AN ANALYTICAL STUDY OF EARTH AND LIME BASED BUILDING MATERIALS

in the Blumenau Region Southern Brazil

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ABSTRACT

An Analytical Study of Earth and Lime Based Building Materials in the Blumenau Region, Southern Brazil

In the last fifteen years, there has been a growing state and national interest in the preservation of historic rural settlements of the nineteenth and twenty centuries in southern Brazil. This interest has generated a need to develop appropriate conservation methods which will safeguard the integrity and technology of vernacular buildings in Brazil.

This study focuses on the Blumenau region, an area in the state of Santa Catarina which was settled by German and Italian immigrants in the late 19th century. As was typical in such settlements, the immigrants brought with them European methods of construction which were then adapted to the local environment and available local materials. Though somewhat deteriorated, Blumenau still retains a large number of vernacular building types and good documentary sources of information. Thus, it provided an ideal context in which to develop a methodological approach to the study and conservation of regional building materials in Santa Catarina.

Twenty domestic buildings dating from approximately 1870 to 1930 and representing the four principal types of construction in the area were chosen for the pilot project. In addition to thorough historical and archival research on the architecture and technology of the region, the study includes an in-depth scientific analysis of earth and lime- based buildings materials utilised in the rural settlement. The analytical results are interpreted in light of the historical research and recommendations are made regarding appropriate conservation and repair techniques. The study concludes with general recommendations for improved conservation practice in the region including issues of material production, training, and management.

The work includes an extensive bibliography relating to the characterisation and conservation of earth and lime- based building materials. Full details of analytical techniques utilised are given in the appendix.

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3 RESULTS AND RECOMMENDATIONS

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LIST OF ILLUSTRATIONS

1 INTRODUCTION

1.1 BACKGROUND

This thesis is intended to be a contribution to the development of a scientific approach to the field of practical building conservation in Brazil. The main aim is to develop a set of management recommendations for the scientific conservation of a group of historic buildings in south Brazil and other similar structures; these recommendations are based upon a detailed case study of materials which are critical for the repair of selected traditional buildings in Santa Catarina. The research is informed by thorough study of the history and technology of traditional building materials in this region, the characterisation of the composition of materials through laboratory tests and a review of current best practice of building conservation.

In more detail, this research is an attempt to increase understanding of two main groups of materials made primarily of earth and lime which play a vital role in the character as well as in the maintenance of the original wall systems of these historic buildings. Earth and lime as basic components of materials for buildings were extensively utilised in the past, but the progressive disappearance of these materials and the development of more durable masonry elements and cement mortars which are incompatible with the original construction materials and methods leads to practical difficulties. Although there is a revival in the use of earth and lime materials in some places, traditional practical expertise with these materials in Santa Catarina has been lost and there is an urgent need to consider how these may be reintroduced to enhance correct practice in the conservation of historic buildings.

This research has appeared increasingly timely and important as the continuing lack of advice on the use of compatible materials has had serious consequences for the character and condition of historic buildings and monuments in Brazil, increasing the rate of decay and altering or even destroying the historic fabric. Considerable damage has been done to the historic fabric by the use of unsuitable materials for the repair or rebuilding of earth and lime construction, which are deteriorated but often sound. The replacement of wall coverings and paint or the pointing of joints, for example, by harder and less sympathetic materials has altered significantly the character of many historic buildings and in addition, new and exacerbated problems of deterioration have appeared. Yet, despite the great advances in the subject in many European countries, North America and isolated case studies in Brazil, limited practical information can be found to date in Brazil which deals with the characterisation of historical materials and the definition of parameters for conservation treatments. As a consequence, there is a serious gap between the practical conservation technology and practice which has been developed and recommended and that which is actually practised on conservation sites in Brazil. There is an urgent need for a change in attitudes. It is of paramount importance to study the original materials and construction methods, otherwise there is little hope for understanding old buildings and preventing their decay.

The author's practical experience in conservation has been gained in Santa Catarina State, Brazil. Within that area there are many possible sites for investigating the scope of these problems. In this State, in addition to the survival of early Portuguese settlements there are a number of houses constructed during the late nineteenth and early twentieth century by immigrants. The latter, in spite of being considered historically important, have not been the subject of frequent interventions and so, fortuitously, have retained their authentic materials about which little is known. The area corresponding to the early Blumenau Colony is an excellent and typical example of vernacular architecture in Brazil, exhibiting characteristic building methods and materials introduced by European immigrants. Although this area was selected for the purpose of the investigation, many other areas would be of equal relevance, have equal needs and are at equal risk.

This study of immigrant buildings in Santa Catarina has evolved from the author's experience as a conservation Architect at the Brazilian Institute for Historic and Artistic Patrimony[1] in that state and from further studies at CRATerre, ICCROM and IoAAS/ York[2]. The immigrants' architecture was discussed in the present author's MA thesis in 1992 on the construction technology of timber-framed buildings and conservation problems in Blumenau, Santa Catarina.[3] The current study is intended to develop knowledge with respect to building methods, materials and equipment in common use today in the field of conservation practice, and to make use of this to provide advice on historic building conservation.

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[1]Founded in 1937 the **IPHAN- Instituto do Patrimonio Historico e Artistico Nacional-** has been enlarging its national action through the establishment of local offices. Santa Catarina is a new office set up in 1982 by the Federal Government. The majority of the conservation work in that State occurs after this period.

[2]Courses attended at:
CRATerre/ Grenoble- International Centre for Earth Construction- The Preservation of Earthen Architecture/ 1990.
ICCROM/ Rome- International Centre for the Study of the Preservation and Restoration of Cultural Property- Architectural Conservation Course/ 1992
IoAAS/ York University- Institute of Advanced Architectural Studies- MA in Conservation Studies/ 1992.

[3]Kanan, M.I.C. (1992), "An Introduction to the Conservation of Traditional Timber Framed Buildings in Brazil: with examples drawn mainly from the former Blumenau Colony", MA dissertation in Conservation Studies, IoAAS, University of York, October 1992.

The first chapter of the thesis is the introduction which sets out the reasons, objectives and scope of the study. This part of the thesis is concerned in identifying the problems and the field of conservation which relates to the study on earth and lime materials.

The second chapter defines the geographical limits and the historical and architectural context of the Blumenau region. It describes the methodology followed and questions asked and used to gain information about the history and technology of materials, the analytical determinations of earth and lime materials and the interpretations of findings as a basis for conservation recommendations. This section includes the literature review that has contributed to the study and details of the analytical work.

The final chapter reviews definitions and the basic components and technology of earth and lime materials to formulate the basis for recommendations. The results from different sources are approached systematically in order to characterise the materials. Technical guidelines are organised based on the characteristics of the materials and supported by conservation principles. In addition, further recommendations are made on implementation of conservation work.

Finally there are appendices where analytical results are considered in more detail.

1.2 PREVIOUS WORK/ CONCEPTUAL PARAMETERS

> The word *preservation* — in the broadest sense, being equivalent in some cultures to *conservation* or restoration — can be considered, from this point of view, as expresssing the modern way of maintaining living contact with cultural works of the past... If the conservation of an object or building requires an intervention or substitution, the intervention should be recognized as a modern, critical action. How to integrate the modern intervention without faking the original object is an essential question of conservation...The first operation in any conservation process is to assess accurately the substance of the object to be safeguarded.[4]

This definition in Paul Phillipot's paper is a valuable starting point for an understanding of contemporary architectural conservation, which may be defined broadly as the action taken to guarantee the survival of historic buildings — critical action to maintain the integrity of the historical fabric.

Conservation embraces legislation to protect the buildings, regular inspections, documentation and town planning as well as actions to prevent decay detailed in treatments or degrees of interventions based on critical assessment of the building. This thesis deals specifically with conservation in the form of repairs and replacements.[5]

The application of modern science and technology to conservation allows conservators to develop detailed analysis and diagnosis of the materials, the structural system, and the condition of the buildings with a view to their conservation. At this level of specialisation, architectural conservation is defined as the science of observing and analysing buildings, determining the cause, effect and solution of building problems, and directing remedial interventions focused on maintaining the historical, aesthetic and physical integrity of the existing historic fabric.

There are many studies dealing with earthen or stone materials that date from the early

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[4]Phillipot, P. (1972), "Historic Preservation: Philisophy, Criteria, Guidelines", in Proceedings of the North American International Regional Conference Preservation and Conservation: Principles and Practices, pp. 367; 369-370.

[5]See the Section 3.1.2 Definitions of Conservation Treatments and the following references:

Erder, C. Jokilheto, J. "Technical Knowledge in the Preservation of Cultural Heritage", ICCROM, pp. 1-3.
Feilden, B. (1994), Conservation of Historic Buildings, pp. 1-22.
Feilden, B. and Jokilheto, J. (1992), "Evaluation for Conservation", Extract from the Draft Guidelines for the Management of World Cultural Heritage Sites.
Fitch, J.M. (1990), Historic Preservation, pp. 39-47; 83- 135.
Philippot, P. op cit, pp. 367-390.
Torraca, G. (1982), "The Scientist's Role in Historic Preservation, with Particular Reference to Stone Conservation", in Conservation of Historic Stone Buildings and Monuments, pp.13-21.

1970's and before. For instance, in 1981 ICCROM devoted its technical symposium to mortars and grouts in old buildings and since that time the interest in traditional building materials such as lime and pozzolanic/ hydraulic mortar and surface materials has increased. Over the last thirty years the study of building and conservation materials for the benefit of the world's historic buildings has developed into a major field of applied science.

Many significant science- based studies of historic building materials and technology have been made in Europe, North America and elsewhere. Scientific research on the characteristics of historic materials is also being developed in Brazil, but the results have not yet been developed into guidelines for architectural conservation.[6]

Although efforts have been made by institutions in Santa Catarina to protect the immigrants' architecture, no systematic system of investigation and diagnosis leading to appropriate conservation action has been developed. In particular no systematic study including analysis of materials has been carried out in Santa Catarina. Specifically this work constitutes a first contribution to the analytical study of the historic materials of Blumenau based on documentary research in order to establish a selection of criteria for designing suitable earth and lime based materials.[7]

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[6]In Salvador, north Brazil the Federal University of Bahia has a group of researchers in charge of the analysis and development of materials for conservation projects. The group formed by Mario Mendonça de Oliveira, Cybele Celestino Santiago and Sylvia Pimenta d'Affonseca has produced studies about lime mortars, the historical use of lime as a stabiliser and organic additives in old mortars. Results are published in the Proceedings of 6th International Conference on the Conservation of Earthen Architecture 1990, Lime and Other Alternative Cements (1992) and 7th International Conference on the Study and Conservation of Earthen Architecture (1993).

[7]Institutions involved in the preservation of European Immigrant's Architecture in Santa Catarina:
IPHAN- the Brazilian Institute of Historic and Artisitic Patrimony
FCC- Santa Catarina Cultural Foundation.
Town Halls from immigrants' settlements occasionally have technical teams working on architectural conservation.

1.3 FOCUS OF THE STUDY

Masonry materials deteriorate naturally, but the rate of deterioration is accelerated by factors such as water access, chemical processes, mechanical stresses and biologic action. Most of the decay problems can be attributed to water from rain, soil and air. However, as each material has its own chemical and physical characteristics, each will have its own deterioration problems and conservation practices.[8]

Traditional buildings in the Blumenau region are of two types — monolithic mass masonry or timber structures — with varying combinations of the following materials:

- Wood: timber frames, boards, doors, windows and tiles
- Ceramic: Brick and tiles
- Earth: adobe, daub, plasters and mortars
- Stone: foundations
- Lime: Pointing mortars, renders, plasters, stuccos and limewashes
- Gypsum: ceiling plasters
- Glass: window glazing
- Metals: roof of zinc sheeting and copper

Although this study looked at the historical development of all the building materials listed above, the focus is on the materials which are primarly composed of clay/ earth or lime. These materials were considered to have priority over brick and timber because of the greater risk of being lost; in addition the survival of the materials is commonly dependent on their existence and they are frequently an invaluable source of information on specification and technique. The extent of the deterioration of these materials, mainly due to lack of maintenance, poor workmanship, unsuitable components or inappropriate conservation is a potential cause of damage allowing free water access to the whole of the masonry and threatening major losses of historic fabric. The conservation of masonry materials made with earth and lime is thus a crucial issue in Santa Catarina which urgently deserves attention; unfortunately the subject has so far been neglected. However, it is believed that given the opportunity, ie, availability of technical information and training,

[8]Comprehensive text related to deterioration and conservation practices of masonry materials is written by Giorgio Torraca. See: Torraca, G. (1972), "Brick, Adobe, Stone and Architectural Ceramics: Deterioration Process and Conservation Practices", in Proceedings of the North American International Regional Conference Preservation and Conservation: Principles and Practices, pp.143-162; and Torraca, G. (1988), Porous Building Materials, pp.109-121.

most architects working with conservation would be eager to utilise the information contained in this study; it is hoped that this will contribute to a more scientific approach to historic prerservation in Santa Catarina and that a model for other settlements and areas may be created.

This study explores the composition of three systems – infill materials; mortar, render and plaster materials; and paint materials for the design of specifications when both minor repairs or replacements should be undertaken to ensure long- term survival of the historic buildings of Blumenau.

1.4 AIM OF THE INVESTIGATION

The appearance, texture and colour of early daubs, mortars and plasters varied greatly, depending on the locality, the types of clay, sand and lime available and mixing and application techniques. Earth and lime materials can be thoroughly investigated to provide a framework of information that must form the basis of remedial work specifications. The hypothesis is that historical research, and documentation and analysis of materials can be used as a tool in the design of guidelines and contracts for building conservation.

Therefore, the general aim of this study is:

To investigate the materials and technology utilised in the architecture of the Blumenau region, Santa Catarina, Brazil, and, on the basis of this research, to develop technical guidelines for appropriate conservation practices, and recommendations for the implementation of such practices. Historical, technological and analytical investigation of earth and lime materials were involved in this study.

2 RESEARCH

2.1 STUDY AREA CONTEXT

Over the last fifteen years there has been a growing national and state interest in the preservation of the historic rural settings of the nineteenth and early twentieth century in southern Brazil. However, this patrimony now needs to be defined on the level of compatible materials and minimum intervention techniques in order to preserve the authenticity and integrity of vernacular architecture in Brazil.

2.1.1 Aspects of the Itajai Valley in Santa Catarina

Santa Catarina is the geographic centre of South Brazil. In this state, as opposed to the States of São Paulo and Parana where there is a straight coastline and then the enormous 'Serra do mar', the plateau area is some distance from the coast and various important rivers start on the border of the high plateau and are drained into the Atlantic Ocean. The Itajai- Açu river is the main river of the Atlantic drainage system.[9] The inland valleys of the Itajai- Açu river (between the plateau and the coast) are formed by mountains (70% of the area/ high average is 400m) and low reliefs of meadows. The latter constitute the alluvial plains where also terraces of clay, sand and silt are found. The weather according to the Kröppen system is mesothermic (average of the coldest month is lower than 18° C and higher than 3° C), with wet hot summers (average of the hottest summer months is 22° C). In addition the annual average relative humidity is 75%. The original forest of the region, the Atlantic Tropical Forest, is directly related to this type of weather, ie, abundant rain and high temperatures. The Atlantic forest in this region is characterised by heterogenous species for use in construction. Both resources of the region, wood and clay deposits, have been extensively used since the nineteenth century; today, the Atlantic Forest in the Itajai valley is reduced to only 30% of the original area and clay resources have also been reduced. (fig.1)

Santa Catarina was occupied by Indians who settled on the coast or in the inland valleys and plateau. In the early seventeenth century, with the expansion of the Portuguese conquest to the south, three settlements appeared along the coast created by Portuguese

[9]In the past there were legends created by Portuguese and Jesuits about the Itajai- Açu river that the region was rich in gold. Van Iede discovered the river and Manoel Gonçalves de Aguiar named 'Taehi' in 1689. Zedar, P.S. (1954), O vale do Itajai: Documentario da Vida Rural no. 6, p. 54.

from the 'capitania' of Sao Vicente and later from the Azores and Madeira. These early settlements along the coast developed into villages and later into the towns of Sao Francisco do Sul (1658) – north; Desterro (1662), later named Florianopolis – centre, in S.Catarina Island; and Laguna (1682) – south.[10] In 1820, the first sawmill and shipyard were established on the coast near the mouth of the Itajai- Açu. Later Itajai village developed as a town and harbour. During the nineteenth century settlements were established inland along the river predominantly by German and Italian immigrants. Colonies appeared such as Blumenau (1850), Brusque (1860) and Rio do Sul (1911). (Fig. 2) At the same time, other European immigrants' settlements were founded in Santa Catarina.

Blumenau was founded as a private colony by Dr Hermann Blumenau.[11] Until 1860 the colony consisted only of the private parcel of land located on the right bank near the mouth of Garcia river. In 1860 the Imperial Government bought the Colony and there was a colonial extension with the foundation of new settlements along the Itajai- Açu river and its tributaries (eg Encano, Warnow and Testo rivers) by German and Italian (1875) immigrants. In 1880 the former Colony had become the town of Blumenau. The early colonial extension also saw the founding of the towns of Indaial, Timbo, Pomerode, Ascurra, Rodeio and Rio dos Cedros. After this period new colonies were founded in the river valley. The enlarged municipal area of Blumenau in 1905 reflects all these colonial occupations. Today, all these immigrant settlements became towns and a separated municipal area. Blumenau reduced in area and became the economic and cultural centre of the Itajai valley. (fig.3)

2.1.2 Potential Area for Research

No previous attempt has been made in Santa Catarina to conduct a systematic study of regional building materials to approach the problem of conservation. The early settlements of the former Colony of Blumenau provide a context for such study. Both the considerable number of historic buildings and sites and the historical information available present a potential research opportunity which is summarised as follows:

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[10] Sao Francisco do Sul, Laguna and the group of the eighteenth century fortresses located in the municipal area of Florianopolis (one is located in S.Catarina Island and three are located on small surroundings islands) are listed as conservation areas by IPHAN.

[11] Hermann Bruno Otto Blumenau was born in 1819 in Hassefelde, ducat of Brunsvique. In 1836 he started as a pharmacy student and in 1846 he was awarded Doctor of Philosophy. In 1848 he went to Brazil and visited the valley of Itajai- Açu and presented a project to the president of the province of Santa Catarina to colonise the region. To realize this project Dr Blumenau bought some land to start a private colony.

1. Most of the rural areas settled by German and Italian immigrants still retain a large number of building types constructed during the nineteenth and early twentieth century. This select group of vernacular architecture exhibits special methods of construction and materials that European pioneers brought to Brazil. Many timber- framed and brick buildings scattered in rural sites provide an attractive and interesting collection of regional architecture. The virtuosity of the crafstmanship reflects each ethnic group who settled and translated the methods of construction and materials to the new environment, using local sources of materials. In addition minimal maintenance and repair and the evident deterioration of the materials based on earth and lime (two common materials nearly always utilised in all similar groups of buildings) mean that urgent technical advice is needed as well as instruction in good conservation practice.

2. Blumenau's municipal records contain old books and several other documents (such as annual lists of buildings including types of the structures and materials. They also include annual lists of brickyards/sawmills, building contracts, reports describing settlements and origin/ profession of immigrants, old letters by immigrants describing houses, colour of walls and preparation of materials, projects with specifications, old postcards and photographs of the buildings showing methods of construction, maps containing the early settlements and drawings of the buildings. All these provide primary sources of information on the historical development of building materials in this specific geographic area.

3. The region of the early settlements of Blumenau also retains the old brickyards, sawmills, equipment and tools to make building materials from local sources. In addition residents of the building sites (some of whom are also craftsmen) still remember traditional practice and traditional construction methods.

Recognizing these resources and the need to provide guidelines for the conservation of immigrant architecture, the research programme was developed to study the traditional materials of Blumenau's architecture. Methods included documentary research, oral accounts and scientific analysis of earth and lime building materials. This study investigated the historical documentation of Blumenau Colony, emphasis was placed on the sites and buildings in the early colonial expansion of Blumenau. Lime kilns were investigated in the region of Itajai- Mirim river where in 1860 the Colony of Brusque was founded. (fig.4,5)

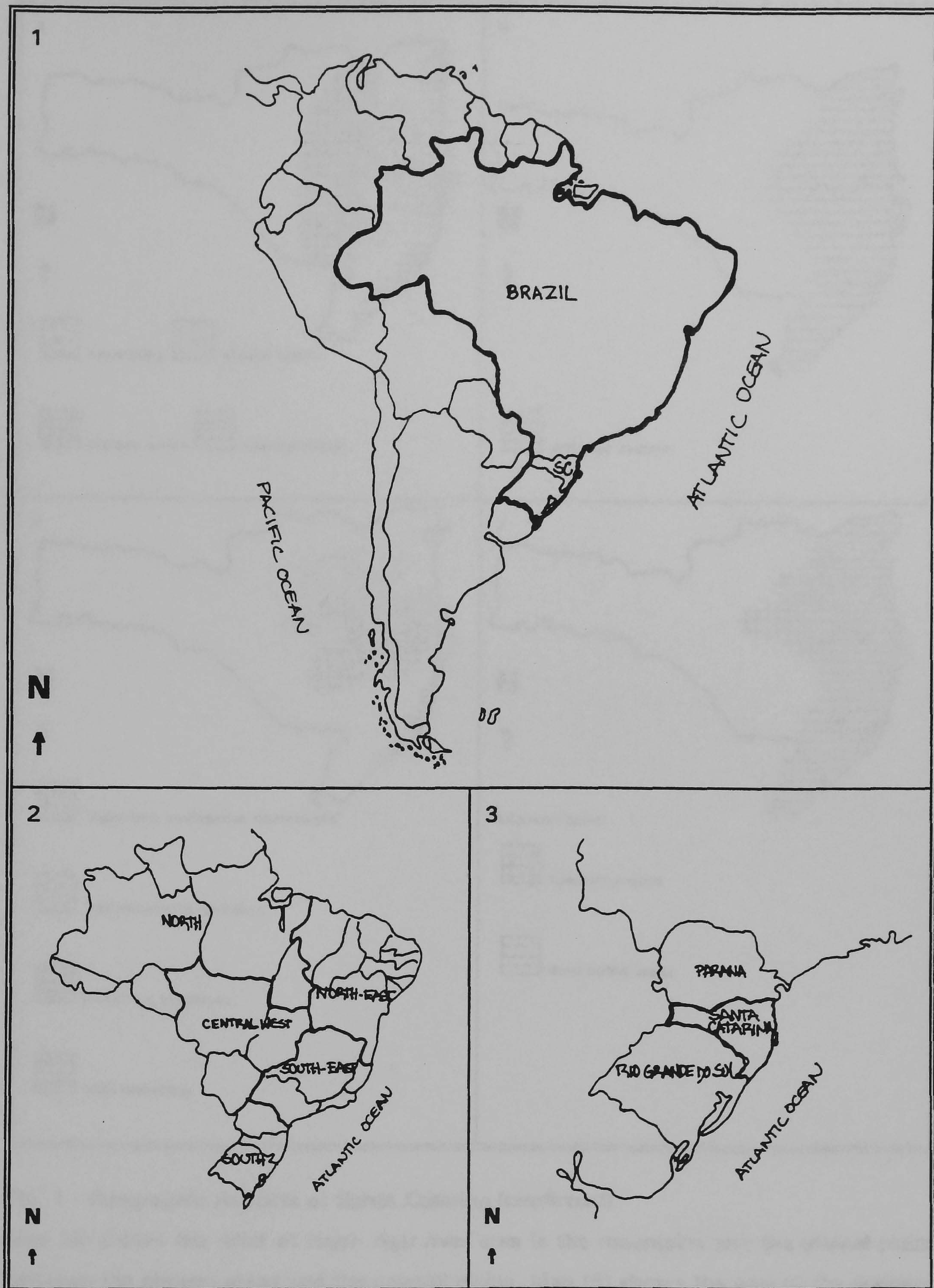


Fig. 1 - Geographic Aspects of Santa Catarina

Map (1) shows the location of Santa Catarina in South America and maps (2),(3) show Santa Catarina between the two other southern states — Parana and Rio Grande do Sul.

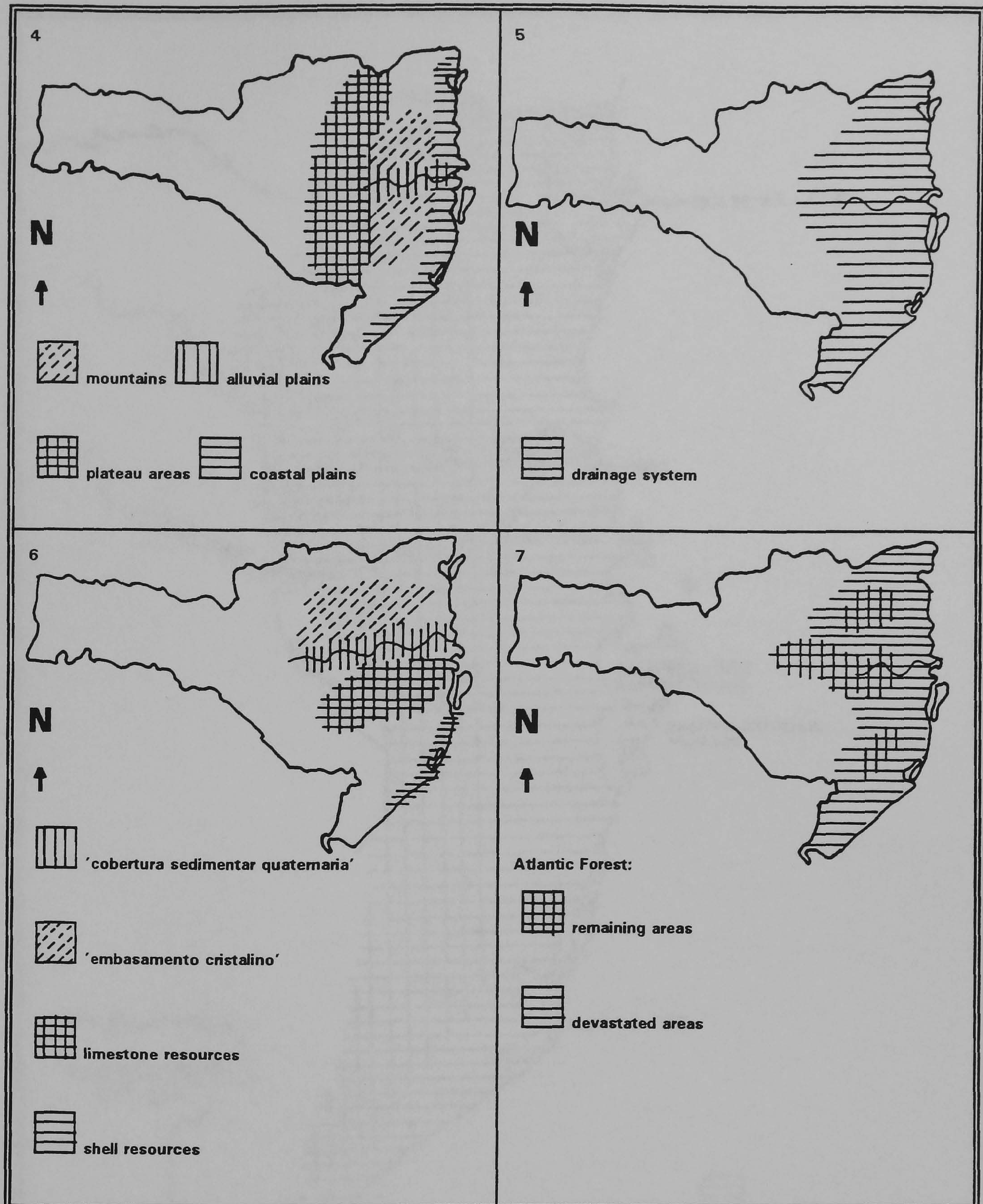


Fig. 1 - Geographic Aspects of Santa Catarina (continued)

Map (4) shows the relief of Itajai- Açu river area ie the mountains and the alluvial plains between the plateau areas and the coastal plains. Map (5) shows the area of the drainage system of the Atlantic. Map (6) shows the geology of the area — along the Itajai- Açu river the ' cobertura sedimentar quaternaria '(deposits of clay, sand and silt); to the north — the 'embasamento cristalino'; to the south — the limestone resources and on the coast the shell resources. Map (7) shows the Atlantic Forest — the original areas and the devastated areas.

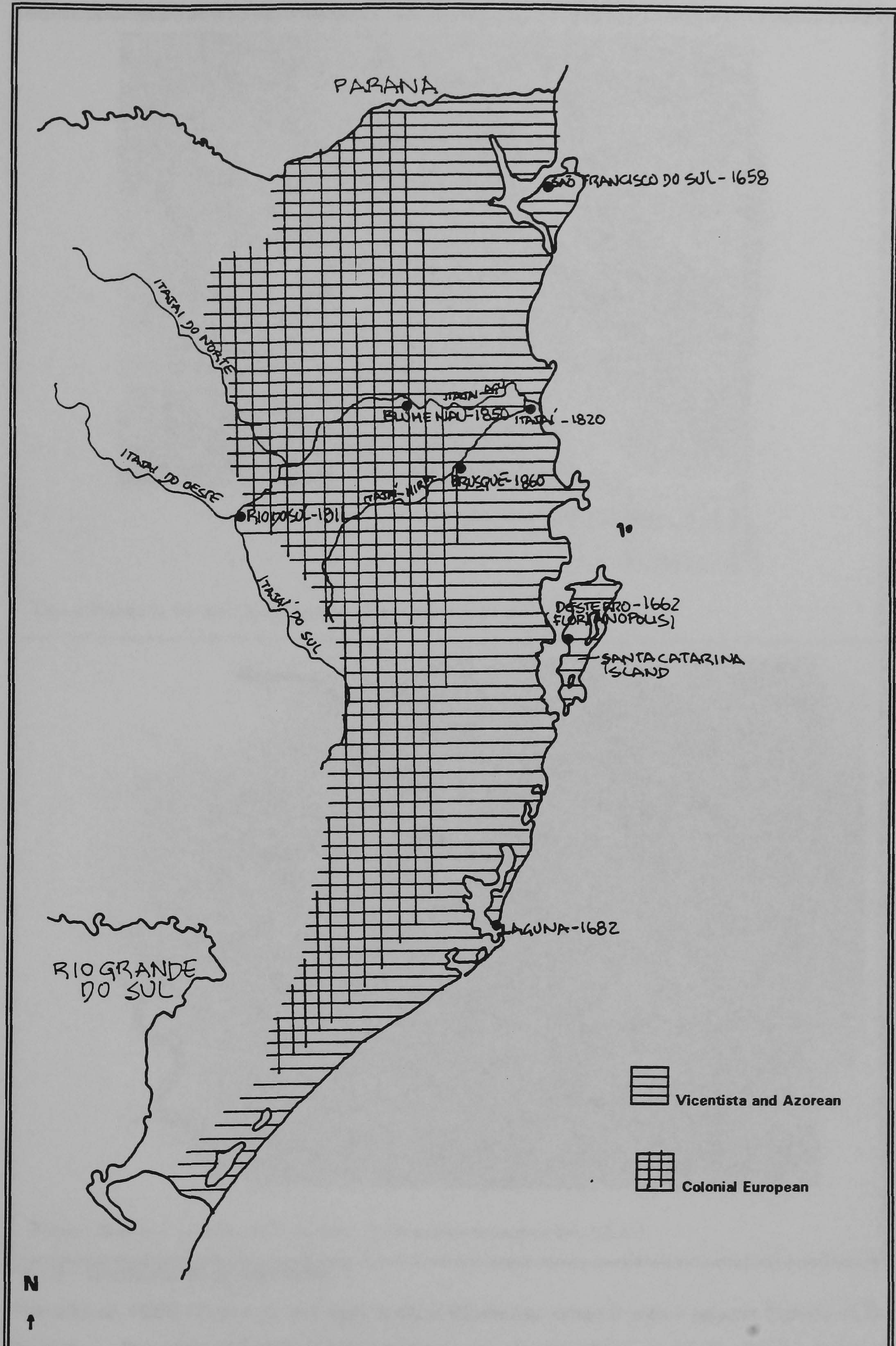
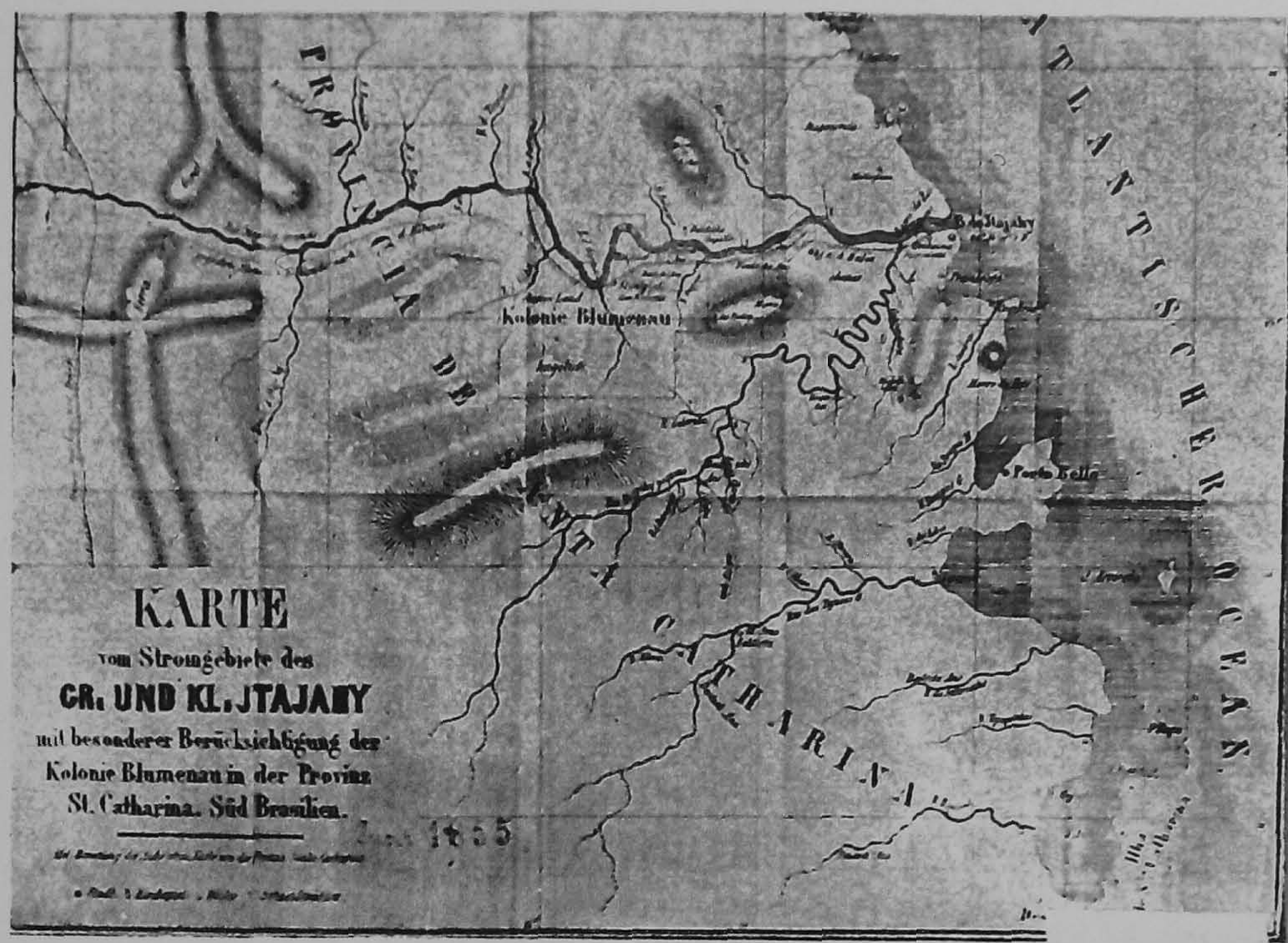
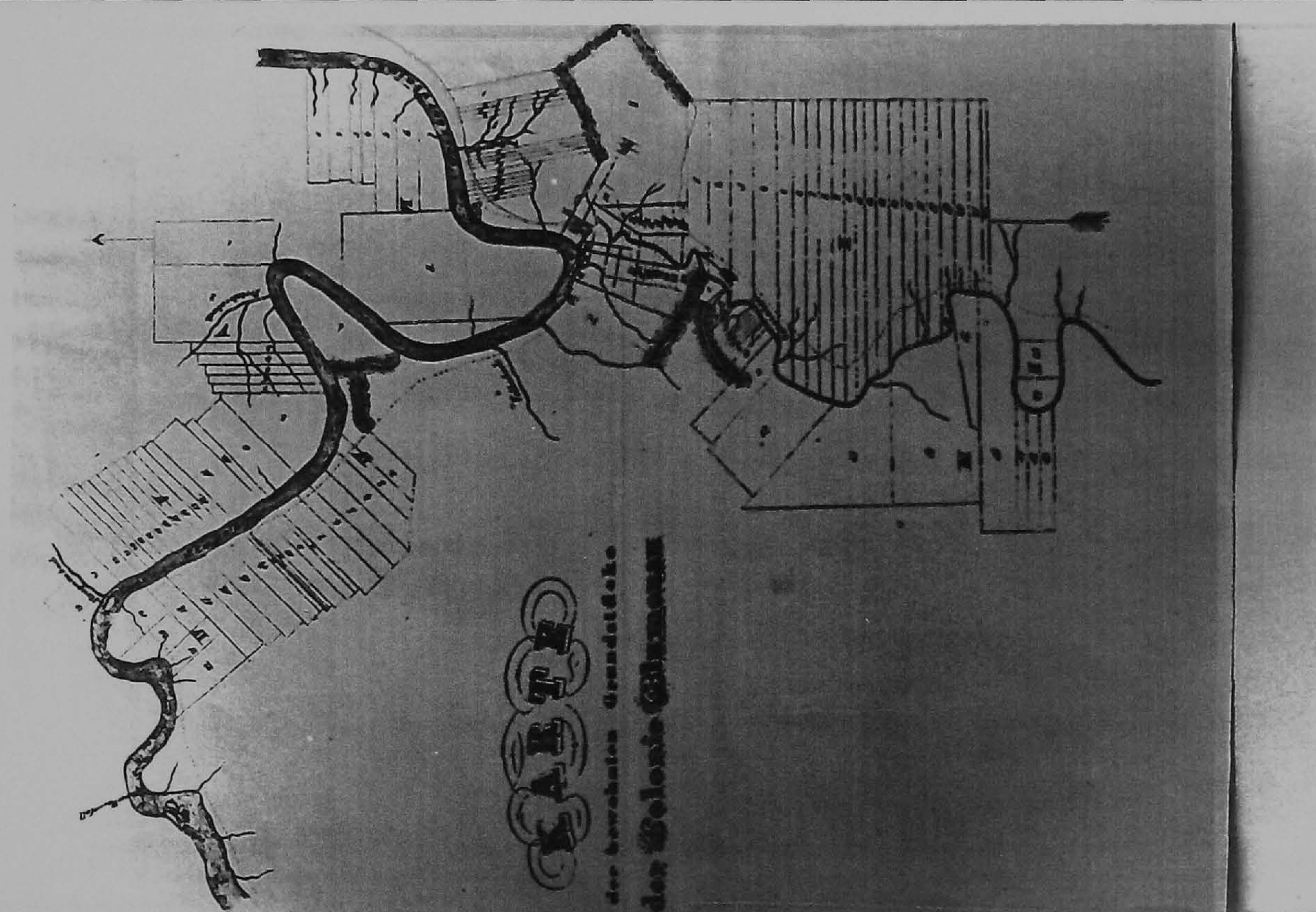


Fig. 2- Settlements of Santa Catarina



Karte vom Stromgebiet des Itajahy vom Jahre 1855 P02.7.1 72.1

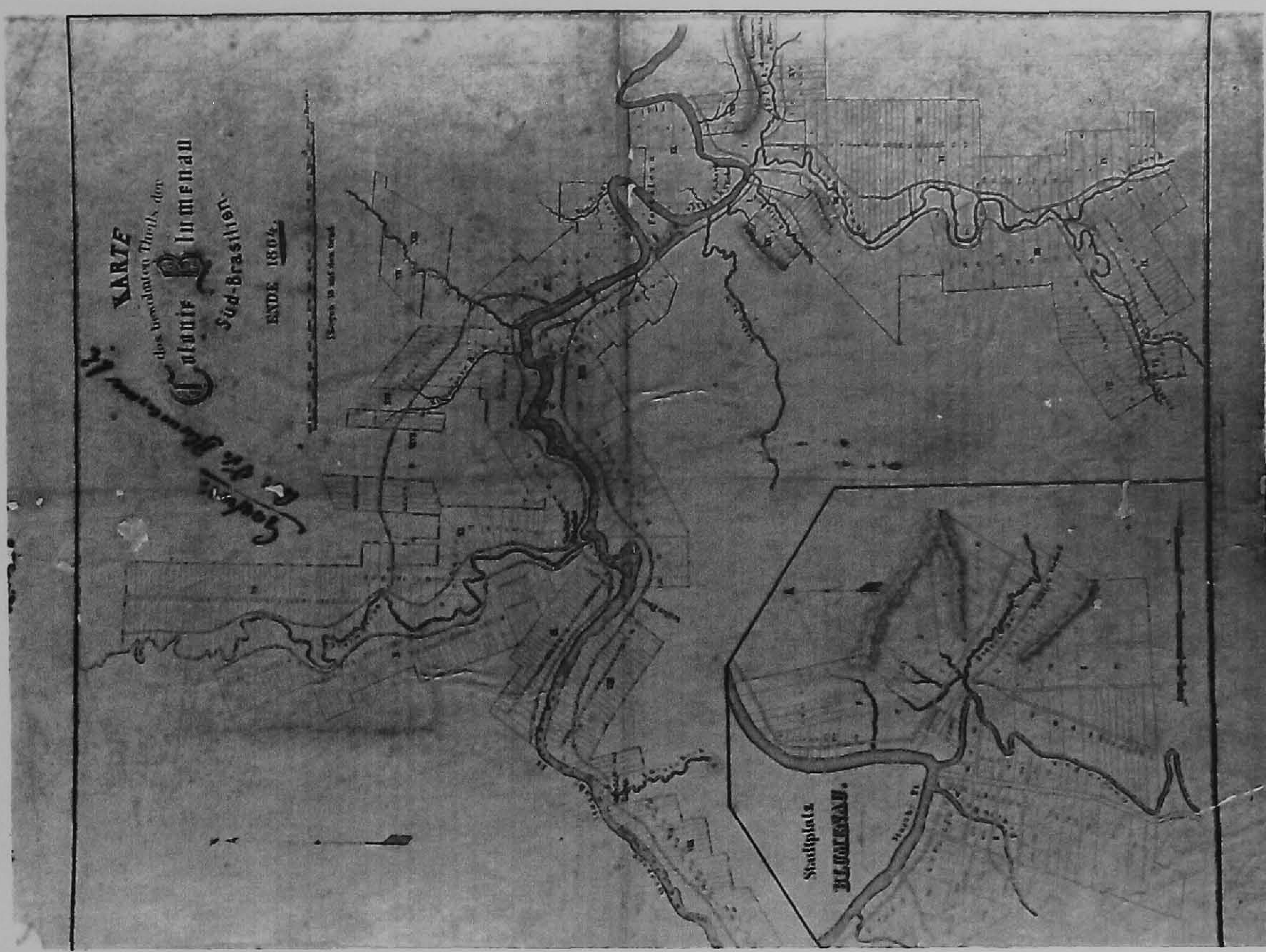
1 (from Blumenau Archive 'Jose Ferreira'- Colonization Collection Doc.02.71/72.1)



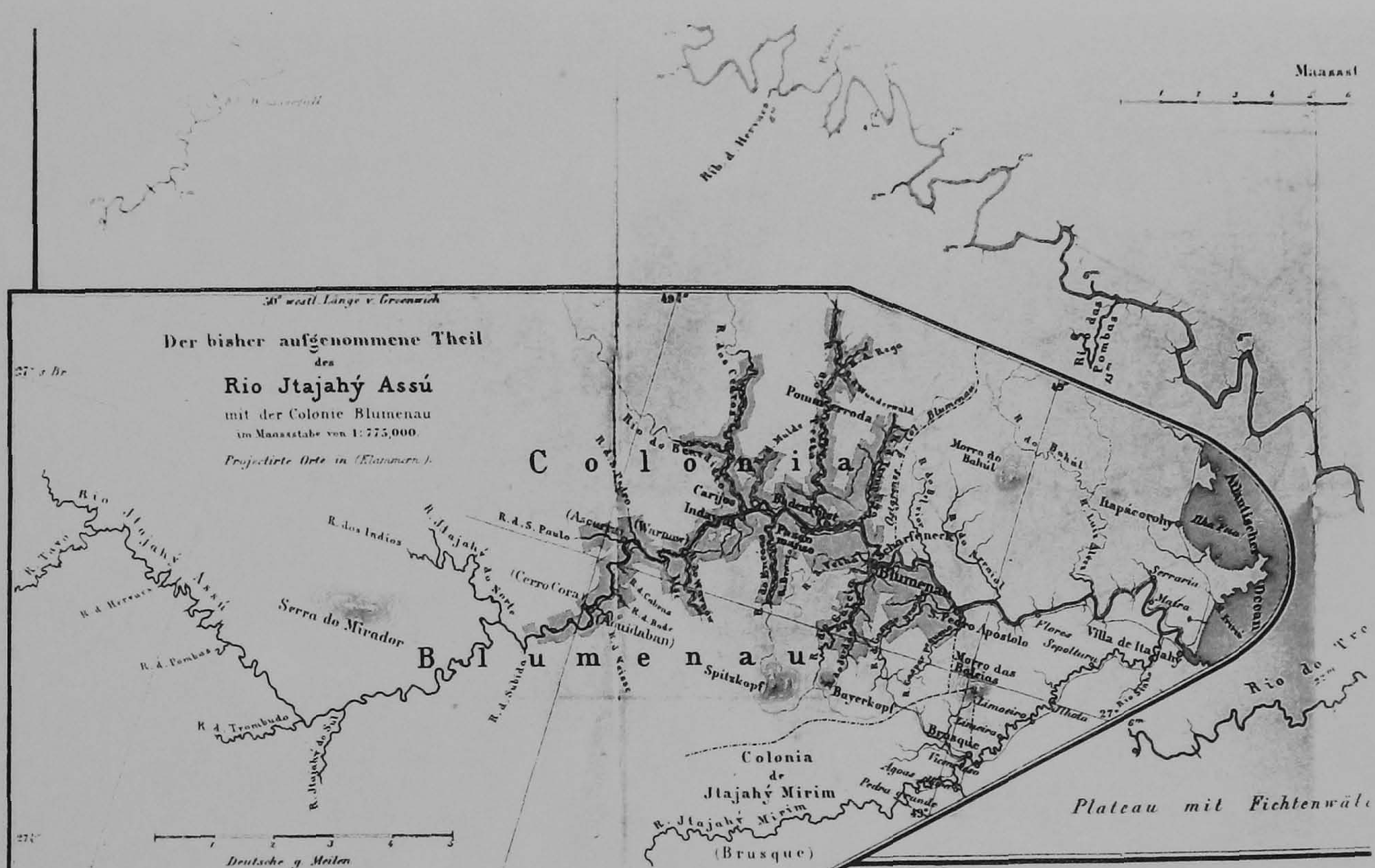
2 (from Blumenau Archive 'Jose Ferreira' - Colonization Collection Doc.02.11)

Fig. 3 - Settlements of Blumenau

The map of 1855 (1) shows the early area of Blumenau when it was a private Colony of Dr Blumenau. The map of 1858 (2) shows the same private colony in detail with the form of the plots along the Itajai- Açu river near the mouth of the Garcia river.



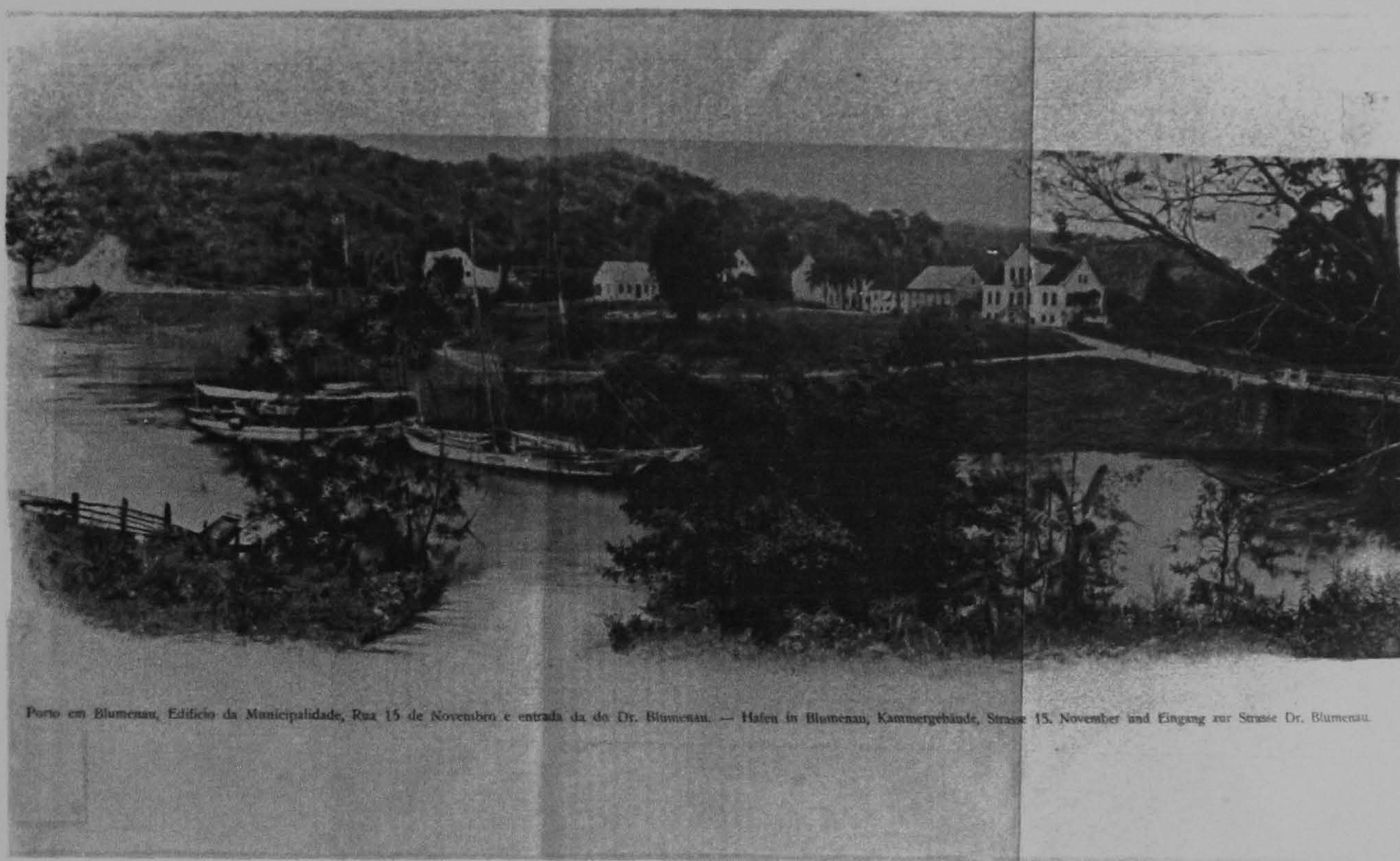
3 (from Blumenau Archive 'Jose Ferreira' - Colonization Collection Doc.2.24/250)



4 (from Blumenau Arquive 'Jose Ferreira' - Colonization Collection Doc. 2.47/479)

Fig. 3 - Settlements of Blumenau (continued)

The map of 1864 (3) when Blumenau was an Imperial settlement showing the early Blumenau and the beginning of the colonial extension. The map of 1874 (4) showing the extension of the colonial expansion.



5 (from Commemoraçao do 50 Anniversario da Fundaçao de Blumenau)

6 (from Blumenau Archive 'Jose Ferreira' - Photograph Collection Doc. 3.1.1

Fig. 3 - Settlements of Blumenau (continued)

The view of the 'stadplatz' of Blumenau (5) (approx. 1875) on the Itajai river at the mouth of the Garcia river. The Town Hall (6) project of the architect Henrique Krohberger built in 1874.

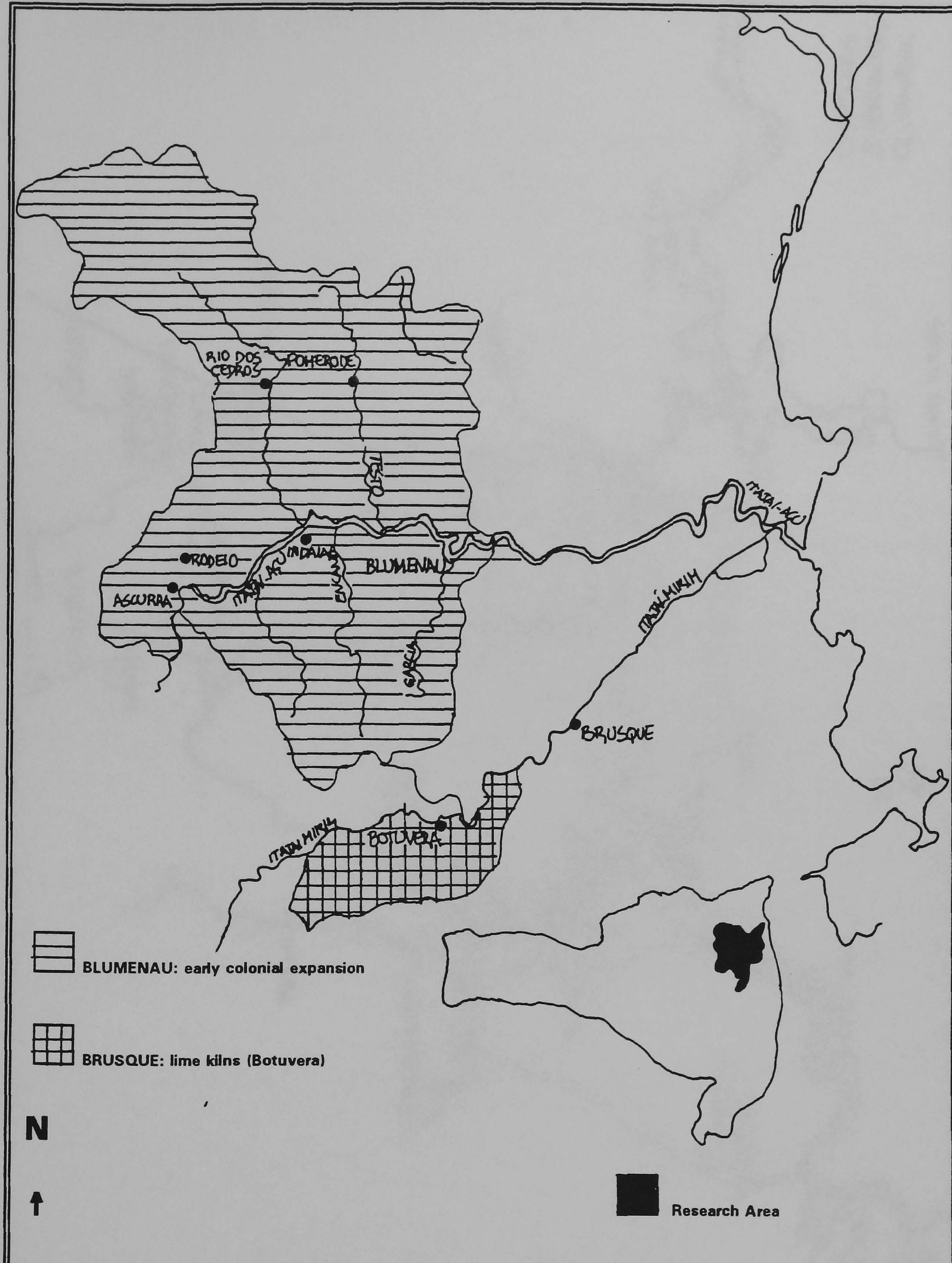


Fig. 4 - Research Area

The map shows the municipal areas of Blumenau, Timbo, Indaial, Pomerode, Ascurra, Rodeio and Rio dos Cedros along Itajai- Açu river and its tributaries and Botuvera along Itajai- Mirim river, the subject area of the research (scale 1: 750.000).

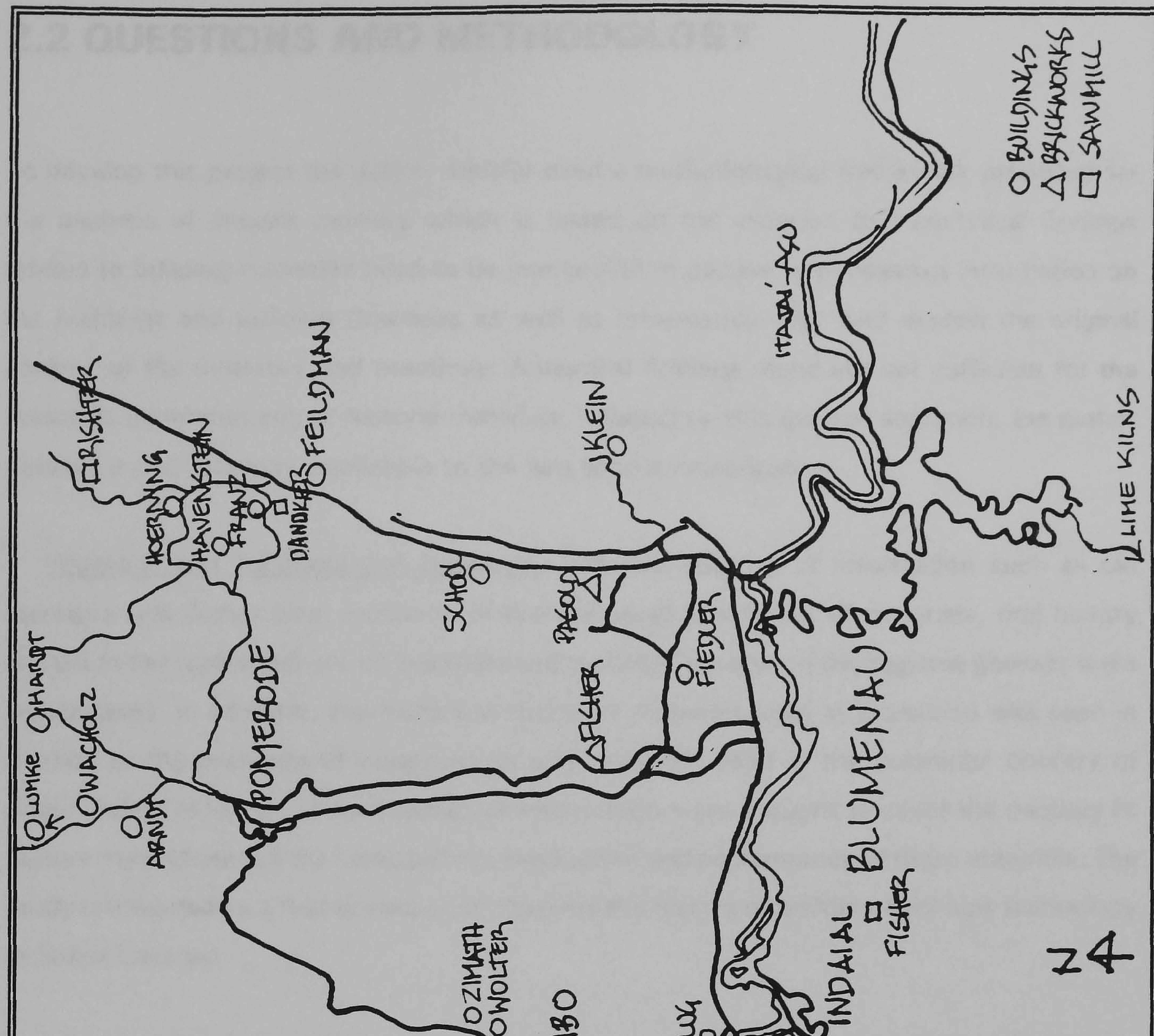


Fig. 5 - Location of Sites and Buildings

2.2 QUESTIONS AND METHODOLOGY

To develop this project the author initially used a methodological framework proposed for the analysis of ancient mortars which is based on the criterion that analytical findings related to building materials need to be interpreted in parallel with relevant information on the buildings and building practices as well as information that may explain the original context of the materials and practices. Analytical findings alone are not sufficient for the scientific understanding of historic materials.[12] Based on this general approach, the author detailed a methodology applicable to the aim of this investigation.

1. Historical and Technological Research. Different sources of information such as old literature and documents, evidence of technological production of materials, oral history related to the traditional use of materials and technical reports on the regional geology were investigated. In addition, the historical choice of materials used in Blumenau was seen in relation to the methods of construction and materials used in the colonists' country of origin. Taken together, these sources of information were thought to cover the majority of factors that influenced the composition, production and performance of these materials. The study is intended as a first contribution towards the history of building materials technology in Santa Catarina.

2. Analytical Research. Analytical work was designed to give scientific information about the composition of selected materials based on earth and lime taken from four types of construction. The study included the classification of buildings types, selection of buildings, samples and analytical methodologies.

3. Interpretation of Research and Recommendations. The interpretation of analytical findings in the light of all other evidence provided the background to review current conservation practice in Santa Catarina and to make recommendations on principles and practical guidelines for the specification of repair materials which are historically, aesthetically and physically compatible with the historic structures.

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[12] The broad framework that the author used to set the research project is well defined in the article by Jedrzejewska, H. (1982), 'Ancient Mortars as Criterion in Analysis of Old Architecture', in Mortars, Cements, and Grouts Used in the Conservation of Historic Buildings, pp.311-29. In fact, this methodological approach is also defended by Ashurst, J. & N. (1988), Practical Building Conservation Vol 2, pp.22-8, where it is said that analytical interpretation of mortars are based on factors such as method of mixing and placing, conditions of the aggregates which analysis alone will not reveal. A similar methodological approach is given by Teutonico, J.M. (1988), A Laboratory Manual for Architectural Conservators, 137-38. There the author advises carrying out a complete documentary research project before starting the analytical work.

2.2.1 Historical and Technological Research

The information gained from historical documentation and technological evidence together with other sources of information constitutes relevant data for the interpretation of the specific analytical findings from the Blumenau region. However certain areas of knowledge are applicable to other similar settlements and research into issues such as the technology of lime production should be seen as nationally relevant. The research starts by looking at a wide range of information about a group of building materials used in vernacular buildings from the nineteenth to the early twentieth century in the Blumenau region and progresses in more detail, focusing the study on earth and lime based materials. The study utilised several sources of information including documentary research in the State and Blumenau archives located in Santa Catarina, accounts of craftsmen and local people, accounts of architectural historians, reports on geological studies, physical remains of lime- burning, sawmills and brickwork, inventories of buildings and observation of German buildings constructed with similar materials. In addition, documentary research was carried out on the buildings prior to the sampling.[13]

Archival Research

This research was developed to trace any kind of relevant literature documents or visual sources that could provide information about the history and technology of materials in the region. Therefore, a thorough study in the Santa Catarina and Blumenau archive was conducted with the aim of gaining information about the following.

- The range of building materials used in the region and how they developed during the period of 1850 to 1950.
- The group of local and imported materials.
- Identification of the materials utilised in the town and in the rural buildings.
- Methods of obtaining, producing and transporting the materials.
- Building techniques, tools and equipment used to produce materials.

Although most of the documents found in the Blumenau archive are general documentation of the history of the Blumenau Colony and few are, in fact, specifically about architecture and materials or about production sites of materials, this kind of research proved to be a valuable and truly important source of information.

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[13]The documentation of buildings is described below in Section 2.4.

Technological Evidence

The aim here was to locate evidence that explained the production technology of the building materials. Research to find the location of existing sites was made by looking in technical reports and questioning local people. Sawmills, brickworks and lime kilns (working or abandoned) were located. Information was sought about the following:

- The date of the site.
- The source of raw material.
- Dating and understanding equipment such as kilns, tools, pugmills.
- Recording the craftsmen's descriptions about the making of materials and difficulties for the production of these materials today.[14]

The study of manufacturing sites proved to be a very consistent source of information and offers great potential for the didactic interpretation of history. Such work might be accomplished in the future by embracing site interpretation for the public with information on wood- working, brick making and lime- burning.

Craftsmen's Accounts

Craftsmen in the region were located by local enquiry. No previous records about craftsmen were found in Santa Catarina. The purpose of this research was to identify the craftsmen's knowledge about the use of materials in the past as well as the current practice of using them. However, this study had its own limitations since the craftsmen's information generally refers to current practice in using traditional materials. Therefore, in fact, the old practice of using earth and lime often was based on the recollection of parents' accounts. In addition, this study was limited by difficulties of the craftsmen in communicating their practical knowledge, either because of age or language (some craftsmen speak very few words in Portuguese).[15] The study sought to gain information on the following:[16]

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[14]See the Section 3.5 Production and Supply where the list of sites visited as well as the results of this study is given.

[15]For instance, the account of Mrs' Emma Klitzque — an eighty year old woman who explained in detail how she helped her father to make hand- made bricks for their timber- framed house.

[16]The list and profession of the craftsmen located are the following:
Rudolph Achterberg- 1906, bricklayer
Helmut Dandker- sawmill operator and owner and joinery
Werner Duwe- 1937, bricklayer
Arthur Fisher- 1907, sawmill craftsmen
Baltazar Fisher- brickmaking
Busquirolli- 1950, lime- burning craftsmen and owner
Olindina Colsani- 1911, lime- burning craftswomen
Grimm- 1938, brickmaking
Emma Klitzque- 1913, brickmaking assistent for her parents' house

• Age and profession of the craftsmen.
• The sources of the ingredients used to make materials.
• The proportion of the ingredients to prepare the materials.
• The mixing methods used.
• The application methods used.
• The tools and equipment employed to make these materials.

No entirely satisfactory account was given by the craftsmen. The majority of the information should be seen as indicative of the use of materials rather than conclusive. By the end of this study the author understood that the craftsmen's knowledge would be better recorded if the accounts were accompanied by practical demonstrations. Two site demonstrations by craftsmen were organised for trial making of bricks, daubs, mortars and renders.[17] In addition, it is evident that there is an immediate need to record and maintain such craft knowledge by developing formal training with craftsmen in the region. Whilst verbal record is less important, future research should include video recording of craft activities.

Study Visit to Germany

The aim of this research was to locate and study buildings constructed in similar materials and similar construction methods in north Germany so as better to understand the material techniques employed by German colonists in Brazil and in particular the use of materials in Blumenau. The study aimed to answer the following questions:

Heribert Klug- bricklayer
Rudibert Manske- blacksmith's grand son with a collection of tools and brick mould
Ana Mafra- 1920, lime-burning craftswomen
Gerhard Maas- 1932, bricklayer
Herbert Noldi- 1937, bricklayer
Carlos Pasold- 1923, brickmaking with knowledge on bricklayer and carpentry.
Curt Rahn- 1930, bricklayer
Dimas Rezini- 1950, lime- burning crafsmen
Egon Sasse- , bricklayer master
Egon Wermeister- 1941, bricklayer and carpentry
Willy Moegel- 1943, bricklayer
Otto Wolter- 1940, brickmaking
Vandelin Wolter- brickmaking
Miguel Augusto Werner- 1935, lime- burning craftsmen and owner
Arthur Zindars- 1918, retired trader with craftsmen knowledge

The results of this study is given in Section 3.3 when the materials of S. Catarina are described.

[17]The description of this practical demonstration is given below in the Section 3.6 Production and Supply.

• Date and choice of earth or brick materials.
• The range of techniques utilised for the making of earth infill materials and plasters.
• The problems of conservation of these materials.

Contacts were made with architects and institutions in Brazil and Germany to locate sites to be visited during a short period of studies on the subject in Germany. Although the immigrants' architecture in Santa Catarina and Rio Grande do Sul has been studied by some architectural historians in Brazil and Germany, reports or books on the subject are scarce concerning Santa Catarina and information from researchers is difficult to acquire. All the information on sites visited in north Germany — Schleswig- Holstein and Lower- Saxony — is the result of the author's work. The itinerary is given below for reference for future research. It is apparent from the current research that the immigrants in Blumenau (mostly Pomeranian Germans) used late forms of timber- framed buildings and solid brick structures as models for their houses which have similarities with the structures found in north Germany. However, for the specific needs of this research, analogies between construction details and the use of materials and decorative patterns between Germany and Santa Catarina can also be found in central Germany.[18]

The following selection of photographs represents significant sources of information for this research. (fig. 6,7,8,9)

[18]**Itinerary of Sites visited in Germany:**
The study concentrated on Lower Saxony, Schleswig- Holstein, Westphalia and Hessen. The following sites were visited — the Open- Air Museums of Kiel and Dortmund; the towns and villages of Aerzen, Hameln, Wehbergen-Lunerburg, Molln, Lubeck, Rendersburg, Rothenhahn- Wolfenbutel, Goslar and Einbeck in northen Germany. In addition there was a guided tour by the architect Udo Baumann to visit the following sites in Hessen: Marburg, Ebsdorf, Kirtorf and Asfeld. There were also visits to training centres for crafts and preservation of historic monuments located in Castle Raesfeld and Johannesberg Priory in Fulda.

Uma residencia primitiva de um colono em Blumenau. — Provisorische Kolonistenwohnung in Blumenau.

1 (from Commemoraçao do 50 Anniversario da Fundaçao de Blumenau)

Colonie Hansa - Blumenau   Das erste Haus eines Hansa-Colonisten

Verlag: G. Artur Koehler, Blumenau. St. Catharina, Brazil

2 (from Blumenau Archive 'Jose Ferreira'- Photograph Collection Doc. 55.1.2.6)

Fig. 6 - Documents

Photograph (1) shows a type of temporary dwelling — an early load- bearing framed house. Photograph (2) shows a type of temporary dwelling and the construction of a timber-framed house.

3 (from Blumenau Archive 'Jose Ferreira')

Le Case primitive,
e l'origine dei mattoni nelle valate Italiane.

I coloni Italiani 20 anni fa, rarissimi o nessuno che avessero fabricati in mattoni; le case loro erano tutte costruite in legno e chiuse di tavole, o di stecchi di palmito, coperte di foglie o di scandole (che sono piccole tavolete di legno.) Il bosco qui da noi ci fornisce di tutte le materie necessarie per costruire una decente abitazzione e sufficientemente per diffenderci dal freddo e dal caldo che questa zona ci manda: dal bosco come ho detto si ha il legno di canella, di Jacarandà, di Tachuba, di canharana, queste sono qualità di legno molto resistibbili piantate in terra; quindi ci dà, le colonne per piantare la casa, poi per travi, e palcatura del coperto, abbiamo la Caruba, il Cedro, ed altri; per il coperto v'ha nel bosco, certe pianticine che han le foglie propriamente che si dirrebbe coltivate a quello scoppo, resistono quando sono bene conservatte, anche 10 anni, con 200 foglie più, o meno si ha un metro quadratto di coperto. Per le pareti poi c'è il palmito questa pianta non ha rami, cresce a guisa di palma, in cima ha le foglie della larghezza di 2 metri e più tutte in un sol gruppo, il fusto di questa pianta misura appena da 20, a 25 centimetri di diametro, la sua altezza è in generale da 10, a 15, metri venendo poi diviso in pezzi della lunghezza necessaria, si fende in quarti ed in sesti od anche in ottavi, come necessitano la grossezza degli stecchi; questi vengono posti gli uni presso gli altri, e legatti destramente in sieme formano le paretti.

Per legare abbiamo il zipò d'Imbè questo giunco ha una curiosità nel suo sviluparsi, la madre che lo produce, non esce dalla terra ma prende esistenza in cima delle piante più alte, e da là crescere giù sciorinati questi giunchi della grosezza d'un lapis più o meno, fino a discendere al suolo; ed ivi prendono radici e si maturano e resistono a suspendere un' uomo comodamente, se vercissero recisi, disseccano. Il suo nome è d'origine selvaggio dai Tupi Guarani.

Le casine così elegantemente costruite dano al passagiero una prospetiva assai pitoresca.

Ven ha anche di costruizione più semplice ma di meno duratta, queste sono costruite con le materie che ci forniscono due sole piante, ciò è il palmito e le foglie da coperto, queste ci da il coperto, ed il palmito ci da collone, travi e palcatriva ed anche si può fare con esso una specie di solajo, che per mancanza di tavole è servibile sufficientemente.

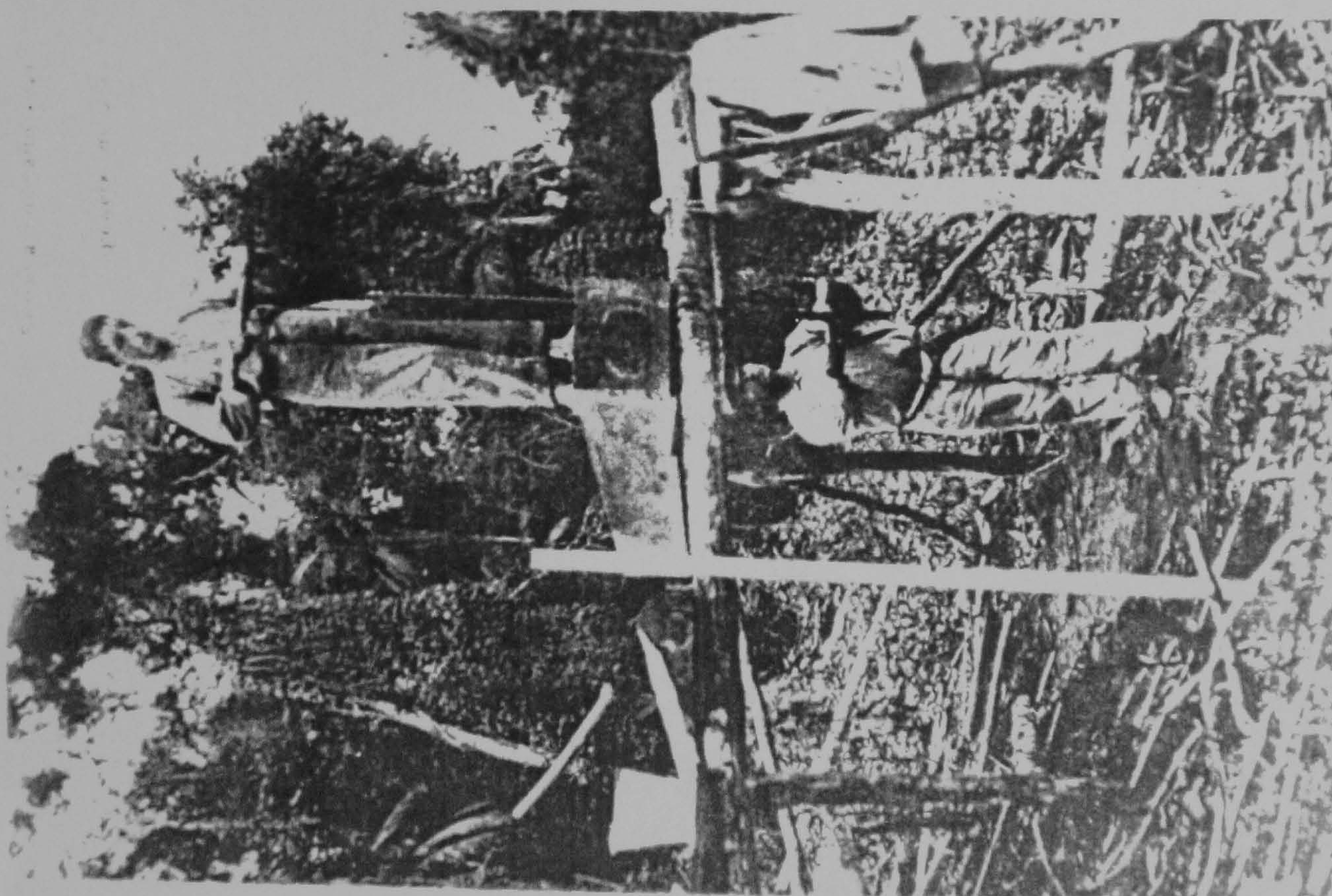
Come siè detto più sopra, dall' anno 1880, incominciò a divulgarsi l'uso dei mattoni, questo ebbe principio col sistema che io portai dall' Italia, ciò è di fabricare mattoni senza fornace stabile, ad esempio chi avesse fatto costruire 20 mila mattoni, si costruivano sul luogo dove più tardi, venivano adoperatti nel fabricatto, che siò non richiedeva nessuna spesa di trasporto; mano, mano che venivano costruiti dei mattoni, si richiedevano anche dei muratori, e non cen'erano ed animato non dalla mia capacità, ma dalla fiduccia che la gente nutrivano in mè, essi sapevano che nel mio servire al militare ebbi 6 mesi di scuola in Casale monferratto, studiavamo in molte materie, e fra le qualli, anche in muratura, ove io apresi teoricamente, ma non praticamente qualche cosa; quindi mi provai, e riuscii, no di spaciarmi per maestro ma quello che mi conteniava era puramente di sodisfare la gente; ed ajutatto da mio compadre Bassan Luigi e nostri figlii, nel periodo di 20 anni non secutivi abbiamo costruiti e posti in opera circa 450 mila mattoni: dei quali ne abbiamo adoperatto a fabricare alcune chiese. Non da credere però, che mi sia occupatto in lavori dell' arte finissimi, abbiamo sempre lavoratto grezamente alla meno spesa dei coloni, e a maggior nostra comodità.

Pietro Trentini.

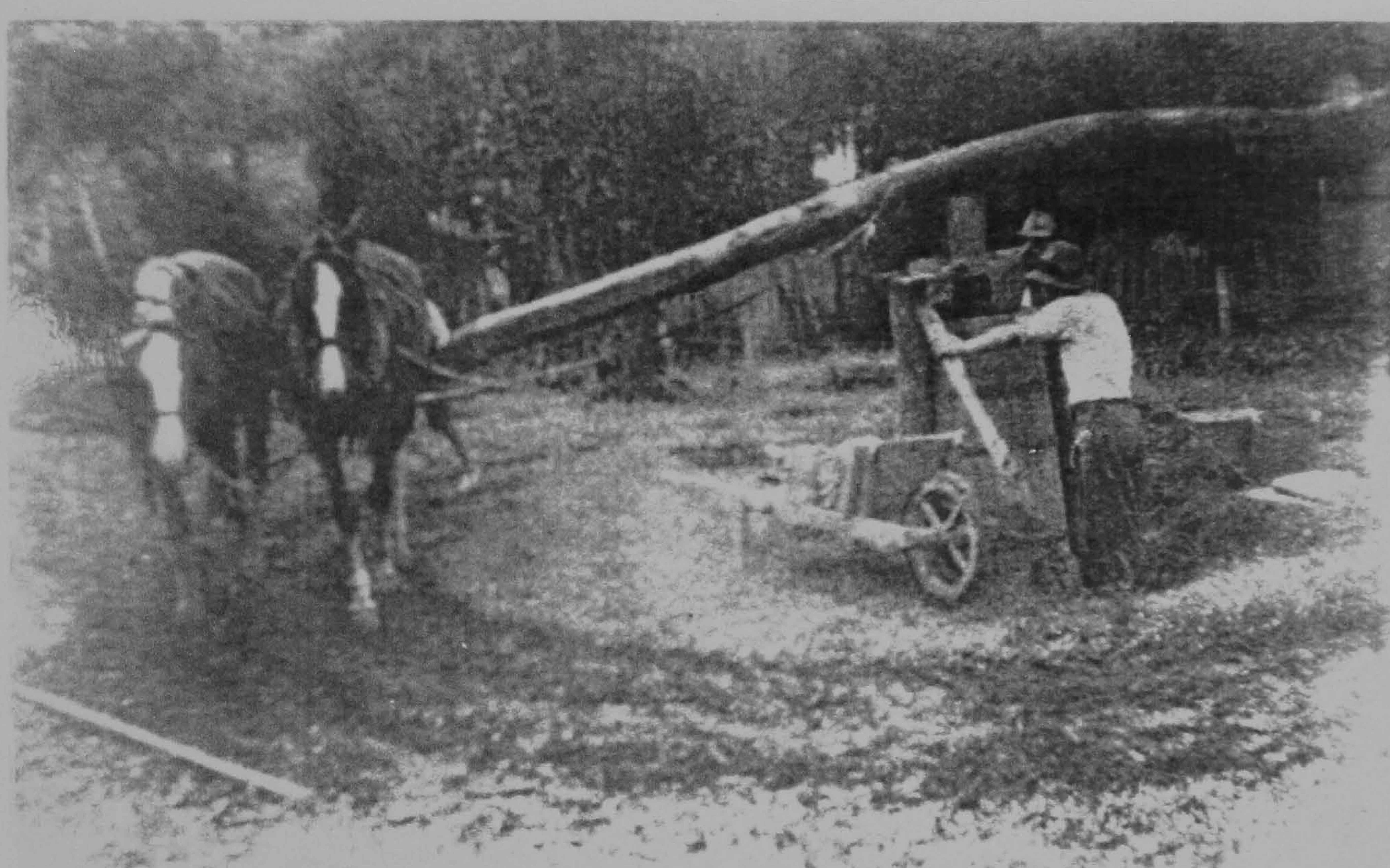
4 (from Commemoraçao do 50 Anniversario da Fundaçao de Blumenau)

Fig. 6 - Documents (continued)

Photograph (3) shows the early quarters of Blumenau Colony sketched by Bruggemann in approx. 1860. Photograph (4) shows the description of primitive houses and hand- mould bricks in the Italian valley.



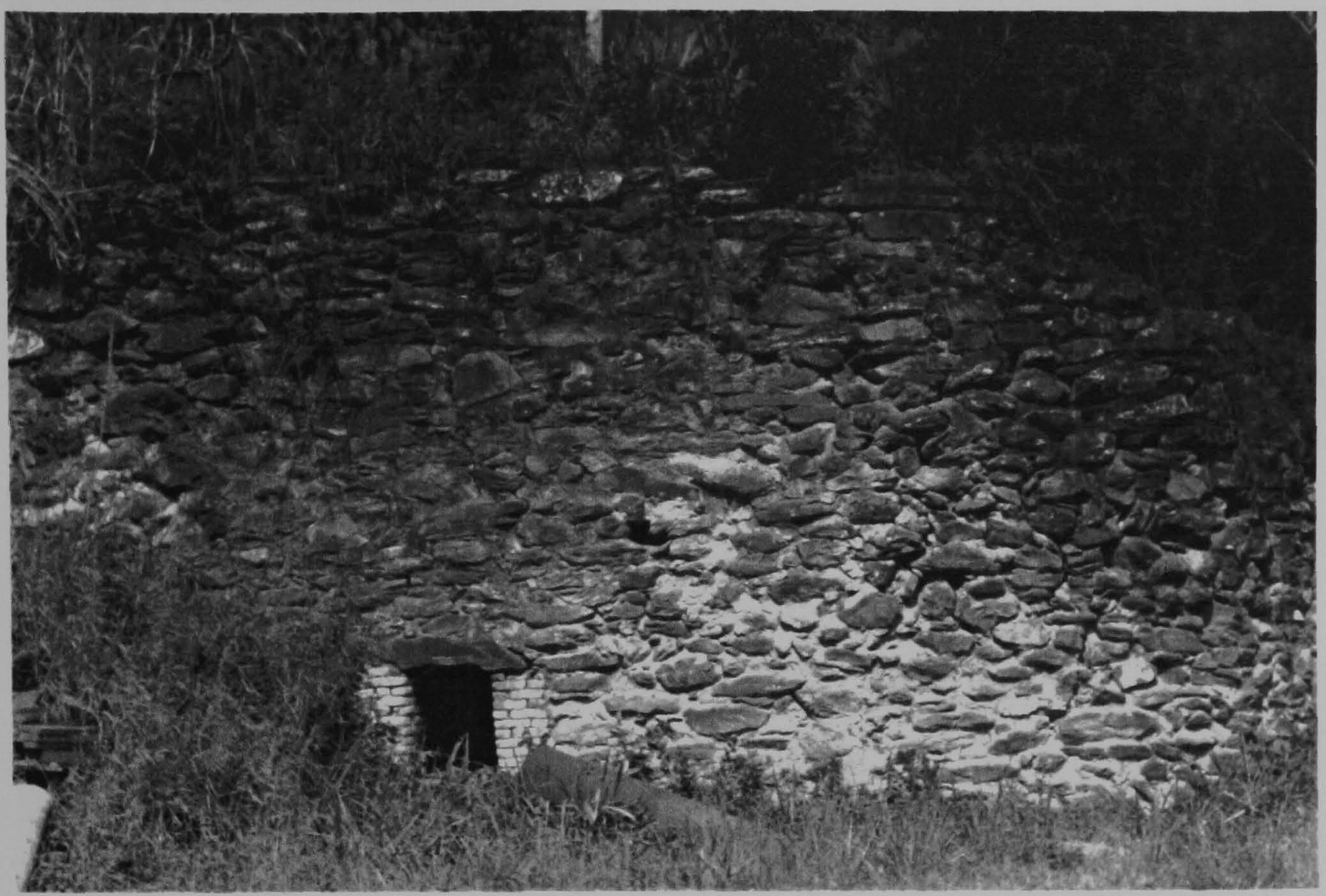
5 (from Blumenau Archive 'Jose Ferreira'- Photograph Collection Doc. 5.13.2.14)



6 (from Blumenau Archive 'Jose Ferreira' - Photograph Collection Doc. 5.13.0.1.3)

Fig. 6 - Documents (continued)

Photograph (5) shows a primitive pit saw. Photograph (6) shows a rudimentary pug mill driven by horse power.



