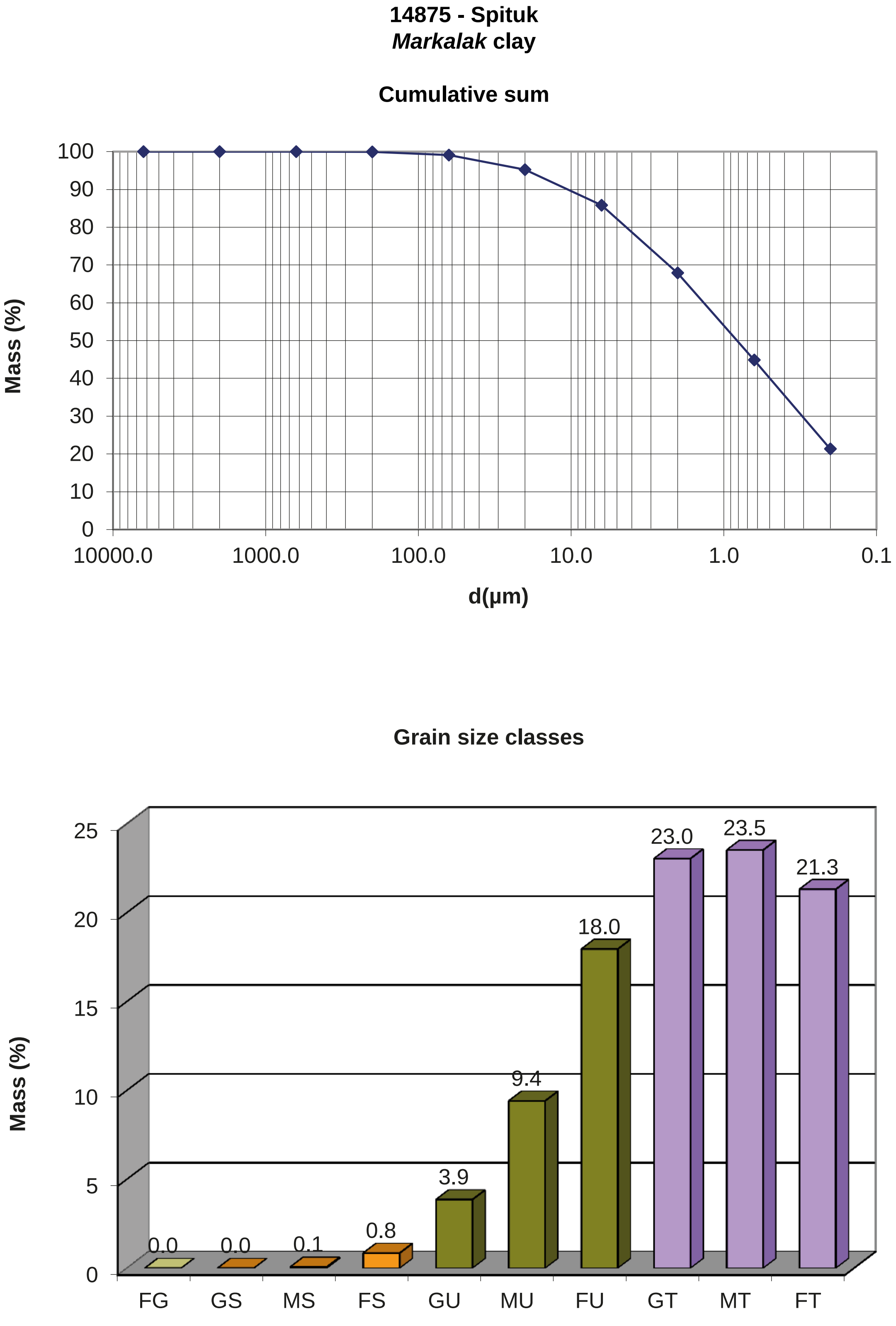


GSD 2.4 Spituk. Sample 8466. *Markalak* clay. Top: Cumulative sum. Bottom: Grain size classes.



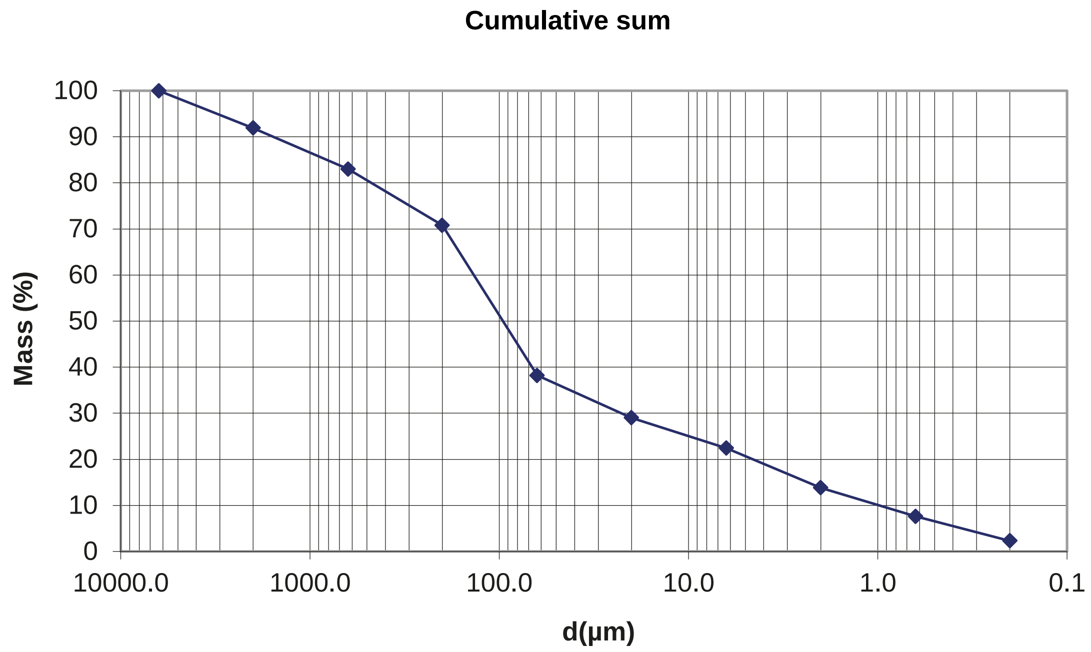


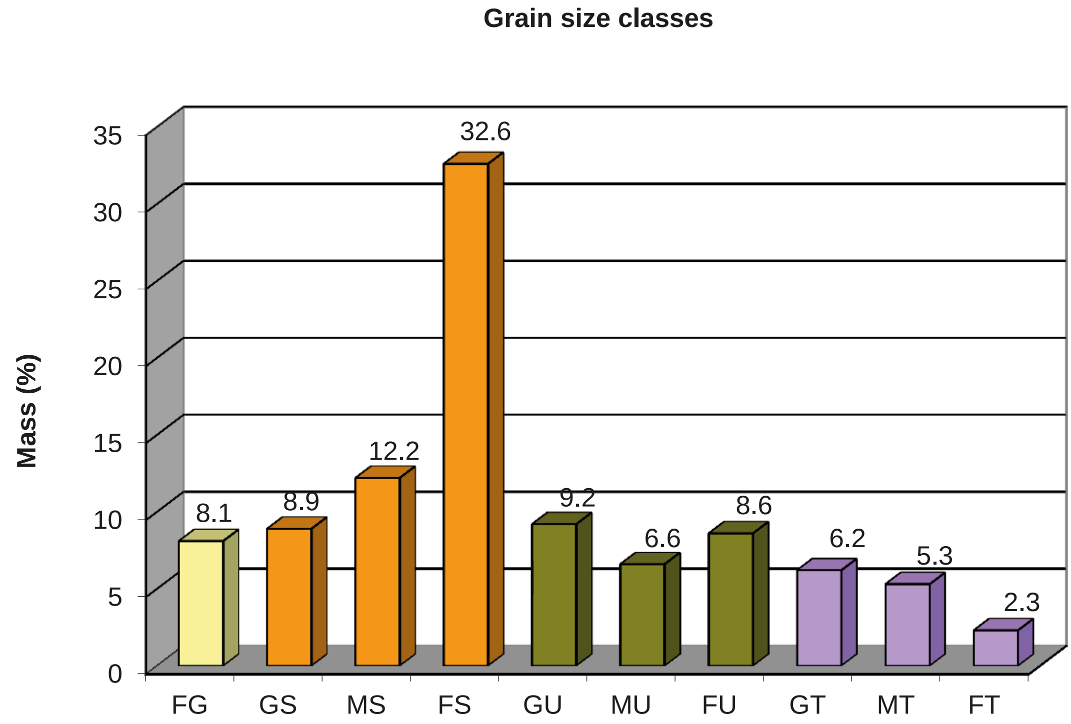
GSD 3.4 Spituk. Sample 8481. *Markalak* clay. Top: Cumulative sum. Bottom: Grain size classes.



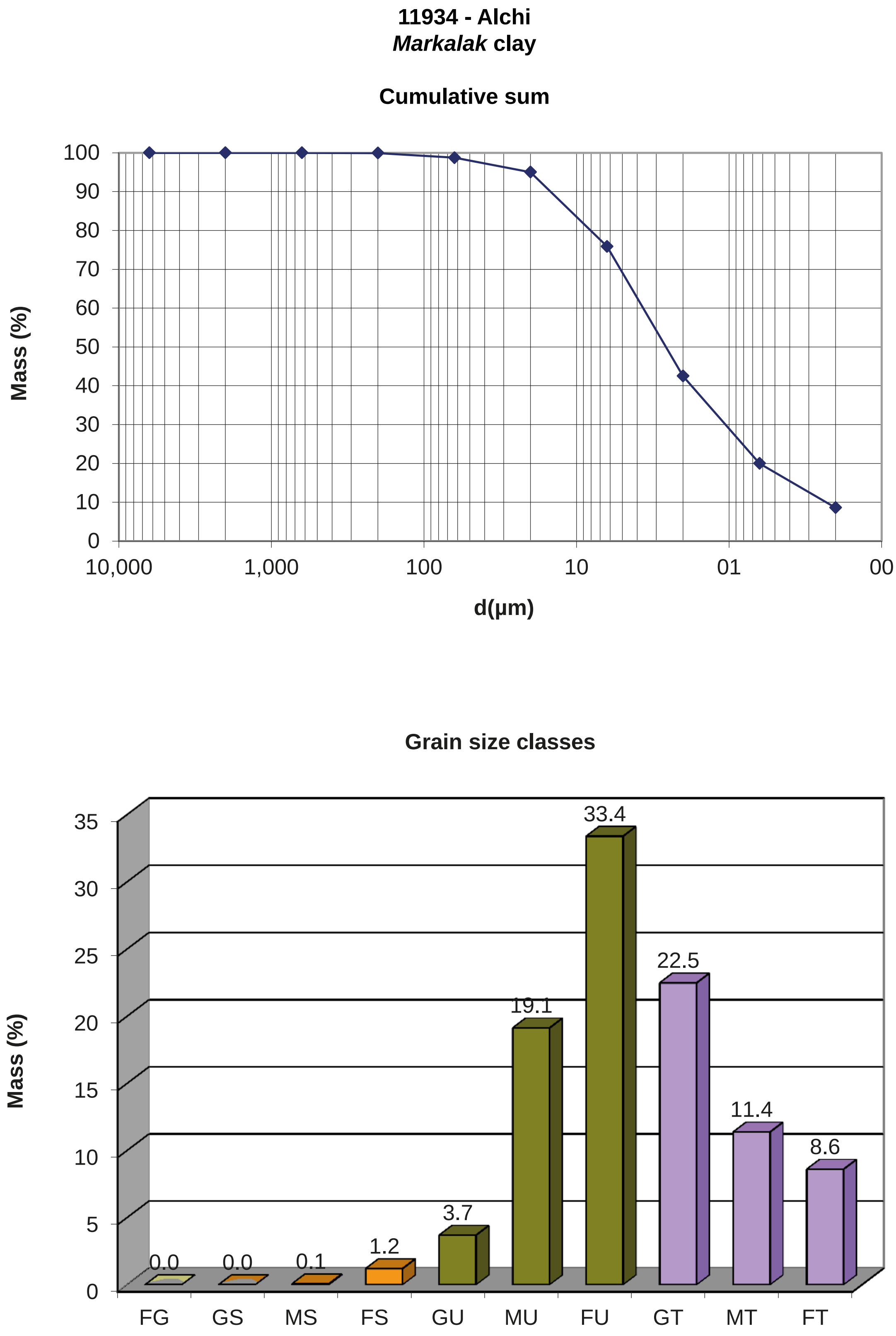
GSD 4.4 Spituk. Sample 14875. *Markalak* clay. Top: Cumulative sum. Bottom: Grain size classes.

## 8526 - Alchi
## *Markalak* clay



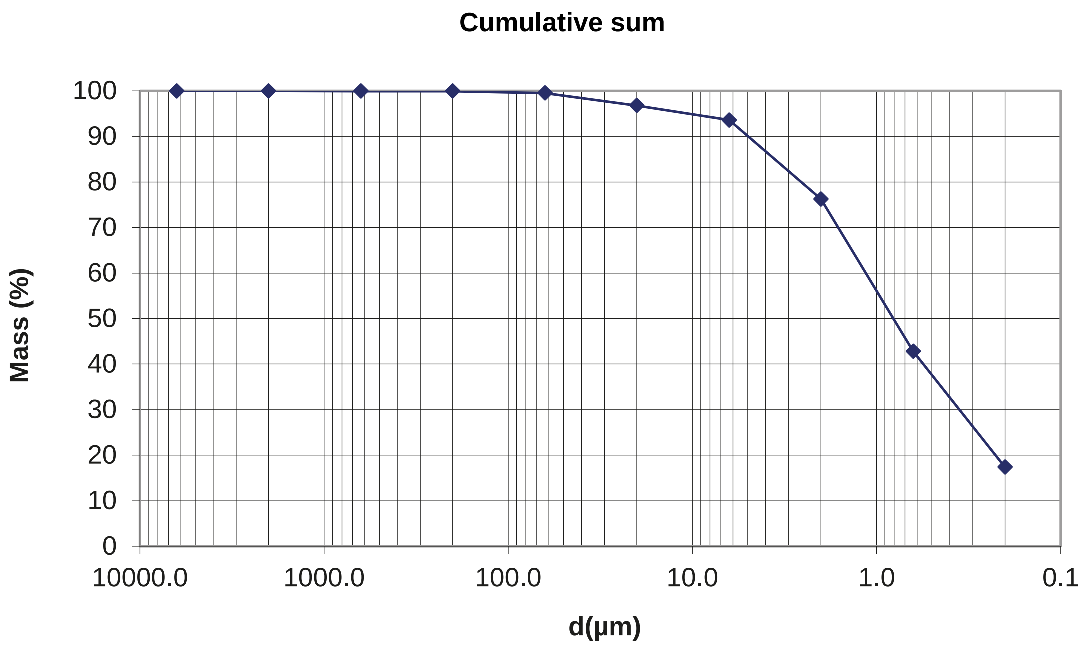


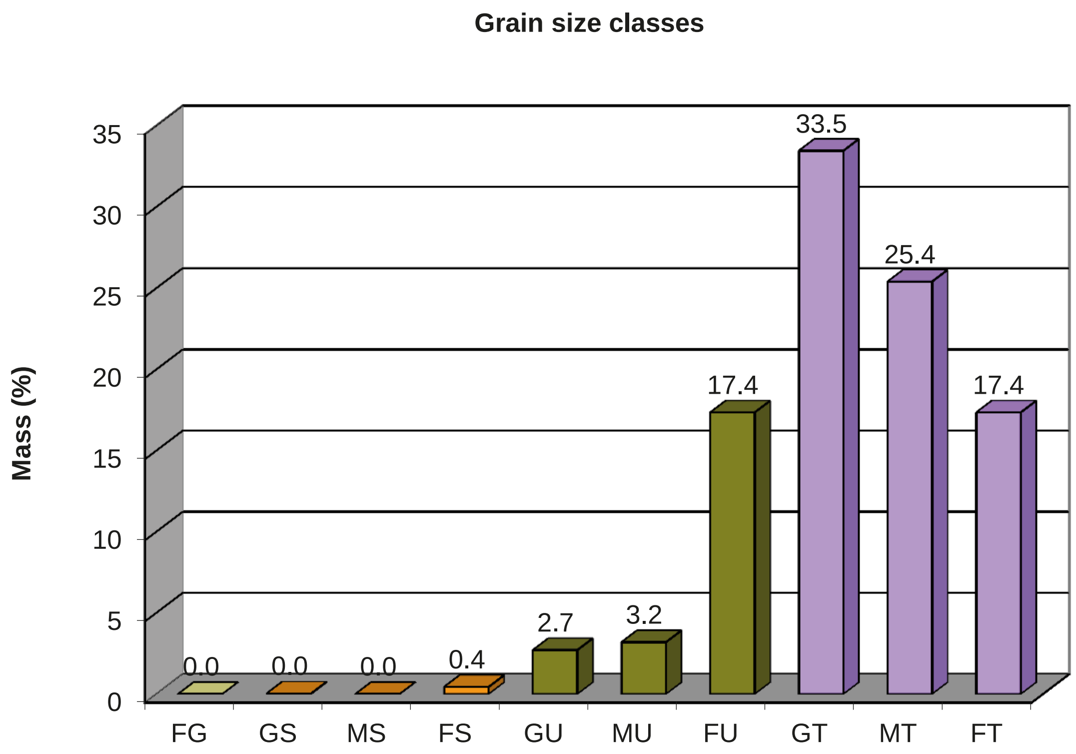
GSD 5.4 Alchi. Sample 8526. *Markalak* clay. Top: Cumulative sum. Bottom: Grain size classes.



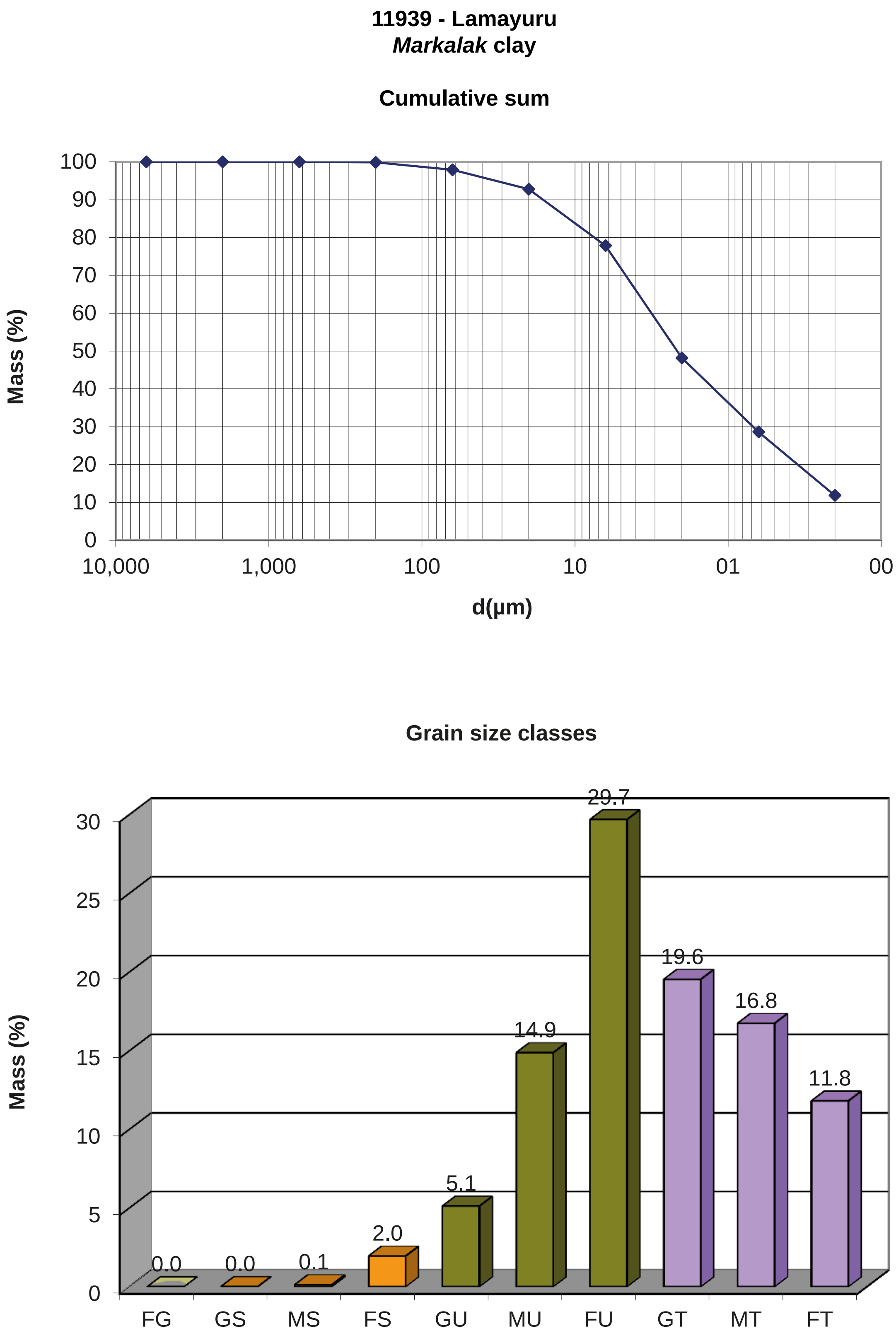
GSD 6.4 Alchi. Sample 11934. *Markalak* clay. Top: Cumulative sum. Bottom: Grain size classes.