1

2

Fig. 7 - Technological Evidence

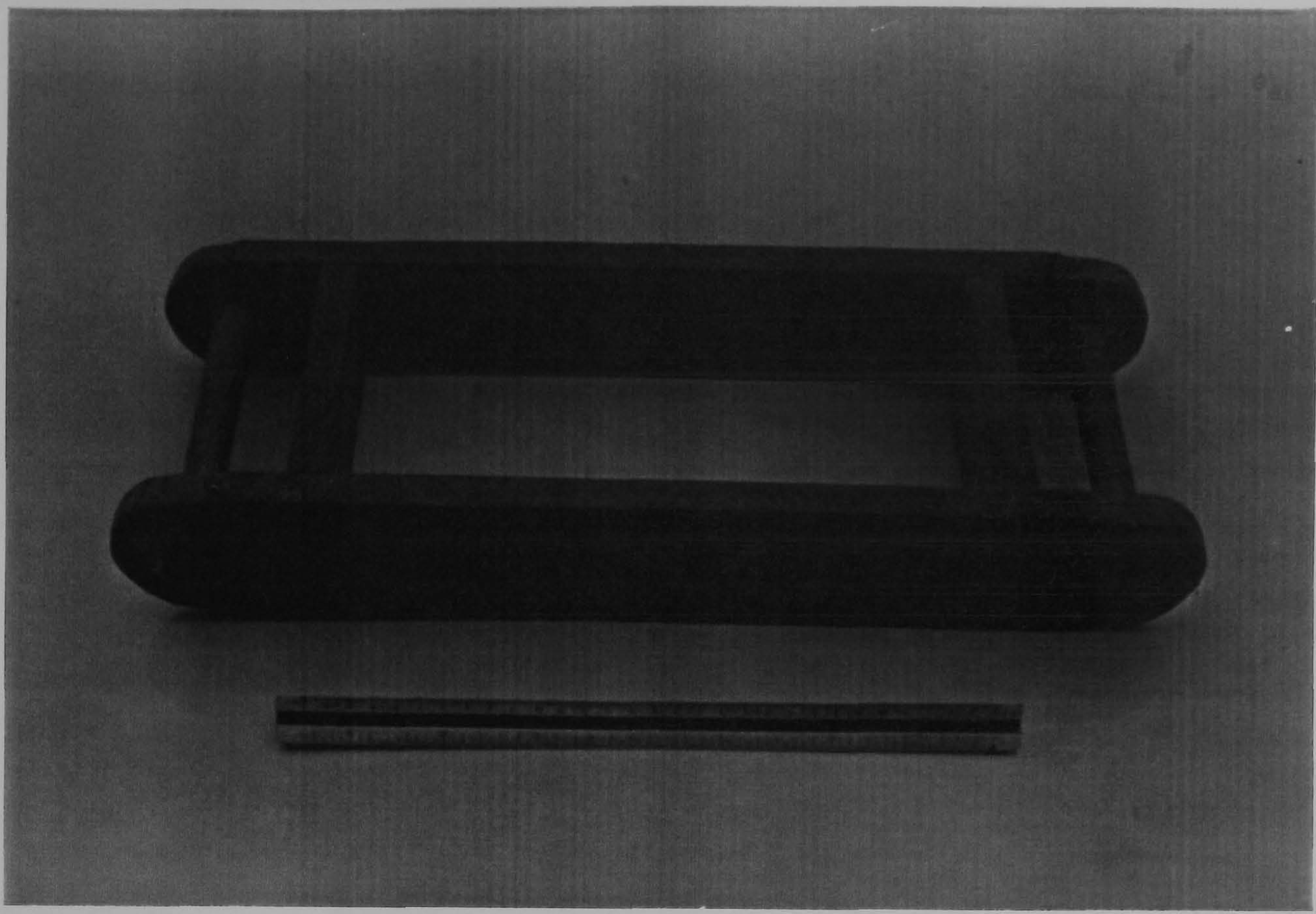
Photograph (1) shows a traditional lime kiln in Itajai - Mirim river valley. Photograph (2) shows a stone mill to crush lime.

3

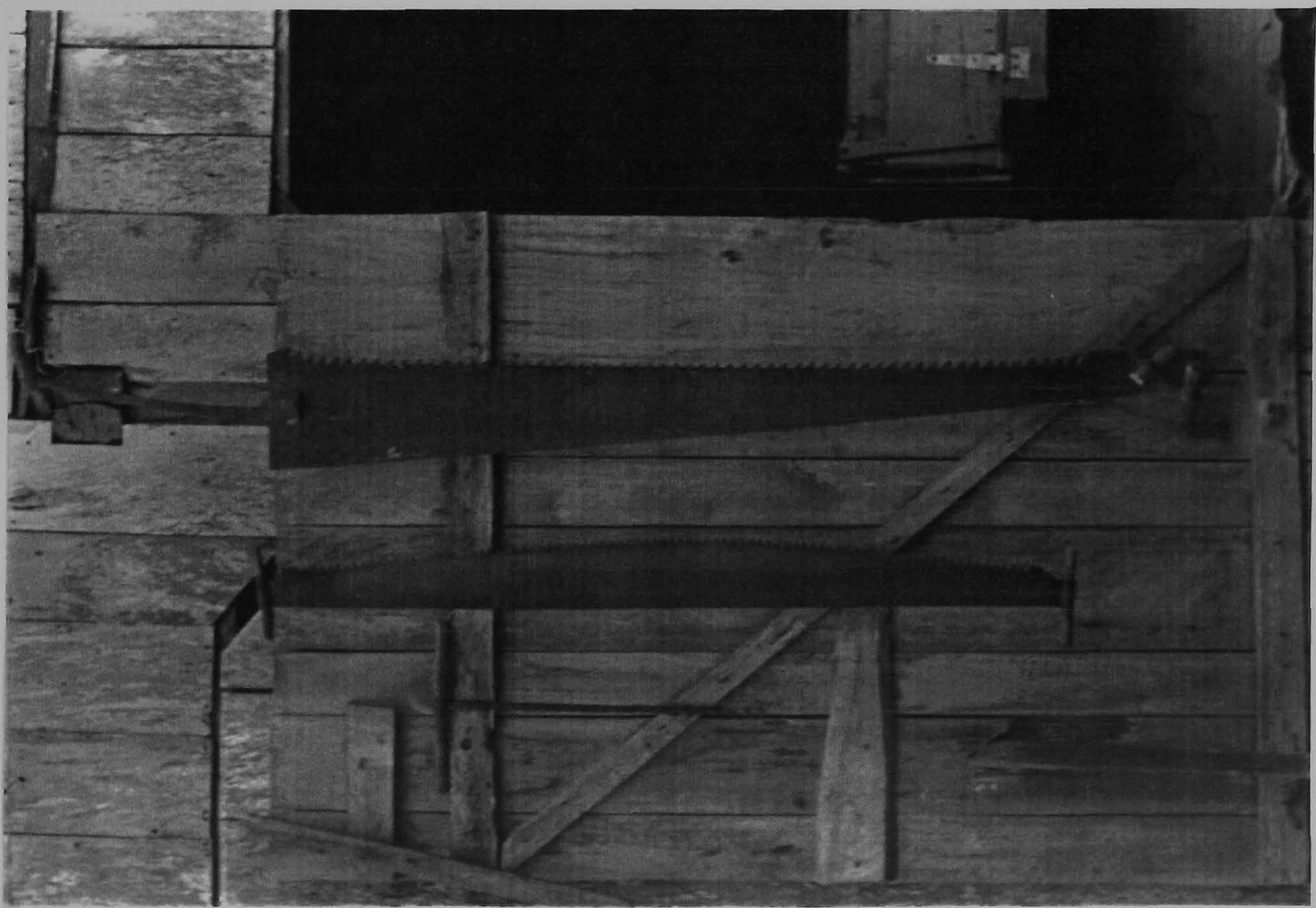
4

Fig. 7 - Technological Evidence (continued)

Photograph (3) shows the internal form (double cone) and material (brick masonry) of a traditional lime kiln in Itajai- Mirim valley. Photograph (4) the shed of the Busquirolli kiln which is the only traditional kiln in S. Catarina that maintains the wood burning process.



5



6

Fig. 7 - Technological Evidence (continued)

Photograph (5) shows a brick mould. Photograph (6) shows two types of pit- saws. Both mould and saw as well as various types of plane were found in the Manske family house, Itoupava Rega, Blumenau.

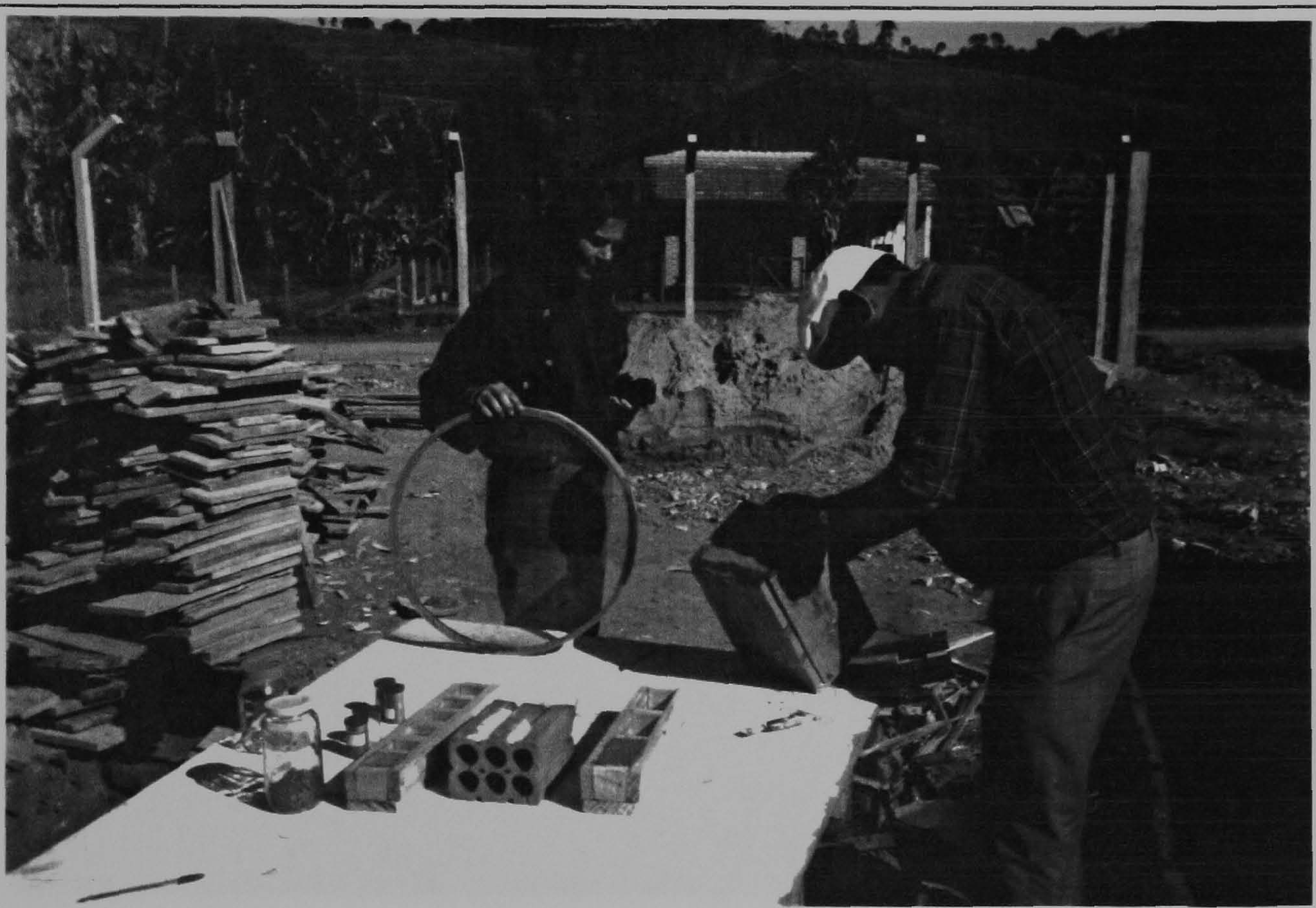
7

8

Fig. 7 Technological Evidence (continued)

Photograph (7) shows a type of traditional pug mill, originally driven by horse power in the Fisher brickyard, Itoupava Central, Blumenau. Photograph (8) shows the early pug mill of the Wolter brickyard in Pomeranos, Timbo.

1



2

Fig. 8 Craftsmen's Accounts

Photograph (1) shows Mr Egon Sasse a builder from Fortaleza Alta, Blumenau explaining the function of a big wood float in early times. Photograph (2) again shows Mr Sasse demonstrating trials of mortars based on traditional mixtures.

3

4

Fig. 8 - Craftsmen's Accounts (continued)

Photograph (3) shows Mr Sasse slaking lumps of quicklime by adding water to the lumps.

Photograph (4) shows the exothermic reaction between the water and quicklime.

Traditionally quicklime should be added to water and not the inverse process.

1

2

Fig. 9 - Germany

Photograph (1) shows narrow panels (close studding) with upright course of bricks in Rothenhahn, Schleswig-Holstein — a common feature in Blumenau architecture. Photograph (2) shows maintenance problems in adobe panels in Aerzen- Lower Saxony.

3

4

Fig. 9 Germany (continued)

Photograph (3) shows daub panels in Asfeld, Hessen. Photograph (4) shows repairs of daub panels performed using blocks of a new material and not traditional materials, again in Aesfeld.

2.2.2 Analytical Research

In this phase the objectives and methods of the analytical investigation were defined and developed in order to gain the desired analytical results. This was developed in the following sequence.

Objectives and Methodology of Sampling

Prior to sampling the objectives were defined and the following information was hoped to be gained:

• The evidence of any characteristic patterns regarding earth materials (clay/ aggregate/ fibre) or lime materials for each method of construction of the buildings.
• The composition of the materials in relation to the chronology of the buildings such as the sucession of layers of plasters and paints (single or double- layer plasters).
• The understanding of the construction systems that utilised earth or lime materials and their degree of compatibility.
• The geographic distribution or chronological/ typological periods of these materials that might indicate the work of specific masons and geological characteristics of the place that led to the use of specific materials.

A sampling methodoloy was developed to undertake sufficient scientific elements to inform these questions in four types of construction.[19] The methodology for sampling follows general recommendations on the subject, but was adjusted for the specific kind of information needed for this research and the limitations that this field presents (ie taking samples from historical buildings).[20] Taking these points into consideration, the necessary samples of earth and lime materials were collected. In general, an attempt was made to take samples that had the following characteristics.

• Truly representative of the range of earth and lime materials of the four types of buildings found in architecture of Blumenau.
• A sufficient number to classify these materials in accordance with the four types of buildings was required and there had to be enough samples of sufficient size for primary analysis and for storage as reference material.

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[19]See the description of the four types of buildings in the section Documentation of Buildings.

[20]General recommendations for sampling mortars are given by the same references given in the footnote 12.

• Given these requirements only the minimum amounts of material to ensure reasonable accuracy were removed.

Questions and Methodology of Analysis

An analytical programme was designed according to the aim of the investigation. This study sought to characterise earth and lime based materials through the determination of relevant components, ie binders, aggregates and in some cases additives and where possible the proportion of each.[21] The materials were primarily classified by the binder and aggregate used. In addition to the appropriateness of the analytical programme to determine the desired information, the analytical programme had other objectives including the following.

• The provision of a broad understanding of techniques useful for architectural conservation.
• The understanding of accuracy/ and precision of analytical methods and results developed in a laboratory basis in comparison to field tests.
• The evaluation and comparison of simple analysis with more sophisticated techniques and equipment.
• The practical limitations of using analytical results for the replication of historical materials and finally.
• The interpretation of experimental findings in the light of other evidence and utilisation of the results for practical conservation guidelines.

2.2.3 Interpretation of Research and Recommendations

The aim of this study was the interpretation of analytical findings for the recommendations of scientific conservation. The analytical findings were interpreted bringing together all the information gained from the buildings and documentary research. Interpretation proved more indicative than decisive, and identified general principles relative to the examination, specification, preparation/ application and maintenance of construction systems and earth and lime- based materials. Areas which required further study were also identified. The methodological model to develop interpretation of results and make recommendations for scientific conservation was based on the following approach and areas:

• The classification of the materials according to three types of systems (ie infill materials, render, plaster and mortar materials and paint materials).

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[21]According to Stewart, J. and Moore, J. (1981), "The Chemical Techniques of Historic Mortars", in Mortars, Cements and Grouts used in the Conservation of Historic Buildings, p.303 constituents and proportions is the normal question asked by an analyst working with historic mortars.

- The classification of the binder and aggregate according to hardening mechanisms and further characterisation with comparative studies from the literature.
- The set of a group of technical guidelines and recommendations for the repair approach of earth and lime based materials, production and supply of these materials and future work.

For this study, a review of recent literature on the current usage of earth and lime as well as conservation practice related to these materials was assessed. A complete bibliography of earth and lime building would be extensive; this literature review is, therefore, a synthesis of essential information. (fig. 10)

(1) HISTORY AND TECHNOLOGY OF EARTH, LIME AND PAINT MATERIALS

ISSUES	AUTHORS	DATES
BRAZIL/ S. CATARINA/ BLUMENAU		
Early Lime Production in S.Catarina	VARZEA, V.	1900
Early use of lime in Brazil	MENDONÇA DE OLIVEIRA, M.	1990
Development of lime in Brazil	PASSOS GUIMARAES, J. E.	1990
Early lime - shell from Archaeological sites	MORLEY, E.	1994
GENERAL AND GERMANY		
Earth & Lime: daub/adobe; mortar/stucco; paint	DAVEY, N.	1961
Clay Materials in Germany	GUNTZEL, J.G.	1990/ 1994
Earth Construction	HOUBEN, H. & GUILLAUD, H.	1994
SPECIFIC COMPONENTS		
Binders	TORRACA, G.	1988
Pigments/ media	DOERNER, M.	1935
	WEHLTE, K.	1975
	HARLEY, R.D.	1982
	OSBORNE, R.	1980
	FELLER, R.	1986
	McLAREN, K.	1986

Fig. 10 - Literature Review

(2) METHODOLOGIES FOR THE CHARACTERISATION OF EARTH MATERIALS

ISSUES	AUTHORS	DATES
Standard Soil Testing	BRITISH STANDARD INSTITUTION	1975
	HEAD, K. H.	1980
	NORTON, J.	1986
Microscopy/ Thin Section Descriptions	GRAY, P.	1973
	BULLOCK, P., ET AL.	1985
	COURTY, M.A. ET AL	1989
Critical Review of Methods	CLIFTON, J.R.& BROWN, P.W.	1978
	CHIARI, G.	1983

Fig. 10 - Literature Review (continued)

(3) METHODOLOGIES FOR THE CHARACTERISATION OF LIME MATERIALS

ISSUES	AUTHORS	DATES
Sampling / documentation/ classification	PIANA, M. & ARMANI, E.	1981
	JEDRZEJEWSKA, H.	1981
	TEUTONICO, J.M.	1988
Critical Review of Methods	PERANDER, T. & RAMAN, T.	1985
	KNOEFEL, D.	1990
	ALESSANDRINI, G.	1992
Chemical techniques	CHIARI, ET AL.	1992
	JEDRZEJEWSKA, H.	1960/ 1967/
	STEWART, J. & MOORE, J.	1981
	TEUTONICO, J.M.	1988

Fig. 10 - Literature Review (continued)

(4) METHODOLOGIES FOR THE CHARACTERISATION OF PAINT MATERIALS

ISSUES	AUTHORS	DATES
Sampling & review of methods	PLESTERS, J.	1956
Stratigraphy/ Pigments	FELLER, R. L.	1972
	GRAY, P.	1973
	PERRAULT, C. L.	1978
	WELSH, F.S.	1982/ 1990
	TEUTONICO, J. M.	1988
	MATERO, F.	1992
	FERRETI, M.	1993
	BATY, P.	1995
	PIKE, A.	1995

Fig. 10 - Literature Review (continued)

(5) CHARACTERISATION OF EARTH MATERIALS

ISSUES	AUTHORS	DATES
General	DOAT, P., ET AL	1991
	HOUBEN, H. & GUILLAUD, H.	1994
	NORTON, J.	1986
	MINKE, G.	1994
England/ Scotland	BOWENS, D.	1990/ 1993
	HARRISON, R.	1990
	HURD, J.	1994
	WALKER, B.	1994
Adobes	CLIFTON, J.R.	1977
	BROWN, P.W. & CLIFTON, J.R.	1978
	BROWN, P.W., ET AL.	1979
	CHIARI, G.	1983
	HUGHES, R.E., ET AL.	1988
Daub	LAHURE, F.	1986
	LEZNER, T. & STEIN, I.	1987
	WRIGHT, A.	1991

Fig. 10 - Literature Review (continued)

(6) CHARACTERISATION OF LIME MATERIALS

ISSUES	AUTHORS	DATES
Lime Chemistry and Technology	BOYTON, R.	1980
	WINGATE, M.	1985/ 1987
	SPIROPOULOS, J.	1985
Mortars, Renders, Plasters and Stuccos: Definitions, Components, Function	MORA, P. & L.	1981
	ASHURST, J	1983
	SICKELS, L.B.	1981
	ASHURST, J & N.	1988

Fig. 10 - Literature Review (continued)

(7) CHARACTERISATION OF PAINT MATERIALS

ISSUES	AUTHORS	DATES
Definitions/ components/ function	GETTENS, R.J./ STOUT, G.L.	1966
	MATERO, F.G.	1994
	EVERETT, A.	
Paint Systems	DEAN, Y.	1971
	MATERO, F.G.	1989
		1993

Fig. 10 - Literature Review (continued)

(8) ANALYTICAL CASE STUDIES OF EARTH MATERIALS

ISSUES	AUTHORS	DATES
Walls	DASSLER, L.	1990
Adobe	BROWN, P.W.	1979
Daub	SOLIANI, C.T.	1990
Finishes	SILVER, C.S.	1990

Fig. 10 - Literature Review (continued)

(9) ANALYTICAL CASE STUDIES OF LIME MATERIALS

ISSUES	AUTHORS	DATES
Mortars	NEWTON, R.G.& SHARP	1987
	KNOFEL, D.	1989
	PETTIFER, K.	1986
	KNOFEL, D. & MIDDENDORF,B.	1991/ 1992
	MONTE, M. & LUCA, M	1993
	TEUTONICO, J. M. ET AL	1994

Fig. 10 - Literature Review (continued)

(10) ANALYTICAL CASE STUDIES OF PAINT MATERIALS

ISSUES	AUTHORS	DATES
	WELSH, F.S.	1990
	MATERO, F. & SNODGRASS, J.C.	1992
	CONSTANCE, S., ET AL.	1993

Fig. 10 - Literature Review (continued)

(11) CONSERVATION OF BUILDINGS

ISSUES	AUTHORS	DATES
Philosophy and Conceptual Parameters	PHILIPPOT, P.	1977
	TORRACA, G.	1980
	FEILDEN, B.	1982/ 1995
	FITCH, J.M.	1990
Principles of Repair	FEILDEN, B. JOKILHETO, J.	1992
	FEILDEN, B.	1982
	BRERETON, C.	1995
Deterioration Process and Conservation Practices	TORRACA, G.	1972/ 1988/
	HUGHES, P.	1986
	THOMAS, A.R.	1992

Fig. 10 - Literature Review (continued)

(12) CONSERVATION OF EARTH MATERIALS

ISSUES	AUTHORS	DATES
Conservation of Earthen Architecture	ALVA, A. HOUBEN, H.	1993
Earth Construction		
	NORTON, J.	1986
	DOAT, P. ET AL.	1991
	WEBB, D.J.T.	1992/ 1995
	GERNOT, M.	1994
	HOUBEN, H.	1994
Conservation Practices: Earthen Buildings	HUGHES, R.	1982/ 1985/ 1988
	PEARSON, G.	1992
	MESBAH, O.	1994
Adobes/ earth blocks, Daub and Mortars/ Renders	FIDLER, J.	1987
	ASHURST, J. & N.	1988
	CARON, P. & LYNCH, M.	1988
	REID, K.	1989
	WRIGHT, A.	1991

Fig. 10 - Literature Review (continued)

(13) CONSERVATION OF LIME MATERIALS

ISSUES	AUTHORS	DATES
Requirements for lime mortars	PHILLIPS, M.W.	1973
	HOLMSTROM, I.	1981/ 1991
	ASHURST, J.	1993/ 1988
	ROSSI-DORIA, P.	1986
	WINGATE, M.	1992
	TEUTONICO, J. M., ET AL.	1994
Conservation Practices: Bedding Mortars, Pointing Mortar, Renders and Plasters	ASHURST, J.	1983
	ASHURST, J. & N.	1988
	INDUNI, B. & L.	1990
	WILLIAMS, G.B.A.	1991

Fig. 10 - Literature Review (continued)

(14) CONSERVATION OF PAINT MATERIALS

ISSUES	AUTHORS	DATES
Requirements	PHILLIPS, M.W.	1972
	MATERO, F.	1993
Conservation Practices: Limewash	ASHURST, J.	1983
	SCHOFIELD, J.	1985
	ASHURST, J. & N.	1988
	VAN JESSEN, C.	1989

Fig. 10 - Literature Review (continued)

2.3 BUILDINGS AND SAMPLES

2.3.1 Selection of Buildings and Samples

The sample collection of Blumenau building materials was designed to cover the range of earth and lime based materials utilised in four types of building construction identified for this study. The buildings are located in the rural area along the Itajai- Açu river and its tributaries, which corresponds approximately to the early colonial expansion of Blumenau Colony.[22] The aim was to select a group of twenty representative buildings and to collect at least three samples of each category of material in order to correlate further analytical studies with the archival data and other information gained in this study. The selection of buildings of each type of construction for sampling was subject to the following criteria.

• Representative of the type of construction (example of a widespread type or unique type).
• Date of construction (representative of early and late examples).
• Condition of building (survival original fabric and not restoration material).
• Available information (preference was given to examples that were recorded, where drawings and historical research were available).
• Acessibility for sampling.

It was sometimes difficult to find suitable building types for sampling as they were not widespread in the rural settings. The selection of materials for sampling and subsequent number, quantity and location of samples were subject to the following factors.

• The potential relationship between the material and the type of construction and date.
• The availability of the material (some materials were used less than others eg ceiling plasters and adobes as opposed to pointing mortar).
• The owner's consent.
• The condition of the elements (where possible samples were taken in accessible and

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[22]Blumenau colony and its early colonial expansion according to the date of the settlements and ethnic group that settled:
Blumenau 1850- head- quarters and early farmsteads
Pomerode 1860- mainly immigrants from Pommerania
Timbo 1863- mainly German immigrants
Indaial 1866- mainly German immigrants
Rio dos Cedros and Rodeio 1875 and Ascurra 1876 - mainly Italian immigrants predominantly from the north of Italy, from Trento.
The group of immigrants that went to Blumenau and colonial extension were mostly craftsmen rather than farmhands.

protected areas such as verandahs, but also preferably not in locations likely to damage the wall).

Sampling problems were principally associated with the soft, powdering nature of the earth bedding mortars and plasters and with the attempt to avoid too much damage to the wall. The following paragraphs describe the buildings and the materials collected.

The buildings selected for sampling were a group of domestic buildings built approximately between 1870 to 1930. The group also includes buildings of domestic and commercial use. The same methods of construction and materials are also found in churches, schools, and factories. Some of the buildings have the date of construction recorded in the lintel or the gable, but for the great majority of the buildings the date has been estimated by the owners.

The four types of construction classified for this research were based on the author's observation and studies of the records of historic buildings gained from different sources. As far as it is known they are the typical methods of construction utilised in the region of Blumenau.[23] They were grouped in this research in order to facilitate the sampling of materials. The main criterion used to group the buildings was the predominant type of external wall ie the methods of construction and category of materials employed. The types are also described according to variations in methods and materials, architectural decoration, the interior and typical conditions focused on earth and lime- based materials. The four types of walling methods and materials and a typical description of these buildings are as follows:

EARTH PANEL: This is a type of construction where the main volume of the building is constructed of timber- frame and daub or adobe infill. Outshots, verandahs and additions and occasionally partitions are constructed from wooden boarding. Daub is the common infill material, but adobe has also been recorded.

General: The survival of this method of construction consists of a few small houses located in different parts of the Blumenau region and is probably not restricted to one place; it is possible that more buildings of this type will be found in the inland villages not yet studied. This form of construction is no longer in use, the original function having sometimes been replaced by storage. This type of construction reflects the most modest way of life of the

[23]See also below the sections about infill systems and mortars, renders and plasters systems where further information about these types of buildings is given in detail relating types of dwellings and materials.

Blumenau immigrants.

Architectural Decoration: This type of building is rarely decorated, although window frames adorned with profiles may be found.

Interior: The interior is divided basically into two- rooms usually with the same method of construction and materials as for the external walls. The decoration is very simple; soft plasters are contained within the panel and limewashed.

Condition: The most common deterioration problem of these structures is largely associated with the maintenance of the renders and limewashed surfaces. If the panel is not maintained and is exposed to the weather the decay of daubs and adobes is invariably apparent.

BRICK PANEL: This is a type of building where the external walls of the main volume of the building are made entirely of timber- frame and brick infill. Outshots, verandahs and additions are often made with brick walling. Variations of this type are encountered when two compartments of a building are divided by a cross passage or when a shed is built against an external wall; in these cases, passage and shed wall may be constructed in earth panels. Closer examination of the buildings shows external walls with bricks that were manufactured by different processes, but in both cases similar methods of construction where bricks are bonded with earth mortars and pointed with lime mortars.

General: Approximately one thousand buildings of this type have survived and are widespread in the region. This is the most typical type of construction in the Blumenau region and includes a variety of buildings reflecting early and later houses, both small and large, with hand- made bricks or extruded bricks.

Architectural decoration: External decoration is provided by the design of panels and bonding of the bricks. Panels exhibit a variety of features including brick nogging in herringbone, diaper, glazed headers and zigzag brickwork. Other features are painted decoration of doors and windows and roof and verandah details.

Interior: The interior is divided into a minimum of three- rooms, but a greater number of rooms are seen in larger houses. The partitions are timber- framed and the infill may be either earth or brick panel. The decoration reflects the immigrants' craftsmanship in the hand- made furniture and plasters which conceal the frames and are decorated in limewash and stencilling.

Condition: In general the condition of the pointing mortars around the edges of the panels and the internal plasters applied over the timbers are extensively cracked, requiring emergency repairs. It was observed that deteriorated pointing mortar was always associated with decay of timber and internal plaster.

BRICK WALLING: This is a type of building where the main volume of the building has the external walls made entirely of exposed solid brick. Outshots, verandahs and additions often have brick walls. Variations of this type are encountered when smaller enclosures of timber-framed walls and brick infill are linked to the main brick building. This is usually a timber-framed survival with a late brick construction added to it. Close observation of the building shows bricks manufactured with different processes and variations in size and colour.

General: About one hundred examples of buildings constructed in this way have survived. All examples exhibit elaborate brickwork. The buildings of this type of construction reflect the brickworking skills of German and Italian immigrants. The origin of the ethnic group is evident on plan- forms and facades of the brick houses.

Architectural Decoration: External decoration is provided by the bonding type of the walls (alternate courses of headers and stretchers) or the use of diagonal bricks seen in the upper parts of the wall (cornice), polychromy - coloured pattern in the brickwork with examples of diapers, crosses, zigzags or glazed header patterns and openings designed with arch heads. Decoration may also be provided by stuccos for the finishing of openings, corners and cornices.

Interior: The interior is divided into a minimum of three rooms with brick walls. Painted decoration might be expected. The furniture is again hand- made by the early owners.

Condition: The condition of these buildings is usually better than that of the timber- framed structures, but cracks above the openings or along the walls are common. The pointing mortar may sometimes be deteriorated and the internal plasters showing defective areas. Specific problems of these structures are sometimes associated with the deterioration of bricks.

RENDERED WALLING: This is a type of building where the main volume of the building has the walls made entirely of rendered and stuccoed brick walls. Outshots, verandahs and additions are usually built by the same method. Internal walls are usually in brick, but early examples may have timber- framed walls.

General: Only a few buildings of this construction type survive. It is expected that more buildings of this type may be found in areas where urban development has occurred. The buildings of this type reflect the choice of architecture for the more prosperous immigrants and the transfer of the more polite architecture of Blumenau headquarters to the villages of the farmsteads. Buildings of this type were not built as a result of the collective effort of owners, neighbours or one bricklayer/ carpenter, but as a building contract. This type of building was well documented in the Blumenau archives. After 1930 rendered brick structures became widespread in rural areas, but the architectural characteristics changed and with them the methods and materials. Examples of early rendered brick were limited to remains and isolated buildings.

Architectural Decoration: External decoration is provided mainly by stuccos adorning openings, balconies, arches, verandahs or simulated stone walls.

Interior: The interior is divided into several rooms indicating a greater number of functions than the former types. Basements, improved lofts or even two storeys typify these buildings. The internal painted decoration is usual in ceiling plasters made with lime or gypsum, extensive use of stencilling for living rooms, dining rooms and bedrooms and the presence of elaborate staircases. Elaborate furniture is likely to have been imported rather than locally made.

Condition: There are some deteriorations and detachments evident in the original stucco and plaster almost certainly related to moisture penetration, but as detailed inspection could not be made the causes of these failures are not specifically addressed in this thesis.

A group of twenty buildings representative of the four construction types described above was pre- selected for sampling earth and lime- based materials. Although more than twenty-four buildings were observed and useful information was gained for this thesis, eighteen buildings were finally selected for sampling and more than fifty samples were taken from these buildings. Samples were taken from three earth panels, eight brick panels, six brick walls and one rendered wall. The sample collection organized by building type and category of materials is listed in the following table. (fig. 11) The following photographs illustrate the types of buildings and their characteristics that were observed and selected for the sampling and study of earth and lime based materials. (fig. 12,13,14,15)

EARTH PANEL	BRICK PANEL	BRICK WALLING	RENDERED WALLING
DAUB			
Franz 1/2 Lumke 1	Hoerning 4 Wacholz 1	Poffo 4	Fiedler 5
ADOBE			
Tottene 4/5	Klein 1		
BEDDING MORTAR			
Tottene 3/5	Cheminelli 1 Reincke 2/7 Duwe 6	Zimath 5 Wolter 2 Buzzi 1 Fiamoncini 3 Evald 2	
RENDER			
Franz 3 Lumke 2 Tottene 1/2		Buzzi 2	Fiedler 1/8
POINTING MORTAR			
	Reincke 1/6 Hoerning 2 Thurow 3 Duwe 1/7 Havenstein 2	Zimath 3/4 Wolter 1 Buzzi 4 Fiamoncini 1/2 Poffo 1 Evald 1	
PLASTER			
Franz 4	Hoerning 1 Wacholz 2 Thurow 2 Reincke 8/9 Cheminelly 2 Thurow 1 Wacholz 3 Duwe 5 Havenstein 1	Poffo 4 Buzzi 3	Fiedler 2/3/4

Fig. 11 - Sample Collection Organized by Building Type and Category of Material

1

2

Fig. 12 - EARTH PANEL EXAMPLES

Photograph (1) shows the Franz family house (circa 1870). Photograph (2) shows a detail of deterioration of the daub panel in the Lumke House (1890). Note the wooden profiles of the window.

3

4

Fig. 12 - EARTH PANEL EXAMPLES (continued)

Photograph (3) shows the Tottene house, the only timber structure entirely built with adobe panels. As far as is known, this is a unique example. Photograph (4) shows a detail of the Tottene adobe elements exposed to rain penetration due to loss of renders.

1

2

Fig. 13 **BRICK PANEL EXAMPLES**

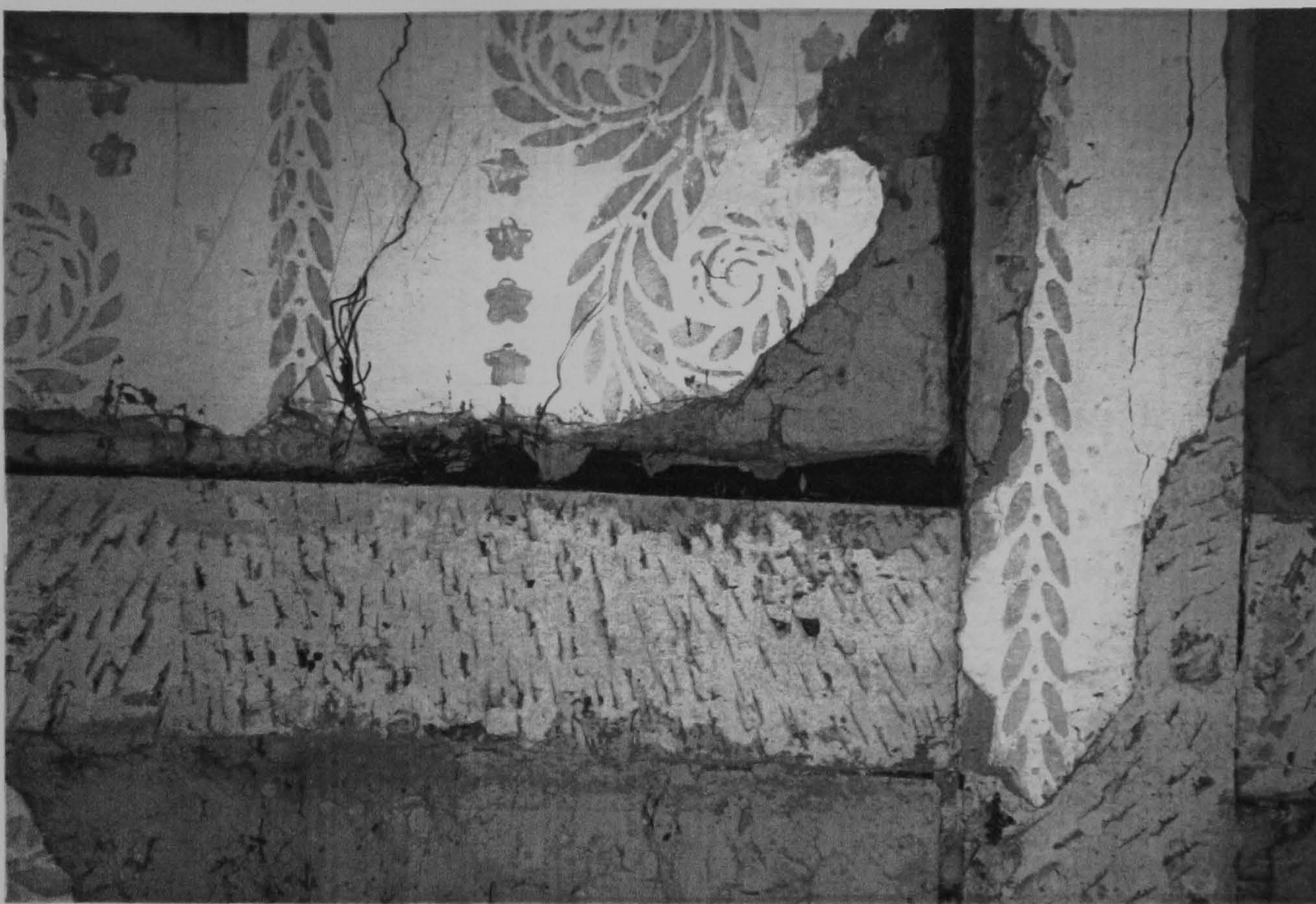
Photograph (1) shows the Reincke house – a pioneer building (circa 1890) with a later verandah in brick walling. Photograph (2) is a detail of the same house showing the pointing mortar decay and the subsequent deterioration of the bedding mortar and the timbers.

3

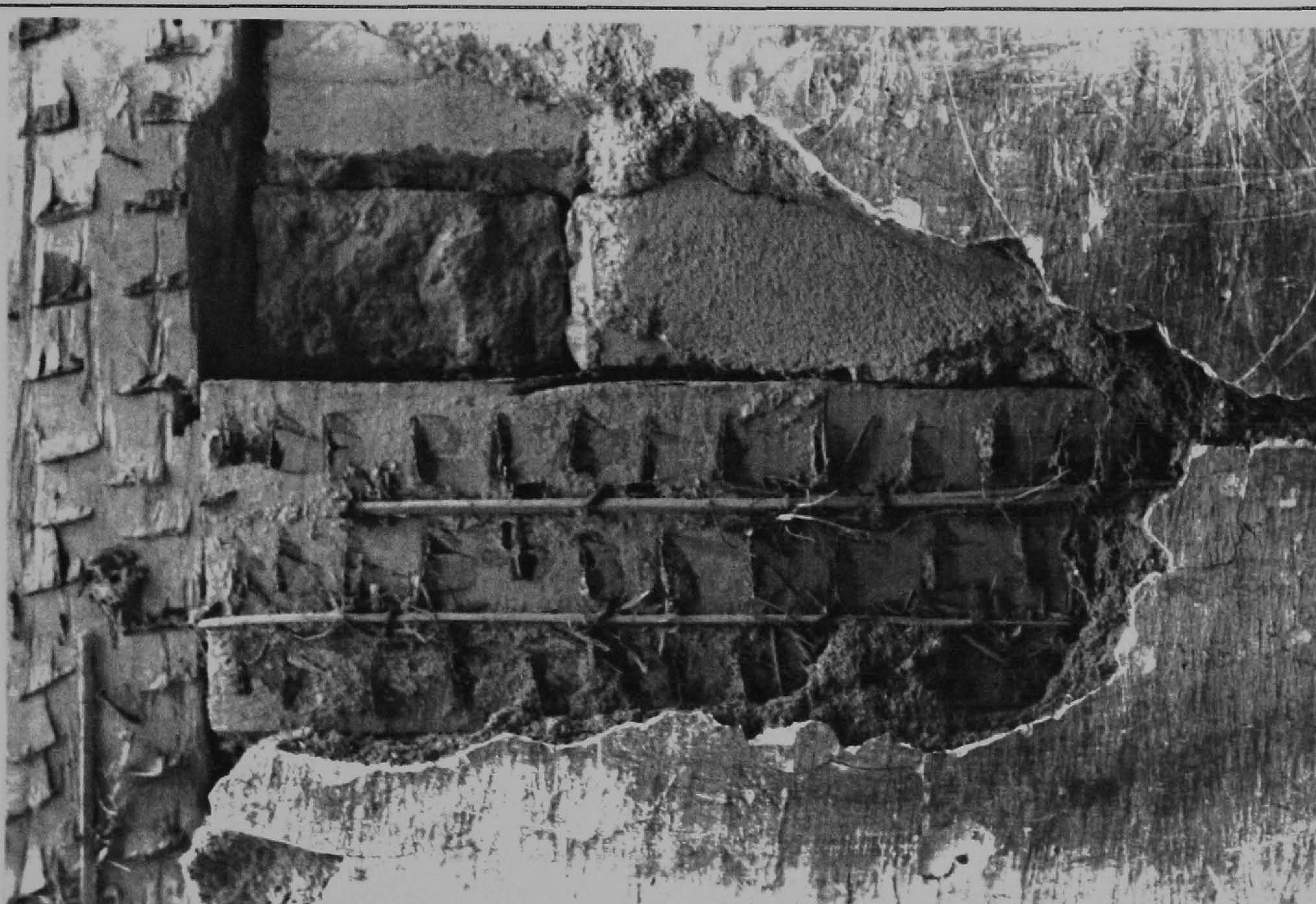
4

Fig. 13 - <u>BRICK PANEL EXAMPLES</u> (continued)

Photograph (3) shows the Duwe house — a later timber- framed building (1902) exhibiting polychrome herringbone panels in zigzags and headers. Photograph (4) shows deterioration at the pointing mortar around the edges of the panels.



5



6

Fig. 13 - BRICK PANEL EXAMPLES ((continued)

Photograph (5) shows Wacholz house — a pioneer building (circa 1870) and the extensively cracked areas of stencilled plasters. Photograph (6) shows Thurow house — a pioneer house (circa 1890/ 1920) and the detail of deterioration problems of the internal plasters.

1

2

Fig. 14 - **BRICK WALLING EXAMPLES**

Photograph (1) shows the Zimath house — a pioneer building (circa 1890) constructed of two- units and a cross passage entirely made with hand- moulded bricks. Photograph (2) shows the same building and the detail of the structural crack above the window.

3

4

Fig. 14 - <u>BRICK WALLING EXAMPLES</u> (continued)

Photograph (3) shows the polychrome diapers of the brickwork in the Evald house — a brick building (1910) and the remains of the previous timber- framed building (circa 1890). Photograph (4) shows the two different types of structures in the same building.

5

6

Fig. 14 - BRICK WALLING EXAMPLES (continued)

Photograph (5) shows the Buzzi house (1886) a two- storey brickwork structure decorated with stucco. Photograph (6) shows the Rinco house (circa 1880) a two- storey brickwork structure bonded only with earth bedding mortar. Both are houses of Italian immigrants.

1

2

Fig. 15 RENDERED WALLING EXAMPLES

Photograph (1) shows the Fiedler house (1888) a structure with a basement and upper storey decorated with stucco. Photograph (2) shows the same house and the detail of the facade and stuccoed profiles around the openings.

3 (from Blumenau Archive 'Jose Ferreira' - Photograph Collection Doc. 3.1.2)

4 (from Commemoraçao do 50 Anniversario da Fundaçao de Blumenau)

Fig. 15 - <u>RENDERED WALLING EXAMPLES</u> (continued)

Photograph (3) shows the early Blumenau Town Hall (1875) designed by the architect Henrique Krohberger. Note the similarities of the Fiedler house with this building. Photograph (4) shows a rendered brick structure.

2.3.2 Documentation of Buildings and Samples

The eighteen buildings and the collected samples were recorded following general recommendations and according to the methodology developed for this thesis.[24] Most of the descriptive information gained during the field work was recorded using a tape recorder to shorten the period of time in the field. This information was later transferred to data sheets.

All buildings were identified by family name, date of construction, building type and location and were plotted on maps (scale 1:50000). The owners' account of the history of the house and the problems of conservation were recorded at each site. The environment, form and structure, types of materials, condition of the materials, repairs and interventions of all the buildings were logged.

Before taking the samples, photographs, drawings or sketches were prepared in order to record the location and condition of the samples. All samples of materials were taken using a small chisel and mallet and kept in sealed and labelled plastic bags or inert containers. The samples were identified by the house family name, category of material and sequentially numbered in the order in which they were collected. In addition the label included the name of the samples, date of the sampling and name of the person collecting the samples. The complete sequence for the documentation of the samples and an example of the information that was recorded from the buildings and samples are illustrated below. (fig. 16,17)

[24]The documentation of buildings and samples is recommended by Jeanne Marie Teutonico (1988), A Laboratory Manual for Architectural Conservators, p. 137.

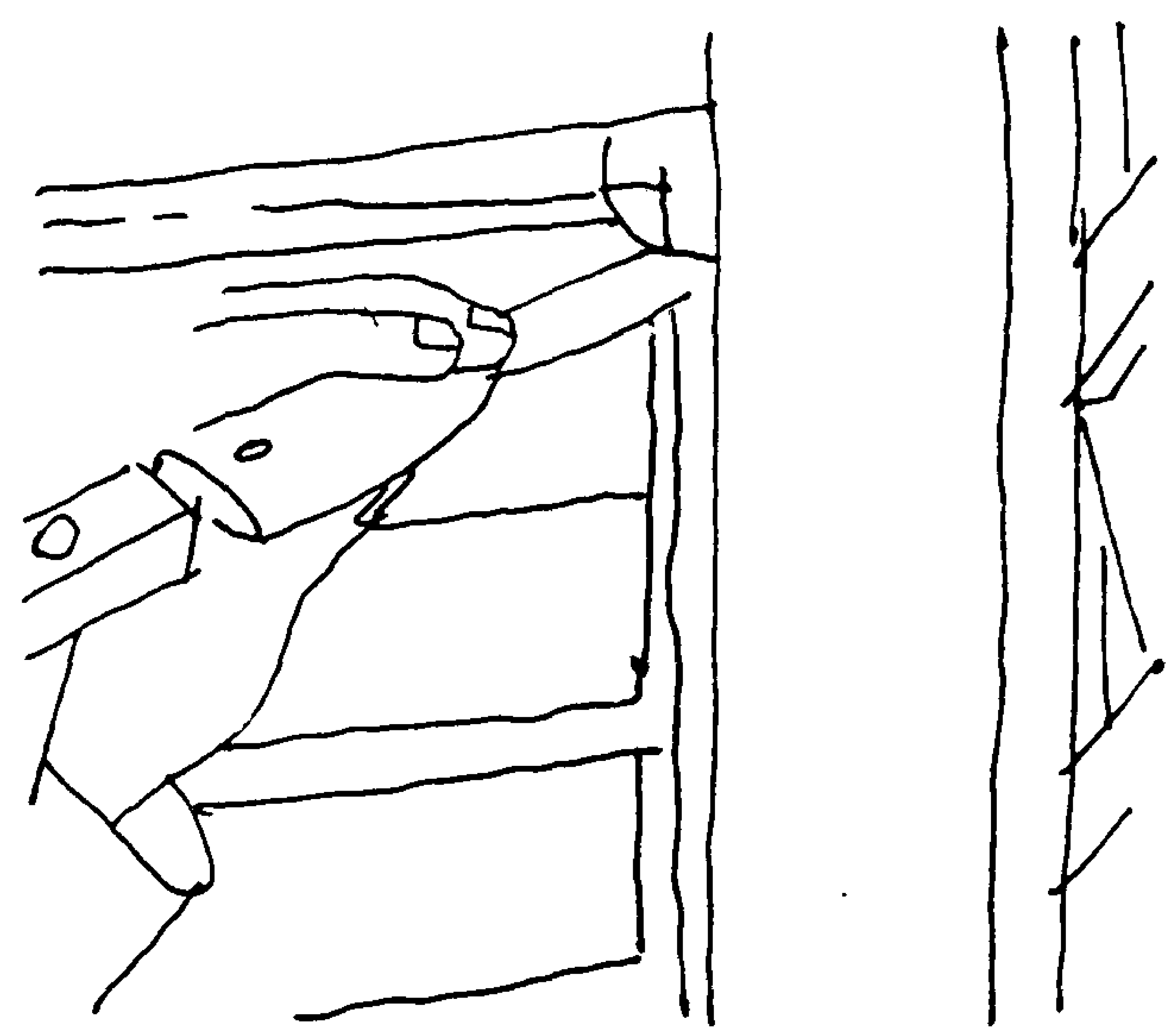
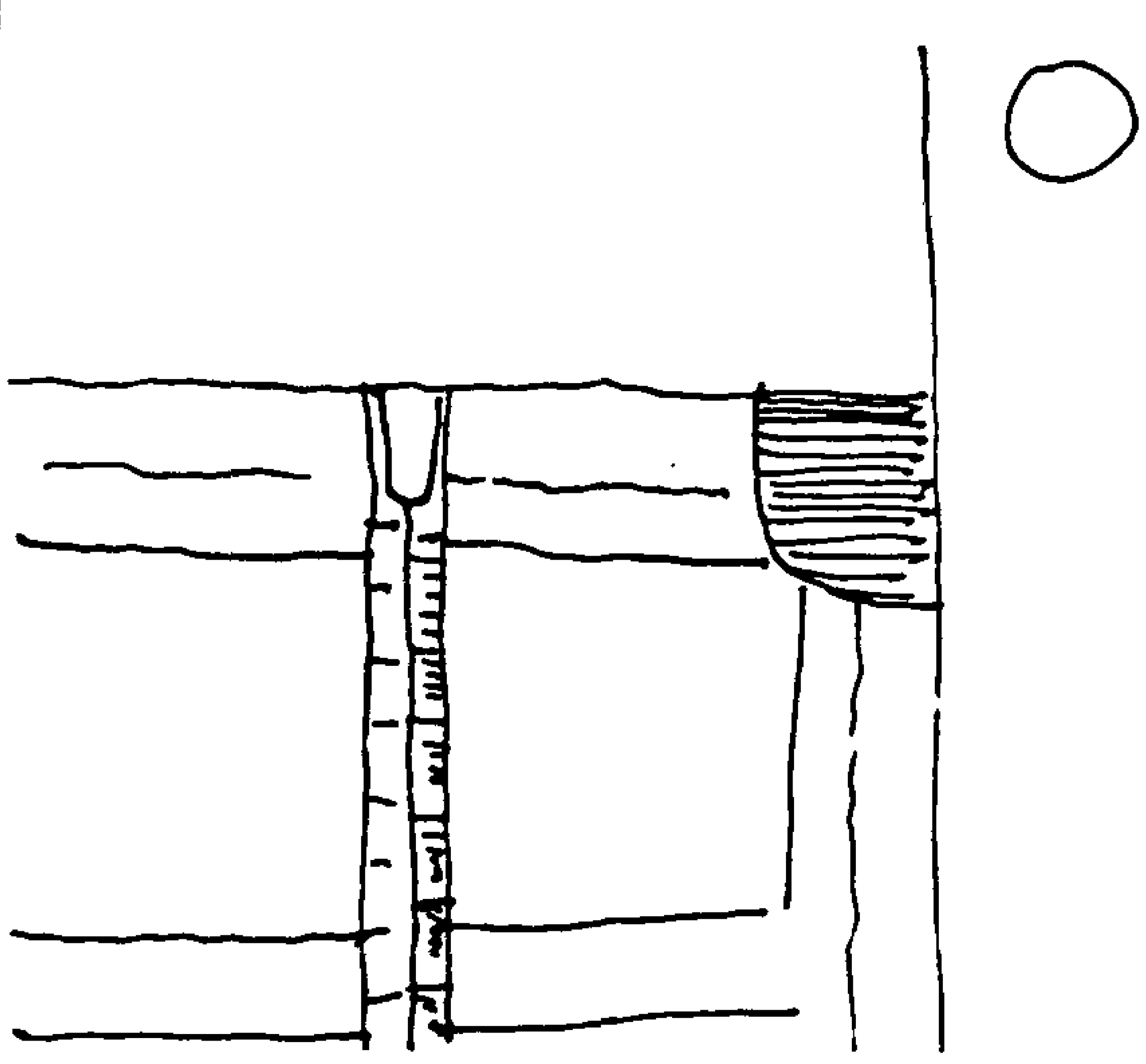
1. IDENTIFICATION OF THE BUILDING •FAMILY NAME •LOCATION OF BUILDINGS •BUILDING TYPE	2. ACCOUNTS OF THE OWNERS OWNERS' ACCOUNTS OF THE HISTORY OF THE HOUSE WERE RECORDED
3. DESCRIPTION OF THE BUILDINGS DESCRIPTIONS OF BUILDINGS WERE TAPE-RECORDED INCLUDING THE FOLLOWING: • ENVIRONMENT • FORM AND STRUCTURE • TYPE OF MATERIALS • CONDITION OF MATERIALS • REPAIRS AND INTERVENTIONS	4. COLLECTION OF THE SAMPLES SAMPLES WERE COLLECTED USING CHISELS AND MALLETS 
5. LOCATION OF THE SAMPLES LOCATION OF SAMPLES WAS RECORDED IN SKETCHES OR PHOTOGRAPHS AND BY MEASUREMENT 	6. SAMPLE IDENTIFICATION AND CONTAINERS SAMPLES WERE KEPT IN PLASTIC BAGS AND INERT CONTAINERS, LABELLED AND SEALED. IDENTIFICATION WAS PROVIDED BY: • FAMILY NAME, NUMBER AND CATEGORY OF MATERIAL. • BUILDING TYPE AND WALL WHERE THE SAMPLE WAS TAKEN • PLACE • SAMPLER

Fig. 16 - Sequence of the Documentation of Buildings and Samples

DUWE HOUSE:

ADDRESS: Estrada de Arapongas, Indaial

BRIEF HISTORY: The house was built in 1902. The owner and builder was Moritz Leetne.

ENVIRONMENT: The region is a plain and used for rice plantation as well as brickworks. The house stands out from other buildings due to the large volume of the roof. Close to the house the surrounding ground is wet, but the timber structure is built above the level of the ground, thus this does not seems to constitute a problem.

FORM AND STRUCTURE: The house comprises two volumes. The main volume is a timber- framed structure with slim frames indicating the conversion of timbers made in a sawmill and not by a manual method using a pit saw. It is a large volume when compared with other houses of the region. The elaborate and unique roof is designed so that the front side is a large mansard and the two left and right sides are large gables. The second volume located into the rear is a replacement of the old kitchen and was built in 1950.

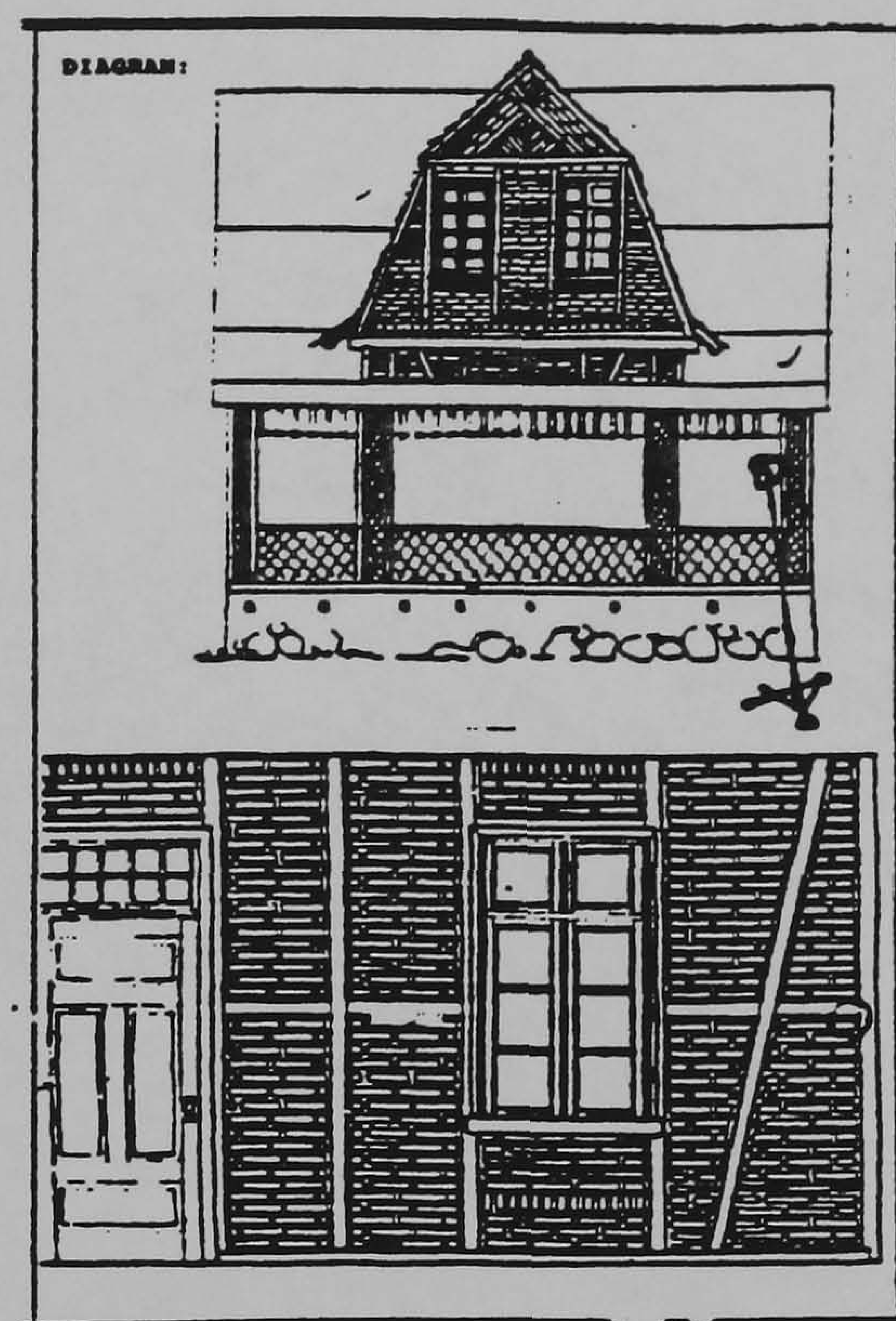
TYPES OF MATERIALS: The foundation is made with stones and bricks (1 m above the ground). All the external panels are built from extruded bricks bonded with earth mortars and pointed with lime mortars. The internal panels are likely to be of the same material. The panels present polychromic effects with zigzag and glazed brick headers. Windows and doors are in wood and painted light green. Inside, all the rooms have plasters concealing the structure and the majority are decorated with stencilling. In the living- room, the motifs of the stencilling are in green and red.

CONDITION OF MATERIALS: Deterioration of timbers and pointing mortar is more evident in the left side wall - a south wall. South walls are usually wet because they are not dried by the sun. Evidently the front wall which is protected by the verandah is well conserved. Inside, cracks on the plasters are widespread and located along the edges of the timbers. However, the plasters of the south wall present problems such as loss of adhesion due to water penetration. Lack of maintenance is obvious; therefore leaking areas on the roof, installation of taps without appropriate plumbing and windows and doors without paint are visible.

REPAIRS AND INTERVENTIONS: Few areas with evidence of mortar or timber repairs.

DUWE 1: POINTING MORTAR

LOCATION: Duwe 1: Pointing Mortar was taken from the front wall, right side, h = 1.43 m from the verandah level.



CONTAINER:

DUWE 1: POINTING MORTAR

BRICK PANEL: FRONT WALL

INDAIAL: M(C KANAN. 11.6.93

Fig. 17 - Example of Building Description and Sample Documentation

2.3.3 Selection of Samples for Analytical Research

After the field work sample was given, a preliminary assesment was carried out to select the best examples for the analytical work. The samples were weighed and their relative usefulness assessed. The best samples were intact, of reasonable size and unweathered, and were adequately representative of the earth and lime- based materials found in the four types of construction.Twenty seven samples were selected for analysis. These included three daubs, one adobe, six renders, five pointing mortars and nine plasters. The collection offered a representative profile of the materials and the results of the analysis when viewed in conjunction with the information gained from different sources can be interpreted to give a preliminary understanding of the types and main components of the earth and lime based building materials. The collection of samples selected for analysis is organized in the following table according to the building type and category of materials. (fig. 18) This is followed by a summary of the information acquired from the buildings. (fig. 19)

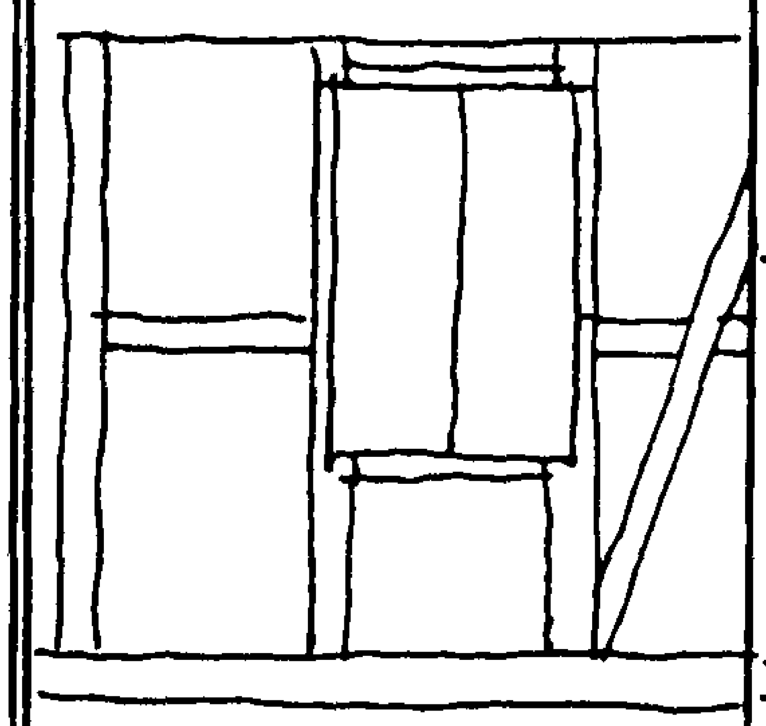
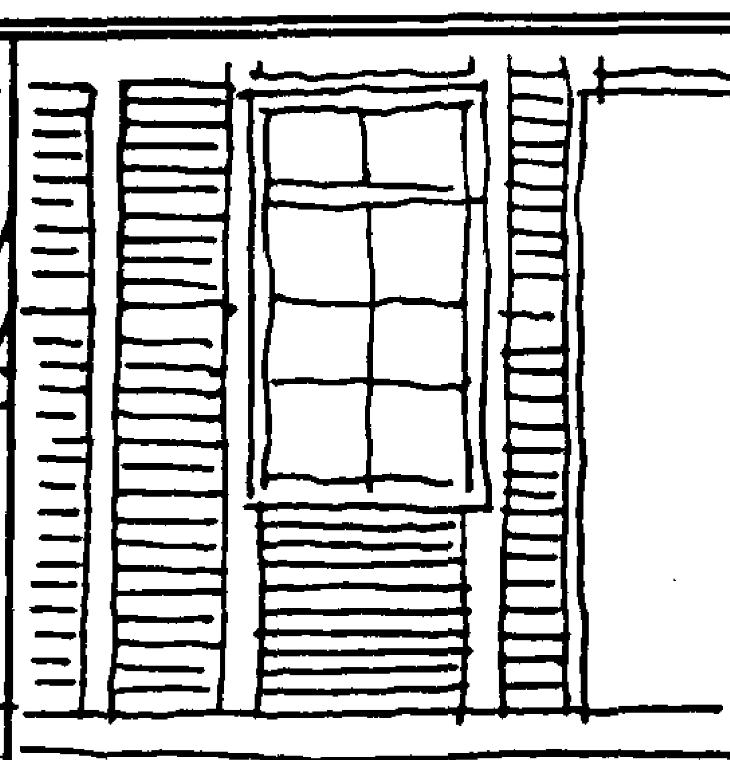
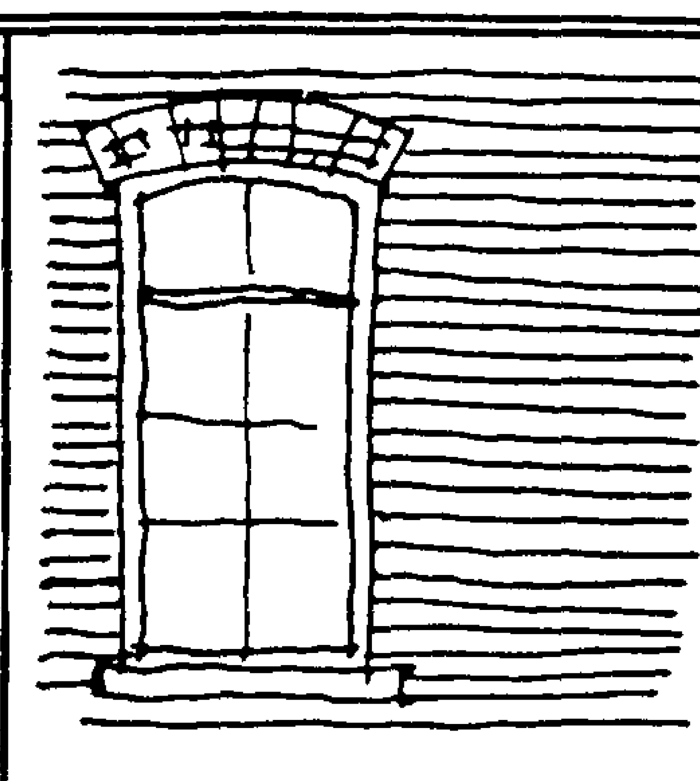
			
EARTH PANEL	**BRICK PANEL**	**BRICK WALLING**	**RENDERED WALLING**
DAUB			
Franz 1 Lumke 1	Wacholz 1		
ADOBE			
Tottene 5			
BEDDING MORTAR			
Tottene 5	Cheminelli 1	Buzzi 1	
RENDER			
Franz 3 Lumke 2 Tottene 1		Buzzi 2	Fiedler 1/8
POINTING MORTAR			
	Reincke 1 Thurow 3 Havenstein 2	Zimath 3 Poffo 1	
PLASTER			
	Wacholz 2/3 Reincke 8 Havenstein 1	Poffo 4 Buzzi 3	Fiedler 2/3/4

Fig. 18 - Selection of Samples by Building Type and Category of Material

INFORMATION FROM BUILDINGS AND SAMPLES

FRANZ HOUSE c.1870

Site: Rua Sarmento, Itoupava, Blumenau, Santa Catarina, Brazil.

Date: 23.6.1993

Building Description: The Franz House was built circa 1870. A simple timber- frame structure with external and internal daub panels. Deterioration problems are mainly due to daub decay.

Sample Location:

Franz 1: Daub The sample was taken from the west wall. Left hand- side window. (h= 1m from the sill beam)

Franz 3: Render The sample was taken from the west wall. Left hand- side of the window. h= 1m (from the sill beam).

LUMKE HOUSE c.1890

Site: Testo Alto, Pomerode, Santa Catarina, Brazil.

Date: 6.7.1993

Building Description: The Lumke House was built circa 1890. A simple timber- framed structure with external and internal panels filled with daub. The window profiles have careful wood work. Deterioration problems are mainly due to daub decay.

Sample Location:

Lumke 1: Daub - The sample was taken from the north wall, last panel on the left hand- side of the door. (h= 1.00 from the sill beam).

Lumke 2: Render - The sample was taken from the north wall, last panel on the left hand- side of the door. h= 2.00 (from the sill beam).

WACHOLZ HOUSE c.1870

Site: Testo Alto, Pomerode, Santa Catarina, Brazil.

Date: 7.7.1993

Building Description: The Wacholz House was built circa 1870. Interesting example of a pioneer building: timber-framed with brick and daub panels. The lounge is plastered and decorated with stencil paintings. Deterioration problems are observed in plasters, pointings and sill beams.

Sample Location:

Wacholz 1: Daub The sample was taken from the internal partition which divides the lounge and bedroom. It was observed that the panel gaps (resulting from the daub shrinkage) between the daub and the frame were filled with a sort of 'rolled' fibre.

Wacholz 2: Plaster The sample was taken from the internal partition which divides the lounge and bedroom. The support is daub.

Wacholz 3: Plaster The sample was taken from the lounge wall (west wall). The support is the timber frame.

Fig. 19 - Summary of Information: buildings and samples

TOTTENE HOUSE c.1890

Site: Guaricana, Ascurra, Santa Catarina, Brazil.

Date: 5.7.1993

Building Description: The Tottene House was built circa 1890. A very simple timber-framed structure with external adobe blocks. Inside access was not possible. The house is completely neglected. Areas of adobe are missing and are exposed to rain penetration.

Sample Location:

Tottene 5: Adobe/ Bedding Mortar The sample was taken from the front wall- north. The last panel on the right. (h= 1.0m)

Tottene 1: Render The sample was taken from the front wall- north, right hand- side of the main door- twisted side posts, above the rail frame.

CHEMINELLI HOUSE c.1890

Site: Rodovia 470, Diamante, Rodeio, Santa Catarina, Brazil.

Date: 5.7.1993

Building Description: Cheminelly House was built circa 1890. A timber- framed structure with brick panels. The masonry detail does not include pointing mortar. The timber structure was split by axe. The house is partially demolished ie back outshot (kitchen and service). This internal plaster is now exposed and is eroded at points. Nevertheless walls and internal plasters are well conserved.

Sample Location:

Cheminelli 1: Bedding Mortar The sample was taken from the west wall, left hand- side. (h= 1,70m from the ground).

BUZZI HOUSE 1886

Site: Ribeirao Sao Paulo, Ascurra, Santa Catarina, Brazil.

Date: 5.7.1993

Building Description: The Buzzi House, an Italian immigrant's house, was built in 1886. A brick structure- unrendered. Two floors. Openings and corners are detailed with rendered profiles. The plan- form is based on three equal- sized rooms. The house had problems from floods in 1893/1910. Deterioration of the brick pointing, bedding mortar and renders/ plasters are largely evident.

Sample Location:

Buzzi 1: Bedding Mortar The sample was taken from the south wall, second floor, under the window.

Buzzi 2: Render The sample was taken from south wall side, second floor, window profile- right hand-side.

Buzzi 3: Plaster The sample was taken from the main hall above the door opening between the hall and the kitchen.

Fig. 19 - Summary of Building Information: buildings and samples (continued)

FIEDLER HOUSE 1888

Site: Itoupavazinha, Blumenau, Santa Catarina, Brazil.

Date: 17.3.1993

Building Description: The Fiedler House and Shop was built in 1888. The building is a fine example of a rendered brick structure with front shed supported by colonnades and symmetrical staircase. Inside the partitions are timber-framed at the first floor and wooden planks at the loft. The plan includes basement (high cellar), first floor and loft. The plasters cover the frame structure and are decorated with stencil.

Sample Location:

Fiedler 1: Render The sample was taken from outside- front wall, left hand- side of the main house entrance.

Fiedler 2: Plaster The sample was taken from the corridor wall near the staircase leading to the loft. The support is brick.

Fiedler 3: Plaster The sample was taken from the corridor wall near the staircase leading to the cellar. The support is the timber- frame.

Fiedler 4: Plaster The sample was taken from the ceiling of the dining room. It is stencil decorated. The support is daub.

Fiedler 8: Render The sample was taken from outside (front wall, left- hand side) of the basement staircase.

REINCKE HOUSE c. 1890

Site: Rua Blumenau, Timbo, Santa Catarina, Brazil

Date: 19.6. 1993

Building Description: The Reincke family house was built circa 1890. It is a timber- framed structure with brick infilling in the outer walls. The infill material of the partitions is concealed and therefore not identified. The plan-form is two units: main house and kitchen linked by a cross passage. All the rooms have plaster covering the frames and panels. The master bedrooms were at an early stage (approx. 1930) converted into a lounge and decorated with stencil painting. The house is very deteriorated due to lack of maintenance. Decay is widespread in timbers, plaster and pointing.

Sample Location:

Reincke 1: Pointing Mortar The sample was taken from the front wall (brick panel) above the window immediately to the right of the door.

Reincke 8: Plaster The sample was taken from the front bedroom (south wall). The support is brick.

HAVENSTEIN HOUSE 1932

Site: Sarmento, Blumenau, Santa Catarina, Brazil.

Date: 23.6.1993

Building Description: The Havenstein House is a typical example of a late timber-framed house built in 1932. The front wall is adorned with herringbone bricknogging panels. Inside all the timber- framed walls and timber structure of the ceiling are concealed by plaster. It is decorated with stencil painting. Deterioration is just appearing with problems in the pointing.

Sample Location:

Havenstein 1: Plaster The sample was taken from the service area.

Havenstein 2: Pointing Mortar The sample was taken from the front wall- herringbone panel the right hand- side window.

Fig. 19 - Summary of Information: buildings and samples (continued)

THUROW HOUSE c.1890

Site: Estrada Rio dos Cedros, Timbo, Santa Catarina, Brazil.

Date Removed: 6.7.1993.

Building Description: The Thurow family house was built circa 1890. The plan presents two attached timber-framed structures probably built in two phases. The left hand structure has the outer panels infilled with hand-made bricks and the right hand with extruded ones. The internal back walls have evidence of adobe infill suggesting that all internal walls are infilled with adobe infill. Decay problems are mainly the deterioration of mortar pointing and plaster.

Sample Location:

Thurow 3: Pointing Mortar The sample was taken from the left- hand structure. Lower panel of the twisted post, immediately to right of door.

ZIMATH HOUSE c.1890

Site: Pomeranos, Timbo, Santa Catarina, Brazil.

Date Removed: 11.6.1993

Building Description: The Zimath house was built circa 1890. It is a fine example of solid brick structure ie unrendered. The plan- form is two units — main house and kitchen linked by a small cross passage. The house has careful joinery and brick work. Every room is plastered inside. The owner remembers that the master bedroom had stencil painting. Decay problems are mainly structural. A few bricks at the bottom of the kitchen wall are eroded. The mortar pointing is in very good condition.

Sample Location:

Zimath 3: Pointing Mortar The sample was taken from the front wall below the right hand- side window

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POFFO HOUSE c.1890

Site: Ribeirao Sao Paulo, Ascurra, Santa Catarina, Brazil.

Date: 5.7.1993

Building Description: The Poffo family house was built circa 1890. It is an Italian Immigrant house. It was built originally with unrendered brickwork- polychrome brickwork (flared bricks), but in 1937 it was rendered. All the rooms are plastered including the ceiling. The later plaster is now falling down and the brickwork with decorative effect of dark bricks and pointing mortar is revealed.

Sample Location:

Poffo 1: Pointing Mortar The sample was taken from the west wall, above the right hand- side window.

Poffo 4: Plaster The sample was taken from the veranda- ceiling plaster with daub support.

Fig. 19 - Summary of Information: buildings and samples (continued)

2.4 ANALYTICAL PROCEDURES

2.4.1 Description of Samples and Selection of Analytical Procedures

The laboratory programme was based on a careful examination of the collection of the selected samples. Before undertaking chemical and instrumental analysis that would modify the original condition of the samples, they were studied under low magnification and the general characteristics recorded. Fragments of samples were systematically observed to record state, texture, inclusions, characteristic features and colour. Chemical spot tests to check the presence of calcium carbonate were also carried out. A portion of the samples were kept intact as reference material and sub- samples for further analysis were separated and prepared. The sequence of the visual description of samples and the visual data to assist in the evaluation of further analytical results are illustrated in the following tables. (fig. 20,21)

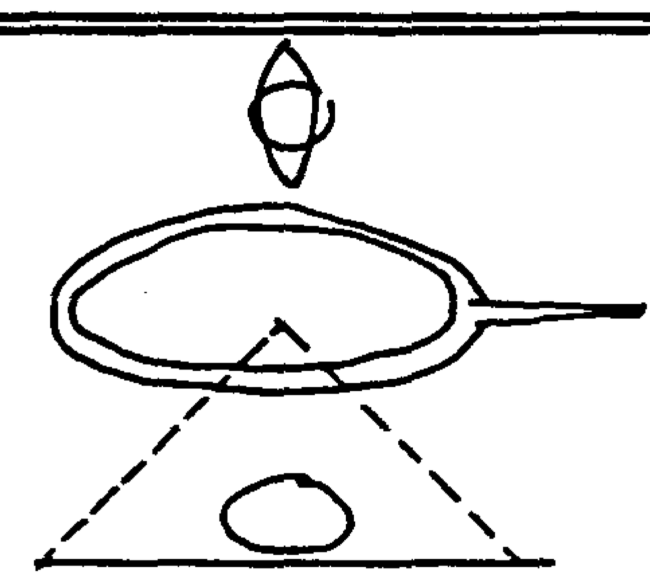
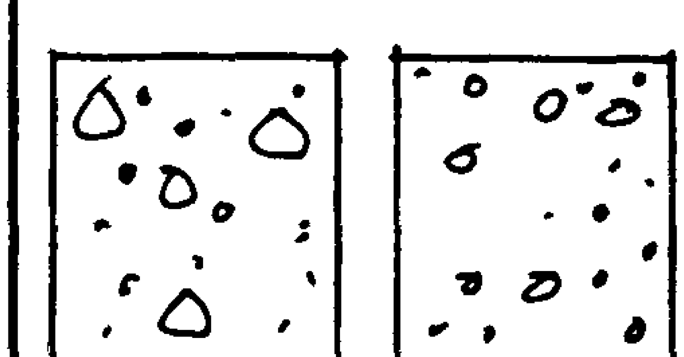
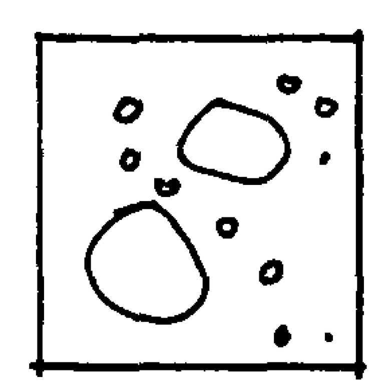
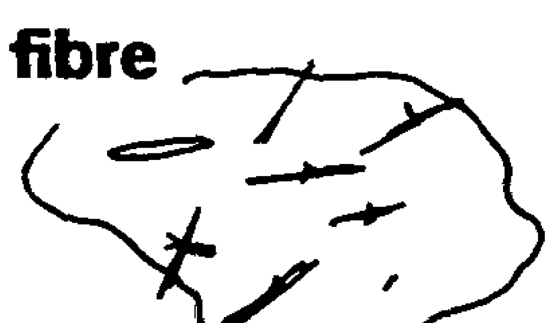
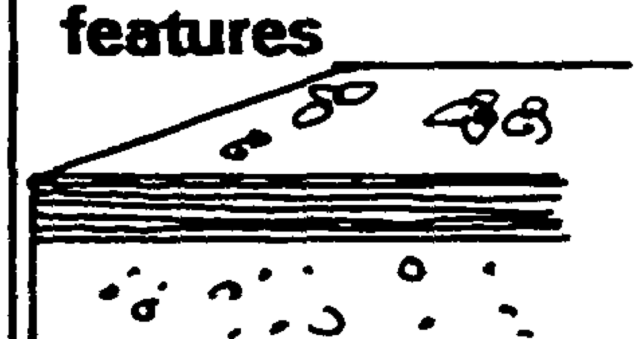
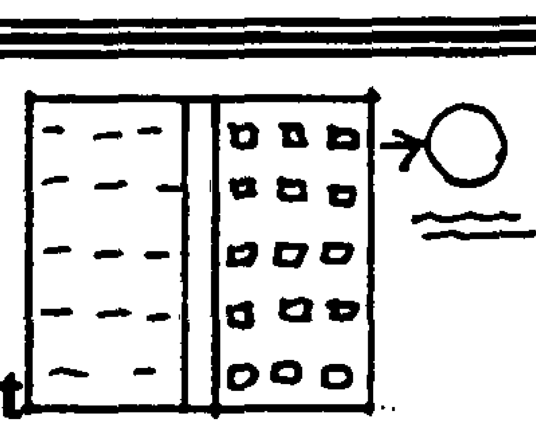
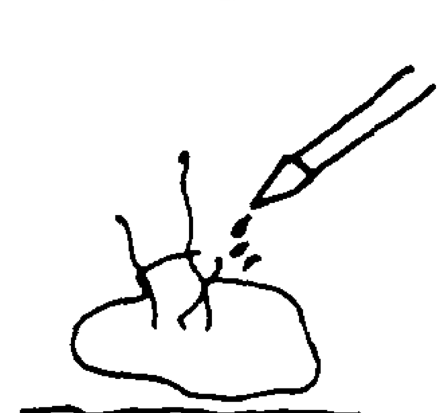
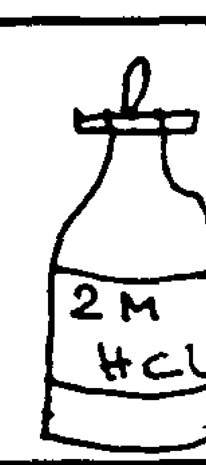
state **fragments or powder.** **strong or weak**	 **observe under low magnification**	**texture**  **rough or fine**	**inclusions**  **coarse grains of lime, shells?**
fibre  **straw, hair, dung?**	**features**  **Paint, coating types.**	**other**	
Colour **•Specify colour by the Munsell Soil Chart** 		**• visual comparison with Hue, Value and Chroma scales for colour matching.** **• light source- natural daylight.**	
Bubbles? **vigorous reaction?** 		**HCL** **• Drops of hydrochloric acid.** **• Observe reaction.** 	

Fig. 20 - Visual Description: procedural stages

PRELIMINARY OBSERVATION OF SAMPLES

SAMPLE	DESCRIPTION	COLOUR	HCL TEST
Tottene 5: ADOBE	Solid fine grained piece (1312g) of adobe and bedding mortar. The adobe fragment: 13cm 9cm x 5,5cm. Fibres are not evident, but fine elongated voids are visible.	PINKISH GREY Hue 7.5 YR 6/2	Negative
Franz 1: DAUB	Solid clayey lumps (813g). The largest 9cm x 4cm 3cm. Possible to break down, but difficult. Fibres are evident.	REDDISH YELLOW Hue 7YR 6/6	Negative
Lumke 1: DAUB	Some lumps (412 g). Weaker material comparing with the other daubs. Largest fragment: 7cm x 4cm x 5cm. Fibres are not evident. Pebbles and gravel.	YELLOWISH BROWN Hue 10YR 5/8	Negative
Wacholz 1: DAUB	Solid clayey lumps (813g). The largest 9cm x 4cm 3cm. Possible to break down, but difficult. Fibres are evident.	REDDISH YELLOW Hue 10YR 6/6	Negative
Tottene 5: BEDDING MORTAR	Fine grained lumps as well powder material. Largest lump: 5cm x 5cm x 1cm. Very easy to break. Evidence of fibres.	REDDISH YELLOW Hue 7.5YR 6/6	Negative
Cheminelli 1: BEDDING MORTAR	Fine grained lumps. Medium and small as well powder material (246 g). The largest: 5cm x 2,5 cm x 1cm. Fibres are not evident. Easy to disintegrate.	REDDISH YELLOW Hue 5YR 6/8	Negative
Buzzi 1: BEDDING MORTAR	Lumps of fine grained material medium and small fragments (251g). The largest: 3cm x 2cm x 1,5. Fibres are not evident. Easy to disintegrate.	REDDISH YELLOW Hue 7.5YR 6/6	Negative
Franz 3: RENDER	Brown rough mortar (coarse aggregates). Lumps of weak material. Medium and small fragments (362 g). The largest: 4cm x 3cm 1cm. Weak material. Weathered limewash. Small lumps of lime. Fibres are not evident. Easy to disintegrate.	BROWNISH YELLOW Hue 10YR 6/6	Positive Low

Fig. 21 - Summary of Sample Observation

PRELIMINARY OBSERVATION OF SAMPLES

SAMPLE	DESCRIPTION	COLOUR	HCL TEST
Lumke 2: RENDER	Brown rough mortar. Lumps of weak material. Two small fragments (87 g). The largest: 5cm x 3cm x 2,5cm. Limewashed. Fibres are not evident. Easy to disintegrate.	YELLOWISH BROWN Hue 10YR 5/4	Negative
Tottene 1: RENDER	A pale brown mortar with big lumps of lime. Fine grained texture. Many small and medium fragments (134g). The largest: 3cm x 2cm x 1,5cm. Fibres are not evident. Limewashed - ochre colour. Weak material.	LIGHT YELLOWISH BROWN Hue 10YR 6/4	Positive
Buzzi 2: RENDER	A pale brown mortar. Fine grained texture. Few medium/ small lumps and powder (162g). The largest: 4cm x 2cm x 0,5cm. One coat of appox. 3cm width. Weathered limewash. Visible lumps of lime. Weak material, possible to disintegrate.	YELLOW Hue 10YR 7/6	Positive
Fiedler 1: RENDER	Large lump of well bound reddish material. Fragment: 6cm x 5,5cm x 2cm (150g). Medium/fine texture. One coat of approx. 2cm width. Limewashed. Visible lumps of lime, but small. Lumps of reddish fine particles.	REDDISH YELLOW Hue 7.5YR 6/6	Positive
Fiedler 8: RENDER	A well bound mortar. Well sorted grainy texture. Small fragments (29g). The largest 3cm x 5cm 1cm. Few and small lumps of lime. Not possible to disintegrate.	REDDISH YELLOW Hue 7.5YR 6/6	Positive
Wacholz 2: PLASTER	Two big fragments (481g). Two coats applied at intervals of years linked by a thin layer, probably the early finish. Thick white top layers of limewash and stencil paint. Rough texture. Easy to disintegrate. Few fibres are observed.	PALE BROWN Hue 10YR 6/3 BROWNISH BROWN Hue 10YR 6/6	Negative

Fig. 21 - Summary of Sample Observation (continued)

PRELIMINARY OBSERVATION OF SAMPLES

SAMPLE	DESCRIPTION	COLOUR	HCL TEST
Wacholz 3: PLASTER	Medium and small fragments (120 g). The largest: 4cm x 3cm 1cm. Possible to desintegrate. Two coats: lime undercoat (visible lumps of lime) and earth top coat. Thick paint - layers of limewash and stencil decorated with green motifs. Visible fibres.	PINKISH WHITE Hue 5YR 8/2 BROWNISH YELLOW Hue 10YR 6/6	Positive lime undercoat
Reincke 8: PLASTER	One medium and small size fragments (111g). The largest: 5cm x 2,5cm x 2cm. Very weak lumps. Two coats applied at intervals of years and linked by layers of paint white and blue colours. Rough texture. Easy to disintegrate. Several layers of limewash and stencil with blue motifs.	LIGHT YELLOWISH BROWN Hue 10YR 6/4	Negative
Havenstein 1: PLASTER	Well bound mortar. Medium texture. Only one lump (74g). Fragment size: 4cm x7cm x 1cm. The paint is resistant compared with the other samples.	VERY PALE BROWN Hue 10YR 7/4	Positive
Poffo 4: PLASTER	Large and small fragments of ceiling daub and plaster (490g). The largest: 15cm x 9cm x 2cm. The plaster coats are not homogeneous — bits of clayey earth and bits of lime earth with different textures and colour.	VERY PALE BROWN Hue 10YR 7/4	Positive
Buzzi 3: PLASTER	One coat of white mortar. Rough texture and appearance. Large and small fragments. Well bound. Visible lumps of lime. The layer is a dark red paint.	WHITE Hue 10YR 8/2	Positive
Fiedler 4: PLASTER	Four fragments (83g). The largest 7cm x 6cm x 0,5cm). A white mortar of one coat. Very fine texture. The top layer is green in colour, very soft textured.	WHITE Hue 10YR 8/2	Positive

Fig. 21 - Summary Sample Observation (continued)

PRELIMINARY OBSERVATION OF SAMPLES

SAMPLE	DESCRIPTION	COLOUR	HCL TEST
Fiedler 3: PLASTER	Some fragments (115 g). The largest: 4cm x 2,5cm x 1cm. Two coat- fibre and lime undercoat and earth coat. Small lumps of lime are visible. The top paint layers are white and green.	WHITE Hue 10YR 8/2 REDDISH YELLOW Hue 7.5YR 6/6	Positive undercoat
Fiedler 2: PLASTER	Some lumps of medium size (89g). The largest: 5,5cm x 3cm x 1cm). One coat medium size medium texture. Possible to disintegrate. Small lumps of lime are visible. The paint has layers of white, green and white colours.	REDDISH YELLOW Hue 7.5 YR 6/6	Positive
Reincke 1: POINTING MORTAR	A white mortar. Very fine texture and well bound. Small fragments (9g). The largest: 3cm x 1,5cm x 0,6 cm. Thin face mortar and joint profile.	WHITE Hue 10YR 8/2	Positive High
Thurow 3: POINTING MORTAR	A white mortar. Rough texture. Well bound. Six small fragments (28g). The largest: 3,5cm x 1cm x 1,5cm). Difficult to disintegrate.	WHITE Hue 10YR 8/1	Positive High
Havenstein 2: POINTING MORTAR	A white mortar. Rough texture and well bound. Some fragments (19g). The largest: 2cm x 2cm x 1cm. Smooth surface and joint profile.	WHITE Hue 10YR 8/1	Positive High
Zimath 3: POINTING MORTAR	A white mortar. Good fragments (37g). The largest: 2cm x 3cm Very dense bound material. Deep face. Smooth surface and joint profile	WHITE Hue 10YR 8/1	Positive High
Poffo 1: POINTING MORTAR	A white mortar. Some small lumps a weak material (32g). Rough texture. Smooth surface. Joint profile.	WHITE Hue 10YR 8/2	Positive High

Fig. 21 - Summary Sample Observation (continued)

Visual analysis by low magnification and HCL spot test provided a better understanding of the materials to define further analysis which was useful in developing and selecting sub-samples. The characteristics of the materials described may be summarised as follows:

1. The daubs and adobe are compact materials which are difficult to disintegrate. They tend to be brown to yellow in colour. Straw is present in daub infills.
2. The bedding mortars tend to be finely textured and reddish yellow in colour. Clay seemed to be the principal binder.
3. The renders have variable visual characteristics. They range from very weak materials which are rough in texture and not reactive in HCL to more dense materials which react positvely to HCL. They are not homogeneous, contain coarse grains of lime (> than 2mm) and present different texture and colours.
4. Compared to the renders, the plasters have similar visual characteristics. The great difference occurs in the number of layers of paint and colour/ decoration. Only one plaster — a ceiling plaster — is white.
5. The pointing mortars are all white, more compact materials and fairly positive to HCL. They tend to be gritty in texture.

Considering factors such as the characteristics of the materials described above, the information required, the time needed to carry out the analysis and the available facilities to develop analytical procedures, the laboratory programme was organized in two large groups of analytical studies as follows:[25]

GROUP 1: ADOBE, DAUB AND BEDDING MORTAR MATERIALS

These are soil based materials used as infill material or bedding mortar. The soil is a natural mortar where the clay acts as a binder and the inert portion (silt, sand and gravel) as an aggregate. For this group, the determination of the grain size, organic matter content and Atterberg limits were general procedures for all selected samples.

GROUP 2: RENDER, PLASTER AND POINTING MORTAR MATERIALS

These are surface materials, the nature of which cannot be clearly identified without analysis. For this group, observation in thin section was the general procedure for all selected samples; other tests were performed only on selected samples. These include the

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[25]See above the Section Questions and Methodology.

determination of the content of calcium carbonate, aggregates and organic matter. Microscopic examination of cross sections was carried out only on selected internal plasters where the chronological study of paint layers is of particular concern. Pigment identification was performed only on selected samples that had coloured layers of paint.

The following table shows the laboratory progamme of the selected samples organised by building type and the selected procedures according to the group of materials and characteristics. (fig. 22) The procedures employed to analyse the samples and the discussion of results are described below, further descriptions of the analytical data are given in the Appendices.

GROUP 1

EARTH PANEL	BRICK PANEL	BRICK WALLING	RENDERED WALLING
DAUB			
Franz 1 Lumke 1	Wacholz 1		
ADOBE			
Tottene 5			
BEDDING MORTAR			
Tottene 5	Cheminelly 1	Buzzi 1	

Analysis performed:

Organic Matter Content, Grain Size Analysis and Atterberg Limits

GROUP 2

EARTH PANEL	BRICK PANEL	BRICK WALLING	RENDERED BRICK
RENDER			
Franz ◇ ○ Lumke 2 ◇ Tottene 1 □■ 1		Buzzi 2 □	Fiedler 1 □■ Fiedler 8 □
PLASTER			
	Wacholz 2 ◇◆ ○ Wacholz 3 □ Reincke 8 ◇◆ ○ Havenstein 1 □■	Poffo 4 □ Buzzi 3 □■◆	Fiedler 4 □◆ ○ Fiedler 2 □◆ Fiedler 3 □◇
POINTING MORTAR			
	Reincke 1 □ Thurow 3 □■ Havenstein 2 □	Zimath 3 □■ Poffo 1 □	

Analysis performed:

Microscopy Examination of Thin Sections, Determination of Calcium Carbonate Content □, Determination of particle size of aggregates ■, Determination of Organic Matter Content ◇, Microscopy of Cross Sections ◆, Pigment Identification and Fat Spot Tests ○

Fig. 22 - Laboratory Programme: analytical procedures for selected samples

2.4.2 Determination of Particle Size Distribution

Aim

Particle size analysis was undertaken to determine the composition of the earthen materials.

Preparation of Samples

Air dried samples were selected and crushed lightly with a mortar and a rubber covered pestle. The samples were weighed to the nearest 0.01g. Larger samples were subdivided using a riffle box. About 45g of each sample was used for grain size analysis. The majority of the organic material (plant fibre) was removed from the sample. Prior to separation of the particles, the samples were completely dispersed with 25ml sodium hexametaphosphate solution.

Method

Earthen materials consist of particles of soil. The particle size distribution or texture of the soil is one of the main characteristics of earthen materials. This can be evaluated by simply rubbing the soil between the fingers, but for the accurate determination of particle size the soil needs to be broken up, dispersed and the fractions separated. There are simple particle separation tests with varying degrees of precision. The sieving of the coarse fraction and sedimentation of the silt and clay fraction in a suspension measured by pipette or hydrometer are analytical methods which give exact measurements. The particles are separated into gravel, sand, silt and clay because each of these particle types behaves in a characteristic way. Gravel, sand and to a lesser extent silt are characterised by their stability when exposed to water. Clay is unstable acting as a binding between the coarser particles. The choice of procedure depends upon the characteristics of the soil material, the level of accuracy needed and the available apparatus. The size of sample required for testing depends on the size of the largest particles of soil; fine grained soils require a lesser quantity of material.[26]

The British Standard method selected herein is used for cohesive sandy soils which require a relatively small sample (approx. 60g). The sieving procedure selected was a dry sieving procedure (BS 1377:1975, Test 7(B). The material was pretreated to disperse the particles and then washed on a 63μm sieve to separate clay and silt from sand. The retained particles

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[26]Tests to determine the particle size requiring very simple apparatus are described in the literature consulted. See Norton, J. (1986), Building with Earth. A Handbook, pp. 11- 14. More accurate tests are described by Head, K.H. (1980) Manual of Soil Laboratory Testing, Vol.1, pp. 143- 215.

were dried and sieved in a set of standard sieves. The material which passes the 63μm sieve is too fine to be sieved and a sedimentation test was used to determine particle sizes distribution. The procedure selected was the pipette method (BS1377: 1975, Test 7 (C)). This is the primary British Standard procedure for fine particles. The material passing the 63μm sieve was transferred with a funnel from the receiver into a 500ml sedimentation cylinder and the water level was made up to the calibration mark. In the sedimentation test the particles are allowed to settle in a known volume of water under gravity. Measurements of mass from pipette samples are taken at known intervals and silt size particles and clay are determined.

Calculation

To draw up a particle size curve the mass of each grain size was calculated as a percentage of the total initial mass as well as the percentage passing through the sieve. The calculations were made according to the following formulae: (fig. 23)

Percentage of mass retained $R_1 = \frac{m_{s1}}{m_1} \times 100$

Cumulative percentage of mass retained $P_1 = 100 - R_1$

m_1 = total initial mass

m_{s1} = mass retained on the first sieve (m_{s2} the second and so on)

Fig. 23 - Calculation Simple Dry Sieving

Pipette samples were taken at three specified time intervals according to the specific gravity of the particles in the suspension (SG) to determine the mass of solid m_1, m_2 and m_3 and a pipette sample was taken from the sedimentation tube containing only dispersant which determines the mass of solid material m_4. All the pipette samples were placed in an oven at 105°C until the samples were evaporated to dryness and weighed to the nearest 0.001g. The mass of solid material in the whole 500 ml of suspension is denoted by W_1, W_2, W_3. It is calculated as a proportion of the measured mass in the pipette volume V_p using the formulae below: (fig. 24)

Pipette Sample Time	Pipette Mass Calculation	Mass in 500ml Suspension	Percentage Calculation	Size Category
4 min 5 s	m_1 = Mass First Sample	$W_1 = m_1 \times \frac{500}{V_p}$	$P_M = \frac{(W_1 - W_2)}{m} \times 100$	Medium Silt
46 min	m_2 = Mass Second Sample	$W_2 = m_2 \times \frac{500}{V_p}$	$P_F = \frac{(W_2 - W_3)}{m} \times 100$	Fine Silt
6 h 54 min	m_3 = Mass Third Sample	$W_3 = m_3 \times \frac{500}{V_p}$	$P_{cy} = \frac{(W_3 - W_4)}{m} \times 100$	Clay
	m_4 = Mass Sample dispersant	$W_4 = m_4 \times \frac{500}{V_p}$	PC = 100 - total percentages	Coarse Silt

Fig. 24 - Calculation Pipette Test

Evaluation

Particle size analysis is the first test to be performed on earthen materials to characterise samples and to select soil for repair and replacement. The results collected here were considered useful to determine the most important properties of the adobe, the daubs and the mortars.[27] Although the analysis undertaken requires time to perform, they do not require specialised operators and analysts.

2.4.3 Determination of Liquid and Plastic Limits

Aim

In this study the analysis of liquid and plastic limits was undertaken to determine the plasticity of the earthen materials ie the behaviour of the soil with different moisture contents and the durability of the soil as a building material.

[27]See Chiari, G. (1983), "Characterisation of Adobe as a Building Material", paper in the Proceedings of the International Symposium on the Conservation of Adobe. Adobe 84, pp. 31-40. The author reviews the types of analysis available and gives a critical evaluation of the information obtainable.

Preparation of Samples

Samples of approximately 140g were prepared by sieving through a 425 μm sieve. The samples were mixed with distilled water and left for a period of 24 hours inside an airtight container. The samples were thoroughly mixed with spatulas for at least 10 min. For the cone method about 100g was used and for the plastic limit test two subsamples of about 15-20 g were used. The samples were weighed to the nearest 0.001g.

Method

Earthen materials consist of clay, silt and sand particles. The clay fraction which greatly influences the plasticity of a soil differs according to its mineralogical and chemical composition. Particle size distribution alone will not necessarily indicate how a soil will behave with a change in water content. The physical state of the soil at different moisture contents is defined as its consistency; the consistency will differ from soil to soil at the same moisture content. Consistency can be evaluated by simple tests requiring minimal equipment. For more precise results, the variations in soil consistency are determined by measuring the moisture content of a soil in a plastic and liquid state. The consistency limits also known as Atterberg limits provide the measurements in numerical terms. These measurements give useful indications about clay types and properties of earthen materials.[28]

The measurements performed herein were the plastic and liquid limits applied for cohesive soils (the fraction passing a 425 μm sieve). The method selected for assessing the liquid determination was the cone penetrometer test (BS 1377: 1975, Test 2 (A)). The cone method is based on the measurement of a cone's penetration into the soil (the penetration of the cone at the LL is 20mm). The preparation of the samples followed the standard procedures of the above test. The plastic limit procedure selected was the rolled thread test (BS 1377: 1975, Test 3). This test determines the lowest moisture content at which the soil is plastic.

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[28]Tests to evaluate the consistency of the finer fraction of soils (diameter < 0,4mm graded by sieving) requiring simple apparatus are described in the literature consulted. The 'dry strength test', 'tapping test' or 'ribbon test' can be used. See Doat, P., et al. (1991) Building with Earth, pp.180-1 and Norton, J. (1986), Building with Earth. A handbook, p.17. See also the same references above and Head, K.H. (1980), Manual of Soil Laboratory Testing, pp.51- 75 for the methods to determine the Atterberg limits of a soil.

The Swedish researcher Dr Atterberg defined the boundaries of the plastic state of a soil. Five 'limits' can be measured: the liquid limit, the plastic limit, the shrinkage limit, the adsorption limit and limit of adhesion. The first two are the most important.

Calculation

The liquid limit (LL) is defined as the moisture content at which a soil passes from the plastic to the liquid state. The moisture content of four samples from each soil was determined. The average depth of penetration ranged from approximately 15mm to 25 mm (measurements below and above 20 mm penetration). The moisture content (%) from each penetration was calculated from the wet and dry weighings according to the following calculation. (fig. 25) The results of each penetration were plotted against the moisture content and a graph was drawn from which the liquid limit was determined.

The plastic limit (PL) is the moisture content at which a soil passes from the plastic to the solid state. The method for determining PL was repeated for four subsamples. The moisture loss and moisture content of the four subsamples together was calculated according to the following formula. (fig. 25) The plastic limit of the soil was calculated from the average of four determinations.

The plasticity of the soil is indicated by the plasticity index (PI) which is defined as the liquid limit minus the plastic limit (PI = LL-PL) and it is largely dependent on the amount of clay present in the soil.

The relationship between these three determinations (LL, PL, PI) and the percentage of clay were plotted in diagrams (liquid limit vs. plasticity index and percentage of clay vs. plasticity index) and the cohesiveness, expansivity and activity coefficient of soils were estimated. The activity coefficient of the soils is also equal to the ratio of the plasticity index and the percentage of clay particles.[29]

m_2 = wet soil and container

m_3 = dry soil & container

m_1 = container

Moisture loss (g) = $m_2 - m_3$

MOISTURE CONTENT (W %) = $\frac{m_2 - m_3}{m_3 - m_1} \times 100\%$

Fig. 25 - Calculation of Moisture Content

[29]See Houben, H., Guillaud, H. (1994), Earth Construction. A comprehensive Guide, pp. 58-9 for the understanding of the diagrams of the relationship between the liquid limit, plasticity index and quantity of clay which were used to plot the results of this study and make considerations about the earthen materials. See characterization section below.

Evaluation

Important information concerning the behavioural response of a soil to moisture is provided by the liquid and plastic limits determinations. The analyses undertaken require time to perform, but they do not require specialised operators and analysts. The results obtained can be used to characterise historic samples and to select soil for repair and replacement.

Although definitive identification of clay type is provided only by mineralogical analysis such, as the X-ray powder diffractometry method, liquid and plastic limits give useful information to supplement the identification of the clay types. For instance, high plasticity index may indicate the presence of highly active clays like montmorillonite. This clay type is avoided because of its tremendous swelling and contraction which adversely affect the earthen materials. High plasticity is also correlated with greater expansion of wet soil and greater shrinkages of dry soil.[30] Any replacement soil should be compatible with a mortar soil in terms of plasticity index.

The cone test selected to determine the liquid limit is prefered to the Casagrande test as it has been proved to be a more reliable and consistent test then any other. The Casagrande test can be useful in certain cases as it requires only a small amount of material and is quicker than the cone method.[31]

2.4.4 Determination of Organic Matter

Aim

The loss on ignition analysis was undertaken to determine the amount of organic matter in earthen materials. The materials chosen for this analysis exhibited strong or weak evidence of fibre admixtures according to visual analysis.

Sample Preparation

Approximately 20g of air- dried material was separated from the samples for testing.

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[30]For a comprehensive understanding of the information that can be obtained from the determination of plastic and liquid limits see: Clifton, J.R. and Brown, P.W. (1978) Methods for Characterising Adobe Building Materials, pp. 22-6 and Houben, H., Guillaud, H. (1994), Earth Construction, pp.58-9.

[31]See comparison of Casagrande and Cone methods by Head, K.H. (1980), op cit, p.67.

Method

Earthen materials may include organic compounds in their composition. Usually plant fibres are found which may influence the behaviour of the material, controlling shrinkage and providing reinforcement. The amount of fibre can be evaluated by dispersing the material in water and retrieving the organic matter. The fibre fraction is less dense than water and can be removed and weighed. The amount of organic matter can also be calculated by ignition, ie heating a sample to burn off all organic material and measuring the weight difference. More sophisticated methods such as differential thermal analysis (DTA), Fourier Transform Infra-Red Spectrophotometry (FTIR) and Gas Choromatography (GC) are used to gain more detailed information about organic materials.[32]

The measurement performed herein was the loss on ignition determination. The test is an approximate method for measuring the organic matter content of soils and earthen materials. It is based on the fact that when a soil is heated to 450°C, only the organic matter is oxidised. This method was followed to measure the percentage of organic matter.[33]

Calculation

Calculation of the loss on ignition was based on the following formula: (fig. 26)

mass of the sample = A

mass of the ignited sample = B

$$\% \text{ loss on ignition} = \frac{(A-B)}{A} \times 100$$

Fig. 26 - Calculation Loss on Ignition

[32]See Newton, R.G., Sharp J.M. (1987, "An Investigation of the Chemical Constituents of some Renaissance Plasters", paper in Studies in Conservaiton, vol. 32 pp. 163-175. The authors explain that in the differential thermal analysis (DTA) the exothermic reaction in the range of 300-400°C is due to oxidation of the organic components of the plasters tested, such as hair and gelatine.

And Pettifer, K. (1986), "A petrographic Investigation of Ancient Mortars and Concretes", BRE Special Report No.44, pp. 44- 86. Organic substances were detected by thermal analysis in several specimens and present characteristic exothermic peaks consistently at about 325 °C due to the burning of organic substances.

[33]The method selected is based on the determination of ignition of a soil at low temperature described by Hesse, P.R. (1971), A Textbook of Soil Chemical Analysis, pp. 209- 10. The method was Procedure 6 of the Laboratory Practicals Handbook/ Soil Science Level 2, Department of Conservation Sciences.

Evaluation

The loss on ignition test is a simple determination that requires only standard apparatus to weigh the samples and burn them. The results obtained were in accordance with the visual evidence of fibres; the samples which had the most fibres on visual examination presented the highest percentages of mass loss, ie organic matter content by the loss on ignition test.

2.4.5 Microscopic Observation of Thin Section

Aim

The examination of thin sections using light microscopy was carried out to characterise the fine fraction (the matrix or the binder material and fine/silt size inclusions), coarse fraction (the aggregates) and the relationship between the coarse and fine fractions. Photomicrographs of selected thin sections were taken to record the types of microfabric.

Preparation of Thin Sections

The preparation of the thin sections was carried out following standard procedures applied to friable materials. In general, the thin section procedure involved embedding the pre-selected samples in a cold- setting resin, preparing a slice of the impregnated block (approx. thickness 5mm), mounting the slice to a glass slide and then grinding it until the standard thickness was achieved (25 to 30 μm).[34]

Problems were encountered in the preparation of some samples. Difficulties included dirty edges of the specimen, incomplete impregnation and excessive thickness. The latter problem in many cases made it impossible to use polarising light microscopy to diagnose the samples. Some examples were sectioned a second time until a group of thin sections of better quality was produced. However, due to the limited sample material, it was not possible to produce new sections of some samples and these were examined under the oblique light microscope and interpreted in the light of the examination of similar materials.

Method

Polarising Microscopy

When a source of transmitted light vibrates in a single plane polarised beam through an object cut to the standard thickness of 25 to 30 microns (at this thickness minerals within the sample are mainly transparent), many optical properties of crystalline and amorphous

[34]The common procedure for impregnation and grinding is outlined by Courty, M.A., et al. (1989), Soils and Micromorphology in Archaeology, pp. 58- 61.

substances may be observed and described which are not apparent with ordinary light. The polarising or petrological microscope is the instrument used to observe thin sections. The observation and evaluation of thin sections depends on several factors. The factors relevant to this thesis are explained in the following paragraphs:[35]

In polarising microscopy, two light planes are used: 1. plane polarised light (PPL) when the polarising filters are parallel and 2. cross polarised light (XPL) when the polarising filters are crossed. The properties of the minerals observed under plane and cross polarised light are used for their identification. Among these properties, the colours seen in thin sections when viewed between crossed polarised light are the most useful diagnostic characteristic for mineral identification. Isotropic minerals (ie neither optically active nor birefringent) when viewed under plane polarised light are transparent or coloured, but remain dark under crossed polarised light. Anisotropic minerals (minerals that have double refraction, ie which are birefringent) transmit coloured light (interference colours) under crossed polarised light and become dark four times when the stage is rotated 360°. The range of colour varies according to the type of crystal, orientation and thickness of the minerals. For instance, at the standard thickness of thin sections (25 to 30 μm) quartz varies from light grey to white (first order) and calcite has a bright white interference colour in the higher order. Quartz has a low birefringence in contrast to calcite which has a high birefringence.[36]

The resolution power of the light microscope is limited to two microns and only a few square millimiters of a slide is observed. It is sometimes difficult to distinguish the nature of very small particles (eg clay, organic matter or charcoal). Clay minerals are too fine-grained to be studied with a polarised light microscope and the clay mineralogy (types of clay) cannot be determined by this technique. The character of the fine fraction is determined mainly by the manifestation of the fine fabric under crossed polarised light. The degree to which a thin section is observed and understood depends upon the experience of the observer.

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[35]The principles and techniques of optical mineralogy are outlined by Wahlstrom, E.e. (1961), in Encyclopedia of Microscopy, ed by George L.Clark, pp.470- 73.
A comprehensive text about the techniques of optical microscopy as well as an approach to the observation applied to the study of archaeological sediments and soils can be found in Courty, M. A., et al. (1989), Soils and Micromorphology in Archaeology, pp. 44- 50; 57-75; 118- 125.
Concepts and descriptive criteria for this technique applied to the field of soil science can be found in Bullock, et al. (1985), Handbook for Soil Thin Section Description, pp. 17-38.
Although the above references were used for understanding the general interpretation of thin sections, the sources do not apply specifically to the field of this thesis.

[36]The light reflected by anisotropic minerals is split in two directions which is appreciated under crossed polarised light and called **birefringence**.

Reflected Light/ Oblique Incident Light

In reflected light microscopy, the light beam that illuminates the object is usually perpendicular to the object. When the source of light is incident from an oblique angle (light from the side), the colour and characteristics of the fine fraction (clay and silt particle size) may be observed.

Thin sections were examined using a standard polarised light microscope (James Swift) with rotating stage and four objectives, having a magnification ranging from x 50 to x 400. In addition some thin sections were examined using a reflected light microscope (Carl Zeiss Jena), with zoom, having a magnification ranging from x 8 to x 40.

The fine fraction was described in plane polarised light (PPL) to indicate the colour and purity or mixture (inclusions) of the matrix and cross polarised light (XPL) to note the nature of the matrix represented by the interference colours and birefringence of the fine particles.

The coarse constituents of mortar materials were described to estimate the sorting and particle size (finer or coarser texture).[37] A general description of mineral grains and of plant/ fibrous material was noted. Detailed petrographical identification, which can be used to compare the mineralogical composition of the aggregates in the sample with potential aggregate sources surrounding the site of the buildings was not performed.

Evaluation

Examination of thin sections of historic and conservation materials has been reported extensively in scientific papers concerning the characterisation of building materials in the field of conservation.[38] In this work, the technique was found to be a powerful tool for the

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[37]McCrone, W.C., et al. (1978) Polarized Light Microscopy, pp.95-97. The authors give comprehensive information about methods of particle size measurement.
See also Alessandrini, G., et al. (1992) "The compositional ratio of mortars", paper in the Proceedings of 7th International Conference Deterioration and Conservation of Stone, pp.667- 675. The paper evaluates two techniques to measure binder and aggregate ratio of mortars: the weight aggregate percentages by chemical analysis and the volume aggregate percentages obtained by point counting thin sections. Both techniques were considered valid for the evaluation of the binder to aggregate ratio of historic mortars.

[38]Clifton, J.R., Brown, P.W. (1978) Methods for Characterising Adobe Building Materials, pp. 31-40. The authors report different microscopic techniques using slabs of impregnated blocks or thin sections of adobe and soil samples.
The following are some of the articles which report thin section analysis of historic building materials:
Middendorf, B. and Knöfel, D., " Use of Old and Modern Analytical Methods for the Determination of Ancient Mortars in Northern Germany", pp. 78; 86- 92. The analysis revealed features of old mortars such as the identification of dry- slaked lime in a calcareous mortar, pieces of brick in a gypsum mortar with a reaction border
Monte, M., Luca, M., (1993), "The Medieval Stuccoes in the Abbey of S. Stefano in Bologna", in European Cultural Heritage Newsletter on Research, pp. 73-4. The analysis of thin sections revealed gypsum and terracotta dust in a size range from a few tens to several hundreds μm and 15-30 % of the total content in the composition of the stuccoes.

analysis of the fine fraction (the matrix ie the binder material and inclusions of fine and silt size particles) and the geometric arrangement of mortar materials. In addition, the technique requires only small amounts of the material and results in a thin section of the material which can be used again for further interpretation and comparison with other samples. For the basic level of understanding required for this thesis, thin section examination revealed the features of the different types of binder material in correlation with the aggregates. In addition, it was possible to distinguish the purer from the less pure calcitic samples and the very thin earth samples (ie the matrix is low in clay content and only forms bridges linking the grains). However, the technique is costly and time consuming, requires skilled technicians and special machinery for the preparation of the thin sections and requires a specialist to analyse the optical properties, as well as the participation of the researcher familiar with the sampled materials to interpret the results.

2.4.6 Determination of Calcium Carbonate and Particle Size of Aggregate

Aim

The aim of the chemical analysis was to determine the main constituents of the mortar materials: 1. to measure the total amount of calcium carbonate in the samples that were evaluated previously by applying dilute hydrochloric acid and noting the positive resulting effervescence, 2. to determine the particle size distribution of the aggregates of a smaller number of selected samples.

Sample Preparation

For the determination of calcium carbonate approximately three sub- samples of 1.5 g from each of the sixteen selected samples were powdered and weighed to the nearest of 0.001g. Six samples were then selected from this group to determine the particle size distribution of the aggregate. Samples were selected if they were representative of types of materials and of sufficient weight (approx. 10g of aggregate). Each sample was slightly crushed in a mortar and pestle and weighed accuratelly to the nearest 0.01g.

Pettifer, K. (1986), "A Petrographic Investigation of Old Mortars", pp. 1-9. The analysis of thin sections of specimens, Roman origin revealed, for instance, the isotropic inclusions of probably volcanic glass (30/40μm) in the highly carbonated matrix; mixture of fragments of brick or tile and limestones and sand of medium and fine size of calcareous and quartz.

Method

There is no single standardized method to determine the constituents of a historic mortar. Different chemical techniques are used; such methods are described in the literature consulted.[39] The basic wet chemical analysis of historic mortars is based on the dissolution of the sample in hydrochloric acid with separation of the calcium carbonate, aggregate (sand or crushed brick and stone) and fines (clay, cement, brick and stone dust).

In this experimental work such procedures were applied to determine firstly the calcium carbonate content of a larger number of samples which were previously noted as calcium carbonate rich materials and then the particle size distribution of the aggregates of a smaller number of samples selected from the previous analysis. The procedure used to determine calcium carbonate content in the samples is based on the dissolution of carbonates in a sample and subsequent measurement of the carbonates by titration process.[40] The samples were treated with 50ml of Hydrochoric acid of known concentration (0.1N), boiled with water (about 50ml), allowed to cool and drops of Bromophenol Blue were then added. A buret was used and the solution titrated with a known concentration of Sodium Hydroxide (0.1N) to a blue/ violet end point.

For the determination of particle size distribution of aggregate standard methods were used. First, each sample was treated for calcareous matter and then the particle size was determined using a standard dry sieving method (BS 1377: 1975, Test 7 (B)).[41]

Calculation

The calcium carbonate content was calculated as the average value obtained after three dissolution tests according to the following formula: (fig. 27)

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[39]For instance, the technique of Jedrzejewska, H. (1967), "New Methods in the Investigation of Ancient Mortars", paper in the Symposium Archeological Chemistry, pp. 166, is designed as a simplified procedure to determine the contents of the three main ingredients in a historic mortar: lime, a certain proportion of hydraulic components and an inert filler (mostly sand), but well suited for kinds of mortars such as calcium carbonate mortars, gypsum mortars and clay. See also a simplified technique described by Teutonico, J. M. (1988), A Laboratory Manual for Architectural Conservators, pp.113-5.

[40]The method followed herein is based on a standard titration method to determine calcium carbonate. See Hesse, P.R. (1971), A Textbook of Soil Chemical Analysis, pp.523.

[41]See pretreatment for calcareous matter described by Head, K.H. (1980), Manual of Soil Laboratory Testing, p.189 based in the 1967 Bristish Standard.

$$\frac{[(50.0 \times F1) - (T \times F2)] \times 0.005005 \times 100}{W} = CaCO_3\%$$

F1 = Factor of Hydrochloric Acid

F2 = Factor of Sodium Hydroxide

T = Titre

W = Weight of Sample

Fig. 27 - Calculation Calcium Carbonate Content

The percentage of aggregate retained and passing through each size of sieve was calculated according to the British Standard Method.[42] (fig. 23)

Evaluation

Simple chemical analysis has been used to determine the main constituents and proportions of binder to aggregate in historic mortars. The results obtained may be used as indications for the design of compatible repair mortars. The limitations of the chemical technique are the difficulty in distinguishing carbonated lime from crushed limestone serving as aggregate and in characterising precisely the hydraulic constituents. The chemical techniques were used as simple methods to obtain basic information about historic mortars. However, they must be used in conjunction with other techniques (microscopy, instrumental analysis) for more complete and precise interpretation of the components of historic mortars.

2.4.7 Microscopic Observation of Cross Section

Aim

The examination of cross sections of paint samples from internal plasters using reflected light microscopy was carried out to describe the historical sequence of layers of paint.

Cross Sections Preparation

The samples were impregnated in a cold- setting resin, cut and polished with a series of three or four grades of emery paper and mineral oil until the section was completely flat and smooth.

[42] See the British Standard calculation for simple dry sieving in section 2.4.2.

Method

The technique of examining a cross- section of surface materials was developed for the study of paint and finish layers. For a proper microscopic examination, the sample needs to be mounted in a suitable mounting medium, cut and ground smooth in order to give a plane surface for focusing the microscope. The section required for this technique is an opaque section which is examined under reflected light. There is no need to produce a thin section.[43]

A binocular zoom microscope (Carl Zeiss), magnification ranging from x 8 to x 40, was used. A transparent micrometer scale graticule was used to measure the thickness of the layers. The substrate was identified and the sequence of layers recorded in chronological order. Each layer was identified by colour (usually without using a colour system notation) and visual characteristics. For instance, the following characteristics were recorded – discountinous layers associated with stencilling, chalky appearance of layers associated with limewashes and dirty layers or separations between layers. The samples were drawn to scale to provide an indication of the thickness and relative position of the layers.[44]

Evaluation

The technique was evaluated as reasonably simple to execute, although analysis and interpretation require a certain degree of knowledge and experience. The instrumentation is not sophisticated. The amount of information revealed in a sample is much greater than that obtained with techniques such as layering or cratering layers of paint on the site. Difficulties in the examination of cross sections may be associated with the interpretation of a greater number of surface layers and difference between layers of similar colour and characteristics. Conservation works of complex decorative surfaces may need a large number of samples for the identification of colours and decorative patterns, as well as confirmation through site investigation.

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[43]For the understanding of this techique see the following articles:
Batty, P. (1995) "The Role of Paint Analysis in the Historic Interior", article in the Journal of Architectural Conservation, pp. 30-31. The author describes the technique applied to the conservation of historic interiors.
Perrault, C. (1978), "Techniques employed at the North Atlantic Historic Preservation Center for the Sampling and Analysis of Historic Architectural Paints and Finishes", article in APT Bulletin, pp. 11-23. The author develops the methodology to describe the sequence of paint layers by the observation of cross- sections.
Plasters, J. (1956), "Cross- Sections and Chemical Analysis of Paint Samples", article in Studies in Conservation, pp. 110-114. The author describes the technique applied to the field of paint sections from pictures.
Teutonico, J.M. (1988), A Laboratory Manual for Architectural Conservators, pp. 139- 151. The author describes two methods of mounting samples in a cold setting resin, cutting and polishing. Further there is guidance for the observation of cross sections under reflected light microscope.

[44]The procedure is described in Teutonico, J.M. (1988), op cit, p.145.

2.4.8 Identification of Pigment

Aim

The identification of the pigments was carried out to provide initial information on the use of pigments. The aim was to obtain additional information about original colours and decorative characteristics of previous and existing paints.

Sample Preparation

A minute sample of paint was dispersed and mounted on aluminium support. Three specimens were scanned from each sample in the scanning electron microscope.

Method

Microchemical techniques which do not depend on sophisticated instrumentation may sometimes be used and can be reliably identified in nearly all common inorganic pigments.[45] Polarising microscopy and a scanning electron microscope (with a resolution power in the range of 2 to 20 Å) often provide reliable information for the determination of pigments.

Energy Dispersive X-ray Analysis (EDAX) on the Scanning Electron Microscope (SEM) was the technique used for the identification of pigments. With this system, the sample is bombarded by a beam of electrons and the energy dispersed emits X- rays of specific wavelengths which are analysed by a detector system, the instrument EDAX. The energy spectrum is related to the periodic table to determine the elemental composition of the sample. In addition to elemental analysis, a line profile of the density distribution of elements in an image is displayed.

Evaluation

The analytical results of EDAX/SEM are the elemental components of the pigments and not the compound. The elements are interpreted according to the composition of pigments. The technique is often sufficient to identify most of the pigments, but it is a sophisticated method, requiring expensive instrumentation and an experienced analyst to operate the equipment. Differences between some elements may be difficult due to interference (eg

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[45]See Matero F.G., Tagle, A.A. (1992), "Laboratory Exercises: Qualitative Analysis: Microchemical Identification of Pigments", in Advanced Architectural Conservation, University of Pennsylvania and Perrault, C.L. (1978), "Techniques Employed at the North Atlantic Historic Preservation Center for the Sampling and Analysis of Historic Architectural Paints and Finishes, in APT Bulletin, Vol. 10, No 2, p.29.

Barium and Titanium).[46] Elements present only in small amounts (<0.1%) are difficult to detect.

2.4.9 Identification of Oil

Aim

Microchemical tests were carried out for the detection of oil components in paint samples.

Sample Preparation

Approximately 1g of powdered selected samples of paint were prepared.

Method

A simple identification of organic substances can be performed with microchemical methods. Organic substances are proteins, oils and waxes, natural resins and polysaccharides and tests are performed according to each group. Samples are mixed with various reagents to determine whether certain materials are present. More sophisticated and reliable methods such as Gas Chromatography may sometimes be used to analyse organic compounds of a paint media.

Microchemical spot test was the technique used for the identification of oils. Lipids produce a red stain with Sudan III. An oil can be detected by adding it to a small amount of water in a test tube and shaking with a few drops of Sudan III. On standing, the oil separates from the water and will be seen to have taken up the red stain.

Evaluation

Organic substances are complex products and microchemical tests for their identification as additives in paint layers often present difficulties. Such difficulties are related to the identification of the exact substance, the relatively low amount of organic additive in a paint which rarely reaches 10% of the total weight. In addition the ageing of the paint material may have caused a change to its physical and chemical properties.[47] In general, these tests will often not yield results, ie organic components in paint are difficult to identify.

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[46] Pike, A. (1995), "Notes on Laboratory Techniques for Conservation". English Heritage Training Course. May 15-19, 1995.

[47] See ICCROM (1989) "Identification of Organic Binders and Fixatives in the Paint Layer", in Conservation of Mural Paintings Course and Mills, J., White, R. (1994) 2nd ed. The Organic Chemistry of Museum Objects, pp. 177-8.

3 RESULTS AND RECOMMENDATIONS

3.1 GENERAL NOTES

The information gained in this study as a result of archival research, interviews with craftsmen, analysis of critical materials and further studies has been summarised and the results used to develop guidelines with the aim of assisting Institutions, architects and owners in the conservation of buildings.

3.1.1 Research Findings

Whilst there are dangers in generalising the findings of this research, as it is based primarily on materials from the four construction types found in the Blumenau region, the results have validity for similar historic buildings which utilise earth and lime- based materials as part of their construction.

This chapter comprises recommendations that are strictly related to the materials characterised in this study; however, general information for each subject area of the guideline is always given.

3.1.2 Definition of Conservation Treatments

These guidelines are organized to ensure that conservation, specifically when dealing with earth and lime- based materials, achieves good standards.

Conservation, in this study, was defined as a general term which refers to a whole range of activities to preserve the world's architectural patrimony. It embraces the various levels of intervention when dealing with historic buildings which are outlined in the following diagram. The extent of the conservation treatment for earth and lime materials is determined by their nature and physical condition defined in this study by the following terms.[48] (fig.28)

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[48]Sir Bernard Feilden and Dr J. Jokilehto give detailed definitions of different conservation treatments. See: Feilden, B., Jokilehto, J. (1992), "Evaluation for Conservation", extracted from Draft Guidelines for the Management of World Cultural Heritage Sites pp. 7-14.

Conservation or Retention: an action of safeguarding the existing material; arresting decay, where the great value of the material requires a special treatment for the survival of existing parts such as consolidation and grouting.

Restoration or Repair of decayed parts: an action where significant portions of the material survive, requiring minimal intervention with compatible materials and techniques.

Replication or Replacement of missing or decayed parts: an action where significant portions of the material are decayed or are missing, necessitating interventions with compatible materials and techniques. However, where traditional methods are inadequate, modern techniques are acceptable.

Maintenance: a preventive action involving regular building inspection and protection against deterioration.

Retention

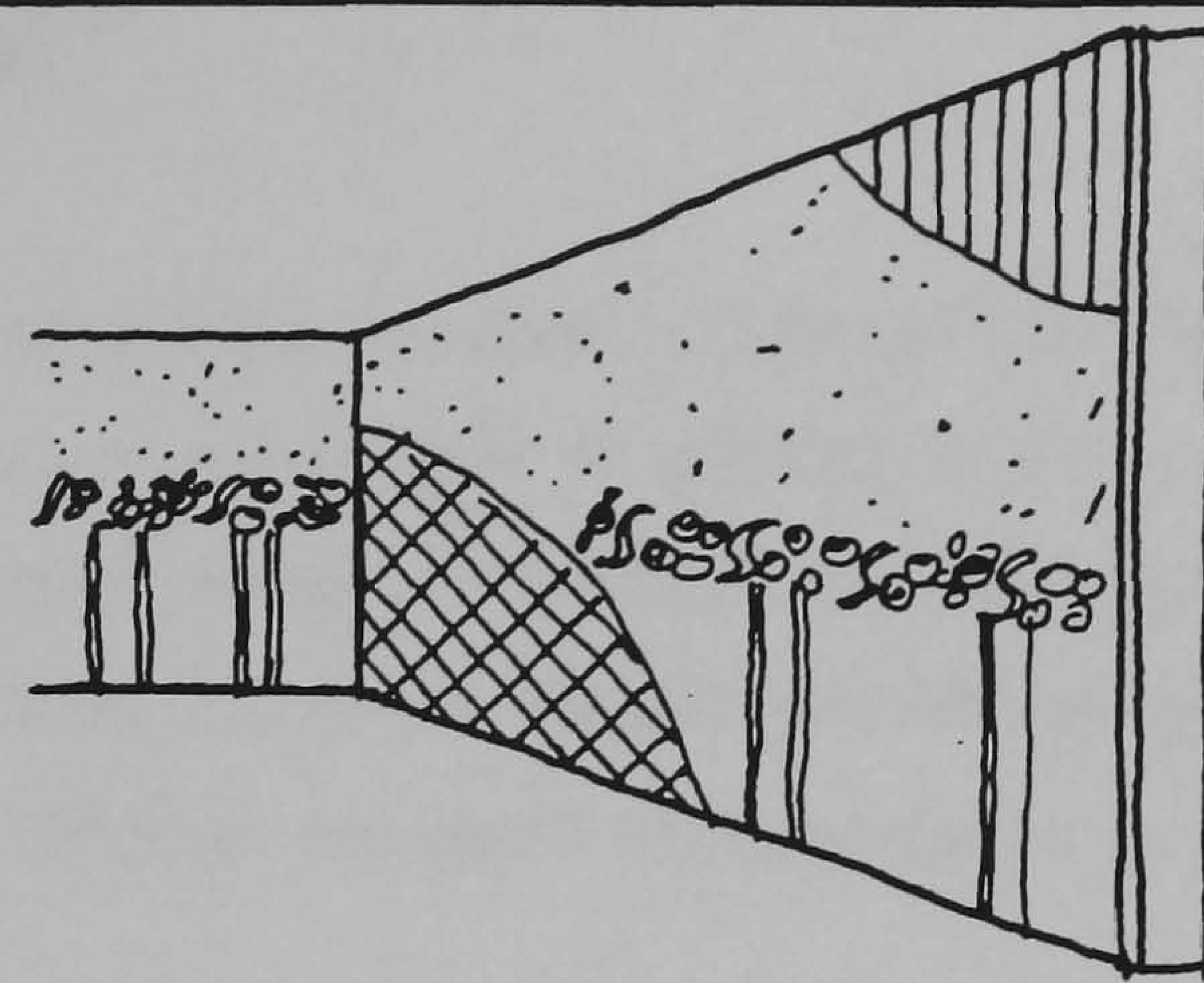
State of Conservation:

detachment of plaster

detachment of paint

Treatments:

- cleaning
- injections and grouting



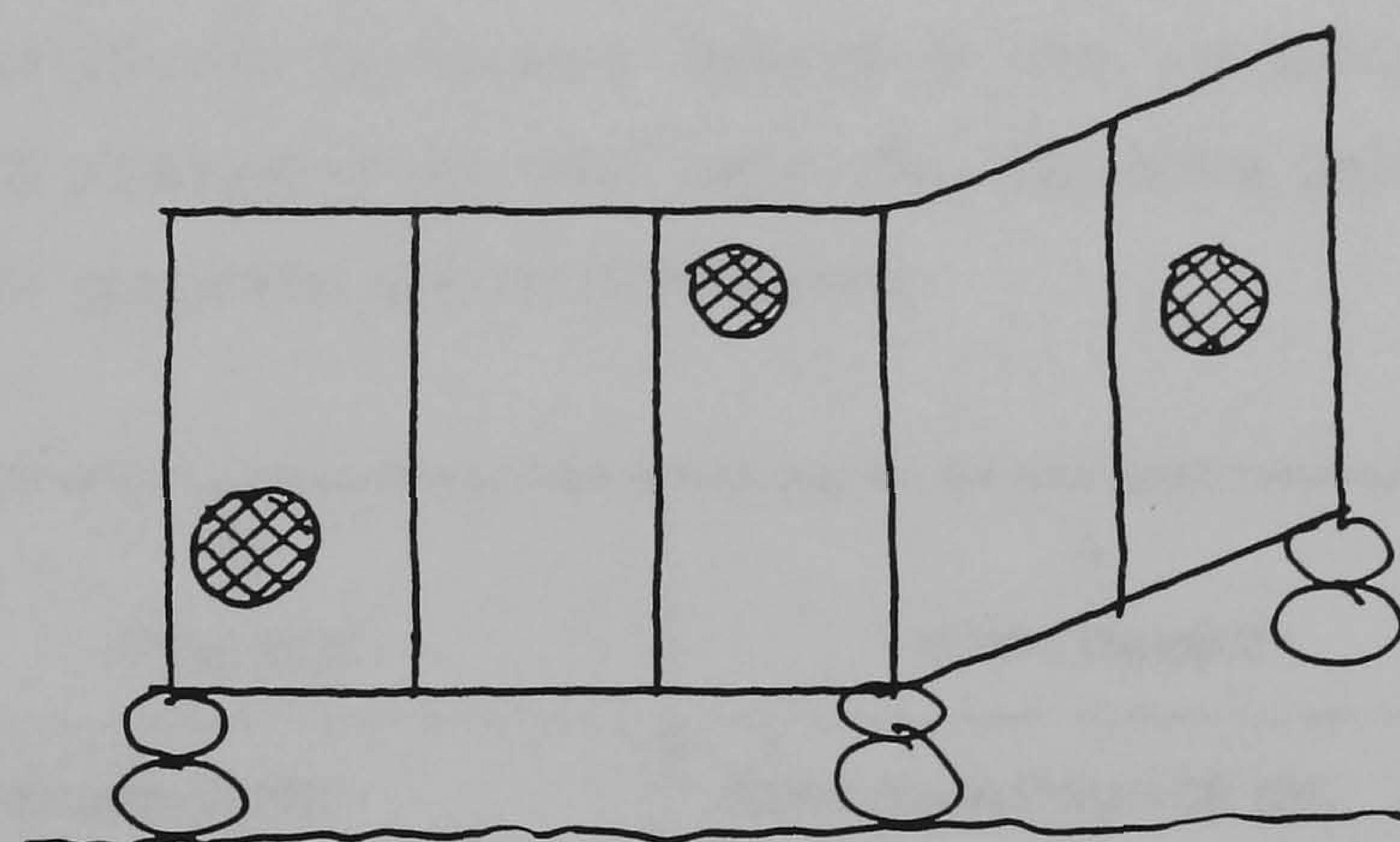
Repair

State of Conservation

loss/ decay

Treatments:

- use of compatible materials and techniques

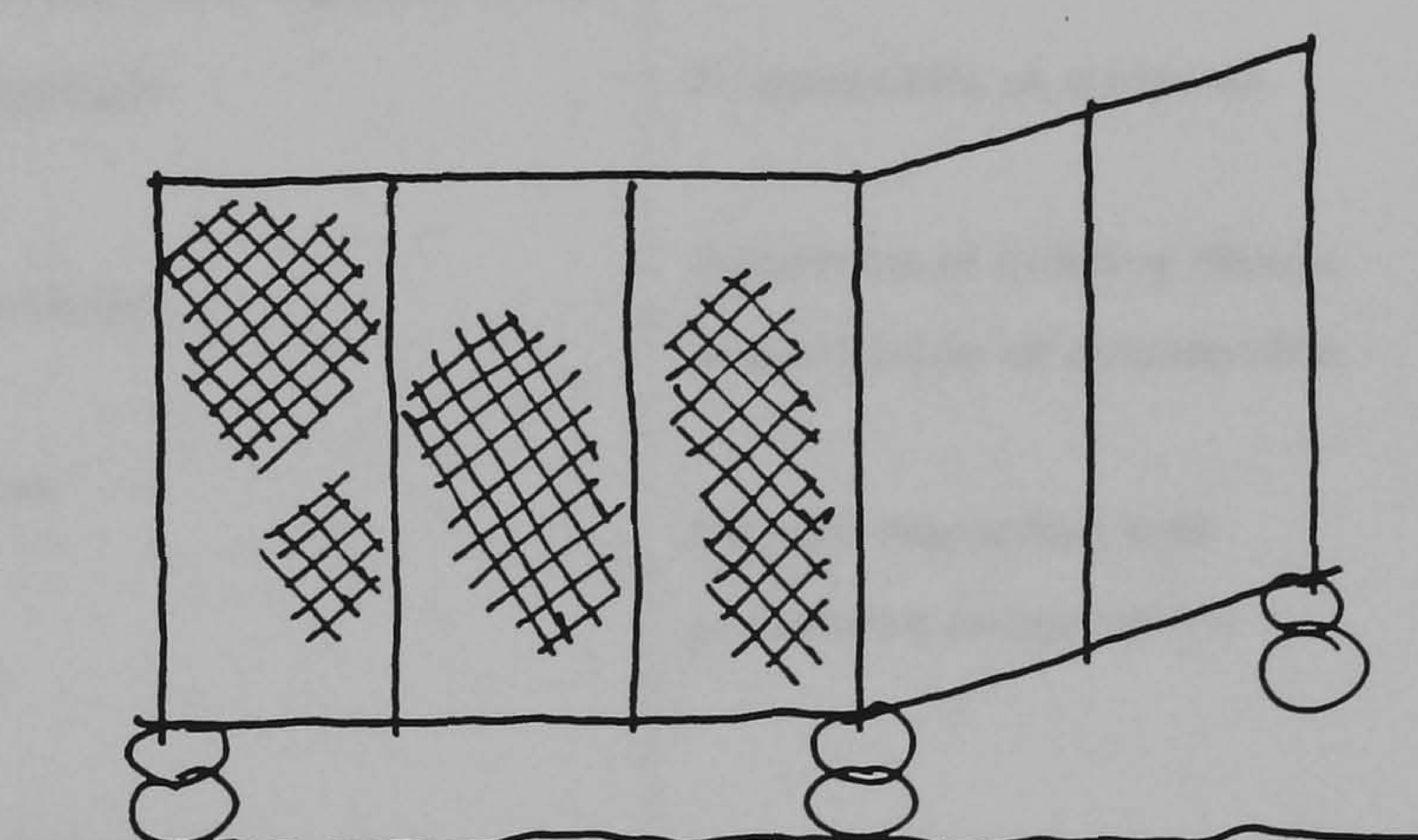


Replacement

State of Conservation:

loss/ decay

- use of compatible materials and traditional or modern techniques



Maintenance

State of Conservation:

open areas

impervious material

↑ rising damp

Treatments:

- roof maintenance
- moisture control
- lime plasters, limewash and lime mortar repointing

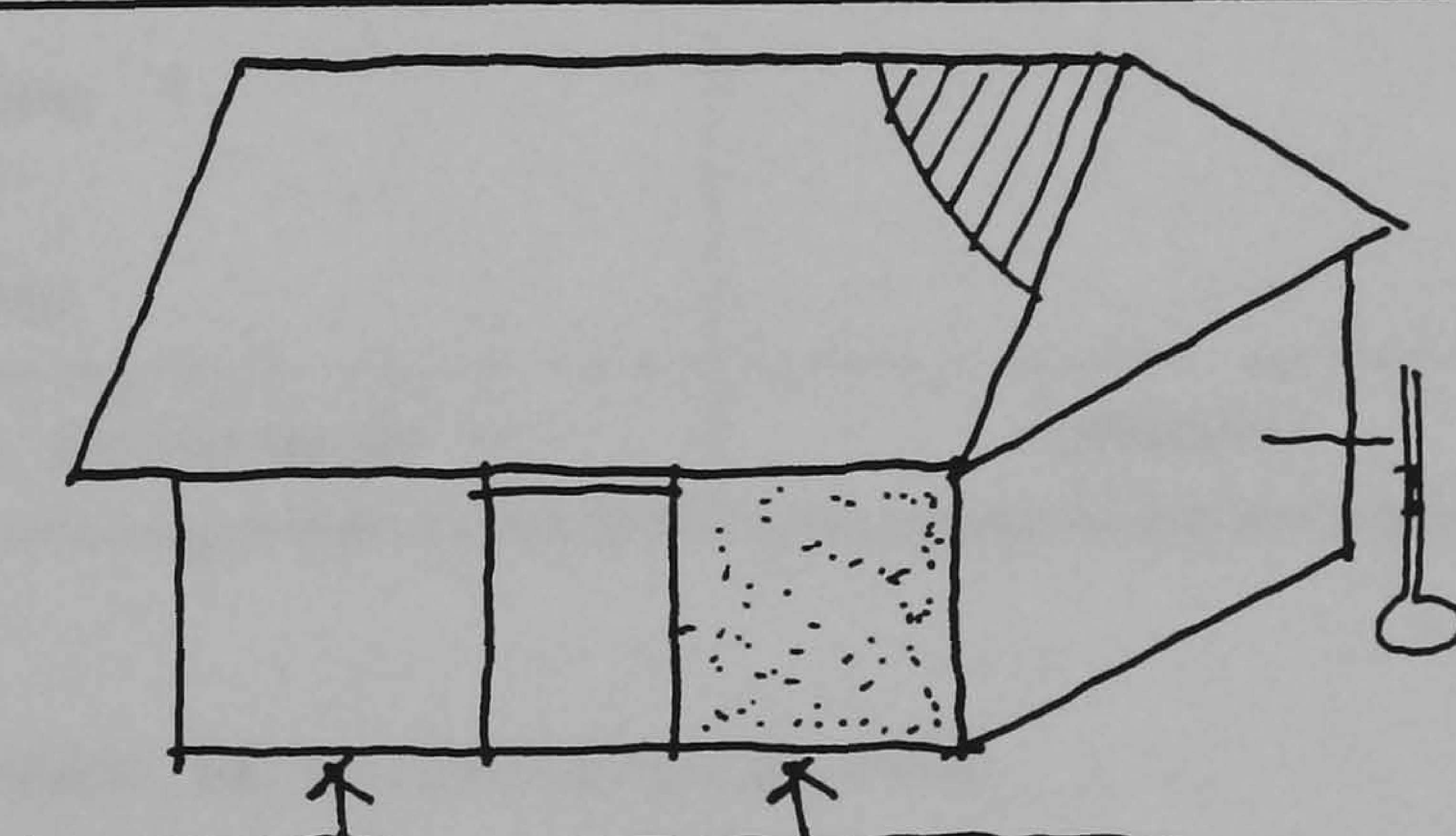


Fig. 28 - Physical Condition of Materials and Treatments

3.1.3 A Strategy for Specifications

At some point every architect, builder or contractor involved in conservation works deals with the specifications of materials which, in short, aim to prolong the life of historic buildings. Too often specifications are written based on materials available today and not on the nature and composition of the existing materials. Specifications for conservation must be based on principles such as compatibility, minimum intervention, and appropriate use of similar historic materials.

A strategy for minimising the unacceptable continuous failures in the conservation treatments in Santa Catarina is briefly outlined in the next table. (fig. 29) More detailed explanation is given in the body of the guidelines about these issues.

1 COMPOSITION	2 PRACTICE	3 MAINTENANCE
Select appropriate raw materials: **earth:** **range/shape/** **grain size;** **free organic matter;** **stable clays** **lime: preferably quicklime transformed into limeputty**	***Control adequate preparation and application of materials:*** **Builders Skills** **Hydration** **Mixing** **Consistency** **Application** **Drying/** **hardening**	***Base maintenance on:*** **Compatibility of materials** **Protection of building design and methods of construction** **Regular inspection and preventive conservation**
BETTER COMPONENTS	**+ BETTER MADE ->**	**LONGEVITY**

Fig. 29 - Earth and Lime based Materials: factors affecting longevity

3.1.4 How to Use these Guidelines

These recommendations are set out in a group of subject areas identified in this research as the requirements to develop compatible and appropriate use of earth and lime in Blumenau building conservation. The presentation of each subject area is always introduced by a master statement, which is basically the guiding principle. Every subject area presented contains a general introduction in the relevant section, as a means of understanding how the results were interpreted to arrive at recommendations. However, for the complete understanding of these recommendations, all previous sections should be read first. This section includes two main groups of subject areas:

(A) TECHNICAL RECOMMENDATIONS: MATERIALS AND PRACTICE

This group of guidelines consist of technical recommendations to carry out conservation when dealing with earth and lime- based building materials. This is not intended to be a master document for specifications, but a checklist of parameters that can be used to write specifications in architectural or research projects. This group comprises the following subject areas:

DOCUMENTATION AND INVESTIGATION

The aim of this section is to give reminders and guidance to record and to document materials, as a means of developing a diagnostic attitude for the understanding of materials. This includes, for example, site practices for the recording and sampling of materials.

CHARACTERISATION

This is the master guideline as it comprises the major focus of this study, ie the primary data on which to determine appropriate conservation measures. All other subject areas are considered a consequence of these studies. The characterisation section is organised into materials according to their respective material system ie, infill systems; mortars, renders and plaster systems and paint systems. For each material, a securing structure is used which includes: a general context including definitions and typical components and composition, a specific context which is basically a description and a summary of the Blumenau results followed by the recommendations for remedial work divided into four parts:

(1) Principle; (2) Testing; (3) Treatments; (4) Specifications.

It will be seen that certain general contexts are repetitive where relevant to more than one type of system or component. This is to facilitate use of the guideline which can be separated into sections if necessary.

SITE INSTRUCTIONS

This section offers advice on good practice regarding the preparation and application of materials. The recommendations here were organised by relating the nature and composition of S.Catarina materials', the information from craftsmen, possible methods of application, with information from study visits to centres where traditional and similar materials are being prepared. This section was further developed by a literature review of manuals regarding similar materials.

MAINTENANCE

This section offers advice for routine building maintenance where earth and lime materials are part of the building construction.

(B) RECOMMENDATIONS/ PROPOSALS: INFRASTRUCTURE AND CONTEXT

These guidelines are the recommendations to create the conditions for the practical building conservation to be properly executed. These are larger issues, which are outlined as proposals. They are included because, unless efforts are made to create the conditions necessary for conservation, the technical guidelines will be very hard to execute. This group of guidelines comprises the subject areas of production and supply and further recommendations on training, future research, technical information and collaboration.

3.2 DOCUMENTATION AND INVESTIGATION

- Whether conservation deals with repair or replacement of materials, it is essential to develop systematic documentation based on inspection, archival research and oral communications with craftsmen together with samples and analysis of building materials.

DOCUMENTATION AND INVESTIGATION: GENERAL

Introduction

These guidelines are not intended to address standard methods for documentation and investigation in a comprehensive way, but only to present observations and discuss techniques used for this thesis and constitute useful recommendations for systematic documentation and investigation of architectural materials. The investigation of samples of architectural materials in- situ and further in the laboratory provide important indications for best conservation treatments. However, methodologies of investigation and analysis of architectural sample materials are based on related sciences and techniques are not yet sufficiently standardized.

Definitions

Documentation is the systematic recording of information to provide a detailed report or dossier of the results of historical and physical investigation or conservation treatments. There are various forms and techniques for documentation; the following types are commonly used for reports on historic structures. (fig. 30)

- Historical Documentation. This constitutes primary or secondary sources of historical documents which provide visual or written forms of information such as descriptions of buildings, contracts, methods of fabrication of materials and specifications.
- Interviews with craftsmen, owners or ordinary people. These are sources of oral historical information regarding various aspects of the building construction such as date and methods of construction, making and application of materials, or repairs, replacements and interventions in the building.
- Graphic Documentation. This is an essential form of documentation which usually consists of drawings of the buildings such as plans, sections and elevations. It is primarily used to record the architectural form and state of preservation/ conservation of the building.
- Photographic Documentation. This is always used for different purposes such as recording the architectural form, state of conservation and treatments. Depending on the technical proficiency of the photographer, the number of photographs, the angles, the type of film and lighting used, photographs can provide useful information, but can never entirely replace drawings.
- Photogrammetry. This is a more sophisticated technique which gives precise graphic documentation through the resolution of stereo pairs. It is suitable whenever a highly accurate record is necessary, but it is extremely costly compared with other methods such as rectified photography.

Note: It is common to record all the above mentioned information on questionnaires or survey forms which usually include general information on the object such as location, a brief history, condition of the building and the drawings of plans, elevations and sections.

Fig. 30 - Forms and Techniques for Documentation and Ivestigation of Historic Buildings

DOCUMENTATION AND INVESTIGATION: S. CATARINA

In Santa Catarina, there were two main objectives for the documentation of historic buildings. One objective was to identify buildings of special architectural and historic interest in order to recommend listing them and the other was to design projects for their conservation and use. Graphic documentation through drawing plans, sections and elevations and photography were used.

Prior to this study, no historical or physical investigation of architectural materials of S. Catarina for conservation purposes had been carried out. The documentation and investigation of buildings and materials studied in this thesis was based on two main methods summarised as follows:

(A) General Contextual Information

The major sources of information listed below gave a broad historical and environmental context for the analysis of the samples.

- Study of documents such as old maps, photographs, manuals, letters, reports and contracts.
- Study of technological evidence such as kilns and tools.
- Study of oral accounts by craftsmen, owners and other local people. Those oral accounts included mainly traditional recipes and practices for the preparation and application of materials.
- Study of recent sources of material information such as geological maps, reports and projects regarding mineral resources.

(B) Detailed Investigation and Analysis of Sample Materials

Prior to the sample and analysis of materials a thorough description of the subject buildings were carried out. The sample and analysis of materials are specific sources of information which gave a scientific understanding of the nature and composition of sample materials. These included both in- situ investigation techniques and laboratory analysis.

DOCUMENTATION AND INVESTIGATION: RECOMMENDATIONS FOR EXAMINATION METHODS, RECORDING SYSTEMS AND EQUIPMENT

When dealing with the investigation of architectural materials it is always advisable to use the following methods, systems and equipments:

Historical Documentation

A systematic documentation of all historical sources is important as it will provide corroborating evidence for the understanding of analytical findings. Such sources include:

Visual and Written Sources. Old manuals, letters, budgets are valuable sources of information. Such documentary sources can be found in regional and national libraries, archives and museums.

Sites of Technological Evidence. Early sites of manufacturing materials can be important sources of information. The documentation of old tools, kilns and equipments by identifying early manufacturing sites is advisable.

Oral Communications/ Interviews. Old recipes and practices for making materials should be recorded by oral communication with craftsmen or other local people. It is advisable to document traditional practices by recording the following points: (fig. 31)

ORAL COMMUNICATION WITH CRAFTSMEN

1. Identification of the craftsmen including name, address, profession and origin.

2. Description of characteristic materials including the following points:

- **components: sources of raw materials such as aggregates, soils, additives (fibres, casein and others) and pigments; production of some meterials such as lime including sources of limestone, kilns and forms of lime.**
- **preparation: methods of preparing mortars, renders, plasters/ stuccos and other materials.**
- **application and drying: methods of application including tools and techniques.**
- **maintenance: period and methods employed to maintain these materials.**

Note: It should be noted, however, that such information may be based on the most recent modifications of traditional techniques rather than on exact record of historical practice.

Fig. 31 - Documentation of Traditional Practices

Field Documentation and Investigation

The documentation and investigation of materials in the field with the naked eye and through the use of simple instruments constitute an important step in conservation as this provides a preliminary assesment of the state of conservation and the nature of materials. A complete field documentation will normally deal with the following points:

Architectural Study. This is the general information about the building including environment, form and structure. This documentation is normally available from conventional records of historic buildings and the methods are not included here. However, it is advisable that the researcher who gathers the historical information and covers the field survey also takes the sample for further laboratory analysis.

Material Study. The study is concerned with the visual characteristics of materials, ie size, colour, texture and layers. In particular the following should be recorded: (fig. 32)

CHARACTERISTICS OF MATERIALS

- **The size and/ or shape of materials such as thickness of joints, number of brick courses and number of render coats.**
- **Colour identification by using of a universal system and good lighting conditions.**
- **Kind of surface texture such surface observation sometimes with the aid of magnifying glass will give indications about issues such as manufacture, ie information about methods of fabrication and tools used in the past, smooth or rough of the material, thus giving information about its properties.**

Note: materials and equipments should include a tape measure, magnifying glass, colour charts, standard metre stick for photographs.

Fig. 32 - Recording Characteristics of Materials

Condition of the Materials. This study involves the recording of visible zones of deterioration due to weathering, biological attack, salt efflorescence and crystallization, dampness and alterations. Types of deterioration and location should be recorded on drawings and photographs. It is advisable to use a uniform scale, and standardized codes or symbols.[49]The following should be recorded or indicated on drawings, sketches or photographs: (fig. 33)

[49]See diagnosis of damp problems and example of annotated sketch in Ashurst J. & N. (1988), Practical Building Conservation, Vol. 2, pp.11-21 and Blades, K., Stewart, J. (1990) "The Repair and Remedial Treatment of the East Block Parliament Buildings, Ottawa, Canada", in Conservation of Buildings and Decorative Stone, Vol. 2, p.121.

CONDITION OF BUILDINGS AND MATERIALS

- Temperature and relative humidity levels within the building.
- Moisture content levels in the walls at several locations in the building.
- The extent of damage levels such as salt efflorescence and crystallization.
- The extent of alteration such as evident recent replacements of materials.
- The extent of missing parts.

Materials and equipments should include thermometer, psychometer, pH test strips, measuring tapes, 'Speedy' moisture meter or similar for necessary moisture content.

Fig. 33 - Recording Physical Condition of Buildings and Materials

Methods of Investigation. There are methods of investigation for different materials, some of which involve in- situ examination and some the examination of samples for analysis in laboratory. For instance, general procedures for the investigation of architectural finishes are given below:[50] (fig. 34)

The objectives for sampling characteristic materials should be well defined eg for the study of the composition of materials, the study of levels and types of dampness present in masonry, the study of the chronology of surface materials. The study of sample materials is a valuable source of information. However, examination should be carried out properly and samples collected in a correct fashion if they are to yield useful information in the laboratory.[51] (fig. 35)

[50]See: Perrault, C. L. (1978) "Techniques Employed at the North Atlantic Preservation Centre for the Sampling and Analysis of Historical Architectural Paints and Finishes", in APT Bulletin, Vol.10, No.2., p.11.

[51]For detailed information about sampling methodology see the following authors:
Jedrzejewska, H. (1981) "Ancient Mortars as Criterion in Analysis of Old Architecture", In Symposium of Mortars, Cements and Grouts used in the Conservation of Historic Buildings, pp. 324-5 and Teutonico, J. M. (1988) A Laboratory Manual for Architectural Conservators, p. 138.

METHODS OF INVESTIGATION OF ARCHITECTURAL FINISHES

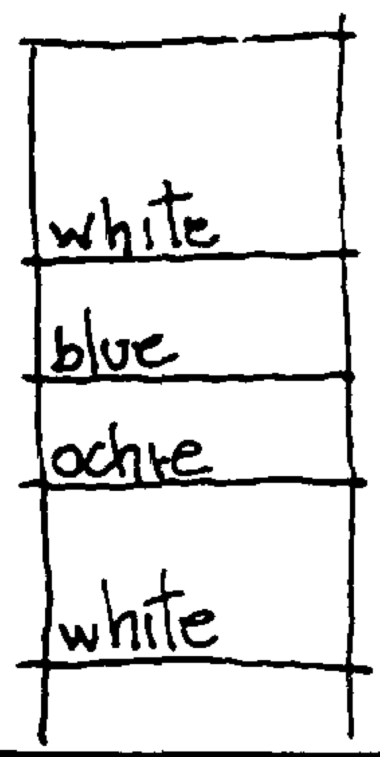
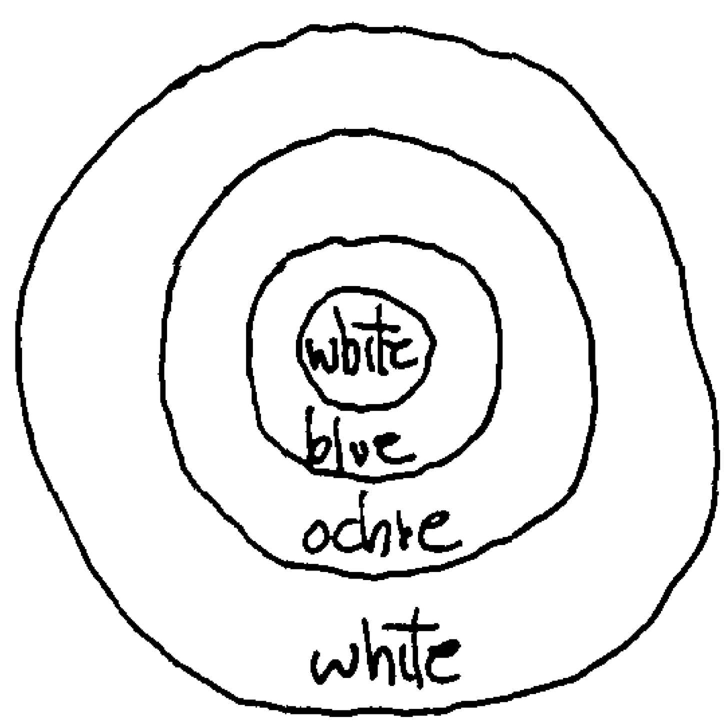
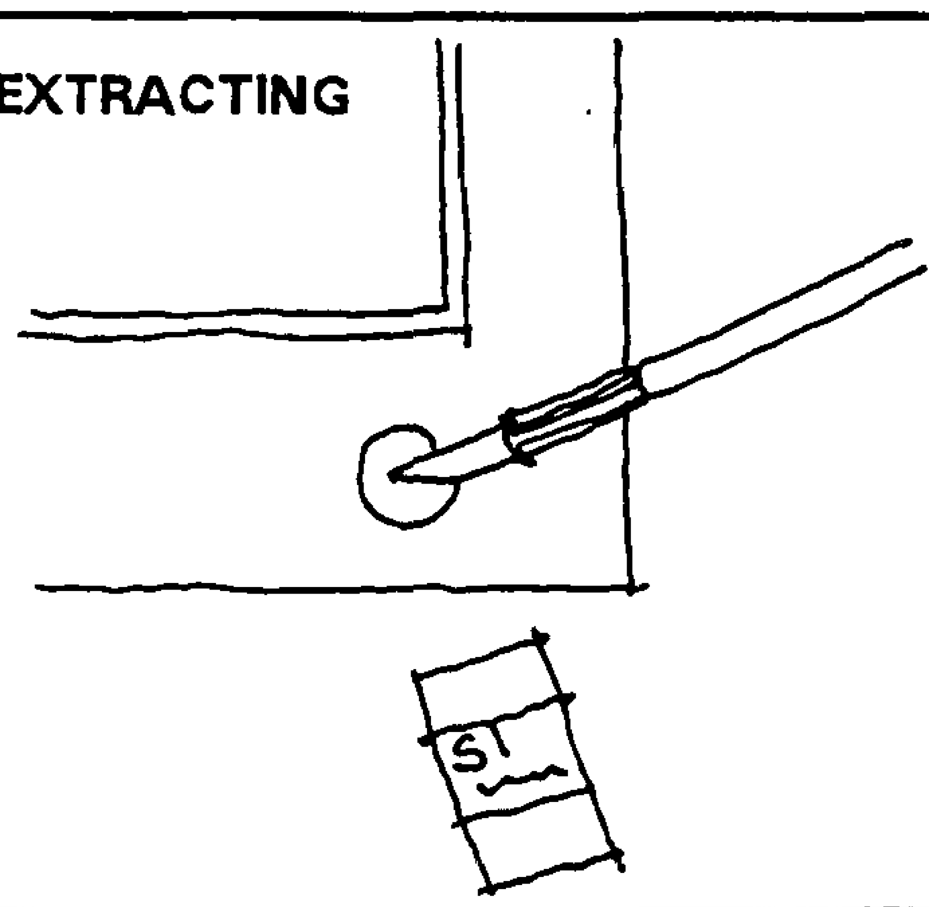
SCRAPING/ LAYERING 	• These are in- situ method of exposing layers of paint, by scraping with a type of knife or scalpel and sometimes with the aid of solvents. Observations regarding the colour and characteristics of each layer can be documented. These techniques are usually preliminary techniques and they are not accurate as laboratory analysis of extracted samples.
CRATERING 	• This technique also exposes the sequence of paint layers. It involves a craterlike cavity down to the substrate and then sanding the finish layer until the statigraphy is revealed. The technique is usually performed in- situ but can also assist in examining extracted samples. This is a useful method, but it is not as accurate as the examination of extracted samples for laboratory analysis.
EXTRACTING 	• This involves the extraction of a sample of material including the substrate and all finish layers for laboratory analysis of: - Cross Section Examination - Pigment Identification - Media Identification - Cratering Examination

Fig. 34 - Examples of Architectural Finishes Investigation

SAMPLING PROCEDURE

• Number of Samples. The number of samples should be adequate to reveal necessary information with as little destruction as possible to the building. A single sample is nearly always insufficient for a precise study.

• Weight and Size of Samples. The necessary quantity of samples is defined by the objective of the study as the type of analysis to be performed. Therefore, the objective of the sampling should be clearly defined. For example, if the objective of the study is to understand the original colours and paint systems so as to describe an appropriate scheme, laboratory investigation will probably involve the microscopic examination of the stratigraphy of significant samples. In this case only millimetres of a sample will be necessary. For mortar analysis, samples weighing 20-50g will probably be sufficient, yet a more thorough study will require about 150g[52]. On the other hand the analysis of daub or adobe materials may require about 200-500g for the characterisation of the properties such as grain size distribution, requiring much greater quantities.

• Location of Samples. The location of a sample should be recorded on diagrams, drawings, or photographs, with the help of coordinates. It is advisable to collect samples from protected areas such as under the roof line or corners which have not deteriorated where the most reliable historical information will be revealed.

• Tools. Samples are removed with appropriate tools according to the nature of the materials. Scalpels are used for paints and other small samples of finish materials. Chisels and mallets are necessary for materials such as mortars, plasters and daubs. For core samples, drills with specially fitted bits are quite useful. Other field equipment useful for extracting samples includes a torch to illuminate the surface and a magnifying glass.

• Containers and Field Equipment. The samples should be collected in containers which are inert and can be adequately labelled and sealed. Polyethylene bags which are sealed on the top or film canisters are good examples. The sample container should be labelled with a permanent marker and contain the number of the sample, the date, the name of the building, the location of the sample and the name of the person who removed the sample.

• Sample Documentation Form. It is useful to create standard forms for recording descriptive data in the field.

Fig. 35 - Sampling of Materials

[52]See: Middendorf, B. and Knöfel, D. (1991) "Use of Old and Modern Analytical Methods for the Determination of Ancient Mortars in Northern Germany", in Proceedings of the 4th Expert Meeting Amersfoort, 25- 27 October 1990/ Nato-CCMS Pilot Study Conservation of Historic Brick Structures, pp. 76-7. The report present a flow chart of the analytical method to determine ancient mortars where 150 g of mortar is indicated as the quantity usually required.

Laboratory Investigation and Analysis

This investigation can be divided into two phases:

Processing Samples. The preparation of samples to be analyzed requires some procedures which should be recorded. Systematic organization of information is advisable to facilitate further historical and technical interpretation. Therefore, it is advisable to create a number system which enables any sample to be easily identified and situated in the context of historic structures in the region.

Recording Analytical Results. Systematic documentation of analytical procedures and results should be developed. The analysis of historic architectural samples should result in information which provides a data bank for comparative studies and sound recommendations for conservation. Some examples of basic information and analysis which might be useful for each type of material are indicated below: (fig. 36)

ANALYTICAL PROCEDURES

1. Earth Construction Materials. Common procedures for earthen materials are colour identification, particle size analysis and liquid and plastic limits. Other possible procedures include embedding samples for examination in of cross and thin section to determine composition; analysis of salts and organic matter.

2. Lime- based Construction Materials. Common procedures are colour identification, wet chemical analysis to determine proportion and type of the binder and aggregate particle size. Other possible procedures include embedding samples for examination in thin section.

3. Surface Materials. Common procedures are colour identification, embedding samples in resin for documentation of statigraphy, identification of pigments and medium type through microchemical or microscopic analysis.

Fig. 36 - Examples of Analytical Procedures

Storage and Final Reports

The storage of samples as well as photographs, drawings, and any other source of documentation should be adequately and systematically provided for in archival quality materials. Careful use and maintenance of special field and laboratory equipments and tools is advisable as the correct recording of measurements, colour and location of samples can be affected by damaged equipment.

The compilation of information from field and analytical studies should be based on a questionnaire including the description of the building, visual characteristics of materials, condition of the materials, field tests, sampling and also the results of anlaysis. This should result in a final report which gives complete information about the research project. Such reports should be held in archives accessible to specialists and researchers. The systematic recording and publications of technical dossiers constitutes an important step in the conservation process. The dissemination and further interpretation of statistical data can be of interest to specialists and researchers and advance scientific knowledge regarding historic materials and techniques.[53]

The creation of a sample collection system is also recommended as a means of facilitating future works. Such collections should include both historic materials and currently available materials which could be used for replacements purposes.[54]Finally, it is purposed for S.Catarina some steps to develop the documentation and investigation of architectural materials which are outlined in the following diagram. (fig.37)

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[53]See Knöfel D., Shubert P.(1993) Handbuch. Mörtel und Steinergänzungsstoffe in der Denkmalpflege, pp.24-32. The authors give examples of forms to record laboratory analysis of mortars.

[54]Information on existing sample system may be obtained from ICCROM - The International Centre for the Study of the Preservation and Restoration of Cultural Property and PENN- The Graduate Program in Historic Preservation/ University of Pennsylvania.