**14876 - Alchi**
***Markalak* clay**

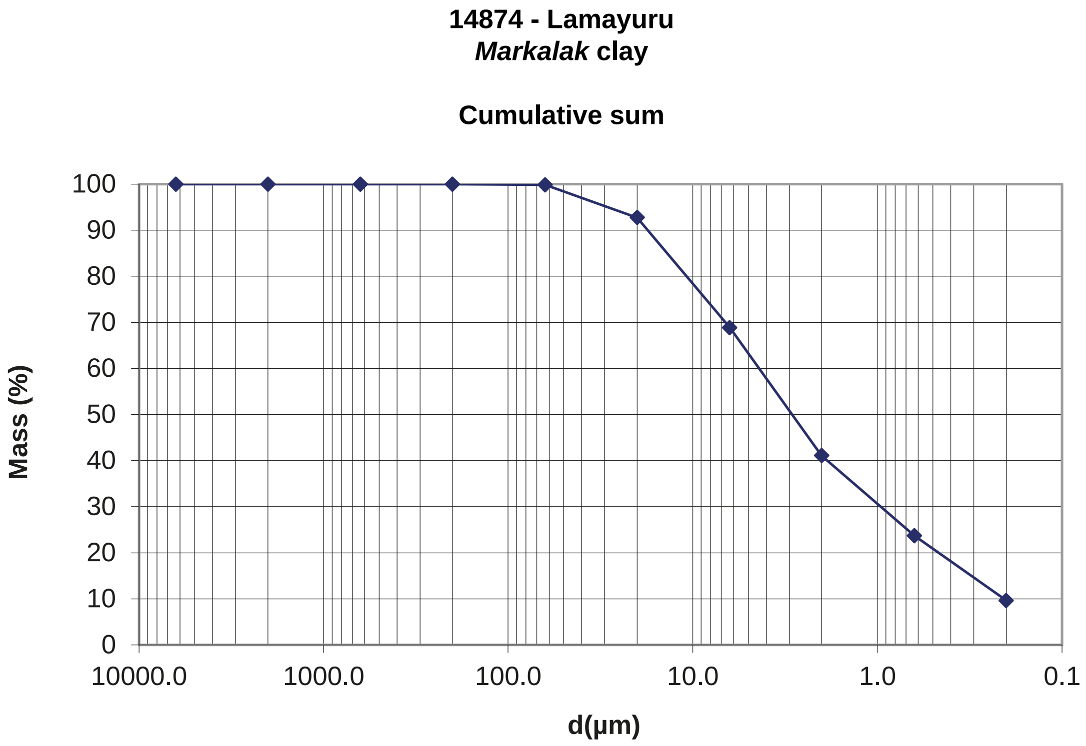


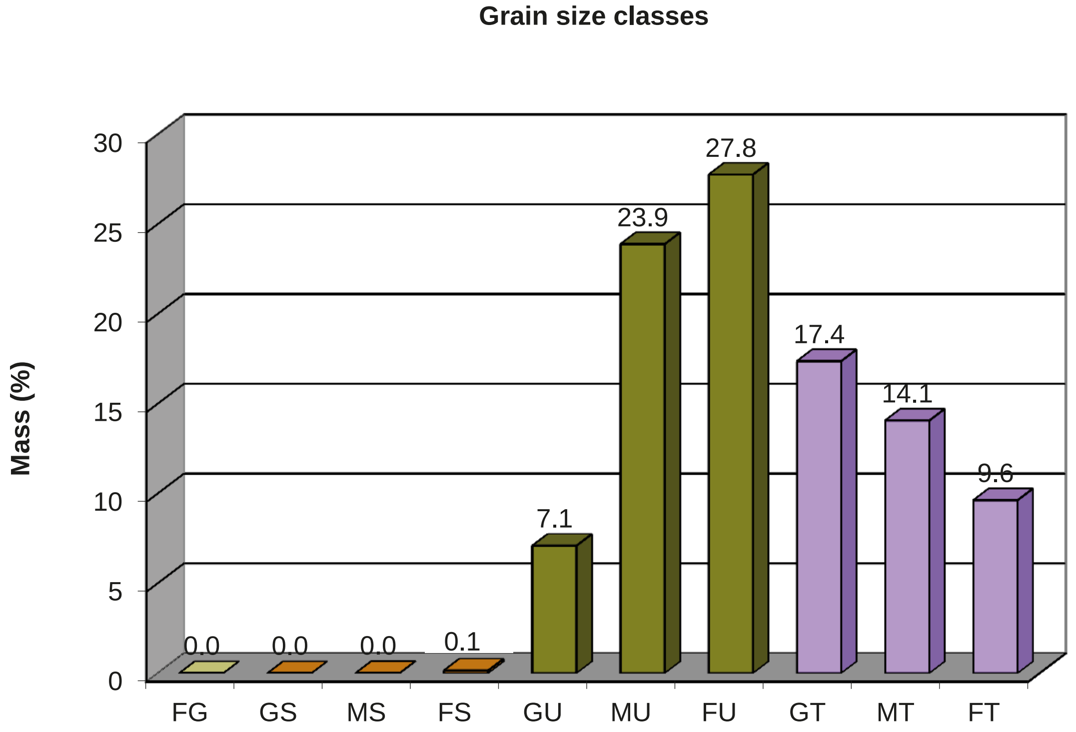


GSD 7.4 Alchi. Sample 14876. *Markalak* clay. Top: Cumulative sum. Bottom: Grain size classes.

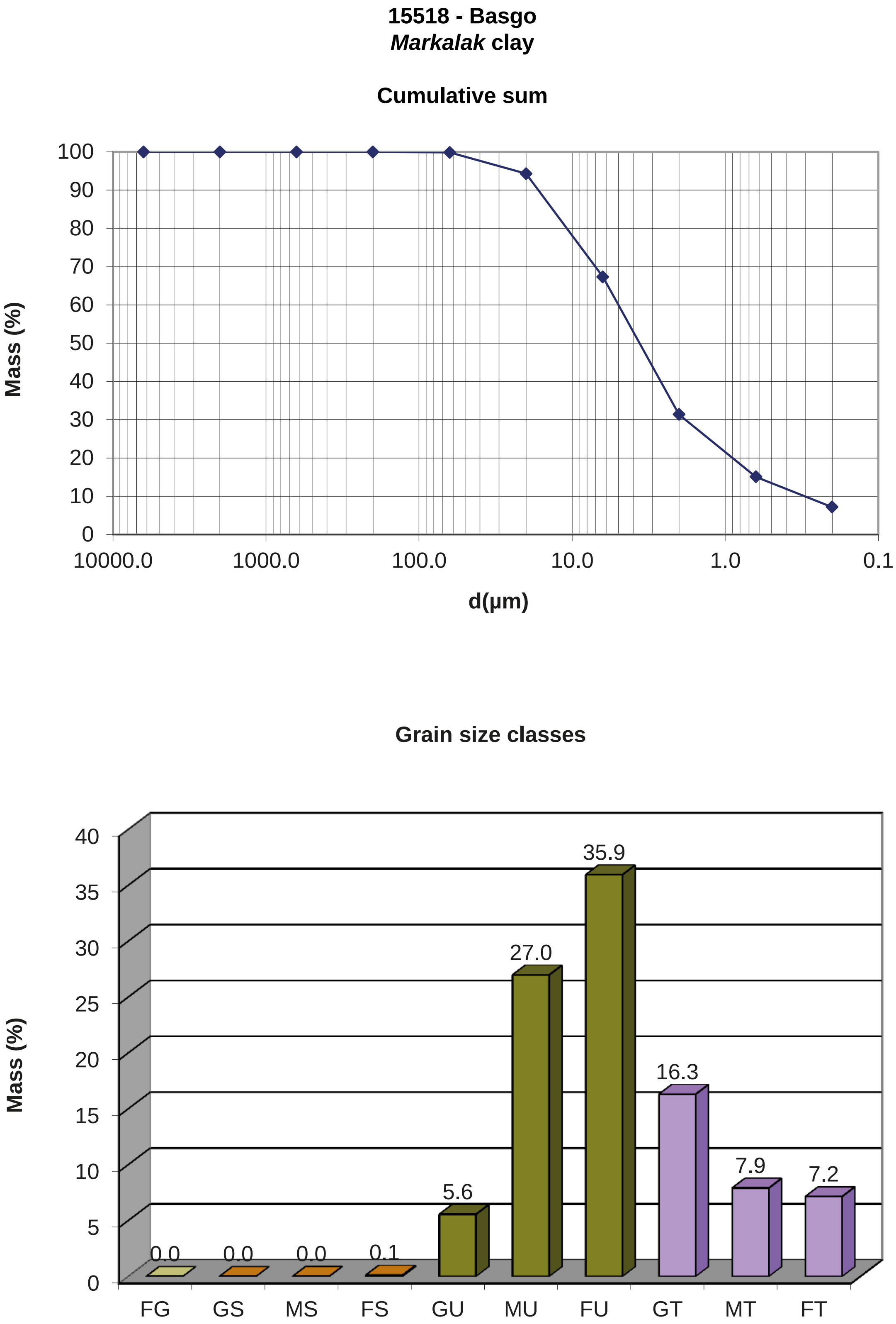


GSD 8.4 Lamayuru. Sample 11939. *Markalak* clay. Top: Cumulative sum. Bottom: Grain size classes.

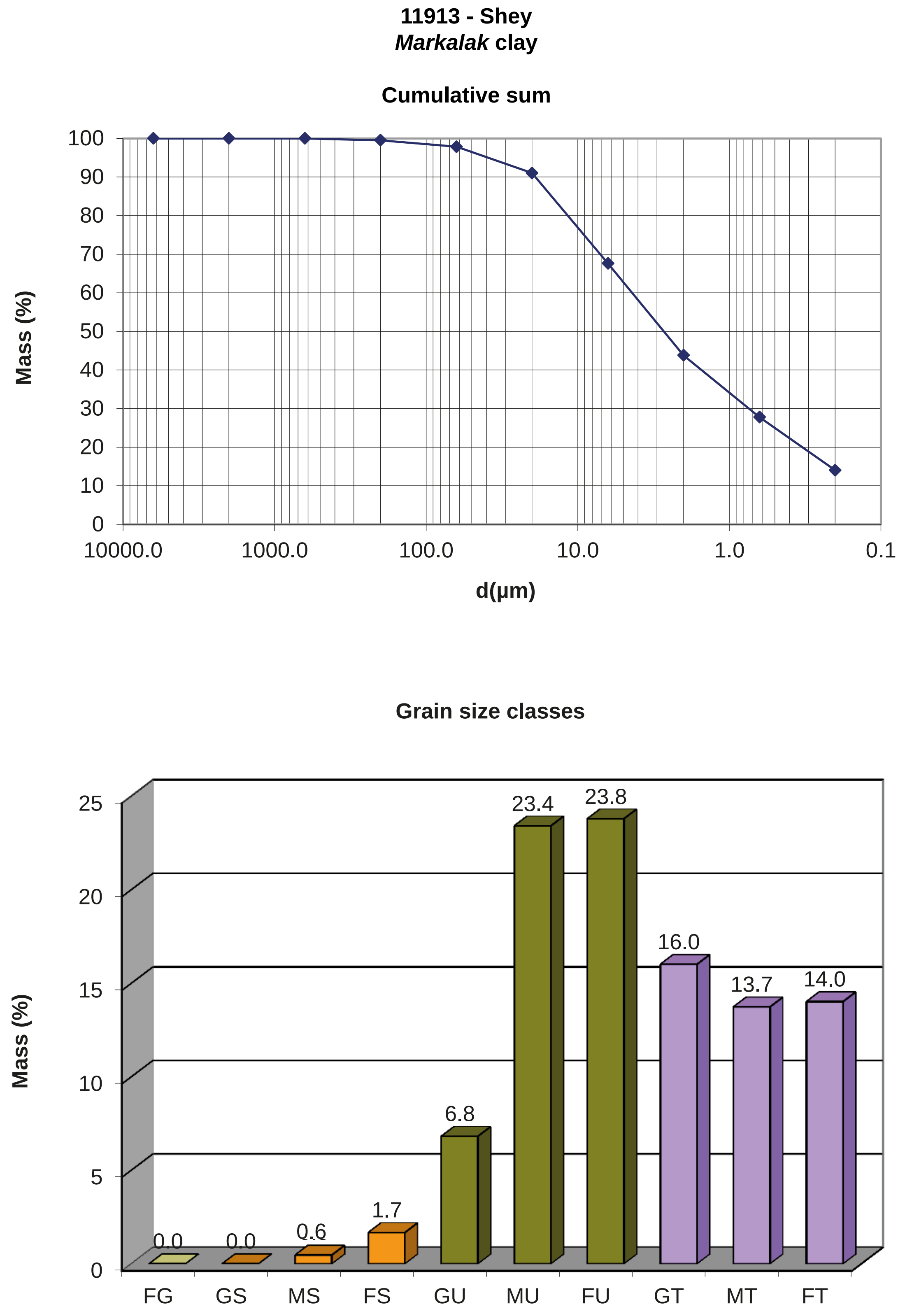




GSD 9.4 Lamayuru. Sample 14874. *Markalak* clay. Top: Cumulative sum. Bottom: Grain size classes.

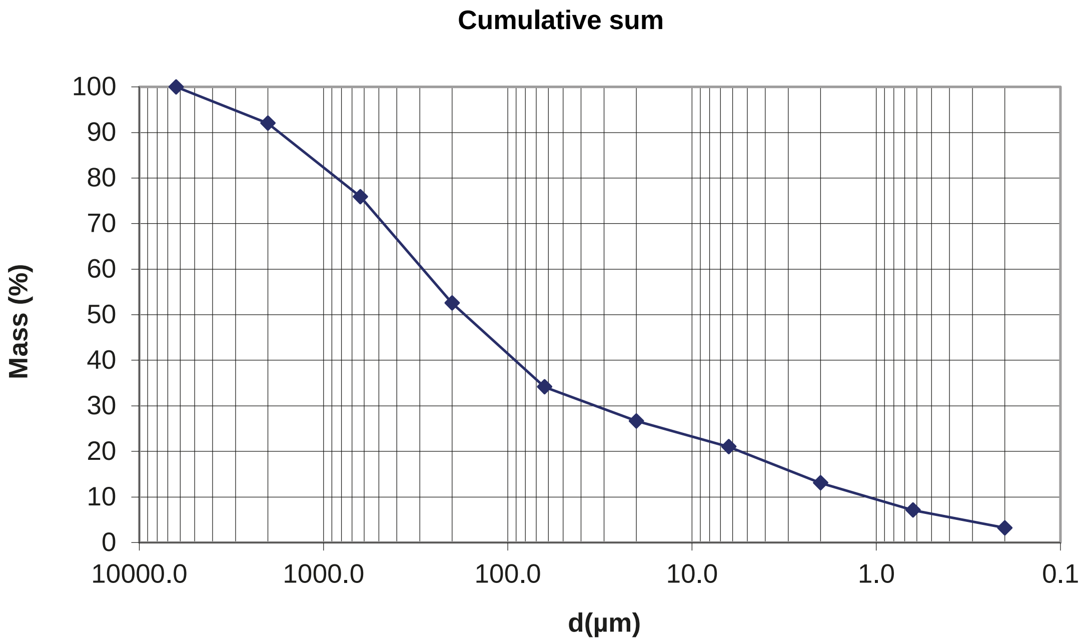


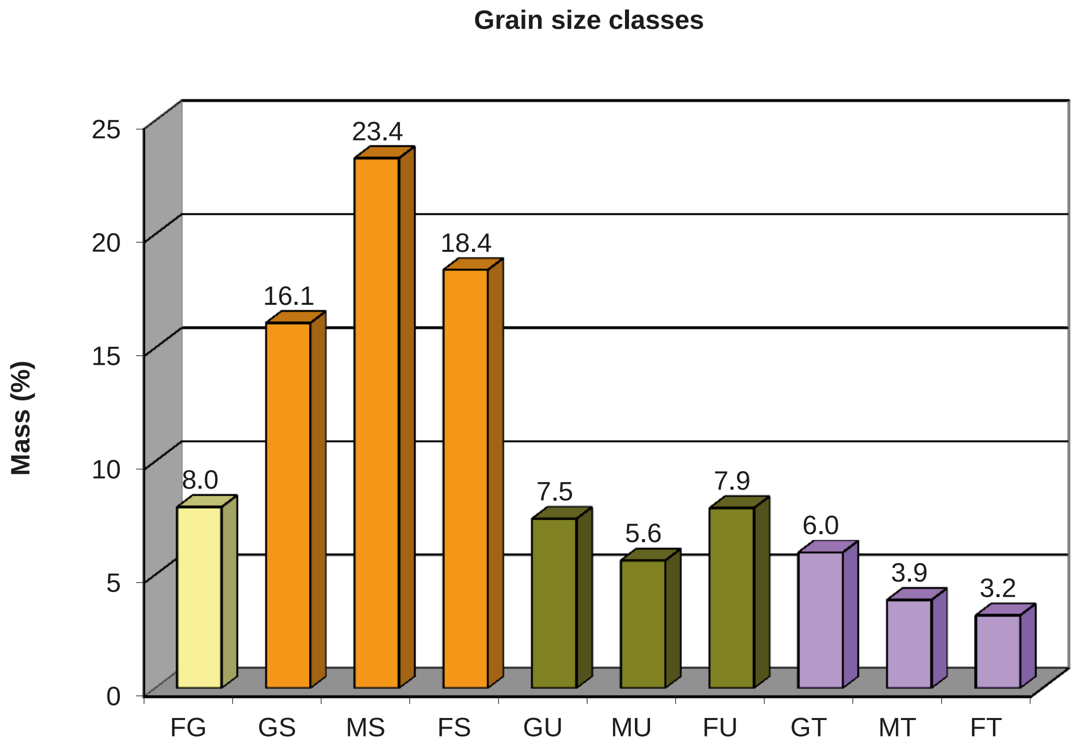
GSD 10.4 Basgo. Sample 15518. *Markalak* clay. Top: Cumulative sum. Bottom: Grain size classes.



GSD 11.4 Shey. Sample 11913. *Markalak* clay. Top: Cumulative sum. Bottom: Grain size classes.

## 15404 - Shey
## *Clay pit - raw material for bricks*

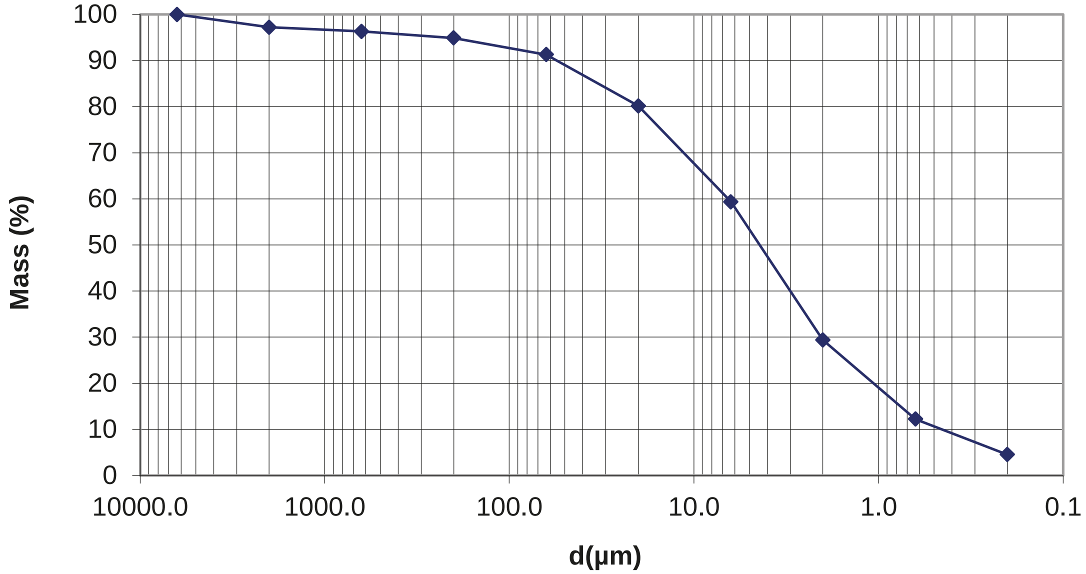




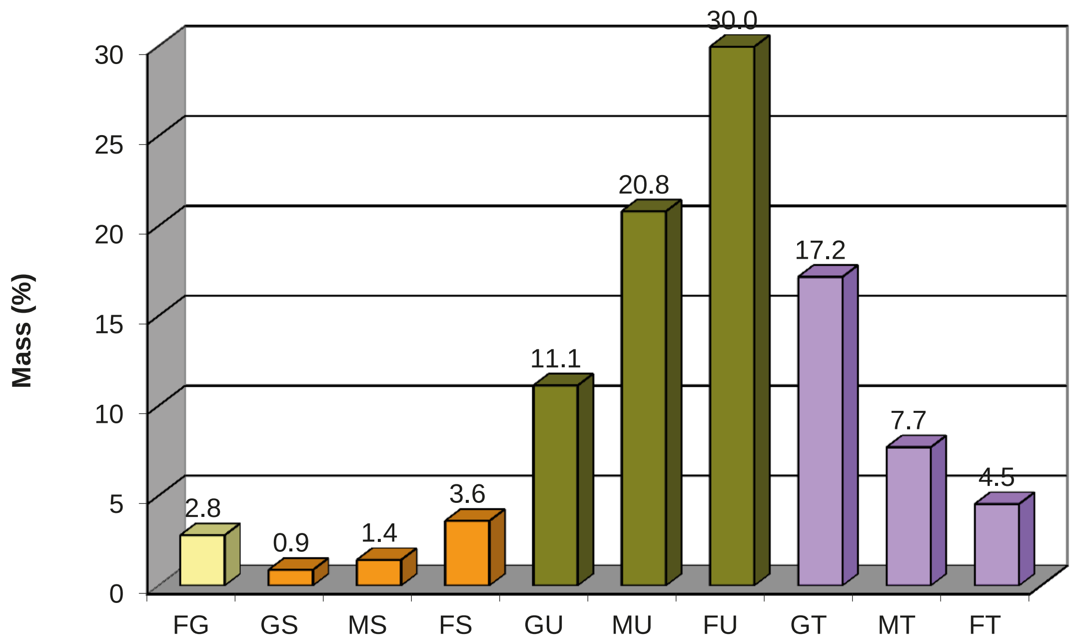
GSD 12.4 Shey. Sample 15404. Clay pit. Raw material for bricks. Top: Cumulative sum. Bottom: Grain size classes.

**15516 - Nako**
***Tua* clay**

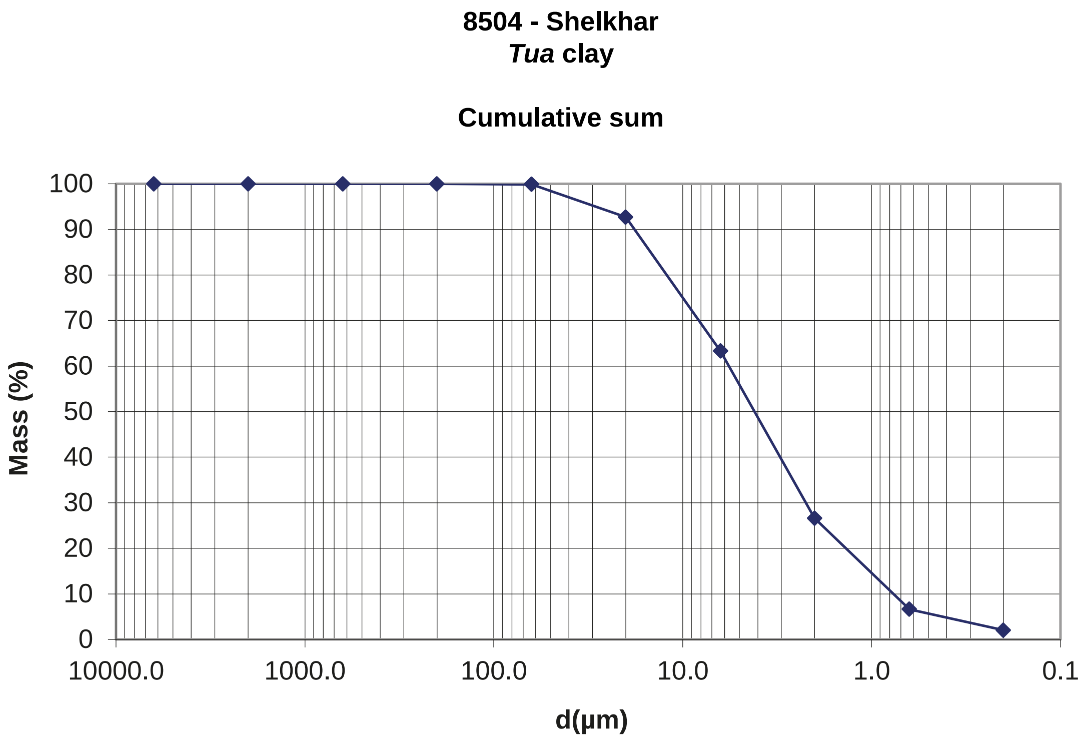
**Cumulative sum**

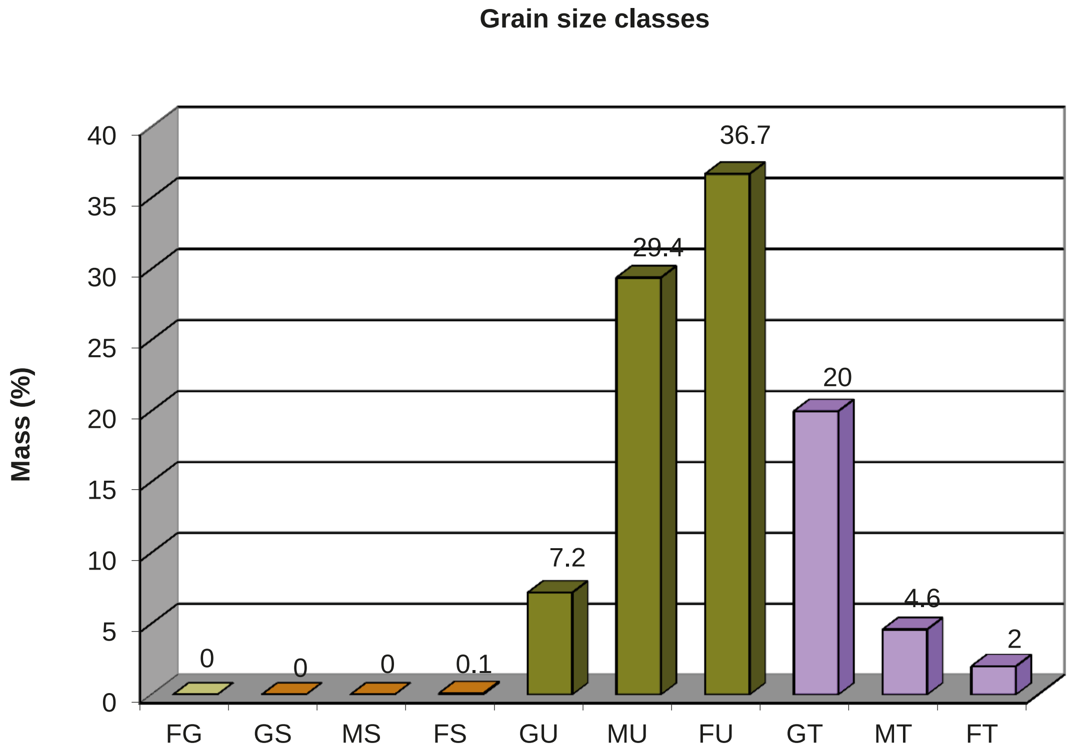


**Grain size classes**



GSD 13.4 Nako. Sample 15516. *Tua* clay. Top: Cumulative sum. Bottom: Grain size classes.

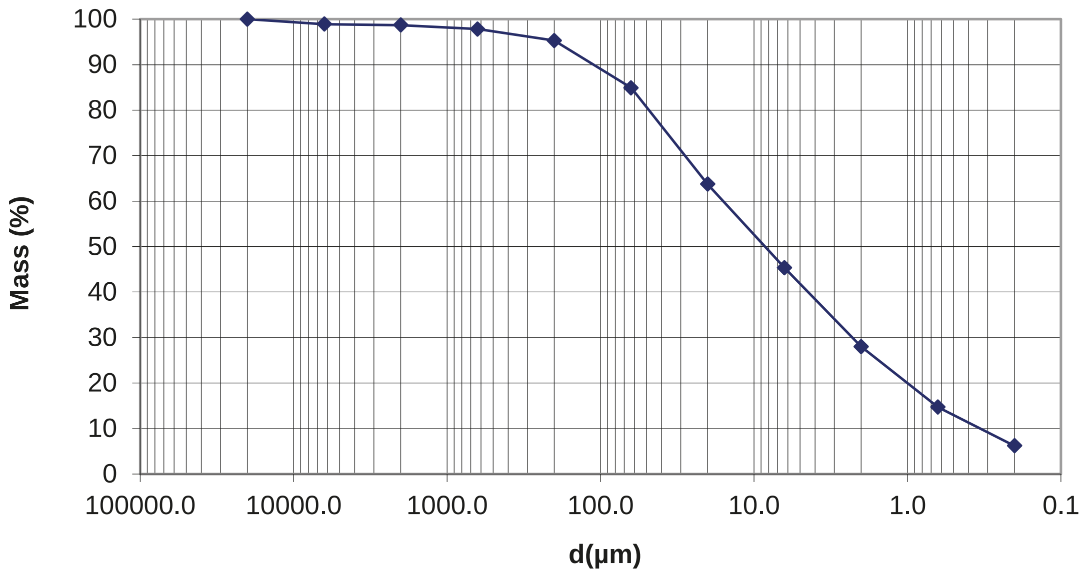




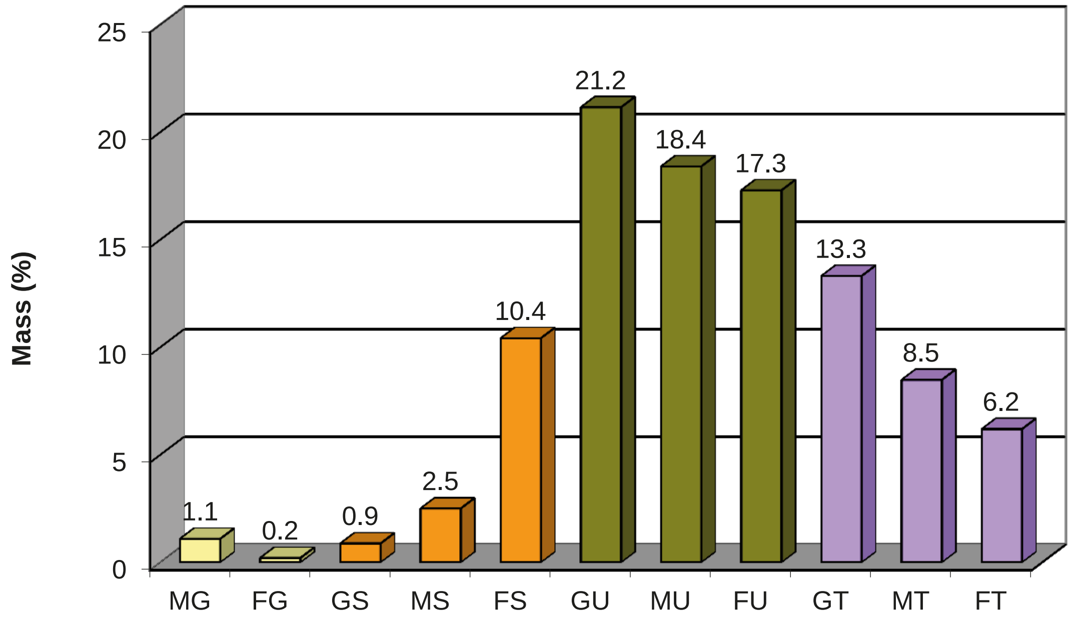
GSD 14.4 Shelkhar. Sample 8504. *Tua* clay. Top: Cumulative sum. Bottom: Grain size classes.

**15377 - Khorchag**
***Narkalak* clay**

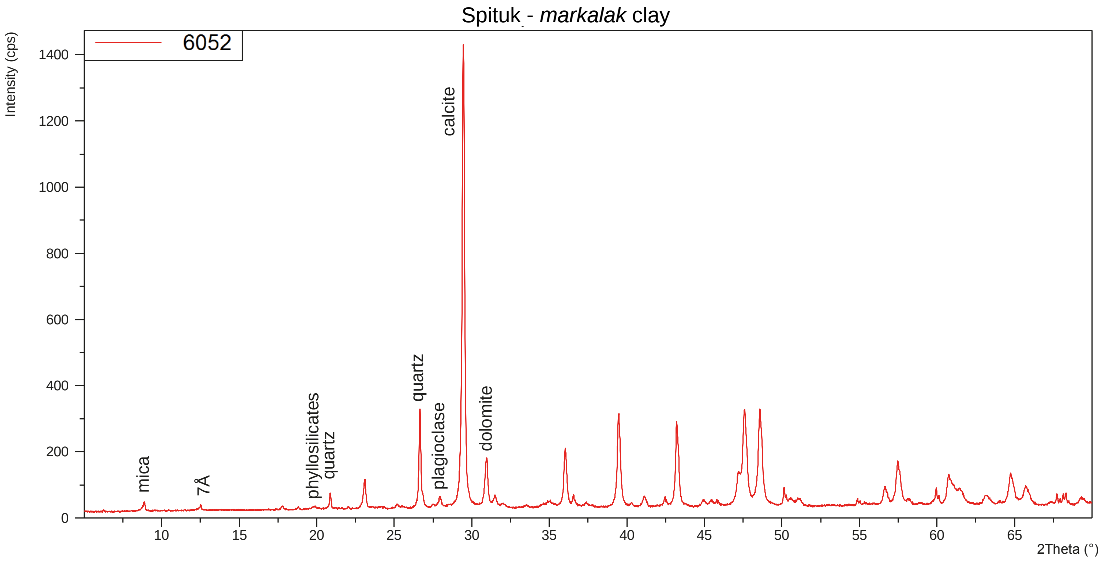
**Cumulative sum**



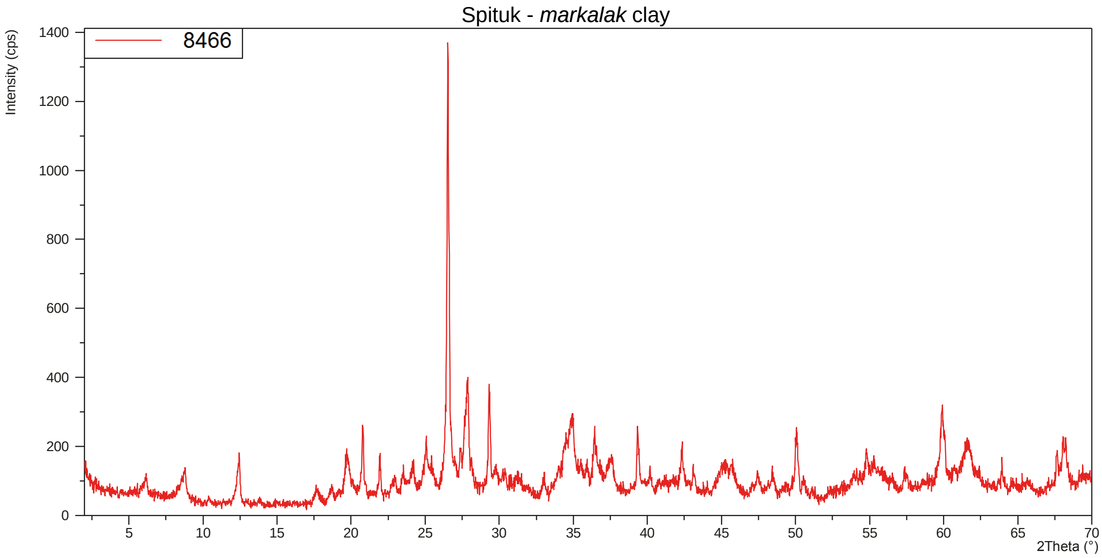
**Grain size classes**



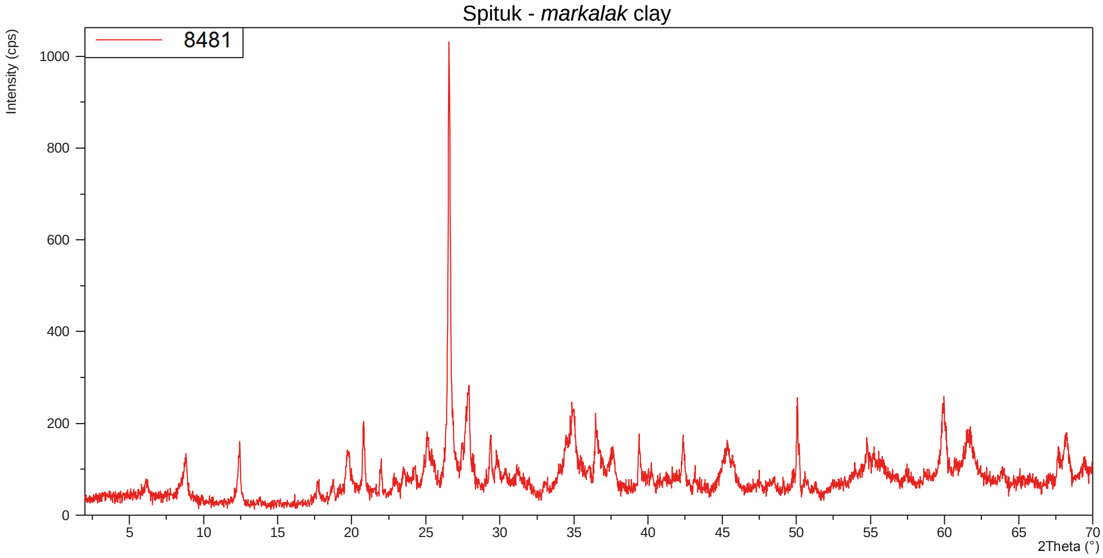
GSD 15.4 Khorchag. Sample 15377. *Narkalak* clay. Top: Cumulative sum. Bottom: Grain size classes.



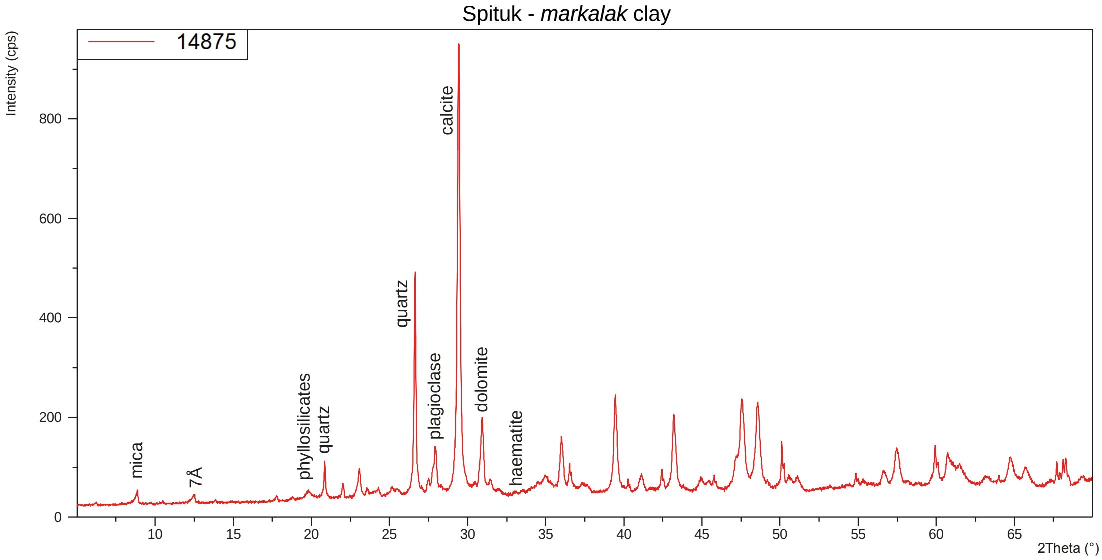
BMA 1.4 Spituk. Sample 6052. *Markalak* clay. Bulk mineral analysis.



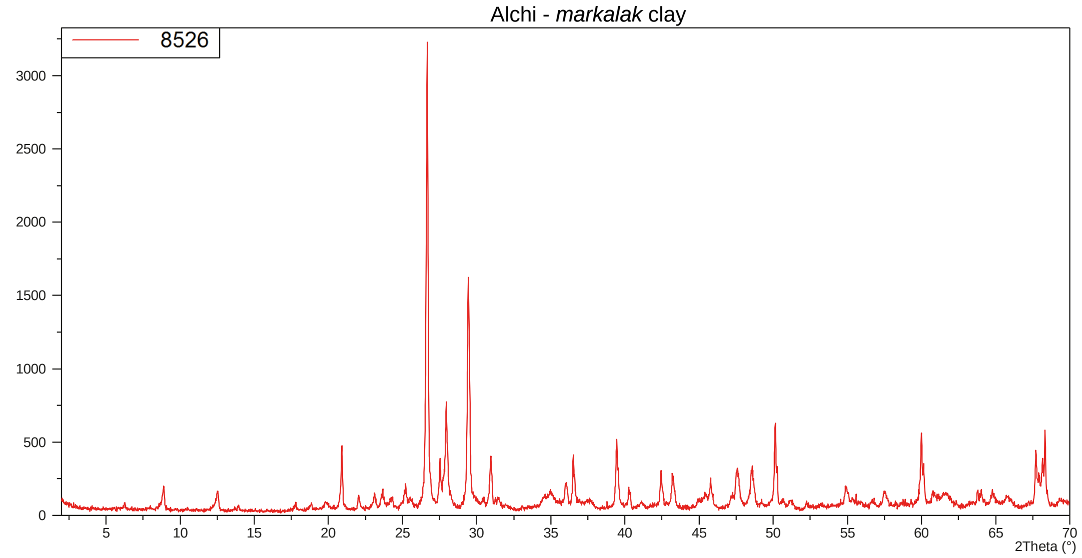
BMA 2.4 Spituk. Sample 8466. *Markalak* clay. Bulk mineral analysis.



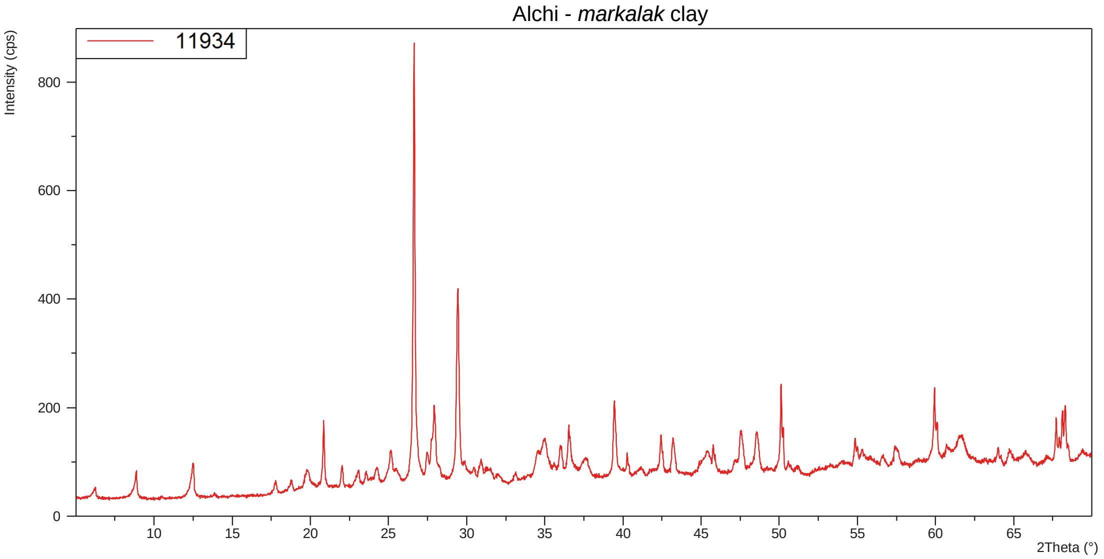
BMA 3.4 Spituk. Sample 8481. *Markalak* clay. Bulk mineral analysis.