1 TO DEVELOP A METHODOLOGY OF INVESTIGATION

- Define the Research Project
- Field Investigation
  - selection of buildings
  - sampling aim
  - sampling methods
- Laboratory Investigation
  - processing samples
  - analytical methods

2 TO DESIGN AND PROVIDE RECORD SYSTEMS

- Field Record Notes
- Complete Questionnaires

- Special Archives/ Storage Units for complete dossiers and collection of sample materials

- Publications of compiled information

Fig. 37 - Steps in the Investigation of Historic Buildings and Architectural Materials

3.3 CHARACTERISATION

- In cases of both repair and replacement, the physical and chemical characteristics of the original materials must be analysed in the way described in order to recommend compatible materials and appropriate conservation treatments.

3.3.1 Infill Materials

INFILL MATERIALS: GENERAL

Definition

Infill materials in this context are are non- structural. In timber- frame construction infill panels comprise the material that occupies the panel without concealing the framing. Traditionally, the types of materials that were utilised to infill panels were wattle and daub, brick, stone and timber boards. Generally selected for insulating purposes, these materials have very different characteristics of appearance, humidity, insulation, density and permeability and require different periods of maintenance.

Today, new infill materials are selected for new criteria related to improved internal environment, economy of labour and materials and ease of construction. They certainly differ in appearance and physical properties as they vary in components and methods of fabrication; frequently this means that they are inappropriate as substitutes for traditional materials.

INFILL MATERIALS: S. CATARINA

Description of S. Catarina Examples

In Santa Catarina, traditional construction located in the Blumenau region and similar areas includes different types of infill panels which are summarised in the following page. (fig. 38) Based on field observation, documentary and technical information it is possible to outline the typology of Blumenau's panels and to relate the infill materials to the period and type of dwelling.[55] However, this subject requires further studies as the variety of techniques used in the past are important to the understanding of building history and conservation treatments. Earth and brick as infill materials of timber-framed buildings were used in the following ways: (fig. 39,40)

[55]See previous section: Description of Sampled Buildings and the author's master thesis (1992), An Introduction to the Conservation of Traditional Timber- Framed Buildings in Brazil: with examples drawn mainly from Blumenau Colony, pp. 27-51; and pp. 64-8.

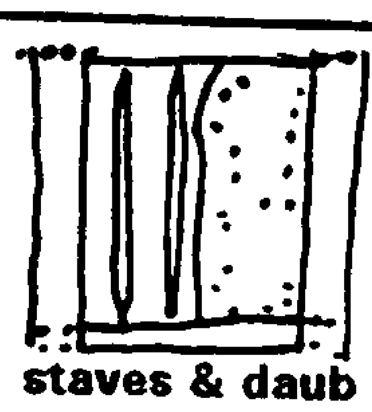
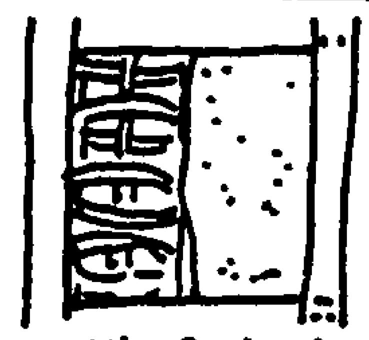
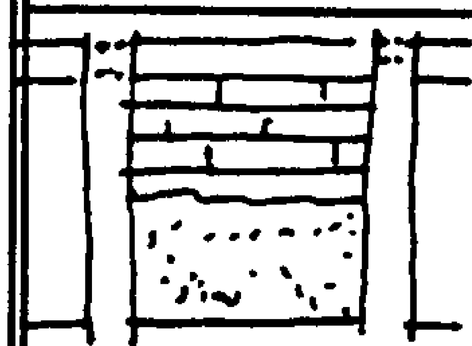
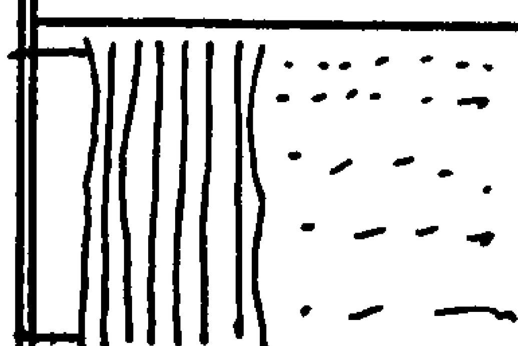
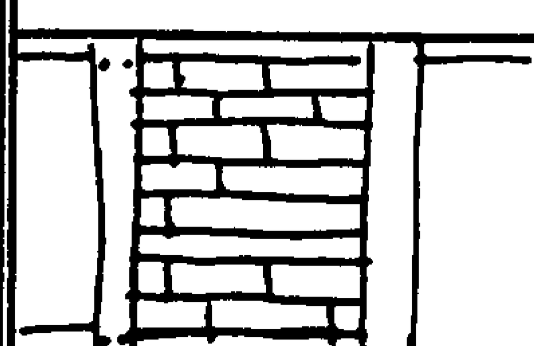
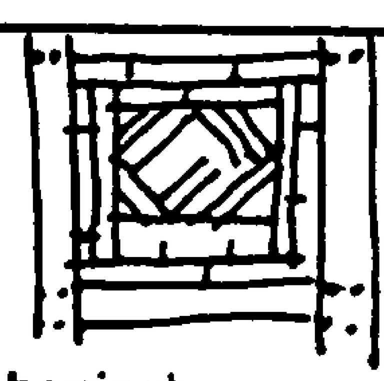
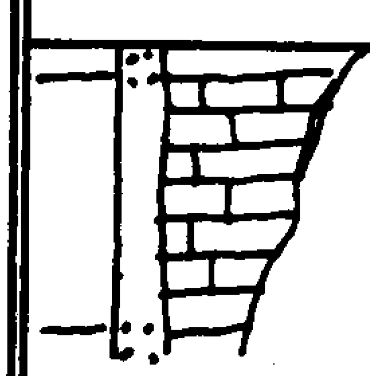
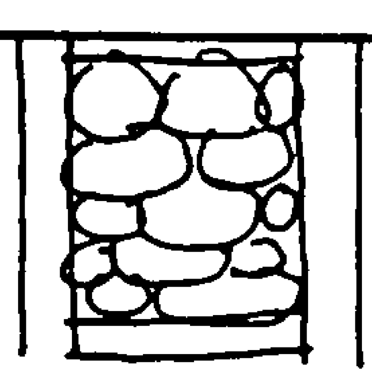
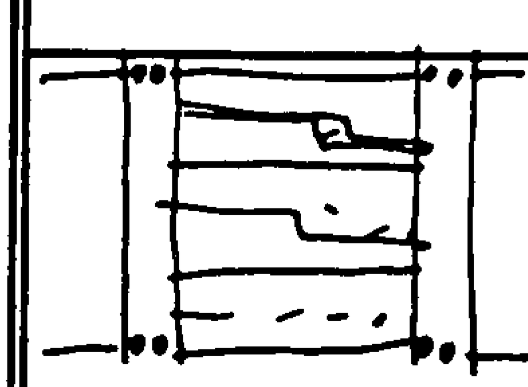
INFILL TYPES	S. CATARINA EXAMPLES
 staves & daub	Typical of Blumenau. Recorded in external and internal panels. Usually decayed showing a piece of split timber inserted directly into grooves to provide reinforcement for the daubed panel.
 wattle & daub	This type of infill is also recorded in Blumenau region.
 rendered adobe	This type of infill was recorded for the first time in this research. Adobe panels may be concealed by plasters.
 lath & plaster	This is the typical infill of ceilings. Usually needs repair.
 coursed brick	This is the more common typical infill material. The bricks are hand- made or extruded, the bedding mortar is earth and the pointing mortar is lime.
 herringbone	This is the infill material of special panels such as close studding panels and window sill panels. They are always made with extruded bricks and usually need re- pointing.
 plastered brick	Inside, brick panels are usually plastered. External panels with rendered brick have not been recorded in Blumenau so far, but documentary sources include this specification.
 stone	Not observed in S. Catarina. However, sandstone was used as infill material in the State of Rio Grande do Sul where similar settlements began.
 timber boards	May be seen in S. Catarina for infill panels of farm buildings, but not dwellings.

Fig. 38 - Types of Infill Materials in S. Catarina

EARTH INFILL MATERIAL:

In general, this material may be related to two or three types of dwellings. (fig. 39)

Type 1: Early load- bearing framed houses (before 1850 and probably until 1900). No examples of this type survive and only through old sketches, reports and letters it is possible to describe the technique.

Type 2: Early timber- framed construction (from early years of the Blumenau colony to approx. 1900) with infill panels made entirely of earth. Although documentary sources provide information for the early use of earth as infill material the few surviving examples of type 2 suggest that they may have been little used, perhaps because of rapid deterioration.

Type 3: Early timber- framed construction, but also possibly a few brick houses, both partially built using earth as infill material, ie partitions or back sheltered walls. In addition because internal surviving panels are concealed by plaster it is possible that earth infill materials were also used in larger houses and until more recent times (approx. 1900 to 1950).

Thus, the use of earth as an infill material reflecting a type of dwelling is restricted to a few examples and was no longer in use by the turn of the century. However, earth used as infill material in sheltered or concealed situations might occur more often and also into the twentieth century. A precise dating of earth panels is not therefore possible as many may be concealed.

In addition, the relationship between type of earth material, period and type of dwelling needs further investigation. Only one timber- framed house entirely built with adobe was recorded during this research and that was located in an Italian immigrants' rural village. However, the use of adobe does not seem to be exclusively used by Italians as timber-framed houses built partially with adobe panels were seen in other parts of the Blumenau region.[56]

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[56]So far the Degrazia Tottene family house in Guaricana, Ascurra town is the only example of a timber- framed house built entirely with adobe.

During the study visit in Germany (September 1994) the author observed the extensive use of wattle and daub in regions such as Westphalia, Hessen or parts of southern Lower Saxony, as opposed to the extensive use of brick in regions such as Schleswig Holstein or northen Lower Saxony. The use of adobes was observed in some timber-framed structures located in Lower Saxony (in the south eg Goslar, Hahausen/ Rudhen or the border with Westphalia ie Aerzen village)and Hessen (eg Ebsdorf and Asfeld), but not in Schleswig Holstein.

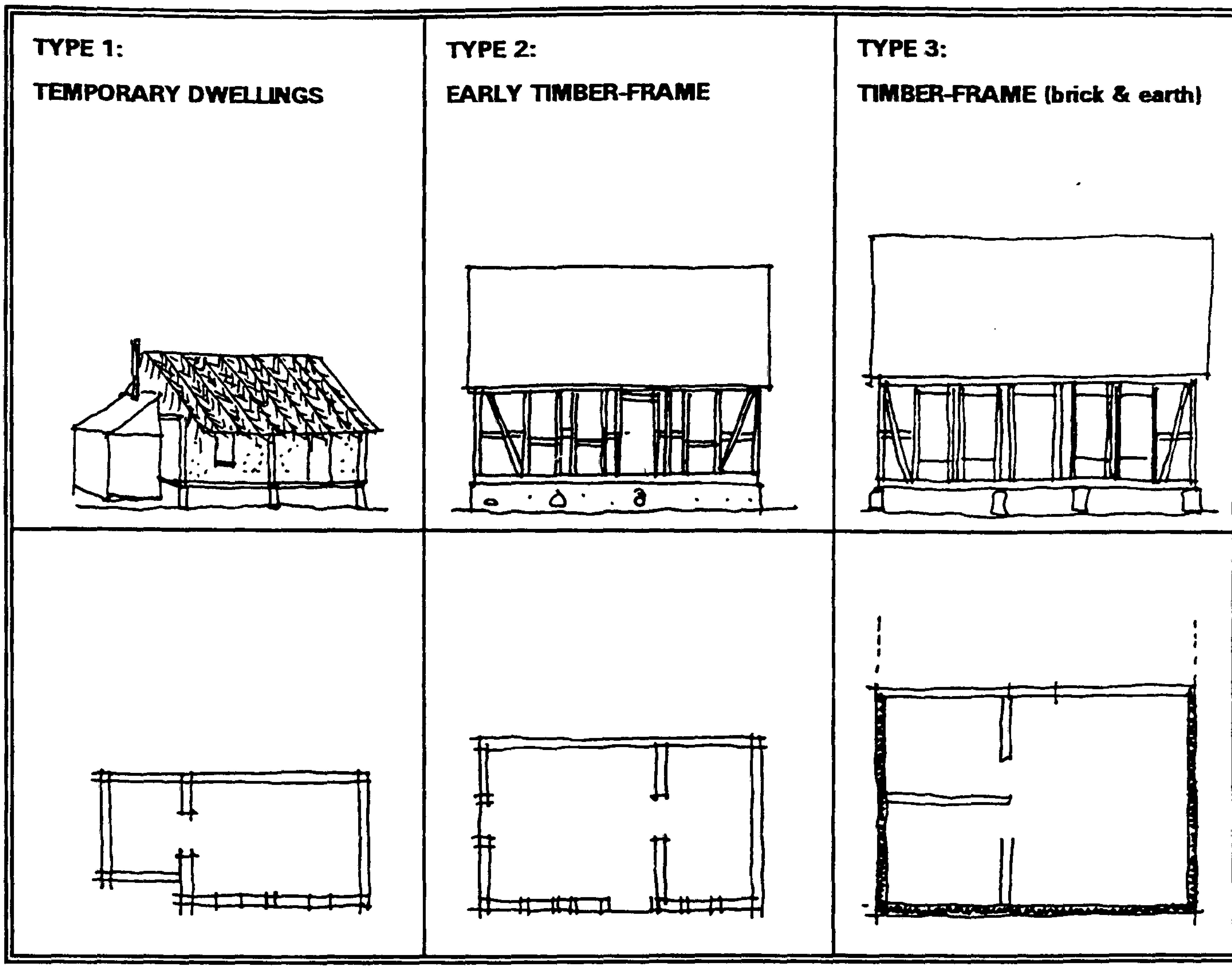


Fig. 39 - Typology of Dwellings with Earth Infill Material

Thus, it seems that adobe as infill material of timber- framed structures is traditionally likely to be less extensively used than wattle and daub. Architect Udo Baumann from Landesamt fur Denkmalpflege Hessen explained that adobe is a later solution than wattle and daub. Although not all the places where the immigrants came from (Germany, 'Pommern'/today Poland, Italy) were visited it seems that, Blumenau reflects broadly the extensive use of brick as the tradition of northern Germany, but at the same time less predominant uses of materials such as earth infill happened, possibly reflecting the immigrants' origin, economic level, fast production- rate, but also adequate solutions for the Brazilian environment.

BRICK INFILL MATERIAL:

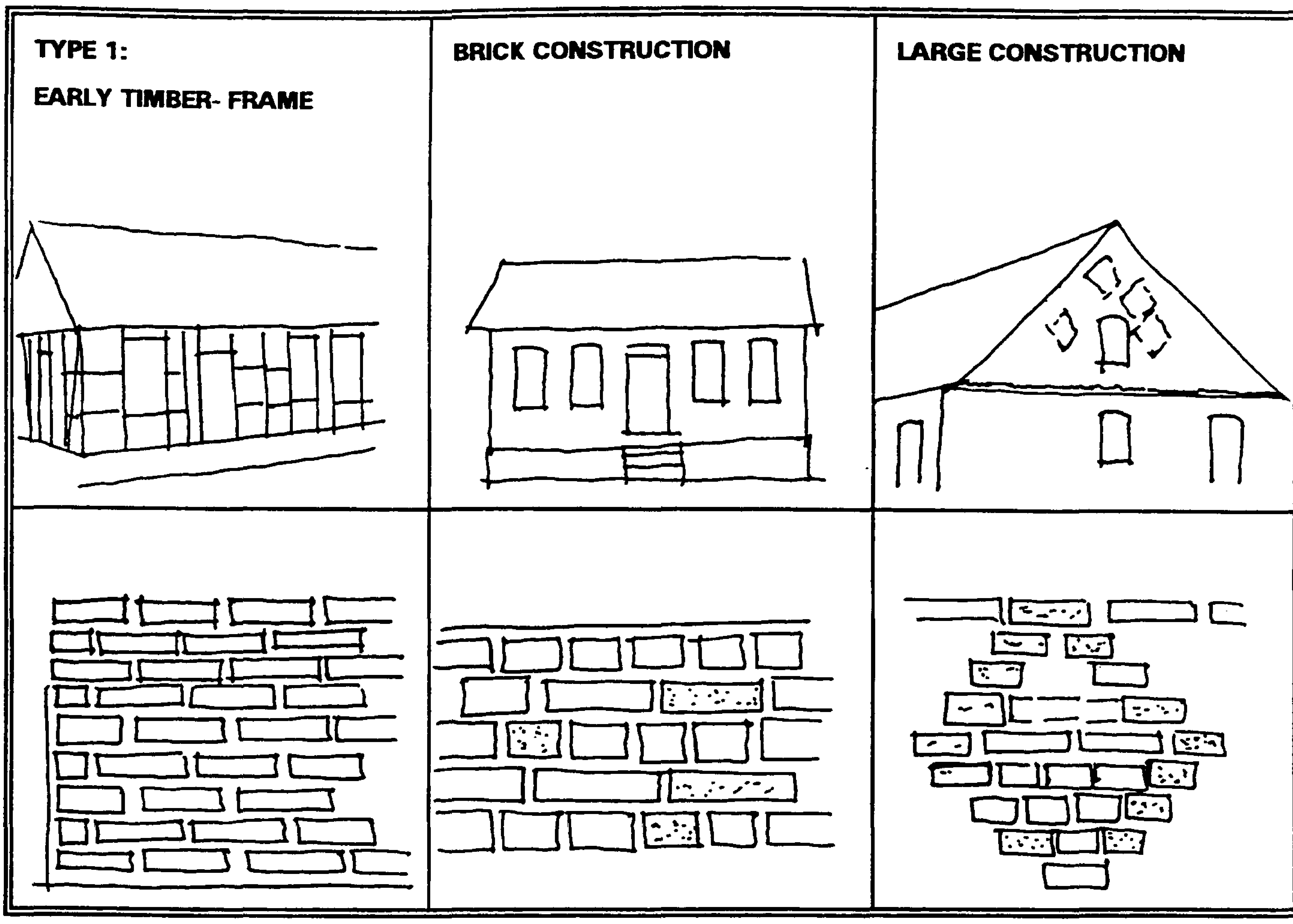
In general, brick was predominantly used as infill material as well as in brick wall. Documentary sources and physical evidence of brick making reveal information about the making of brick from early times and the traditional processes of hand- moulded production or extruded production. The production of brick in Blumenau reflects historical, physical and aesthetic differences in the panels of timber- framed houses which may be found in two distinct types of dwellings. The type of bricks is a useful indicatour of date and dwelling type in Blumenau. These are illustrated with further contemporary brick constructions.[57] (fig. 40)

Type 1: Early timber- framed construction and other types of constructions (from early years of Blumenau colony to approx. 1900) built with bricks apparently made with hand- moulded production, ie mainly plain brick panels. These are bricks with a more rustic appearance, bigger, of different sizes and in a variety of colours including reds, buffs and creams. Examples of bricks from this process indicate that the clays might come from different sources, with different mixing processes and firing temperatures. Evidence shows that rudimentary pug mills, wooden moulds and improvised kilns consisting of a chamber dug into the slope of a small hill might be used.

Type 2: Later timber- framed construction and other types of constructions (approx. 1900 to 1950) built with extruded bricks in herringbone panels. These are smoother bricks of regular size and reddish colours with dark glazes from the firing process. Evidence shows that rudimentary wooden pug mills including an auger and kilns of the small Scotch kiln type were used.

[57]See also below the section Production and Supply where a description about the historical technology of brick is given.

HAND- MOULDED BRICK



EXTRUDED BRICK

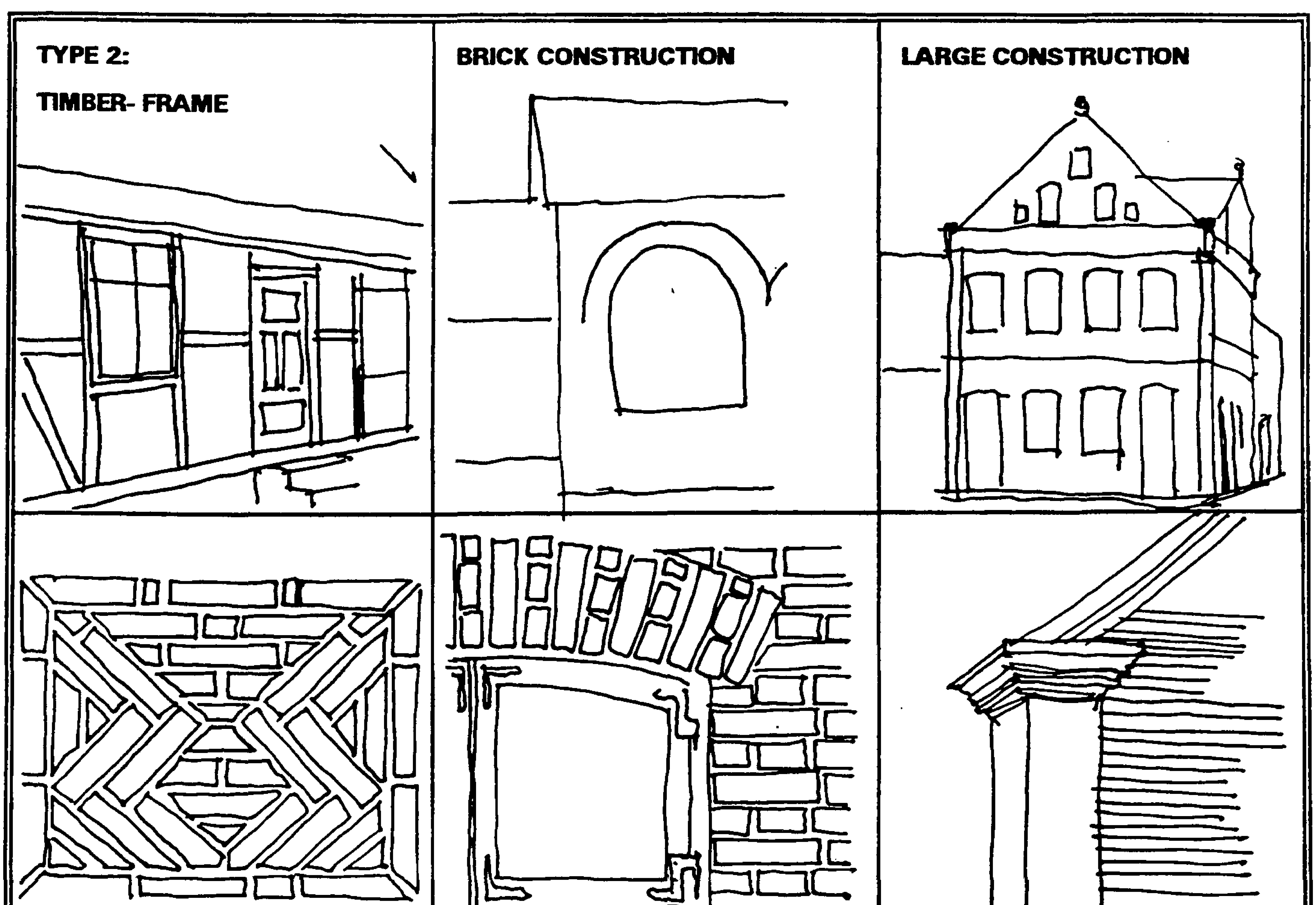


Fig. 40 - Typology of Dwellings with Brick Material

(1) ADOBE

ADOBE: GENERAL

Definition

Adobe is the term used to describe earth blocks made from thick malleable earth to which straw is often added. Traditionally adobe is made by hand from wet earth, pushed or thrown into a wood or metal mould, the mould removed and the brick left to dry in the sun. Today, the use of machines is widespread.[58]

Composition

A typical adobe mix contains clay, aggregates and commonly fibres, but the ranges of soil depend on the nature of the clay, therefore tolerances are possibly found. However, the addition of aggregates and fibres needed varies with the type of soil. Components of typical adobes are discussed below. (fig. 41)

1. Soil

Range of Particle Size:

A typical, serviceable adobe may have the following soil proportion:

Clay 10-30%; Silt: 10-30%; sand: 40-80%; and minimum amount of gravel.[59]

Amount of clay and type:

Clay, and to a certain extent, silt acts as a binder. The clay should be adequate to ensure that all the grains are firmly embedded. Excess of clay or unstable clays even in small amounts result in instability of adobes as they tend to expand in the presence of moisture and shrink when drying.[60]

Fig. 41 - Components of Adobe: soil

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[58]Doat, P., et al. (1991) Building with Earth, pp. 106; Houben, H. and Guillaud, H. (1994), Earth Construction, pp. 4; Norton, J. (1986) Building with Earth, pp. 30.

[59]Chiari, G. (1983) "Characterization of Adobe as a Building Material. Preservation Techniques", in Proceedings of the Int. Symposium on the Conservation of Adobe. Adobe 84, p. 32; Clifton, J.R. (1977) "Adobe. Building Materials: Properties, Problems, and Preservation", in Technology and Conservation, pp.30-4; Doat, P. et al., op cit, p. 111; Norton, J., op cit, pp. 32.

[60]Brown, P.W. and Clifton, J.R. (1978) "Adobe 1: The Properties of Adobe", in Studies of Conservation, no. 23, pp. 139-40; Chiari, G., op cit, pp. 32; Clifton, J.R., op cit, pp. 31.

2. Fibres

Plant Fibres:

Straw of all kinds is commonly used such as barley, rye and wheat. Chaff of cereal crops such as wheat, rice and barley may also be used. Light fillers such as sawdust and shavings are sometimes included.

The function of fibres:

1. To distribute shrinkage cracks evenly.
2. To make mixing ingredients easier.
3. To hold the earth, thus acting as a light reinforcement.
4. To ensure even drying.
5. To increase tensile strength.

Amount of fibre: Generally the minimum proportion of fibres necessary to achieve beneficial results with earth starts at 4% by volume.[61] The amount of fibre added will depend upon the properties of the soil.

4. Animal Products:

Dung is sometimes used as an additive for adobes. Animal hair, casein /whey are more often used for renderings. Animal urine (eg for daub) is used as a plasticiser, helping to eliminate cracks.[62]

Fig. 41 - (continued) Components of Adobe: fibres

[61]Houben H., Guillaud, H. op cit, pp. 83; Pearson, G.T. (1992), Conservation of Clay and Chalk Buildings, p.5. Other suitable vegetable fibres according to Houben include: hay, hemp, millet, cane bagasse, coir fibres, sisal, manilha, elephant grass,and fibres of the bamboo palm and hibiscus, as well as the left- overs after scutching flax.

[62]Houben, H. and Guillaud, H., op cit, pp. 98-9 and 338; Pearson, G.T., op cit, p.6.

3. Lime

The addition of lime:

1. Produces a less plastic mixture.
2. Reduces susceptibility to water by reducing porosity and permeability.
3. Improves mechanical properties by providing additional binder.[63]

However, the effectiveness of added lime is highly dependent on the nature of the soil, that is, the amount and type of clay; and sand particle size distribution.[64]

Types:

Quicklime, lime putty and hydrated lime may be used.

Note: Traditionally, the stabilisation of earth with lime was not extensively practised; however, studies in Brazil suggest its use as early as 1549[65].

Fig. 41 - (continued) Components of Adobe: lime

ADOBE: S.CATARINA

Description of S.Catarina Examples

Adobe has not been researched through historical documents, oral accounts by craftsmen or technical reports in the Blumenau region[66]. However, one of the sampled buildings included in this research which is partially built with adobe was identified as a result of an interview with a craftsman, indicating that adobe is recognized as a traditional material in Blumenau. From this interview, no apparent distinction was made between the raw materials and mixing methods used for burnt bricks and those used for adobes. Firing alone accounted for the essential difference between these two materials.

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[63]See Doat, P., et al, (1991). Building with Earth, p.189.

[64]See: Webb, D.J.T. (1992) "Lime Stabilized Soil Blocks for Third World Housing", in Lime and Other Alternative Cements, pp. 246-257.

[65]Houben, H. and Guillaud, H., op cit, pp.88. Lime stabilization is identified as a systematic practice in 1920s in USA. Mendonça de Oliveira, et al, (1990) "The Study of Accelerated Carbonation of Lime- Stabilized Soils", in 6th Int. Conference on the Conservation of Earthen Architecture, pp. 166-69. Soil- lime stabilization is argued as a traditional practice in Brazil brought by the Portuguese based on a historical document from the time of the foundation of Salvador 1549 and analytical results of an adobe sampled from a nineteenth century house in 'Ilha das Vacas', Bahia.

[66]See also previous information about adobe and relationship between dating and type of dwelling.

The condition of these adobe panels varies considerably from site to site: the very well conserved back sheltered timber- framed wall of Klein House; the evident high moisture content of the back and sheltered timber- framed wall of Thurow house; and the loss of adobe units of the external timber- framed walls of Tottene house.

However, as a complete survey was not made the reasons for problems of water ingress and missing of adobes units were not identified and cannot be correlated with the composition of the materials. Thus, only through further research will it be possible to gain a better understanding of Blumenau's adobe. This research should cover the historical and or environmental reasons for the choice of adobe, differences between adobes and fired bricks in terms of sources of raw material and mixing/ moulding processes, and the quantity of external and internal infill panels built with adobe.

Characteristics of S. Catarina examples

Three adobe panel structures were recorded in this study and two were sampled. Visual observation shows identical size, colour and texture, although they differ distinctly in terms of building sites[67]. A significant characteristic of these materials is their homogeneity and density indicating a much more thorough pugging and compacting technique that for daub. One sample has been selected for analysis and the result is summarised in the next table. (fig. 42)

Results and Discussion

The comparative analysis of this adobe with others from different sources indicates that this is a good building material. The soil of the Tottene adobe falls in one of the ranges eminently suitable for earth construction[68]. The soil of Tottene adobe is of a fine- grained loam texture. Although the analysis shows a low percentage by weight of the organic matter in the sample, the presence of elongated voids integrated with evidence of fibres suggests that the original percentage was higher. Deterioration and loss of some of the

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[67]Tottene adobe was collected from an Italian family house, whereas Klein adobe was collected from a German family house. Both were probably built before 1900. In addtion they are located at a distance more than thirty kilometres from each other where differences in the soil would be expected.

[68]Leszner, T. and Stein, I. (1987) Lehm Fachwerk, Koln, Rudolf Muller, pp. 32-3. The authors give a table with different ranges of soil indicating the suitable ones in Germany for earthen construction. The Tottene adobe fall in the range of 15-25% clay; 15-50 silt; 25-68%sand. These are sandy loam soils suitable for earthen construction.

original fibre content may reasonably be supposed.[69]

Sample	TEXTURE	Plasticity	Colour/Munsell [hue/value/chroma]	Fibre Examination	HCL Spot Test
Tottene 5: Adobe	20% Clay; 40% Silt; 40% Sand	LL: 29.4 PL: 18.8 PI: 10.6 Mildly Cohesive Inactive: 0.54 Not expansive	Pinkish Grey 7.5 YR/6/2	Small short fibres. Organic Matter Content: 4.4% per weight	Negative

Fig. 42 - Results of Adobe

[69]See Courty, M.A., et al, (1989), Soils and Micromorphology in Archaelogy, p. 119. The authors say that a very common characteristic of adobes is the presence of elongated, tubular-shaped voids which are pseudomorphous of the plant temper that has been used.

(2) DAUB

DAUB: GENERAL

Definition

Daub is one of the oldest known construction materials. It is made from clayey earth mixed with straw or other sorts of vegetable fibre to prevent shrinkage during drying. Traditionally it is applied in thin layers, pushed between the supporting framework, by hand or with a trowel, to both sides of the wall. Cracks which occur in the fine layers can be filled in during the drying process. According to the type of framework some traditional daub panel techniques may be outlined and illustrated: (fig. 43)

Wattle and daub. The support is made with vertical staves inserted into the rails and a wattle work of twigs, reeds or thin slats of wood. Materials and patterns may vary throughout regions. The daub mixture is applied in layers to both sides of the framework. This is the simplest and most common method of infill because of its great flexibility and low cost.

Daub and staves. The support consists only of close staves/stakes which were upright into the opening panels. The daub may be applied in balls to both sides of the framework or sometimes wrapped around the staves.

WATTLE AND DAUB **DAUB AND STAVES**

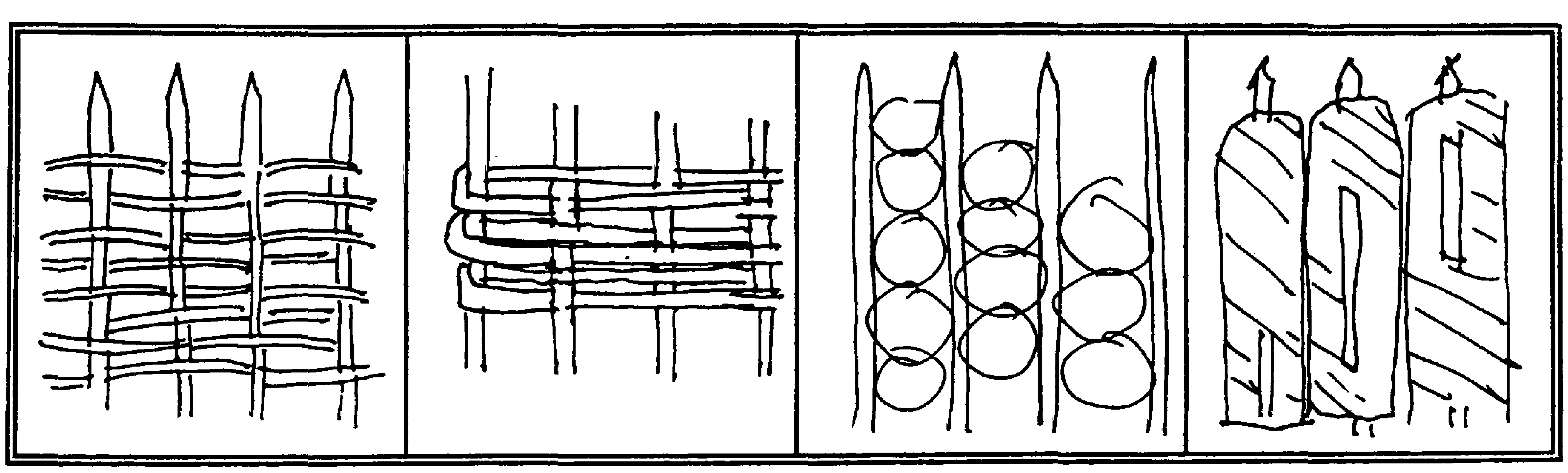

Fig. 43 - Types of Framework and Daub Application.

Daub has remained an essentially manual technique, but has recently been the subject of research. Techniques such as 'easy- to- assemble prefabricated panels' or 'blown earth', in the form of a more liquid daub applied with high- pressure rendering pumps, are being developed.[70]

Composition

The components of daubs can vary considerably, from a more heterogeneous mixture of soil with inclusions to a more fine-grained soil. In spite of these variations the components of adobes and daubs may not differ, thus differences are more related to the technique of mixing and making than the composition of soil.[71]

DAUB: S. CATARINA

Description of S. Catarina Examples

According to archival documents, daubed earth seems to be the oldest material used to fill either primitive and temporary structures or more permanent timber- framed structures in Blumenau, although fired brick has been also produced in the region over the same period of time.[72]

The load-bearing frame and wattle panels were made up entirely of plant materials. These included split palm trees and liana in the early period and these materials continued to be used for temporary dwellings as an alternative to wooden shelters while the timber-framed or brick house was built. This type of construction is mentioned in documents as presenting the Brazilian/ local tradition and contrasts with the more permanent timber-framed structures brought by the German immigrants'.

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[70]Houben, H. and Guillaud, H. (1994), op cit, pp. 4 and pp. 189; Norton, J. (1986) Building with Earth. A Hanbook, pp.25.

[71]See composition of adobes in previous section.

Particle size in daub materials seems to have a broad range where variations on mixture recipes from country to country and even regions are to be expected. Richard Harris says that 'There are as many daubs as there are daubers' in Wright, A. (1991). Craft Techniques for Traditional Buildings, p. 100.

[72]The report referring to the activities and production of Blumenau during 1856 by the director of the Colony Dr. Hermann Blumenau included among the factories the establishment of the first brickworks in the area, but it is possible that less permanent brickmaking was used before and during the early years of Blumenau.

See above the photographs which illustrate the early buildings in Blumenau.

The early quarters for the immigrants, the first permanent houses, the historical views of Blumenau and other documents from the first ten years of Blumenau (1850- 1860) suggest that daub was employed from the early period as an infill for more permanent timber structures. Many documents refer to the use of brick after 1860.

Whatever type of frame is used and whatever period, daub is obviously quicker to produce than fired bricks. In some cases therefore it is possible that it was used while the bricks were being prepared. In addition, documents refer to the problem of daub deterioration during periods of flooding which may well have contributed to the disappearance of these materials from the old sites of Blumenau.

Oral accounts by craftsmen describe daub as an earth mixture (without lime) with fibres (chopped straw or grass for wall daubs and sawdust or dry grass for ceiling daubs). Cow dung is mentioned as an undercoat which is applied to the staves to improve the adhesion of the daub mortar. Dung may also have been added to the mortar itself. Animal urine is also identified as a probable additive to the daub mortar.

It is likely that different framework patterns and variations in application technique, such as earth and straw wrapped into the staves may occur within the area. There is scope for further period research to develop a better understanding of how these materials were used.

Characteristics of S. Catarina Examples

Five wall daubs and two ceiling daubs were sampled. The colour (strong brown/ reddish yellow), texture and amount of fibre and type vary. Plant fibre was also used to fill the edge between the daub and the frame. Three wall samples were selected for analysis and the results summarised in the following tables. (fig. 44,45)

Sample	Texture % of clay/silt/sand	Plasticity LL/ PL/ PI	Colour(Munsell) [hue/value/chroma]	Fibre % of	HCL Spot Test
Wacholz 1	30/ 10/ 60	60.3/32.5/27.8	Reddish Yellow 7.5YR/6/6	11 long	Neg
Franz 1	30/ 15/ 55	67/45.1/22	Reddish Yellow 7.5YR/6/6	13.5 long	Neg
Lumke 1	5/ 50/ 45 also inclusions	44/35/9	Strong Brown 7.5YR/4/6	13 straw/wood	Neg

Fig. 44 - Results of Daub

Sample	Cohesiveness	Activity	Expansivity
Wacholz 1	Very Cohesive	Mildly Active:0.95	Expansive
Franz 1	Very Cohesive	Inactive: 0.74	Mildly Expansive
Lumke 1	Slightly Cohesive	Active: 1.7	Not Expansive

Fig. 45 - Results of Daub Plasticity

Results and Discussion

The results from the three samples indicate two distinct types of daub:

Type 1: A very cohesive reddish yellow soil, with a high clay content and plasticity. Acceptable performance, but susceptible to shrinkage and cracking. The soil of Wacholz and Franz daubs has a sandy clay texture with well graded coarse to fine sand.

Type 2: A slightly cohesive strong brown soil, with a low clay content and plasticity. The soil of Lumke daub is a silty texture with low clay content, well graded coarse to fine sand, but also some inclusions. Acceptable performance but susceptible to erosion.

Both types indicate similar amounts of fibre and wood admixtures of about 13% by weight. Based on this data and comparing these results with typical data for suitable daub soils-compiled from different sources, it can be concluded that these materials fall within acceptable limits for daub soils, although they differ extensively in physical characteristics.[73] In general, more stable soils which exhibit less shrinkage and expansion are desirable. However, since daub is not a structural material, cracking and shrinkage may not be considered critical.

The behaviour of these daub soils differs from the source used for adobe. The latter, presents better plasticity than the daub soils, a more finely graded texture and were probably prepared using different mixing techniques.

ADOBE AND DAUB: RECOMMENDATIONS FOR REMEDIAL WORK

Repair and replacement of adobe and daub should meet the following requirements:

Principle

Retain the maximum amount of existing material. Repairs and replacements should be based on an understanding of earth technology. Advocate simple site repairs with compatible materials rather than expensive solutions with alternative materials. High quality work standards should be specified and achieved by sound specification, suitable instruction and good supervision.

Testing

A thorough investigation of the surviving building material properties and techniques as well as the soil site should be provided by essential tests.[74] Recommended essential tests for choosing repair or replacement soils which are compatible with the existing building are:

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[73]Lezner, T. and Stein, I. (1987), op cit, pp.32-3.
Sandy clay soils with particle size in the range of: 25-65% clay; 0-18% silt; 17-75% sand are good for earthen construction.
Sandy loam soils with particle size in the range of: 5-17% clay; 5-50% silt; 35-90% sand have conditional suitability for earthen construction.

[74]Hughes, R., et al, (1988) "The Geotechnical Study of Soils Used as Structural Materials in Historic Monuments", in Proceedings of the Engineering Geology of Ancient Work, Monuments and Historical Sites, p.1043.

1. Colour identification. This is an indicator of soil texture in the field.[75]

2. Particle size distribution. This determines the main behavioural characteristics of the soil.[76]

3. Plasticity. This is an indicator of clay type and stability, the behavioural response of the soil towards water.

4. Fibre Examination. Size and proportion of fibres.

5. Clay Type. Identification of clay type is desirable, but not usually necessary.[77]

Preliminary tests should be performed on- site. Whenever possible and relevant they should be supported by laboratory testing.[78] Methods of fabrication should also be understood as differences in techniques, may alter physical and chemical characteristics.[79]

Treatments

Where earthen panels are decayed, missing or made with inappropriate materials they should be always preferable repaired or replaced with earthen material as this material offer the following advantages:

1. Earth is the oldest, although not the most widely used or most common survival infill material. Surviving authentic examples are important documents of local earth technology.
2. Contemporary use of earthen materials are being developed on a scientific basis and promoted as a low- cost energy- conscious material, produced either by manual or industrial production, where soil behaviour may be analysed and improved; thus, more durable materials are being developed by understanding of soil sources and techniques making repair using earth a technically viable and preferred alternaltive.
3. Decayed area may be repaired by recycling or re- moulding original material by adding water.
4. Local skills are usually required, thus the technique, even when largely forgotten, may be taught to local people.
5. High porosity of the material. Moisture absorbed is able to evaporate especially when compatible earth or lime renders and limewashes are also maintained. This is a useful quality

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[75]Clifton, J.R., et al, (1978) Methods for Characterizing Adobe Building Materials, p.3.

[76]Chiari, G. (1983), op cit, p.32.

[77]Chiari, G. (1982), op cit, p.32.

[78]Field and laboratory tests for soil materials are described in many sources. See above Analytical Procedures for bibliographical references.

[79]Clifton, J.R. (1977), op cit, p. 31

as it benefits the maintenance of buildings built without damp proof courses, avoiding trapping water which may give rise to the decay of timber and other materials.

6. Lightness and flexibility (especially for wattle and daub), thus moving with the timber framing. So, in addition, fewer cracks and less water penetration.

7. Insulating properties when mixed with fibres. However, earth alone is not particularly insulating.

8. Durability is achieved in moderate or sheltered conditions, and if well prepared and maintained.

Repair or replacements of missing or decayed parts should be carried out with soil similar to the existing building in colour, texture, plasticity and technique.[80] However replacement of whole parts may sometimes be appropriate to consider soil stabilisation or the use of new soil techniques if such changes are better able to conserve the building, ie (1) to increase durability and reduce maintenance or (2) to facilitate replacements in situations where the original technique is difficult to replicate eg compacted earth repair in a restricted space. Thus, replacements which involve whole areas should consider two alternatives:

1. Traditional methods which replicate the original surviving materials in composition and technique.

2. Modified methods to maximise strength and durability of new earth replacements, using more durable materials. Blending of different local soils, soil stabilisation and mechanical compaction are options.[81] In all cases, however, the properties of replacement materials should be similar and compatible with those of the original ones. Any admixture to the earth that retains moisture and encourages decay should be approved.

Specifications

A general selection of materials for earth construction may be specified, however regional characteristics should be investigated and may alter the following requirements: (fig. 46)

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[80] Difficulties in matching precisely new soil with the old found in the building may arise due to the sources of available materials as eg the original borrow pit site was replaced by an extensive urban development. See Hughes, R. (1988) "Problems and Techniques of Using Fresh Soils in the Structural Repair of Decayed Wall Fabric", in Proceedings of 5th Int. Meeting of Experts on the <u>Conservation of Earthen Architecture</u>, p.63.

[81] Hughes, R.E, et al, (1988), op cit, p. 1048.

Soil

The building site should, whenever possible, be the source for earth repairs and replacements. Suitable soils should be:

1. Free of organic matter, usually less than 12%.
2. Similar to the existing material. Typically, a serviceable mix for adobe or daub should contain sandy clays, silt clay loam, clay loam soils, and other soils which composition ensures stable and cohesive clays and well graded particle size distribution with a minimum of gravel. In such a mix, all grains are covered and well bonded in the matrix, strength is adequate and cohesion is assured.

Fig. 46 - Specifications for Earth Materials: soil

Fibres

1. Traditional plant fibre sources such as straw, chaff from cereal crops or light fillers such as sawdust and shavings may be freely specified. However, the need for fibre depends on the type of soil.
2. Traditional animal fibres such as dung found in some of the Blumenau samples may be sometimes specified, but trials are always recommended. Other traditional sources of animal fibre such as hair have not not yet been found in the Blumenau samples, but these may be specified.[82]
3. Plant fibres should usually be dry and chopped. Stalk length is preferably between 4 and 6 cm long. Quantities of fibres can be up 20 to 30% of the volume of the soil, although small amounts are possible depending on the nature of the soil. If too much fibre is added this can reduce strength and be poorly distributed. However, proportion should be similar to the existing material.
4. Synthetic fibres as a substitute for traditional fibres may sometimes be appropriate, but for the time being it is recommended that original materials are replicated in Blumenau unless new research proves that these materials are not advisable.

Fig. 46 - (continued) Specifications for Earth Materials: fibres

Lime

Lime may be specified as a stabiliser in cases of replacement materials. However in general the traditional lime- free earth of Blumenau should be specified.

Fig. 46 - (continued) Specifications for Earth Materials: lime

[82]Current literature indicates that organic products of all types have been added to earth mixes and there is no clear restriction for their use today. However, the same is not applied to lime mixes where current literature is much more emphatic as to avoiding the use of animal organic materials such as dung, eggs and whey because good material may be made just with lime and sand. However, the main drawback of the use of organic materials are that they may be subject to biological attack. Therefore, such materials should always be specified with caution, depending on the climatic environmental conditions in which they are used.

Organic Products

Organic products such as whey, casein, dung and urine known to be traditional ingredients may be specified in some situations, but should be subject to preliminary field trials and approval.

Fig. 46 - (continued) Specifications for Earth Materials: organic materials

Materials not Recommended

Cement should be avoided in historic structures, such as those in Blumenau. Cement contains soluble salts which may cause damage to more porous historic materials when the salts crystallize during evaporation. Depending on the quantity that it is added, cement also produces materials which are too hard or too dense and do not permit water to evaporate evenly. Old, porous materials frequently fail sacrificially at the interface with cement- based repairs. [83]

Fig. 46 - (continued) Specifications for Earth Materials: materials not recommended

The following specifications should also be included.[84]

Contract

1. On- site and laboratory tests including a number of samples of existing and repair materials.
2. The extent of conservation work shown on annotated drawings, with specification notes.
3. Areas to be excavated and sources of the raw material.
4. The desired size of the workforce and the qualification of the workers and supervisor, who should be familiar with earth materials.
5. Planning and setting out the work area.[85]

Fig. 46 (continued) Specifications for Earth Materials: contracts

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[83]See below in mortars, renders and plasters section referring to problems when cement is used in traditional structures.

[84]Finding written specifications for historic building materials is a difficult task. See Caron, P. and Lynch, M., (1988), in APT Bulletin, vol. 20. no. 4, pp. 7-9. The authors identify as general requirements for conservation purposes a careful reading of original fabric on historic buildings, laboratory analysis, a search for raw ingredients, and experimentation.
An example of contract document include requirements such as 1) quality assurance- mud plaster work must be performed by a skilled journeyman mason familiar with the materials and methods; 2) submittal- the contractor must submit two samples of existing building material and two of the proposed material, performed sedimentation tests conducted by an independent materials testing analysis, matching colour acceptance by the indicate colour system and chip number; 3) experimentation and approval of test area and 4) detailed specifications for the making of the material including mixing process by foot and machine.
See below Site Instructions for the preparation and application of earthen materials.

[85]For example of an work area see Webb, D.J.T. and Lockwood, A.J., (1987) Brepack Operators Manual. Watford, Building Research Establishment Report, pp. 15-6.

3.3.2 Mortars, Renders and Plasters

MORTAR, RENDER AND PLASTER MATERIALS: GENERAL

Definitions

Mortar is a general term applied to composite materials consisting of two major components: a hardening medium and fillers, and occasionally additives, in proportions which give important properties such as workability, appearance, strength, adhesion, compatibility with the surface and limited cracking.[86]

Mortars are characterised by a plastic state, when fresh, and a hardened state, when dry. According to function, mortar materials are defined as:[87]

1. MORTARS: Bedding, jointing, pointing.
2. RENDERS: External protective surfaces.
3. PLASTERS: Internal protective surfaces.
4. STUCCOS: Decorative moulded surfaces.

Many components have been employed as binding materials for mortar such as clay, gypsum and lime. However, the use of traditional binders began a long decline with the advent of the first artificial cements in the early nineteenth, and especially Portland Cements, first patented in 1824.[88]

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[86]Various definitions are given by literature. This is based on Jedrzejewska, H. (1981), in Mortars, Cements and Grouts used in the Conservation of Historic Buildings ,p. 313; and Houben, H. (1992), in Lime and Other Alternative Cements, pp. 262-7.

[87]Definitions for bedding mortars, pointing mortars, plasters and renders are organized by function and characteristic of mortars and given in the following pages.

[88]Mortars based on hydraulic reactions of (1) very reactive forms of silica and alumina with lime were used in ancient times (ancient Roman cement) or (2) less reactive forms (iron slag and crushed terracotta bricks, etc.) in classical times and fly ash in modern technology. However, the technology of hydraulic mortars based on reactive earths and lime was scarcely used during the Middle Ages. During the eighteenth century, especially the second half another technology of hydraulic mortars was developed which is based on the reaction of limestone with silica and alumina at high temperatures. This is the technology of hydraulic limes: John Smeaton (1759-1876 in England) experiments blending natural hydraulic lime with Roman pozzuolana; James Parker (1796) patented Roman cement - burning a special argillaceous limestone at a 800° C; James Frost (1811) and Vicat (1818) Hydraulic Lime - fired siliceous limestones or mixtures of clay and chalk. Joseph Aspdin (1824, in England) patented Portland Cement - firing limestone and mixing the product with clay and re- firing at 1000°C / 1200° C. However, modern cement standards of high strength cement started with Johnson (1838)- firing lime and clay at much higher temperatures 1400°/1500°. Torraca, G. (1988), Porous Building Materials, pp.71-7.; and Ashurst (1993), 'Lecture 4', English Heritage Course.

The hardening of Mortar

The hardening of a mortar is basically dependent on the type of binder used, although some additives may modify this process substantially. According to the binder used three main hardening processes are described:

1. Hardening by Loss of water:

This is the hardening mechanism of a clay mortar.

2. Hardening by Addition of Water that Crystallizes with the Material:

This is the hardening mechanism of gypsum.

3. Hardening by Loss of Water and Chemical Reaction with Air:

This is the hardening mechanism of a pure lime, termed air- setting or air limes.

4. Hardening by Chemical Reaction with Water:

This is the hardening mechanism by which certain soils stabilised with lime or cement, lime and pozzuolana, hydraulic lime, Portland cement and similar hydraulic binders set. In principle, the setting reaction of these binders is the same; however, they differ in composition, manufacture and hydraulic and physical properties, and should be treated as different materials.

A summary covering a variety of binding reactions and principal constituents is presented in the following table. (fig. 47) The table outlines the development of binding materials starting from clay mortars and ending with hydraulic and artificial cement mortars, ie, the hardest and most dense of these binders.

HARDENING MECHANISMS	MAIN MATERIALS
1 SLOW SETTING BY MOISTURE LOST **Cohesion** forces (mainly electrostatic forces) of hydrated particles of clay	Clay
2 QUICK SETTING WITH WATER	Gypsum
3 MOISTURE LOSS AND SLOW SETTING BY CHEMICAL REACTION WITH AIR **Carbonation** of Calcium Hydroxide with Carbon Dioxide	Non- Hydraulic Limes (putty or dry hydrate)
4 INITIAL OR HYDRAULIC SET **A) Stabilisation Reactions**	
3.1 Slaked lime added to soils depending on clay type and amount yield a sequence of reactions such as carbonation of lime, pozzolanic reaction ending with a matrix of stabilized clay.	lime soil stabilization
3.2 Cement added to soils depending on the grain size of the inert material yield three mix reactions ending with the formation of sandy matrix or stabilized clay.	cement soil stabilization
B) Pozzolanic Reactions	
3.3 Special clays (reactive silica and alumina) added to slaked lime	lime and volcanic earths such as Trass in Renania
3.4 Other natural pozzolanic additives mixed with lime	lime and volcanic ash forms Rice Rusk ash and lime
3.5 Artificial pozzolanic additives mixed with lime	Pottery, brick or stone dust and lime
3.6 Cement additive mixed with lime	Cement lime
5 HYDRAULIC SET WITH HYDRAULIC BINDERS **Formation of crystals by chemical reaction with water**	
4.1 Hydraulic limes and Natural Cements	Argillaceous limestones/ hydraulic limes
4.2 Artificial Cements	Portland Cement and similar

Fig. 47 - Hardening Mechanisms of Inorganic Binders

Composition

The components of mortars include binders, aggregates, water and occasionally additives. The general function of these components are the following:

1. Binder: to bind aggregates.

2. Aggregate:

Inert aggregates to reduce shrinkage, cracking and contribute to the mortar strength. Examples of inert aggregates include sand, some crushed stone, shells. Porous aggregates, even though inert (no chemical reaction) balance water content, thus contributing to setting and hardening.

Reactive aggregates contribute to the setting, hardening and strength of the mortar by chemical reaction with the binder.

3. Additive: to improve supplementary properties such as setting, waterproofing and cohesiveness.

4. Fibre: to improve the quality of the mortar material such as distributing shrinkage cracks evenly; making mixing easier; holding components and acting as a light reinforcement; accelerating and ensuring even drying; increasing tensile strength; increasing insulating properties.

4. Water: to give workability to the fresh mortar (and assist setting in hydraulic mortars).

According to the components used in historic structures, the following groups may be organized: (fig. 48)

COMPONENTS	TYPES
BINDERS used through history according to tradition, availability and specific needs	EARLY AND TRADITIONAL BINDERS: Clay Gypsum (very early) Air-hardening lime MORE RECENT BINDERS Hydraulic lime (predominantly since 19th century) Modern cement (since 1824)
AGGREGATES (FILLERS)	INERT: give bulk, control shrinkage, additional strength and provide texture, colour Pit sand: clean, angular/ coarse grading or fine grading River sand/ soft sand: rounded shape Soil: sandy texture Crushed stones, seashells or other material REACTIVE: yield hydraulic reactions when combined with lime natural pozzolanic material: high reactive silica and alumina such as pozzuolana, tuff, trass, etc. artificial pozzolanic material: reactive brick dust, iron slag, cement, etc.
FIBRES control shrinkage, provide reinforcement, even drying, provide insulation, lighter material	PLANT FIBRES: Straw, chaff from cereal crops ANIMAL FIBRES: Excrement/ dung (with lime also reacts to form a gel) Fur and Hair
ADDITIVES supplementary properties according to specific situations	EXAMPLES Ashes - improve cohesiveness Sugar/ molasses - improve hardness Tallow - decreases permeability Casein, linseed oil - strengthener binder Urine - eliminate cracking

Fig. 48 - Components of Mortars, Renders and Plasters

Based on the above information and the results of this research, two binder- based systems are defined next as they represent the typical binder components found in buildings which were observed and analysed, ie earth and lime. However, documentary sources show that other binder systems were used in Blumenau between 1850 and 1940/50. The chronology of clay/lime and other binders is organized in the following table. (fig. 49)

LIME AND OTHER BINDERS: HISTORICAL CHRONOLOGY

Pre- Colonial: clayey daubed mortars. At this time the burning of lime shells in clamps is produced along the coast of S. Catarina. This lime was later transported to Blumenau by boat and at the beginning of the twentieth century also by train.

1850 Foundation of Blumenau: early temporary houses made with clayey daubed mortars and limewash.

1854 Blumenau Houses and Establishments: 40 houses, 2 mills for sugar and flour, 1 shop, 1 chemist's shop. Clayey mortars and limewash are likely to be the materials for the walls.

1860 Imperial Blumenau: in the early permanent houses, lime is likely to be used as binder.

1863 School Plan: lime is likely to be included for renders and plasters

1867 Budgets Meyer Spierling Commerce: transport of lime. (12 bags and 6 'moios')

1873/4 Mother Church and Prayer House Construction: 5 'barricas' with 10 'quintaes' of Gypsum in powder is ordered from Germany.

1874 Direction House Construction: lime for the construction was storaged. Lime is reported as a material which is not easily available in Blumenau.

1878 Lime and Hydraulic Cement Storage: Dr Blumenau asked permission to order 150 'hectolitros' of lime from Joinville (coast site)and 12 'barricas' of Hydraulic Cement. These two materials were said to be very expensive and only available in minimal quantities in Blumenau.

1900 Limeburning with stones: by this time Italian immigrants had started the burning of stones (high calcium limestone and dolomitic and magnesium limestone) to produce lime. The site was near Blumenau (Itajay Mirim river). Lumps of quicklime were transported by cart to Blumenau.

1904 Gottlieb Shipyard: the first boat was used specifically to transport lime and sand from Sao Francisco/ Joinville to Blumenau.

1917 Railway S. Catarina: 103.800 kg of lime were transported to Blumenau.

1919 List of Imported Products: 126.640 kg of lime and cement.

1923 List of Imported Products: Gypsum is included.

1926 List of Imported Products: 1.601.731 kg of cement and 100.000 kg of lime.

1930-40 Lumps of Quicklime: the lime produced in Brazil was in the form of quicklime.

1940/50 Hydrated Lime in Powder: in about 1940 hydrated lime in powder was launched in Brazil. In about 1950 a continuous kiln is built at the limeburning sites located in Itajay river and 600 bags of lime were said to be produced daily.

Fig. 49 - Chronology of Lime and other Binders in Blumenau

Earth and lime- based systems are further divided and detailed according to function and aggregate type, comprising earth bedding mortars, earth renders and plasters, lime pointing mortars, lime- soil renders/plasters and lime- sand renders/plasters.

Based on field observation and the analytical results it is possible to outline the relationship between these systems and the typology of dwellings and dates in the Blumenau region which are briefly illustrated in the following pages. (fig. 50,51,52,53) However as this study is based only on limited field observation and collection of samples, further research may alter these preliminary results.

MORTARS: Bedding and Pointing:

Earth bedding mortars were used in all types of dwellings observed in this research including early and more recent construction. Pointing mortar is usually present in the same building types and dates described for earth bedding mortars, although a few buildings without pointing, (ie built only with earth bedding mortar), were observed. These include a timber-framed house, a two- floor brick house and a sheltered wall of a timber- framed house. This raises the question of the pointing mortar being original; it may well be a later maintenance.The typologies comprise: (fig.50)

Type 1: Timber- framed construction with adobe infill (possibly 1870- 1900)

Type 2: Small or large timber- framed construction with brick infill: hand- moulded or extruded (approx. 1880- 1950).

Type 3: Small or large brick construction (approx. 1860-1930).

Type 4: Large rendered brick construction (approx. 1880-1930).

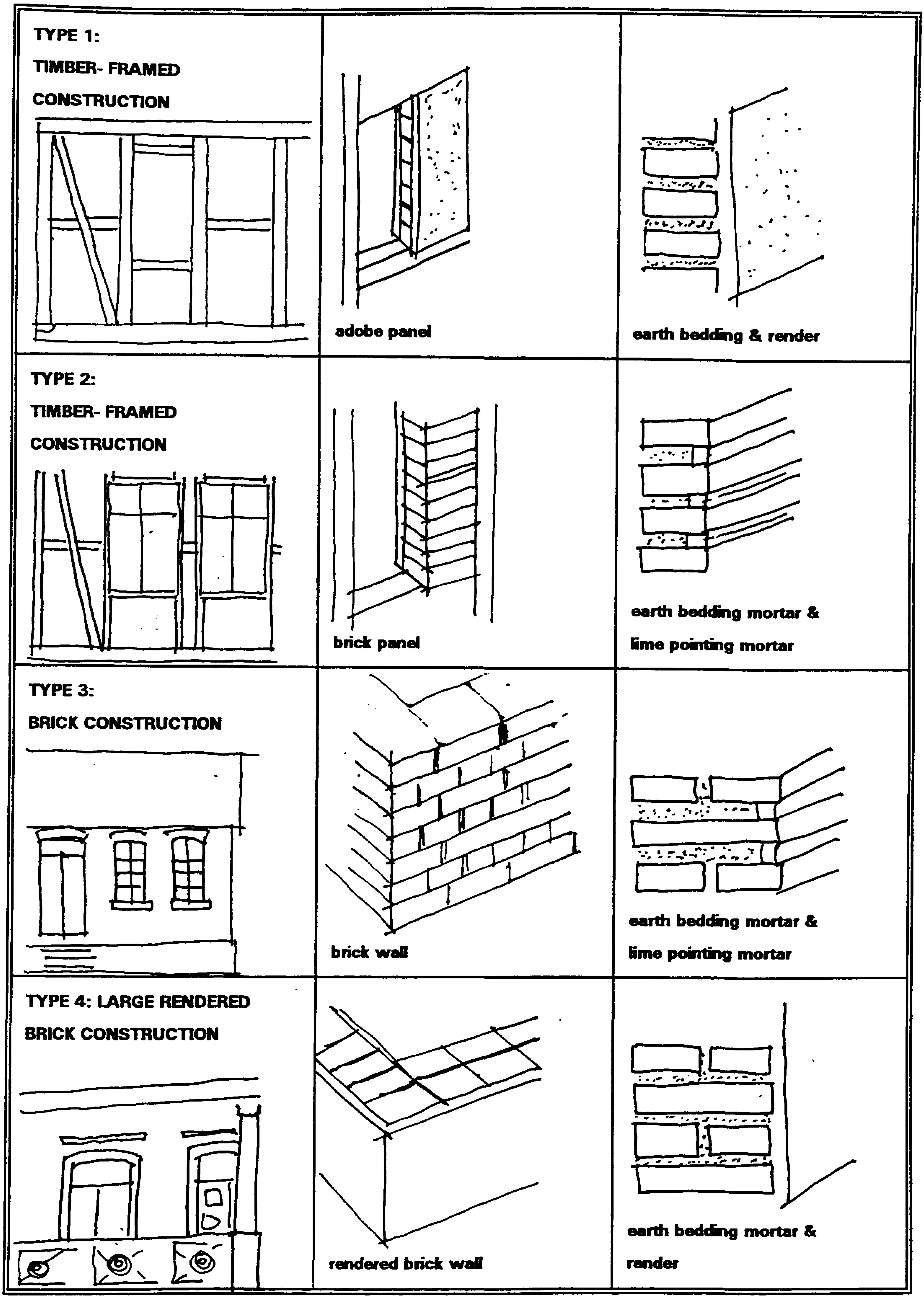

Fig. 50 - MORTARS: earth bedding mortar and lime pointing mortar

RENDERS: External Protective Surfaces

Earth or lime- soil renders were found in few types of dwellings in Blumenau until approximatelly 1940. The great majority of houses in Blumenau rural villages were built with exposed brick. These types consist of: (fig. 51)

Type 1: Timber- framed construction (approx. 1851- 1900). These are houses with earth infill materials.

Type 2: Large rendered brick construction (approx. 1880- 1930) . These are houses or buildings entirely or partially rendered and decorated with stucco.

Type 3: Modified rendered construction (approx. 1920/ 1930). Early and originally exposed brick construction or even timber- frame houses which were rendered as a later alteration.

According to old photographs and documents, Blumenau (early headquarters) and other smaller town centres have the great majority of their buildings rendered or stuccoed. Unfortunately, the majority of these buildings were demolished, and this research is focused on the rural villages of Blumenau region. Further research on the buildings' survival in the town centres and in the rural villages is needed; the results will complement this preliminary research.

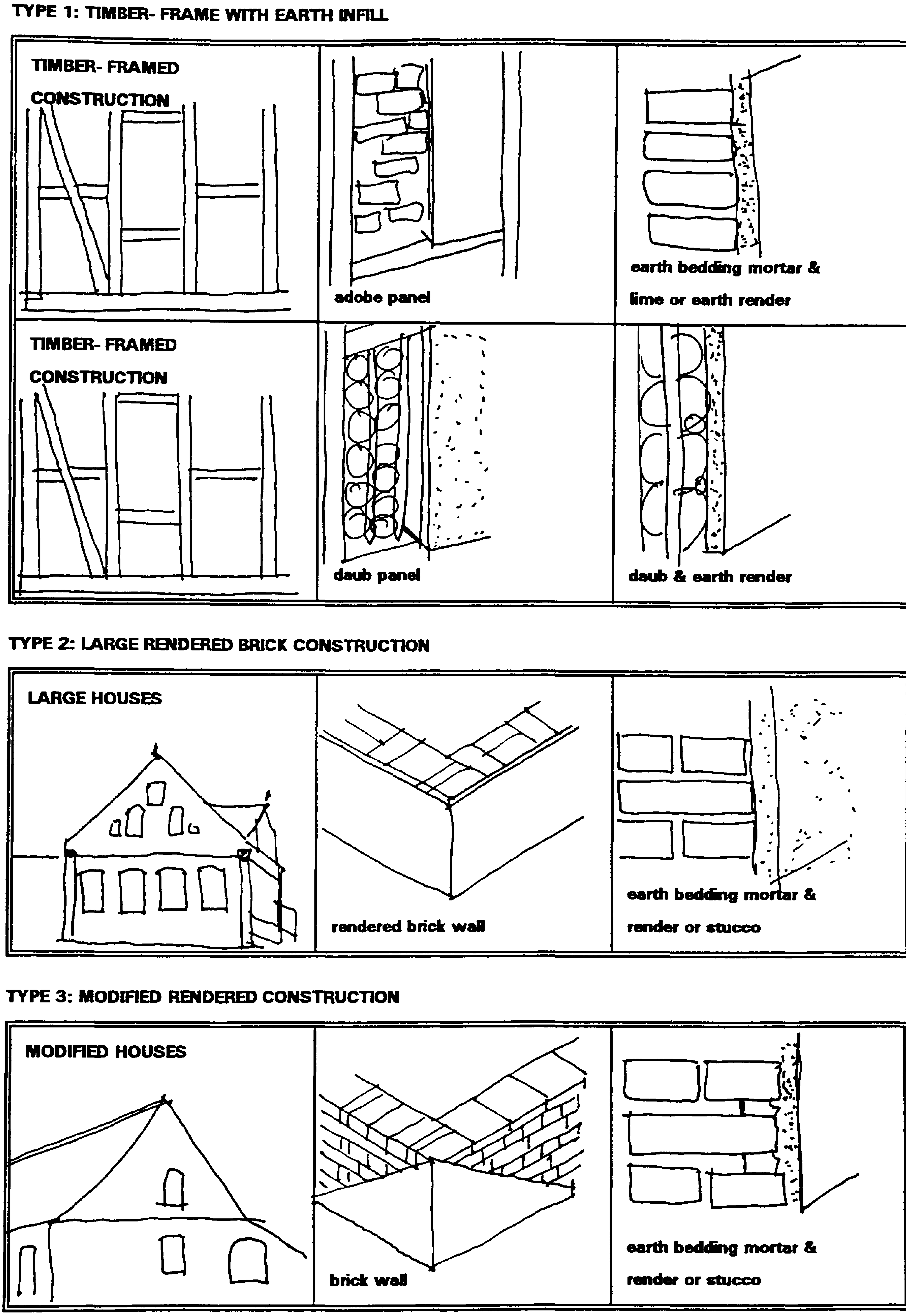

Fig. 51 - RENDERS and STUCCOS: earth or lime- soil render or stucco

PLASTERS: Internal Protective Surfaces

Wall Plasters

Earth or lime plasters were used in all types of dwellings in the Blumenau region. However, a few internal timber- framed walls without plaster were also observed. The relationship between plasters and type/ date of dwellings includes the following: (fig. 52)

Type 1: Timber- framed construction (approx. 1851- 1900). In these buildings earth plasters were predominantly used. In timber- framed walls, these plasters were first used to cover the panel. Later (approx. 1930's), especially in important rooms, the walls were re-plastered to conceal the framing and were often decorated with stencilling. However, some buildings may have had the plasters covering the frame from the beginning.

Type 2: Timber- framed construction (approx. 1900-1950). In these buildings lime plasters with pit sand or soil were predominantly used. It is said that by the end of this period lime was gauged with cement.

Type 3: Brick construction (approx. 1860-1950). In these buildings, according to observations, the early plasters were predominantly based on earth and, later, lime- based mixtures.

Type 4: Large rendered construction (approx. 1880- 1930). These buildings may have internal timber- framed or brick walls. The plasters are possibily the same types as for timber- frame and brick construction.

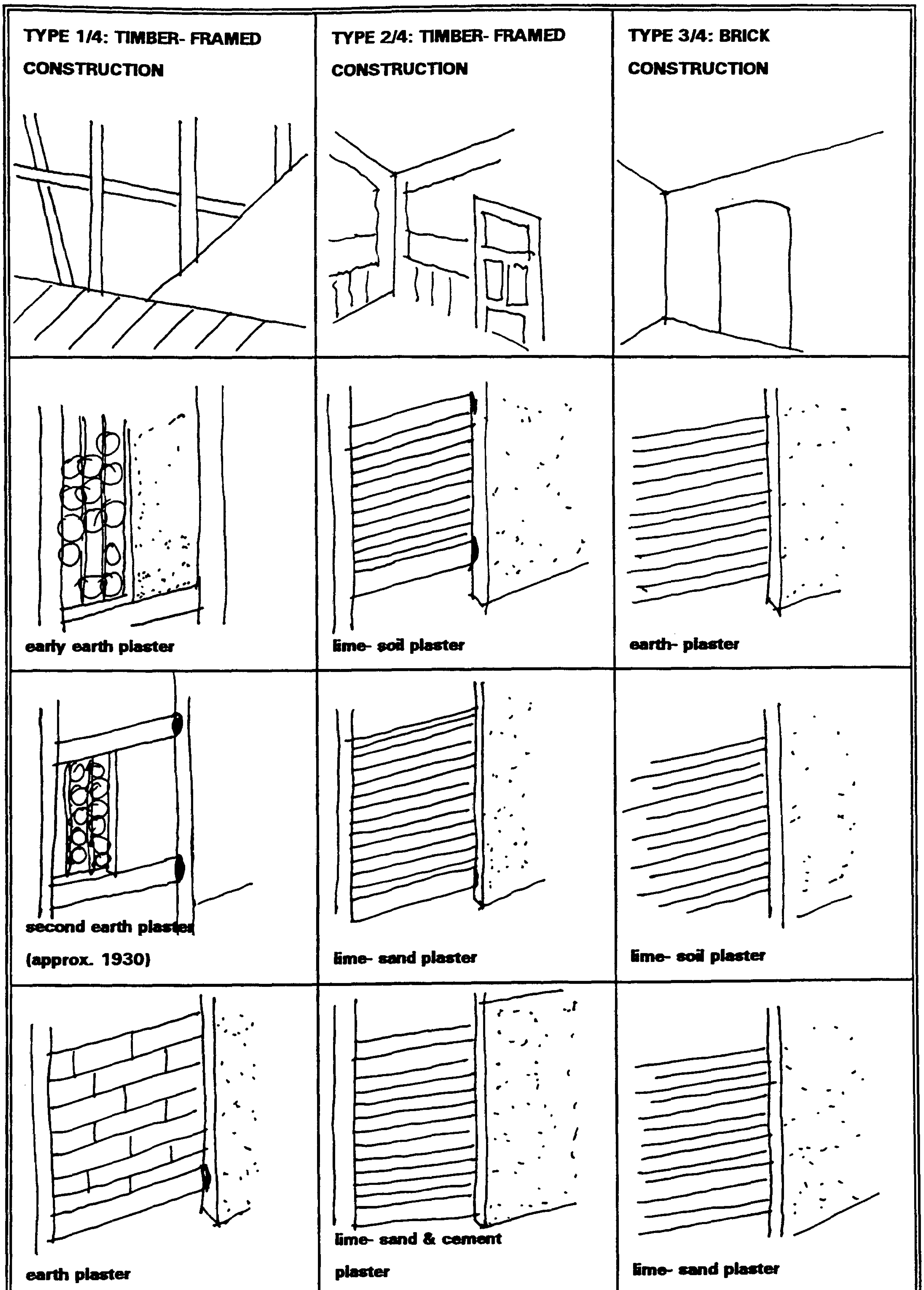

Fig. 52 - PLASTERS: internal protective wall surfaces

Ceiling Plasters

Ceiling plasters were not common. (fig. 53) Usually, the ceiling was simply the exposed wooden floor of the above loft or, in some cases, a ceiling made with wooden planks.

Type 1: Large rendered construction (approx. 1880- 1930). The use of lime ceiling plasters in rural villages is confined to only a few houses[89].

Type 2: Modified rendered construction. Lime- soil ceiling plasters were possibily used occasionally in some early brick constructions that were modified during the 1920's and 1930's.

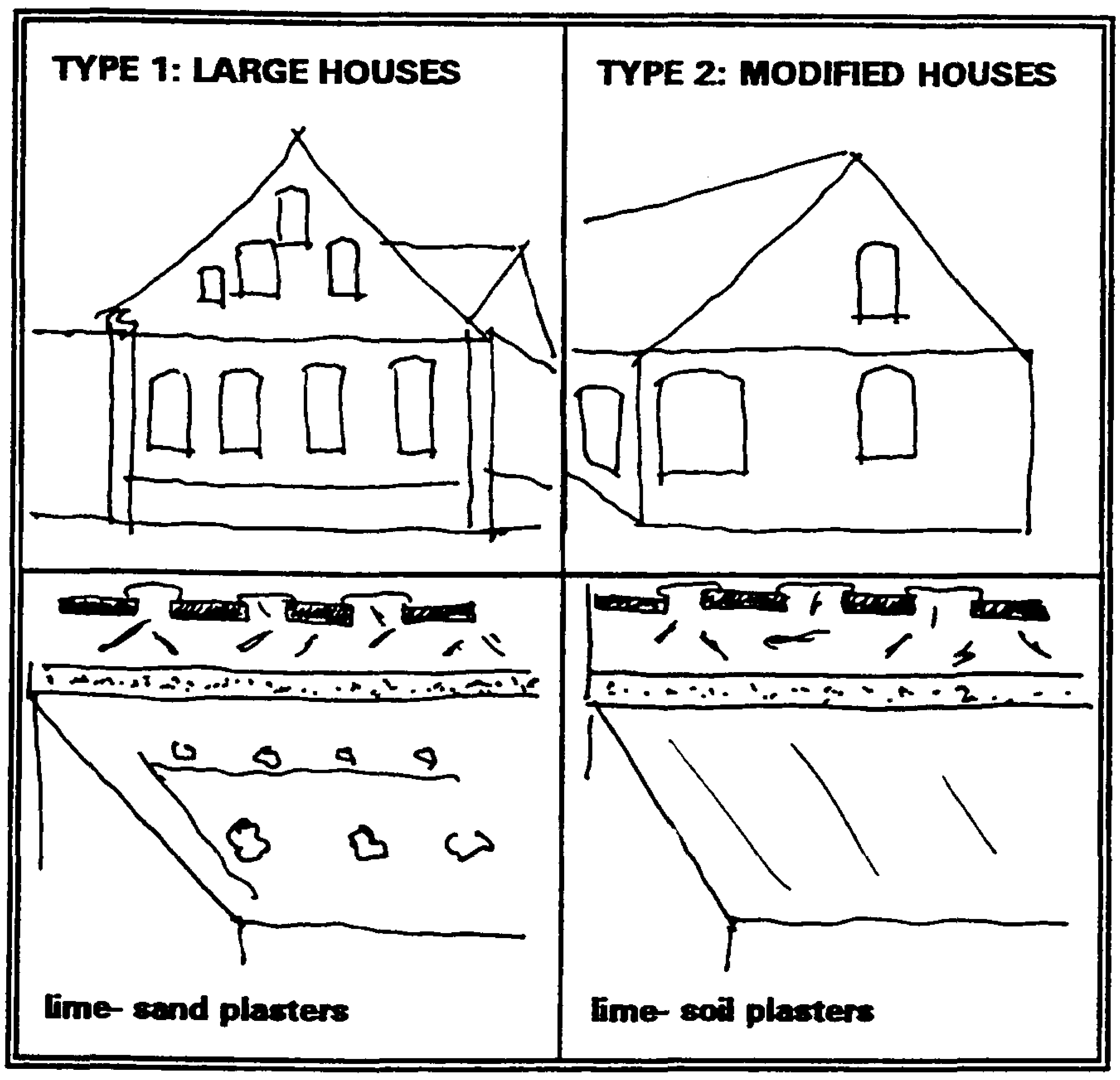

Fig. 53 - PLASTERS: protective ceiling surfaces

[89]According to documents and oral accounts by craftsmen gypsum in Blumenau was mainly used as a binder for ceilings before the use of modern cement.
Gypsum review:
1874- probably the first document referring to gypsum (imported from Germany).
1923- Gypsum is included in a list of imported materials.
Cement review:
1878- probably the first document referring to cement - "hydraulic cement".
1919- cement is included in a list of imported materials.
1926- a report from Blumenau includes: 1.601.731 kg cement and 100.010 kg lime.
See also the previous complete table detailing the chronology of binders in Blumenau.

EARTH- BASED SYSTEMS: GENERAL

Definition

Earth - based systems can be defined as the material in which soil is used as the raw material to provide the binder as well as the aggregate.[90]

Nature of Soil

1. Particle size and characteristics

Many soils are suitable to be used as building materials. Soil particles are classified into sizes: gravel, sand, silt and clay. According to British Standard, gradings are as follows:

Gravel: 60.00mm to 2.00 mm
Sand: 2.00mm to 0.06 mm
Silt: 0.06mm to 0.002mm
Clay: less than 0.002mm

Depending on the proportion of each particle size, the soil will have different textures and properties. The major texture types of soils are classified into the following categories[91]:

1. Organic Soil
2. Gravel Soil: Gravel and pebbles are predominant
3. Sandy Soil: Sand predominates
4. Silty Soil: Silt predominates
5. Clayey Soil: Clay predominates

Usually, the most suitable soils for earth buildings are of a sandy or silty texture. Organic soils are not suitable for building construction; gravel soils are usually avoided; and clay soils are very cohesive, malleable and sticky, but are more likely to shrink when wet, thus their use may be avoided.

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[90]For the understanding of the soil as a construction material the following books were consulted:
Houben, H. and Guillaud, H.(1994), Earth Construction;
Norton, J. (1986), Building with Earth;
Torraca, G. (1988), Porous Buildings Materials.

[91]Soil classification given by Houben, H. and Guillaud, H. (1994), Earth Construction, p.21

2. Mineralogy and Characteristics

A variety of soils exists, dependent on the nature of the parent rock, climate, topography and vegetation in which the soil is formed.[92] The soil is composed of organic and mineral matter, but it is the mineral matter which is the useful fraction in construction. The mineralogical components of a soil are grouped and identified according to the grain size. Sand and silt are inert particles in which mineralogy does not affect the behaviour of the material. However, the identification of soil mineralogy may be occasionally helpful to locate the source of soil used in construction.

The mineralogy of sands and silts may be predominantly siliceous in the form of quartz grains, resulting from the disintegration of sandstones and some other crystalline rocks; or calcareous, resulting from the weathering of limestones.

Clay minerals may be of different types, resulting from chemical weathering of different rocks. Large clay molecules are made of fine crystals which are in the form of thin mineral sheets, commonly with a hexagonal shape. As the mineral sheets are held together with weak bonds of attraction, water separates these sheets, causing them to slide over each other, making the clay plastic. The sheets of minerals have a chemical composition which varies according to the type of clay which in turn influences the degree of hydration. The most common types of clay are kaolinite, illite, and montmorillonite.

Kaolinite has a two- layer sheet of alumina and silica with strong attraction. As a result the water is unable to separate the layers and little shrinkage takes place.

Illite and montmorillonite have three- layer sheets of silica, alumina and silica. Montmorillonite has a very weak bond between the layers. Thus, the water is able to separate the sheets and swelling takes place easily. Montmorillonite is not a stable clay. Illite exhibits a stronger attraction between the layers due to the presence of calcium and is therefore more stable than montmorillonite. Suitable soils for building are likely to have stable clay types.

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[92]In the case of Blumenau, the sites are located in alluvial soils. This specific soil type according to Houben, H. Guillaud, H. (1994), p. 39 has the following description:
These soils border rivers and streams in the wider valleys. The minerals are subject to a continuing weathering process. Their texture varies, although they are usually filtering, with the finest material on the surface (fine sand, silts, clays), and become coarser with depth. The colour varies from brown ochre on higher ground, grey on the flood plain, and black in marshy areas.

3. Soil material: hardening and characteristics

The making of material from soil is a delicate process where the slow hardening by moisture loss is almost always accompanied by reduction and contraction. Certain factors contribute to better soil hardening and therefore the durability of the material. The main factors that should be considered in the hardening of soil materials are:

1. Suitability of the soils

A soil material which is likely to be satisfactory is made of mineral components where grain size distribution in percentages of sands, silts and clays gives adequate cohesion, adhesion, plasticity; and clay amount and types provide stable materials, especially a minimum of shrinkage. Because the natural soil may not possess these characteristics, inert components such as sand and fibres are added to reduce contraction and improve durability.

2. Hydration and Mixing

The amount of water used in mixing is critical in controlling shrinkage and drying. Clay becomes plastic and acts as a binding material when wet. A period of storage of soil in a wet condition will improve the plasticity of the clay, make it less susceptible to shrinkage and dry more quickly. Excessive water disperses clay and increase shrinkage.

As already indicated soil materials become harder only by drying, without chemical reaction. Free access of the water may return the soil material to a gel and enable the materials to be washed away. The durability of soil materials is strongly related to surface protection, making inspection and maintenance of paramount importance.

The effectiveness of mortars, renders and plasters made with soil depends greatly on the control of shrinkage. The components, degree of hydration, mixing and application should be controlled to ensure hardening without cracking.

(1) EARTH BEDDING MORTARS, RENDERS AND PLASTERS

EARTH BEDDING MORTARS, RENDERS AND PLASTERS: GENERAL

Definition

BEDDING MORTAR: A plastic mix of clay, sand and water used to lay/ bond blocks (adobes and bricks), to spread vertical loads, and to prevent water penetration.

RENDER: external coatings. A plastic mix of clay, sand and water applied to the wall or panels to improve surface appearance and to provide a durable protection from weathering (rain, wind, erosion, abrasion and impact).

PLASTER: internal coatings. A plastic mix of clay, sand and water with the same function as above, but also to provide a smooth surface. Internal plasters were often decorated.

Composition

These mortars are made from similar soils to those used for adobe with the addition of more sand. They are often stabilized with natural products. (fig. 54)

1. Soil
Range of particle size:[93]
Sandier soils than soil used for adobe are generally acceptable.
Clay amount and type:
Minimum clay content, but sufficient for binding. Stable clays such as Kaolinite are preferable.