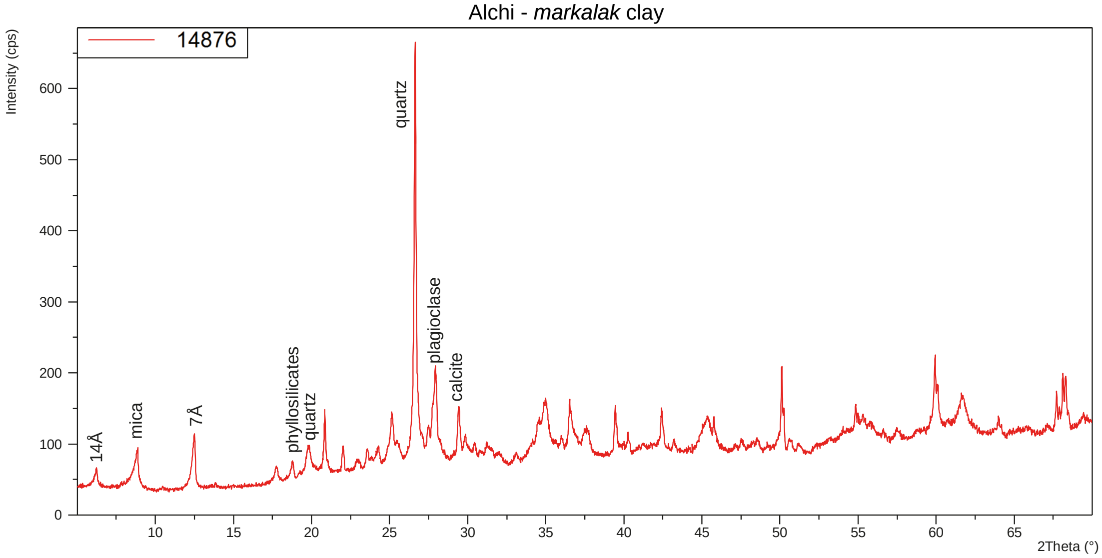
BMA 4.4 Khorchag. Sample 14875. *Markalak* clay. Bulk mineral analysis.



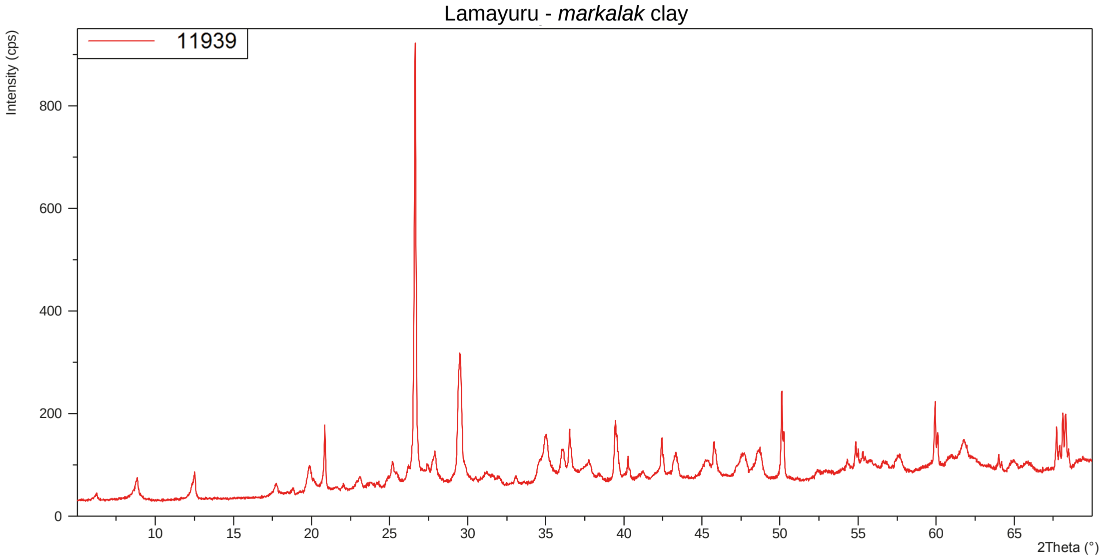
BMA 5.4 Alchi. Sample 8526. *Markalak* clay. Bulk mineral analysis.



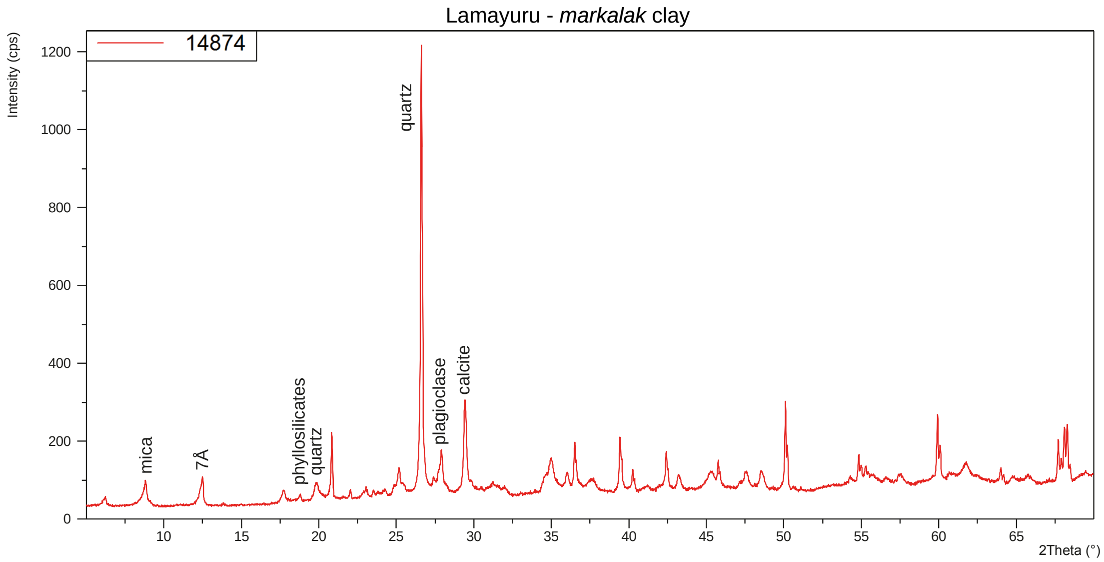
BMA 6.4 Alchi. Sample 11934. *Markalak* clay. Bulk mineral analysis.



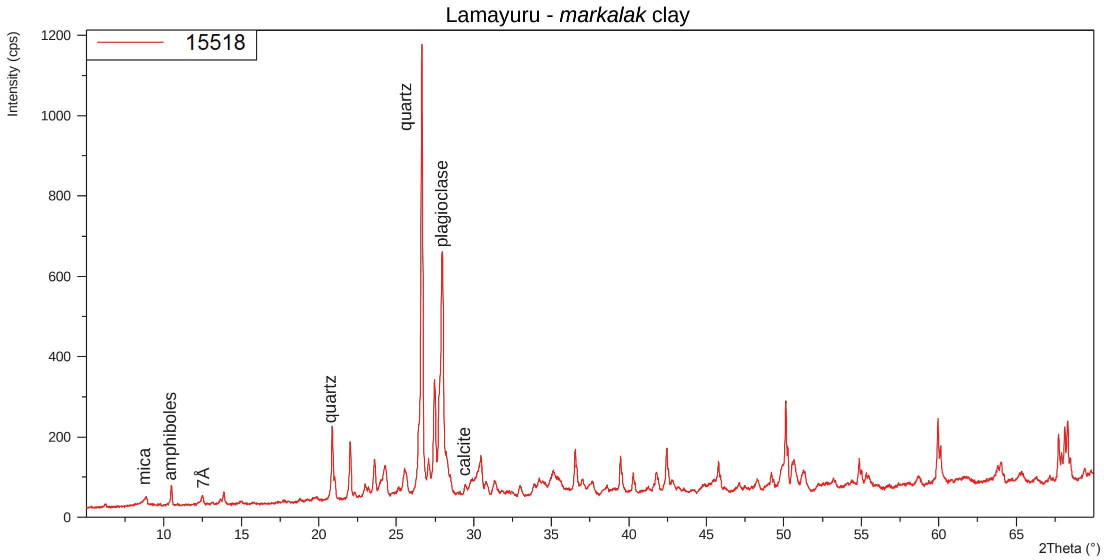
BMA 7.4 Alchi. Sample 14876. *Markalak* clay. Bulk mineral analysis.



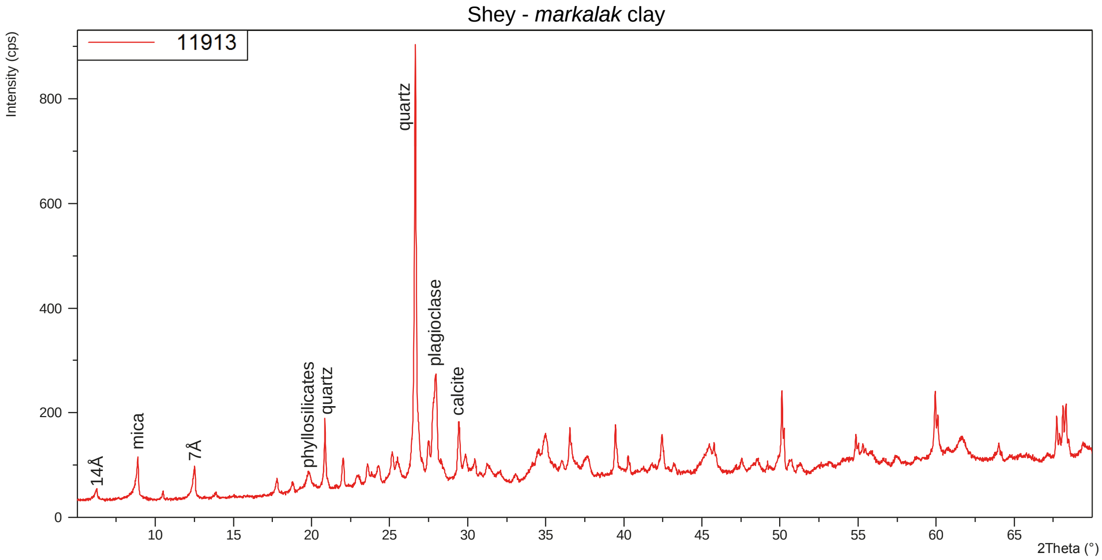
BMA 8.4 Lamayuru. Sample 11939. *Markalak* clay. Bulk mineral analysis.



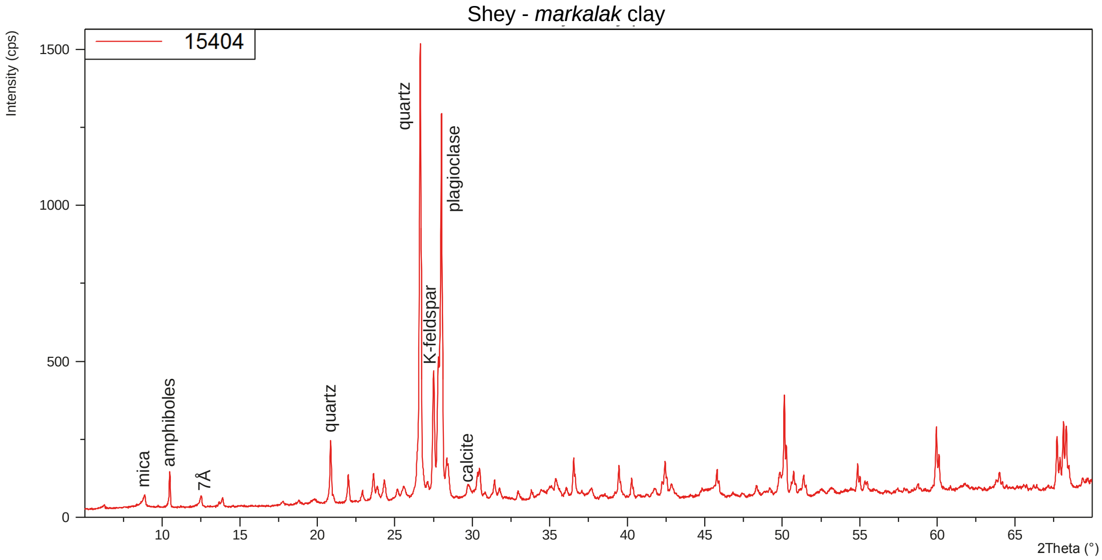
BMA 9.4 Lamayuru. Sample 14874. *Markalak* clay. Bulk mineral analysis.



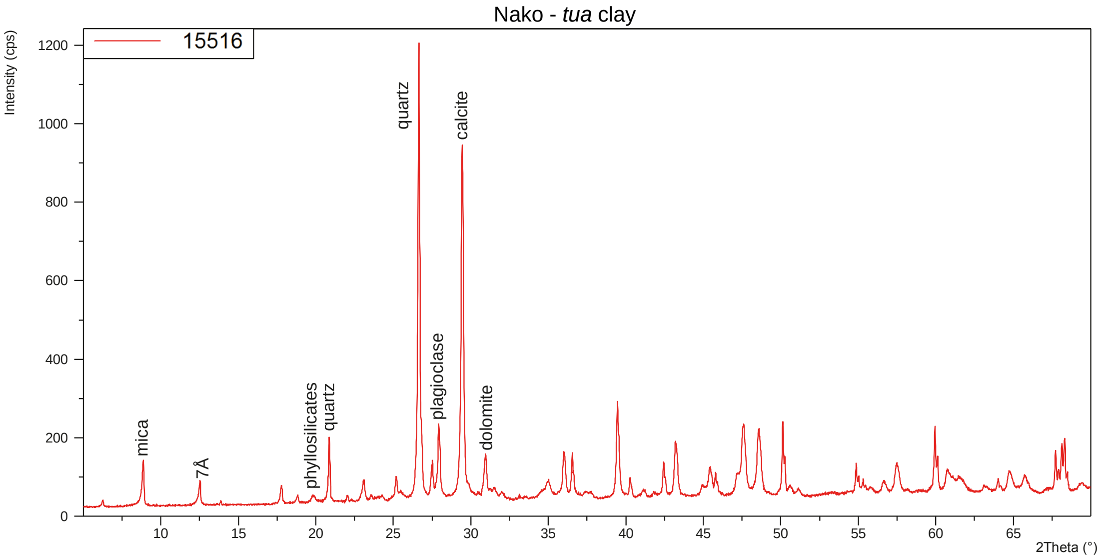
BMA 10.4 Basgo. Sample 15518. *Markalak* clay. Bulk mineral analysis.



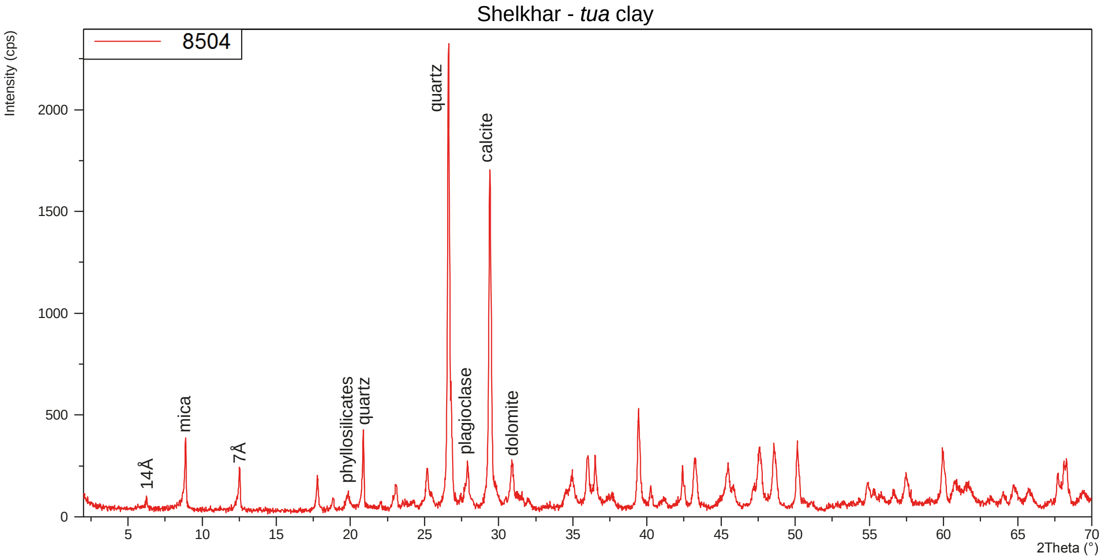
BMA 11.4 Shey. Sample 11913. *Markalak* clay. Bulk mineral analysis.



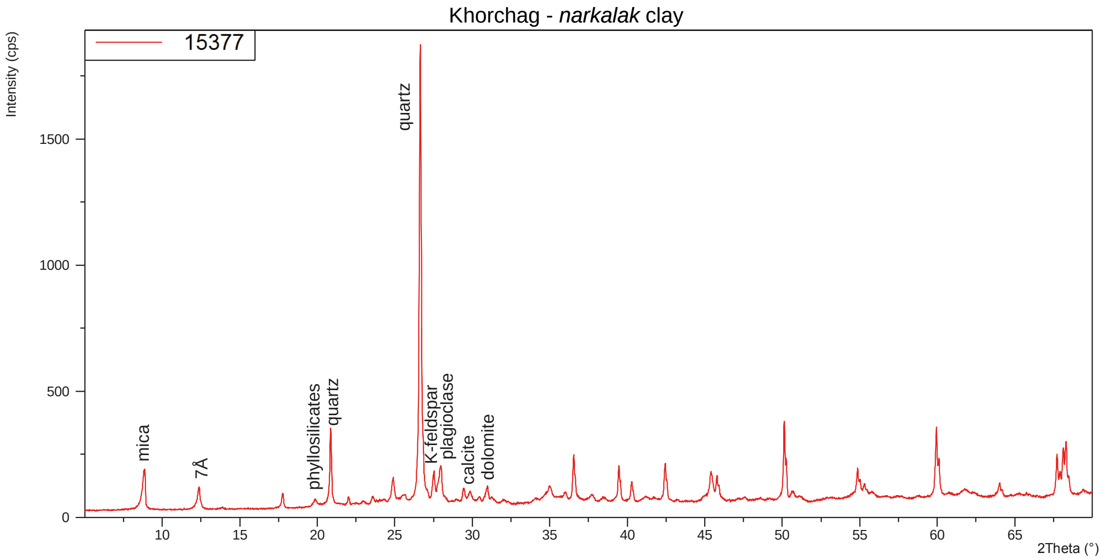
BMA 12.4 Lamayuru. Sample 15404. Clay pit for adobe bricks. Bulk mineral analysis.



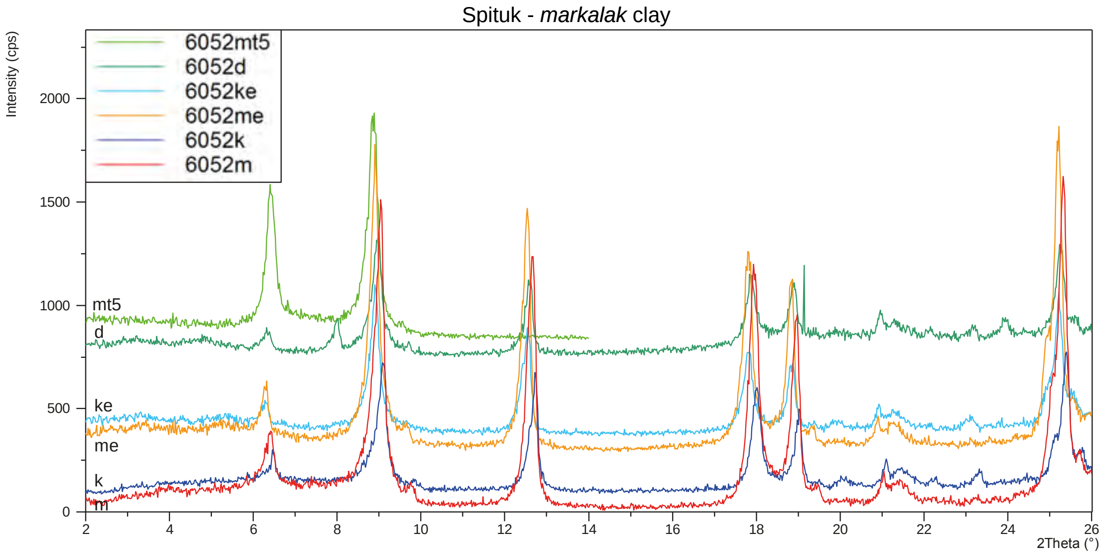
BMA 13.4 Nako. Sample 15516. *Tua* clay. Bulk mineral analysis.



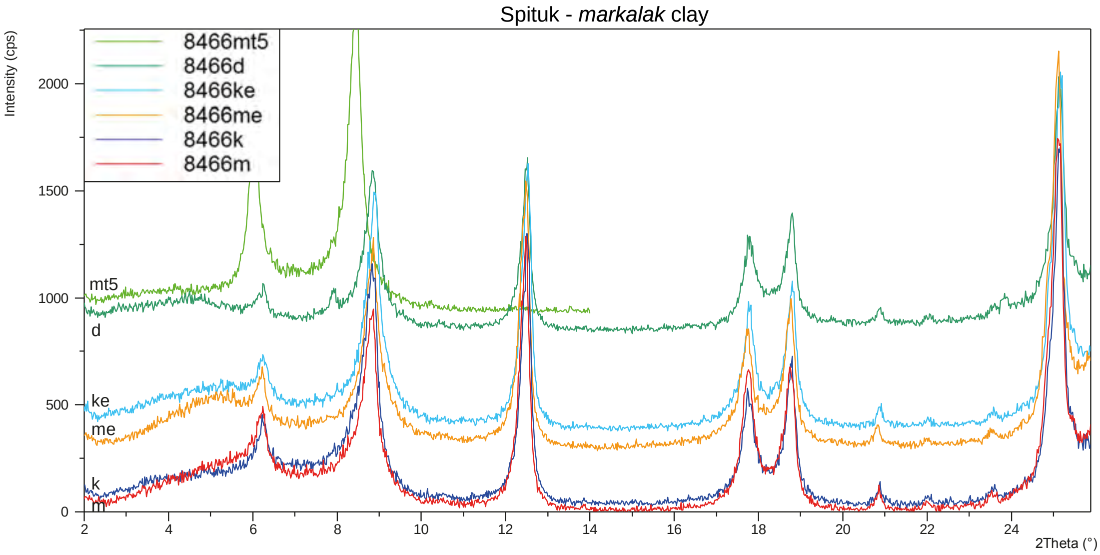
BMA 14.4 Shelkhar. Sample 8504. *Tua* clay. Bulk mineral analysis.



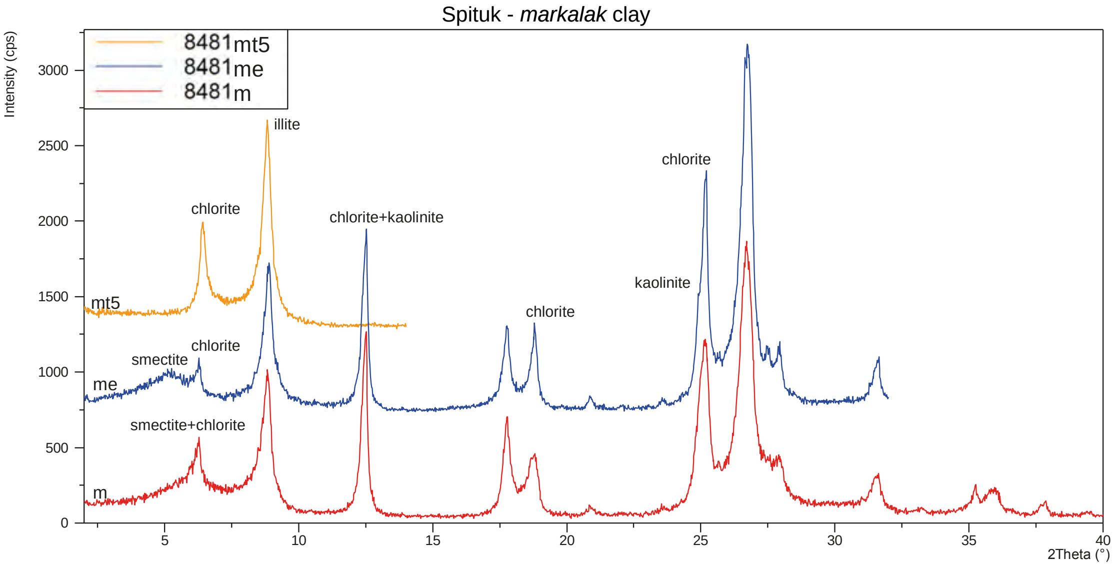
BMA 15.4 Khorchag. Sample 15377. *Narkalak* clay. Bulk mineral analysis.



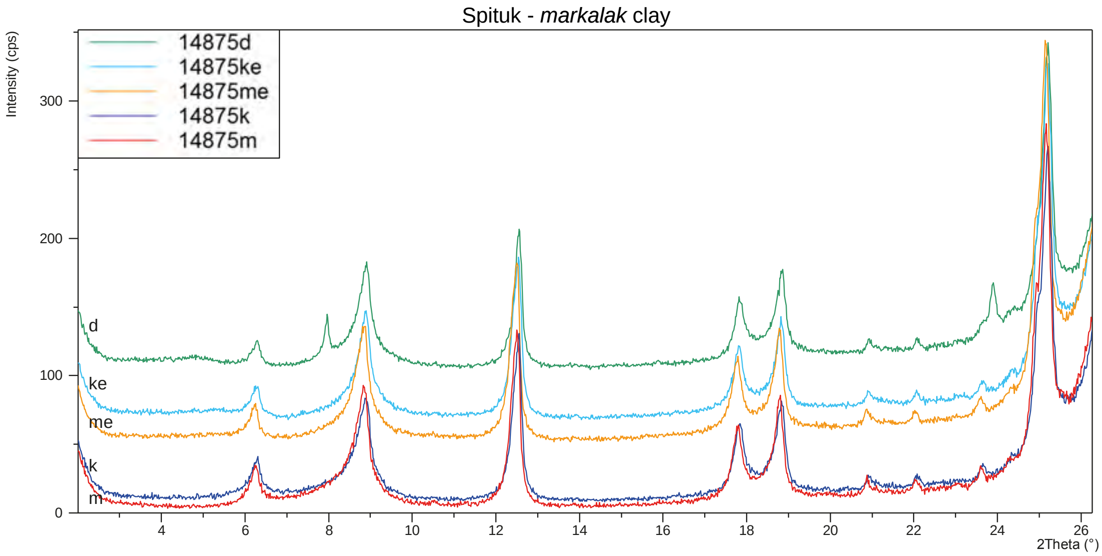
CMA 1.4 Spituk. Sample 6052. *Markalak* clay. Clay mineral analysis.



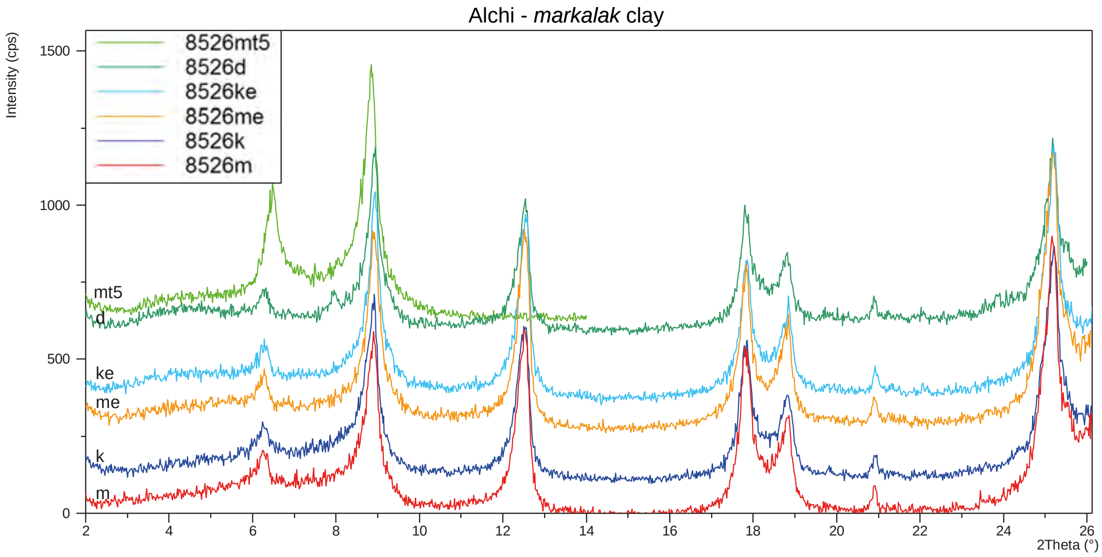
CMA 2.4 Spituk. Sample 8466. *Markalak* clay. Clay mineral analysis.



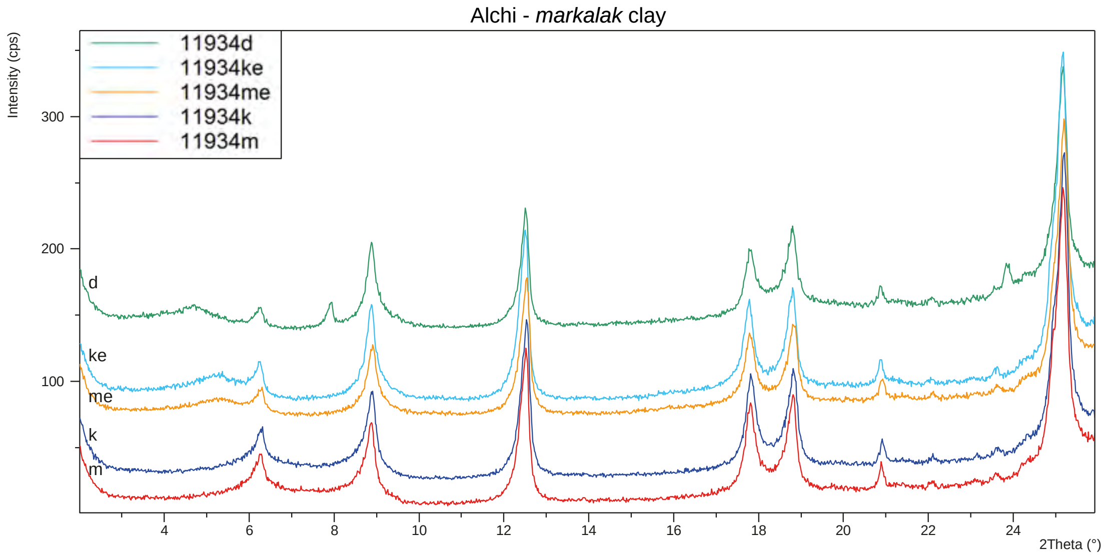
CMA 3.4 Spituk. Sample 8481. *Markalak* clay. Clay mineral analysis.



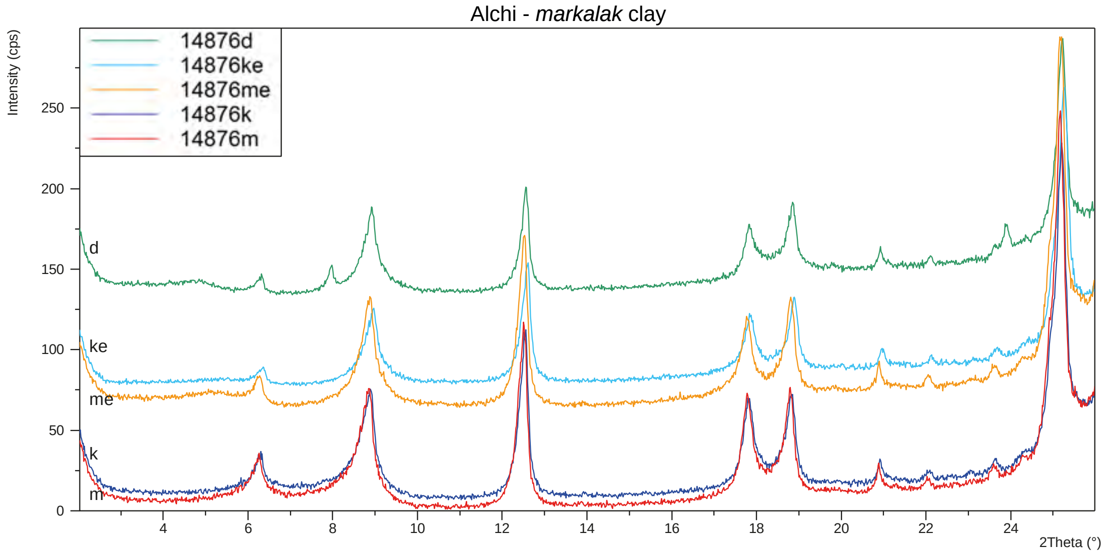
CMA 4.4 Spituk. Sample 14875. *Markalak* clay. Clay mineral analysis.



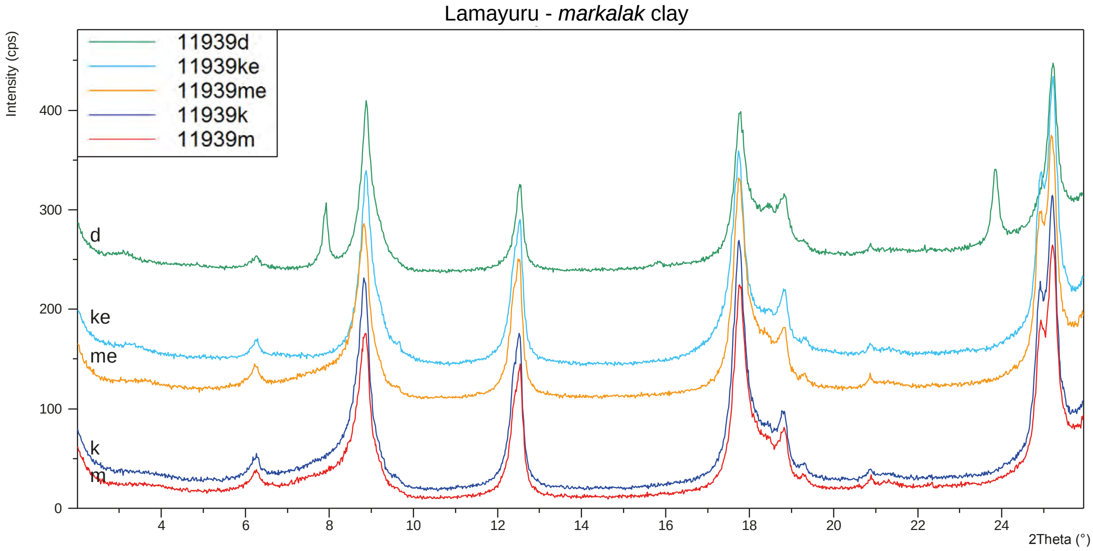
CMA 5.4 Spituk. Sample 8526. *Markalak* clay. Clay mineral analysis.



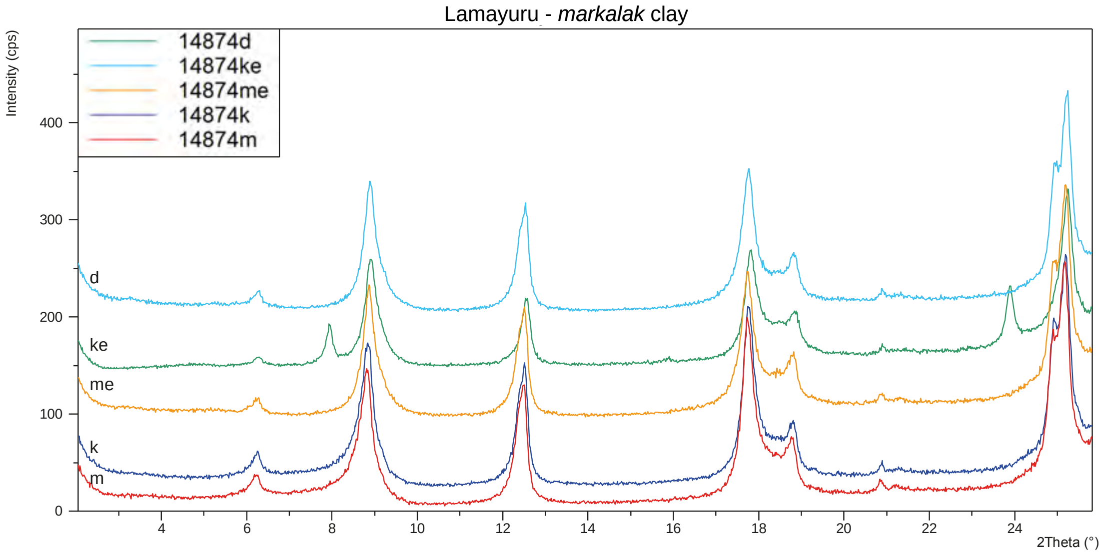
CMA 6.4 Alchi. Sample 11934. *Markalak* clay. Clay mineral analysis.



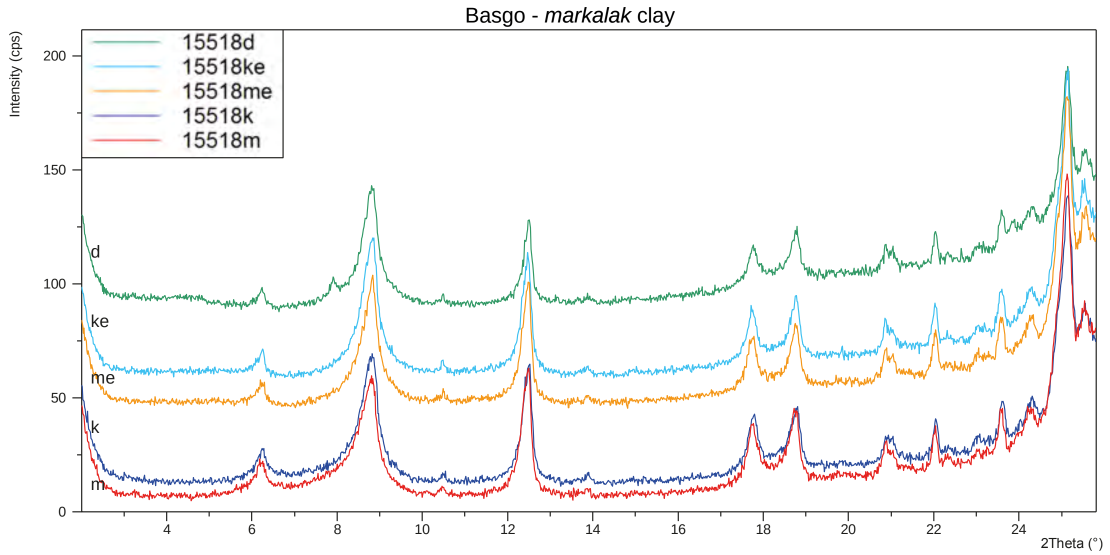
CMA 7.4 Alchi. Sample 14876. *Markalak* clay. Clay mineral analysis.



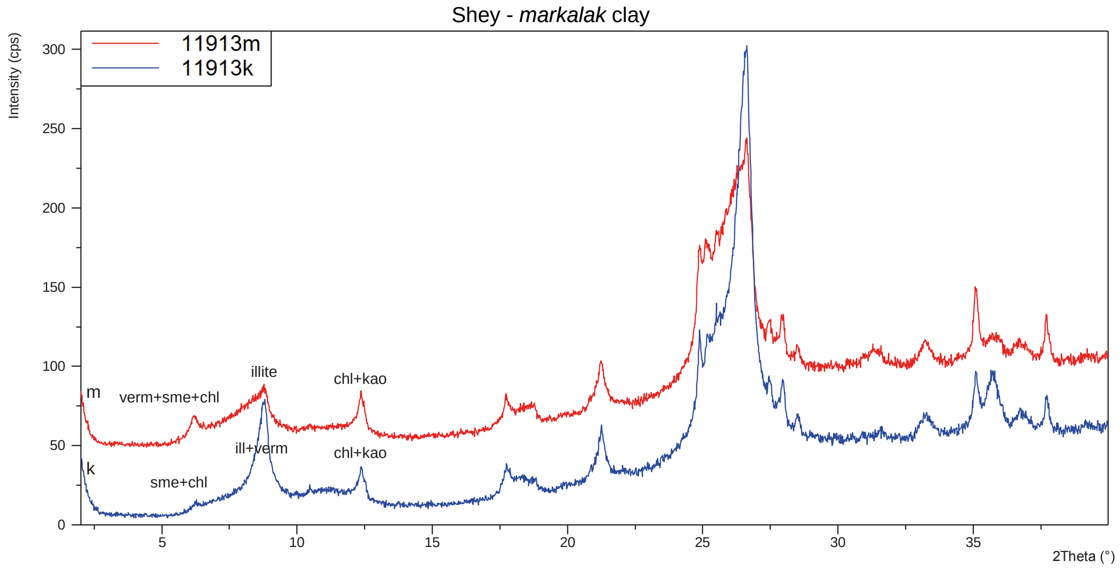
CMA 8.4 Lamayuru. Sample 11939. *Markalak* clay. Clay mineral analysis.



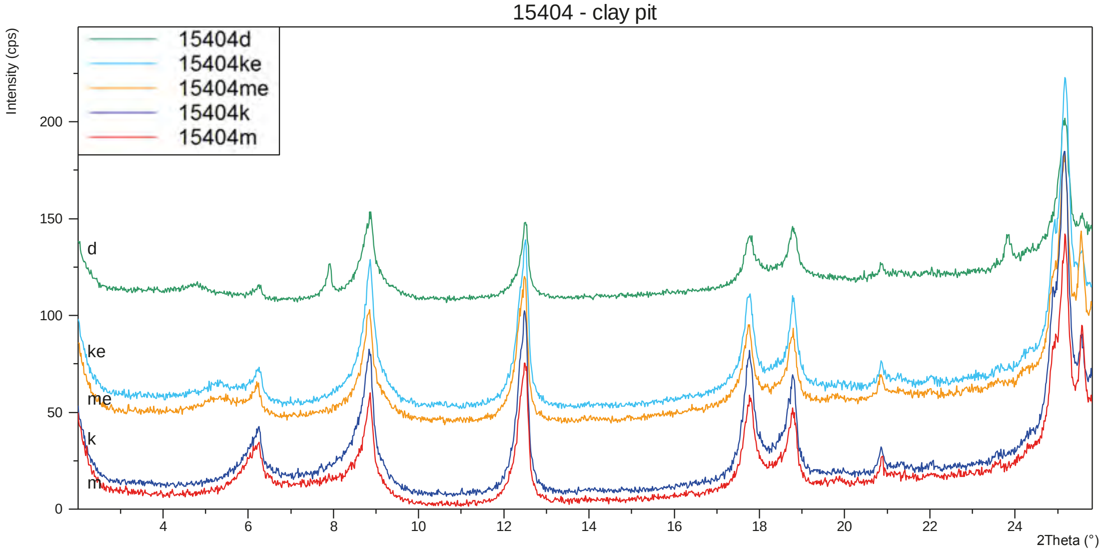
CMA 9.4 Lamayuru. Sample 14874. *Markalak* clay. Clay mineral analysis.