Fig. 54 - Components of Earth Mortars, Renders and Plasters: soil

[93]See: Constance, S.S. (1990). "Analysis and Conservation of Pueblo Architectural Finishes in American Southwest", in Proceedings 6th Int. Conference on the Conservation of Earthen Architecture, pp. 176-181. The author reports the results of Smith's studies during 1930-40 about the composition of earthen mortars in southwest USA. The mortars were composed primarily of 'clay or adobe' with varying admixtures of sand- fine or coarse texture. He observed excellent properties: they were compact, cohesive and cracked and shrank only slightly after drying.
And Caron, P., Lynch M. (1988) "Making Mud Plaster", in APT Bulletin. Vol. 20. no. 4, pp.7-9. The authors reports mud plasters in Ukranian buildings, Alberta, Canada, where the recipe was 60% sand and 40% clayey soil.

2. Fibres and Animal Products

Plant Fibres:

Plant fibres of all kinds were used.

Animal Products:[94]

Dung and hair are more likely to be used in renders and plasters than in mortars, adobes and daubs. Their addition provides effects similar to those achieved with plant fibre.

The addition of horse urine, casein, whey or other products with similar effects such as rain water, humic acid and tannic acid provides:

1. A highly uniform mixture.
2. More adhesion with the clay.
3. A mixture with less shrinkage.
4. Hardness.
5. Good permeability.

Fig. 54 - (continued) Components of Earth Mortars, Renders and Plasters: fibres and animal products

3. Lime

The addition of lime to earth mixtures:

1. Produces a less plastic mixture.
2. Reduces susceptibility to water (reduces porosity, filling spaces).
3. Improves mechanical properties by acting as additive binder.[95]

Types

Quicklime, lime putty and hydrated lime.

Fig. 54 - (continued) Components of Earth Mortars, Renders and Plasters: lime

[94]Houben, H. and Guillaud, H. (1994), op cit, pp.98-9; and Pearson, G.T. (1992). Conservation of Earth and Chalk Buildings, p.6.

[95]See discussion about stabilisation of earth with lime in previous adobe section.

EARTH BEDDING MORTARS: S. CATARINA

Description of S. Catarina Examples

Earthen based bedding mortars are not the subject of historical documents. Oral accounts by craftsmen described bedding mortars as composed of earth from which coarse parts were removed. Occasionally more sand or clay was added in order to achieve an ideal balance. Red coloured earth was said to be preferable. The same mixture was used for renders but lime could be included. Milk whey is mentioned as an ingredient in renders.

Characteristics of Earth Bedding Mortars

All buildings were recorded as having earth mortars. Ten were sampled. Visual observation showed variations in colour, but a similar fine texture and high aggregate percentage. Fibre was not always visible. Three samples were selected for analysis and the results are summarised in the following tables. (fig. 55,56)

Results and Discussion

The mortars showed a high proportion of aggregate, high permeability and low clay percentage by weight. Clay is kept to a minimum to reduce shrinkage and cracking, but may not ensure adequate coating of the aggregate for binding purposes. In general, such mortars have a fine texture with uneven grading (the 150 micron fraction predominates). The mortars present similar plastic behaviour based on slightly cohesive and stable clays.

Based on this data and comparing these results with typical mortars compiled from different sources, it can be concluded that these materials are made from suitable soils, although lower in strength and cohesion than lime mortars. However, earthen mortars have properties which are very compatible with construction elements such as timbers, adobes, and porous bricks.

The inclusion of fibres and probably additives such as milk whey or urine described by craftsmen explains the very low percentage of clay. Such additives ensured workability and provided additional cohesion or stability for the mortars.

SAMPLE	TEXTURE % of clay/silt/sand	PLASTICITY LL / PL / PI	COLOUR (Munsell) hue/value/chroma	FIBRE % of	HCL Spot Test
Tottene 5	6/ 32/ 62	26 / 5 / 5	Strong Brown 7.5YR/ 5/ 6	6 long	Negative
Cheminelli 1	11/ 43/ 56	22.6/18 /3.5	Reddish Yellow 5YR/ 6/ 8	7 short	Negative
Buzzi 1	10/ 40/ 50	32.2/23.1/9.1	Reddish Yellow 7.5YR/ 6/ 6	3 fine	Negative

Fig. 55 - Results of Earth Bedding Mortar

SAMPLE	COHESIVENESS	ACTIVITY	EXPANSIVITY
Tottene 5	Slightly Cohesive	Mildly Active: 0.85	Not expansive
Cheminelli 1	Slightly Cohesive	Inactive: 0.33	Not expansive
Buzzi 1	Slightly Cohesive	Mildly Active: 0.96	Not expansive

Fig. 56 - Results of Earth Bedding Mortar Plasticity

EARTH RENDERS AND PLASTERS: S.CATARINA

Description of S. Catarina Examples

Earthen renders are described by craftsmen as a sandy clay mortar. Suitable mixtures were prepared by removing coarse fractions. Renders are improved by adding milk whey, short fibres such as dung and sometimes ash.[96]

Earthen renders and plasters are recorded in different construction types, ie daub panels, brick panels and solid brick. Internal plasters on timber frame supports were often built in order to embellish internal spaces and conceal the structure. The chronology of plasters (early limewashed plaster followed by later limewashed and stencilled plaster) may be seen in the early or pioneer houses. The presence of fibre of various types is visible. In general, these plasters are cracking and falling down due to shrinkage of the timbers.

Characteristics of Earth Renders and Plasters

Four samples were selected to be examined. Due to the limited quantity of sample material, only microscopic examination was possible and the results are summarised in the next table. (fig.57)

Results and Discussion

The results show that the external renders and plasters have a high ratio of sand aggregate. The sand grains are not thoroughly coated by the matrix. Based on this data and comparing the results with typical renders compiled from different sources, it can be concluded that these materials are composed of suitable soils. Oral information from craftsmen and the results of microscopy suggest that the mortars for renders/ plasters and bedding mortars may have a similar composition. Application techniques of renders and plasters differ extensively from those utilized for bedding mortars, and certainly play an important part in performance.

The inclusion of fibres and probably additives such as milk, whey or urine described by craftsmen explains the very low percentage of the binder. Such additives promoted workability, provided extra binding power and enhanced the stability of the renders and plasters.

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[96]Ash is mentioned by the architect Paulo Zutter as an added ingredient in mortars recorded at Itoupava Chapel built in 1891. Ash, especially with earth, can give a smaller particle size which could help cohesion.

SAMPLE	TEXTURE	MATRIX Arrangment	FIBRE % of by loss on ignition	Colour/ Munsell [hue/value/chroma]	HCL Spot Test
Lumke 2: Render	Mainly Sand Approx. 10% of Clay	Sand linked by bridges of fine material	6	Yellowish Brown 10YR/ 5/ 4	Negative
Franz 3: Render	Mainly Sand Approx. less than 10% of Clay	Sand linked by bridges of fine material	4.5	Brownish Yellow 10YR/ 6/ 6	Positive 3.6Wt%
Reincke 8: Plaster	Mainly Sand Approx. 5% of Clay	Sand linked by bridges of fine material	2.8 Visible under microscopy	Light Yellowish Brown 10YR/ 6/ 4	Negative
Wacholz 2: Plaster	Mainly Sand Approx. 5% of Clay	Sand linked by bridges of fine material	3.9	Brownish Yellow 10YR/ 6/ 6	Negative

Fig. 57 - Results of Earth Renders and Plasters

EARTH MORTARS RENDERS AND PLASTERS: RECOMMENDATIONS FOR REMEDIAL WORK

The general issues discussed in the section on earth infill systems also apply to earth materials used as mortars, renders and plasters. However, there are other considerations. These include:

Testing

Microscopic examination of renders and plasters should be included. Specifically, techniques such as embedding a sample for examination in cross section is extremely advisable in the case of Blumenau dwellings. This technique enables the historical development of the surface materials to be read through microscopic technique of surface layers including plasters, limewashes and painted decoration.[97]

[97]See Teutonico, J. (1988), Laboratory Manual for Architectural Conservators, pp.139, 151: techniques used for embedding samples of plasters or paint for cross section observation.

Treatments

It is recommended that the composition of these materials be mantained in all situations of repair and replacement without modifying the typology of Blumenau buildings. In this sense, any component that modifies the hardening process of these earth systems which function by loss of moisture (without chemical reaction) and where the binder is characterised by the plastic properties of clay, is not advisable. However, any improvement that enhances plasticity and reduces shrinkage through storage and maturing, or perhaps mixture with aggregates, fibres or admixtures could be considered.

Specifications

Great care with the specification of earth mortar materials should be undertaken. In general, the specifications are similar to other earth building materials eg adobes, but they differ in some points. The following are the requirements for earth mortars, renders and mortars: (fig.58)

<u>Soil and Fibre</u>

1. Compatibility with the original historic material.

2. Stable soils, usually sandier than adobe soils.

3. Lower quantity of clay than is usually found in adobe, but sufficient for adequate cohesion and adhesion to the substrate.

4. Fine and well graded aggregate.

5. Finer and shorter fibres than found in adobe.

Fig. 58 - Specifications for Earth Mortars, Renders and Plasters

LIME- BASED SYSTEMS: GENERAL

Definition

Lime- based systems can be defined as the materials in which non-hydraulic lime is used as the principal binder component and the aggregates are inert; therefore the setting and hardening mechanism is characterised only by the carbonation of calcium hydroxide with carbon dioxide. These systems are also termed air- hardening mortars. Other systems which utilise reactive aggregates such as natural or artificial pozzuolana or hydraulic lime binders are not considered here.[98]

Limestone and Lime

1. Raw material

Pure forms of limestones composed mainly of calcium carbonate are the raw material used to produce lime. Thus, high calcium limestones including chalks, dolomitic limestones and seashells are forms of calcium carbonate suitable for the production of lime.

When sources of limestone are impure, ie contaminated by clay and sand impurities in high proportions (10 to 20% clay), the end product is moderately to eminently hydraulic lime, and thus not included here.

2. Mineralogy

The pure mineral form of calcium carbonate is calcite and many limestones are calcitic. However, limestones may be composed of four minerals:

Calcite: $CaCO_3$. The most abundant.
Aragonite: $CaCO_3$
Dolomite: $CaMg\ (CO_3)$
Magnesite: $MgCO_3$

[98]A detailed account of the geology, chemistry of limestones and production of lime is available. The references selected for the section is covered by general textbook such as Boyton, R.S. (1980) Chemistry and technology of Lime and Limestone and specific works such as Wingate, M. (1985) Small- Scale Lime Burning and Spiropoulos, J. (1985) Small Scale Production of Lime for Building.

3. Production of lime: Chemical Reactions

Lime is produced by the chemical thermal reactions stated below:

1. Chemistry of Calcination

Calcination is the reaction of limestone plus heat to produce quicklime. (fig. 59)

LIMESTONE + HEAT (traditional kiln/ to about 800° C) = QUICKLIME

High calcium limestones:

$CaCO_3$	+	heat	->	CaO	+	CO_2		
Calcium Carbonate	+	heat	->	Calcium Oxide	+	Carbon Dioxide		

Magnesian limestones: (two reactions)

$CaMg\ (CO_3)_2$	+	heat	->	$CaCO_3$	+	MgO	+	CO_2
Calcium Magnesium	+	heat	->	Calcium Carbonate	+	Magnesium Oxide	+	Carbon Dioxide
CaCO3	+	heat	->	CaO	+	CO_2		
Calcium Carbonate	+	heat	->	Calcium Oxide	+	Carbon Dioxide		

Fig. 59 - Chemical Reactions in the Production of Lime: calcination

2. Chemistry of Hydration

Hydration or slaking is the reaction of quicklime plus water to produce hydrated lime. Calcium quicklime is very reactive with water, but magnesium quicklime reacts slowly. The slow hydration of magnesium oxide can cause problems in mortars if slaking is not sufficient. (fig. 50)

QUICKLIME + WATER = HYDRATED LIME (heat is emitted)

High calcium quicklime:

CaO	+	H_2O	->	$Ca\ (OH)_2$
Calcium Oxide	+	Water	->	Calcium Hydroxide

Magnesian quicklime:

CaO	+	H_2O	->	$Ca(OH)_2$
Calcium Oxide	+	Water	->	Calcium Hydroxide
MgO	+	H_2O	->	$Mg(OH)_2$
Magnesium Oxide	+	Water	->	Magnesium Hydroxide

Fig. 59 - (continued) Chemical Reactions in the Production of Lime: hydration

According to the quantity of water added to the lumps of quicklime and the slaking time, three useful forms of hydrated lime may result, that is, a dry powder, a putty or limewash.

1. Hydrated lime is a dry powder resulting from the combination of quicklime with just enough water to produce the slaking reaction. By this process, the dry powder of hydrated lime is stored, but as the hydration is a relatively quick process not all the particles might be slaked.
2. Lime Putty is a plastic paste resulting from the combination of quicklime with excess water. By this process, lime putty may be matured and stored which ensures complete slaking of all particles and increased workability.
3. Limewash is lime hydrated in a suspension of water, created by diluting eg lime putty with water.

The desired form with which to make a lime mortar is lime putty as it has the following advantages over the dry hydrate:

1. Finer particles, thus a more plastic paste.[99]
2. Longer slaking time, thus more fully slaked particles.
3. Less water, thus less shrinkage.

Dry hydrated lime is suitable for storage if kept dry and out of contact with air, but may present negative properties for lime mortars including:

1. Both unslaked and carbonated particles.
2. Lower plasticity than lime putty which often results in the addition of too much water to lime mortars.

Historically, calcination and slaking were achieved by traditional processes of heating, burning and slaking which employed wood- burned kilns and slaking pits. This continued until the end of the 19th century. Today, industrial production of lime uses different kilns, material requirements, higher temperatures and a slaking process which usually results in dry hydrate rather than putty lime. Thus, lime produced in these new conditions differs from old limes found in historic buildings.

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[99]Jessen, C (1991), in Eurolime Colloquim, p.41 reports that laboratory research in DK proved that the process of dry slaking results in larger particles ie 30μm as comparing with wet slaking ie 10μm. In addition, the dry slaked particles tend to grow to about 60μm.

3. Chemistry of carbonation

Lime hardens by a carbonation process stated below: (fig.50)

HYDRATED LIME + AIR -> LIME MORTAR

$Ca(OH)_2$	$+ CO_2$	$\rightarrow CaCO_3$	$+ H_2O$	
Calcium Hydroxide	+ Carbon Dioxide	-> Calcium Carbonate	+ Water	

Fig. 59 - (continued) Chemical Reactions in the Production of Lime: carbonation

This results in a return to the material from which the process began ($CaCO_3$ Calcium Carbonate) creating what is usually called the lime cycle described and illustrated as follows: (fig. 60)

THE LIME CYCLE: BURNING, SLAKING AND HARDENING OF AIR- HARDENING LIME

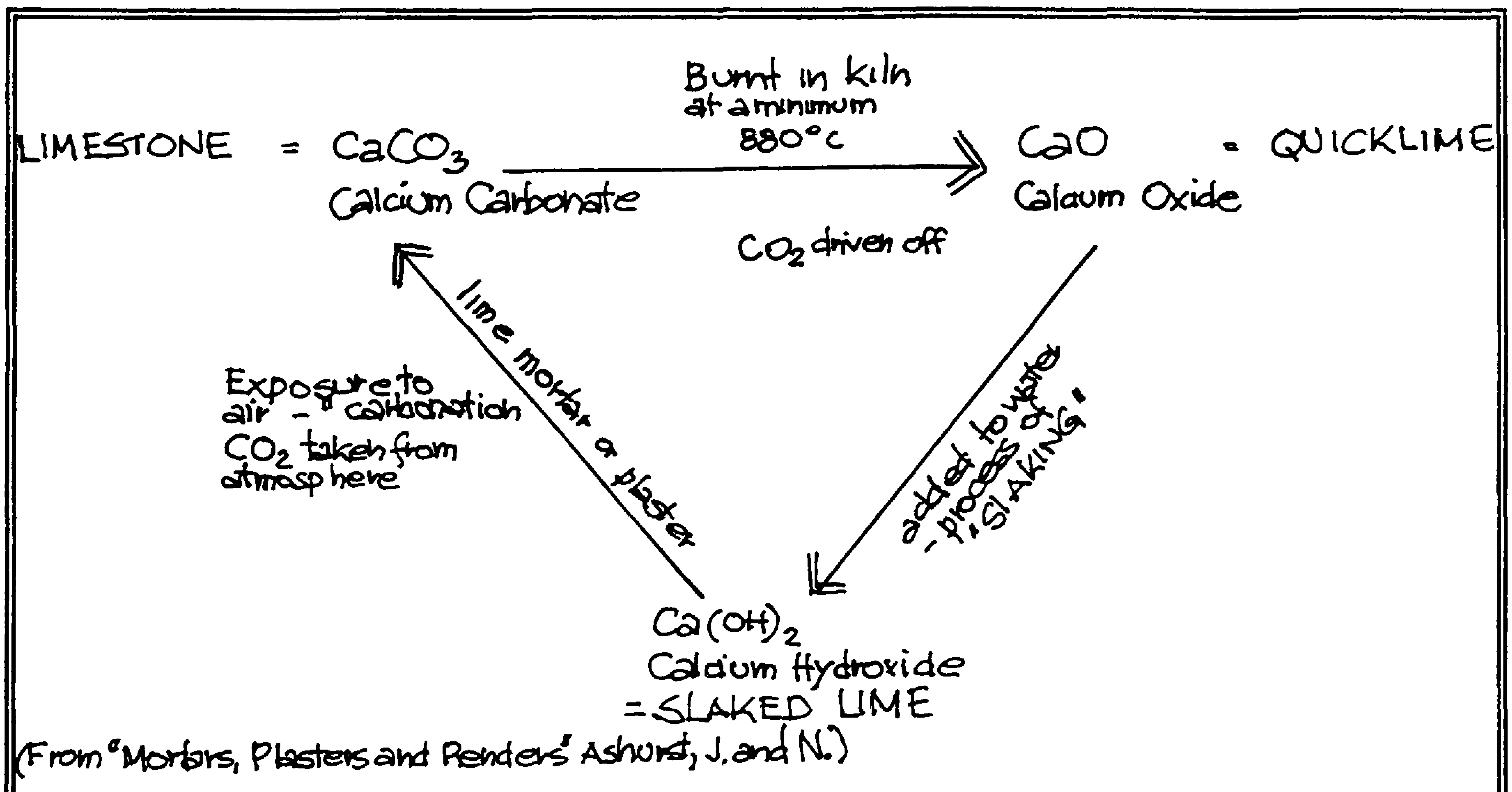

Fig. 60 - The Lime Cycle

4. Lime mortar: hardening and durability[100]

A good quality lime mortar is made with highly reactive pure lime; however, complete carbonation yielding mechanical strength and durability of lime is a sensitive process determined by the speed with which carbon dioxide (CO_2) reacts with slaked lime $Ca(OH)_2$ and $CaCO_3$ is again formed.

[100]The carbonation of lime mortars is well covered in Swedish experiments reported by Holmstrom, I. (1993), in Lime News, Vol.2, No 1, pp.32-41.

The process occurs in two steps: first, evaporation of water, with resultant contraction in volume and second carbonation, a slow reaction of carbon dioxide CO_2 with the slaked lime Ca $(OH)_2$ resulting in carbonated lime $CaCO_3$ and increasing strength.

Many factors affect the carbonation and therefore durability of lime mortars:

1. Content of lime. A high lime ratio increases strength and porosity. However, it may cause shrinkage and affect adhesion.
2. Pore structure. High porosity enables the carbon dioxide to reach all parts of the mortar increasing carbonation. Although lime is porous, an extremely high content of lime may result in severe shrinkage. However, an open pore system can be achieved by the addition of porous aggregates or air- entraining additives.
3. Temperature. At low temperatures, carbonation is slower.
4. Balance of Moisture Content and CO_2. With too much water, the pores are blocked to CO_2; with too little water, CO_2 does not dissolve and react with molecules of calcium hydroxide $Ca(OH)_2$.

Results of analytical studies indicate that greater proportions of lime in old mortars as compared to recent mortars may be explained by the fact that only some of the lime functioned as a binder; the remainder was mixed into the mortar already carbonated, thus acting as a porous aggregate which, in short, promoted carbonation. However, our understanding of the original materials, methods and conditions of old mortars is still incomplete.[101]

5. Lime Mortar: Characteristic properties

1. Pre-conditions

Requires good quality materials: quality of limestone, slow burning, wet slaking.

Requires the skill of the mason.

2. Hardening

Requires proper environmental conditions/ control.

Requires correct materials, proportions and mixing.

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[101]The understanding of coarse and porous particles of calcium carbonate as the reason for the durability of old mortars is defended by Holmström, I. (1992), in Lime News Vol2, No.1 pp. 39-40; and Knöfel, D. (1989), in Proceedings of the 3rd Meeting Hamburg, NATO- CCMS Pilot Study Conservation of Historic Brick Structures.

However, Holmström says that 50% hardened lime putty acting as an aggregate was used to prepare mortars, whereas Knöfel say that probably a source of dry slaked lime was used.

3. Behaviour

Compatible with traditional building systems since lime mortars are relatively permeable, show good mechanical strength, aesthetic harmony and durability if well maintained. However, many factors limit the use of lime mortars and lead to the replacement of these systems by other substitutes. These include:

1. The quality of materials, and experience of masons today. The lime available in the market place is usually a dry powder which is produced to be used as an additive in cement mortars not as a binder. At the same time, almost all masons are trained to work with cement/ lime mortars systems. Thus, the knowledge of lime mortar technology has usually been forgotten.
2. The balance between workability and shrinkage and therefore strength. The correct manipulation of lime materials requires a lot of experience which again is difficult to achieve as this technology is not being used today. The use of dry hydrate, for example, requires excessive water to achieve workability. This leads to excessive contraction upon drying with shrinkage and loss of strength.
3. Slow- setting and hardening. Lime mortars have a slow setting reaction which requires time, special specification and attention. Furthermore, lime may not set in situations of extreme dampness, thus encouraging the addition of hydraulic components.

Some replacement materials may impart desirable characteristics; however, others such as artificial cement, can have very negative effects on historic buildings. Cementitious mortars with a high proportion of cement produce a fast and hard set with water resulting in a overly strong, rather impervious material. Cracks in such mortars will allow water to penetrate while inhibiting evaporation causing decay problems in weak, more porous materials. The addition of small quantities of cement to lime mortars, to aid setting and strength, has also been shown to have a negative effect on mortar strength and durability in recent research.[102] However, this negative effect may be related to the practical problems of blending hydrated cement powder with lime putty.

[102]For a complete list of the dangers caused by cement mortars and plasters if applied to old masonry see Torraca, G. (1988), Porous Building Materials, pp. 79-80.
See also the research paper Teutonico, J. M. , et al. (1994) "The Smeaton Project: Factors Affecting the Properties of Lime- Based Mortars", in APT Bulletin, Vol.25, No.3-4. Lime cement mixtures are said to result in a poor performance. The same result was observed earlier in the Swedish Studies published by Ingmar Holmström in 1977.

Composition

The general components of lime- based mixtures are discussed below: (fig. 61)

1. <u>Lime</u> **The mixture of 1:3 (lime:sand), in terms of volume, is the typical binder: aggregate ratio of lime mortars, although analysis of historic mortars may show much richer mixes of lime such as 1:2, 1:1, 1:0.5.**

Fig. 61 - Components of Lime- based Mortars, Renders and Plasters: lime

2. <u>Aggregates</u> **Traditionally, natural sand from local sources, pits and rivers was used. Clean, well graded, and angular sands are fillers which promote an even distribution of the binder. Fragmented limestones, broken shells and marble were also used.** **In addition to inert fillers, reactive aggregates such as natural or artificial pozzolanic materials (eg brick dust) were used to improve setting and hardening.** **The addition of brick dust for conservation mortars has been studied and the results are positive in two ways. The smaller particles (< 75 microns) seem to act as pozzolanic materials, improving setting and strength; the larger particles (> 300 microns) act as porous aggregates improving carbonation and resistance to salt crystallization and to frost.[103]**

Fig. 61 - (continued) Components of Lime- based Mortars, Renders and Plasters: aggregates

3. <u>Additives</u> **Traditionally, the durability of historical mortars is attributed to additives such as casein, linseed oil, fresh blood and urine.[104] Although, it may be possible to trace these components, the performance of lime mortars is not necessarily dependent on such additives and inclusion of these additives in mortars for conservation should be restricted to very specific needs.[105]**

Fig. 61 - (continued) Components of Lime- based Mortars, Renders and Plasters: additives

[103]See again the conclusions of Smeaton Project already referred to.

[104]Knöfel, D. (1989), in Proceedings of 3rd Meeting NATO-CCMS Pilot Study <u>Conservation of Historic Brick Structures</u>, pp. 67-8 reports that it can be safely assumed that casein in the form of skimmed milk or lean curd was successfully used, however many other additives included in the literature may never have been used or may have had no positive effect. From an analytical research strictly with mortars, most collected from south- west Germany, 40% of the samples proved to contain proteins, but this positive result may be caused by the infiltration of micro- organisms. That is not the case for pozzolanic aggregates, where the positive result is a firm proof of this use in the past.

[105]Ashurst, J. and N. (1988), op cit, Vol.3, pp.12-15.

(2) LIME POINTING MORTAR

LIME POINTING MORTAR: GENERAL

Definition

Pointing Mortar is the jointing material which fills the outer part of the brick or stone masonry, where the bedding materials have been deliberately left or raked back. Pointing mortar has the function of reducing water penetration and enhancing appearance of the wall.[106]

Where masonry is bedded in clay, this material is very susceptible to leaching away by rain. The loss of bedding material in thin brick walls is a great problem. Therefore, the pointing material plays an important protective function in addition to its role in improving appearance.

Composition

Traditionally, the majority of historic mortars for pointing mortars were mixtures of non-hydraulic lime and sand with water; however set- additives, reactive aggregates and hydraulic limes were also included. Especially after 1856 artificial cement may be found as an addition to lime mortars or as a substitute for the lime and therefore may be found in more recent pointing mortars.[107] Although the knowledge of composition and mixing methods of old mortars is still limited, a mixture of lime pointing may be described as follows: (fig. 62)

1. Lime: Traditionally the common source of lime for pointing mortar is a high calcium quicklime converted into limeputty by wet slaking. The average proportion of lime by volume is 1:2/3 (binder: sand), but usually old lime materials are richer in lime contents; therefore quantities may vary.

2. Aggregates: Usually a well graded angular sand. The colour of the sand is the primary contributor to the overall colour of the mortar.

3. Fibre: Ocasionally fibre admixtures such as hair may be found.

4. Water: Clear fresh water source, free from organic impurities. The exact quantities vary according to the source of quicklime.

Fig. 62 - Components of Lime Pointing Mortar

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[106]See Brunskill, 1990, pp. 59-62, for a general understanding of materials and techniques of pointing mortar.

[107]See Ashurst, J. and N. (1988), op cit, Vol.2, p. 40. There is a list of mortar mixes for pointing according to time. Portland cement is referred as possibly found after 1825, but especially after 1856.

LIME POINTING MORTAR: S. CATARINA

Description of S. Catarina Examples

Some old photographs along with written documents indicate that lime mortar pointing was used from early times and developed as a typical building material contributing to the characteristic rural landscape of the Blumenau region.[108]The practice of lime pointing can be outlined by some documents listed in the next table. (fig. 63) According to the craftsmen accounts it is clear that for the lime mortar pointing, 'white lime' or pure sources of calcium carbonate were used which was usually slaked and matured on a building by building basis. In general, it is described in the ratio of 1:3 (binder: aggregate), but the proportion of 1:1 was indicated for pointing.[109]

POINTING MORTAR: DOCUMENTAL CHRONOLOGY
1864 Budget for the pointing of the brickwalls of the Jail by the Architect Krohberger. It is the oldest document referring to the practice of pointing.
1875 The view of the early Town Hall shows a timber- framed house with brick infill likely to have pointing mortar.
1906 The report by Wilhelm Lackmann describes the peasant houses along the Itajai river as: one floor, the walls usually made with red bricks and a brownish timber- frame, the pointing between the bricks made with a white mortar. Although he also mentions the white houses of Indaial which certainly means limewashed walls probably made with earth infill.[110]
1900 The document of the 50th Anniversary of Blumenau shows some timber- framed buildings built with brick infill and likely to have pointing mortar.
1907 onwards: Hering Factory as well as contemporary buildings in Blumenau built with brickwork and stucco are likely to have pointing mortar.
1954 A book about Itajai valley includes the description of the houses by the American writer Roy Nash where brickwork is emphasized as a part of the rural landscape of particular places settled by European immigrants.[111]

Fig. 63 - Pointing Mortar: documental chronology

[108]Sources of documents and old literature are found in bibliographical references.

[109]See below the history of technology of lime in section 3.6: production and supply.

[110]Dr. Wilhelm Lackmann made journeys to southern Brazil during 1903 and 1904. In Blumenau he visited places such as Carijos, Pommerstrasse, Altona and the Stadplatz describing the rudimentary conditions of the roads, the use of rafts for crossing streams and rivers. He distinguishes three types of landscape: the isolated houses of the peasants in plots; the village houses located where the roads crossed; and the stadplatz of Blumenau. The report was edited by Dietrich Reimer in Berlin in 1906 and translated into Portuguese in 1992 by Curt Hennings as Impressoes de Viagens e Estudos da Vida nos Povoaments Alemaes.

[111]Perfeito da Silva, Z. (1954), O vale do Itajai: Documentario da Vida Rural, pp. 45-46.

Various types of finished surface, created with domestic tools (ie spoons) were recorded and are illustrated in the next table. (fig. 64) They can be described as:

1. Flush with the surface of the bricks.
2. Recessed and given a concave or pointed profile.

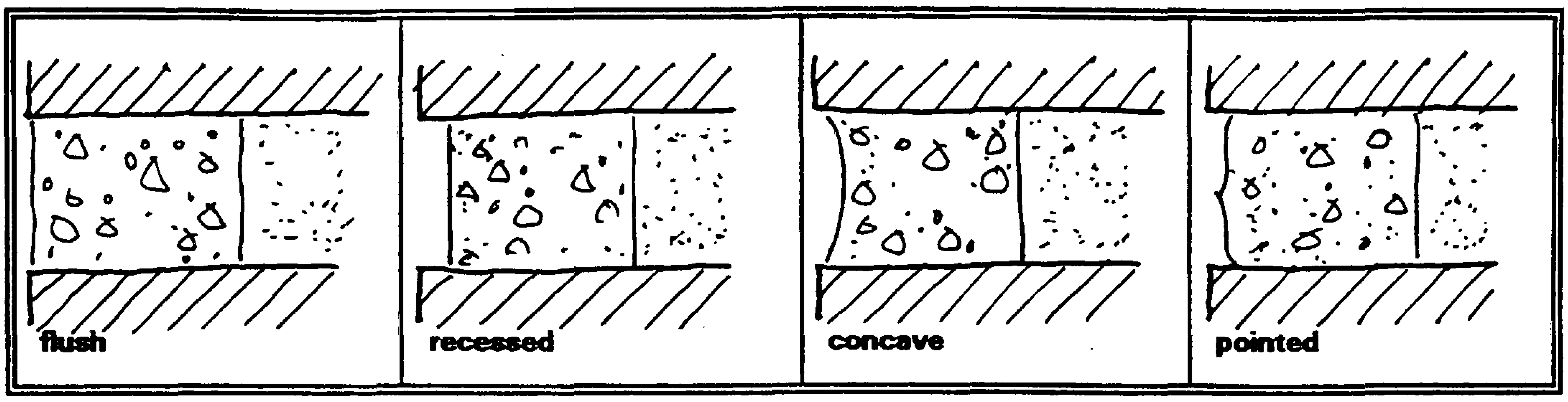

Fig. 64 - Finish Surface of Pointing Mortar

Uneven edges of the hand-moulded bricks result in wide joints; more even edges of the extruded bricks also give a different surface appearance.

The mortar pointing is cracked and missing in all brick panel systems, mainly in the perimeter joints, ie edges between the brickwork and structural frame, and water has begun to penetrate the joints. This problem may be related to the increase of internal humidity/ damp walls contributing to the falling of plasters and decay of timber frames.

In solid brick systems, cracking of mortar pointing is usually associated with structural movements, or where bricks are spalled and decayed.

In either of these methods of construction listed above, the sheltered or exposed conditions of the brickwork may result in differing weathering of these materials. Exposed southern facades, where humidity is high, usually show more severely weathered materials and may allow water to penetrate, but decay was not fully investigated.

In pointing mortars today, lime is usually replaced by white Portland cement. This practice includes works for historic buildings. Recently, for example, the early school of Itoupava, had the traditional lime pointing replaced with a white cement mortar.

Characteristics of S. Catarina Examples

Sixteen samples of pointing mortar were collected from twelve buildings including brick panels and solid brick. The collection covered a range of structures from early buildings with hand- moulded bricks to more recent brickwork made with soft extruded bricks. Visual observation shows similar colour and texture. Five samples were selected for analysis and the results summarised in the following tables. (fig. 65)

SAMPLE	COLOUR /Munsell [hue/ value/chroma	CaCO3 [Wt.%]	MICROSCOPY [reflected light] [*polarized light]
Reincke 1	White 10YR/ 8/ 1	35.8	Fine grained aggregate Fairly pure whitish material
Havenstein 2	White 2.5Y/ N8/	36.7	Coarse grained aggregate Fairly pure whitish material
Thurow 3	White 10YR/ 8/ 1	38.3	Coarse grained aggregate Fairly pure whitish material
Poffo 1	White 10YR/ 8/ 2	38.9	Coarse grained aggregate Fairly pure whitish material *Lime well carbonated
Zimath 3	White 2.5Y/ N8/	56.0	Coarse grained aggregate Very pure whitish material *Lime well carbonated

Fig. 65 - Results of Pointing Mortar: phase I

SAMPLE	PARTICLE SIZE AGGREGATES [passed amount %]BS sieves: 1.18mm/600 μm/300μm/150μm	AGGREGATE [Wt %]	FINES [Wt %]	B/A [ratio]
Thurow 3	76 /36 /13 /5	58	0.7	1:1
Zimath 4	84 /44 /18 /7	47	0.6	1:0.6

B/A: Binder/ Aggregate ratio

Fig. 65 - Results of Pointing Mortar: phase II

Results and Discussion

The results of the investigation listed above and previous information about the practice of limework and pointing mortars suggest that the main characteristics of these lime- based mortars are the high amount of lime, a low level of impurities, together with a clean sand aggregate, imparting the whitish colour. Microscope observation indicates that a positive feature of these mortars is the well carbonated nature of the lime matrix.

A correlation of binder aggregate values with the craftsmen's accounts give safe and useful indications of constituents and sources. It may be said that most probably the proportion 1:1 binder/aggregate was the typical mixture. The materials used fall in the range of suitable lime mortars characterising good qualities of quicklime (pure/ fat); well wet slaked hydrated lime (finer particles/ fully slaked) and a well graded aggregate, where less than ten percent of the aggregate is smaller then fine sand (150 μm).

In addition, the results show that the composition of pointing mortars did not appear to correlate to the age of the buildings (1870 to 1930) or methods of construction. Variations such as the fine grained sand from Reincke house is understood here as resulting simply from the source of sand that was available. The lime content higher than the pattern value of 1:1 (binder: aggregate) of Zimath house ie 1: 0.6 may have been based on best performance or a desire for a whitish mortar; but it is hard to know the original purpose.

Comparing these sample results with similar materials from other sources and the nature of the masonry units which are hand- moulded or soft extruded bricks it is recommended that similar mixtures be used for conservation and maintenance as such mixtures are softer or more porous than the bricks. [112] Thus it is vital that proper consideration be given to the nature of the binder in these mortars. Lime- based are physically compatible, historically accurate and aesthetically appropriate to the Blumenau structures. However, the use of fibre admixtures for the mortars located on the edges of brick panels should be more thoroughly researched. Finally, these mortars based on lime- sand are representative of traditional historic mortars, and therefore should be conserved as evidence of old masonry techniques.

[112] The technique of brick- making affects pore structure. Bricks produced by hand- moulding where large pores derives from pugging the clay and throwing it into the mould, while industrial bricks made by pressure and rotation of the auger differ in patterns, having a smaller pore structure. See Franke, I. and Schoppe, I. (1989), in Proceedings of 3rd Meeting, NATO-CCMS Pilot Study Conservation of Historic Brick Structures, p.11. Similarly Livingstone, R.A. (1988) says that the modern stiff mud extrusion process for brickmaking differs significantly from the traditional soft mud process in Proceedings of the 8th International Conference of Brick & Block Masonry, p.83.

(3) LIME- SOIL RENDERS AND PLASTERS

LIME- SOIL RENDERS AND PLASTERS: GENERAL

Definition

These mortars are defined as lime- based systems where the aggregate is a local soil source with more finely graded river sand instead of a coarse pit sand. They have the following function:

Render: external coating
Plaster: internal coating

Composition

Mixes for renders or plasters made with lime and soil as aggregate have a similar composition of lime- sand mortars, although the source of aggregate is different. The composition of lime-soil mortar may be described below as: (fig. 66)

1. Binder:
The binder is a non- hydraulic lime.
2. Aggregate:
The aggregate is a finely graded soil (inert soil) possibly derived from river bed sources. The more finely graded aggregate requires a higher lime content to achieve good mortar strength.
The use of soil- based aggregate in lime mortars may be related to economic issues such as relative ease of acquisition at little cost when quarry sand was difficult to obtain. Alternately the use of lime- soil mixes could represent the vernacular tradition, typical of certain areas. Otherwise, soil may have been deliberately used to create better adhesion of the render or plaster to the support.
3. Additives:
Ocasionally, additives such as casein, linseed oil, fresh blood, charcoal, plant and animal fibres were traditionally used to improve properties.[113]

Fig. 66 - Components of Lime- soil Renders and Plasters

[113]See previous coments about organic additives in lime mixtures.

LIME - SOIL RENDERS AND PLASTERS: S. CATARINA

Description of S. Catarina Examples

Lime- soil renders and plasters are described by craftsmen as materials where soil is used as an aggregate and the lime source is not necessarily of high quality, as in pointing mortars and limewashes.[114]

Sources of quicklime for these materials are sometimes described as a 'grey lime'in dry form that was mixed immediately with the soil at the time of use or previously soaked for a brief period.[115] Black molasses (sugar) and dung are indicated as additives by craftsmen. The cellar render from Fiedler House is identified by a craftsmen as containing black molasses to improve strength.[116] Large wooden floats are identified as the tools to apply these mortars.

Lime- soil renders and plasters were recorded in different construction types, ie adobe panels, brick panels, and solid brick. The conditions of these renders and plasters are variable. In general, timber- framed structures where plasters are applied to conceal the structures present the same problems already observed for earthen plasters. Externally,

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[114]The soil of the building sites are alluvial soil type.

According to Houben, H., Guillaud H., (1994), Earth Construction, p.39 this type border river and streams in wider valleys. Their texture varies, usually the finer on the surface and coarser with depth.

According to DNPM (1975), p. 11 this soil in S. Catarina has the following texture:
1. Predominant Soil: clay, silt and very fine to fine sand
2. Second predominant Soil: silt, very fine to fine sand
3. Less often Soil: main fraction with medium to fine sand
4. Seldom Soil: fraction with coarse sand

[115]According to Jose Epitacio Passos Guimaraes (1989), Terminologia de Calcarios- Dolomitos e da Cal, p.5 grey lime refers to the colour of quicklime which contains particles that are not completely calcined. Whereas white lime refers to quicklime with which reacts strongly with water, and, after hydration, results in a white colour and high purity.

See also below the history of technology of lime in S. Catarina which reports the range of possible sources of limes used in the past in Blumenau: shell limes; high calcium limes; and dolomitic/ magnesian limes.

[116]The Fiedler house has a plan similar to the early Town House of Blumenau, ie a cellar floor built to protect the building against the flood. In 1874 Dr Blumenau reports the construction of the Town Hall. He wrote that the plan of the Town Hall should be built with protective walls against the flood (ie 2,70m high) and in addition it was said that stones, sand and lime was stored for that purpose. Therefore, if sugar was used as an additive for the mortars of these walls it was not recorded in written documents.

According to Sickels, L.B. (1992), in Mortars Cements and Grouts used in the Conservation, pp. 38-47 sugar is added to: (1) accelerate setting and early strength development; (2) improve hardness; (3) resist against frost penetration; (4) increase workability, etc. and Celestino Santiago, C. (1992), et al., in Lime and other Alternative Cements, pp. 205-209, the authors after carry out some tests with mixtures containing sugar concluded that these mortars present better strength than sugar- free mixes as well as preventing rain penetration and damage from efflorescence.

rendered solid brick structures will present a variety of conditions depending on maintenance and composition.

Characteristics of S. Catarina Examples

Seven samples were collected and six were selected for analysis. Results of the analysis are given in the following tables. (fig. 68)

Results Discussion

1. General

The colour (brownish/ yellowish) and or fine speckled appearance characteristic of the matrix (binder + silt size particles) under microscopic analysis may give indications as to the degree of impurity of these lime mortars. In all the examples investigated the matrix is not pure calcium carbonate. However, without the aid of more sophisticated analysis it is difficult accurately to describe the different components, although some interpretation appears below.

2. Type 1: Samples Tottene, Buzzi and Poffo

These mortars present coarse, roundish white inclusions which consist of extremely fine chalk- like calcite having a porous texture, which may derive from:[117]

1. The mixing of soil aggregate directly with quicklime ie a type of dry slaked process, which resulted in coarse particles of slaked lime in addition to the fine particles.

2. The mixing of soil with dry hydrated lime containing carbonated particles (perhaps due to poor storage), although this form of lime did not begin until 1940.

3. The mixing of soil aggregate with lime containing overburned particles, thus causing slow slaking.

Hence, the result is a heterogeneous mortar where carbonated lime is present both as coarse particles of aggregate and as a thin matrix.

[117]In limestones calcined at low temperatures or insuficiently burned giving rise to unburned lime-stone cores of round shape which remain in the binder. This type of lime- stone aggregate was not found in the samples.

A simple explanation for the making of these mortars would be that the mixing of quicklime (CaO) directly with the wet soil was used as a practice because quicklime absorbs the water it requires for its hydration from the soil. As the storage of CaO is difficult and the product is very unstable, some carbonation might have occured prior to the mixing of the mortar. Thus, the lime in some lime- soil mortars may have been intended as a binding medium, but also functioned partly as a porous aggregate.

In general, it may be said that these mortars are characterised by a uniform size of medium to fine aggregate including a rounded and angular shape yielding a looser mortar structure basically caused by the type of soil. Correlating the grain size of these samples with the samples of earth bedding mortars, the results seem to show some similarities as percentage of mass retention on sieve BS 150μm is large for both materials; however, the lime- soil samples have larger amounts of medium and coarse sand and a drastically diminished proportion of fines as compared to the earth mortars.[118] (fig.67)

In addition to the grain size, the average of proportion of calcium carbonate in the analysed mortars is low (12,3 mass%). This would correspond to a binder- aggregate mixing ratio, in terms of volume, of approximately 1:4. However, it should be remembered that part of this calcium carbonate is probably not actually acting as a binder. Thus, the binding potential of these mortars is further reduced.

What would be the advantages of these mortars over the pure earth used as bedding mortars, plasters and rarely as renders? A good guess might be that the coarse grains of very porous lime have the function of water retention and 'breathing', thus increasing durability of renders against weathering. Better workability and easier preparation might also have been decisive issues; or knowledge of the soils, ie the craftsmen knew that some soils were low in binding quality and added lime as extra binder.

118

SAMPLE	PARTICLE SIZE AGGREGATES [% mass retained] BS sieves: 1.18mm/ 600μm/ 300μm/ 150μm/ 63μm/< 63μm
Tottene 1: lime- soil render	2 / 12 / 33 / 36/ 15 / 2
Tottene 5: earth bedding mortar	/ 1 / 13 / 32/ 14 / 40
Buzzi 1: earth bedding mortar	/ 1 / 9 / 31/ 9 / 50

Fig. 67 - Particle Size of Earth Bedding Mortars and Lime- Soil Renders

3. Type 2: Samples Fiedler 1 and Fiedler 8

The different quality of these mortars in comparison with the above samples is attested to by several characteristics including: the size of the aggregate which contains more coarse and medium size particles and better grading; an even distribution of calcium carbonate, stronger binding action (few and smaller coarse grains of lime), and better preparation.

The Fiedler 8 sample is a much more compact and well- cemented example. The brownish colour of the matrix although similar to the other samples is, in this case, likely to be mainly the effect of organic matter. The blackish colour is likely to be charcoal. Further analysis to identify the nature of the organic matter and also to check if sugar was used as an additive according to the Blumenau's craftsman's account was not performed. Regardless of possible additives, however, the better binding quality of this sample might be enhanced by the increased proportion of lime in comparison to Fiedler 1.

4. Conclusion

The tradition of lime- soil mortars used in the Blumenau region should be better explored and analysed scientifically. The results may indicate that type 1 samples which are Tottene, Buzzi and Poffo eventhough lacking in typical parameters suitable for mortars such as good distribution of grain size, less than 10% amount of silt size impurities, and reasonable proportions of binder (1:3 in terms of volume) may be suitable for the buildings if well maintained and help to eliminate humidity. However type 2 samples may indicate that a better control of the raw materials for making lime- soil mortars will substantially improve the performance and durability of these mortars as indicated by the Fiedler renders and plasters.

Therefore the results of lime- soil samples should be seen as preliminary and used as a basis for future work. The reproduction of these samples at a laboratory base using local sources of soil mixed with different lime qualities and further analytical comparisons with samples drawn from the buildings is advisable.

SAMPLE	COLOUR /Munsell [hue/ value/chroma]	CaCO3 [Wt.%]	MICROSCOPY [polarised light]
Fiedler 2	Reddish Yellow 7.5YR/ 6/ 6	11.3	Moderately well cemented, slightly impure calcium carbonate matrix/ yellowish material.
Poffo 4	Light Yellowish Brown 10YR/ 6/ 4	11.4	Not homogeneous matrix: patches of soil rich or calcium carbonate, basically lumps of lime.
Buzzi 2	Very Pale Brown 10YR/ 7/ 4	12.6	Slightly impure calcium carbonate matrix/ yellowish material. Sand is more medium size/ angular and rounded, thus loose material.
Tottene 1	Light Yellowish Brown 10YR/ 6/ 4	12.8	Slightly impure calcium carbonate matrix/ yellowish material. Lumps of lime. Sand is more medium size mixed and bits of soil, thus loose material.
Fiedler 1	Reddish Yellow 7.5YR/ 6/ 6	13.9	Similar to Fiedler 2
Fiedler 8	Light Brown 7.5YR/ 6/ 4	19.9	Very well cemented material, impure calcium carbonate matrix. Yellowish colour material is the effect of organic matter. Also blackish material which is likely to be charcoal. Better sand size, thus more compact.

Fig. 68 - Results of Lime- Soil Renders and Plasters: Phase I

SAMPLE	PARTICLE SIZE AGGREGATES [passed amount %]BS sieves: 1.18mm/600 μm/300μm/150μm	AGGREGATE [Wt %]	FINES [Wt %]	B/A [ratio]
Tottene 1	98 /86 /52 /17	84	2	1:4
Fiedler 1	94 /61 /25 /9	81	1	1:3

B/A: Binder/ Aggregate ratio

Fig. 68 - (continued) Results of Lime- Soil Renders and Plasters: phase II

(4) LIME - SAND RENDERS AND PLASTERS

LIME- SAND RENDERS AND PLASTERS: GENERAL

Definition

These mortars are defined as lime- based systems where the aggregate is a coarse or clean pit sand which have the following function:

Render: external coating
Plaster: internal coating and undercoating

Composition

Mixes for renders and plasters based on lime and clean pit sand may be very similar to lime-pointing mortars or lime bedding mortars and described as below: (fig. 69)

1. Lime

The lime is a high calcium quicklime converted into lime putty by wet slaking. The average proportion of lime by volume is 1:2/3 (binder: sand), but old mortars may have richer binder content, thus quantities may vary.

2. Aggregates:

Usually a clean and well graded angular sand. Other aggregates constituents could also be added such as crushed brick, tile, stone or shell. The colour of the sand is, primarily, the overall colour of the mortar.

3. Additives[119]:

Occasionally, additives were added to aid carbonation or improve properties.

4. Fibre:

Alternative use of animal hairs, chopped straw, dung mixes, etc.

5. Water:

Clear fresh water source, free from organic impurities. The exact quantities vary according to the source of quicklime.

Fig. 69 - Components of Lime- sand Plasters and Renders

[119] See also the considerations about additives described in lime- soil composition.

LIME - SAND RENDERS AND PLASTERS: S. CATARINA

Description of S. Catarina Examples

Lime- sand plasters or renders were not identified by craftsmen as a common practice in the Blumenau region, although there were exceptions.[120]

Ceiling plaster, scarcely used in the architecture where these samples were investigated, may have had a clean sand aggregate.[121] One of the craftsmen interviewed explained that early ceiling plasters were based on lime, but later (after 1930) on gypsum. By the 1940's, artificial cement was rarely used because it was imported from Holland and extremely expensive.[122] Hence only early and very few examples of lime- sand plaster exist in the region.

The description of the materials used to prepare plasters for walls and ceilings of Havenstein's house (1932) by the owner include sand which was removed from a pit located on the site of the building [123]; earth also from the building site and lime which was bought at the near shop, available in bags. He concluded the description saying that some cement was added for both plasters ie wall and ceiling[124].

The condition of these materials again presents, the problems of plasters applied to timber-framed structures or lath and plaster ceilings. In general, the plasters are cracking. As many of these plasters are decorated with stencil paintings, the conservation of internal plasters requires a special critical understanding of the painted decoration. This study of the material composition of the plaster is intended to contribute to that understanding.

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[120]Whenever craftsmen mentioned renders and plasters they described them as either earth or earth mixed with lime. Therefore descriptions specifically including 'sand' as the ingredients of these mixtures were rare.

[121]Usually the houses examined were built without ceiling plasters. The ceiling is the floor of the loft made with wooden boards.

[122]See also above the chronology of lime and other cements in Blumenau which are organized according to documentary sources. Gypsum was used from 1874, but probably only for the main buildings of Blumenau Town Centre. Cement from 1878, but probably for bridges and special buildings. Although by 1926 the imported quantity of cement is bigger than lime.

[123]This fact shows that a pit sand was also sometimes available in the building sites.

[124]The owner explains that by the time the house was built in 1932 (when he was four), cement was available.

Characteristics of S. Catarina Examples

Very few examples of lime plasters with a clean or coarse sand are presented in the collection of samples. Three examples of wall plaster and one ceiling plaster have these characteristics. Due to limited sample size, one of the wall plasters was not analysed. The analytical results of lime- sand plasters are listed in the following tables. (fig. 71)

Results and Discussion

1. General

The few examples and unequal characteristics of these samples make a general understanding of them impracticable.

2. Type 1: Havenstein 1

The Havenstein sample, unlike the other lime- sand materials has a very low binder content which may be slightly hydraulic in nature. However, confirmatory analysis was not performed.

Although the sample is characterised by a coarse sand texture, microscopy and grain size analysis show that there are also fine impurities which are composed of very fine sand, silt, clay and probably charcoal. The last may impart the brownish/ grey colour of the sample. If a high fines content (particles smaller than 63 μm) is present in a sample, the raw material may contain a hydraulic component. The inclusion of a hydraulic component is in this case indicated by oral historical documentation which may be reinforced by comparing the results with the other samples. The Havenstein sample exhibits a lower proportion of lime and a higher fines content which differ from the other samples.[125] Therefore, it is possible that cement was used, even though by 1932 it was being imported and was expensive.

This slight hydraulic nature would explain the sample's thin, but stronger binder potential when compared with earth mortars (5-10% clay) or even some lime- soil samples (11- 13% lime) in spite of its lower lime binder content.

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[125]The Havenstein plaster presented 2.3 Wt% of fines, whereas the other samples presented less than 1 Wt%. The exception is Tottene render where the fines content was 2 Wt%, however the characteristics of these samples indicate that, in this case, the fines are likely to be silt or clay.

However, the fines 2.3 wt % might not be a sufficient indicator of an hydraulic component.[126] Further analysis was not performed, but appropriate techniques such as SEM or XRD might reveal the presence of cement crystals.[127]

As a conclusion, it might be said that the addition of cement to this sample, although not completely proved, is indicated by chemical analysis and local practice. In fact, this is an important key to the dating of traditional binders in the Blumenau region. The Havenstein sample may represent the end of the tradition of clay and air hardening lime materials in Blumenau region. It would be expected that buildings or additions that came after 1930 would exhibit hydraulic hardening mortars based on lime mortars gauged with Portland cement. It would be interesting to develop this theory further with a larger sample pool.

3. Type 2: Buzzi 3

The Buzzi sample is an interesting plaster characterised by a lime- rich binder together with lime used as an aggregate. However in this case, unlike the lime- soil examples, the particles are completely embedded in a lime- rich matrix. In addition to this, organic matter likely to be dung is present.[128] The clean and well graded aggregate is within the recommended limits, although the sand exhibits a grading most suitable for renders. [129] (fig. 70)

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[126]Stewart, J. and Moore, J. (1981), in Mortars, Cements and Grouts used in the Conservation of Historic Buildings, pp.297-305 experimented chemical techniques to test mortars of known composition. They report that the technique which determines calcium carbonate content, sand content and by difference the soluble fraction, where the last result can act as an indicator of hydraulic components, yields unreliable results.

[127]See Lewin, S.Z. (1981) in Mortars, Cements and Grouts used in the Conservation of Historic Buildings, p.123. The author reports XRD and SEM analysis with mortars prepared with lime, Portland Cement and sand, where cement constitutes 6% or less of these mortars. The small size of cement crystallites makes difficult or impossible to detect by optical microscopy; the low proportion may not expected to be detectable in the x-ray diffraction; however 6% weight of cement in a mortar is clearly recognizable in SEM (scanning electron microscope).

[128]In lime- soil examples the coarse lumps of lime are surrounded by a thin impure calcium carbonate matrix.

[129]Recommended limits for the grading of sand is organized by Ashurst J. and Ashurst, N. (1988), Practical Building Conservation Vol.2, p 43. The limits comprises aggregates ranging largely between 2.36mm and 150 microns. Finer than 150 microns should never be more than 10% for plasters. See the table below which sets out these recommendations:

BS SIEVE SIZE	% OF TOTAL SAMPLE PASSING BS SIEVES FOR:		
	MORTARS	RENDERS	LIME PLASTERS
5.00mm	100%	100%	100%
2.36mm	90-100%	90-100%	100%
1.18mm	70-100%	70-100%	90-100%
600 μm	40-100%	40- 80%	55-100%
300 μm	5- 70%	5- 40%	5- 50%
150 μm	0- 15%	0- 10%	0- 10%

Fig. 70 - Recommended Limits for the Grading of Sand

In this case, the addition of fibre, likely to be dung, was detected under the optical microscope and may indicate with other observations that the use of dung was a practice in the region.[130]

4. Type 4: Fiedler 4

Fiedler ceiling plaster is characterised by a finely graded sand together with lime- rich binder, perfectly adequate for a thin skim coat where the undercoat is a daub mortar.[131]

5. Conclusion

Although the quantity of plasters analysed is not sufficient to make sweeping generalisations regarding the use of traditional lime- sand mixtures, the results indicate possible variations which, when combined with knowledge of the local tradition, provide a useful basis for formulation of recommendations.

Questions such as 'should organic admixtures like dung or hydraulic components like cement be advisable for the replication of these lime plasters' will arise. However as indicated in the previous sections in general the use of cement is not advisable or necessary. Similarly mixtures with dung should be avoided as organic admixtures may be difficult to control and encourage biological attack.

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[130] Fresh dung according to local people was used as a single component for the undercoat of timber framed structures. Dung was also used in combination with earth or lime to make renders and plasters. Undercoat made with dung was observed in timber- framed structures which should provide a better adhesion to the final plaster coat.

[131] Mortars with finely graded sand require more binder than the usual proportion by volume 1:3.

SAMPLE	COLOUR /Munsell [hue/ value/chroma	CaCO3 [Wt.%]	MICROSCOPY [polarised light]
Havenstein 1	Very pale brown 10YR/ 7/ 4	8	A very loose material of low binder content with lime present as inclusions. Coarser sand composed of mica, quartz, feldspar. The yellowish or brownish colour of the fine material under reflected light may be caused by mica or charcoal.
Buzzi 3	White 2.5Y/ 8/ 2	20	A very dense material ie high binder content which is lime rich, but also flakes of organic matter likely to be dung and charcoal. Lime is also presented as inclusions, characterised by coarse, chalky and porous particles. Sand is more coarsely grained.
Fiedler 4	White 10YR/ 8/ 1	31	A high binder content which is lime rich. Sand is more finely grained.

Fig. 71 - Results of Lime- sand Renders and Plasters: phase I

SAMPLE	PARTICLE SIZE AGGREGATES [passed amount %]BS sieves: 1.18mm/600 μm/300μm/150μm	AGGREGATE [Wt %]	FINES [Wt %]	B/A [ratio]
Havenstein 1	79 /50 /30 /12	90	2	1:8
Buzzi 3	67 /39 /20 /8	75	0.8	1:2
Fiedler 4	96 /84 /60 /27	66	1	1:1

B/A: Binder/ Aggregate ratio

Fig. 71 - (continued) Results of Lime- sand Renders/Plasters- phase II

(5) LIME- UNDERCOATS

LIME- UNDERCOATS: GENERAL

Definition

These materials are defined as soft mixtures based on lime; however constituents may vary by the addition of fibre, sand or crushed components. The function of these materials is to act as undercoats between timbers and top plasters based on earth or lime. Therefore, the main properties of these mortars are: to provide good adhesion to timber supports; adequate flexibility, thus creating less differential movement between the panel and the timber- frame; to provide a firm undercoat to receive a top coat of earth or lime. In addition, this system should have the ability to absorb and release dampness, allowing the timbers to 'breathe' which also creates less differential movement between the wall materials.

Composition

Mixes for undercoats are in general prepared with a coarse mixture to provide a connection to the finer plaster. When the plaster is applied to wood supports, there is a need for a sticky material and traditionally dung was used. Components of lime- based undercoats is discussed below: (fig. 72)

1. Lime: The typical source of lime is a high calcium quicklime converted into lime putty by wet slaking.
2. Aggregates: Usually a coarse sand, but also crushed brick, tile, stone or shell.
3. Fibre: The addition of fibres such as cow dung, hair and chopped straw in lime- based mixtures was traditionally used.

Although in general the inclusion of organic additives in lime mortars is neither required nor recommended[132], alternative use of natural fibrous materials for repair works is sometimes recommended in the literature[133].

Fig. 72 - Components of Lime- undercoats

[132]Sickels, L. B. (1981), in Mortars, Cements and Grouts used in the Conservation of Historic Buildings, pp. 28 reports deficiencies in the use of organic additives. During research with trials, problems arise due to the use of organic admixtures, the biggest problem being that of biological attack.

[133]The technical pamphlet Panel Infillings to Timber- Framed Building by Kenneth Reid, p. 11 suggested a mix for renderings using: 1 part lime putty; 1-3 parts sharp sand; 1 part cow dung (fresh and slurry consistency). Chopped straw (100-180mm) lengths; (not included in the finishing coat).
Ashurst, J. and Ashurst, N (1988), Practical Building Conservation, Vol.2, p.96 explain that dung, especially cow dung is a mucus which reacts with lime to form a gel, thus acting as a support before carbonation is achieved.

LIME- UNDERCOATS: S. CATARINA

Description of S. Catarina Examples

The composition of plaster undercoats in timber- framed structures is described by craftsmen and local people as a material which consisting of cow dung (fresh and slurry consistency) so as to create a sticky mortar. Although the use of dung alone was observed as the base for internal plasters, the use of other alternatives was also recorded.

One method that was recorded was to provide a physical connection by applying the plaster over a series of thin strips of lath; the plaster squeezes through the gaps and expands, thus fixing it in the place. Another method involved the use of special mortars based on different materials. This research attempted to understand their composition and function.

In view of the difficulties involved in sampling materials, only two examples of plasters applied to timber-frames are representative of lime undercoats, but possibly a variety of admixtures were used by the immigrants.

In general, as already stated, the cracking and detachment of plasters applied over timber is present in all structures. However, the degree of decay varies substantially.

Characteristics of S.Catarina examples

Two samples were collected and analysed. The analytical results of these undercoats are listed in the following table. (fig. 73)

Results and Discussion

1. General

The two undercoats differ in composition.

2. Type 1: Fiedler 3

The material is characterised by a very soft mixture based on lime and organic material likely to be animal dung.

3. Type 2: Wacholz 3

This material is characterised by a calcium carbonate matrix and sand. However, crystallization of calcium carbonate is not homogeneous and only patches or bridges of the matrix can be observed. This might possibly be caused by wet conditions where absorption of carbon dioxide from the air was so slow that complete carbonation did not happen. From observation, this material appears to have a high porosity which makes it able to shrink and swell, thus fulfiling its fuction as an undercoat. However, original components and preparation are not totally explained here.

4. Conclusion

Although only two samples were analysed and interpretation of the Wacholz mortar is difficult, these two materials may be characterised as soft undercoats where the required properties listed above might be achieved. Thus, some considerations related to undercoats may be recommended.

SAMPLE	**LOSS ON IGNITION [Wt %]**	**CaCO3 [Wt %]**	**MICROSCOPY [polarized light]**
Fiedler 3 undercoat	39	59	Animal organic material likely to be dung is identified.
Wacholz 3 undercoat		14	Fair amount of impurities. The binder is calcium carbonate, but it looks like a weathered material as crystallization is not strong.

Fig. 73 - Results of Lime- undercoats

POINTING MORTARS, RENDERS AND PLASTERS: RECOMMENDATIONS FOR REMEDIAL WORK

Principle

Where repair and replacement of pointing mortars, renders and plasters is needed new mortars should exhibit similar chemical, physical and aesthetic characteristics to the existent materials, matching the old mortars in composition and mortar properties.[134]

Testing

A thorough investigation of the surviving mortar and techniques, as well as local sources of aggregates, and trial mortars should be provided by tests. Recommended tests for matching mortar are:

1. <u>Simple observation of unweathered sample</u>

Simple observation of samples with low magnification may be sufficient for an experienced person to specify approximately the materials and proportions for new mortars of an historic building.

2. <u>Chemical analysis and further aggregate colour and size determination</u>

A more accurate method for analysis of mortar samples should be performed wherever possible. The samples are treated with dilute acid to separate the carbonated lime from the aggregates. The results indicate the binder: aggregate values, colour, texture and strength (according to the grading of sand).[135]

3. <u>Microscopy</u>

Microscopic examination may be advisable according to the needs of the project. Some simple techniques for the examination of mortar samples where samples are embedded and polished require only small quantity of the material and relatively unsophisticated equipment. Such simple techniques can be useful indications regarding distribution and some characteristics of the binder and aggregates and approximate size of components.

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[134]Important properties of lime based mortars are workability of fresh mortars; permeability, compatibility with other masonry materials; appearance including colour of a mortar, the result of the aggregate's fines and binder, and surface texture; moisture, ie pore structure and water absorption; mechanical properties such as movement, strength and adhesion; and durability (resistance to the ambient environmental conditions). Based on the properties listed in "The Smeaton Project: Factors Affecting the Properties of Lime- based Mortars by Teutonico, J.M., et al. (1994), in <u>APT Bulletin</u>, Vol.25, No.3-4

[135]See analysis section above for the understanding and limitations of this test.

More sophisticated methods are also used in some cases and conservation architects may learn some basic usefulness. The examination of thin sections under polarized light is a very specificialized area of knowledge which requires accurate manipulation of samples in addition to expertise for interpretation. This technique is very much used today in the field of building conservation, both in research project and in single building projects.

Microscopic analysis of samples is a relatively non- destructive technique, and allows the material to be kept as a reference collection, thus accumulating knowledge and experience. In the case of lime mortars, optical microscopy may offer indications regarding carbonation of lime and purity of the binder fabric.

4. Other testing techniques

In addition to tests to characterize mortars according to type of binder, sand, additives and proportions, other tests are also recommended in certain instances.[136]The measurement of mechanical strength and properties related to pore structure such as water absorption and porosity are important investigations to correlate old and new mortars. However, it is often difficult to do such tests on samples of historic mortars due to the need for a large size or number of samples.

Treatments

Maintenance, repair and replacement of pointing mortars, renders and plasters must be carried out with identical criteria based on the following main parameters:

- High quality work: Well trained workers and adequate equipment/ tools.

Lime mortar materials involve methodological and practical techniques such as removing damaged mortars, preparation of joints and surfaces and application of mortars. Methods applied to the preparation of constituents will be discussed later in this thesis. However, the scope of this research is focused on the study of the components of earth and lime- based materials. Therefore, long specifications for repair techniques will be not included.

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[136]Further to the composition of old mortars there are other factors that are important characteristics affecting the behaviour of lime- based mortars. Characteristics of old mortars are defined in several ways such as workability of fresh mortars and permeability, mechanical properties, appearance and other properties of hardened mortars.

See Smeaton Project, op cit. A series of trial mortars was prepared in varying proportions of binder, aggregates and pozzolanic or air entraining additives. A testing programme is designed and reported including tests for compressive strength, moisture content and carbonation in addition to exposing the samples on site.

• Correct materials: Where the binder of existing mortars is lime, conservation should be carried out with compatible lime-based mortars. Any addition to these mortars should maintain or promote a similar mechanism of hardening (ie carbonation). Only additives/ aggregates that give higher porosity to the lime mixture may be freely permitted (eg porous particles).[137]

The addition of small amounts of cement to lime- based mortars to accelerate setting must be prohibited as it has been shown that it affects lime- based mortars. Mortars with a high content of cement are also prohibited as they are harder and stronger than the brick units and cause severe damage to old masonry.

The addition of hydraulic additives could be considered, but should be approved by research. In any case, strong hydraulic additives such as artificial cement and eminently hydraulic lime should not be permitted. Low- fired brick dust in appropriate particle size ranges to act as pozzolanic additives and porous particles may be desired. Recent research has shown the positive effects of the addition of brick dust to lime mortars for conservation as it promotes setting, carbonation, and a higher strength without dramatically affecting the characteristic properties of lime- based mortars.

Specifications

A selection of materials required for lime-based mortars may be specified; however, specifications should be based on a careful evaluation of the existing materials and the needs of the site. (fig. 74)

[137]The characteristic feature of traditional mortars in S. Catarina located in Portuguese settlements is the addition of broken shells. Other porous materials can be analysed and recommended as additives for lime mortars in S. Catarina.

Lime, Aggregates and Additives

1. The source of limestone to produce the lime should be a high calcium carbonate not containing impurities of more than 5% clay.
2. The production of lime sources should be, preferably, slow burning.
3. Lumps of quicklime converted in limeputty should preferably be used.
4. The mix proportion suitable for lime mortars, renders and plasters is 1: 2/3, ie 1 part lime to 2 or 3 parts sand, but different sources of lime and aggregates may result in different products; therefore, trials and site modifications may happen.
5. Aggregates should preferably be angular and well graded, but colour and grading of aggregates should be similar to the existing materials.
High porous aggregates such as crushed limestones or shells may be substitutes for part of the aggregate. Reactive aggregates whose reaction is not eminently hydraulic such as brick dust may be specified in specific circumstances.
6. In general, additives should be prohibited.
7. Fibres may be specified for specific cases. Sources such as dung should be subject to control and trials.
8. The water should be clean and free of organic matter.

Fig. 74 - Specifications for Lime- based Mortars, Renders and Plasters: materials

The following specifications should also be included in contracts: (fig. 74)

Contract

1. On- site and laboratory tests including the required number of samples of existing material, trials and testing area.
2. The extent of conservation work shown on annotated drawings, with specification notes.
3. The importance of craftsmanship and supervision are critical to the work; therefore, approval of the skill levels of all workmen is a requirement.
4. Appropriate methods for the preparation and application of lime materials.[138]

Fig. 74 - (Continued) Specifications for Lime- based Mortars, Renders and Plasters: contracts

[138] See below Site Instruction section.

3.3.3 Paint Materials

PAINT MATERIALS: GENERAL

Definition

Architectural paints are surface coatings which combine protective and decorative functions to substrates. In general, paints consist of suspended particles in a liquid phase and a binding material that subsequently hardens to form a solid film.[139]

The components of the paint systems determine the properties of each paint film, such as physical and mechanical behaviour, that is, permanence, elasticity, consistency of the paint and therefore its affinity for various substrates. In this respect, substrate and paint system are both significant parts of architectural surface coatings as they perform together. In some cases, it is the substrate that contains the binding medium to fix the pigments to the support.

Composition

Main ingredients usually found in different paints include:

1. Binder (or medium) which hardens, binding pigments; adhering to and sometimes penetrating and sealing the material. Binders are inorganic or organic substances diluted or dissolved in the paint carrier. Examples of traditional binders for wall paints are lime (calcium carbonate as inorganic binding material); and proteinaceous glues (carbon based binding materials): casein and other glues from animal skin and bones. Drying oil paints, eg linseed oil, plant and tree resins, are other examples of traditional binders.

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[139]Architectural paint is defined in terms of composition and various hardening mechanisms. Therefore, the predominant surface finish in Blumenau buildings, ie limewash and other possible types of paints are seen in the whole context of architectural surface finishes. By defining limewash as one of the four types of paint systems, it becomes clear that compatible substitutes for limewash must take account not only of colour matching, but also the way this paint film hardens.

The main references consulted for the studies of paint systems are:
1. Matero, F. (1993), "Paints and Coatings", in Weaver, M. (ed) Conserving Buildings. Guide to Techniques and Materials, pp. 216-21.
2. Wehlte, K. (1975), The Materials and Techniques of Painting, pp. 169-72; 209-18.
3. Mora, P., Mora, L. and Philippot, P. (1984), Conservation of Wall Paintings, pp.10-6.
4. Teutonico, J.M. (1995). Verbal Information given 9th January, 1995 at English Heritage, London.
5. Everett, H. (1971), "Thin Surface Finishes", in Components and Finishes. Mitchell's Building Construction, pp. 345- 56.
6. Dean, Y. (1989), Finishes, Mitchell's Series, pp. 33-7.

Materials used more recently as binders include soluble mineral silicates and the recently developed of (after World War II) synthetic resins: acrylic, polyurethane, epoxy resins and water- based acrylic emulsions (latex paints), which are perhaps the main substitute for the glue- based paints for interior painting.

2. Carrier: a liquid which dissolves the binder (solvent) or disperses the binder (thinner). Water is a common thinner, as in the case of limewash, glue distempers and emulsion paints.

Vehicle is the term used to describe the paint system resulting from the combination of the binder and carrier. (1 + 2)

3. Colourant: (pigment, dye or lake) to impart colour and opacity to the paint. Pigments are insoluble colouring particles, whereas dyes are soluble organic compounds and lakes are a particular type of pigment obtained by the precipitation of dyes in a paint vehicle.

4. Additives: to impart supplemental properties. Such as:

Extenders are finely ground minerals which give body or help to keep pigments in suspension. China clay, barium sulphate (barytes), whiting (chalk) are examples.

Driers and catalysts are substances to catalyse and speed up early drying in drying oil paints, eg zinc white in linseed oil paint.

5. Other definitions relevant to paint composition are:

Emulsion: a mixture of oily and watery substances with a milk-like appearance which consists of drops of one liquid suspended in a second phase liquid. There are natural emulsions used in paint such as egg yolk and milk; and the synthetic emulsions.

Solution: a mixture of two substances where one is the solvent and the other is the solute. The molecules of the solute are dissolved by the solvent.

Paint Systems

Paints are classified according to the hardening mechanism of the binder which may be divided into four types which are set out briefly in the following tables: fig.75,76,77)

FILM HARDENS BY:	BINDER AND PAINT TYPE
1 Solidification by Crystallisation	
A Crystallization by carbonation /Chemical Moisture Reaction	
1.1 A lime-based substrate supplies the binding medium which cements the pigments to the support by carbonation	Lime in true Fresco
1.2 Film formation by carbonation Smooth film and poor adhesion	Limewash
1.3 Film formation by carbonation and addition of small amounts of oil and tallow. Prolonged setting time improves complete carbonation and eventual hardness	Lime-oil in Limewashes Lime-tallow in Limewash
1.4 Film formation by carbonation and addition of weak solution of casein. Hardness and adhesion is noteworthy.	Lime-Casein in Limewashes
B Crystallisation by silica formation	Silicate Paints
2. Solvent Loss/no chemical reaction	
2.1 Evaporation of water and gelling	Glues in Glue Distempers
2.2 Evaporation of organic solvents and deposition of resin film	Synthetic Resins
3. Oxidation and Cross- linking	
3.1 Evaporation of water and combination with oxygen transforming from monomers to polymers.	Drying Oils eg Linseed Oil Paint
3.2 Reaction of resin monomer with a catalyst forming polymers	Epoxy- Polyamide Paint
4. Coalescence	
4.1 Evaporation of water, causing the resin molecules to coalesce, ie form a thin uniform continuous film with a flexible nature	Synthetic resins in Acrylic and Polyvinyl Emulsions

Fig. 75 - Categories of Film Hardening vs Examples of Paints

SOLIDIFICATION BY CRYSTALLISATION

TRUE FRESCO	LIMEWASH	CASEIN LIMEWASH	SILICATE PAINT
•Skilled technique, mostly applied to mural painting •durability depends on condition of the wall and substrate preparation	•easy to apply •unaffected by rising damp •substrate should not be an impervious material. •externally to improve performance, additives are incorporated	•durability of the limewash is improved by resistance to rubbing off easily and washing by rain. • casein added to limewash may hinder evaporation and the paint may be prone to biological attack	•chemical bond of the paint binder with substrate •substrate is a dry plaster of lime or cement base

SOLIDIFICATION BY SOLVENT LOSS

GLUE DISTEMPER	CASEIN GLUE
•easy to remove •not very permanent •requires dry and absorbent substrate	•insoluble in water after drying •lime substrate does not need to be dry •dries slightly brittle •solid support as high tension film •adheres better on rough support

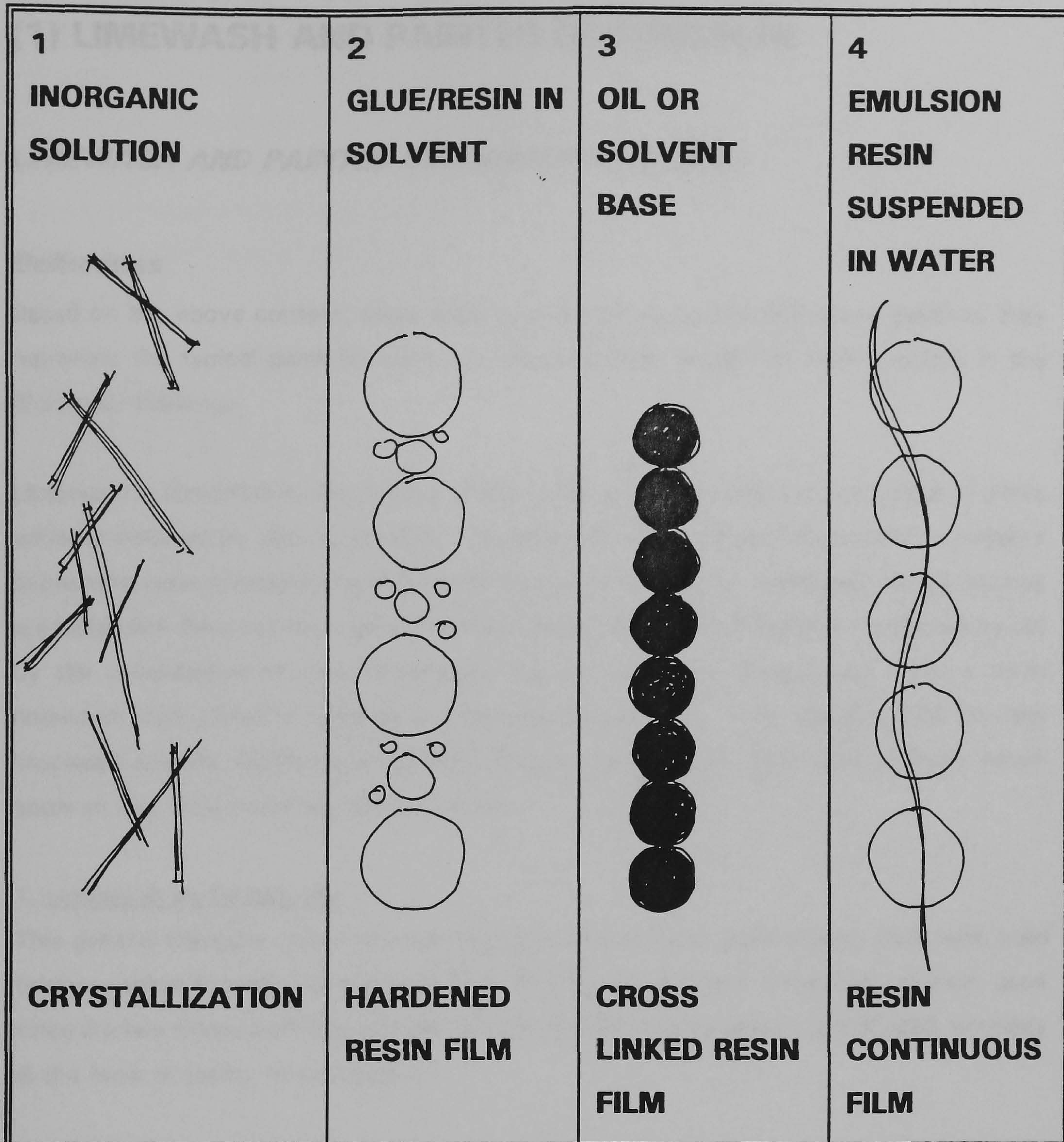
SOLIDIFICATION BY CROSS-LINKING

OIL PAINT/linseed oil	AIR DRYING ALKYDS
•exposed to air in thin layers, becomes a solid elastic film. •resistance to abrasion, heat, moisture	•durable, flexible and do not yellow

SOLIDIFICATION BY COALESCENCE

SYNTHETIC EMULSIONS
•elastic films, adhesion with varying degrees of permeability •cannot be removed by water/non convertible

Fig. 76 - General Remarks Concerning Paint Systems



circles represent molecules of resin/ oil

Fig. 77 - Synthesis: schematic diagram of paint types

(1) LIMEWASH AND PAINTED DECORATION

LIMEWASH AND PAINTED DECORATION: GENERAL

Definitions

Based on the above context, some paint systems are now defined in more depth as they represent the typical paint for walls and most possible decorative paint systems in the Blumenau buildings.

Limewash is identified in the context of this study as a final surface finish, which is either white or coloured by adding pigments. Limewash can also form the substrate for a complex decorative system which utilises different secco or fresco secco techniques. Secco finishes are fixed with skimmed milk, glue or different kinds of tempera.Fresco secco techniques set by the combination of two techniques, fresco and secco. This occurs when a fresh limewash (still damp) is used as a substrate for pigments. They are absorbed into the limewash and the pigments are weakly fixed by carbonation. Two paint systems which apply to this case study are defined below:

1. Limewash and Additives

This general category covers the typical paint used to cover porous walls built with solid brick or timber framing and plastered with earth or lime plasters. Limewash has been used since ancient times, but today its use has diminished. Nevertheless it is still used, normally in the form of ready- mixed product.

Limewash is a type of paint which hardens by crystal formation. Calcium hydroxide in the limewash hardens by the formation of calcium carbonate through the action of atmospheric carbon dioxide. In limewashes therefore, the binding material is calcium hydroxide; the carrier or thinner is water; the colourants, when it is coloured, are lime- proof pigments and common traditional additives are tallow, linseed oil and casein. The addition of certain ingredients to the limewash may modify the binding material in a way that alters the mechanism of cementation of the pigments.

Lime- Casein Limewash. Lime- casein limewash is a paint in which the additive casein reacts with the lime binder to form an insoluble compound (calcium caseinate) which gives resistance to dusting and washing by rain to the limewash and better adhesion to the substrate. The colourants are lime-proof pigments.

2. Glue Distemper; Size Paint; Casein Paint

This type of paint system hardens by the evaporation of the solvent and deposition of a hardened resin film on the surface. These paints are also traditionally used for wall painting, usually for interior decoration, used from early times[140]. These paints are composed of a mixture of water and pigments with organic binding substances such as glues, milk or milk products (casein), yolk or the white of an egg. Most of these paints are usually applied to a dry surface.

Composition

1. Limewash and Additives

Limewash is commonly composed of lime and water, additives and pigments, when it is coloured. (fig.78)

Lime
The best source of lime is traditionally a lime putty prepared from lumps of quicklime which reaches the desired consistency of 'milk'by addition of suitable amounts of water.[141] [142] Today commercial powdered hydrated limes or ready- mixed forms of limewash are commonly used.

Fig. 78 - Components of Limewash: lime

[140]The mixing of water and pigments with organic binding substances such as eggs, glue, or milk and milk products, and applied to a dry surface was used from Egyptian, Greek and Roman times until the present century. Davey, N. (1961), A History of Building Materials, pp. 176-7.

[141]Pearson, G.T. (1992), Conservation of Clay and Chalk Buildings,p. 172. In the chapter on wall decoration the author explains that limewash made from commercial hydrated lime is an inferior product because the particles have been dried and finely ground, offering a greater surface area to carbonation, reducing the binding effect. Houben, H. and Guillaud, H. (1994). op cit, p. 342. The authors give the carbonation limit for commercial hydrated lime: the content of calcium and magnesium oxides should not be lower than 80%, while the carbon dioxide content should not be higher than 5%.

[142]Boyton, R.S., op cit, p. 328. Concentrations of lime solids range from 1 to 20%, so limewash is largely composed of free water. Limewash can be prepared from quicklime by adding extra increments of water or by diluting slurry, putty or hydrated lime.

Traditional Additives

Linseed Oil: the most important of the vegetable drying oils, is obtained from the seeds of flax (Linum usitatissimum). As an additive to limewash (about one table- spoon to each bucket of lime), it is mainly used as a water repellent.

Tallow: is the refined fat of cow, pig or sheep. It is used as an extra binder and waterproofing additive in limewash.

Casein: is a natural compound of milk. Soured milk contains a bacteria which promotes the formation of lactic acid, which will precipitate the casein. Lime- casein (calcium caseinate) is a very stable compound which was used historically and extensively for house painting. The use of casein as a waterproofing additive in limewashes is still a practice in some places.

Sources of Casein Sources: 1. Skimmed milk is a natural low concentration solution of casein. It was probably introduced long ago inplace of water to dilute lime and as an adhesive[143]; 2. Curd Cheese, cottage or pot cheeses are sources of freshly precipitated casein[144]; 3. Commercial casein powder is a ready precipitaded form of casein. It is prepared from skimmed milk by heating and adding hydrochloric acid. The product is used as a strong glue for joiners and cabinet makers. It can be used as a binder additive in limewashes.

Fig. 78 - (continued) Components of Limewash: additives

[143]Wehlte, K. (1975)., op cit, pp. 209; 233. Whelte explains that skimmed milk with casein content is a relatively weak, but surprisingly permanent medium. He also says that the milk should be free from fatty components. The addition of skimmed milk improve the adhesion of lime since the two components combine chemically. The solution was used for lime- secco techniques.
Gettens, R. J. and Sout, G. L. (1966). Painting Materials. A Short Encyclopedia. New York, Dover Publications, Inc., p.8. The authors say that the medium made from skimmed milk and lime has a great adhesive power. Lime-casein sets quickly and become very hard.

[144]It is said that fresh casein prepared daily is better source than casein powder. See: Whelte, K. (1975), op cit, p. 211 and Doerner, M, (1934), pp. 218; 298.

2. Glue Distemper Binders

Many sources of organic substances were used as a binder in glue distempers or tempera paints. The following are some traditional sources for house painting.[145] (fig. 79)

Sources of Glue Distemper Binders
Animal Glue: is an adhesive consisting largely of gelatin. Gelatin or size are terms for the pure forms of animal glue.
Vegetable Glues: Potato starch and cellulose are used.
Eggs: The yolk of eggs and also the white were used as binding substances. They are hardly used today. Egg white (glair/tempera)- albumen is an adhesive substance.
Egg yolk- oily emulsion in which oil particles are suspended in a solution of albumen.
Casein: is also used as the unique glue binding for a casein paint. Casein glue function is yielded by alkalis such as lime. Casein is dissolved in warm water and alkali substances. The same sources of casein explained above can be used.