CMA 10.4 Basgo. Sample 15518. *Markalak* clay. Clay mineral analysis.

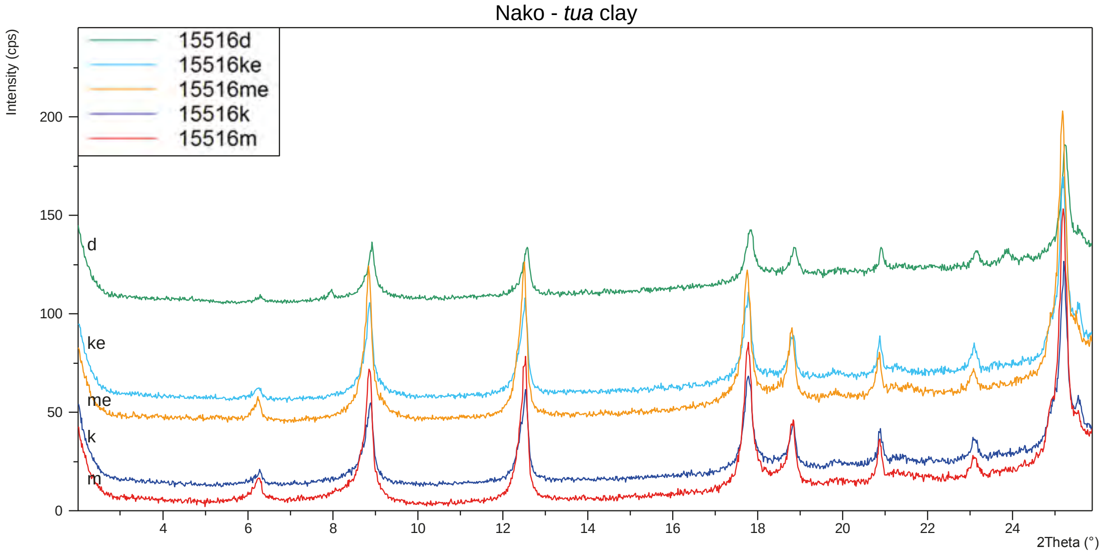


CMA 11.4 Shey. Sample 11913. *Markalak* clay. Clay mineral analysis.



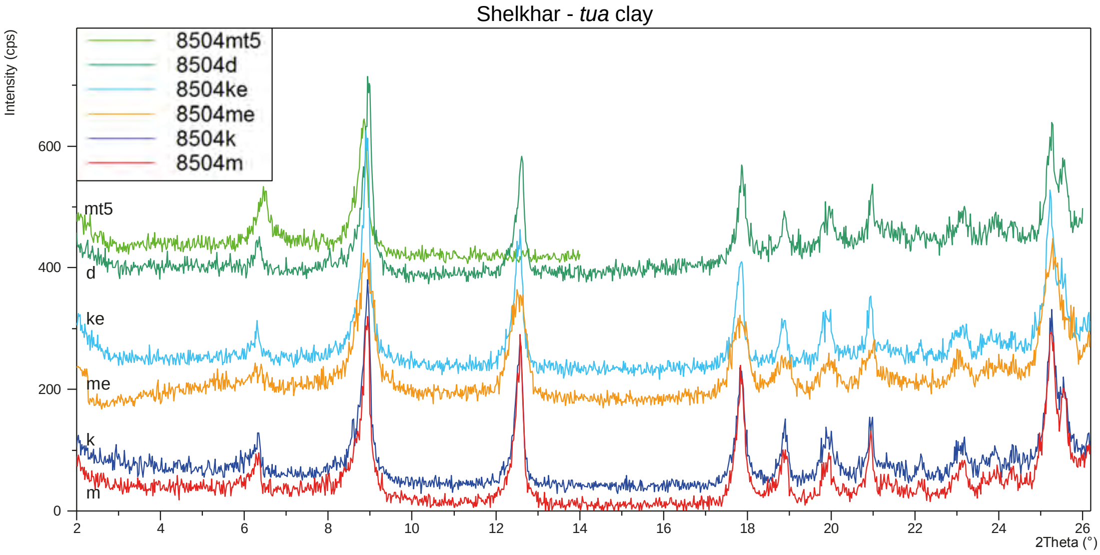
15404 - clay pit

CMA 12.4 Shey. Sample 15404. Clay pit for adobe bricks. Clay mineral analysis.

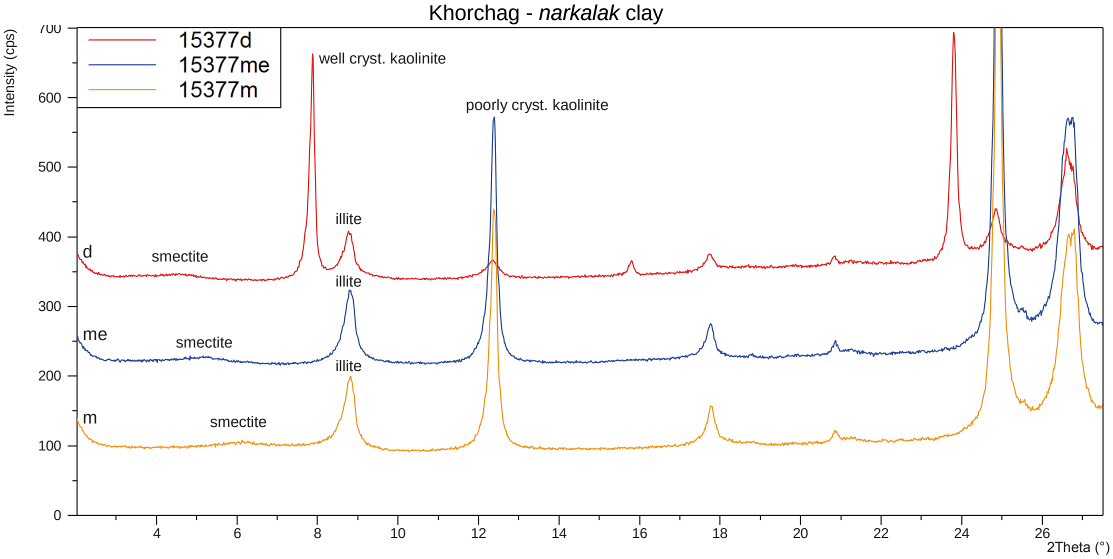


Nako - *tua* clay

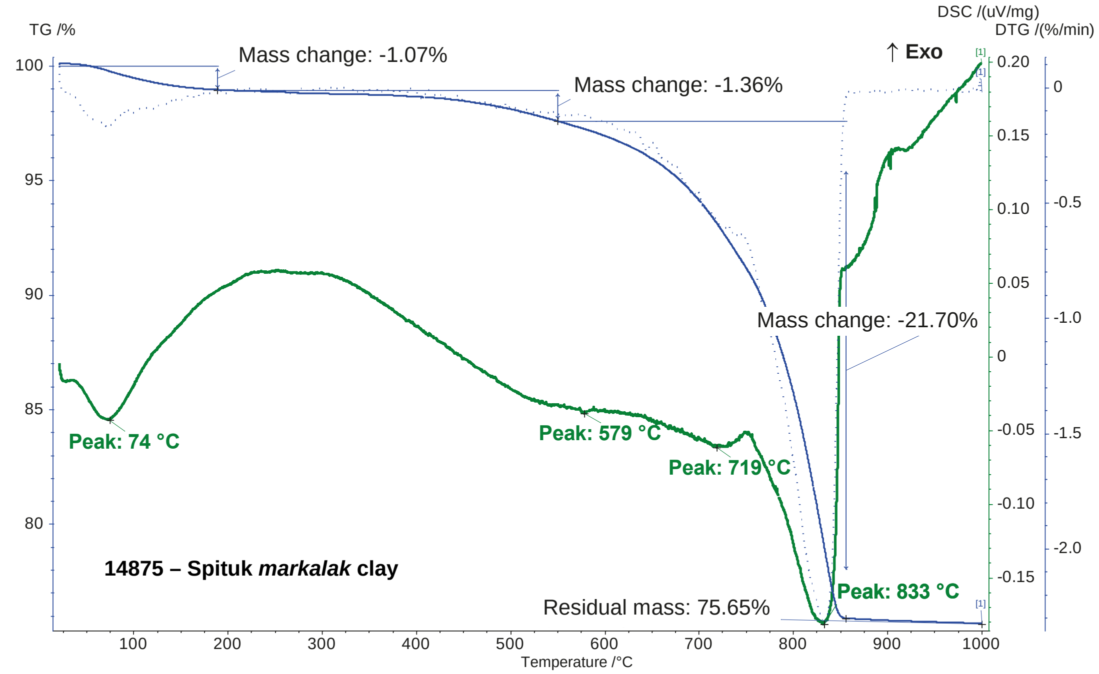
CMA 13.4 Nako. Sample 15516. *Tua* clay. Clay mineral analysis.



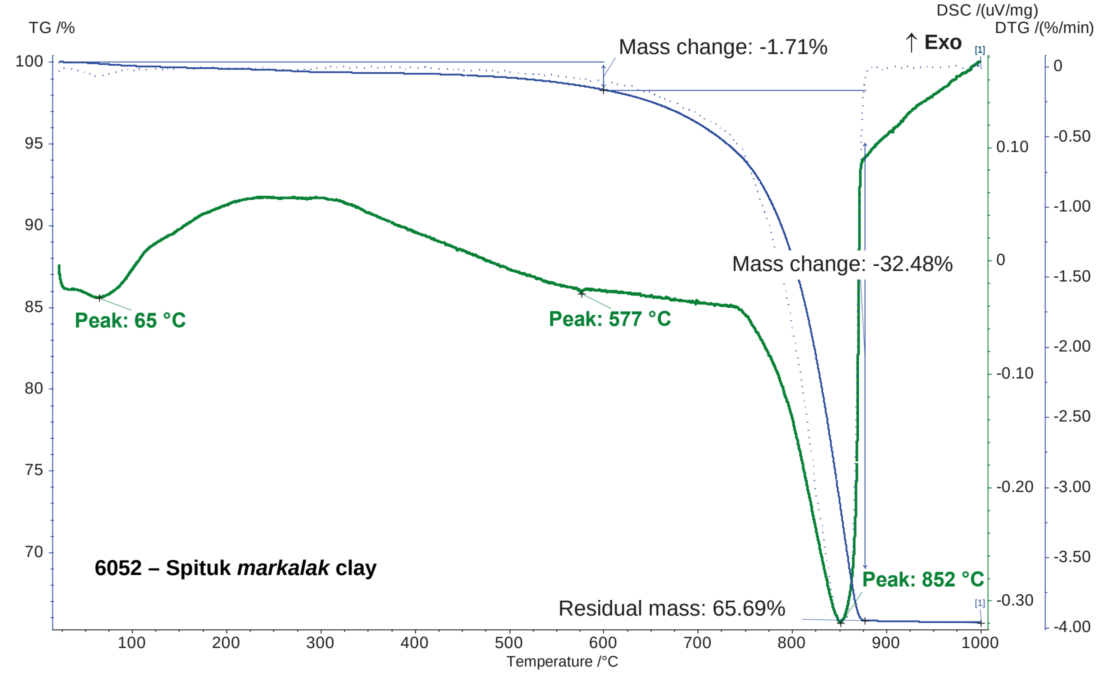
CMA 14.4 Shelkhar. Sample 8504. *Tua* clay. Clay mineral analysis.



CMA 15.4 Khorchag. Sample 15377. *Narkalak* clay. Clay mineral analysis.



STA 1.4 Spituk. Sample 14875. *Markalak* clay. Simultaneous thermal analysis.



STA 2.4 Spituk. Sample 6052. *Markalak* clay. Simultaneous thermal analysis.

# IX. BIBLIOGRAPHY

Alexander, André and Pimpin de Azevedo (1999). *The Old City of Lhasa*, vol. 1, report from a conservation project, Berlin: Tibet Heritage Fund.

Alexander, André (2005). *The Temples of Lhasa*, Chicago: Serindia Publications.

— (2011). *The Traditional Lhasa House. Typology of an Endangered Species*. Series: *Schriften zur inernationalen Stadtentwicklung*, vol. 18, eds. Peter Herrle, Astrid Ley and Sonja Nebel, Zürich, Berlin: LIT Verlag.

Alvares, Claude, *Rehabilitating Indigenous Technologies for Mud Construction*. Online: http://www.undp.org/tcdc/bestprac/social/cases/08-mud%20and%20construction.htm, access: 15.12.2002.

Ariztegui, D., M.M. Bianchi, J. Masaferro, E. Lafargue and F. Niessen (1997). “Interhemispheric synchrony of late-glacial climatic instability as recorded in proglacial Lake Mascardi, Argentina“. *Journal of Quaternary Science* 12, 333–338.

Atkinson, R.H. (1993). “Hardness tests for rock characterization”. *Comprehensive Rock Engineering.* Series: *Rock Testing and Site Characterization*, ed. John A. Hudson, Oxford: Pergamon Press, 105–117.

Basavaiah, Nathani (2011). *Geomagnetism: Solid Earth and Upper Atmosphere Perspectives*, Dordrecht, New York: Springer.

Bassoullet, J.P., M. Colchen, J. Marcoux and G. Mascle (1981). “Les masses calcaires du flysch Triassico-Jurassique de Lamayuru (Zone de la suture de l’Indus, Himalaya du Ladakh): Klippes sédimentaires et éléments de plate-forme remaniés”. *Riv. Ital. Paleont.* 86(4) 1981, Milano, 825–844.

Bayerová, Tatjana (2014). *An Investigation into the Technology of Wall Paintings at the Nako Monastery. North India*, doctoral thesis at the University of Applied Arts, Vienna.

Bender, Willi (1995). *Lexikon der Ziegel*, Berlin: Bauverlag.

Bender, Willi (2004). *Vom Ziegelgott zum Industrieelektroniker. Geschichte der Ziegelherstellung von den Anfängen bis Heute*, Bonn: Bundesverband der Deutschen Ziegelindustrie e.V.

Bertagnin, M., D.D. Antoni, A. Skedzuhn-Safir, M. Oeter and H. Vets (2015). “36 thankas to promote the conservation of the Ladakhi earthen heritage”. *Earthen Architecture: Past, Present and Future*, eds. C. Mileto, F. Vegas, L. García and F. Cristini, London: Taylor & Francis Group, 43–48.

Bielmeier, Roland et al. (Forthcoming), Comparative Dictionary of Tibetan Dialects (CDTD), University of Berne.

Brady, Nyle C. and Ray R. Weil (2000). *Elements of the Nature and Properties of Soils*, New Jersey: Prentice Hall Inc.

https://doi.org/10.1515/9783110591330-011

BRANDON, C.J., R.L. HOHLFELDER, M.D. JACKSON and J.P. OLESON (2014). *Building for Eternity*, ed. J.P. Oleson, Oxford: Oxbow Books.

BROWN G. (1980). “Associated minerals”. *Crystal Structures of Clay Minerals and their X-Ray Identification*, eds. G.W. Brindley and G. Brown, London: Mineral. Society, 361–410.

BURBANK, D.W. (1983). “Multiple episodes of catastrophic flooding in the Peshawar basin during the past 700,000 years“. *Geological Bulletin University Peshawar* 16, 43–49.

BÜRGISSER, H.M., A. GANSSER and J. PIKA (1982). “Late glacial lake sediments of the Indus valley area, northwestern Himalaya”. *Eclogae Geologica Helvet* 75(1), Basel, 51–63.

DAGENS, Bruno, Marc LE BERRE and Daniel SCHLUMBERGER (1964). *Monuments Préislamiques d’Afghanistan, Mémoires de la Délégation Archéologique Française en Afghanistan*, vol. 19, third section observations sur les remparts de Bactria, Paris: Klincksieck.

DAVE, Bharat, Jay THAKKAR and Mansi SHAH (2013). *Prathaa. Kath-khuni Architecture of Himachal Pradesh*, Gujarat: SID Research Cell, School of Interior Design, Faculty of Design, CEPT University.

DEVERS, Quentin (2014). *Les Fortifications du Ladakh, de l’Âge du Bronze à la Perte d’Independence (1683−1684 d.n.è)*, vol. 1, texte, doctoral thesis, École Pratique des Hautes Études, Paris.

DIN 18122-1 (1997). *Zustandsgrenzen (Konsistenzgrenzen)*, Juli 1997.

DIN 18952 (1956). *Baulehm. Begriffe, Arten*, Vornorm, Berlin: Beuth Verlag.

DIN EN ISO 6507-1:2006-03. *Metallische Werkstoffe. Härteprüfung nach Vickers,* Teil 1, Prüfverfahren (ISO 6507-1:2005), Deutsche Fassung.

DUMARÇAY, Jacques (2005). *Construction Techniques in South and Southeast Asia*, Leiden: Brill.

EIDENBENZ, Michael, Patrick FILIPAJ and Sacha MENZ (2010). *Changes – Innovation im Bauprozess*, Zürich: Professur für Architektur und Bauprozess.

Eltgen, U. (2004). “Terrazzo-Fußböden”. *Restauro*, October/November 2004(7), 448–453.

EPPLE, Mathias (2003). *Biomaterialien und Biomineralisation*, Wiesbaden: Teubner Verlag.

FEIGLSTORFER, Hubert (2002, unpublished). *Grundlagenforschung zum Thema Sanierungsmöglichkeiten von buddhistischen Tempeln im Westhimalaya*, Research report, University of Technology in Graz, working paper 50 pages. Online: www.ahdf.at, access: February 2017.

— (2011). *Buddhistische Sakralarchitektur im Westhimalaya. 10tes bis 14tes Jahrhundert. Bebauungsstrukturen, Bautypologien und Proportionssysteme* (*Sacred Buddhist Architecture in the Western Himalayas. 10th to 14th century. Layouts, Typologies and Proportional Systems*), vol. 1, doctoral thesis, Vienna University of Technology.

— (2012). “Research on earthen roof constructions of Buddhist temples in the Western Himalaya”. *Theme 6: Research in Materials and Technology for Conservation.*

*Proceedings of the XI$^{th}$ International Conference on the study and conservation of Earthen and Achitecture Heritage*, Terra 2012, 22–27 April 2012, Lima, ed. Daniel Torrealva Dávila, Sismoadobe 2012, Pontificia Universidad Católica del Perú, CD-Publication, Article 3: 1–10.

— (2014). "Revealing traditions in earthen architecture: analysis of earthen building material and traditional constructions in the Western Himalayas". *Art and Architecture in Ladakh. Cross-Cultural Transmissions in the Himalayas and Karakorum*, eds. Erberto Lo Bue and John Bray, Leiden, Boston: Brill, 364–387.

— (2016). *Making of an Arga Roof*, documentary film on a traditional Tibetan roof made of *arga* stone, 25 minutes, Vienna. Online: www.youtube.com, access: July 2016.

— (2018) "Examining earthen building methods at the Nyarma monastery in Ladakh". Article disponible dans les actes du colloque Terra 2016: Thierry Joffroy, Hubert Guillaud, Chamsia Sadozaï (dir.) 2018, Terra Lyon 2016: Articles sélectionnés pour publication en ligne / articles selected for on-line publication / artículos seleccionados para publicación en línea, Villefontaine: CRAterre. ISBN 979-10-96446-12-4. 2/12.

— (Forthcoming a). *Material Aspects of Building and Craft Traditions. Spatial Program – Building Material – Natural Environment. A Himalayan Case Study.* Habilitationsschrift, Technical University of Vienna.

— (Forthcoming b). "On the Architecture of the Buddhist temple complex of Nyarma". *Early West Tibetan Buddhist Monuments: Architecture, Art, History and Texts*, eds. C. Jahoda and C. Kalantari, Vienna: Austrian Academy of Sciences Press, 33 pages.

Fink, Gerhard, Niklas Holzberg, Rainer Nickel and Bernhard Zimmermann (2007, 1992) *Sammlung Tusculum*, 2$^{nd}$ ed., Düsseldorf: Patmos Verlag GmbH & CoKG.

Fort, M., D.W. Burbank and P. Freytet (1989): "Lacustrine sedimentation in a semiarid alpine setting: An example from Ladakh, northwestern Himalaya". *Quaternary Research* 31, Washington, 332–350.

Fuchs, Gerhard and Manfred Linner (1995). "Geological traverse across the Western Himalaya – a contribution to the geology of Eastern Ladakh, Lahul, and Chamba". *Jahrbuch der Geologischen Bundesanstalt* 138(4), December 1995, Vienna: Geologische Bundesanstalt, 655–685.

Füchtbauer, Hans (1959). "Zur Nomenklatur der Sedimentgesteine". *Erdöl und Kohle* 12 (1959), 605–613.

Gretag Macbeth GesmbH (ed.) (2000): *Munsell soil colour charts*, New York.

Grothmann, Kerstin (2011). *Die 'Arshe'. Arbeitslieder aus dem traditionellen tibetischen Bauhandwerk*, Wiesbaden: Harrassowitz Vlg.

Gruber, Maria (2011). *Gegenwart – Materialität – Kultur – Erhaltung. Lehm-Bau-Tradition in Nako Village, Westhimalaya*, doctoral thesis, Vienna University of Applied Arts.

GSI (2012) = *Geology and Mineral Resources of Jammu and Kashmir State*. Series: *Miscellaneous publication* 30 (part X) third revised edition, Geological Survey of India, Government of India. Online: http://www.indiawaterportal.org/sites/indiawaterportal.org/files/report_himachal_pradesh_state_geology_and_mineral_maps_geological_survey_of_india_0.pdf, access: 05/2016.

Gupta, Om (2006). *Encyclopaedia of India*, Pakistan and Bangladesh, Delhi: Isha Books.

Gyatsho, Thubten Legshay (1979). *Gateway to the Temple, Manual of Tibetan Monastic Customs, Art, Buildings and Celebrations. Traditional Construction Procedures*. Bibliotheca Himalayica, series III, vol. 12, Kathmandu, Nepal: Ratna Pustak Bhandar.

Hangst, K. (1979). *Mineralogische Untersuchungen an altägyptischer Keramik der 18. und 19. Dynastie*, master thesis, University of Cologne.

Harrison, John (1999). *The Restoration of the Wanla Temple*, report of restoration. Online: www.achiassociation.org, access: 2011.

Heibaum, Michael and Wilfried Warnecke (2012). „Versuche zum Abriebverhalten von Gesteinen bei hydraulischen Einwirkungen“. *Geotechnik* 35(2), Berlin: Ernst & Sohn Verlag, 94–108.

Heusinger von Waldegg, Edmund (ed.) (1867). *Die Kalk-, Ziegel-, und Röhrenbrennerei. In ihrem ganzen Umfange und nach den neuesten Erfahrungen*, vol. 2 (Zweiter Theil), Leipzig: Verlag von Theodor Thomas.

Hodges, K.V. (2000). “Tectonics of the Himalaya and southern Tibet from two perspectives”. *GSA Bulletin* 112(3), March 2000, 324–350.

Hofmann, Ulrich (1966). „Attische Vasen und Terra sigillata“. *Heidelberger Jahrbücher*, vol. 10, Berlin, 29–39.

Houben, Hugo and Hubert Guillaud (1984). *Earth Construction*, Project Document of AGDC/UNCHS/PCC-HS-KUL/CRA-UCL/CRATerre, Brussels.

Howard, Neil (1989). “The development of the fortress of Ladakh c. 950 to c. 1650 A.D.”. *East and West* 39, Roma, IsMEO, 217–290.

— (1995). “The fortified places of Zanskar”. *Recent Research on Ladakh 4 & 5. Proceedings of the Fourth and Fifth International Colloquia on Ladakh*, eds. Henry Osmaston & Philip Denwood, Delhi: Motilal Banarsidass Publishers, 79–100.

ISRM (1985) = International Society for Rock Mechanics, Commission on testing methods (1985). “Suggested method for determining point load strength”. *International Journal of Rock Mechanics and Mining Sciences* 22(2), Great Britain, 51–60.

Jaenicke, Friedrich (1980, 1900). *Geschichte der Keramik*, Gütersloh: Prisma.

Juyal, N., R.K. Pant, N. Basavaiah, M.G. Yadava, N.K. Saini and A.K. Singhvi (2004). “Climate and seismicity in the higher Central Himalaya during the last 20–10 ka: Evidence from Garbayang basin, Uttaranchal, India“. *Palaeogeography, Palaeoclimatology, Palaeoecology* 213, 315–330.

JUYAL N., R.K. PANT, N. BASAVAIAH, R. BHUSHAN, M. JAIN, N.K. SAINI, M.G. YADAVA and A.K. SINGHVI (2009). “Reconstruction of last Glacial to early Holocene monsoon variability from relict lake sediments of the Higher Central Himalaya, Uttrakhand, India”. *Journal of Asian Earth Sciences* 34, 437–449.

KATZ, Solomon H. and William Woys WEAVER (eds.) (2003). Encyclopedia of Food and Culture, New York: Scribner Book Company.

KEBER, Franz (1865). *Des Vitruvius Zehn Bücher über Architektur*, übersetzt und durch Anmerkungen und Risse erläutert von Dr. Franz Reber, Stuttgart: Krais & Hoffmann.

KHOSLA, Romi (1979). *Buddhist Monasteries in the Western Himalaya*, Kathmandu: Ratna Pustak Bhandar.

KIENOW, Sigismund (1970). “Keramik”. *Anorganische Chemie*. Series: *Chemische Technologie,* vol. 2, eds. Karl Winnacker and Leopold Küchler, München: Carl Hanser Verlag, 282–342.

KINTER, E.B. and S. DIAMOND (1956). “A new method for preparation and treatment of oriented aggregate specimens of soil clays for X-ray diffraction analysis”. *Soil Science* 81, 111–120.

KIPFER, Barbara Ann (2000). *Encyclopedic Dictionary of Archaeology*, New York: Springer Science and Business.

KLIMBURG-SALTER, Deborah (2003). “The Nako Preservation Project”. *Orientations* 34(5), Hong Kong, 39–45.

KOTLIA Bahadur Singh, Ingelore HINZ-SCHALLREUTER, Roger SCHALLREUTER and Jürgen SCHWARZ (1998). “Evolution of Lamayuru palaeolake in the Trans Himalaya: Palaeoecological implications“. *Eiszeitalter und Gegenwart* 48, 177–191.

KOTLIA, B.S., M.S. BHALLA, C. SHARMA, G. RAJAGOPALAN, R. RAMESH, M.S. CHAUHAN, P.U. MATHUR, S. BHANDARJ and S.T. CHACKO (1997). “Palaeoclimatic conditions in the Upper Pleistocene and Holocene Bhimtal-Naukuchiatal lake basin in south-central Kumaun, north India”. *Palaeogeography, Palaeoclimatology, Palaeoecology* 130, Amsterdam, 307–322.

KRUZIK, Bernhard (2008). *Lehmbau. Prüfung von mineralogisch unterschiedlichen Tonrohstoffen Österreichs auf ihre Eignung als Baulehm*, master thesis, University of Natural Resources and Life Sciences in Vienna.

LARSEN, Knud and Amund SINDING-LARSEN (2001). *The Lhasa Atlas*, London: Serindia Publications.

LEWIS, James and Torrance CRAIG (2003). *Structural Analysis of the Sumtsek at Alchi*, MEng structural engineering with architecture thesis at the University of Edinburgh. Online: http://www.see.ed.ac.uk/~s9901467/Wind%20Loading.html, access: 2003.

LUCZANITS, Christian (2004). *Buddhist Sculptures in Clay. Early Western Himalayan Art, late 10th to early 13th centuries*, Chicago: Serindia Publications.

LUCZANITS, Christian and Holger NEUWIRTH (2009). “The Development of the Alchi Complex”, *Konservierungswissenschaft, Restaurierung und Technologie*, vol. 6, ed. Gabriela Krist, Wien: Die Angewandte, 79–84.

LYNCH, Alban J. and Chester A. ROWLAND (2005). *The History of Grinding*, Society of Mining, Metallurgy and Exploration Inc. (SME), Colorado.

MADANGARLI, Supriya (2002). “Embalming an eroded culture”. *Indian Architect and Builder* 15, August 2002, Mumbai, 42–49.

MALLAYA, N.V (1949). *Studies in Sanskrit Texts on Temple Architecture*, with special reference to Tantrasamuccaya. (Annamalainagar), Südindischer Textauszug aus dem Tantrasamuccaya, original text from c. 1426 CE.

MANI, B.R. (2002). “Emerging trends in archaeology, art, anthropology, conservation and history”. *Structural Conservation of Protected Monuments in Ladakh*, vol. 3, ed. C. Margabandhu, Delhi, 763–766.

MAREL, H.W. van der and H. BEUTELSPACHER (1976). *Atlas of Infrared Spectroscopy of Clay Minerals and their Admixtures*, Amsterdam: Elsevier Scientific Publishing Company.

MAXWELL, T.S. (1980). “Lākhamaṇḍal and Trilokināth: The transformed functions of Hindu architecture in the cross-cultural zones of the Western Himalaya”. *Art International* 24(1–2), September–October 1980, 9–74.

MEYER, Fernand and Corneille JEST (1987). “Milieux, materiaux, et techniques”. *Demeure des Homes, Sanctuaries des Dieux. Sources, Development et Rayonnement de l’Architecture Tibetaine*, ed. G. Beguin, Paris: P. Mortari, 146–165.

MINKE, Gernot (1995, 1994). *Lehmbau-Handbuch*, 2nd ed., Staufen bei Freiburg: ÖkuBuch.

MOHR, Friedrich (1875). *Geschichte der Erde. Ein Lehrbuch der Geologie auf neuer Grundlage*, Bonn: M. Cohen & Sohn.

MOORE, D.M. and R.C. REYNOLDS (1989). *X-Ray Diffraction and the Identification and Analysis of Clay Minerals*, Oxford: Oxford University Press.

MÜLLER, German (1961). “Das Sand-Silt-Ton-Verhältnis in rezenten marinen Sedimenten.” *Neues Jahrbuch der Mineralogie* 7, 148–163.

MÜLLER, Karl (2002, 1905). *Kunststeinbau*, Leipzig: Reprint Verlag.

NOLL, Walter (1984). “Antike Keramik und ihre Dekoration in naturwissenschaftlicher Sicht”. *Ancient Greek and Related Pottery.* Proceedings of the International Vase Symposium in Amsterdam, April 1984, ed. H. A.G. Brijder, 42–53.

— (1991). *Alte Keramiken und ihre Pigmente*, Suttgart: E. Schweizerbart’sche Verlagsbuchhandlung.

OTTNER, Franz (2006). *Endbericht Stierschweiffeldtunnel*, University of Natural Resources and Applied Life Sciences, Vienna, commissioned by STRABAG AG in A-3141 Kapelln, made on 25th of October 2006.

ÖNORM B 4412 (1974). *Korngrößenverteilung*, Wien: Österreichisches Normungsinstitut, 1. Juli 1974.

ÖNORM L 1084 (2006). *Chemische Bodenuntersuchungen, Bestimmung von Karbonat*, Wien: Österreichisches Normungsinstitut.

PANDEY, K. (1975). "A brief history of Lamayuru monastery". *Hindu Art Press*, Godowha.

PHARTIYAL, Binita, Anupam SHARMA, Rajeev UPADHYAY, RAM-AWATAR and Anshu K. SINHA (2005). "Quaternary geology, tectonics and distribution of palaeo- and present fluvio/ glacio lacustrine deposits in Ladakh, NW Indian Himalaya – a study based on field observations". *Geomorphology* 65. Online: www.sciencedirect.com, access January 2017, 241–256.

PRESS, Frank and Raymond SIEVER (1995). *Allgemeine Geologie*, Heidelberg: Spketrum Akademischer Verlag.

RAGETTE, Friedrich (1974). *Architecture in Lebanon. The Lebanese House during the 18th and 19th Centuries*, Beirut: American University of Beirut.

RAMAMURTHY, T. (ed.) (2010). *Engineering in Rocks for Slopes, Foundations and Tunnels*, 2nd ed., Sonepat, Haryana: Asoke K. Gosh.

RIDGE, J.C. (2017). *The North American Glacial Varve Project.* Online: http://eos.tufts.edu/varves.http://eos.tufts.edu/varves/Geology/varves.asp, access: 12.1.2017.

RIEDMÜLLER, G. (1978). "Neoformations and transformations of clay minerals in tectonic shear zones". *TMPM Tschermaks Mineralogische und Petrographische Mitteilungen* 25, 219–242.

RÖSCH, Friedrich et al. (2010). "Der Rohstoff Ton". *TonArt. Virtuosität Antiker Töpfertechnik*, eds. Martin Bentz, Wilfred Geominy and Jan Marius Müller, Petersburg: Michael Immhof Verlag GmbH & Co. KG, 8–9.

RUPP Erwin and Friedrich GÜNTHER (1993). *Die Geschichte der Ziegelherstellung*, 3rd ed., Bonn, Bundesverband der Deutschen Ziegelindustrie.

SAMSONOV, G.V. (ed.) (1968). "Mechanical Properties of the Elements". *Handbook of the Physicochemical Properties of the Elements*, New York: Springer.

SANAN, Deepak (1998). *Exploring Kinnaur & Spiti in the Trans-Himalaya*. New Delhi: Indus Publishing Company.

SANGODE, S.J. and R.K. MAZARI (2007). "Mineral magnetic response to climate variability in the high altitude Kioto palaeolake, Spiti valley, Northwestern Himalaya". *Himalayan Geology* 28(2), 1–9.

SATISH, Chandra (2003). *History of Architecture and Ancient Building Materials in India*, New Delhi: Tech Books International.

SATPREM, Maïni (2004). *Nako Preservation Project, Training and Evaluation Mission*, 20th to 30th May 2004, Report June 2004, Auroville: Earth Institute Auroville.

Sax, Franz (1814). „Von den Baumaterialien“. Series: *Bau-Technologie und Bau-Oekonomie*, erster Band, Wien: Verlag Anton Doll.

Schmitts, Christoph (ed.) (1826). *Kunst- und Gerwerbeblatt*, Polytechnischer Verein für das Königreich Baiern, 12ter Jahrgang, 4ter Band, München.

Schönberg, Kurt (2011). *Historische Beschichtungstechniken*, 3rd ed., Berlin: Beuth Verlag.

Schönberg, Kurt (2012). *Techniken der Wandmalerei am Bauwerk*, Zürich: Beuth Verlag.

Schultz, Leonard (1964). “Quantitative interpretation of mineralogical composition from X-ray and chemical data for the Pierre Shale”. *Geological Survey Professional Paper* 391(C), Washington: U.S. Goevernment Printing Office, 1–31.

Schumann, Walter (2007). *Steine- und Mineralienführer*, München. BLV Buchverlag.

Shah, S.K., M.L. Sharma, J.T. Gergan and C.S. Tara (1976). “Stratigraphy and structure of the western part of the Indus suture belt, Ladakh, North West Himalaya”. *Himalayan Geology* 6, Dehra Dun, 534–556.

Shalu Association, *Conservation project of Drathang Monastery.* Online: http://www.asianart.com/shalu/drathang/index.html, access: 17.12.2002.

Shukla, Lalit Kumar (1972). *A Study of Hindu Art and Architecture*. Series: *The Chowkhamba Sanskrit Studies*, Varanasi: Chowkhamba Sanskrit Series Office.

Singh, Sandeep and Arvind K. Jain (2007). “Liquefaction and fluidization of lacustrine deposits from Lahaul-Spiti and Ladakh Himalaya: Geological evidences of paleoseismicity along active fault zone“. *Sedimentary Geology* 196. Online: www.sciencedirect.com, access: January 2017, 47–57.

Sorkhabi, Rasoul (2010). “Geological Formation of the Himalaya“. *Himalayan Journal* 66, ed. Harish Kapadia, pp. 87–102. Online: www.himalayanclub.org, access: January 2017.

Stachowiak, Gwidon W. and Andrew W. Batchelor (2013). *Engineering Tribology*, 4th ed., Oxford: Elsevier, eBook ISBN: 9780123977762.

Taylor, E.W. (1949). “Correlation of the Mohs’ scale of hardness with the Vickers hardness numbers“. *Mineralogical Magazine* 28, 718-721.

Tertsch, Hermann (1949). *Die Festigkeitserscheinungen der Kristalle*, Wien: Springer.

Thorez, J. (1975). *Phyllosilicates and Clay Minerals. A Laboratory Handbook for their X-Ray Diffraction Analysis*, Dison (Belgium): G. Lelotte.

Tributh, H. (1970). “Die Bedeutung der erweiterten Tonfraktionierung für die genauere Kennzeichnung des Mineralbestandes und seiner Eigenschaften”. *Plant Nutrition and Soil Science* 126.

Tschudin, Peter F. (1996). “Werkzeug und Handwerkstechnik in der mittelalterlichen Papierherstellung”. *Europäische Technik im Mittelalter. 800 bis 1400. Tradition und Innovation,* 4th ed., ed. Lindgren Uta, Berlin: Gebrüder Mann Verlag, 423–428.

TUCKER, Maurice E. (1985). *Einführung in die Sedimentpetrologie*, Stuttgart: Ferdinand Enke Vlg.

VALDIYA, K.S., R.S. RANA, P.K. SHARMA and P. DEY (1992). "Active frontal fault. Main boundary thrust and Ramgarh thrust in southern Kumaun". *Journal of the Geological Society of India* 40(6), Bangalore, 509–528.

VITRUVIUS, Markus: *de Architectura, Book VII, chapter 4, paragraph 5*, translation and Latin version. Online: http://penelope.uchicago.edu/Thayer/E/Roman/Texts/Vitruvius/7*.html, access: 8.9.2015.

VKI (2003) = Verband der Keramischen Industrie. *Brevier, Technische Keramik*, chapter 4.2.2.4 Polierte Oberflächen, ed. Verband der Keramischen Industrie e.V. Informationszentrum Technische Keramik (IZTK). Online: http://www.keramverband.de/brevier_dt/4/2/2/4_2_2_4.htm, access: 10.9.2015.

VOTH, B. (1978). *Boden, Baugrund und Baustoff*, Wiesbaden, Berlin: Bauverlag GmbH.

WIEBEKING, Carl Friedrich von (1826). *Theoretisch-practische bürgerliche Baukunde: durch Geschichte und Beschreibung der merkwürdigsten Baudenkmahle und ihre genauen Abbildungen bereichert*, Band 4, München: Lindauer.

WHITTIG, L.D. (1965). "X-ray diffraction techniques for mineral identification and mineralogical composition". *Methods of Soil Analysis*, part 1, ed. C.A. Black, Wisconsin: American Society of Agronomy.

WILSON, M.J. (ed.) (1987). *A Handbook of Determinative Methods in Clay Mineralogy*. Glasgow, London: Glasgow Blackie & Sons Ltd.

WIMMER-FREY, I. and B. SCHWAIGHOFER (2002). "Österreichische Ziegelrohstoffe". *Berichte der Deutschen Tonmmineralgruppe e.V.*, Band 9, Beiträge zur Jahrestagung, Wien, 18th to 20th Sept. 2002, eds. Franz Ottner and Susanne Gier, Wien, 257–268.

WINCHELL, H. (1945). "The Knoop microhardness tester as a mineralogical tool". *American Mineralogist* 30, 583-595.

WINKLER, E.M. (1975). *Stone. Properties, Durability in Man's Environment*, Wien: Springer.

WINKLER, H.G.F. (1954). "Bedeutung der Korngrößenverteilung und des Mineralbestandes von Tonen für die Herstellung grobkeramischer Erzeugnisse". *Bericht der Deutschen Keramischen Gesellschaft*, vol. 31, Bonn, 337–343.

Wriessnig, Karin (2013). *Tonminerale und Huminsäuren in Paläoböden auf Löss*, doctoral thesis, University of Natural Resources and Life Sciences in Vienna.

## GEOLOGICAL MAPS

FUCHS, Gerhard (1981). *Geologic-Tectonical Map of the Himalaya*, 1:2 Mio, Vienna: Geologische Bundesanstalt.

— (1985). "Geological map of Ladakh". *Jahrbuch der Geologischen Bundesanstalt* 128(4), Plate 1, 1:500,000, map dated with 1984, Vienna: Geologische Bundesanstalt.

— (1987). "Geological map of SE-Zanskar". *Jahrbuch der Geologischen Bundesanstalt* 130, Beilage 2, Plate 1, 1:100,000, map dated with 1986, Vienna: Geologische Bundesanstalt.

GANSSER, Augusto (1964a). *Geological Map of the Himalayas*, Plate A, 1:2 Mio, London, New York: Inter Science Publication.

— (1964b). *Tectonic Map of the Himalayas and Surrounding Areas*, Plate B, 1:10 Mio, London, New York: Inter Science Publication.

IGS, BGMRX (1989) = Institute of Geological Sciences and Bureau of Geology and Mineral Resources of Xizang (Tibet) Autonomous Region. *Map of Xizang (Tibet),* 1:800,000, China Geological Map Printing House.

SHANKER, Ravi, G. KUMAR and P. SAXENA (1989). *Geological Map of the Himalaya. Western Sector*, Sheet No. 1, 1:1 Mio, New Delhi: Geological Survey of India.

## CORRESPONDENCE AND INTERVIEWS

ANGCHUK, Sonam (2011). Personal communication in Leh in autumn 2011. At the time of research he was engineer at Basgo in Ladakh.

ANGMO, Deldan (2002 and 2011). Personal communication in Leh in autumn 2002 and autumn 2011. At the time of research she was Senior Conservation Architect at INTACH.

BODH, Rajkumar (2002). Personal communication in Sangnam in July 2002. At the time of research he was teacher in Sangnam in Pin Valley.

CERING, Sonam (2002). Personal communication in Tabo in July 2002. At the time of research he was tourist guide in Spiti.

CHANDAR, Haresh (2002). Personal communication in Dhankar in July 2002. At the time of research he was carpenter working at the new monastery in Dhankar.

CHATURVEDI, Anuradha (2002). Personal communication in Delhi in spring 2002. At the time of research she was teacher in the field of Conservation at the School of Architecture and Planning in Delhi and a researcher on Western Himalayan architecture.

CHAUDHURY, Sujoy (2002). Personal communication in Delhi in spring 2002. At the time of research he was researcher at Development Alternatives in Delhi, a branch of TARA. He was working on the development of alternative building materials and searching for stabilisers of clay within the conservation project in Nako.

Dawa, Sonam (2002). Personal communication in Leh in autumn 2002. At the time of research he was director of LEDeG in Leh.