Fig. 79 - Glue Distemper Binders

3. Pigments

Pigments are particles which inpart colour to painting materials and which remain insoluble but suspended in the binding media. Pigments differ in properties such as appearance (ie colour), chemical composition, permanence to light, fastness to media which determines their selection.[146] For example, the nature of the medium determines the type of pigment to be used. Limewashes and lime- casein limewashes require pigments which are resistant to alkalis; these are primarily the inorganic mineral pigments, ie numbers (1) and (2) of the table below: (fig. 80)

[145]Frank Welsh (1990) in his article 'Microchemical Analysis of Old House Paints with a Case Study in Monticello', in Microscope vol. 38 p. 256 says that egg tempera, gum arabic, and starch media are generally not used in house paint, but there exceptions. Therefore water- based paints which are not limewashes are usually animal- glue distempers.

[146]Whelte, K. (1975), op cit, pp. 51- 168. The section pigments includes the sources of pigments as well as the properties.

Sources of pigments:[147]

1) Natural inorganic pigments. Ores, minerals and sedimentary deposits of the earth's crust (native clays) high in metal content.

2) Artificial inorganic pigments which are basically metallic compounds chemically produced by different processes such as calcination.

3) Natural organic pigments. Dyes of animal or vegetable origin are the sources for these pigments which should be made into lakes first to be used as pigments.

4) Artificial organic pigments are complex synthetic products produced from dyes.

Fig. 80 - Sources of Pigments

Until the nineteenth century, the great majority of pigments available were of natural origin and only a small number of artificial agents were known.[148] Examples of inorganic natural pigments used since early times are the native clays, eg red ochre, yellow ochre and silicates of iron, aluminium, magnesium and potassium, eg green earth. Ores of semi-precious stones are also sources of inorganic pigments eg ultramarine blue or lapis lazuli. By the nineteenth century when most of the houses of S. Catarina were built, a much greater variety of pigments was available. The list of colours completed by Willhem Keim (1886) included the pigments listed in the following table. [149] (fig. 81) In 1934 Doerner added other pigments to the list: cadmium red, lithopone, titanium white, and manganese violet.

[147]A complete list of pigments is given in the following sources: Gettens, R.J. and Stout, G.L. (1966), Painting Materials. A short Encyclopedia, pp. 91-181; Harley, R.D. (1982), Artist's Pigments c. 1600- 1835, pp. 43- 180; and Wehlte, K. (1975), Materials & techniques of Painting, pp. 69-168.

[148]Osborn, R. (1980), Lights and Pigments, pp. 58-62.

[149]Doerner, M. (1934), The Materials of the Artist, pp. 93-5.

LIST OF PIGMENTS BY WILHEM KEIM 1886
1. Cremnitz white.
2. Zinc White.
3. Cadmium, light, dark, orange.
4. Indian yellow.
5. Naples yellow, light, dark.
6. Yellow and brown, natural and burnt ochre,sienna.
7. Red ochre.
8. Iron oxide colours.
9. Graphite.
10. Madder lake.
11. Vermilion.
12. Umber.
13. Cobalt blue.
14. Ultramarine blue.
15. Paris blue.
16. Oxide of chromium, opaque and transparent.
17. Green earth.
18. Ivory black.
19. Vine black.

Fig. 81 - List of Colours completed by Wilhem Keim in 1886

LIMEWASH AND PAINTED DECORATION: S. CATARINA

Description of S. Catarina Examples

Documentary sources and oral accounts by craftsmen suggest that, in the early years of the settlement, simple daubed walls were protected by clay slurries. However, since 1856 limewash is mentioned in old documents including colours such as red and green. [150] Craftsmen described the mix as a white lime material to which components, such as linseed oil, whey, skimmed milk, industrial casein and joinery glue, are added to provide durability. Linseed oil is added to delay the drying process. Other components mentioned as possible additives in the preparation of painted decoration are eggs and the pigment zinc white. Documentary sources suggest that the pigments were preferably imported from Germany. Pigments at the time of the buildings were available in powder form.

[150]Blumenau was founded in 1850.

In general, limewashing has survived in the use of ready- mixed products available in shops rather than in the mixing of washes from quicklime and subsequently lime putty. Fortunately, little replacement of original finishes with modern paint products has occurred in the region. Yet many of the surveyed structures lack paint maintenance and internal painted decoration may be concealed: colours and stencilling may be hidden by layers of whitewash. The survival of early painted decoration and of the stencil decoration from the 1930's is often at risk due to movements in the timber structure and panels which are exacerbated by the general poor condition of the buildings, ie, brickwork requiring re-pointing, decay of timber framing and roof and lack of maintenance leading to internal damp.

Characteristics of S. Catarina Examples

From the six renders and the nine plasters chosen for mortar analysis, samples were selected to document layer stratigraphy and to identify pigments, colour and oil additives.[151] (fig. 82)

Results and Discussion

Observation of the physical characteristics of the paint layers, microscopic examination, basic microchemical spot tests and traditional practice indicate that in most cases the principal binder for internal and external finishes in S. Catarina was lime traditionally modified by adding linseed oil and freshly precipitated casein or later by adding manufactured casein. Today casein is replaced by chemical fixers. It is possible that egg tempera, skimmed milk ie modified lime applied over limewash (dry or slightly wet) or various secco techniques were used in Blumenau buildings, but the paint systems of the stencil decoration should be further investigated.

Examination of the samples suggests that internal plasters have multiple layers on limewash contrasting with the fewer layers on external limewashes. There is evidence in the stencil decorated samples that the original paint was monochromatic, but often coloured washes were used alternately with whitewashes. Washe colours were often yellow ochre, or 'grey' whites either inside or outside, but internal samples also indicated light reds, greens and blue. Similar colours are shown in the stencilled surfaces.

[151] For complete results see appendix F, G and H.

The analysis of some pigments by scanning microscopy provides evidence regarding the chemical composition of the pigments. Interpreted in the light of the historical background of the settlements and technical information regarding pigments, the results seem to indicate that earth- iron oxides pigments such as greens, ochre, red, were extensively used, while pigments such as blue probably artificial ultramarine had a more limited use. The identification of zinc, barium and sulphur in only one of the green layers indicates a possible use of lithopone. This is intriguing as zinc white is a common pigment in oil based paint and this green paint layer exhibits slightly different physical characteristics compared to other layers, ie, it is a more brittle film. (fig. 83)

Although the results derived from the paint studies are preliminary and based on limited analytical data, they nevertheless provide important indications as to the nature of these surface finishes which have been used in formulating the following recommendations.

Selected Pigments in Sample Stratigraphy (Chosen pigments are bold)	**Probable Pigments in Chosen Layers**	**Colour/ Munsell [hue/value/chroma]**
WACHOLZ 2 PLASTER 1st SUBSTRATE: limewash 2nd SUBSTRATE: multiple layers of limewash presenting: white, **ochre,** **pink** and finally **green** in the stencil motifs	 **Yellow Ochre,** **Clay** **Green Earth**	 **Reddish Yellow** (7.5YR/6/6) **Pinkish White** (7.5 YR 8/2) **Olive Grey** (5Y/5/2)
REINCKE 8 PLASTER 1st SUBSTRATE: multiple layers of limewash presenting the following colours: white, **blue,** white. 2nd SUBSTRATE: multiple layers of limewash presenting: white, **ochre,** and finally stencil with blue motifs	**Artificial Ultramarine** **Yellow Ochre**	**Blue** (6.25 PB/3/12) **Strong Brown** (7.5YR/5/6)
FIEDLER 2 PLASTER Multiple layers of limewash and on top possibly a glue distemper presenting: light ochre, light green, **dark green** and finally interrupted white.	**Green Earth mixed with Zinc White and Barium White**	10Y/3/4 or 2.5GY/3/4
FIEDLER 4 PLASTER Multiple layers of limewash presenting: white, cream, **green.**	**Green Earth**	**Light Olive Grey** 5Y/6/2
BUZZI 3 PLASTER Multiple layers of limewash presenting:ochre, greens, **red.**	**Red Iron Oxide**	**Dusky Red** 10R/3/3
TOTTENE 1 RENDER Limewash presenting: **ochre**	**Yellow Ochre**	**Brownish Yellow** 10YR/6/8

Fig. 82 - Results of Paint: colour and pigment identification

Sample	Fat Spot Test
WACHOLZ 2 PLASTER: White Limewash /2nd SUBSTRATE	POSITIVE
REINCKE 8 PLASTER: White Limewash /2nd SUBSTRATE	NEGATIVE
FIEDLER 4 CEILING PLASTER: White Limewash	NEGATIVE
FIEDLER 1 RENDER: White/ Grey Limewash	NEGATIVE
FRANZ 3 RENDER: White Limewash	NEGATIVE

Fig. 82 - (continued) Results of Paint: oil additive identification

Earth pigments or clays

Composed essentially of hydrous aluminum silicate.

May be coloured by iron oxides and other minerals. Earth colours are ochre, umber and green earths.

Clay may be used as a filler necessary for the manufacture of some pigments or naturally present. In earth pigments clay is the body and iron oxide the colouring principle. Pigments containing clay are, for instance, ochre, green earth and ultramarine.[152]

Whites

Clays: $Al_2O_3.2SiO_2.2H_2O$. China clay (Kaolin)

Natural pigment used since pre- historic times.

Lime: Quicklime CaO

Slaked Lime $Ca(OH)_2$

Calcium Carbonate $CaCO_3$

Produced artificially since ancient times.

Lime is the bulk of limewash. It provides the mineral binding medium, but also the colour in whitewashes. White lime is a pure variety (less than 10% silicates and magnesia) produced by burning natural limestone.

Zinc White: ZnO

Artificial origin. Manufactured after 1721.

Very light- fast. Causes no yellowing in oil. May be used in all media, except lime-casein and alkaline casein medium.

Slight drying effect.

Barium White: $BaSO_4$

Natural and artificial origin since early times.

Brilliant white.

Light- Fast. May be used in lime techniques. Compatible with all pigments. Often used as a extender/ filling material.

Litophone: $ZnO + BaSO_4$ (Zinc White + Barium White)

Artificial mineral pigment. Manufactured from Zinc White and Barium White since 1926.

Light fast. Compatible with other pigments. Like zinc white not used in lime techniques.

Fig. 83 - Brief Information on the Observed Pigments[153]

[152]Doerner, M. (1934)., op cit, p. 47.

[153]Compiled mainly from Whelte, K. (1975)., op cit, pp. 69- 168.

Yellows

Ochre: Siliceous Clay containing hydrated iron oxides.

Natural pigment used since pre- historic times. Possible to manufacture in a variety of concentrations.

Great variety of shades ranging from pale yellow to brown.

Light- fast and weatherproof. Compatible with all pigments. Remains unchanged in all media. Coarser and even gritty grades are preferred because their larger particles resemble the mortar aggregate helping to reduce cracking.

Mars Yellow: F_2O_3. H_2O. Pure hydrated iron oxide. Hydrated oxide of iron and aluminium.

Artificial mineral pigment. On sale only in recent times.

Light- fast as natural ochre. Compatible with all pigments. Fast in all media. Suitable for casein and lime paint.; for interior and exterior.

Red

Ochre, red: Oxides of iron containing various impurities. Varieties rich in clay and silica.

Natural mineral pigment. Used since pre-historic times. Gradually replaced by numerous artificial red- iron oxides. Perfectly light- fast and weatherproof. The most permanent of all pigments. Compatible with all pigments. Safely used in all medias and techniques. The high content of iron oxide has a drying effect on oil. For centuries the most common use for iron- oxide pigments has been house painting on wood, plaster, sgraffito mortar. For painting exterior walls the pigment was strongly diluted with quicklime.

Mars, red: Synthetic iron oxide.

Artificial mineral pigment made by different processes. They resemble the natural earth pigments, but are manufactured by calcination or precipitation.

Light- fast (only the pure iron oxide). Adulterates or mixtures containing gypsum are not weatherproof. Compatible with all pigments.

Green

Green earth: Ferrous and ferric silicates of potassium, magnesium and aluminium.

Natural earth pigment used since pre- historic times. Green earth is still being prepared and sold today.

Variety of shades from pale, cool, greenish- gray to warmer, yellowish or brownish green.

It is considered light- fast and weatherproof[154]. Compatible with all pigments. Suitable for all media, except plaster of Paris.

Fig. 83 - (continued) Brief Information on the Observed Pigments

[154]Whelte, K. (1975), op cit, p.121. The author observed that strong shades of green lose their colour when exposed to light and air or in conjunction with plaster of paris.

Blue

Ultramarine: The exact formula has not been determined. Represented by $(Na_8(Al_6Si_6O_{24}S_4)$.

Artificial mineral pigment manufactured since the beginning of the nineteenth-century. In Germany, the 'Vereinigte Ultramarin Fabriken' produced the pigment since 1894.

It is made in a wide range of shades.

The appearance depends on the binding medium.

Should not be combined with copper and lead pigments.

Fast to all medias. In external lime medium only special shades. Opaque in lime.

In Germany blue lime- wash on all walls has been a common sight throughout west Munsterland for several decades.[155]

Black

Mineral black: Aluminum silicate with carbon.

Natural earth pigment. Probably known since antiquity. Nowadays it is often used to colour cement.

Bluish- gray or black. With white it is bluish.

Light- fast and weather- proof. Reliable for lime mortar and sgraffito. Compatible with all pigments. May be used in all media.

Fig. 83 - (continued) Brief Information on the Observed Pigments

[155] Baumeier, S., et al, Westphalian Open Air Museum, Landschaftsverband Westphalia Lippe, 1989, pp.88-90.

LIMEWASH AND PAINTED DECORATION: RECOMMENDATIONS FOR REMEDIAL WORK

Repair and replacements of limewash should meet the following requirements:

Principle

Where the traditional paint material is limewash, the surface finish should always be conserved with limewash from a technical, aesthetic and historic reasons. Any alternative paint system should be strongly discouraged as no other substitute material will have the same characteristics and compatibility with earth and lime substrates, the same porosity and permeability (allowing the coating "to breath"), simplicity of application and appearance as limewash. Incorrect substitutes can lead to technical failures and to unacceptable visual alterations.

Testing and Survey

When choosing appropriate matching of repair and replacements material to the existing painted surfaces, the following tests and survey are recommended:[156]

1. Colour/ appearance

Colour matching using a standard universal colour system provides the most significant physical characteristic for replication.[157] To determine the universal colour name, different techniques can be used. Direct visual comparison with chips from the Munsell colour chart, finding the proper Munsell hue diagram, and then locating the Munsell value and Munsell chroma are methods often used. This can be done by the following procedures:

a. On- site by different techniques.

b. With samples collected by microscopic techniques.

Both site and laboratory work should be carried out by a skilled professional with good

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[156]See Phillips, M.W. (1977), "Problems in the Restoration and Preservation of old House Paints", in Proceedings of the North American International Conference Preservation and Conservation: Principles and Practices, pp. 273-79 and Feller, R. (1977), "The Deterioration of Organic Substances and the Analysis of Paints and Varnishes", ibidem, pp. 293- 296 for limitations of analysis and problems to produce a new paint to match the original colour of the old house.

[157]See: Matero, F. (1993), "Paints and Coatings", in Weaver, M. (ed) Conserving Buildings. Guide to Techniques and Materials, pp. 172- 173.

colour sense and well- lit environment.[158]

2. Pigments and Media Optical Effect

Pigments and media impart optical qualities to the paint film. Old pigments are generally coarse and not even grain size, ie granular and impart a certain quality to the paint film. Pigments produced by modern industry are fine, well- dispersed pigments which result in a different effect[159]. The optical effect achieved with limewash can only be achieved through renewal with the same material.

If required, pigment analysis, should be preferably achieved by simple microchemical spot tests rather than sophisticated techniques requiring specialized knowledge and analytical equipment.

Determination of medium by basic spot tests and physical characteristics of the layers. These tests can be difficult to interpret and more complex analysis may be required in certain cases.

3. Surface Examination

Examination of the surface characteristics including:

a) Tools employed.

b) Types of Paint or Finishes used. Investigation of the stratigraphy (sequence of paint layers). This can be achieved by cutting through and exposing craters of painted layers and then through removal of samples for laboratory examination in cross section under the microscope.

c) Application Process.

4. Composition of the Substrate

The choice of the paint also depends on the composition of the substrate. For technical reasons earth and lime based substrates require lime- paint techniques to ensure proper adhesion between paint system and substrate and retention of substrate permeability.[160]

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[158]The universal colour may be also obtained by spectrophotometric measurement and subsequent appropriate calculations. See: Feller, R.J. (1986). 'Standard Specifications of Pigment Composition and Colour', in Feller, R.J. (ed), Artists' Pigments. A Handbook of their History and Characteristics., Vol. 1, pp.299-300.

[159]Gettens, R.J. and Stout, G.L. (1966), op cit, p.146.

[160]See above mortars, renders and plasters section and therefore tests for the identification of these substrates.

5. Historical Survey

In addition to characterisation of painting materials by chemical and microscopic analysis, the historical background and technology of materials should be thoroughly investigated. Historical survey of what was available during the period in terms of pigments, and painting practices. Specifiers should know about the historical background of paint techniques and be acquainted with the technology of materials in order to make a correct technical choice.

Treatments

Maintenance, repair and replacement of limewashed surfaces should be carried out with similar materials which match the existing painted material in terms of pigment and media properties such as colour/ appearance, optical effect and compatibility with the composition of the substrate. Where painted decoration is applied over limewashed surfaces every effort must be made to retain the existing painted decoration.

Specifications

The general requirements for the specification of limewashes are the following: (fig. 84)

Lime Sources

1. Lime putty is the best form of lime. It has not been dried and ground and as long as the putty is properly stored, carbonation will not take place until it is applied.
2. Hydrated lime (powder form) is an inferior product. It has been dried and finely ground so that more surface area is exposed to the atmosphere and therefore, carbonation is more likely to take place prior to application.
3. Ready- mixed products may contain only hydrated lime or may be mixed with ingredients that will completely modify the limewash characteristics making them unsuitable for conservation work.

Fig. 84 - Specifications for Limewash: lime

Pigments

1. Source: Preferable pigments are mineral sources, free of accelerators and plasticisers. Natural sources, for example earth pigments are preferred, but where they are not available, light- stable synthetic alternatives should be used.[161]

2. Alkali- fast: Pigments for limewashes, lime- casein should be alkali- fast (ie lime- fast) pigments which are the same as those suitable for lime- fresco techniques.[162] In this sense it is advisable to use mineral pigments. Those which are not alkali- fast such as white zinc, white lead, red lead and green verdigris should not be used. Organic pigments are not advisable.[163]

3. Light- fast: Pigments should be light- fast, particularly on external walls where higher light levels can alter light- sensitive pigments and therefore cause colour changes. Ultramarine and some green earth pigments are usually not light- fast.[164]

4. Grain- Size: Coarse- grained pigments as opposed to finely/ even grained are quite acceptable as they are less likely to crack. Yellow ochre pigments are highly recommended due to their coarse grains which makes them suitable for external use.[165] Usually old pigments are less finely ground which gives very different visual characteristics as finely ground pigments disperse more.

Other requirements include: similar colour, similar visual effect and availability.

Fig. 84 - (Continued) Specifications for Limewash: pigments

[161]Natural mineral pigments are often coarse and uneven in particle size which impart texture to painted surfaces. See: Gettens, R.J. and Stout, G.L. (1966), op cit, pp. 133-4.

[162]The pigment fastness in media, ie, the behaviour of the pigments in binding media is more important than the compatibility of pigments. Some pigments are not fast to lime such as Chrome yellow or Prussian blue. Wehlte, K. (1975), op cit, p. 61.

[163]Pigments in lime techniques, specifically lime fresco are given in Mora, P, Mora L.,and Philippot, P. (1984), Conservation of Wall Painting, pp. 63-6.

[164]See: Wehlte, K. (1975), op cit, pp.59-61.

During the experimental work it was observed that one plaster sample from Wacholz family house which had a green stencil motif on the top of the limewash discoloured by light when accidentally left in front of the window.

[165]See: Doerner, M. (1934), op cit, p. 49. The author explains that coarse- grained pigments are less liable to crack and that could be the reason for their better preservation. The practice of grinding by hand is therefore particularly suitable. See also: Wehlte, K. (1975), op cit, p. 79. Larger particles eg yellow ochre resemble the mortar aggregate in size and this tends to reduce mortar cracking.

Additives

Casein Sources:

1. Skimmed milk may be used as a natural solution of casein, although it contains a relatively small proportion of casein.

2. Curd or cottage cheese are the best sources of freshly precipitated casein and are therefore usually preferred. These sources should not be mixed with cream or show liquids which affects the technical properties of this additive.

Casein Powder is a safe source of casein when freshly precipitaded casein is not reliable. High quality casein is an even fine powder that should look pale yellow. Casein powder cannot be stored indefinitely as it hardens on ageing which reduces its solubility.

Linseed oil:

Liquid form is used.

Fig. 84 - (continued) Specifications for Limewash: additives

Not Recommended Materials

•Ready mixtures of limewash or substitutes including components which diminish the permeability of the substrate and do not adhere properly to it.

•Paints of inappropriate colour and optical quality must be avoided.

•Materials with properties of plastic paints should not be used.

•Pigments which contain synthetic oxides combined with accelerators and plasticizers are not recommended. Their reduced permeability due to their microscopic, even particle size creates an almost waterproof paint.[166]

Fig. 84 - (Continued) Specifications for Limewash: not recommended materials

Contracts should also include the following specifications: (fig. 84)

[166]Pearson, G.T. (1992). Conservation of Clay and Chalk Buildings, pp.177-8.

Contract

1. On- site and laboratory examinations and tests including a number of samples of existing and repair materials.

2. The extent of conservation work shown on annotated drawings with specification notes.

3. Replication trials in order to achieve the correct visual appearance prior to full- scale reproduction.

4. Site instructions for the preparation and application of good quality material.[167]

5. Specifications for limewashes may also include recommended suppliers of pigments, additives and lime.

6. Specifications for special paint techniques such as stencilling should include:

- Guidelines for the retention and reintegration of damaged or missing areas of the original painting.
- Recommended suppliers of pigments, additives and or binding media.
- Provisions for a skilled painter familiar with stencilling techniques.
- Tools, special brushes, stencils should also be specified.

Fig. 84 - (Continued) Specifications for Limewash: contract

[167] See below site instruction section for methods of preparation and application of limewashes.

3.4 SITE INSTRUCTIONS

- High standards of preparation and application are critical to the successful performance of earth and lime based materials. Good specification is essential, but never enough.

EARTH AND LIME: ESSENTIAL PRACTICES

The identification and use of correct materials is essential, but unless correct methods are employed in their preparation and application the results will always be unsatisfactory and could lead to failures.[168] Traditionally, earth and lime materials required laborious processes. Today mechanized processes have been developed and may sometimes be used. Since approximately twenty years ago technical and scientific groups from various countries have begun to study, re- evaluated and develop techniques, equipment and tools to prepare and apply new mortar mixtures based on lime and earth for the repair of historic buildings. Much of the practical, scientific and craft knowledge related to conservation is today concentrated in Building Conservation Training Centres or workshops associated with conservation courses.

These guidelines are not intended to be a comprehensive manual for the production of earth and lime materials, nor of repair techniques. The site instructions given here aim to give basic guidance to help avoid some of the common problems identified at S. Catarina, but in addition, are general recommendations on the production of similar compatible and durable materials for other historic buildings.[169]

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[168]The author reports that in 1990 she was participating in the restoration works of the fortress of S. Antonio (built early eighteenth century with rough stone walls laid with wide joints and originally rendered and limewashed), Ratones island, S. Catarina. By that time she was received technical information about the importance of use compatible mortar systems such as pointing mortars and protective surfaces. The preparation of lime mortars to render some surfaces as well as pointing mortars were tried. As nobody from the technical team nor the craftsmen knew the requirements to prepare and apply lime mortars the result was negative and then it was decided to add cement to help setting. Dry hydrated lime mixed directly with the sand was the base for these mortars. In addition the stones were incorrectly pointed, they were not recessed. As a consequence the effect created a misunderstanding of the original character of the construction which left the author in quite a lot concerned with its lack of practical knowledge to conduct successfully the work.

[169]During the field work in Brazil, the author had the opportunity to interview craftsmen about their knowledge about how to prepare and apply earth and lime materials. Some craftsmen showed interest in demonstrating their skills. To check this knowledge some trials were developed on the following issues:
Moulding adobes with the brickmaker Carlos Pasold. Timber moulds were prepared and mud pastes were used to make some blocks. Difficulties on moulding and removing the blocks from the mould were identified.
Earth and lime mixtures with the bricklayer Egon Sasse.
The **lime**, he slaked lumps of quicklime that the author got from the only one traditional lime burning in S. Catarina. He used a small wooden box where he put some lumps of quicklime and over them water. There was a strong reaction. He said that hydrated lime in powder is on the shops since approx. 25 years ago and so wet slaking is not used any more. He does not sieve the lime putty, but he said it should be sieved. He explained that the use of lime to prepare renders and plasters depends on the soil quality. Some soils do not have sufficient cohesion and by practice the craftsmen learned that they should be made with lime. However there are soils in the region that are suitable for mortar mixtures without lime.
The **sand**, he used a river/ stream from the site which he said was a bit dirty, but he also explains that for the pointing mortar they used in the past the sand which accumulated on the roads. That sand had a irregular size ie well graded aggregate.
The **soil**, he explains that for earth making it was used the 'chamote' ie a soil dug from a small hill not containing organic matter. He dug some of this soil from the site to prepare the mixtures. He said that it was not a good soil for a plaster without lime ie poor cohesion. The bottle test with this soil showed 1 of sand to 5 of clay and silt.
The **plant fibre**, he used grass not completely dry.

Only by understanding the surviving materials and by being aware of the materials which are available now in Brazil it is possible to specify and use correctly earth and lime mixtures for the repair of its historic buildings. Testing and practice with the sources of materials available on the building sites are pre-conditions for any conservation work. The following illustrated notes are the result of observing essential practices during visits to Conservation Centres and additional studies of selected technical literature.[170]

The **dung**, he used fresh. He said that fresh dung contains ammonia and this is important as a binder.
The **tools**, he said that in early times 1) the 'cadete' was used for renders and plasters- a big wooden float (1,20mx0,20m), see fig. 8; the mixture was thrown into the wall and then it was used this big board which had more than one handle to hold, and that results in an irregular surface; 2) to make the pointing they made a special bricklayer tool which was concave, but some people used domestic spoons such as skimmers or ladles as the handles were enamelled and rounded.
Six different mixture were prepared. The components and proportions were the craftsmen recipes.
1) lime: finely sand (1:3); 2) Soil: sand: grass (2:1) the grass was cut 3cm length and not completely dry, the mixture should be dry so it does not squeeze much into the framework; 3) Soil: finely sand (1:3) the soil is sieved-3mm sieve; 4) Soil: lime: finely sand; 5) Soil: finely sand; fresh dung (1:5:5); 6) lime: medium sand (1:2).
The best results were with the samples 2 and 4, although since the preparation was made with small quantities, water, workability and therefore shrinkage was difficult to control.

[170]Specific training for these guidelines are indicated here see also above the chapter 2 and the Building Conservation Training Centres visited for this research.
The Training Centre for Crafts and the Preservation of Historic Monuments, Johannesberg Priory, Fulda, Germany: Daubed Earth training with Eckhard Schnell, bricklayer master in 7.9.1994; traditional paints with Frank Lux, Dipl/Des.
The English Heritage Building Conservation Training Centre: lime mortars and lime treatments.
Course Instructors: John Ashurst, Colin Burns, David Sleight, Nick Durnan and Bill Martin.

Specific technical literature consulted for these guidelines are indicated below:
Earth literature: Doat, P., et al (1992), Building with Earth; Houben, H., and Guillaud, H. (1994), Earth Construction; Norton, J. (1986), Building with Earth- a Handbook; Wright, A. (1991), Craft Techniques for Traditional Buildings.
Lime and limewash literature: Ashurst, J. and N. (1988), Practical Building Conservation, Vol. 2 and 3; Induni, B. and L.(1990), Using Lime; Schofield, J. (1985) Information Sheet- Basic Limewash (SPAB); Spiropoulos, J. (1985), Small Scale Production of Lime for Building; Wehlte, K. (1975), The Materials and Techniques of Painting; Williams, G.B.A. Technical Pamphlet 5, Pointing Stone and Brick Walling (SPAB); Wingate, M. (1985), Small- Scale Lime-Burning; Wingate, M. An Introduction to Building Limes; Jessen,v. C. (1989), "Lime, Lime Mortars and Lime Colours", in Building Conservation 88 Symposium, pp.204-213.

SOIL

The performance of soil as a building material is affected by many factors. The rate of hydration, mixing and hardening of soils depend on the type of clayey soils chosen. Experimentation with trials samples is always advisable. Well prepared soils applied with suitable compaction always show better performance.

SOIL INSTRUCTION 1: EXCAVATION AND SELECTION

Choosing the correct soil from the site is the first practice for making compatible and durable earthen materials. (fig. 85)

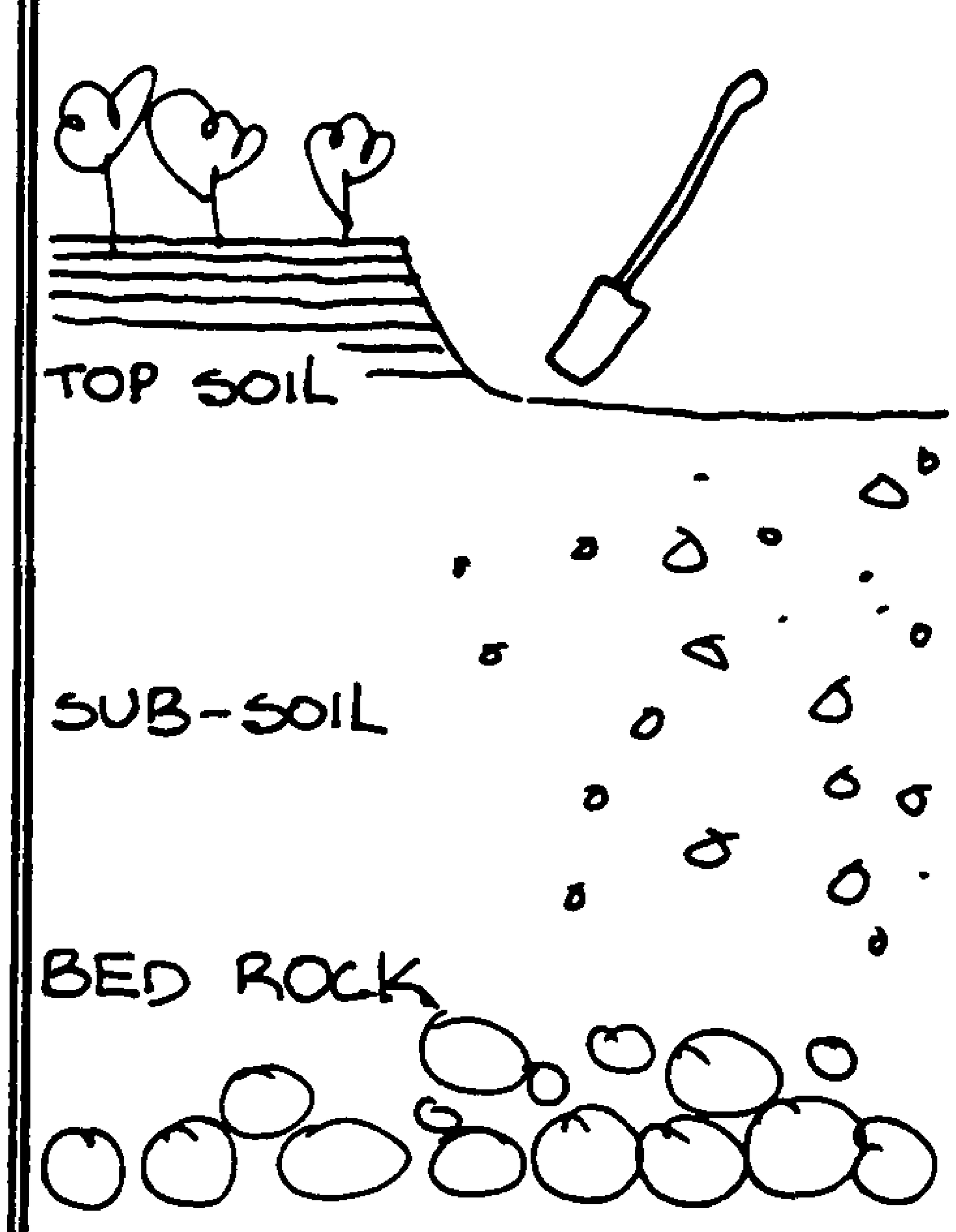
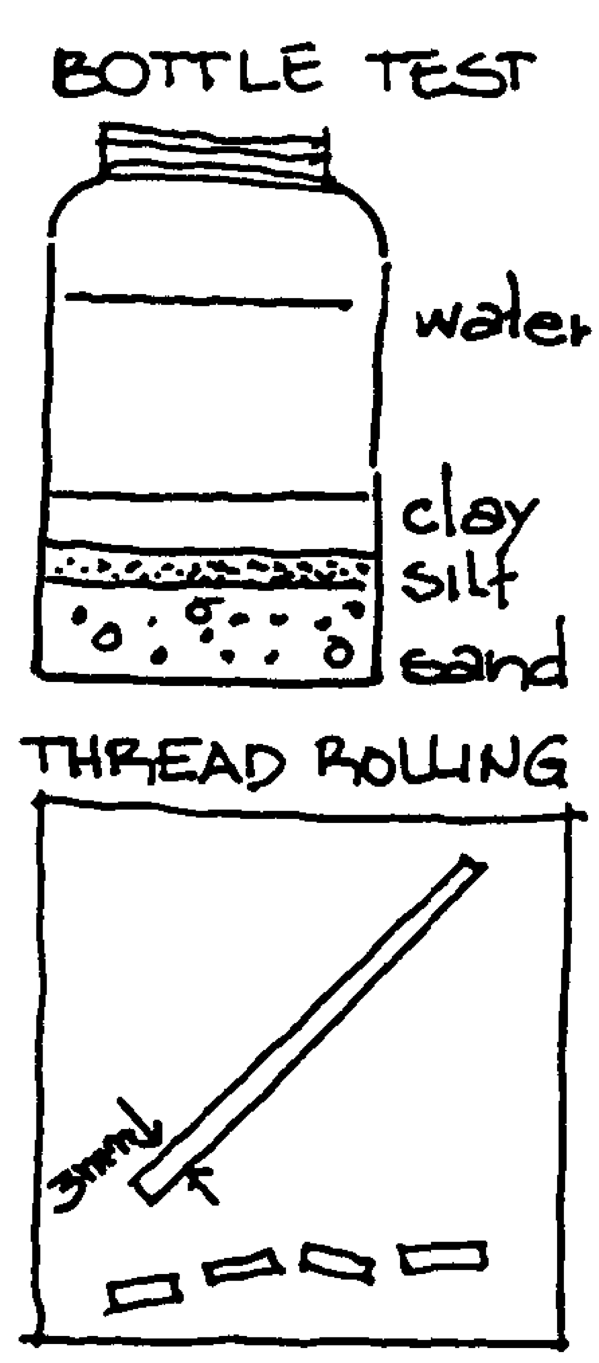
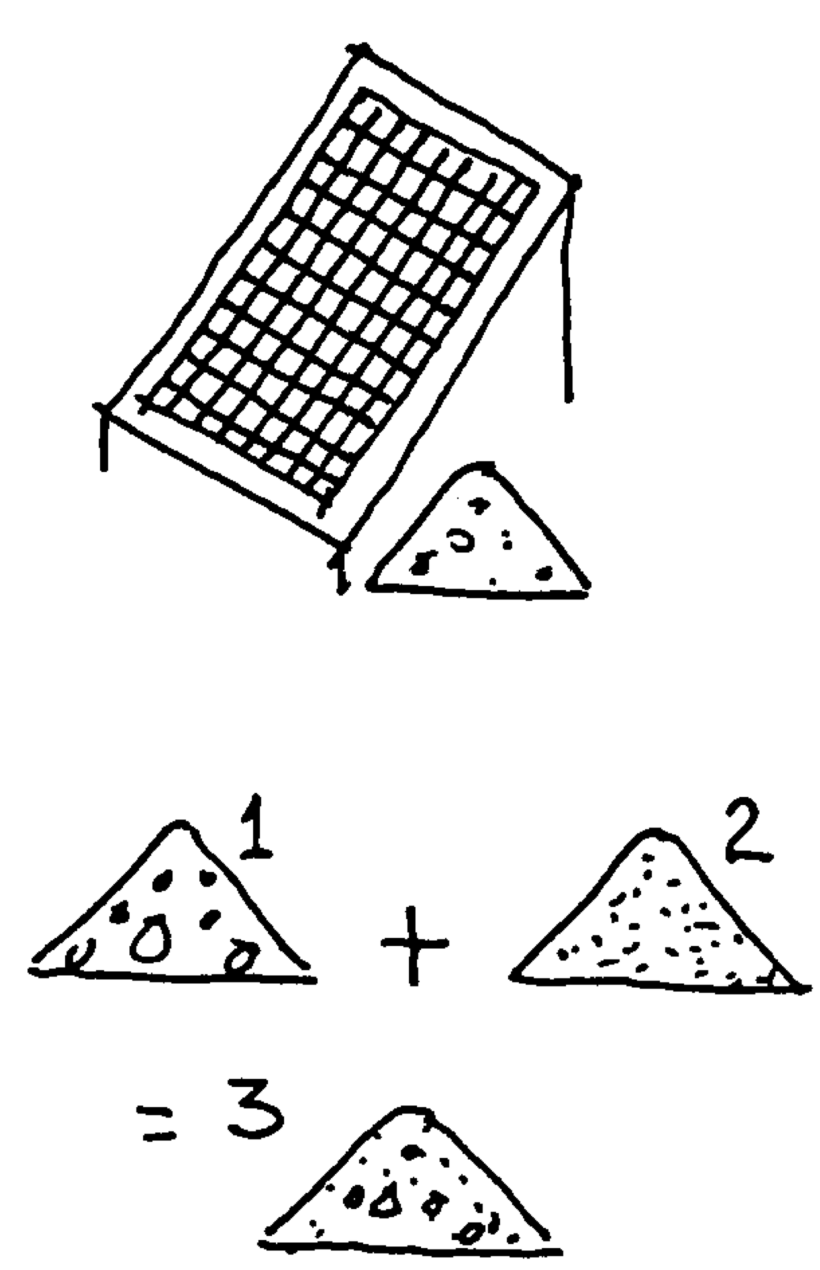
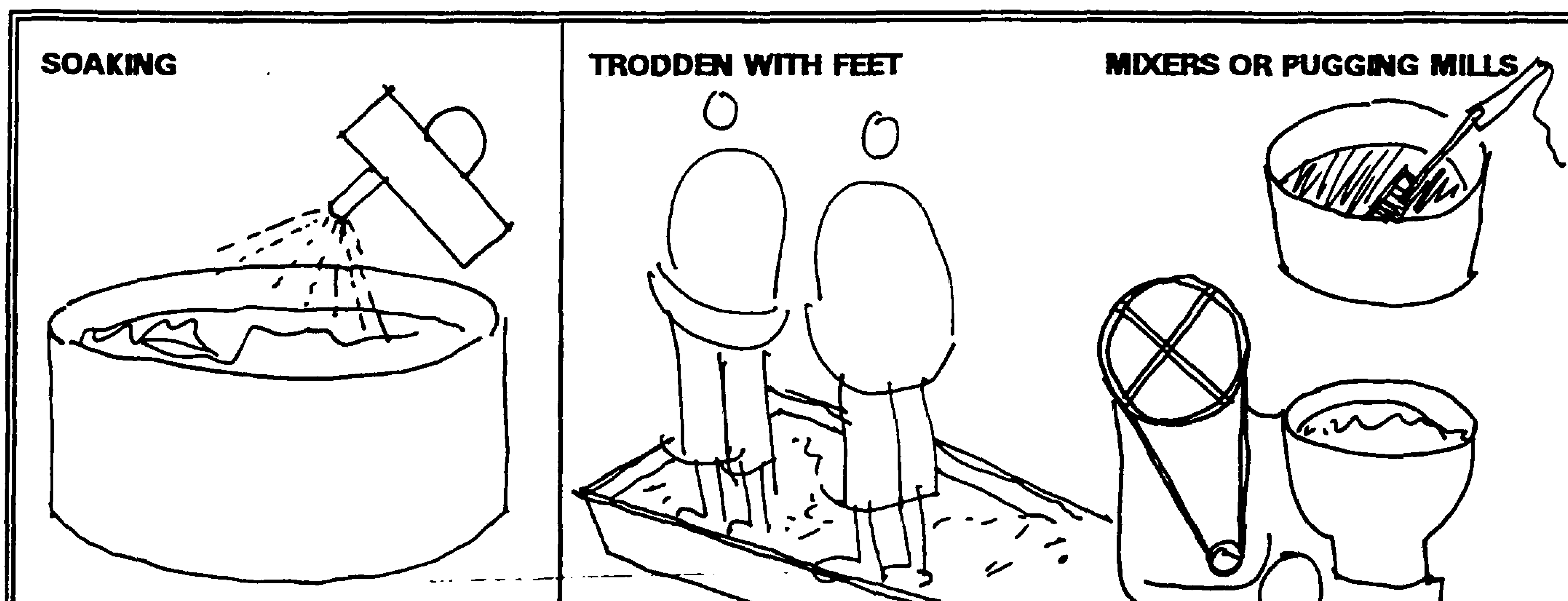
EXCAVATION .	ON- SITE TESTS	SIEVING/BLENDING
		
• Excavate the soil by using simple manual tools or with mechanical equipment. • Remove top- soil which contains organic matter. • Use sub-soil layers.	• Test on -site for quick indications of suitable soils. Tests such as the bottle and rolling test can be carried out.	• Remove particles larger than 6mm by hand or sieving. • Blend soils, if necessary, to correct the grain size.

Fig. 85 - Soil Excavation and Selection

SOIL INSTRUCTION 2: HYDRATION AND MIXING METHODS

Hydration and mixing are required to saturate the clay particles with water helping to break down all the lumps of earth and create a homogeneous mixture. Different states of hydration such as solid paste, semi- paste, mud and slurry are associated with different methods of construction such as moulded earth, extruded earth, straw clay, daubed earth, or blown earth. The quantity of water varies with the soil, but should be sufficient to ensure all grains are completely coated and the mixture is homogeneous. Insufficient water results in the grains being badly bonded and of poor strength. Too much water results in a mixture which is slow to dry, increasing shrinkage and creating a material which lacks strength. Thorough mixing improves binding performance by producing a homogeneous and plastic material. Many sorts of mixing processes are appropriate depending on the amount of material required. (fig. 86)



• Soak the soil at least overnight and preferably for 24 hrs or more.	• Initial thorough mixing and at intervals is recommended, checking the right moisture content suitable for each material.	• Always prepare small quantities of mixture.

Fig. 86 - Soil Hydration and Mixing Methods

SOIL INSTRUCTION 3: WORKABLE CONSISTENCY AND ADDITIVES

Use of the correct quantity of water, proper gauging of soil, adequate mixing and maturing are usually sufficient to achieve good workability. Traditionally, in many circumstances, additional products were used to improve workability. Plant fibres, animal products, and lime all affect the soil workability. (fig. 87)

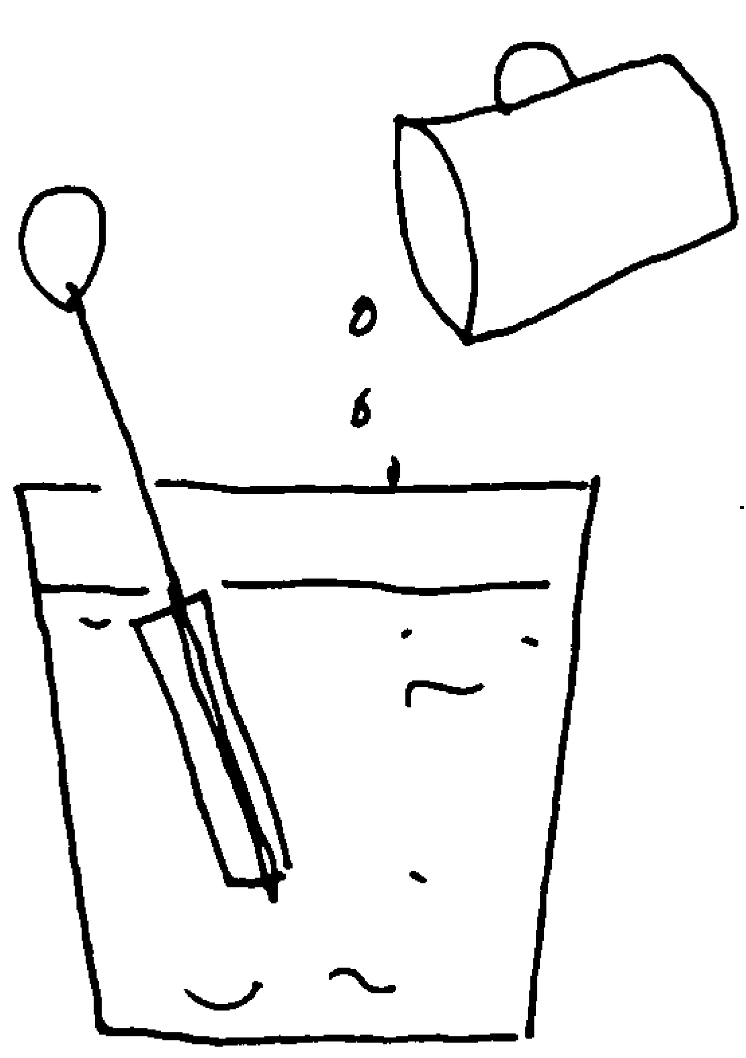
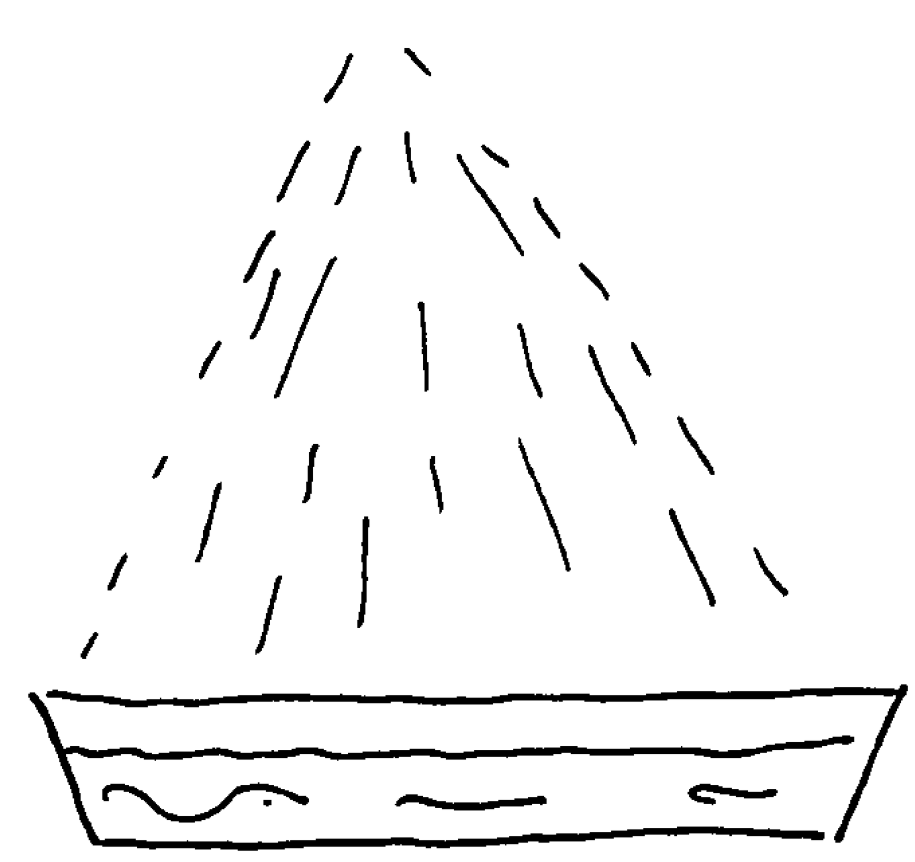
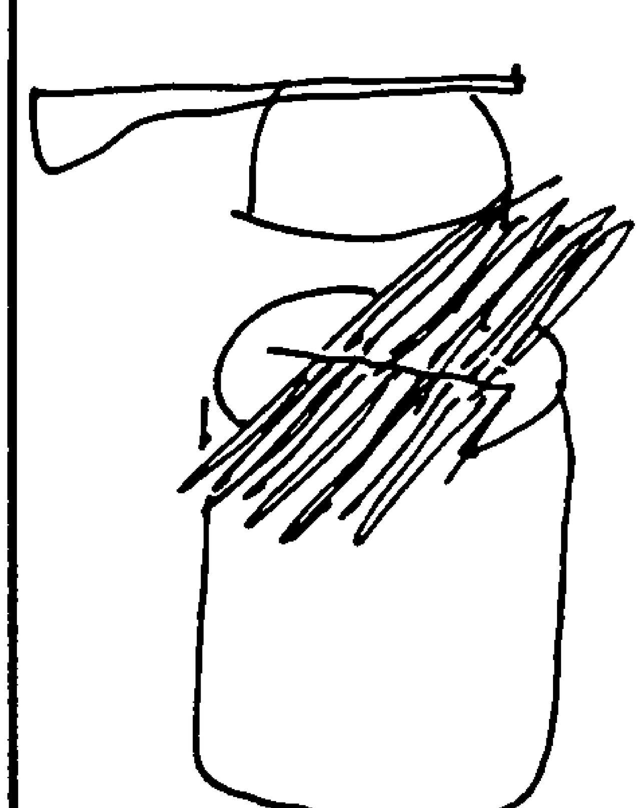
WATER AND MIXING	FIBRE ADMIXTURE	CHOPPED FIBRE METHOD
		
• Avoid excessive use of water in mixing, which can cause instability.	• Add fibre slowly and ensure that it is well dispersed through the mix.	• Use manual or power choppers.

Fig. 87 - Soil Workable Consistency and Additives

SOIL INSTRUCTION 4: ADOBE BLOCKS

A suitable moisture content and correct consistency of adobe mixtures can be tested. The traditional hand- moulded adobe can be made either from a semi- soft or semi- solid paste using moulds made of timber, either with or without bases. However, adobes may also be machine- moulded. In addition, the use of soil in the form of masonry blocks may employ traditional and new methods such as extruded earth, compressed earth or poured blocks. (fig. 88,89,90)

SOIL INSTRUCTION 4.1: ADOBE BLOCKS

WET METHOD: a mould without a base and a semi- soft paste

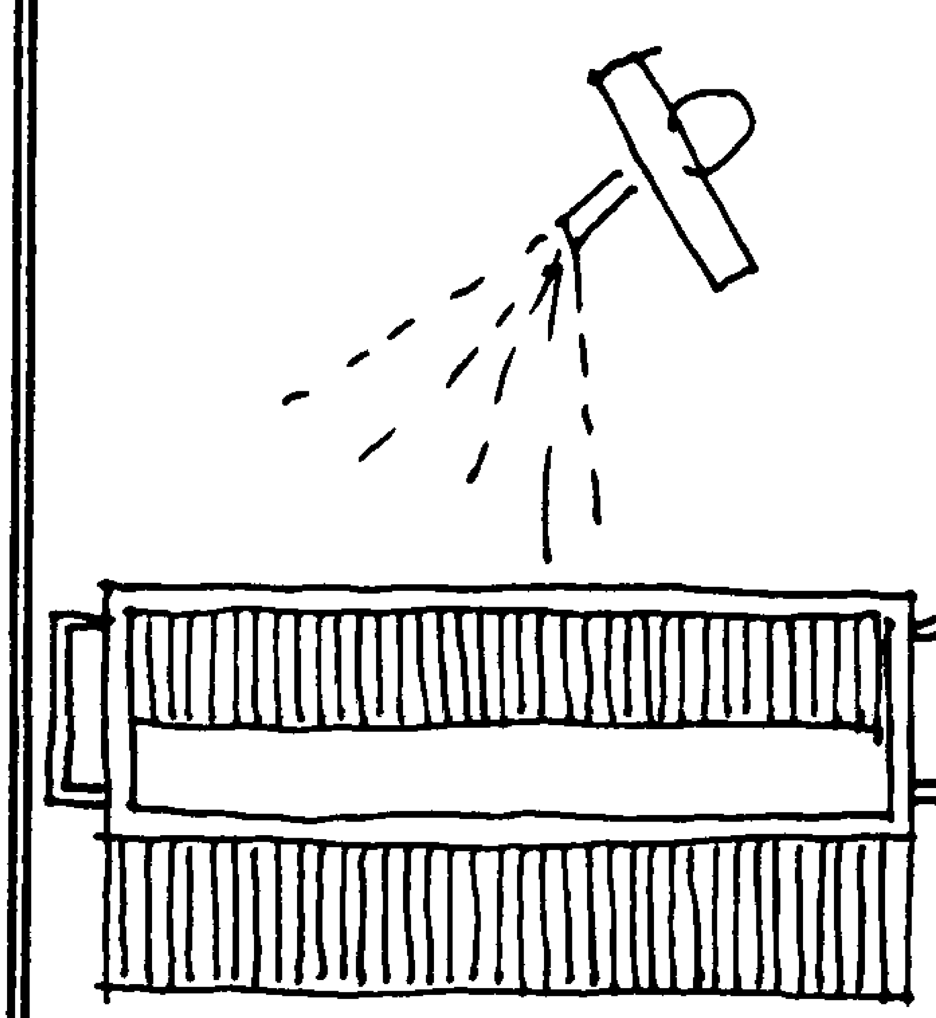
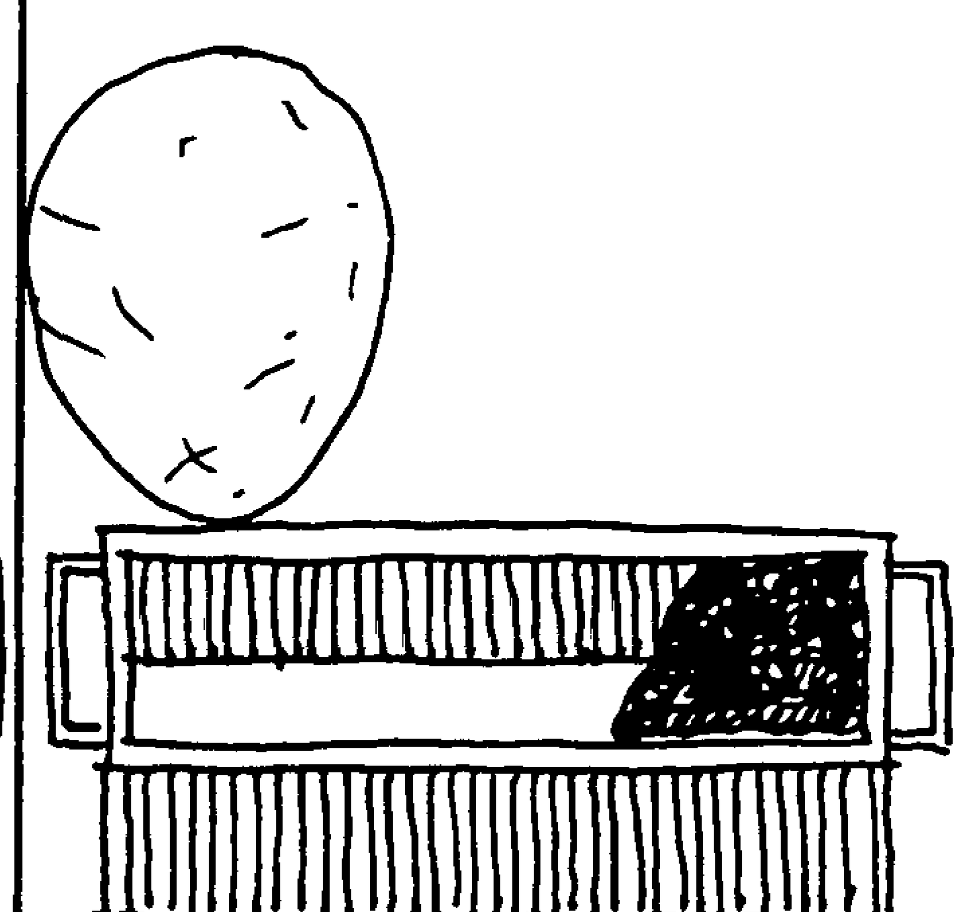
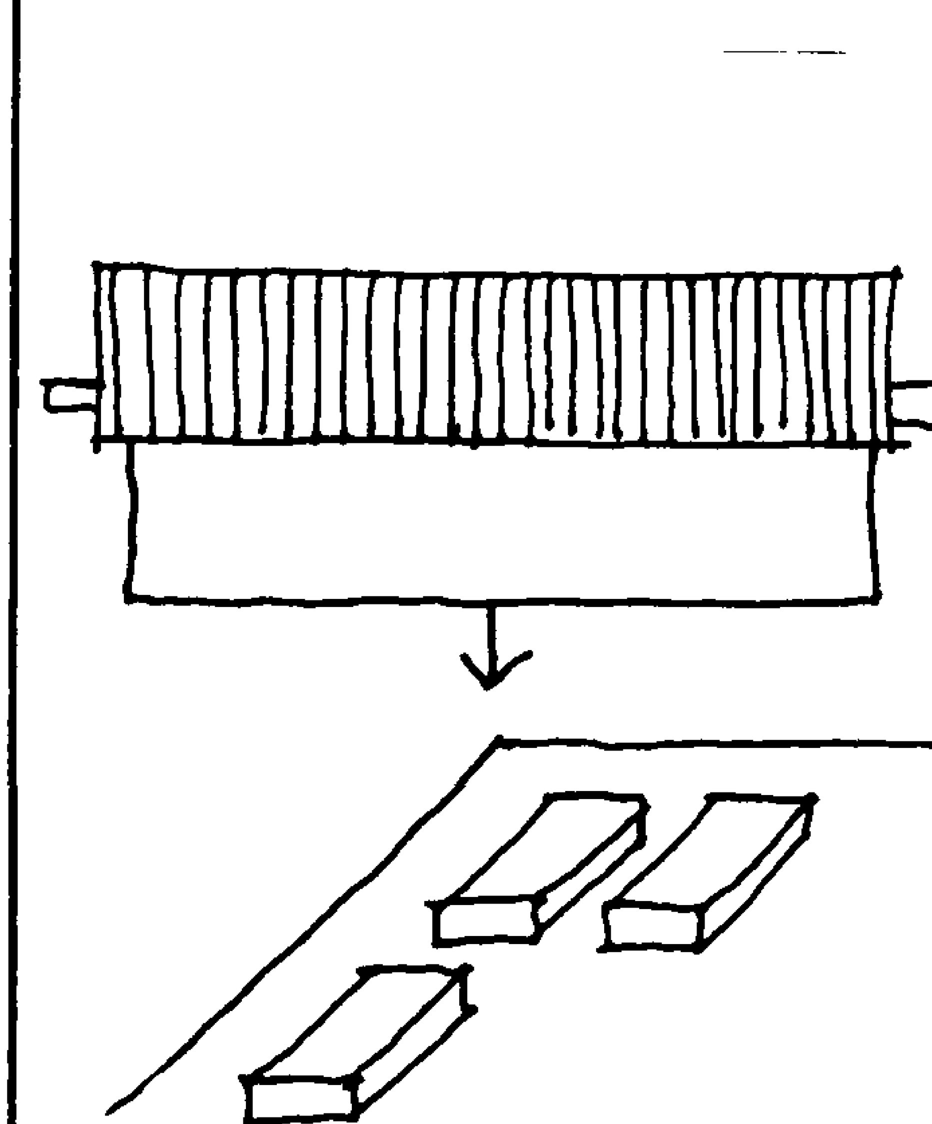
WETTING THE MOULD	MOULDING THE ADOBE	REMOVING THE ADOBE
		
1. Ensure the mould is wet.	**2. Place the mould on the ground and several lumps of earth are thrown into it starting with the corners. The compaction effect produces lubricating film between the earth and the mould making it easier to remove the mould. The wet mixture can be smoothed off by hand or using a rounded stick.**	**3. Remove the mould vertically in one brisk movement.** **4. Prepare the surface on which the bricks are left with sand, straw or paper.**

Fig. 88 - Hand- moulded Adobe: wet method

SOIL INSTRUCTION 4.2: ADOBE BLOCKS

SAND/ DRY METHOD: a mould with a base and a semi- solid paste

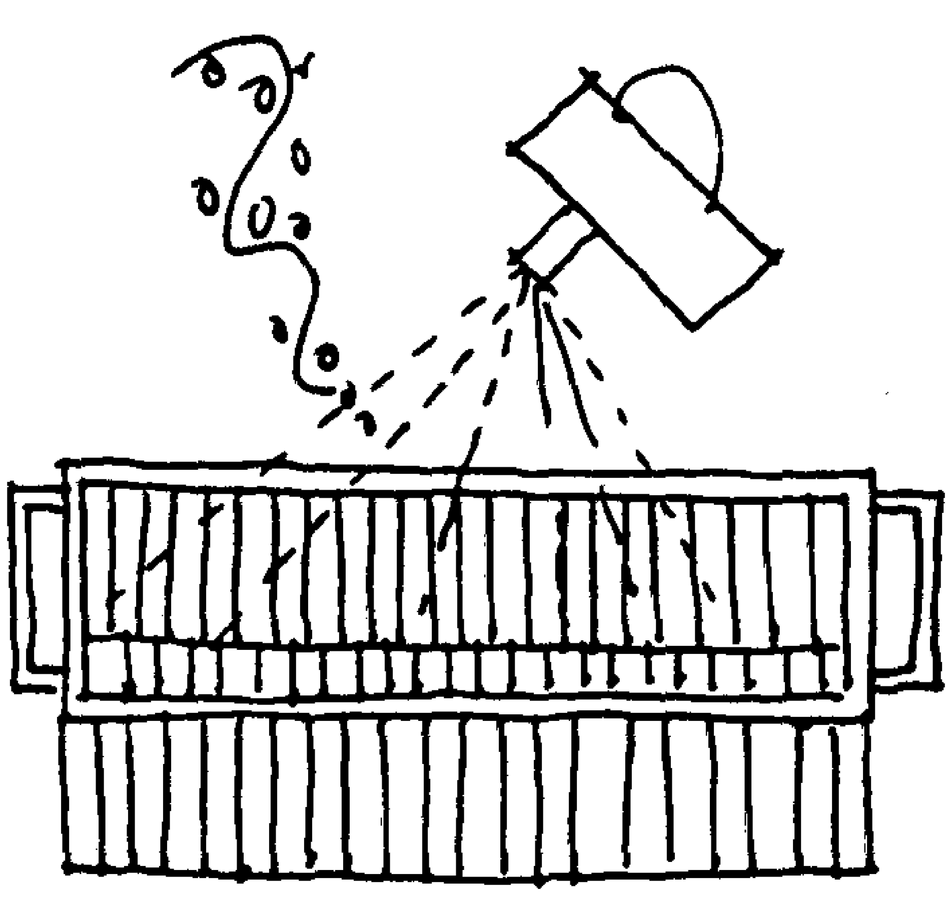
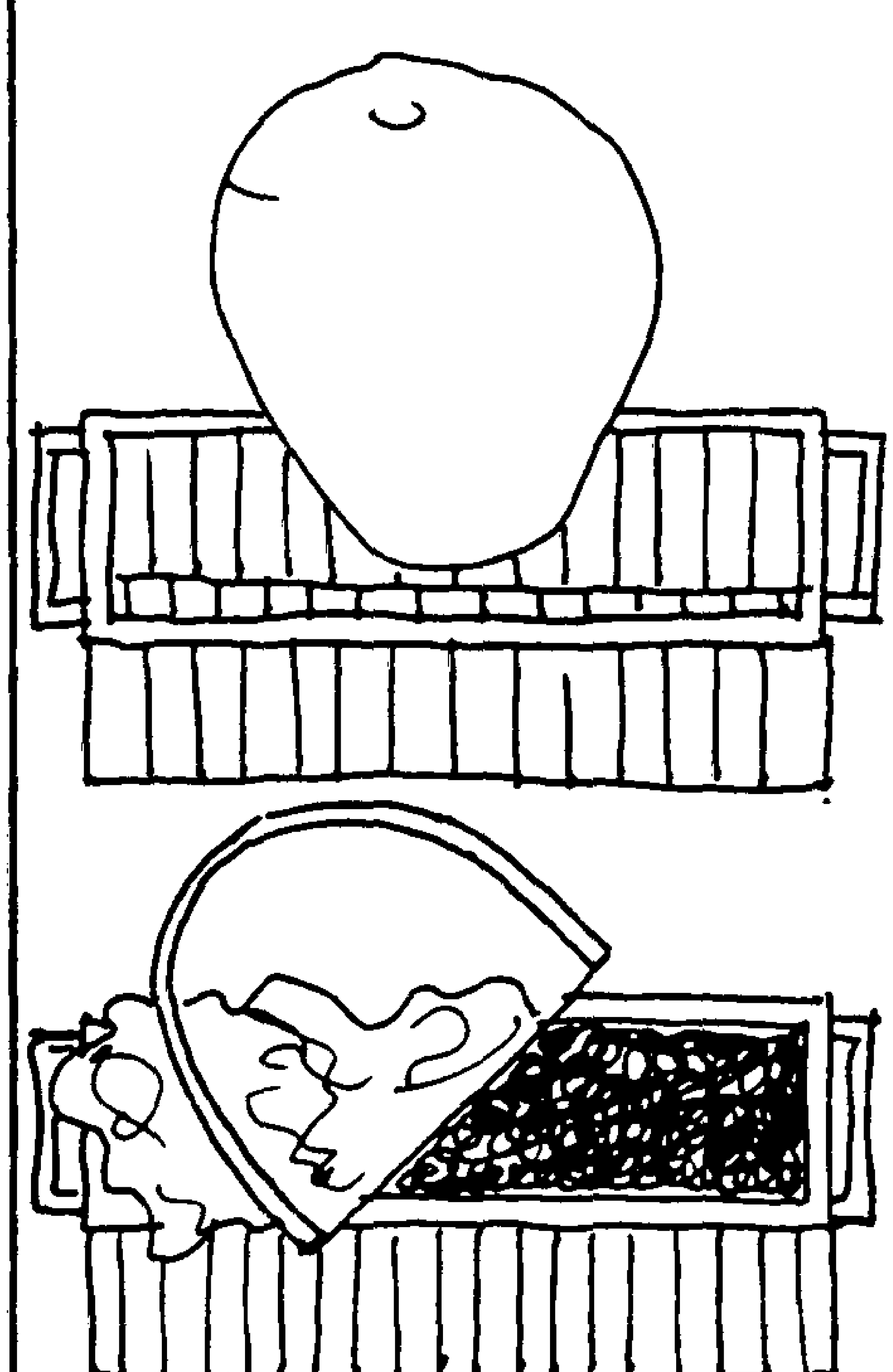
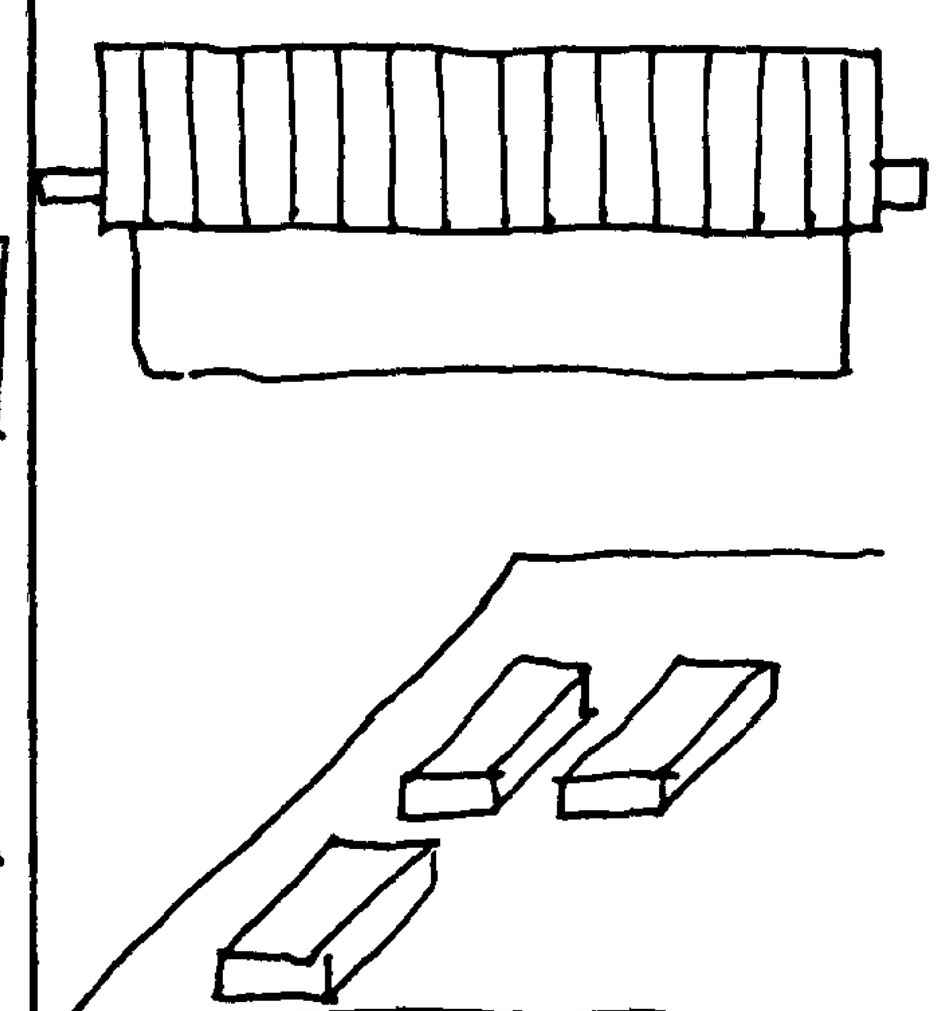
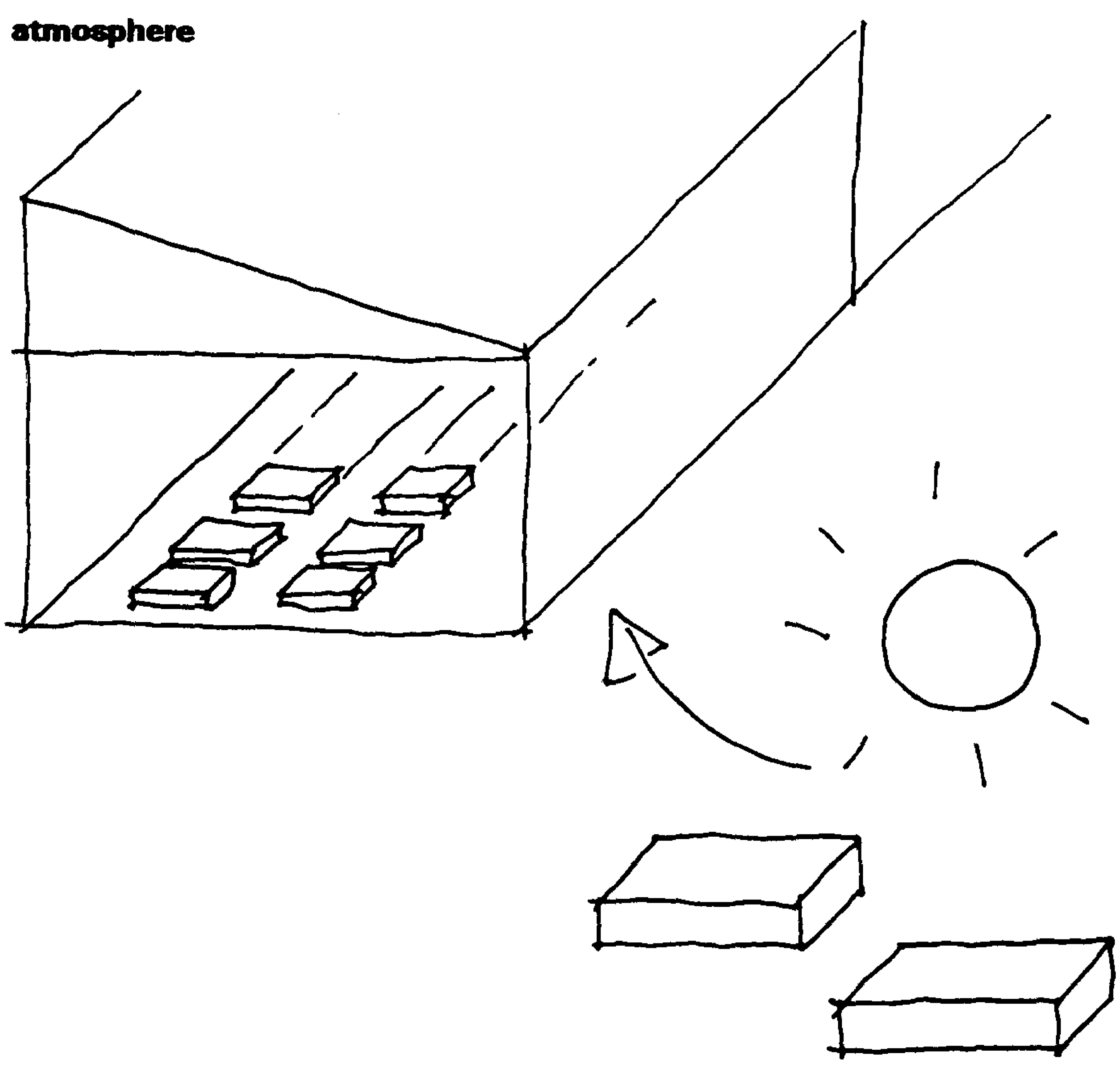
WETTING AND SPRINKLING SAND INTO THE MOULD	MOULDING THE ADOBE	REMOVING THE ADOBE
		
1. Ensure the mould is wet and sprinkle with sand.	2. Fill the mould with a single lump of earth. Excess mixture is cut off using a wire stretched between two ends of a bent piece of wood. A period of two days should be allowed while the brick is shrinking.	3. Knock the brick out of the mould with one shake, this being made easier by holes or ridges in the bottom of the mould or a removable base. An alternative method is to roll the mixture with sand or straw, so that the outer surface is coated; then throw the lump into the mould.

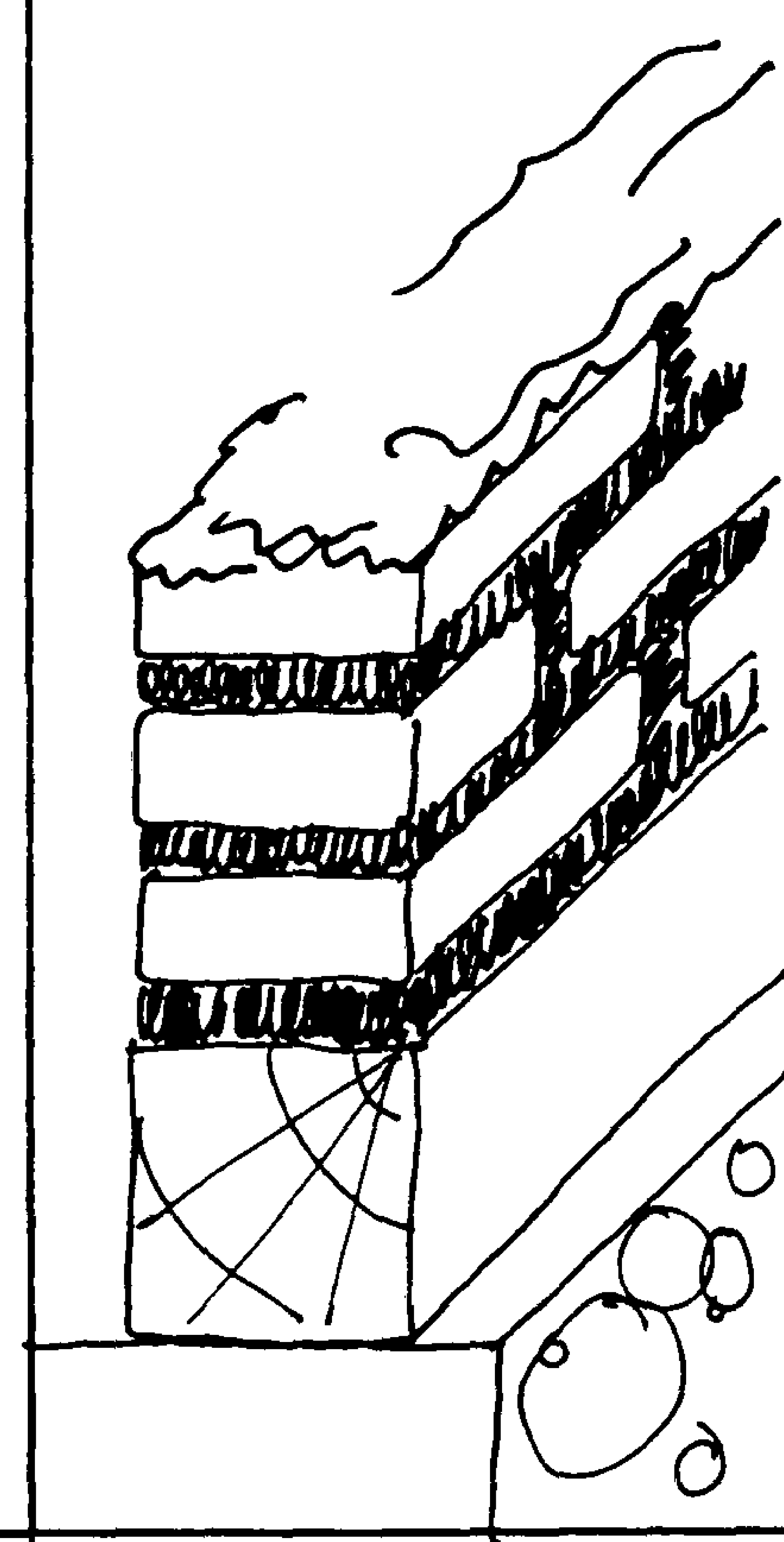
Fig. 89 - Hand- moulded Adobe: dry method

SOIL INSTRUCTION 4.3: ADOBE BLOCK

HARDENING: Exposure to atmosphere



PLACING



- **After the mould has been removed cover the blocks to protect against the sun and rain and leave them to dry for a few days- at least three to five days before being turned to ensure even drying.**

- **Rapid drying results in excessive shrinkage and distortion.**

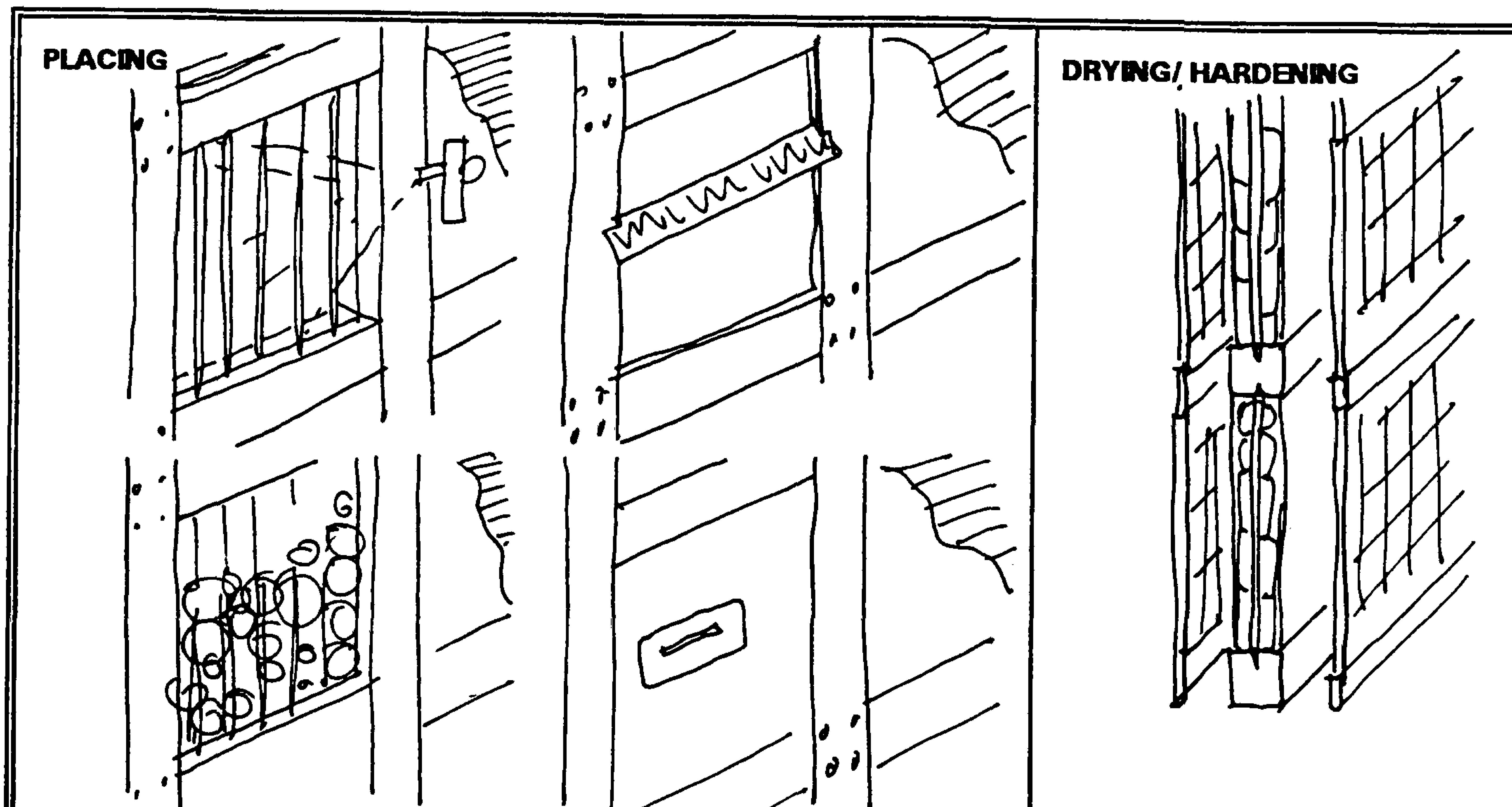
- **Three weeks to four weeks depending on the nature of the soil and weather conditions, should be allowed for drying.**

- **Lay adobe blocks in 20mm (average) bedding mortar of clay or lime.**

Fig. 90 - Hand- moulded Adobe: hardening and placing

SOIL INSTRUCTION 5: DAUB

The correct consistency for making daub can be tested using a consistency or drop test. Traditional daubing involves pressing the mixture into the interstices between the wattle framework, although there are variations on this technique. New techniques using high-pressure application by blowing earth renderings are being tested. (fig. 91)



1. Daub cannot be mixed too much. If the mixture is too wet it is too heavy for the background. If the mixture is too dry, becomes crumbly. Only small batches of daub should be prepared at a time. 2. Laths should be lightly sprayed with water before applying the daub.	3. Apply the daub to the wattle work or stud framing. The best method is to throw handfuls of daub, with some force down on to the laths. The daub is applied to both sides of the staves in layers, finishing with a total thickness of up to 300mm but usually less. 4. The surface is then worked and smoothed for the following four or five days closing up contraction fissures. A float is used to fill any cracks that may develop as the daub dries.	• Control the shrinkage by damping the area, reworking the surface while the material is still mouldable. • Cover the panels on external walls on both sides with a double layer of hessian sacking which should be kept damp. Panels on internal walls should be protected around the edges where the rate of drying is fastest. • Drying time of daub is three to four weeks depending on the nature of the soil.

Fig. 91 - Daub: placing and drying

SOIL INSTRUCTION 6: MORTARS, RENDERS AND PLASTERS

The most critical factor is the control of moisture in blending and curing. The mixture is left to soak for a minimum of 24 hours, but for several days if possible. If the clay is well dispersed, it becomes more adhesive. Cracking and adhesion should be checked over a period of a few days after application. Rapid drying usually results in shrinkage, powdering and micro cracking. (fig. 92,93)

SOIL INSTRUCTION 6.1: MORTARS, RENDERS AND PLASTERS

RECOMMENDED CONDITIONS OF APPLICATION

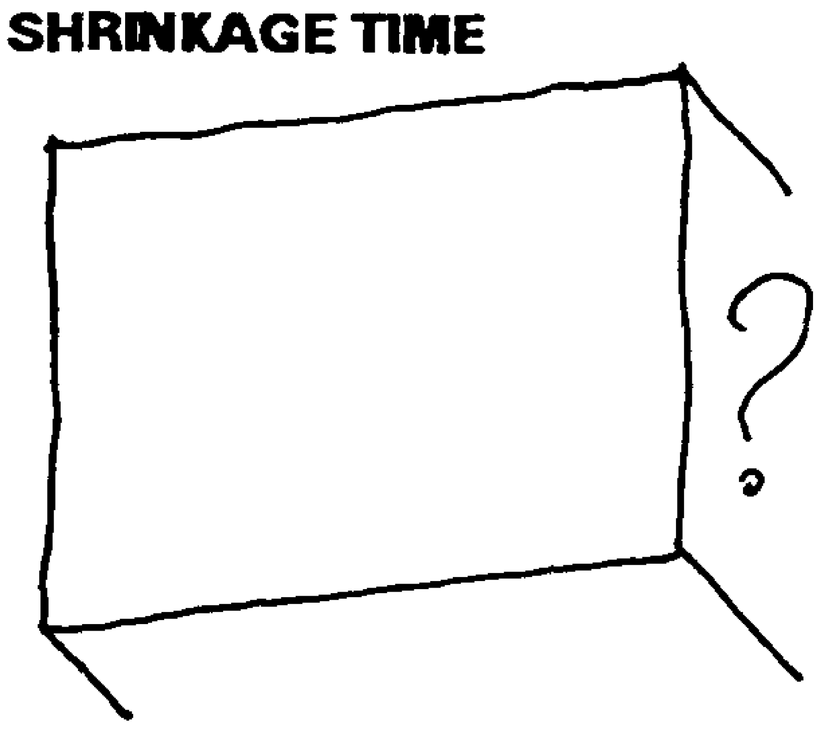
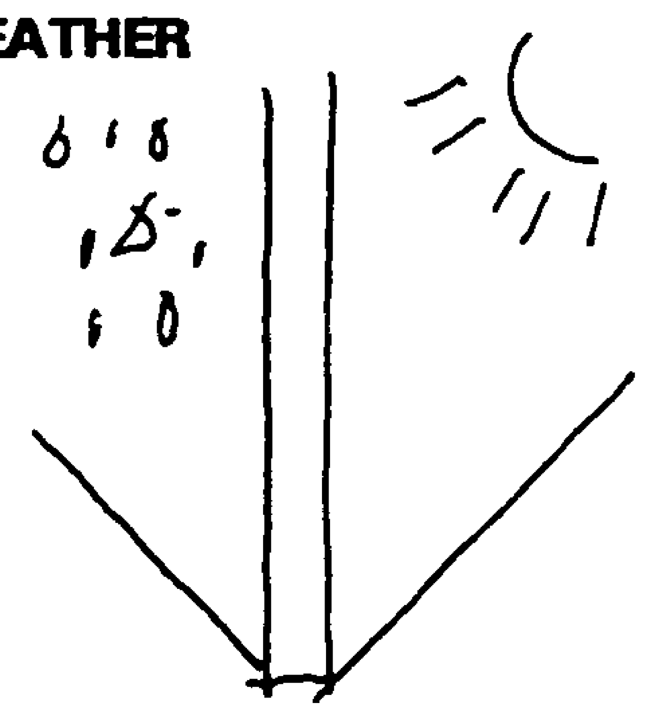
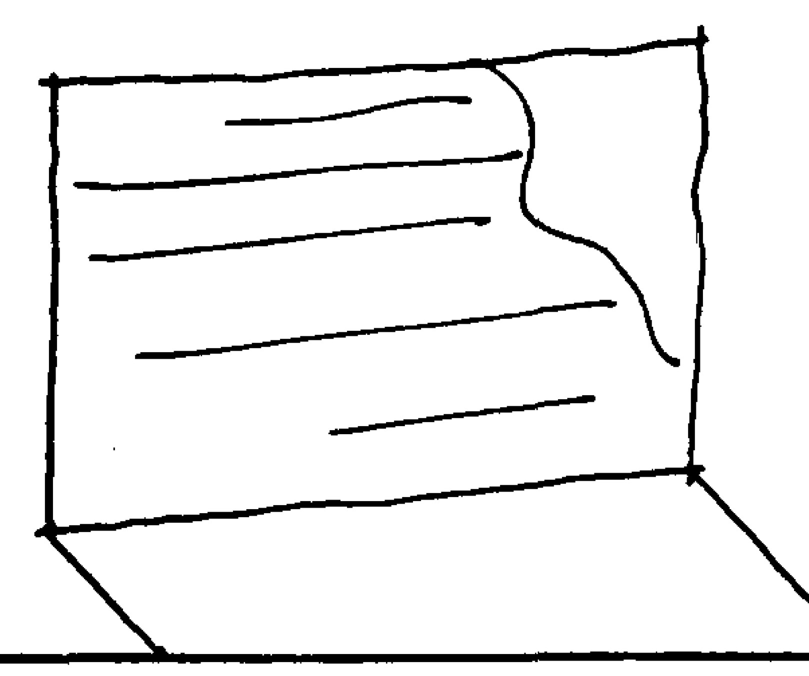
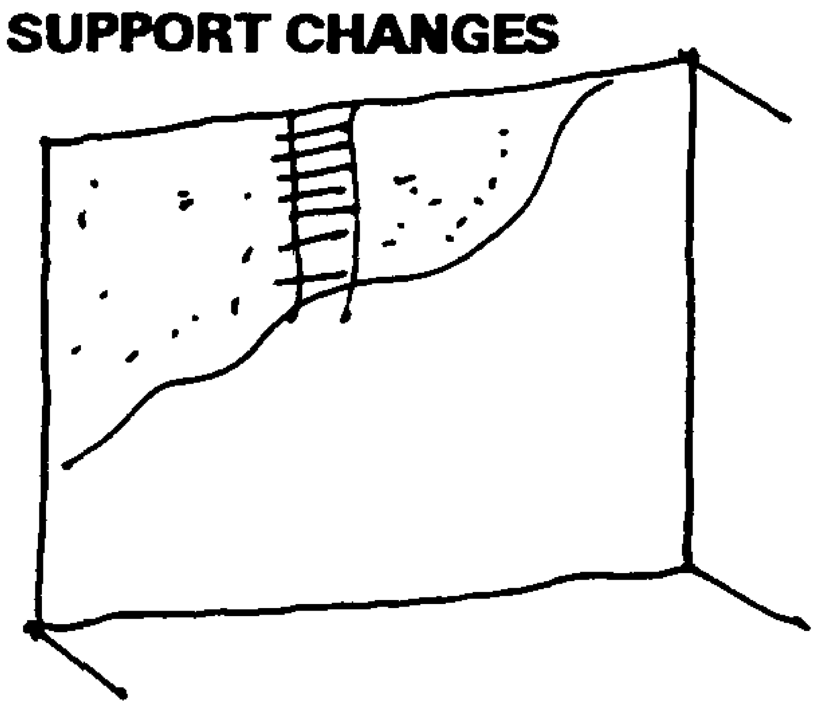
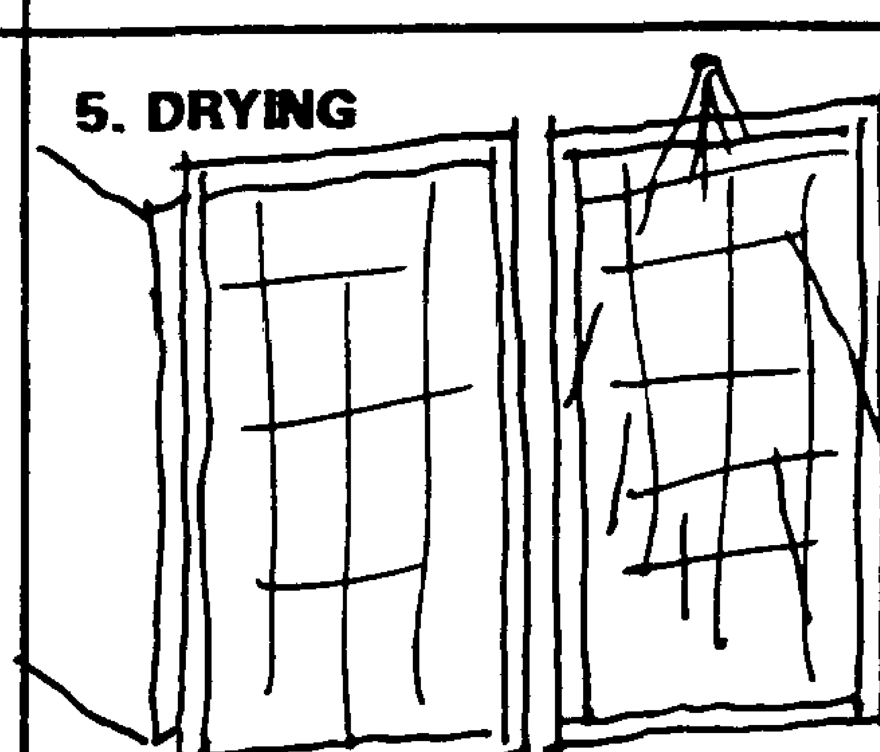
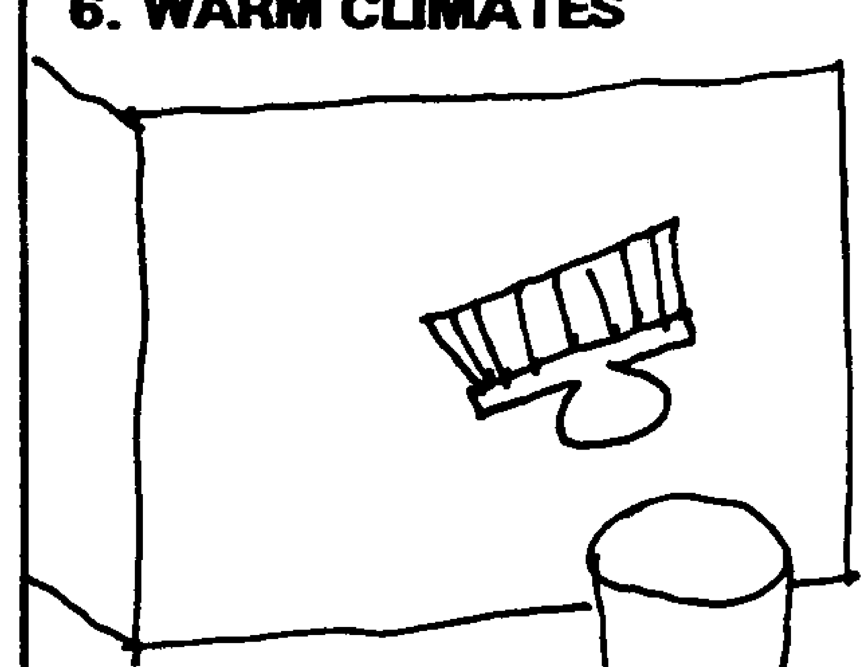
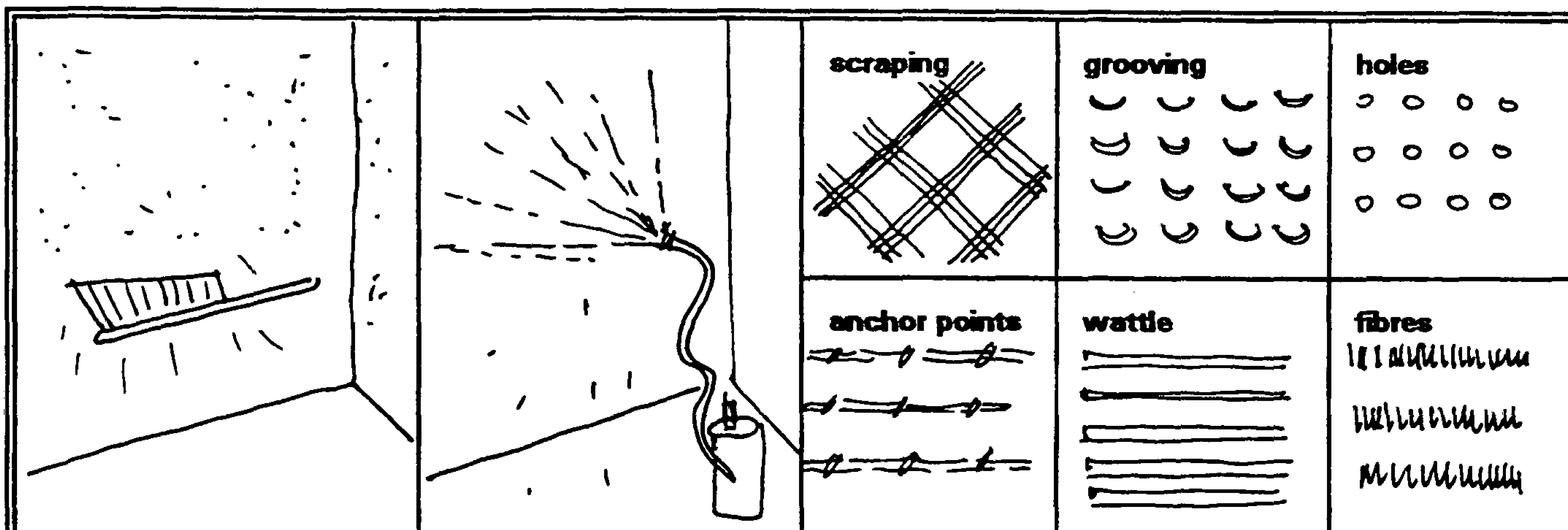
1. SHRINKAGE TIME 	**2. WEATHER** 	**3. WORKING AREA AND TIME** 
1. Shrinkage should be stabilised. Times may vary between several weeks and months, according to the method of construction of the support.	**2. The best climate is moderately warm and slightly humid. Avoid working in extreme weather conditions such as excessive cold, or heat or high winds.**	**3. Complete the wall plastering in one day.**
4. SUPPORT CHANGES 	**5. DRYING** 	**6. WARM CLIMATES** 
4. Incorporate reinforcements at intersections.	**5. Control drying by moist spraying of water on the surface, protecting the surface with sheets and keeping the environment humid.**	**6. It is advisable to apply a wash to the rendering about three weeks after application, to bridge the hair cracks.**

Fig. 92 - Mortars, Renders and Plasters: conditions of application

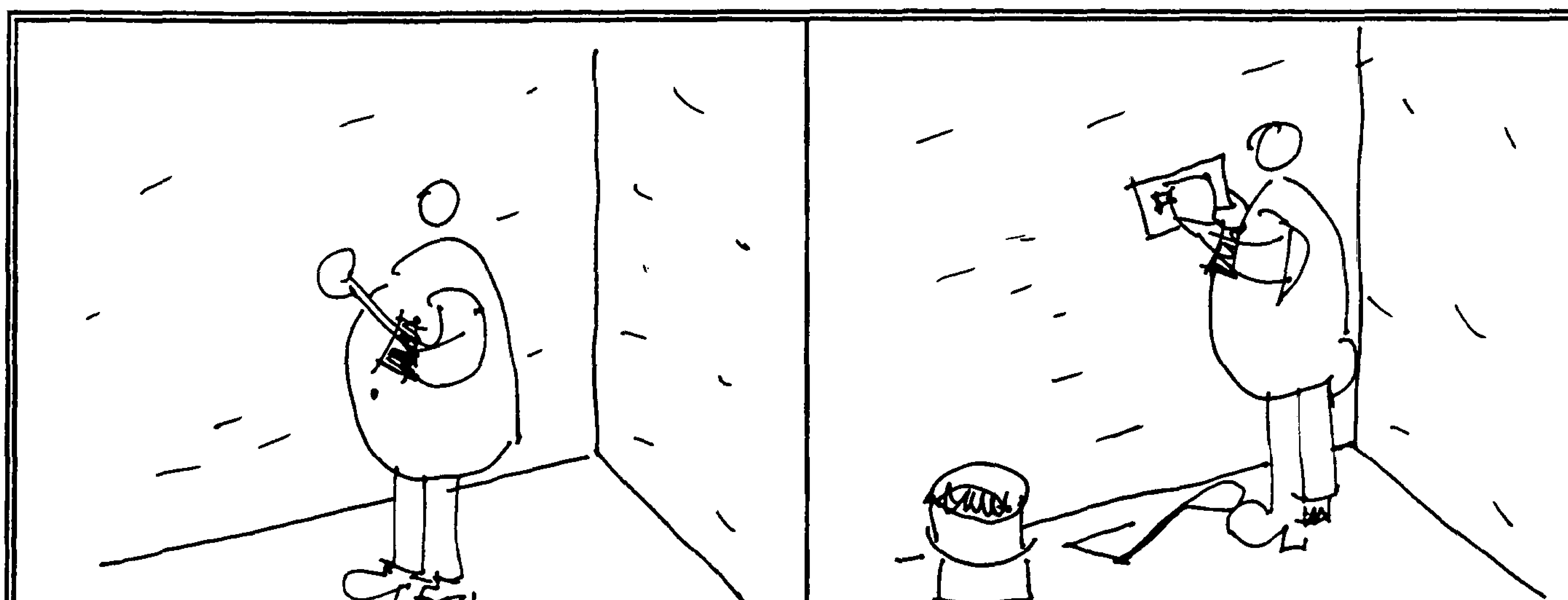
SOIL INSTRUCTION 6.2: MORTARS, RENDERS AND PLASTERS

RECOMMENDED PREPARATION OF THE SUPPORT



1. DUST REMOVAL	2. MOISTENING	3. KEYING AND ANCHORING

APPLICATION



1. BY HAND	2. WITH CONVENTIONAL TOOLS
• Throw mortar balls energetically against the wall and then smoothed with the palm of the hand, avoiding excessive finger pressure.	• Use tools such as metal trowels and metal and wood floats avoiding excessive compression. Note: The support must provide sufficient bond to the wet plastic render and plaster.

Fig. 93 - Mortars, Renders and Plasters: support preparation and application

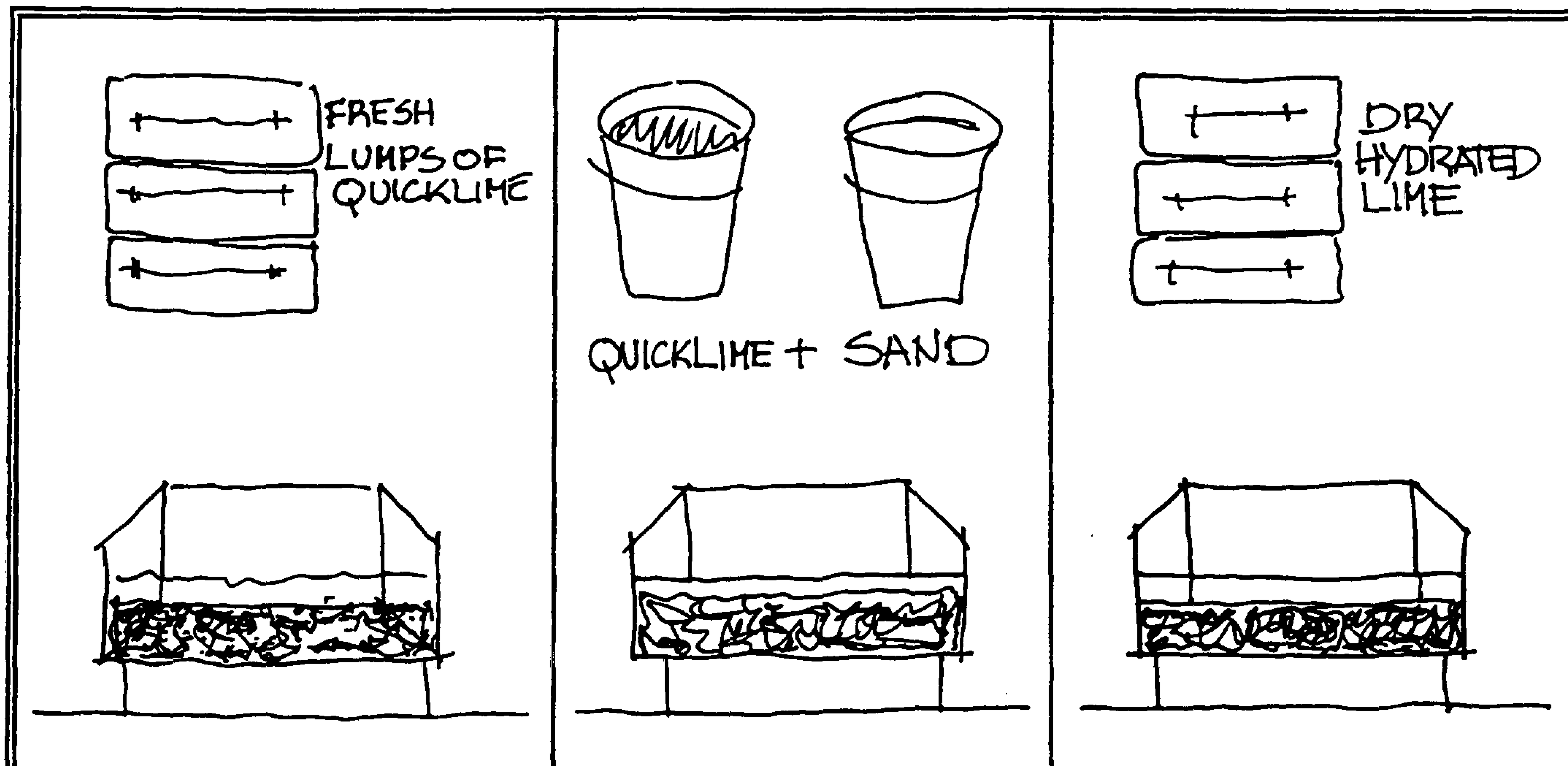
LIME

The performance of lime mortars or limewash is affected by many variables including firing temperatures, slaking methods, storage, blending of aggregates and application techniques. Trial mixing and application must always be carried out.

LIME INSTRUCTION 1: SLAKING AND HYDRATION

Lime for mortar and plaster needs to be burned at low temperatures (900° -1000° C) and thoroughly slaked without overbeating to a putty. If fresh quicklime is available locally, slaking can conveniently be carried out on- site, or putty can sometimes be purchased. Coarse stuff can be prepared by blending powdered quicklime with aggregates before slaking. Both putty and coarse stuff can be stored in air tight containers. If quicklime or putty are not available, hydrated lime can be soaked in water for 24 hours to produce a serviceable putty, but it is generally agreed that better performance, especially for plaster, is obtained by using a putty direct from slaking. (fig. 94)

FORMS OF LIME



1. LIME PUTTY BY WET SLAKING FRESH QUICKLIME AND STORAGE FOR A MINIMUM PERIOD OF 3 WEEKS (3 MONTHS IS BETTER)	**2. COARSE STUFF BY WET SLAKING FRESH QUICKLIME WITH SAND AND STORAGE FOR A MINIMUM PERIOD OF 3 WEEKS (3 MONTHS IS BETTER)**	**3. DRY HYDRATED LIME RUN TO PUTTY BY SOAKING THE LIME IN WATER FOR A MINIMUM PERIOD OF 24HRS SUBSEQUENTLY STORAGE OF 3 WEEKS IS RECOMMENDED**

Fig. 94 - Forms of Lime

LIME INSTRUCTION 1.1: WET SLAKING TO A PUTTY

The process of wet slaking or hydrating a quicklime needs to be carried out in a controlled manner, adding the quicklime to enough water to cover the slaking mass. The quicklime (calcium oxide) is converted to lime putty (calcium hydroxide) during the exothermic reaction. The rate of hydration depends on many factoros, including the calcium carbonate content, the freshness of the quicklime and the stirring of the lime during slaking. (fig. 95)

WET SLAKING METHOD WITH FRESH LUMPS OF QUICKLIME FOR SMALL BATCHES

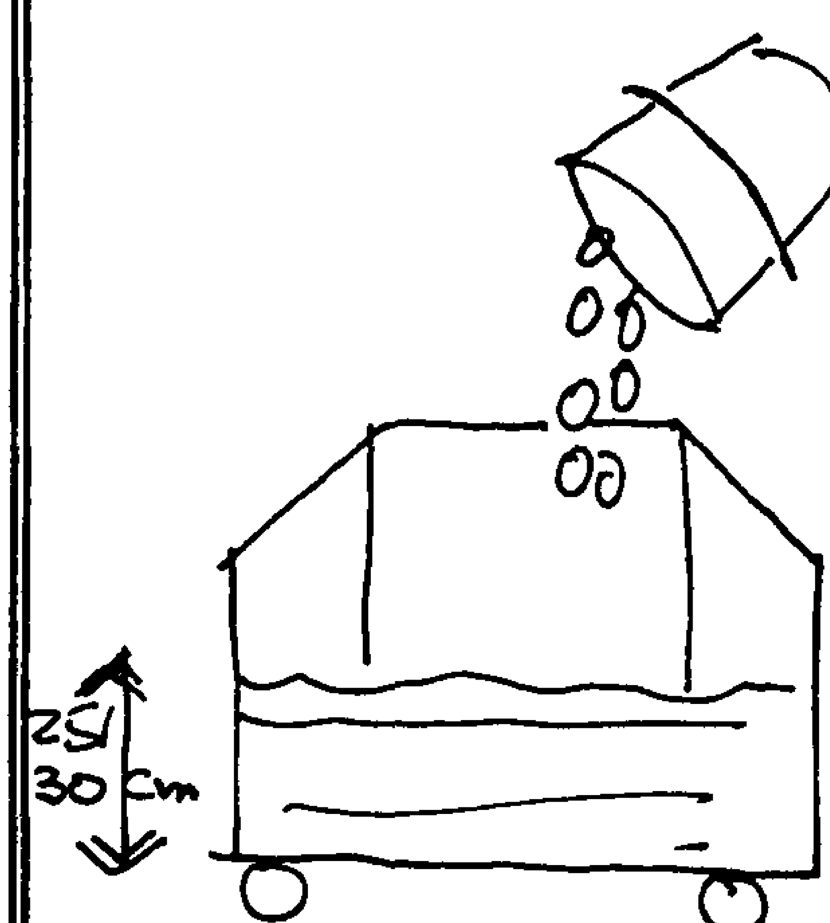
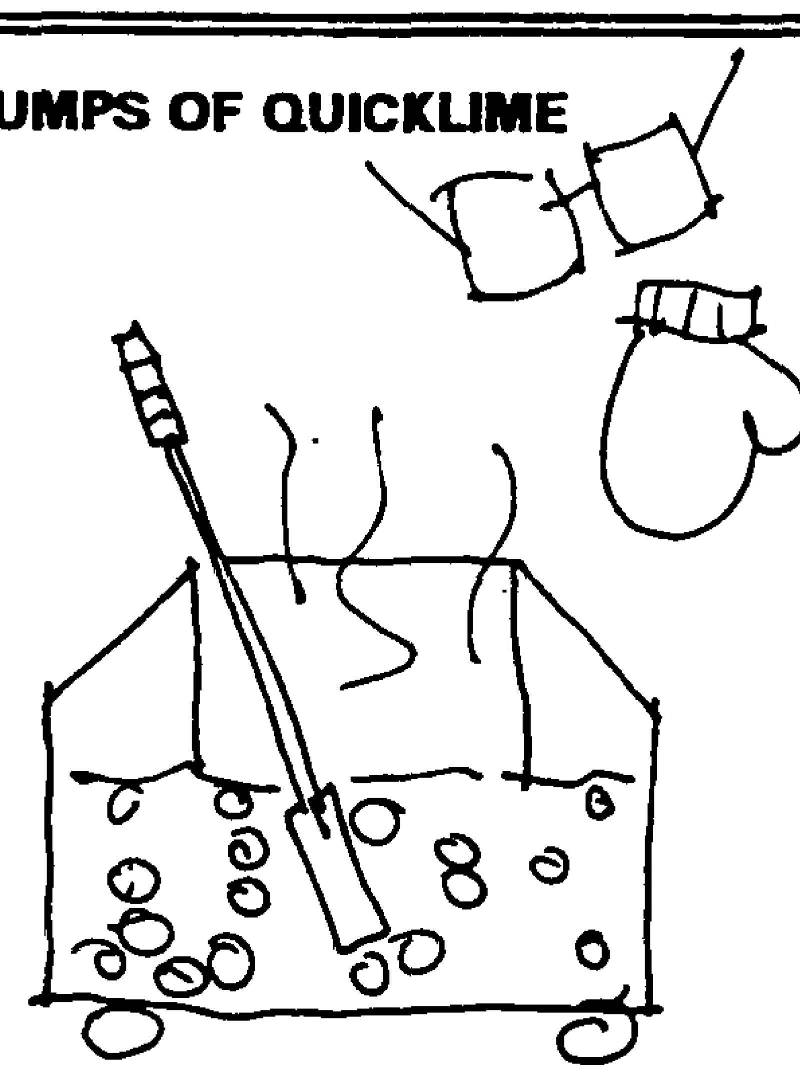
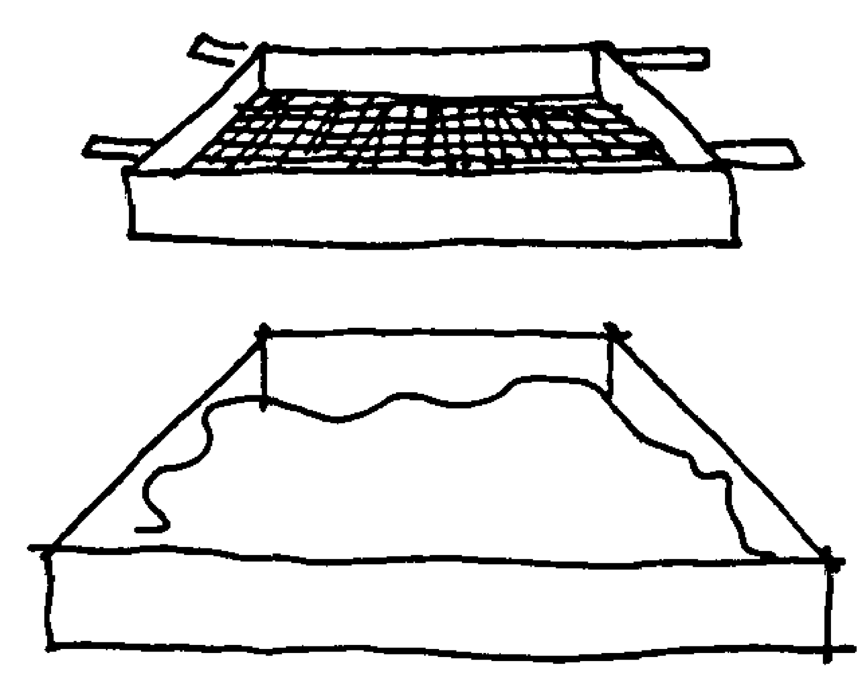
EQUIPMENT AND WATER	LUMPS OF QUICKLIME	SIEVES AND STORAGE
		
1. FILLING A TANK **Add lumps of quicklime to a shallow waterproof tank filled with water to a depth of 25cm to 30 cm. Keep always the lumps below water to prevent "burning" the lime.** **Special notes:** **• Use clean potable water. Hot water helps slaking.** **• The exact amount of water should be adjusted for each lime. Inadequate water reduces plasticity.** **• Avoid adding water too quickly or adding too little water, both result in incomplete slaking.**	**2. STIRRING** **Cover the bottom of the tank with approx. 15 cm of quicklime and stir the mixture constantly with a long handled paddle as it helps the water to reach the interior of the quicklime preventing drowning. Further water and quicklime is added according to the quantity needed.** **Special notes:** **• Slaking frequently raises the water temperature to boiling point. Protect eyes and hands with goggles and gloves.**	**3. SIEVING AND MATURING** **After complete slaking (12/24hrs) sieve core and overburnt lumps through a 5 to 2 mm screen. Store the putty alone or combined with the aggregate protected against the air. Plastic bins or similar containers can be used.** **Special notes:** **• Lime putty should remain covered with water. Mature the lime putty as long as possible. Lime putty continues to absorb water and swell, improving plasticity.** **• Magnesian limes are slower in slaking than calcium limes. Therefore the minimum period for maturing should be one month.**

Fig. 95 - Method of Wet Slaking Quicklime for Small Batches

LIME INSTRUCTION 2: BLENDING AND MIXING WITH AGGREGATE TO PRODUCE "COARSE STUFF" OR "ROUGHAGE"

Lime to be used as a mortar should be mixed accurately by volume with aggregate and the resultanting coarse stuff improved initially by maturing in a wet slake and finally by beating or milling. (fig. 96)

LIME MORTAR PREPARATION

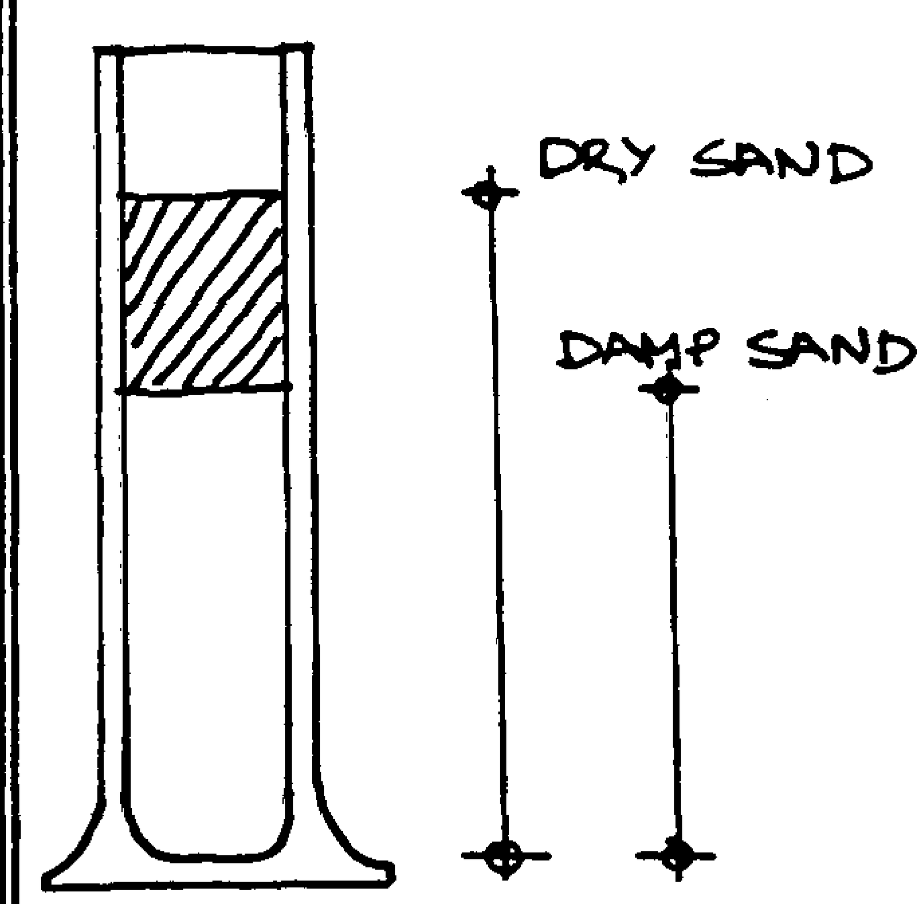
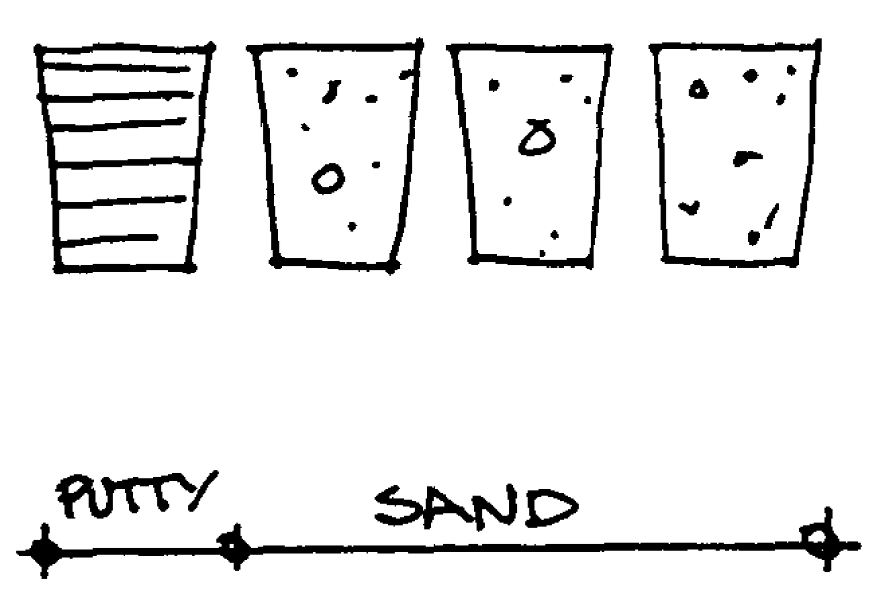
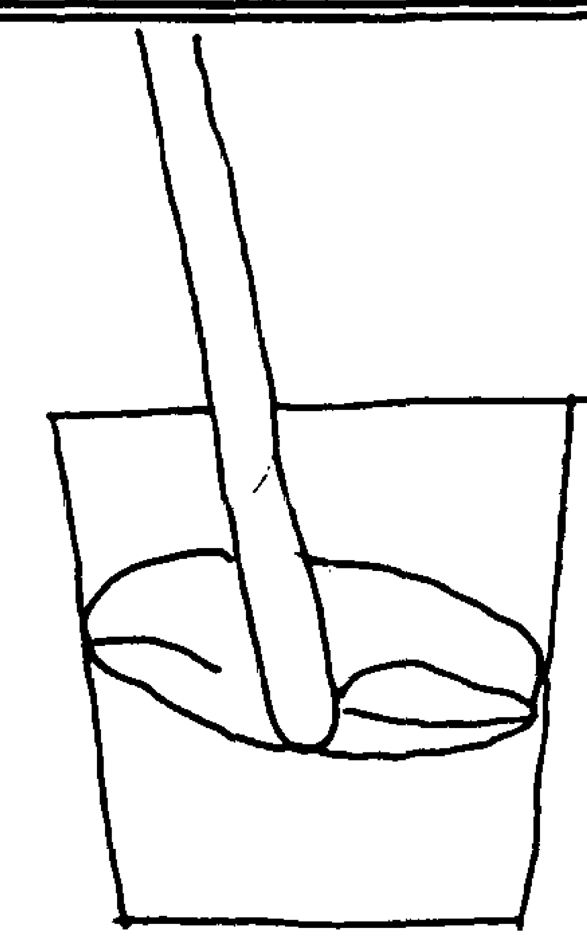
		
1. BATCHING AGGREGATES •The constituents of the original sample are matched as closely as possible and batched on- site by volume. Modern recommendations on quantities of different sizes of aggregates may be used as a guide for good performance. • Accurate batching requires the difference in level between a dry and a damp sand to be calculated. • Damp sand "bulks", ie takes up less volume than dry. • If the slaking of lime with sand is being utilised granulated quicklime should be batched before slaking. Note: The description "sand" here refers to any aggregates incorporated in the mix.	**2. BLENDING, MIXING AND MATURING** • Accurate volumes of lime putty are mixed with the aggregate. No water should be added unless absolutely essential to produce workability. • Lime mortar should be thoroughly mixed either by using a mortar mill, hand mixers or with a shovel. • After thorough mixing, store the coarse stuff as long as possible. This improves workability and final durability of the material.	**3. BEATING COARSE STUFF** • When required for use, the coarse stuff should be rammed and beaten to produce the requiring plasticity. Very little or no water should be added. The compaction of the coarse stuff by this technique reduces water contraction and increases the overall contact between binder and aggregate.

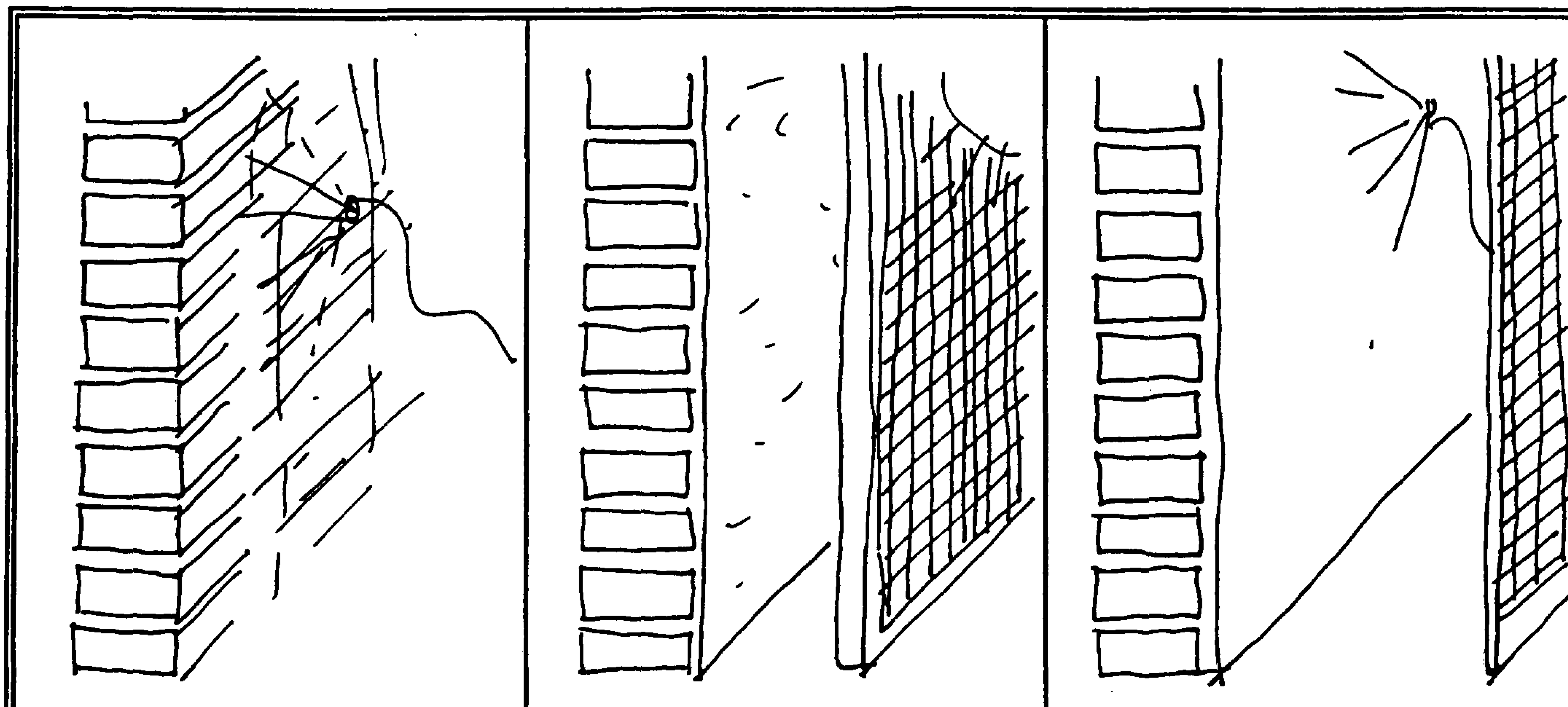
Fig. 96 - Lime Mortar Preparation

LIME INSTRUCTION 3: APPLICATION

In addition to correct composition and preparation of lime mortar for repair and replacement of joints, renders and plasters, it is essential to develop good application techniques and to acquire or make appropriate tools. The application of lime renders and plasters are similar to instructions for earthen renders and plasters. Techniques are similar to those described for the application of earthen renders and plasters, but trowels and floats (the conventional tools) are used instead of hand application. (fig. 93,97)

CONDITIONS OF APPLICATION

Rapid drying may limit carbonation and result in shrinkage and cracking. The following conditions and or treatments control drying, and facilitate carbonation.



1. Ensure the wall is damp to control suction and rapid loss of water.	**2. Screenig the work against hot weather.**	**3. Periodic wetting by moisting promotes slow and good carbonation.**

Fig. 97 - Conditions of Application of Lime Materials

LIME INSTRUCTION 3.1: POINTING MORTAR APPLICATION

The application of pointing mortar is one of the most familiar maintenance techniques. However, it is also most often inadequate carried out due to poor technique and the use of inappropriate tools. (fig. 98)

POINTING MORTAR APPLICATION TECHNIQUES

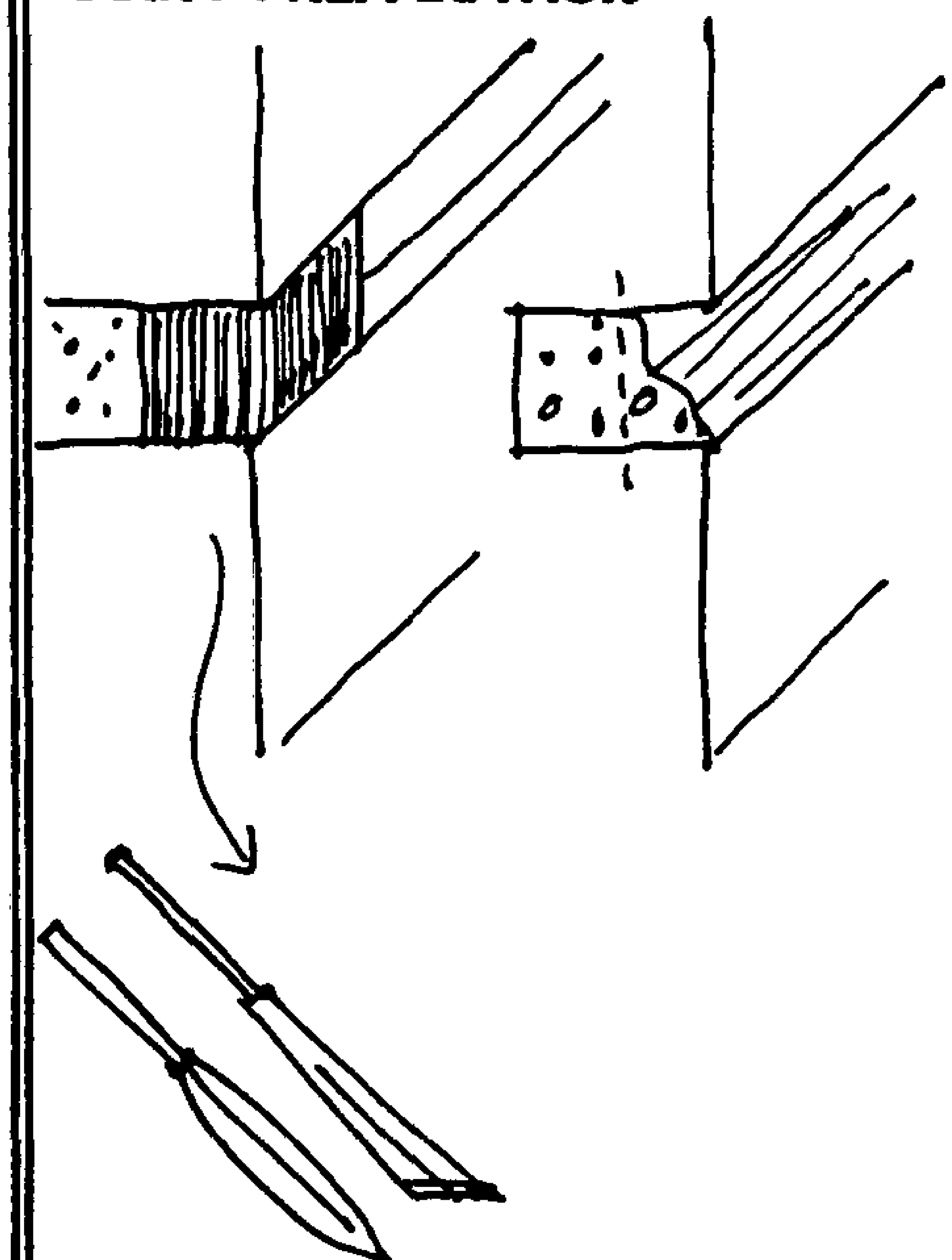
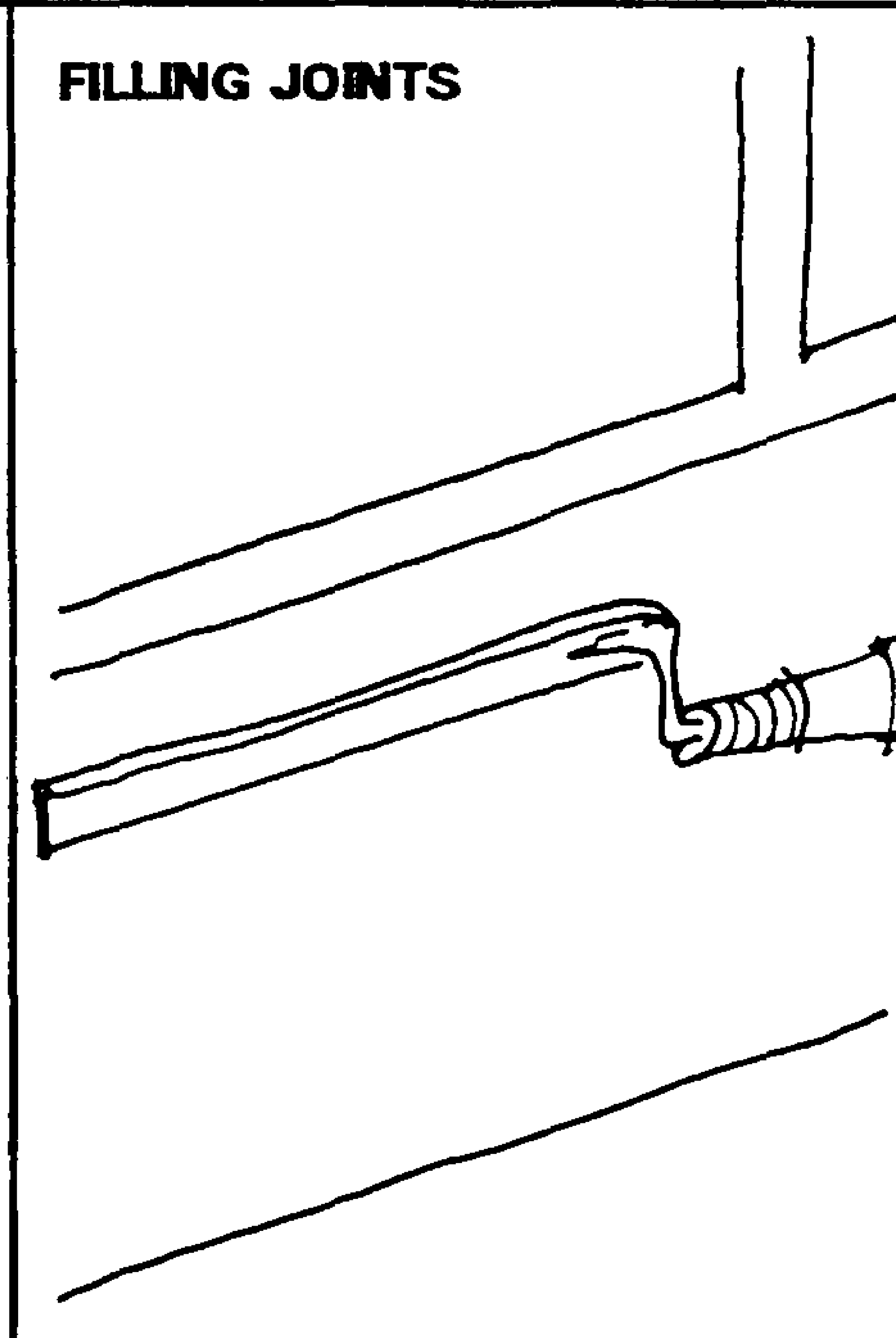
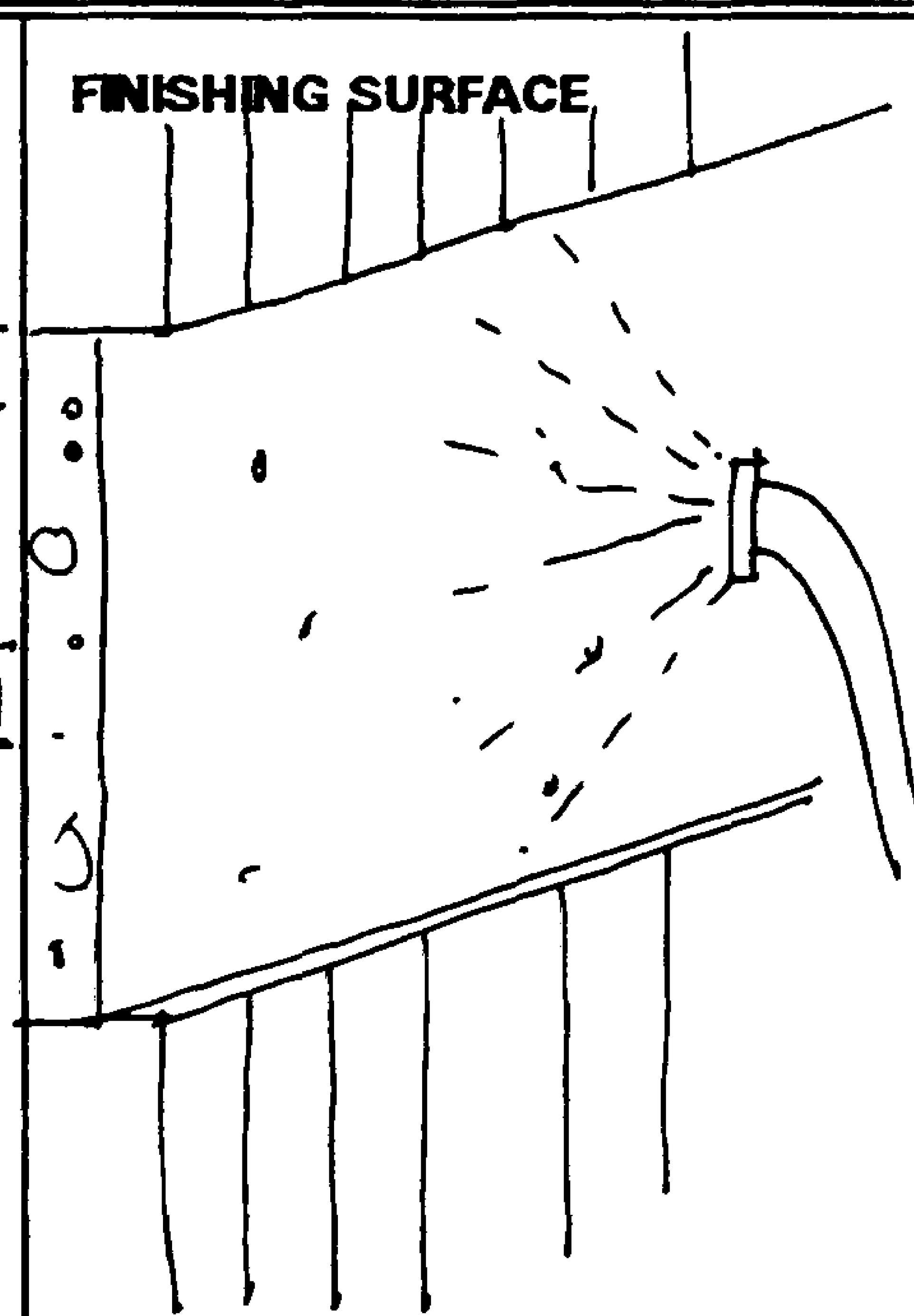
JOINT PREPARATION	FILLING JOINTS	FINISHING SURFACE
		
1. CUTTING OUT **Cutting out old defective mortars or new and incompatible hard mortars should be deep enough and in accordance to the masonry type. It must be a careful operation and requires correct tools to avoid damage to the masonry (eg pugging chisel and flat- bladed quik).** **2. RAKING OUT** **Defectuose, failed soft mortar may be raked out with a saw blade or a bent spike.** **3. WASHING OUT** **Using a low pressure hose, wash all debris and loose material from the joint.**	**4. FILLING JOINTS** **Pack the joints with pointing tools of the correct dimensions to fill into the joint, packing in layers from the back.**	**5. FINISHING SURFACE** **The surface is generally finished by the following method:** **• after some hours expose the smooth surface of the new mortar to a coarser texture by stippling with a stiff bristle brush or by a fine water spray, or any other appropriate way to promote a weathered appearance with good drying characteristics.** **• If evidence of an original joint profile survived, this should be matched.** **Note:** **Curing techniques is also important, as similar techniques should be used as for renders.**

Fig. 98 - Lime Mortar Pointing Techniques

LIME INSTRUCTION 4: LIMEWASH

To use lime as a paint it should be slaked from quicklime and diluted in water. Carbonated lime reduces the binding quality. The best source of limewash is a lime putty which has not been dried and ground, so the carbonation will only take place when it is applied. But if lime putty is not available, dry hydrated lime or ready-mixed products may be used. Traditional additives such as oil, tallow or casein may be used to improve adhesion and impart some water repellency. (fig. 99,100,101)

LIME INSTRUCTION 4.1: LIMEWASH PREPARATION

PREPARATION OF LIMEWASH

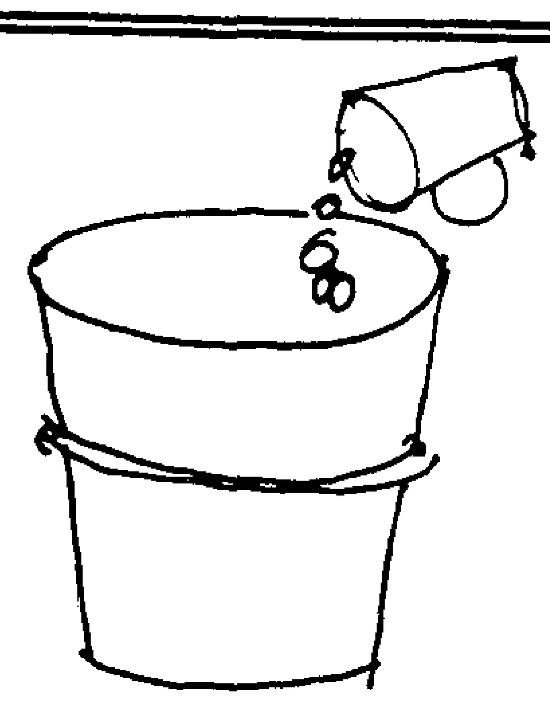
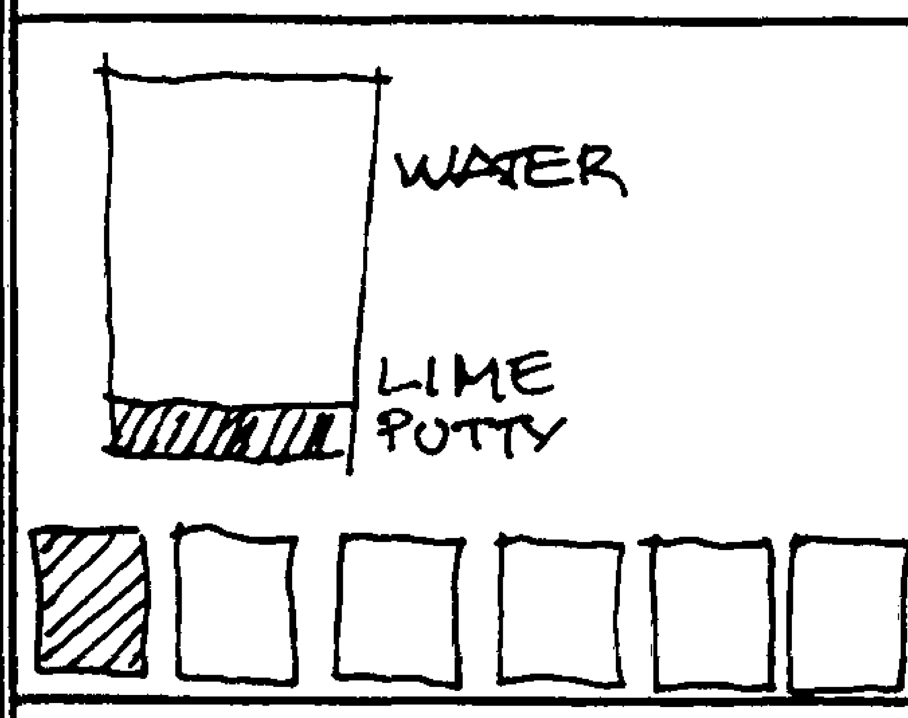
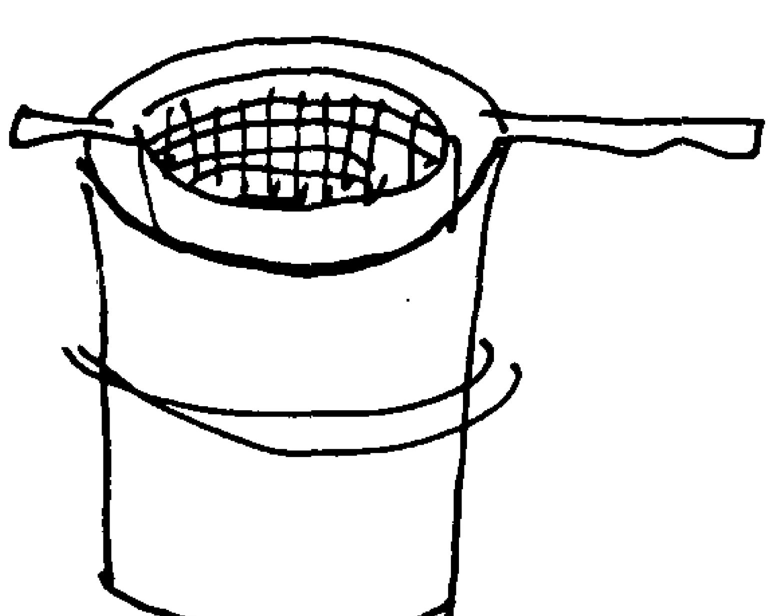
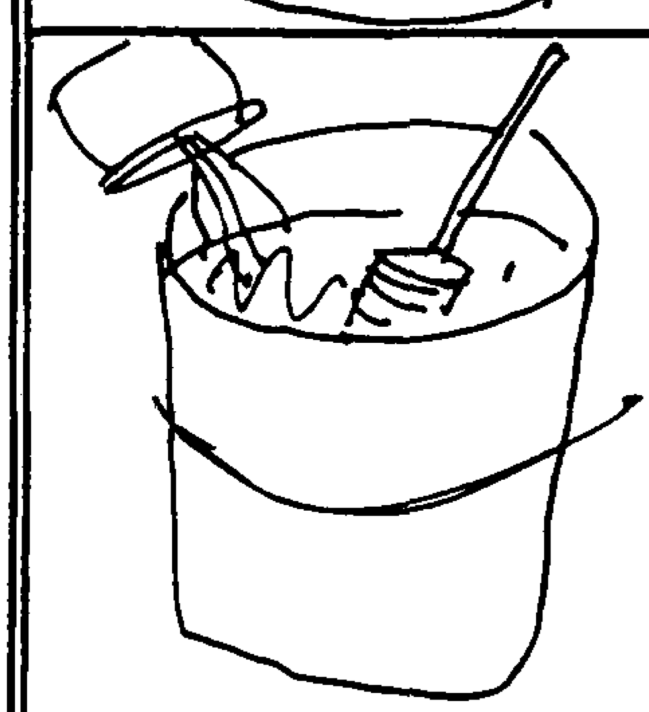
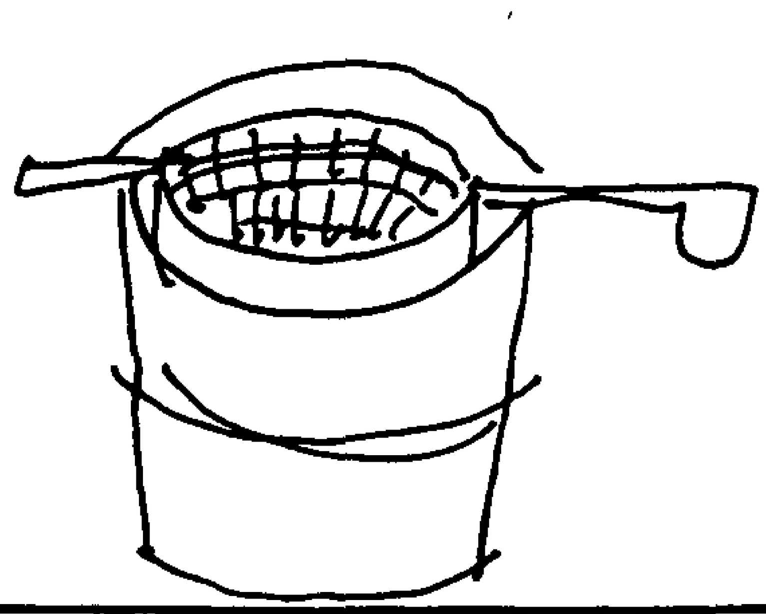
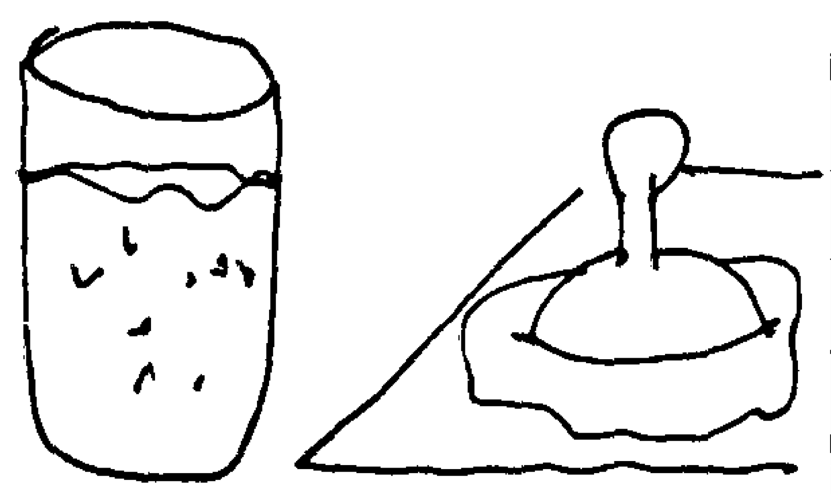
	**1. A lime putty is prepared either from freshly slaked lime or dry hydrate lime.** **If tallow or casein is being used, add casein powder or lumps of tallow to the quicklime before slaking or add fresh casein to the lime putty.** **See the following instructions for casein preparation. (fig. 100)**
	**2. Add to the lime putty sufficient water to make a thin cream (1 part of lime putty to 5 parts of water may be suitable).** **At this stage linseed oil may be beaten to the creamy lime.**
	**3. Screen the lime mixture through a coarse muslin.**
	**4. Add and stir in the pre- dispersed pigments with a whisk or hand mixer. See the following instructions for pigment preparation. (fig. 100)**
	**5. Dilute the mixture until it is the consistency of milk and sieve again.**
	**6. Limewash is formed when a clear water appears at the surface. The bottom thin putty is used for paint.**

Fig. 99 - Limewash Preparation

LIME INSTRUCTION 4.2: PIGMENTS AND CASEIN PREPARATION

PIGMENT

Amount of pigment depends on the intensity of the shade required. Colours tend to look darker when wet. Pigment quantity varies and shades are better tested by sample trials, but as an approximate guide 400g pigment to 5 litres of lime putty will provide light shades and 1 kg pigment to 5 litres of lime putty darker shades. Too much pigment reduces the lime binding quality.

	**1. Soak the pigments in hot water to ensure thorough dispersion or disperse in limewater at least one day before use.** **Grinding by hand with heavy glass plate, medium sized runner or muller, horn or steel spatula may be appropriate for small quantities.**
	**2. Stir the pigments thoroughly and follow the instructions for limewash. (fig. 99)**

CASEIN

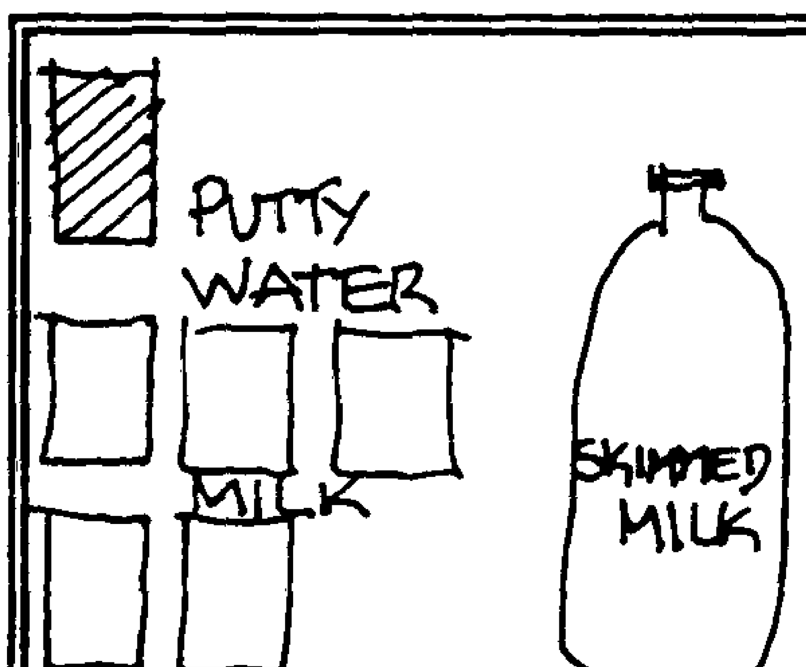
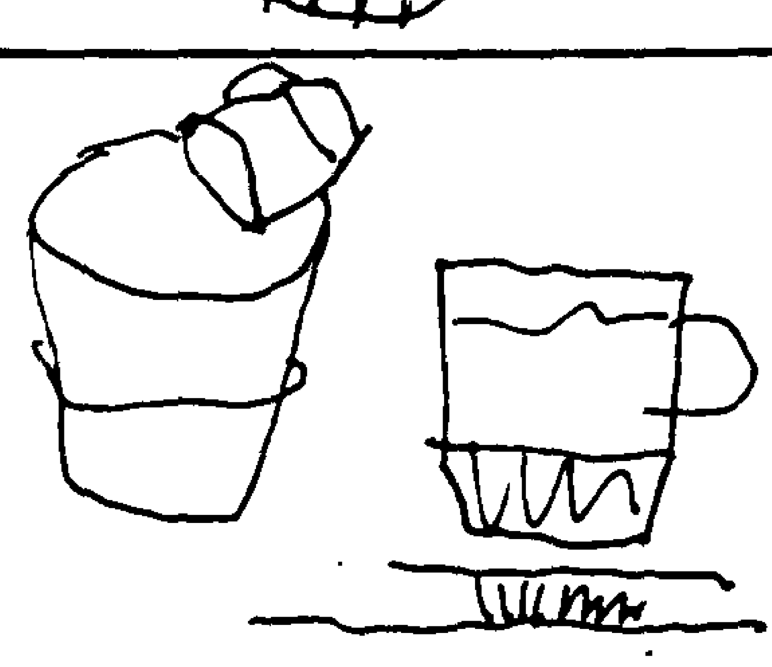
	**SKIMMED MILK** **Skimmed milk only contains a small proportion of casein, but may be used effectivelly.** **In this case, add skimmed milk instead of 50% parts of water to dilute the lime putty and follow the instructions for limewash.**
	**CURD OR COTTAGE CHEESE** **1. The fresh curd is first squeezed in a cloth to remove the excess whey (water and soluble proteins).** **2. The fresh curd can be ground to remove lumps.** **3. Thoroughly mix 5 parts of fresh casein to 1 part lime putty and then follow the instructions for limewash preparation. (fig. 99)**
	**ORDINARY COMMERCIAL CASEIN** **1. Add a 10% solution of industrial casein to fresh quicklime. The highly alkaline nature of the lime ensures that the casein is dissolved.** **Or, alternatively,** **2. dissolve the casein in hot water and a little lime and add 15% hydrated lime.**

Fig. 100 - Limewash: pigments and casein preparation

LIME INSTRUCTION 4.3: LIMEWASH APPLICATION

The wall surface must be prepared by vigorous brushing with stiff bristtle brush and if necessary treated with a biocide. The support must be pre- wetted to receive the wash which is applied using soft long haired brushes. (fig. 101)

SUPPORT PREPARATION AND LIMEWASH APPLICATION

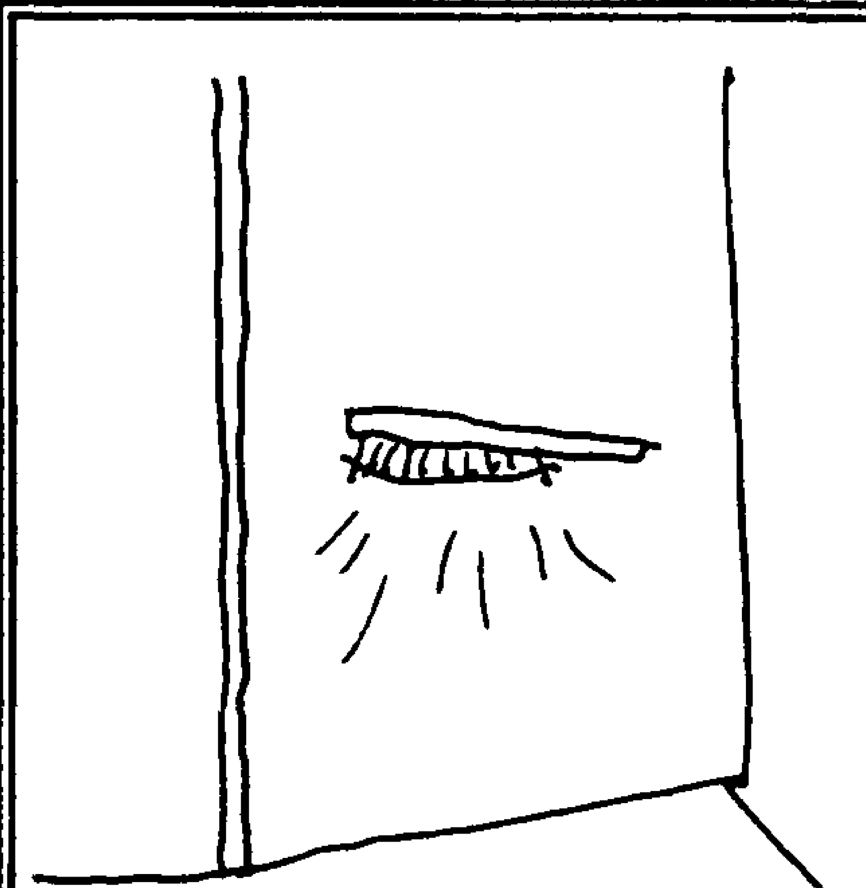
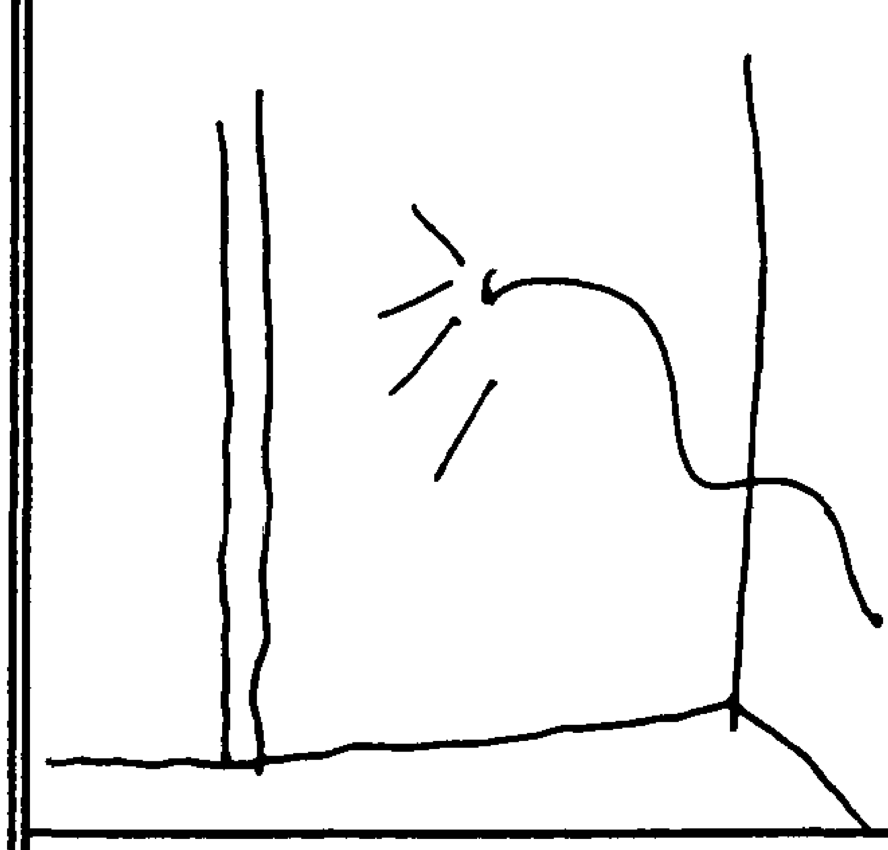
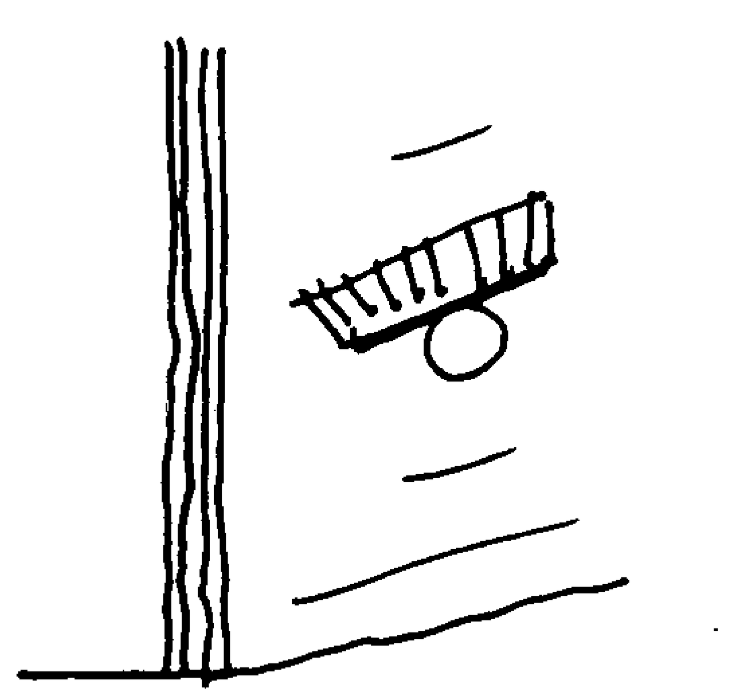
	**DUST REMOVAL** **Brush and wash the surface to be limewashed to remove dust, loose particles and dirt with stiff and soft bristle brushes.**
	**MOISTENING** **Spray the surface to be limewashed with an adjustable sprayer to avoid rapid drying and the development of fine cracks.**
	**APPLICATION** **1. Apply the first thin coat of limewash evenly over the dampened area and leave overnight to dry.** **2. Apply the subsequent thin coats preceded by light wetting of the surface.** **3. Allow to dry out slowly. Several weeks will be needed for the limewash to harden completely.**

Fig. 101 - Limewash Application

3.5 MAINTENANCE

- Earth and lime based building elements require regular inspection and maintenance as outlined in the following guidelines.