Dechen Lundup (2014). Telephone communication with Dechen Lundup from Tabo in Spiti in September 2014.

Dhar, Sanjay (2002). Personal communication in Basgo in spring 2002. At the time of interview he was working as conservator of wall paintings in Basgo.

Dorje, Ringzen (2002). Personal communication in Leh in spring 2002. At the time of research he was construction manager at LEDeG in Leh.

Drongshar, Tsering (2015). Interview in Vienna in September 2015. He is researcher at IKGA/ÖAW.

Gyalpo, Tsering (2015). Personal communication in Vienna in spring 2015. He was researcher in West Tibet and was the former director of TASS in Lhasa. He passed away in 2015.

Holler, David (2014). Personal communication in Lhasa in June 2014. He is a researcher in the field of Tibetan Culture.

Hurd, John (2008). Personal communication in Bamako in Mali in winter 2008. At the time of interview he was the head of ISCEAH / ICOMOS.

Kalantari, Christiane (2011). Personal communication in Vienna in December 2011 and ongoing communication.

Kelsang, Jampa (2014). Personal communication in Lhasa during his work on the roof of the Gyüme Dratsang in Lhasa in June 2014. At the time of research he worked as *zhépön*.

Khosla, Romi (2002). Personal communication in Delhi in spring 2002. He is an architect in Delhi, specialised in the field of architectural research in the Western Himalayas and working on the conservation of the temples of Nako.

Lama Ishay Jamyang (2011). Personal communication in Saspol in August 2011. At the time of interview he was 79 years old. As a monk he was associated with the monastery of Timosgang. The years from 1946 till 1959 he spent in Central Tibet where he collected the knowledge about working with *arga*.

Lama Konchok Tarchin (2011). Personal communication in Lamayuru in August 2011. At the time of research he was Lama at the Lamayuru Monastery.

Lama Lobsang Lawang (2002). Personal communication in Mangyu in autumn 2002. At the time of interview he was the responsible Lama for the Mangyu Monastery.

Lama Mingme Dorje (2002). Personal communication in the Chamba Temple in Hunder in the Nubra Valley in autumn 2002.

Lama Palgor (2002). Personal communication in Keylong in Lahaul in August 2002. At the time of research he was Lama at the Kardong Gompa in Lahaul.

Lama Rinchen Dorje (2002). Personal communication in Kungri in Pin Valley in July 2002. At the time of research he was Lama at the Monastery in Kungri in Pin Valley.

Lama Sherap Chansem (2002). Personal communication in Thikse in Ladakh in autumn 2002. At the time of research he was Lama the monsatery of Thikse.

Mani, B.R. (2002). Personal communication in Delhi in winter 2002. At the time of research he was Superintending Archaeologist at the ASI in Delhi.

Morup, Dorjay (2002). Personal communication in Alchi in autumn 2002, in 2006 and 2011. At the time of research he was teacher in Alchi and Leh in Ladakh.

Nawang, Tsering (2011). Personal communication in Mangyu (Ladakh) in August 2011. At the time of research he worked as mason, following the family tradition since his father was a mason and carpenter. He received his knowledge about *arga* by an elder monk from Central Tibet.

Phuntsog, Choe (2002). Personal communication at the Norbulingka Institute close to Dharamsala. His origins are in U-Tsang in Tibet where he was employed as carpenter at Shigatse before leaving to India. At the time of research he was 81 years old. At the Norbulingka Institute he was teaching as master of woodcarving.

Phuntsog, Tsering (2002). Personal communication at Mc Leod Ganj, where he lived at the time of research when he was 75 years old. Before he left Tibet he was working as a master mason in an area close to Lhasa.

Prakash, Sanjay (2002). Personal communication in Delhi in spring 2002. At the time of research he was working as an architect in Delhi and coordinator at TARA Information and Marketing Services Limited. He was concerned with the realisation of solar concepts.

Riahi, Azimeh (2015). E-mail communication on 3.9.2015. She is working as a conservation architect in Iran.

Satprem, Maïni (2006). Personal communication in Auroville in 2006 and ongoing e-mail communication (30.9.2015). He is director of the Earth Institute at Auroville in Tamil Nadu.

Sharma, Janhwij (2002). Personal communication in Delhi in spring 2002. At the time of research he was working in the architectural section of INTACH with a focus on architecture in the Western Himalayas.

Sharma, Tara (2002). Personal communication in Delhi in spring 2002. At the time of research she was working at NIRLAC.

Stauffer, Vincent (2002). Personal communication in Leh in autumn 2002. At the time of research he was working at GERES where he was concerned with the realisation of solar concepts in the Western Himalayas.

Tashi, Nyema (2014). Personal communication in Lhasa in June 2014.

Tashi, Penba (2014). Personal communication in Lhasa in June 2014 and on December 3rd in 2015. He is resident in the village Grib in Lhundup (Phenpo).

Tendop, Giacho (2002). Personal communication in Dhankar in July 2002. At the time of research he was carpenter at the new monastery in Dhankar.

Thakur, Nalini (2002). Personal communication in Delhi in spring 2002. At the time of research she was professor and head of the Department of Architectural Conservation at the School of Planning and Architecture in Delhi.

Thampi, Rajesh (2002). Personal communication in Delhi in spring 2002. At the time of research he was working at Development Alternatives in Delhi.

Tsewang, Norbu (2011). Personal communication in Ne in Ladakh in August 2011. At the time of research he was a stove maker in Ne.

Viswanathan, Rachana (2002). Personal communication in Delhi in winter 2002. Interview in the office of Romi Khosla where she was employed at the time of research. She was working on the conservation project in Nako.

Wangchuk (2005). Personal communication in Leh on November 7th in 2005. At the time of research he was working at the Archaeological Survey of India, Jammu and Kaschmir Circle in Leh.

Wangchuk, Sonam and and his wife Rebecca Norman. Personal communication in Ladakh in August 2011. They guided the author in Ladakh and translated during interviews. They run the SECMOL Campus at Phey in Ladakh.

Wangyal, Tsering (2002). Personal communication in Leh in autumn 2002. At the time of research he was project manager in Leh with a focus on conservation of historic structures.

## PRESENTED PAPERS AND POSTERS MENTIONED IN THE TEXT

*2008. Bamako, Mali.* Poster presentation. *Archaeological Buddhist sites in the Indian Himalaya: A study on the methods of construction*, 10th TERRA Conference, Bamako, Mali, 1–5 Feb. 2008.

*2016. Lyon, France.* Paper presentation. *Examining Earthen Building Methods at the Nyarma Monastery in Ladakh*, 12th TERRA Conference in Lyon, France, 11–14 July 2016.

# X. LIST OF ILLUSTRATIONS

Unless otherwise stated, the copyright is with the author.

The maps are north-oriented. Different sources were used. Several maps are drawn on the basis of satellite images such as Google Earth. Other maps were created with the free and open source geographic information system QGIS Development Team, 2016 (QGIS Geographic Information System. Open Source Geospatial Foundation Project. http://www.qgis.org/). For that purpose GIS data based maps were created by Jakob Gredler and graphically finalised by the author. Details were provided by the author. For the maps data were downloaded and adapted. The following data were used. The particular sources are mentioned with abbreviations in the caption of each map.

- VD = Vector data (rivers, lakes, mountain peaks, borders, etc.): made with Natural Earth. Free vector and raster map data @ naturalearthdata.com.
- BM = Basemaps: made with maps.stamen.com. Map tiles by Stamen Design, under CC by 3.0. Data by OpenStreetMap, under ODbL.

## CHAPTER I

*Maps*

Map 1.1. Generalised topographic map of the Himalaya and Tibetan Plateau. NP = Nanga Parbat. NB = Namche Barwa. Map after Hodges (2000: Fig.1). GIS data based map: Jakob Gredler. Map adjusted and final graphics: author. GIS data based on data from VD and BM.

Map 2.1 (Below, double page). Geological map of the Himalaya. Map after Sorkhabi (2010). For a complete depiction of the direction of faulting (normal fault and thrusts) see Sorkhabi (2010). GIS data based map: Jakob Gredler. Map adjusted and final graphics: author. GIS data based on data from VD and BM.

*Figure*

Fig. 1.1 (Top). Structural cross section of the Himalaya. Red lines show the thrust faults with various names. Map after Sorkhabi (2010) and adjusted by the author.

## CHAPTER II

*Maps*

Map 1.2 Historical Western Tibet with Nyarma as a centre of Maryül, today located in Ladakh. GIS data based map: Jakob Gredler. Final graphics: author. Map based on data from VD and BM.

Map 2.2 Nyarma settlement. Source: Satellite image with additions by the author; Earth Data Analysis Center, University of Mexico, Albuquerque, Sept. 9, 2006; courtesy

https://doi.org/10.1515/9783110591330-012

*Tables*

*Figures*

| | |
|---|---|
| Fig. 80.2 | (Top, right) REM observation. |
| Fig. 81.2 | (Centre, right) REM observation. |
| Fig. 82.2 | (Bottom, right) REM observation. |
| Fig. 83.2 | to Fig. 88.2 show different REM magnifications of a moistened surface. Observation at BOKU / Vienna. |
| Fig. 83.2 | (Top, left) REM observation. |
| Fig. 84.2 | (Centre, left) REM observation. |
| Fig. 85.2 | (Bottom, left) REM observation. |
| Fig. 86.2 | (Top, right) REM observation. |
| Fig. 87.2 | (Centre, right) REM observation. |
| Fig. 88.2 | (Bottom, right) REM observation. |
| Fig. 89.2 | System sketch of effects of burnishing on the layering of phyllo silicate sheets along the surface of a sample. The depiction of the sheets with the same size is a simplification of different sizes <2 µm. |
| Fig. 90.2 | (Left) Magnetic stirrer. |
| Fig. 91.2 | (Middle) Coarse material left in the bucket, fine material caught in the ceramic bowl. |
| Fig. 92.2 | (Right) Openings of different size and height. |
| Fig. 93.2 | Scheme of the experimental arrangement of desludging. |
| Fig. 94.2 | Nyarma. GSD. Sample 8505. Coarse and fine remains. Desludging after a period of sinking of 60 minutes,1 minute and 0 minutes. |
| Fig. 95.2 | Scheme of the experimental arrangement of desludging, focussing on method using the holes of the container. Finally we receive a coarse and a fine portion of the 1 min (sinking) sample and a coarse and a fine portion of the 0 min (sinking) sample – in total 4 different portions and the original sample for further comparison. |
| Fig. 96.2 | Nyarma. GSD. Sample 8505. Desludging after a sinking period of 1 minute in comparison with the original sample. |
| Fig. 97.2 | Nyarma. GSD. Sample 8505. Desludging after a sinking period of 0 minute in comparison with the original sample. |
| Fig. 98.2 | Nyarma. GSD. Sample 8505. Coarse remains. Desludging after a sinking period of 1 minute and 0 minutes, in comparison with the original sample. |
| Fig. 99.2 | Nyarma. GSD. Sample 8505. Fine remains. Desludging after a sinking period of 60 minutes and 1 minute, in comparison with the original sample. |
| Fig. 100.2 | (Bottom). Nyarma. BMA. Sample 8505. Fine and coarse remains juxtaposed. |
| Fig. 101.2 | (Top) Nyarma. BMA. Sample 8505. Fine and coarse remains juxtaposed in detail. |
| Fig. 102.2 | Nyarma. GSD. Sample 8505. Fine remains. Desludging after a sinking period of 1 minute and 0 minute compared with original plaster samples 11745 and 6073. |

## Chapter III

*Maps*

| | |
|---|---|
| Map 1.3 | Western and Central Himalayas. Sites related to *arga*. GIS data based map: Jakob Gredler. Final graphics: author. Map based on data from VD and BM. |

| | |
|---|---|
| Map 2.3 | Lhasa. Location of the Jokhang and the Gyüme Dratsang. Source: Google Earth. © 2015 Image Digital Globe. |

*Tables*

| | |
|---|---|
| Table 1.3 | Earth roof layering. Recommendation for various types of clay, dimensions and mix ratio for Nako given by Maïni Satprem 2004. |
| Table 2.3 | List of the samples. |
| Table 3.3 | Bulk mineral analysis. |
| Table 4.3 | Clay mineral analysis. |

*Plants*

| | |
|---|---|
| Plant 1.3 | Plant used as organic layer for Himalayan flat roof constructions. Local terms known for *wormwood*. |
| Plant 2.3 | Plant used as organic layer for Himalayan flat roof constructions. Local terms known for *chipyang*. |
| Plant 3.3 | Plant used as organic layer for Himalayan flat roof constructions. Local terms known for *horse tale*. |
| Plant 4.3 | Plant used as organic layer for Himalayan flat roof constructions. *Umbo* from Ladakh. |

*Figures*

| | |
|---|---|
| Fig. 1.3 | Labrang. Kinnaur. India. Flat roof constructions. |
| Fig. 2.3 | Lamayuru. Ladakh. India. Wooden subconstruction of a flat roof. |
| Fig. 3.3 | (Left) Monk at Shalu Monastery in Tibet polishing the floor. Photo: Christiane Kalantari, 2010 (FWF P 21806). |
| Fig. 4.3 | (Right) Gyüme Dratsang. Lhasa. Woolen bag made of sheep skin filled with barley for polishing the floor. |
| Fig. 5.3 | Spituk. Ladakh. Assembly hall. *Arga* partially coverd with PVC. |
| Fig. 6.3 | Lamayuru. Ladakh. *Zimchung*. *Arga* after removing the covering PVC floor. |
| Fig. 7.3 | Khorchag. West Tibet. *Arga* floor in the *Jokhang* at the entrance to the assembly hall. |
| Fig. 8.3 | Section of a traditional flat earth roof construction. 1 = *cham* (secondary beam); 2 = *tsherma* (bush) CT; (e.g. willow) branches WT; 3 = *dölma*, CT; organic layer, grass WT; 4 = *thogda*, *silbu* (stones and small pebbles) CT; no stone layer in WT; 5 = *thogdag* (clay) CT; layer of clay WT; 6 = *thigsa* CT; fine clay WT. CT = Central Tibet. WT = Western Himalayas. cf. Feiglstorfer (Forthcoming a). |
| Fig. 9.3 | (Left) Purthi. Chamba. India. Birch bark as organic layer below the clay. |
| Fig. 10.3 | (Right) Purthi. Layer of clay covering the birch bark. |
| Fig. 11.3 | (Left) Lamayuru. Ladakh. *Yakses* is pulled on top of the roof and placed on the wooden subconstruction. |
| Fig. 12.3 | (Right) Lamayuru. Ladakh. *Yakses* is pulled on top of the roof and placed on the wooden subconstruction. |
| Fig. 13.3 | (Left) Lebanon. Metal roller. After to Ragette 1974. |
| Fig. 14.3 | (Right) Iran. Bāgh-e Fin. Metal roller compressed straw-clay as upper surface. |
| Fig. 15.3 | Lhasa. Gyüme Dratsang. *Arga* roof. |

| | |
|---|---|
| Fig. 50.3 | (Left) Mangyu. Mountain slope behind the monastery showing the path towards the *arga* deposit in front left. |
| Fig. 51.3 | (Right) Mangyu. A*rga* deposit. |
| Fig. 52.3 | Mangyu. Sample 11953. |
| Fig. 53.3 | (Left) Phugtal. Zangskar. The arrow showing the yellowish shining *arga* deposits. |
| Fig. 54.3 | (Right) Pugtal. *Arga* deposit. |
| Fig. 55.3 | Phugtal. Sample 8473. Sample colour (after Munsell): 10YR8/6 yellow. |
| Fig. 56.3 | Sample 15370. BMA. Comparison of different periods of grinding. |
| Fig. 57.3 | Tool for the compression of samples. |
| Fig. 58.3 | (Top, left) Sample 15370. Specimen I. *Arga* powder compressed. |
| Fig. 59.3 | (Top, right) Sample 11947. Specimen II. Plaster from Nyarma (see Chapter I) unburnished, for comparison. |
| Fig. 60.3 | (Centre) Sample 11947. Specimen II. Plaster from Nyarma (see Chapter I) burnished, for comparison. |
| Fig. 61.3 | (Bottom, left) Sample. Burnished. |
| Fig. 62.3 | (Bottom, right) Sample. Unburnished. |
| Fig. 63.3 | (Left) Sample 15370. Rammed. Specimen II. Bright unburnished part in front. |
| Fig. 64.3 | (Right) Sample 15370. Rammed. Specimen II. Shiny dark burnished parts. |
| Fig. 65.3 | Phases of the process of the compaction of the *arga* roof. Measurements in centimetre. A = Wooden subconstruction; B = Ashlars; C = Layer of stones; D = Layer of clay; E = *Arga*.<br>Phase 1: Beginning of the compression.<br>Phase 2: Addition of water and compression. Soft clay is pressed upwards. *Arga* is crushed and pressed into the clay below.<br>Phase 3: Further addition of water and compression. Upper most *arga* pieces are crushed at most. *Arga* and clay are mixed up. The finest crushed *arga* pieces are mixed with the clay-*arga* paste in the most upper area. Spaces between are filled up with fine material until no spaces remain and the water is pressed up onto the surface, which is the time when the compression is finished. |
| Fig. 66.3 | Lhasa. Jokhang. *Arga* parapet. |
| Fig. 67.3 | (Top) Lhasa. Jokhang. Not completely finished burnishing. Surface remains coarse and rough. |
| Fig. 68.3 | (Bottom) Lhasa. Jokhang. Surface smoother than at the sample shown in Fig. 68.2. |

## Chapter IV

*Maps*

| | |
|---|---|
| Map 1.4 | Origin of the samples. GIS data based map: Jakob Gredler. Final graphics: author. Map based on data from VD and BM. |

*Tables*

| | |
|---|---|
| Table 1.4 | List of the samples. |
| Table 2.4 | Grain size classes. |

| | |
|---|---|
| Table 3.4 | Bulk mineral analysis. |
| Table 4.4 | Clay mineral analysis. |

*Figures*

| | |
|---|---|
| Fig. 1.4 | (Top) Spituk. Ladakh. The clay is collected in big bags. |
| Fig. 2.4 | (Bottom) Spituk. Remains of a lacustrine palaeolake in front. The Spituk Monastery is visible in the background. |
| Fig. 3.4 | Spituk. The level marks show the incline of the cross-country tread from the riverbed of the Indus on top of the remains of the lacustrine basin. Source: Google Earth. Image © 2015 CNES / Astrium. Image Landsat. Image © 2015 Digital Globe. |
| Fig. 4.4 | Spituk. Sample 6052. Sample colour (after Munsell): Dry 2.5Y6/2 light brownish grey. Semi-dry 2.5 Y 6/3 light yellow grey. |
| Fig. 5.4 | Shapes of grains in sample 6052. Same scale (see upper left corner of the left picture). Shape of fraction >2,000 µm (Left), 630–2,000 µm (Centre), 200–630 µm (Right). |
| Fig. 6.4 | Spituk. Sample 8466. Sample colour (after Munsell): Dry 10YR 7/1 light grey. Semi-dry 10YR 5/2 greyish brown. |
| Fig. 7.4 | Spituk. Sample 8481. Sample colour (after Munsell): Dry 10YR 6/1 grey. Semi-dry 10YR 4/2–5/2 dark greyish brown to greyish brown. |
| Fig. 8.4 | Spituk. Sample 14875. Sample colour (after Munsell): Dry 10YR 8/1–10YR 7/1 partially white – light grey – yellowish. Semi-dry 10YR 6/2 light brownish grey. |
| Fig. 9.4 | (Left) Sample 8466 from Spituk. Sample for shrinkage test. |
| Fig. 10.4 | (Top) Sample 8466 from Spituk. Fine surface after the shrinkage test showing just one hair crack. |
| Fig. 11.4 | Sample 8466 from Spituk. Atterberg limits. |
| Fig. 12.4 | Sample 8466 from Spituk. Specimen used for the hardness test according to Vickers. |
| Fig. 13.4 | Alchi. Sample 8526. Sample colour (after Munsell): Dry 2.5YR 7/2 light grey. Semi-dry 2.5YR 6/3 light yellowish brown. |
| Fig. 14.4 | Alchi. Sample 11934. Sample colour (after Munsell): Dry 10YR 8/2 very pale brown. Semi-dry 10YR 5/3 brown. |
| Fig. 15.4 | Alchi. Sample 14876. Sample colour (after Munsell): Dry 7.5YR 6/3 light brown. Semi-dry 7.5YR 5/3 brown. |
| Fig. 16.4 | Lamayuru. Ladakh. The level marks show the incline of the cross-country tread from the riverbed to the remains of the lacustrine basin. Source: Google Earth. Image © 2015 Digital Globe. Image NASA. |
| Fig. 17.4 | (Top) Lamayuru. Area of clay pits. |
| Fig. 18.4 | (Below) Lamayuru. Striped *markalak* clay. |
| Fig. 19.4 | Lamayuru.Sample 11939. Sample colour (after Munsell): Dry 10YR 7/1 light grey. Semi-dry 10YR 6/2 light brownish grey. |
| Fig. 20.4 | Lamayuru. Sample 14874. Sample colour (after Munsell): Dry 10YR 7/2 light grey. Semi-dry 10YR 5/3 brown. |
| Fig. 21.4 | Basgo. The level marks show the incline of the cross-country tread from the riverbed of the Indus to the remains of the lacustrine basin. Source: Google Earth. Image © 2015 CNES / Astrium. |

## APPENDIX CHAPTER II

*Figure*

*Vickers needle tests*

*Grain size distribution analysis*

*Bulk mineral analysis*

*Clay mineral analysis*

*Simultaneous thermo analysis*

## APPENDIX CHAPTER III

*Vickers needle tests*

## APPENDIX CHAPTER IV

*Clay mineral analysis*

*Simultaneous thermo analysis*