MAINTENANCE: GENERAL

As a general rule historic structures are built without damp proof courses; however, adequate weatherproofing is provided by earth and lime based materials provided that proper maintenance is carried out. Mortars, renders, and surface treatments which are compatible with the original materials are essential to the on- going survival of traditional buildings. Neglect or incorrect maintenance procedures permitting excessive water penetration will lead to premature deterioration of earth, timber and brick.[171]

The condition of the roof, ground levels and water disposal and the use of the building are additional important issues. The general condition of the building may alter the behaviour of the walls and lead to decay of materials and even the collapse of the building. The following diagram groups together the maintenance problems associated with earth and lime systems. (fig. 102)

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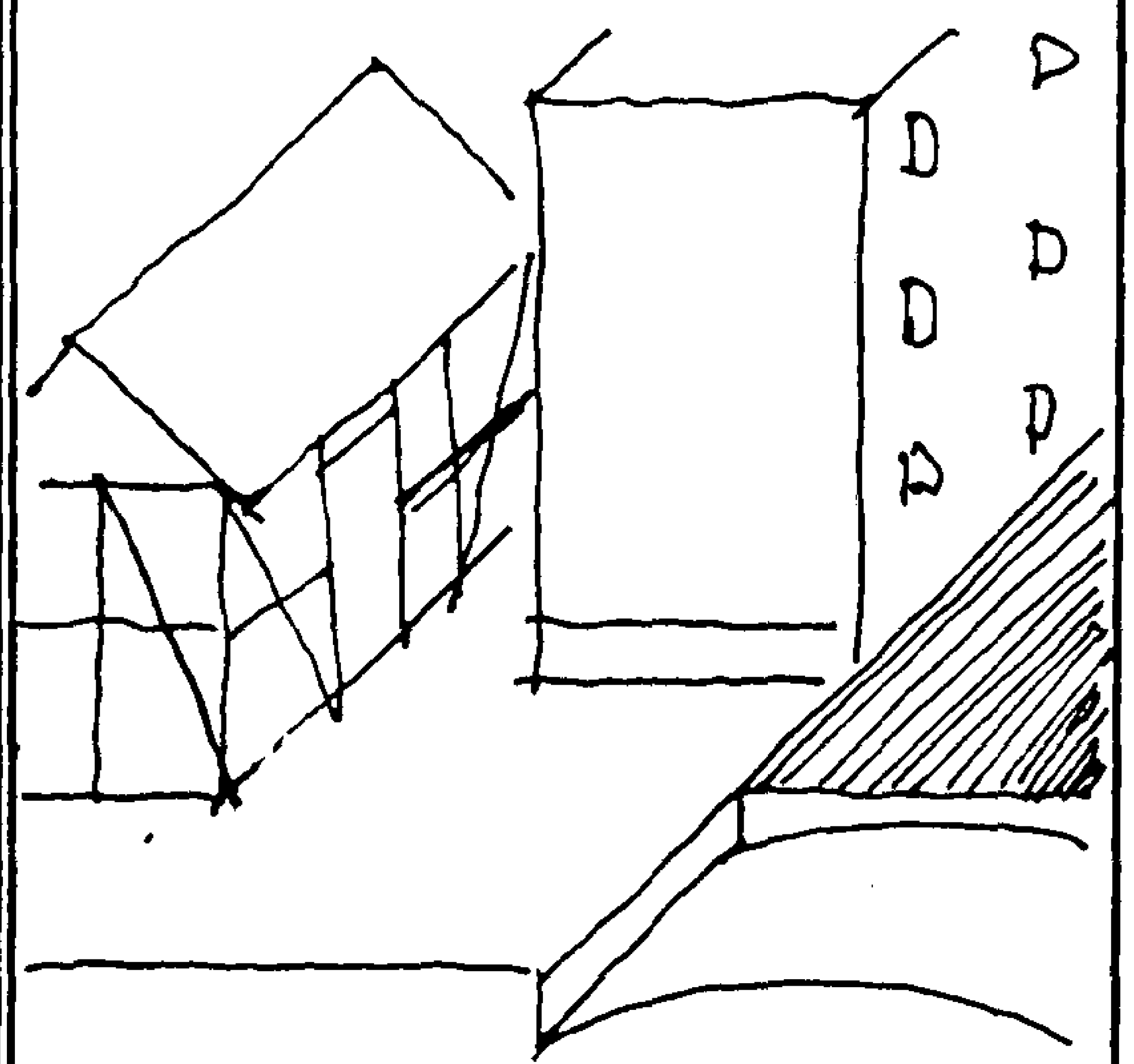
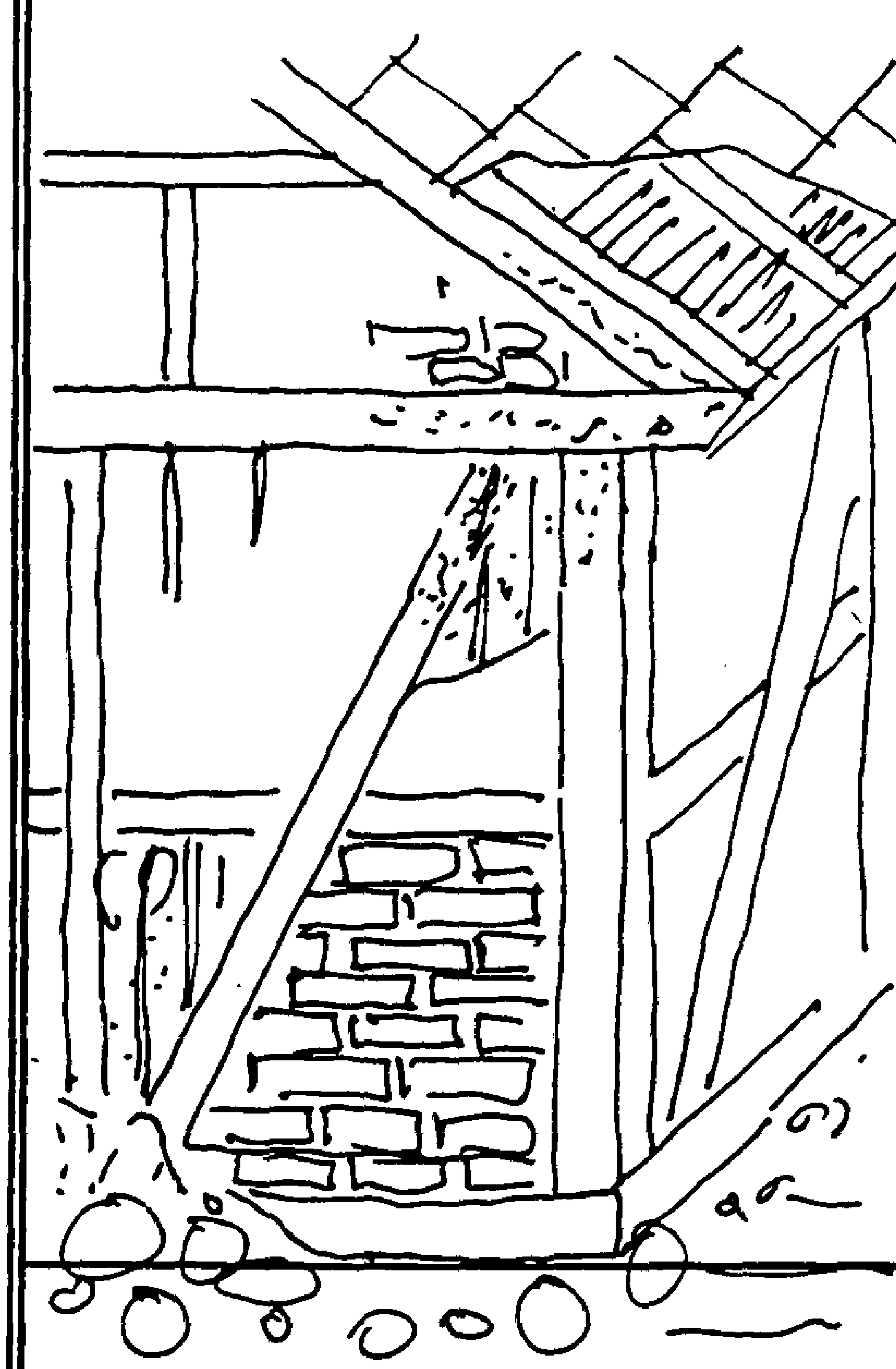
[171]Recommended further reading:
Hughes, P. The Need for Old Buildings to Breathe; Torraca, G. (1988), Porous Building Materials; Thomas, A. Treatment of Damp in Old Walls; Williams, G.B.A. Pointing of Stone and Brick Walling.



1. SURROUNDING LANDSCAPE MAINTENANCE

Frequently the area surrounding old buildings has changed with time. New road construction, adjacent development and addition or remove of trees can alter water tables and the stability of foundations, or can increase the uptake of water into the walls.



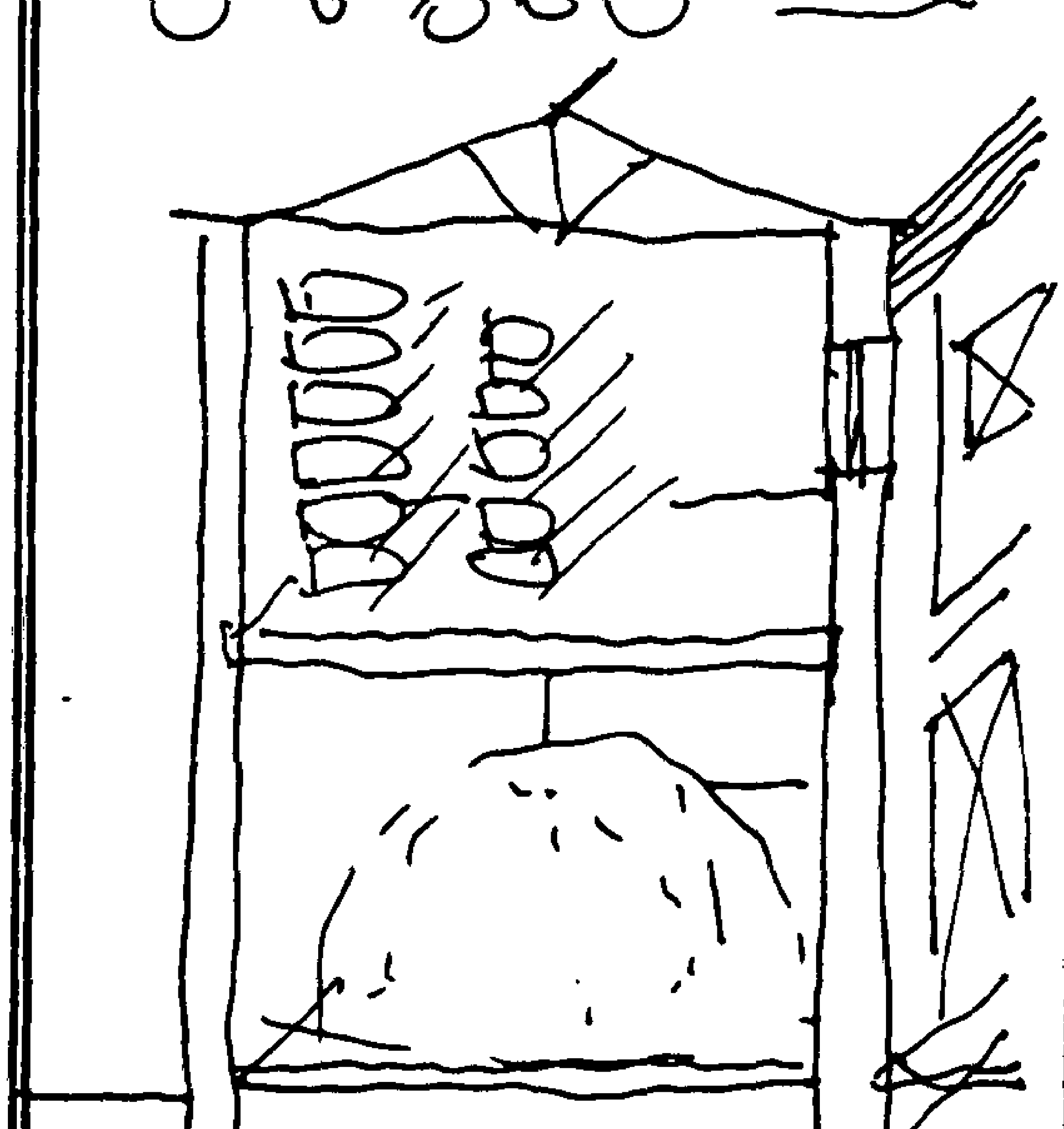
2. BUILDING SYSTEMS MAINTENANCE

- **Wall Systems**

Historic walling systems are built with materials such as earth, timber or soft bricks which are bonded in and protected by earth and lime based materials. The lack/ or incorrect maintenance of joints, renders and surface coats is a threat to the wall, attracting water and encouraging decay.

- **Roof Systems**

Rain penetration through cracked, displaced or missing tiles, chimneys and blocked gutters are a serious cause of water passage into the building, encouraging the development of organisms growth, staining and decay.



3. USE AND ROUTINE MAINTENANCE

- **Closed and abandoned houses or alterations in life-style may decrease ventilation and increase moisture levels and decay.**

Fig. 102 - Maintenance Problems

MAINTENANCE: S. CATARINA

According to the observations during field work in Brazil it seems that for decades, lack of building maintenance in addition to changes of use rather than incorrect maintenance have lead to premature decay of earth and lime materials. In some cases, changes in local development may also adversely affect these buildings. The maintenance problems in Blumenau buildings may be divided as follows:

Landscape Changes

The landscape of the rural buildings in the Blumenau region is not yet sufficiently protected. As the land is being constantly subjected to change, with agricultural land being developed for domestic or industrial use many changes are inevitable. Some areas have not changed in such way as to threaten the orginal buildings, and these need planning legislation to preserve the buildings in their original settings and to control the immediate environment to avoid adverse effects at the buildings fabric.

Building Systems

The maintenance of the Blumenau buildings may be divided as follows:

1. Infill Systems

These are adobe, daub and brick infill materials in timber- framed structures where maintenance is provided by earthen or lime based plasters/renders and limewash or pointing mortars. In general, these systems are prone to crack around the edges caused by the movements of the timber framing. External panels exposed to the weather are subject to premature decay if not frequently inspected and maintained.

2. Masonry Systems

These are structural walls where the bricks are laid with earthen mortars and, as a general rule, maintained by earthen or lime based renders and limewash or pointing mortar. Earthen mortars are easily eroded/ washed out, if not well maintained and lack of maintenance may be a threat to the walls.

Use and Routine

Many buildings located in the study area are closed or incorrectly used to store different types of things such as agricultural products, construction materials and broken and spare furniture or even to house animals. The addition of external plumbing to buildings which did not orginally have and is of the poorly installed. It is clear that these new conditions are increasing the level of moisture and encouraging the decay of plasters, pointing mortars, earth panels and timbers.

MAINTENANCE: RECOMMENDATIONS FOR MAINTAINABLE SYSTEMS

It is essential that a general inspection be carried out on these buildings in order to identify in detail all the types of maintenance problems in the region. From this study guidelines on maintenance and repair for owners, architects and institutions may be developed. (fig. 103)

Surrounding Landscape Maintenance

• Carry out frequent inspection of the buildings context, especially of drainage patterns, planting, roads and new construction in order to evaluate any changes that may encourage decay due to moisture or water penetration.

Building System Maintenance

Walls

• Carry out frequent inspection of panels of timber-framed buildings in order to identify and provide maintenance of (1) cracks on renders and pointing mainly around the edges of panels that should be patched or re- pointed with compatible materials; (2) loss of limewash that should be re- washed.

• Carry out frequent inspection of brick masonry buildings in order to identify and provide maintenance of (1) cracks on renders and pointing that should be patched or re- pointed with compatible materials (2) loss of limewash that should be re-washed.

Roofs

• Carry out frequent inspection of roofs in order to identify cracks, missing tiles or any other source of water penetration that should be maintained with compatible materials.

Use and Routine Maintenance

• Use of the buildings should give adequate ventilation, cleaning and plumbing in order to maintain the building in a clean, weatherproof condition. Frequent inspection measuring moisture levels, cleaning habits and installations is recommended.

Fig. 103 - Maintenance Recommendations

3.6 PRODUCTION AND SUPPLY

- Lack of appropriate replacement materials for historic buildings should not be a justification for the use of substitutes but a stimulus for a revival of production.

PRODUCTION AND SUPPLY: GENERAL

Historically, until the technological improvements of the nineteenth century, the production and supply of traditional materials was mainly dictated by the nature, kind and composition of locally available materials; manual and small scale production; and local suppliers (due to difficulties with transport). Stone of all sorts, bricks, earth, timbers, lime and earth were traditionally the choice of materials. However, from about the second half of nineteenth century to the present day many changes have occurred, such as experimentation with other sources of raw materials, mechanized production and transport developments which created conditions for substantial alterations in the production and supply of materials. As a result, some of the materials or components of the materials produced in the past are not produced today or substitutes are produced in a new production technology which may change completely their physical and chemical characteristics. In addition, many new materials have been invented recently and experimental development continues to meet the demand for new construction systems.

In general, a great difficulty in the repair and replacement of all traditional materials in historic buildings is the availability of compatible materials. Thus, the continued production and supply of traditional materials is often supported and implemented by special projects, made for specific circumstances and encouraged by Government policy. However, in some cases, the continuity of old site works still maintains a supply of materials produced in the traditional way.

European project initiatives which promote the manufacture of traditional materials for historic buildings are being developed; for instance, projects such as Eurolime promote research regards the manufactured use of lime for the preservation of historic buildings. In England a wide range of initiatives are being taken to promote the production of traditional materials. This is illustrated by the activities of conservation training workshops that create a demand for producing traditional materials; traditional brickyards that may supply special bricks for conservation; private suppliers of special materials or components such as quicklime/ putty lime, pigments, linseed oil that may be referred to in technical leaflets on conservation; manufactured clay/straw blocks that may be ordered to replace earth walls; and the supply of traditional woods such as chestnut and oak. All these initiatives attempt to remedy the problems of available materials for conservation works.

PRODUCTION AND SUPPLY: S. CATARINA

Introduction

German and Italian immigrants settled in the Blumenau region sought local sources of raw materials and drew on their knowledge from their countries of origin for the production of building materials. The Blumenau region provided sources of wood from the sub- tropical Atlantic forest, clay from the alluvial deposits of Itajay river valley, but not for lime. Timber and clayey/ earth soils were the base for all the vernacular materials until lime was acquired from other sites. At the beginning simple tools were brought by the immigrants and the production of materials was developed in the building site utilising temporary provisions. Later, some immigrants became prosperous and methods of transport developed in such a way that made it possible to import more sophisticated machinery. However, the main mechanized improvement during the first century of Blumenau (1850-1950) was in carpentry and joinery [172] and not in brickwork[173]. (fig. 104,105)

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[172]The use of wood to be converted into structural timbers, windows, doors, furniture in Blumenau may be divided into three phases: (fig. 104)

MANUAL METHOD Utilising pit saw, hatchet, adze, large knives, planes.
SAWMILL AND WATER POWER Vertically- mounted reciprocating single or multiple blades.
SAWMILL AND BOILER A variety of machines to plane boards and profile joinery sections.

Fig. 104 - Wood: tools and machines

The great development achieved by the timber trades in Blumenau may be illustrated by immigrants' memories:
Gottlieb who was born in 1852 in Schwallungen ('Gram Ducat de Meiningen'), Germany. He came to Brazil in 1856. He started the business with a sawmill in 1873. In 1885 he brought from Germany the first boiler engine in the region (Wolf trademark). In 1892 he imported another vapour machine. In 1900 he also started a transport business in building materials. In 1924 he bought a 'Lanz' engine (locomovel) which was transported by the S. Catarina railway and machine plane were installed.
The Max Brueckheimer family was from Gersheim, Reno region in Germany. The family came to Brazil in 1858. He learned carpentry and joiner with Rudolph Herbst. In 1910 he worked for exhibition of the centenary of Buenos Aires explaining the machines to improve timber from the firma Fuchs & Cia, Kirchner, Leipzig. In 1913 he worked as a joiner in Germany and visited the International Architecture Exhibition in Leipzig. After that he came back to Brazil to apply his knowledge.
From Blumenau em Cadernos (1972), No.8, pp.141-156 and (1969), No 9/10, pp.157-203.

[173]The development of brickyards by imported and more sophisticated machines to produce bricks and tiles was not identified in documentary sources as in the case of sawmills. An old photograph found in the Blumenau archive shows a rudimentary pug mill driven by horse power, the horses treading a circular path. (see: fig. 6.2) However Mr Curt Bosse, the president of the ceramists' association in the Itajai valley, states that the German immigrants worked in more permanent brickyards from the early period of settlement. There they made use of extruding

Sawmills and brickyards constituted the main establishments for the production of materials in Blumenau region. However, the biggest commercial trade of the region was wood. The following table shows the development of these two establishments according to documentary reports during early times of Blumenau: (fig. 106)

YEAR	1856	1858	1860	1862	1864	1870	1872	1874
SAWMILL	2	3	2	3	5	19	23	29
BRICKYARD	1	1	3	3	5	7	10	9

Fig. 106 - Number of Sawmills and Brickyards from 1856 to 1872

In addition to the local sources of raw material and immigrants' knowledge the production and supply of materials in Blumenu was strongly dependent on the transport system as shown in the following table: (fig. 107)

machines to produce brick and tile which were almost certainly imported from Germany. Although this would be possible, this research identified written descriptions, physical evidences and the oral accounts of old people showing that from 1850 to about 1900/20 the usual method of producing bricks for the peasants' houses utilised 1) building site alluvial clays; 2) site production of bricks; 3) clay trodden by men or horses, but also sometimes a rudimentary pug mill turned by a horse; 4) hand- moulding and 5) temporary kilns dug against the slope of the hills or clamps to fire the bricks; 5) wood for fuel. This method may be illustrated by the description of Pietro Trentini in 1900 (from Vicenza, Italy in Commemoracao do 50 Anniversario da Fundacao de Blumenau 1900, p.32) and Max Brueckheimer and oral account by Arthur Zindars (1993). The extruded brick method which was probably introduced from early times utilised 1) raw- materials: brickyard site alluvial clays; 2) mixing and extrusion: a pug mill turned by horse- engine or later by electricity; 3) Kilns; 4) Wood for fuel. (fig. 105)

HAND- MOULDING METHOD	EXTRUDED METHOD/ BRICK YARDS
• A hole was dug in the ground (about 5m diameter and 0.5m deep). The hole was filled with the clay materials and horses or men were used to tread the material or a rudimentary pug mill driven by horse power was used. • Bricks and tiles were moulded by hand. • Bricks and tiles were left to dry. • Bricks and tiles were fired in clamps or temporary kilns.	• Clay material was mixed in a pug mill and then in the same pug mill was extruded. • Bricks were left to dry in open- sided sheds. • Bricks were fired in kilns. The early type of kiln was likely to be a Scotch type. Later other types of covered kilns with flues and chimneys (downdraught kilns) were used.

Fig. 105 - Brick: hand- moulding and extruded methods

Hand- moulding processes gradually died out and all brick and tile production was carried out in the established, more mechanised brickyards. The hand and modern machine processes are different in several aspects of production, but any significant physical or chemical differences in the product have yet to be identified by further research.

1st Phase: RIVER TRANSPORT 1852- The first road was opened; river transport was the only other option. 1863- River transport was still the only option and the reason for high prices of materials.
2nd Phase: RIVER TRANSPORT AND ROADS 1864- Roads for small oxen pulled carts were improved. Villages appeared as a consequence of development. 1871- Boats to carry building materials.
3rd Phase: RIVER TRANSPORT ROADS AND RAILWAYS 1904- Immigrants started to build ships exclusively to transport building materials. 1906- A railway was installed connecting Blumenau with main centres in Brazil as well as the near villages.

Fig. 107 - Transport and Materials

The development of production and sources of traditional materials during the first century of Blumenau and today may be summarised and illustrated by the following table: (fig.108)

1850 TEMPORARY MATERIALS FROM THE FOREST AND SOIL • Timber and brick started to be produced. • Lime was possibly supplied, but limited by difficult transport.
1875 DEVELOPMENT OF MATERIALS AND TECHNIQUES • Brick/tiles and timbers were produced. • Lime was supplied from coastal sites. • Some materials were imported such as gypsum, glass and paints.
1900 LOCAL MATERIALS SUPPLEMENTED BY IMPORTS • Brick/tiles and timbers were produced. • Lime was supplied from coastal and inland sites. • Improvement in transport encourage the importation of materials.
1925 IMPROVEMENTS IN PRODUCTION • Brick and tile production methods were improved. • Lime was still supplied. • The production of timber was more mechanized.
1950 DECREASE • Hydrated lime was produced and supplied from inland sites.

Fig. 108 - Development of Materials: 1850- 1950

THE CURRENT PRODUCTION AND SUPPLY

- Hydrated lime and quicklime in powder form is produced and supplied from Parana.

- Timber is supplied in S.Catarina by sawmills or building construction shops, but the wood may come from northern Brazil because native specimens are protected by environmental law.[174]

- Solid bricks and plain tiles are in very small quantities supplied by old brickyards[175], but the products have changed. Differences are likely to be in raw material, moulding methods and firing which results in materials which differ in size, colour, surface appearance and porosity from the originals. Difficulties such as permission to dig the clays, the use of wood as fuel, competitive prices of modern products and the new legislation affecting production have discouraged the continuity of traditional brickyards.

Fig. 108 - (continued) Development of Materials: today

[174]The traditional sawmills using water power to move the reciprocating blades are not the actual suppliers for most of the timber used in the region, but a few of these early sites survive and still may produce some building material. They are like open- air museums, although unfortunately not protected. During this research three sawmills still working with water and the original equipment were located and visited: Rieger Fisher in Encano, Indaial; Dandker and Richter in Itoupava, Blumenau.
A comprehensive text about the ecology and vegetation of Itajai Valley is given by Klein, R. M. (1980), 'Ecologia da Flora e Vegetaçao do Vale do Itajai', in Sellowia - Anais Botanicos do Herbario 'Barbosa Rodrigues', pp.326-339. He describes the original pluvial Atlantic forest as powerful/ robust in specimens for building and ship construction. The highlight of this pluvial forest is 'canela preta' (Ocotea catharinense) and peroba- vermelha (Aspidosperma olivaceum) which were responsible for the development and expansion of Itajai Valley. The Itajai Valley could be an important centre for the supply of timber for building construction through a technical and scientific plan to explore the actual resources and to plant the forest in slopes of the region. Observation of the region records that 30% of the original forest is still there, although 20% of these areas have already suffered from intervention.
From the time of the above article to a decade later it is likely that the resources of native specimens have been seriously diminished; the following decrees protect the actual resources of native wood.' DECRETO No. 99.547 de 25 de Setembro 1990' is about the prohibition on cutting native specimens of the Atlantic Forest. 'DECRETO No. 750 de Fevereiro de 1993' is about regulations on exploring the Atlantic Forest.
See also the study of Raulino Reitz, et al, (1979) about wood specimens in Santa Catarina which includes the use of wood as raw- material for building construction. For instance, the study of 'canela preta' (the most used source in the historic buildings in Blumenau) says that the tree may be 25/30m high and 60/to 100 cm diameter, as a timber it is employed for structural elements, boards, furniture and openings. It is extremely durable for outdoor use.

[175]During this research some brickyards in the region were visited and five were located with traditional pugmill production: Pasold in Itoupava Central, Blumenau (the family had a brickyard since the times of Carlos Pasold's grandfather who died in 1877); Baltazar Fisher Brickyard (1919), rua Zimmerman, Blumenau; Otto Wolter, Sao Roque, Timbo, (by 1940 his father started/ everything was carried out by hand); Wandelin Wolter, Mulde, Timbo (more then 100 years); and Grimm Brickyard. Evidence of the traditional pugmills is still there, although some modifications such as the substitution of electricity for horse power have taken place.

Lime: History of Technology

Sources of raw material for the production of lime are not found in the Blumenau region. Therefore the supply of lime in Blumenau came from other locations in S. Catarina. Until 1900 all the production of lime which was located at the coast utilised cockle shells as the source of calcium carbonate. From this time to about 1970 inland sources of limestones were also used. Archival sources such as a letter written in 1863 by the director of Blumenau Colony requiring lime from shell sites to be stored, and further oral accounts describing the use of lime from limestone sites placed in the near region of Itajai Mirim river suggest that both sources of raw material were used in Blumenau. Documentary sources, physical evidence of lime works, oral accounts, and research projects indicate the following preliminary historical understanding of this material.

Coastal Sites: Raw material and Production

Early settlements placed along the coast of S. Catarina, following the Brazilian tradition, used local sources of shell, mainly cockles, to produce lime for buildings. Cockles are abundant on the S. Catarina coast. During early times, before the Portuguese this sea food was a staple diet of the Indian people. 'Sambaquis' are hills of compacted shells, remains of these Indian sites (4.000 BC) were later explored (1556-1960) for the production of lime.[176]

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[176]The co- ordinator of IPHAN in S. Catarina, archaeologist Edna Morley (fax May, 26 1995) says that little is known about the 'Sambaquis'. Until recently these high hills of compacted layers of shells mixed with pottery, tools and human bones (highest 30m) were attributed mainly to remains of food from the Indians diet. A new research project coordinated by IPHAN has interpreted that some of these sites may also be a sort of construction resembling a pyramid.

The early indication of the use of Sambaquis for lime production was in 1556. The practice persisted until the 1960's with great intensity, mainly in south Brazil. The fact was the reason for the creation of the Brazilian archaelogical law (Lei no. 3.924, de Julho de 1961). Later many lime kilns were closed by IPHAN.

Documentation shows that until the 1900's, lime sites, utilising clamps, were still used in S. Catarina.[177] (fig. 109) The tradition of burning shells might have continued locally until the 1970's; however, using natural shell deposits and small brick kilns as attested to by a site documented during this research in Florianopolis.

Inland Sites: Raw Material and Production

By the 1900's, along with the burning of shells on the coast, wood- kilns for the burning of limestones in the inner parts of S.Catarina began. Old workers of the lime- burning sites stated that suitable stones were selected by experience and extracted with hand tools. Appropriate raw material was used to feed the kilns and wood was used as a fuel. It seems that (oral accounts from different sites confirm this) the lime produced from limestone sites in S. Catarina resulted in two different end products. One refers to lumps of quicklime, denominated 'white' lime, which was taken away in carts, and later wet slaked on sites; the other type was referred to as 'grey product' which was crushed on the kiln site and sold in wood barrels or bags. The latter suggests an impure lime, or possibly a slightly hydraulic lime. Although the fact that this lime had a grey colour may not indicate hydraulic

[177]A type of clamp used to produce lime from cockle shells in S.Catarina Island was described by Virgilio Varzea (1900) in A Ilha de Santa Catarina, p. 84-85 and a similar clamp to produce lime from limestones is shown in Jornal da Cal (1980), No.21, p.3. (fig. 109)

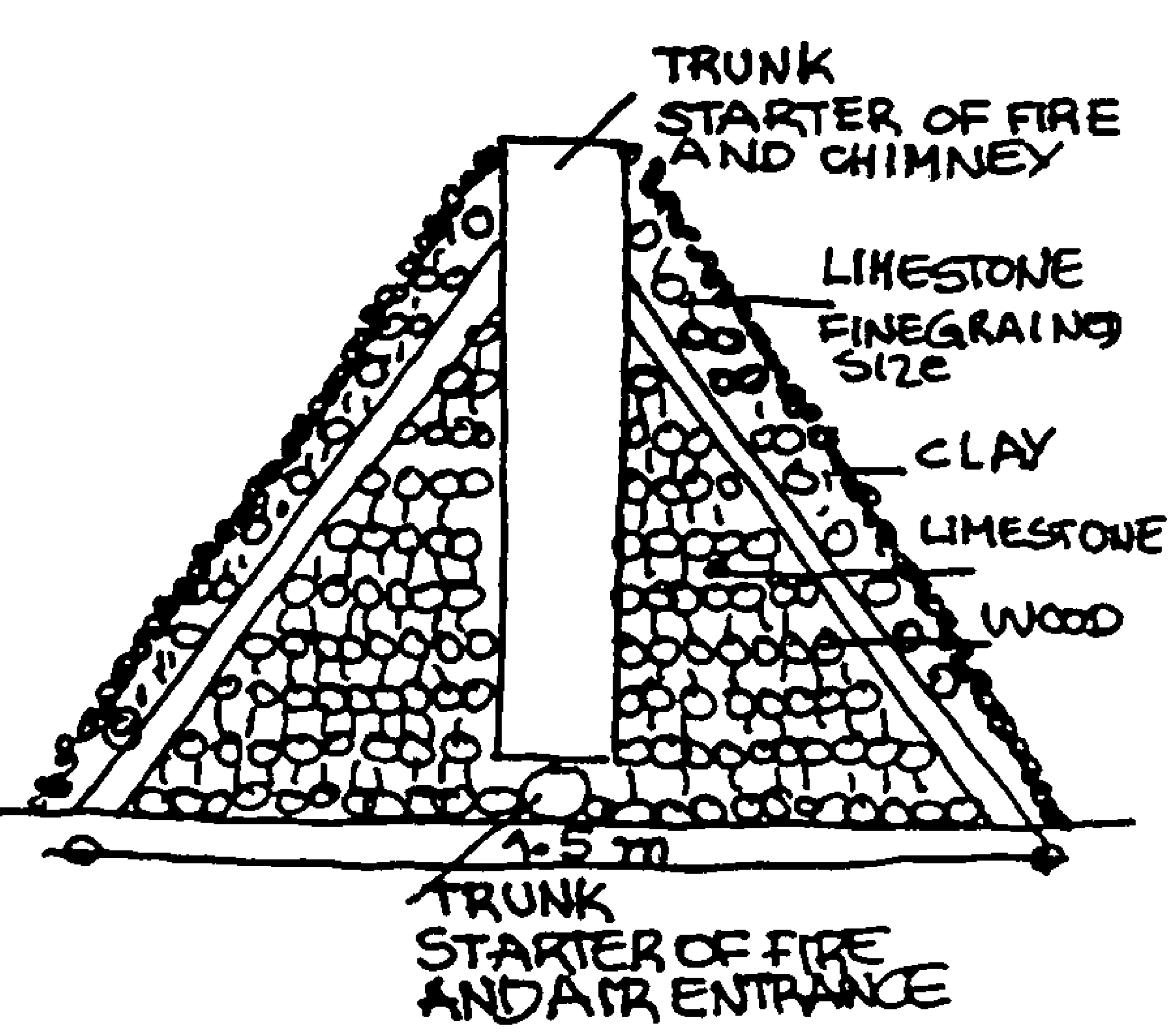
CLAMPS FOR LIME PRODUCTION FROM COCKLE SHELLS USED IN S.CATARINA ISLAND 1900	**CLAMPS FOR LIME PRODUCTION FROM LIMESTONES USED IN THE STATE OF SERGIPE/ BRAZIL**
• Two or three men were needed for a period of two months to produce lime. • The clamp was circular. The first layer started with a thick layer of peat (about 1 feet). • Sticks were arranged in a radial form; linked in the axial centre; and supported by a sheaf of sticks in a vertical position. • Over the peat layer a shell layer was laid to a depth of about 1 foot (usually cockles- abundant in rivers' mouth or 'sambaquis') • A sequence of peat and shell was arranged to the same depth until a length of 4m was reached. • After the clamp was ready it was burnt for 2/3 days producing an acrid smell. Each of these clamps produced 7/8 'moios' of lime (7 moios equal to 150 hectolitre).	

Fig. 109 - Clamps for Production of Lime from Cockle Shells and Limestones

properties, the absence of slaking seems to suggest that this is so.[178] What exactly 'grey' limes means and when and how it was utilised in Blumenau architecture, is not fully understood in this research. However, it is clear that for the lime mortar pointing, 'white' lime[179] or pure sources of calcium carbonate were used, while quicklime was hand slaked using wooden boxes, with substantial quantities of water to convert it into putty; stored in ground holes covered by wooden boards during the construction; sieved; and mixed with sand at time of use. This process may not have been used for renders and plasters.[180]

By the 1950's, new modern kilns were implemented on limestone sites and hydrated lime (dry powder) is likely to have been produced, gradualy replacing the traditional use of wet slaking quicklime. Until 1976 some of the traditional wood- kilns were still operating. [181] Today, however, lime for building construction is not produced in S. Catarina. The only traditional kiln in operation in S. Catarina, even though in a precarious state, produces lumps of quicklime to be used in steelworks. Lime- burning sites are still there, but abandoned. Some of the sites are now producing lime for use in agriculture. This research included visits to the sites and recording of kilns, physical evidence of production, the old quarries, accounts by the old craftsmen and review of recent reports. A summary of this study is illustrated in the following tables. (fig. 110,111,112,113)

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[178]According to the Brazilian lime terminology a quicklime is denominated grey referring to the colour of the end product when it has an heterogeneous calcination, thus a high percentage of the stones have superficial calcination with a core of uncalcined material. Passos Guimaraes J. E. (1989), Terminologia de Calcarios-Dolomitos e da Cal, p.5; 21.

[179]White lime or pure lime means a product with an energetic reaction with water which after hydration exhibits a white colour and high purity. Passos Guimaraes, J.E. (1989), op cit. This definition and the process of slaking indicated below is also applicable to lime burned from shells.

[180]For the slaked forms of lime used for renders and plasters see previous sections on lime- soil.

[181]The Report of DNPM (1976) lists some wood- fired kilns which were operating by that time using inland sources of limestone.

SITES: Located along Itajai Mirim river. One site near Camboriu town and some near the town of Botuvera, region of Ribeirao do Ouro.

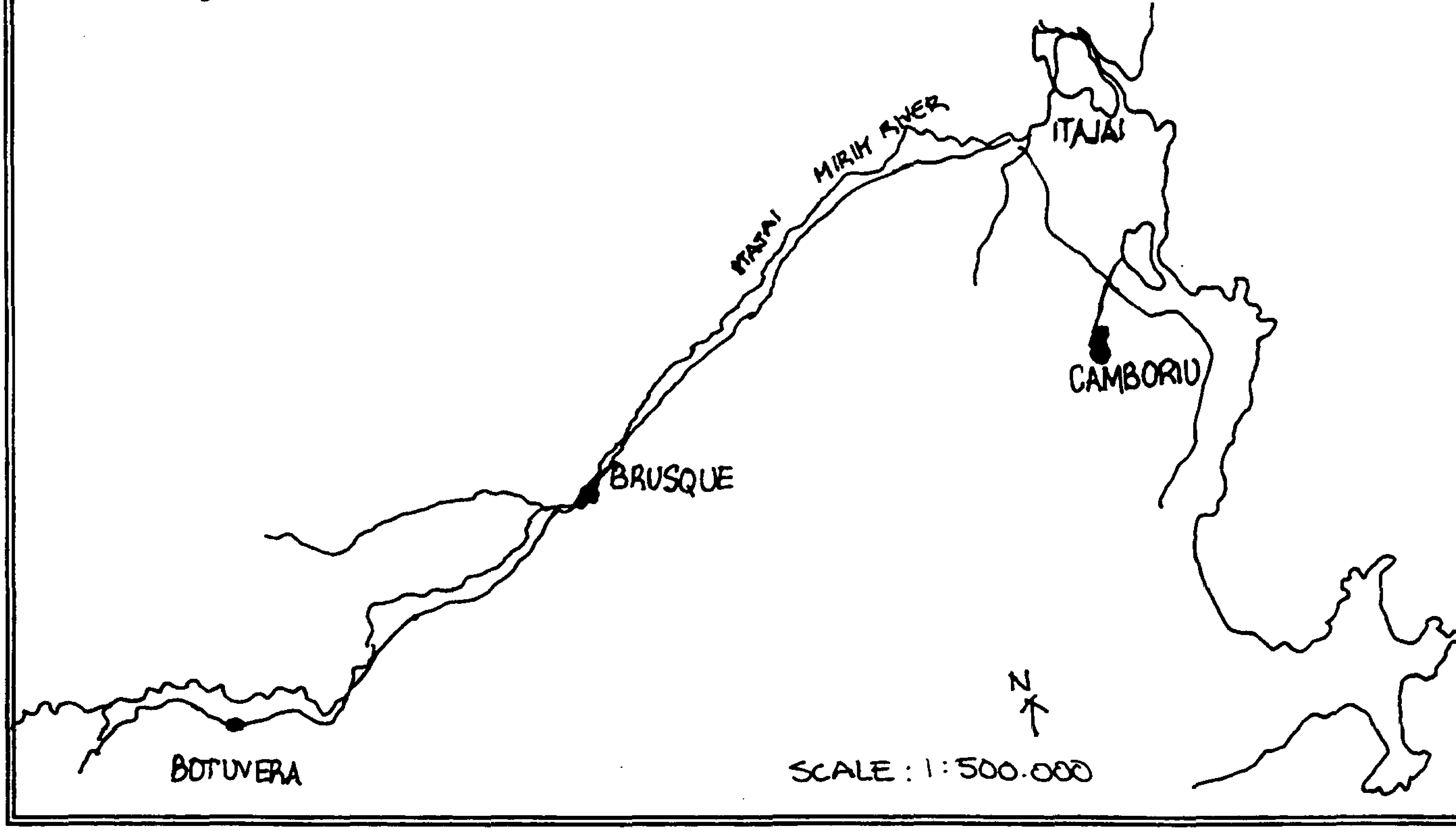

Fig. 110 - Lime Kilns visited in S. Catarina

KILNS: Traditional batch fired kiln - updraught type where the stones and fuel are kept separate and usually provided with grate and ash pit ie a pot kiln and built against a hillside. The form is a double cone shape; masonry material is brick or soft stones; size may vary. Only one is in use ie Busquirolli Kiln (measuring about 4.5m high and 2.5m maximum width); the rest are abandoned and sometimes covered by vegetation.[182]

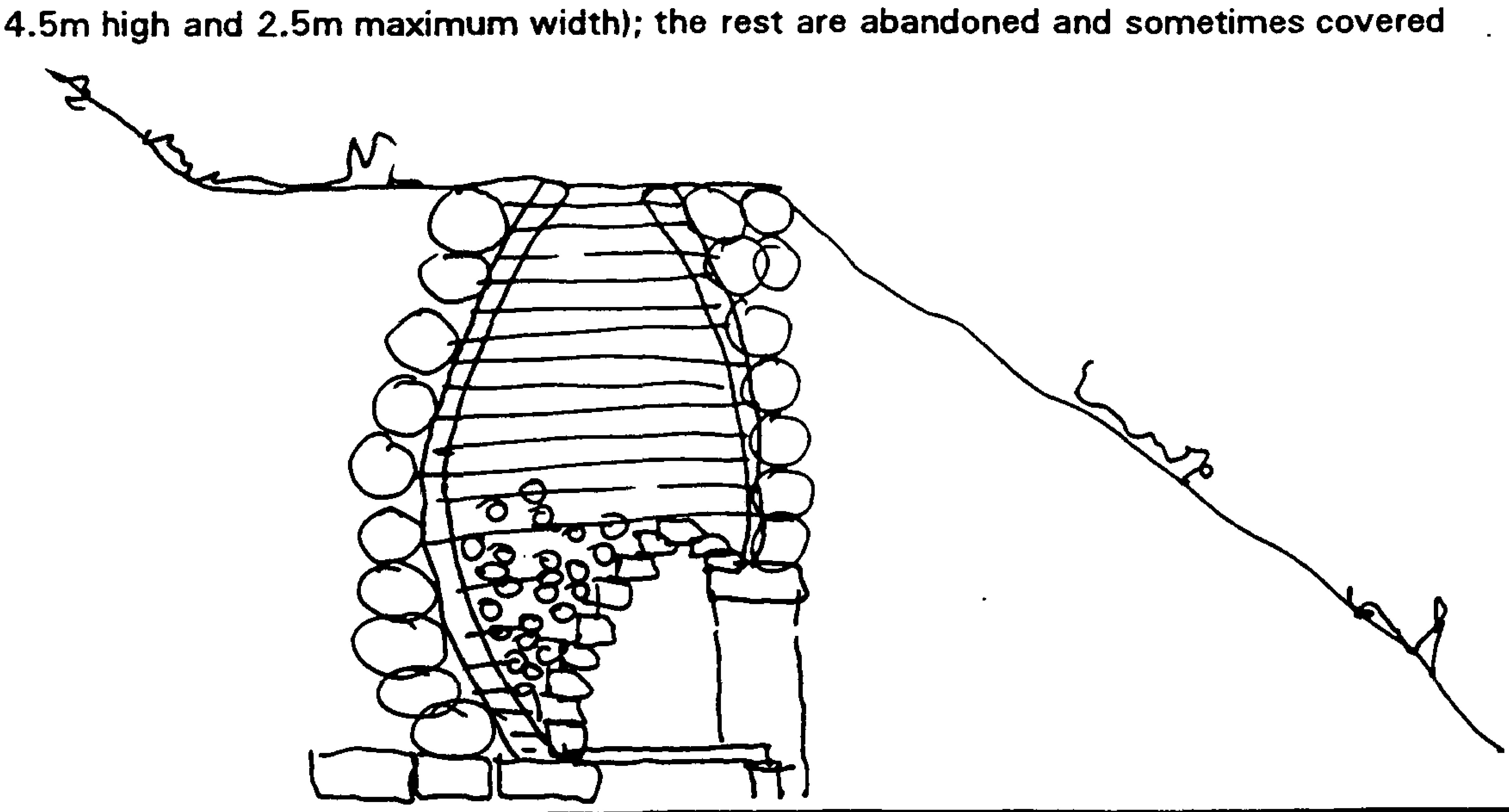

Fig. 111 - Lime Kiln Type in S. Catarina

[182] Pot kilns are described by Wingate, M. (1985), op cit, pp.73-76, as a type of flare kiln provided with grate and ash pit; where the height is usually between 3 and 8 metres; the internal maximum diameter of about half the height and top opening about one third of the maximum diameter. Good quality lime can be produced, but there are difficulties: overburned lime near the heat; overburned lime as a result of firing too long; underburned lime when the firing period is too short or stopped too early. See also Spiropoulos, J. (1985), op cit, pp.35-58 about kiln design.

LIME BURNING: TYPICAL ACCOUNTS

Werner family: The first kiln in Ribeirao do Ouro started in 1900 with Andrea Colsani and was located in Ribeirao do Ouro. The second in 1910 by Miguel Colsani. The family came from Bergamo, Italy. An experienced man loaded the kiln with care choosing the right size of stones for the 'arch'. They started the lime burning with a short fire and then increased it. When the stones were completely calcined they withdrew the brazier/hot coal immediately as the stones fell down. The old people knew how to distinguish the stones for white lime, from the ones with sand and also the grey sources which Mr Werner referred to the limestones with 'cement'contents. Until 1963 they produced only white lime in lumps. After that they started to burn also the grey lime which was then dry hydrated and crushed. The burning time of stones for white lime was longer than for the grey lime.[183] The white sources were harder and therefore needed more time to burn.

Colsani family: The family had a 'superior lime' ie when slaked was like a butter. The lime when dark has a content of 'rough grains'. If some of the lumps of lime were not well calcinated they removed all of them by hand. The lumps of lime were transported by carts in containers made with leather. The 'dark' lime was crushed with stone mills (evidence is still there) while the white was sold in lumps.

Fig. 112 - Examples of Lime Production Accounts

[183]Calcination temperatures and concentration of firing time depend on many factors such as:
Dense, coarse crystalline limestones - higher temperature
Porous, fine grained or poorly crystalline limestones - lower temperature
Proportions and amount of $MgCO_3$ - $MgCO_3$ begins to decompose at lower temperature than $CaCO_3$ (average between 725°/900°)
Spiropoulos, J. (1985), op cit, 34-35.

LIME IN BRAZIL

- 1549 - The early lime works in Salvador Brazil to produce quicklime with sea shells for render and limewash. [184]
- From 1549 to about 1930 - Lime is produced mainly for building construction.
- Until 1930/40 - Lime was produced mainly in clamps or traditional kilns, the end product, ie quicklime, was sold to the consumer in bags, barrels or straw baskets.
- From 1950 - Rapid development of the lime industry using limestones and dolomitic limestones. New modern kilns and fuel improvements.
- The main production of lime is from metamorphosed limestones/dolomites which differ in geological age: usually very old (pre- Cambrian) and of variable purity. The production from sedimentary limestones or natural sources of recent shell deposits is minimal.
- The south and southeast regions are predominantely dolomites and magnesian limestones and the northeast- north and centre calcium limestones.
- 30% of lime production is used for building construction (Magnesian or Dolomitic hydrated type, while for other uses such as steelworks 45,9% (Quicklime/ mainly high calcium lime).
- The main product resulted from the calcination of calcium limestone and magnesian limestone is quicklime which is mainly used for steelworks, sugar and cellulose. This quicklime production is sold packed in containers (plastic, metallic or other) or bulk buying. The types may be fresh lumps, pebble grains (grains of 1 to 6 cm), or crushed/grind and pulverized (85% to 95% passing sieve 0.149 mm).
- Other product is hydrated lime. This is a white powder which is packed in plastic or 'Kraft' paper bags. The grain size 85% less than 0.074 mm (sieve 200).

Fig. 113 - Lime in Brazil: notes from 'A cal no Brazil 1980'

[184] 'Caieiras' is the name attributed to the tradtional sites to produce lime. The use and meaning of 'caieiras' were associated to the name of the places such as 'Caieira do Pirajubae', 'Caieira da Lagoa' and 'Caieira da Barra' in S. Catarina Island. However, it is likely that remains of these lime burnings are barely survived. 'Caiar' is the verb 'to whitewash'.

Discussion of Problems

In general all the materials used in the Blumenau buildings are difficult to acquire today; further study and field research is essential to match original native types of timber and to obtain closer matches than is now possible for the bricks and tiles.

This study, concentrating on lime and earth has already been able to progress an understanding of the use of these materials and their repair and replacements. Earth is likely to be available at the Blumenau building sites. However, in some cases and for other similar buildings where the land is being divided, and the landscape is changing, this might be an immediate problem. In S. Catarina the production of ready- to -use earth materials locally or from neighbouring sources is not available. The problems of production and supply of earth may be summarised as follows and illustrated in the next table: (fig. 114)

- A decrease of suitable earth sources, due to development.
- Ready- to -use earthen materials are not supplied.
- Some projects may need a ready supply of earthen materials.

YESTERDAY	TODAY	PRODUCTION/SUPPLY NEED
Clayey/ earth was dug from sub- soil of 'ravines' in Itajai river valley.	**Landscape in change. New building site soils should be investigated.**	**Compatible stable soils or in some specific cases ready- to-use earth: eg extruded and compressed blocks.**

Fig. 114 - Production and Supply of Earth Materials

The production and supply of lime for the conservation and repair of the Blumenau buildings presents some problems which are listed below and therefore some needs which are illustrated in the following table. (fig. 115)

- Lumps of quicklime are not supplied in S. Catarina. This research located available forms of lime at the shops in the Blumenau region and in Florianopolis. The result was that: 1) a crushed form of quicklime is available to be used in limewash; 2) the common form is hydrated lime.
- Lumps of quicklime are produced in other states in Brazil (Parana, Minas Gerais, Sao Paulo) and used mainly for steelworks. This is a possible source for building conservation

in S. Catarina which should be examined further.

• Local kilns are not in use, thus any bought of fresh quicklime has to be transported from considerable distances: this will require forward planning and special orders, will require care in packing and is likely to be expensive.

• Magnesian limes may be the only available product, but special care must be taken to ensure that thorough slaking has taken place.

• Other sources of high calcium limes for S. Catarina should be investigated as these offer a better material for the preparation of lime mortars.

YESTERDAY	TODAY	PRODUCTION/SUPPLY NEED
RAW MATERIAL: Brazil: shells since 1549 S.Catarina: cockle shells since probably early villages (seventeenth century); limestones since 1900	High Calcium or Magnesian/ Dolomitic Limestones are the sources used.	High calcium limestones are usually the best sources.
BURNING: S. Catarina: clamps of shells or burning of limestones in wood-kilns (chambers built against the hill) fuel: wood	Brazil: new modern kilns/ fuel: oil, wood and other sources. S. Catarina: One traditional wood- kiln is operating.	Wood firing usually produces the best quality limes.[185]
FORMS OF LIME: Lumps of quicklime slaked on-site.	Quicklime: Lumps, pebbles and powder produced for steelworks, sugar and cellulose production. Hydrated Lime and quicklime in powder produced as additives in mortars and limewash.	Lumps of quicklime are the best form for building conservation allowing wet slaking into putty, resulting in a plastic and completely slaked material with a better final performance.

Fig. 115 - Production and Supply Lime

[185]Advantages of wood as a fuel for lime -burning are: 1) long flame enables the heat to penetrate into the limestone, thus gives uniform calcination; 2) steam is generated, thus helping to lower the temperature needed for dissociation. See: Wingate, M. (1985), Small- Scale Lime- Burning, p. 43.

PRODUCTION AND SUPPLY: PROPOSALS

To solve the problems outlined above it is proposed that the following action be taken by the institutions in charge of historic buildings:

1) To develop a data base programme aiming at the classification of raw materials, products and supplies.

It is proposed that a thorough investigation is undertaken in S. Catarina, collecting samples of raw materials and products complemented with a list of suppliers. The collection of samples and further analytical studies on them should be developed in parallel with the studies made of the historic samples. The collections will be a useful and safe way to establish compatibility between old and new materials, will help to design future research needs and the correct production specifications for new materials in Brazil. This will be a major step in improving conservation. The research programme should produce a library of materials which can be used as a reference for the specification of materials, products and supplies. Technical information leaflets should be designed and distributed for private architects and offices, owners and builders who are involved with conservation works. The following table shows raw materials and products that should be included in this research. (fig. 116)

CLAYEY SOILS	Alluvial and slope hills soils
LIMESTONES	High Calcium Limestones, Magnesian/Dolomitic Limestones, Shells.
LIME	Quicklime: lumps of high calcium and magnesian/dolomitic; Lime putty; Coarse Stuff; Hydrated Lime; Ready- Mixed Limewash.
INERT AGGREGATES	Sands; Inert soils; Shells; Crushed Stones.
REACTIVE AGGREGATES	Crushed bricks (range of grain size);
FIBRES	Plant Fibres; Animal Fibres; Synthetic Fibres.
ADDITIVES	Casein; linseed oil.
PIGMENTS	Light - fast Pigments.

Fig. 116 - Classification of Raw Materials

2) To promote the production of lime and earth for building conservation

Small-scale production. The production of lime and earth may be developed by education and research projects in establishments such as museums, universities or crafts centres. Small enterprises might be also interested if the government provided them with the necessary technical resources.

Large- scale Production. Companies already in production might be interested in providing special materials for repair and replacement.

3) To develop Joint Projects and Collaboration

There are organisations with international experience able to provide advice on developing and manufacturing earth and lime for building conservation. During this study some organisations were identified and outlined below:

ITDG is the Intermediate Technology Development Group set up to help introduce technologies suitable for rural communities in developing countries. The group is involved in projects concerning earth and lime production as well as on conservation methodologies for repair. Intermediate Technology is also a member of BASIN - Building Advisory Service and Information Network on building materials and construction technologies where IT is an advisory service on cements and binders.

CRATerre - Eag is the International Centre for Earth Construction. The centre is involved in research, training, technical assistance and dissemination of information on earth construction in the fields of conservation, industrialisation and economic construction. They respond as an Earth Building Advisory Service in BASIN.

GAIA Project in collaboration with ICCROM is a research project for conservation of earthen architecture.

BRE is the Building Research Establishment in England. The overseas division provides information and advice on housing and construction in developing countries with the overseas information papers.

THE BUILDING LIMES FORUM in England was set up to encourage the development of expertise and understanding in the use of lime in building by means of different objectives such as exchanging information through publications and holding meetings and seminars, training and practical research.

Although this study did not make a thorough search of Brazilian organizations involved with earth and lime, some names came across during the developing of these studies. Further research in Brazil to locate the national and regional organizations developing projects which might finance or assist the developing and manufacturing of lime and earth is necessary. The following organisations or groups might be of interest:

ABPC is the Brazilian Association of Lime Producers. 'Jornal da Cal' is the information paper.

CEPED is the Centre of Research and Development in Salvador, Bahia. Through the programme of House Technology, research and application of stabilised earth materials is being developed.

IPT is the Institute of Research and Technology in Sao Paulo, Brazil which is involved with materials research projects through its Materials Group and Building Division.

CNPq is the National Council for the Scientific and Technological Development which finances and promotes research.

4) To promote lime and earth as building materials

The promotion of new construction in conservation areas using lime and earth technologies should be an added incentive to produce traditional materials and this should make the producing of lime and earth for old buildings, more economical and should, additionally create a much more sympathetic built environment for the historic areas.

3.7 FURTHER RECOMMENDATIONS

- Where building conservation is needed or practised, it is recommended that training, research, technical information and partnership or collaboration with other centres of expertise should be encouraged.

FURTHER RECOMMENDATIONS: INTRODUCTION

This study has endeavoured to achieve preliminary objectives in the field of building materials research related to the conservation of the historic buildings of Blumenau; it has brought together substantial information about historic materials in the Blumenau region and has made a significant contribution to the body of conservation in Brazil, giving technical advice for the design of specifications.

The above guidelines included results, interpretation and specifications for technical issues in building conservation focusing on earth and lime materials. In addition, they emphasize that the conservation of historic structures requires a twofold understanding. First, there is a need to work with the same sort of materials employed in the past; thus characterisation of samples of historic materials as well as modern substitutes through an analytical investigation is a requirement in building conservation. Second, historic buildings have survived in different stages of physical condition and use. Therefore, buildings that have survived present a changed fabric as a result of weathering, air pollution, lack of maintenance and incorrect repairs which require conservation with appropriate materials, tools, skills and techniques. Architectural conservation is a very specialised endeavour as modern specifications and technology are not applied to these buildings. In some countries, the revival of traditional materials such as lime for conservation (eg England) or earth for modern architecture (eg France) is considered a welcome step towards conservation. However, failures in the use of lime and earth for the repair of historic buildings due to inadequate knowledge of the materials have principally led Europe, but also some other countries, to develop the following activities:

Research. Research programmes whose objective is to achieve better building conservation are being established often as joint programmes with partners sharing expertise and resources. Most of the research programmes attempt to use analytical results to understand deterioration processes and to design specifications for conservation materials and techniques. Research in this field requires both laboratory and field work. It is possible to establish basic architectural conservation laboratories without enormous expenditure. Where needed, such simple analytical facilities can utilise the more sophisticated instrumentation available at laboratories of universities and research institutes.[186]

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[186]See Teutonico, J M (1992) Draft for Architectural Conservation Module, ICCROM. Aproximate equipment costs were estimated at $20.000. The function of this proposed laboratory module are basic analysis and interpretation of samples for repair and replacements materials; teaching and research on building materials and treatments.

Technical Information. Technical information on aspects of practical conservation such as leaflets, handbooks and videos are designed to assist architects, and other professionals, as well as a wider audience in building conservation.

Practical Architectural Training. Practical training courses or demonstrations located in places such as studios, workshops or centres are designed to provide practical training or demonstrations. The programme of the courses is usually tailored to typical problems encountered in the historic building structures of the related country or region. Architectural conservation laboratories are often developed as part of the training centre for both research and didatic purposes. The characteristics of some of the training centres established in Europe are listed as follows:[187]

- Training is usually a costly activity, requiring specialised staff.
- Many of the centres are located in a historic building which is state- owned.
- The establishment of these centres frequently involves collaboration of international and national organisations or partners.
- Long term courses are usually part of academic training.
- Short term courses are addressed to a broad interest.
- The management of such centres tends to have a certain autonomy.
- Such centres are usually assisted by Government and/ or international grants.

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[187] The following places were visited by the author:

- CRATerre - The International Centre for Earth Construction, France. It includes a laboratory for earthen analysis, workshops and open sites for training on earth materials and techniques.
- ICCROM - The International Centre for the Study of the Preservation and the Restoration of Cultural, Property, Italy. It includes a didatic laboratory for architectural conservation.
- European Centre for Training of Craftsmen in the Conservation of Architectural Heritage, San Servolo, Italy. It includes workshops on wall paintings, wood and ironwork.
- Institute of Advanced Architectural studies, University of York - The Centre for Conservation Studies, England. It includes temporary workshops specifically designed for practical training on building conservation.
- Bournemouth University - Conservation Sciences Department, England. It includes a laboratory for conservation in the field of building, and also archaeology and environment. In addition a permanent workshop for architectural stone conservation is included.
- Fort Brockhurst English Heritage Training Centre, England. This is a practical conservation training centre specialising in historic stonework and including practical workshops and a laboratory.
- Bursledon, The Centre for the Conservation of the Built Environment, England. This includes a range of specialised courses with special reference to the manufacture, use and conservation of historic brickwork.
- Singleton, Weald and Downland Open Air Museum, England. It includes practical courses specifically in the field of vernacular architecture.
- Johannesberg Priory near Fulda- The Training Centre for Crafts and the Preservation of Historic Monuments, Germany. It includes workshops for practical training on carpentry/ joinery, blacksmith, wall paintings, plasters/ stucco, brickwork and daub/ adobe techniques.
- Craft Academy (SME'S) Raesfeld Castle, Germany.It includes workshops for practical training in carpentry/ joinery, wall paintings, ironwork and daub/ brick panels.

FURTHER RECOMMENDATIONS: PROPOSAL

This study can only be of practical value in the field of conservation if its principles are well understood and if the guidelines are used and translated into practical field work. Although it is not the intention of this thesis to give ready solutions in the field of practical conservation, there exists a clear demand for the production of conservation materials, for research, training and dissemination of good practice through technical information. An overview for future work in Brazil may be outlined. The following paragraph is meant to be a first attempt to offer a framework for the needs identified in the course of this thesis.

A collaborative project should be designed as a national and international institutional effort to raise the standards of practical conservation in Brazil. The broad objectives of this project should be to promote, contribute and coordinate experiences in the areas of production, research, training and information in Brazil. Santa Catarina can be chosen as a strategic location to launch such a project due to its context and geographic position in the centre of south Brazil and its potential for the creation of alliances in a collaborative response to these needs. It is hoped that the results of the proposed project will benefit building conservation in Brazil with an emphasis on national and international collaboration.

APPENDIX A: Particle Size Distribution

PARTICLE SIZE ANALYSIS

SAMPLE: Tottene 5 Adobe

Mass of sample (m): 47.61g

Mass retained on 63μm sive (m_s): 20.48g

Weight percentage retained (m_s %): 43

SIEVING

sieve size	mass retained (g)	weight % retained	% passing
1.18 mm	0.88	1.8	98.2
600 μm	1.94	4.1	95.9
300 μm	5.21	10.9	83.2
150 μm	6.65	14	69.2
63 μm	5.78	12.1	57.1
pass 63 μm	0.93		

SEDIMENTATION

Volume pipette (Vp): 11.1075 ml

Temperature: 21.5°C Specific Gravity silt and clay fractions (SG): 2.65

pipette sample time	pipette mass calculation	mass in suspension	percentage calculation	size category
4 min 5 s	m_1 = 0.497	W_1 = 22.372	15.6	medium silt
46 min	m_2 = 0.332	W_2 = 14.944	8.7	fine silt
6 hours 54 min	m_3 = 0.24	W_3 = 10.803	19.5	clay
	m_4 = 0.034	W_4 = 1.530	13.2	coarse silt

CUMULATIVE PERCENTAGES FINER THAN EACH PARTICLE SIZE

Clay	0.002 mm		19.5
Fine Silt	0.006 mm	8.7 + 19.5	28.2
Medium Silt	0.02 mm	15.6 + 28.2	43.8
Coarse Silt	0.06 mm	13.2 + 43.8	56.99
Sand and Gravel	retained on 63μm	43 + 57	100.00

PARTICLE SIZE ANALYSIS

SAMPLE: Lumke 1 Daub

Mass of sample (m): 46.99g

Mass retained on 63μm sive (m_s): 25.75g

Weight percentage retained (m_s %): 54.8

SIEVING

sieve size	mass retained (g)	Weight % retained	Weight % passing
1.18 mm	4.07	8.7	91.3
600 μm	3.55	7.5	83.7
300 μm	4.8	10.21	73.5
150 μm	6.98	14.8	58.7
63 μm	6.35	13.5	45.2
pass 63 μm	0.54		

SEDIMENTATION

Volume pipette (Vp): 11.1075 ml

Temperature: 21.5°C Specific Gravity silt and clay fractions (SG): 2.65

pipette sample time	pipette mass calculation	mass in suspension	percentage calculation	size category
4 min 5 s	m_1 = 0.321	W_1 = 14.449	12.0	medium silt
46 min	m_2 = 0.196	W_2 = 8.822	10.0	fine silt
6 hours 54 min	m_3 = 0.091	W_3 = 4.096	5.4	clay
	m_4 = 0.034	W_4 = 1.530	17.8	coarse silt

CUMULATIVE PERCENTAGES FINER THAN EACH PARTICLE SIZE

Clay	0.002 mm		5.4
Fine Silt	0.006 mm	10.0 + 5.4	15.4
Medium Silt	0.02 mm	12. + 15.4	27.4
Coarse Silt	0.06 mm	17.8 + 27.4	45.2
Sand and Gravel	retained on 63μm	54.8 + 45.2	100.00

PARTICLE SIZE ANALYSIS

SAMPLE: Wacholz 1 Daub

Mass of sample (m): 47.86g

Mass retained on 63μm sive (m_s): 19.42g

Weight percentage retained (m_s %): 40.6

SIEVING

sieve size	mass retained (g)	Weight % retained	Weight % passing
1.18 mm	3.38	7.1	92.9
600 μm	3.80	7.9	85.0
300 μm	4.57	9.9	75.1
150 μm	5.40	11.3	63.8
63 μm	2.26	4.7	59.1
pass 63 μm	0.02		

SEDIMENTATION

Volume pipette (Vp): 11.1075 ml

Temperature: 21.5°C Specific Gravity silt and clay fractions (SG): 2.65

pipette sample time	pipette mass calculation	mass in suspension	percentage calculation	size category
4 min 5 s	m_1 = 0.539	W_1 = 24.262	8.5	medium silt
46 min	m_2 = 0.448	W_2 = 20.166	9.6	fine silt
6 hours 54 min	m_3 = 0.346	W_3 = 15.574	29.3	clay
	m_4 = 0.034	W_4 = 1.530	12.0	coarse silt

CUMULATIVE PERCENTAGES FINER THAN EACH PARTICLE SIZE

Clay	0.002 mm		29.3
Fine Silt	0.006 mm	9.6 + 29.3	38.9
Medium Silt	0.02 mm	8.5 + 38.9	47.4
Coarse Silt	0.06 mm	12.0 + 47.4	59.4
Sand and Gravel	retained on 63μm	40.6 + 59.4	100.00

PARTICLE SIZE ANALYSIS

SAMPLE: Franz 1 Daub

Mass of sample (m): 45.64g

Mass retained on 63μm sive (m_s): 15.63g

Weight percentage retained (m_s %): 34.2

SIEVING

sieve size	mass retained (g)	Weight % retained	Weight % passing
1.18 mm	0.67	1.5	98.5
600 μm	2.65	5.8	92.7
300 μm	3.21	7.0	85.7
150 μm	4.61	10.1	75.6
63 μm	4.48	9.8	65.8
pass 63 μm	0.42		

SEDIMENTATION

Volume pipette (Vp): 11.1075 ml

Temperature: 21.5°C Specific Gravity silt and clay fractions (SG): 2.65

pipette sample time	pipette mass calculation	mass in suspension	percentage calculation	size category
4 min 5 s	m_1 = 0.556	W_1 = 25.027	7.9	medium silt
46 min	m_2 =0.476	W_2 = 21.426	13.8	fine silt
6 hours 54 min	m_3 = 0.336	W_3 = 15.124	29.8	clay
	m_4 = 0.034	W_4 = 1.530	14.3	coarse silt

CUMULATIVE PERCENTAGES FINER THAN EACH PARTICLE SIZE

Clay	0.002 mm		29.8
Fine Silt	0.006 mm	13.8 + 29.8	43.6
Medium Silt	0.02 mm	7.9 + 43.6	51.5
Coarse Silt	0.06 mm	14.3 + 51.5	65.8
Sand and Gravel	retained on 63μm	34.2 + 65.8	100.00

PARTICLE SIZE ANALYSIS

SAMPLE: Tottene 5 Mortar

Mass of sample (m): 48.01g

Mass retained on 63μm sive (m_s): 29.61g

Weight percentage retained (m_s %): 61.7

SIEVING

sieve size	mass retained (g)	Weight % retained	Weight % passing
1.18 mm	0.24	0.5	99.5
600 μm	0.54	1.2	98.3
300 μm	6.44	13.4	84.9
150 μm	15.44	32.1	52.8
63 μm	6.95	14.5	38.3
pass 63 μm	0.51		

SEDIMENTATION

Volume pipette (Vp): 11.1075 ml

Temperature: 21.5°C Specific Gravity silt and clay fractions (SG): 2.65

pipette sample time	pipette mass calculation	mass in suspension	percentage calculation	size category
4 min 5 s	m_1 = 0.276	W_1 = 12.423	8.4	medium silt
46 min	m_2 = 0.186	W_2 = 8.372	8.4	fine silt
6 hours 54 min	m_3 = 0.096	W_3 = 4.321	5.8	clay
	m_4 = 0.034	W_4 = 1.530	15.7	coarse silt

CUMULATIVE PERCENTAGES FINER THAN EACH PARTICLE SIZE

Clay	0.002 mm		5.8
Fine Silt	0.006 mm	8.4 + 5.8	14.2
Medium Silt	0.02 mm	8.4 + 14.2	22.6
Coarse Silt	0.06 mm	15.7 + 22.6	38.3
Sand and Gravel	retained on 63μm	61.7 + 38.3	100.00

PARTICLE SIZE ANALYSIS

SAMPLE: Cheminelli 1 Mortar

Mass of sample (m): 46.93g

Mass retained on 63μm sive (m_s): 26.56g

Weight percentage retained (m_s %): 56.6

SIEVING

sieve size	mass retained (g)	Weight % retained	Weight % passing
1.18 mm	0.14	0.3	99.7
600 μm	0.07	0.1	99.6
300 μm	2.10	4.5	95.1
150 μm	18.87	40.2	54.9
63 μm	5.38	11.5	43.4
pass 63 μm	0.19		

SEDIMENTATION

Volume pipette (Vp): 11.1075 ml

Temperature: 21.5°C Specific Gravity silt and clay fractions (SG): 2.65

pipette sample time	pipette mass calculation	mass in suspension	percentage calculation	size category
4 min 5 s	m_1 = 0.312	W_1 = 14.044	10.1	medium silt
46 min	m_2 = 0.207	W_2 = 9.317	5.8	fine silt
6 hours 54 min	m_3 = 0.146	W_3 = 6.572	10.7	clay
	m_4 = 0.034	W_4 = 1.530	16.8	coarse silt

CUMULATIVE PERCENTAGES FINER THAN EACH PARTICLE SIZE

Clay	0.002 mm		10.7
Fine Silt	0.006 mm	5.8 + 10.7	16.5
Medium Silt	0.02 mm	16.5 + 10.1	26.6
Coarse Silt	0.06 mm	26.6 + 16.8	43.4
Sand and Gravel	retained on 63μm	56.6 + 43.4	100.00

PARTICLE SIZE ANALYSIS

SAMPLE: Buzzi 1 Mortar

Mass of sample (m): 48.2g

Mass retained on 63μm sive (m_s): 24.75g

Weight percentage retained (m_s %): 50.1

SIEVING

sieve size	mass retained (g)	Weight % retained	Weight % passing
1.18 mm	0.17	0.3	99.7
600 μm	0.36	0.7	99.0
300 μm	4.46	9.2	89.8
150 μm	14.93	31.0	58.8
63 μm	4.23	8.8	50.0
pass 63 μm	0.27		

SEDIMENTATION

Volume pipette (Vp): 11.1075 ml

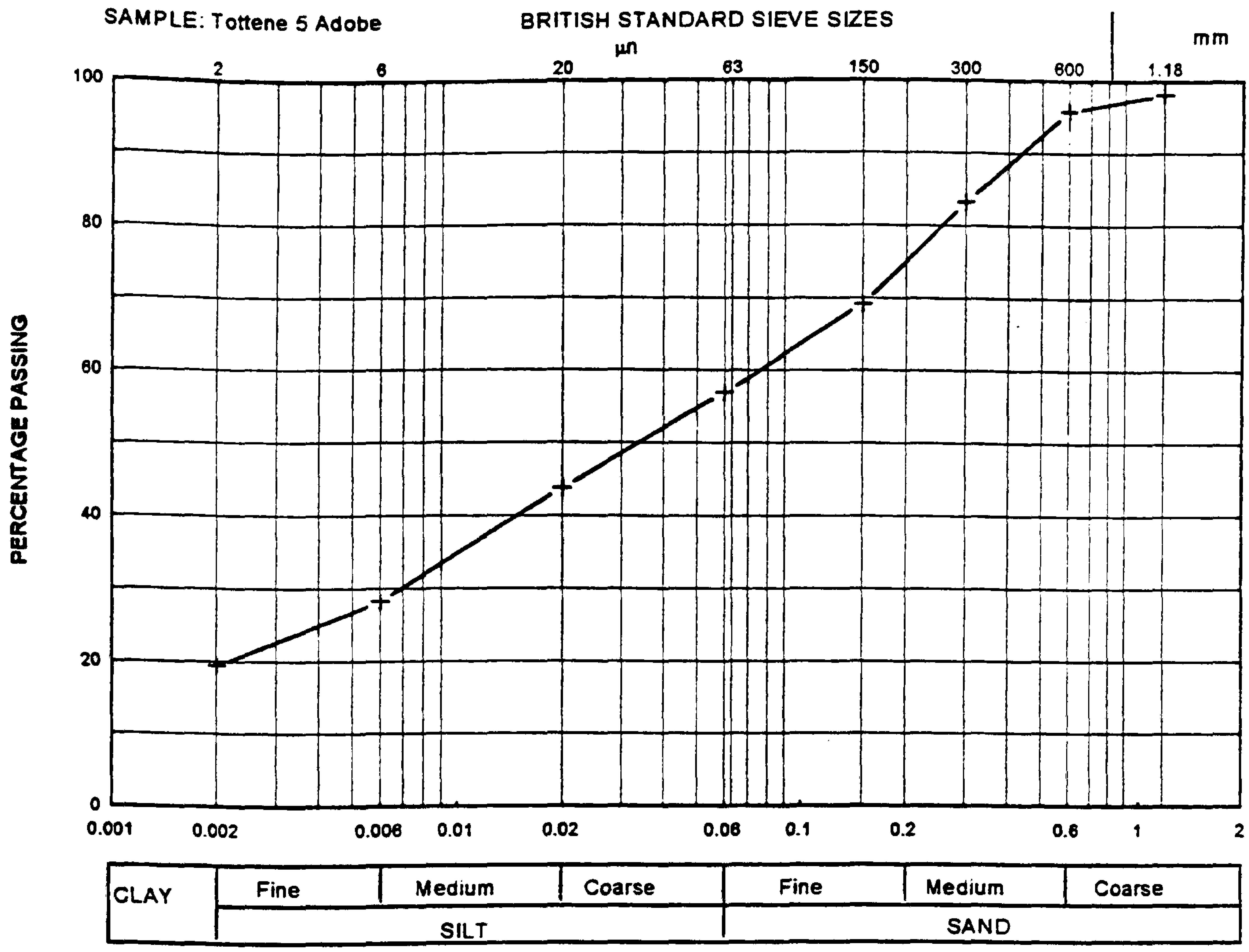
Temperature: 21.5°C Specific Gravity silt and clay fractions (SG): 2.65

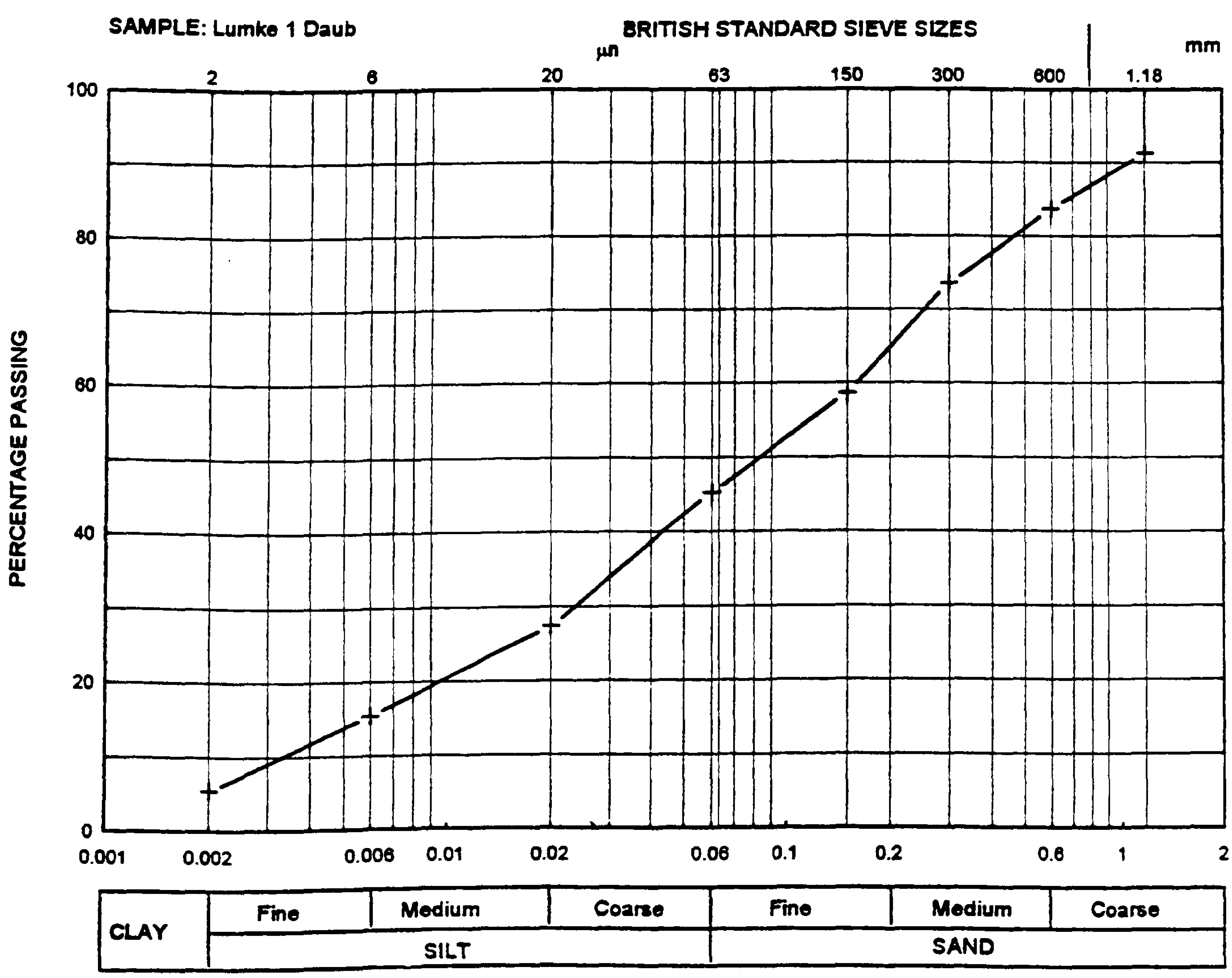
pipette sample time	pipette mass calculation	mass in suspension	percentage calculation	size category
4 min 5 s	m_1 = 0.396	W_1 = 17.825	11.7	medium silt
46 min	m_2 = 0.271	W_2 = 12.198	12.6	fine silt
6 hours 54 min	m_3 = 0.136	W_3 = 6.121	9.5	clay
	m_4 = 0.034	W_4 = 1.530	16.1	coarse silt

CUMULATIVE PERCENTAGES FINER THAN EACH PARTICLE SIZE

Clay	0.002 mm		9.5
Fine Silt	0.006 mm	12.6 + 9.5	22.1
Medium Silt	0.02 mm	11.7 + 22.1	33.8
Coarse Silt	0.06 mm	16.1 + 33.8	49.9
Sand and Gravel	retained on 63μm	50.1 + 49.9	100.00

GRADING CURVE FROM SIEVING AND SEDIMENTATION RESULTS





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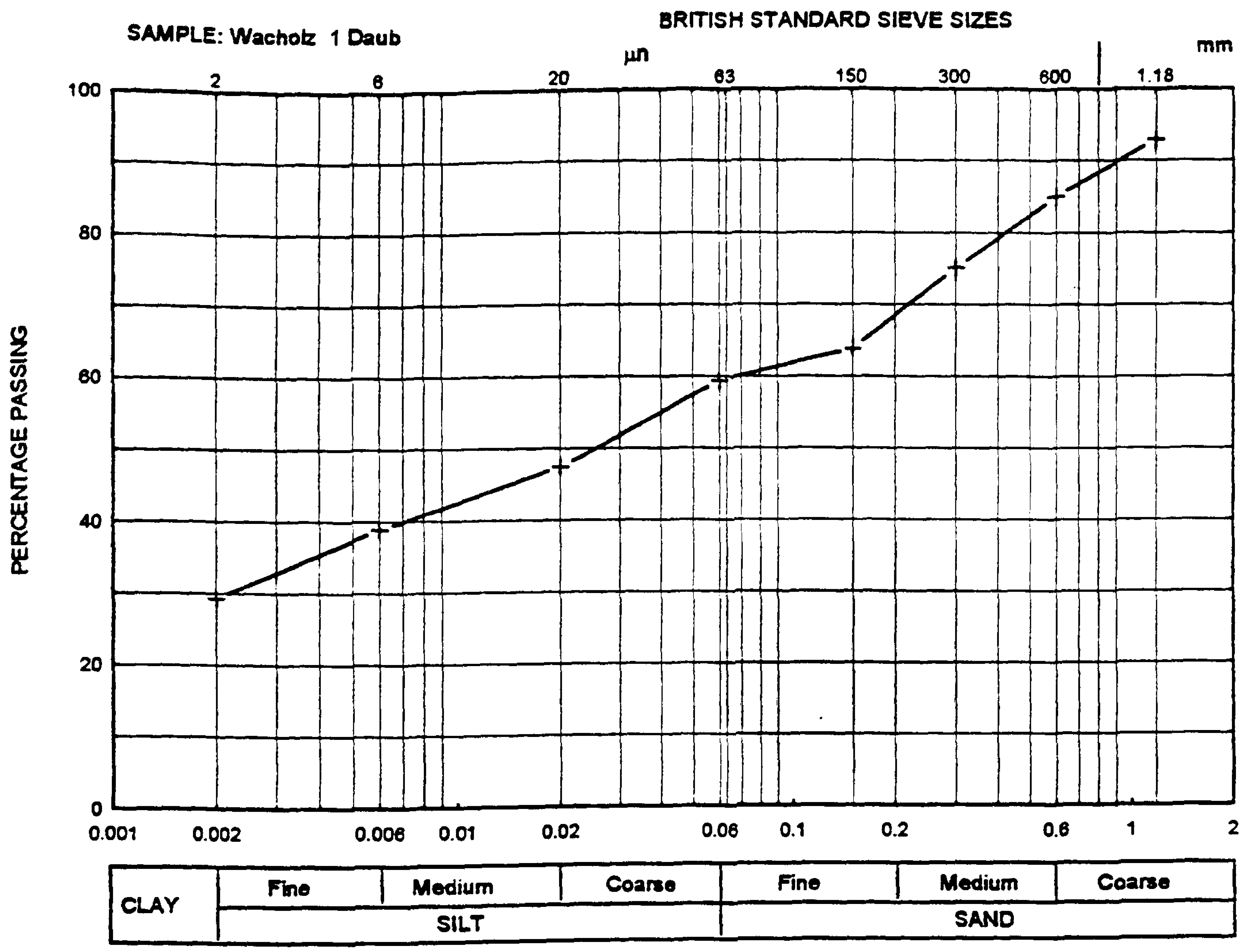
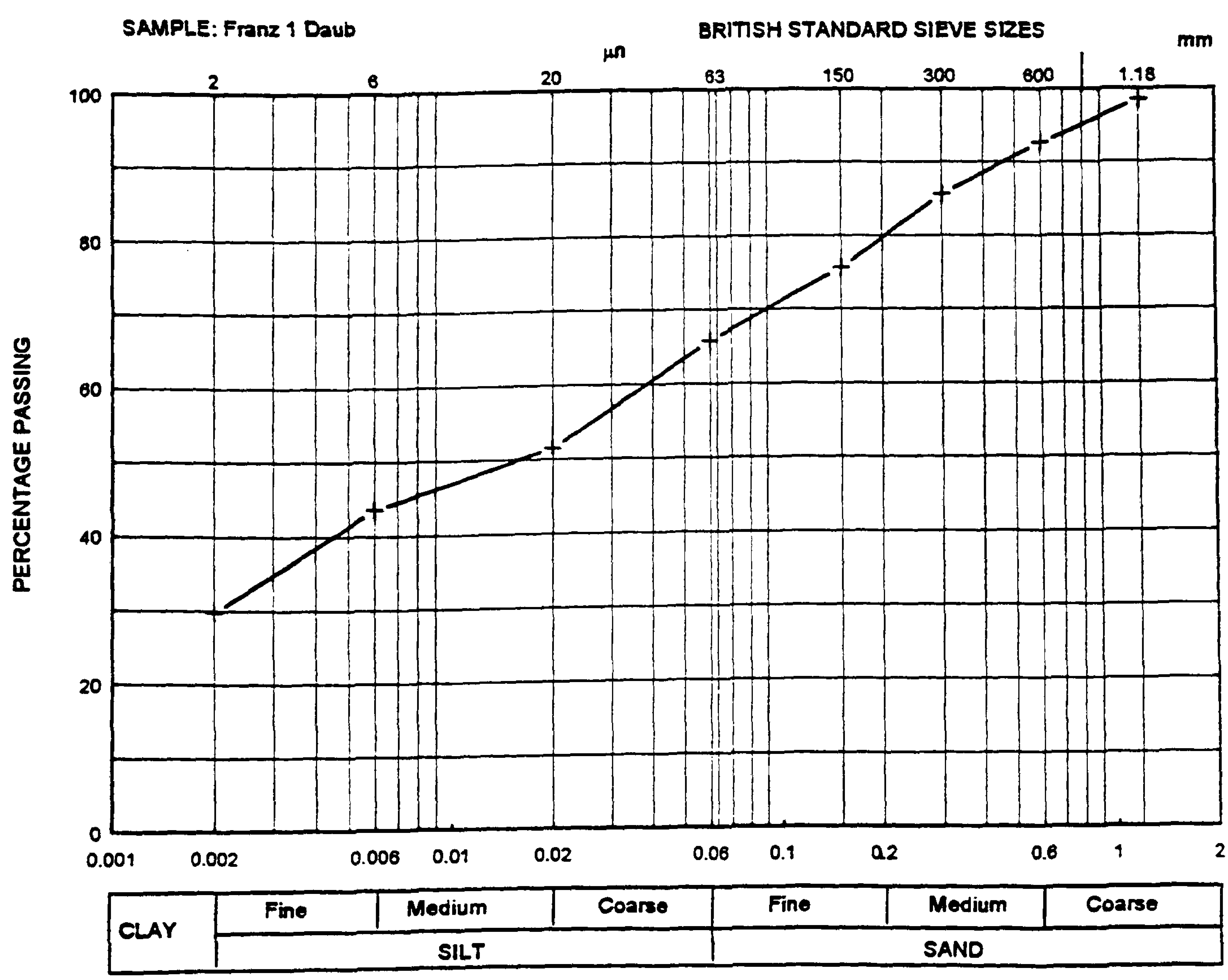
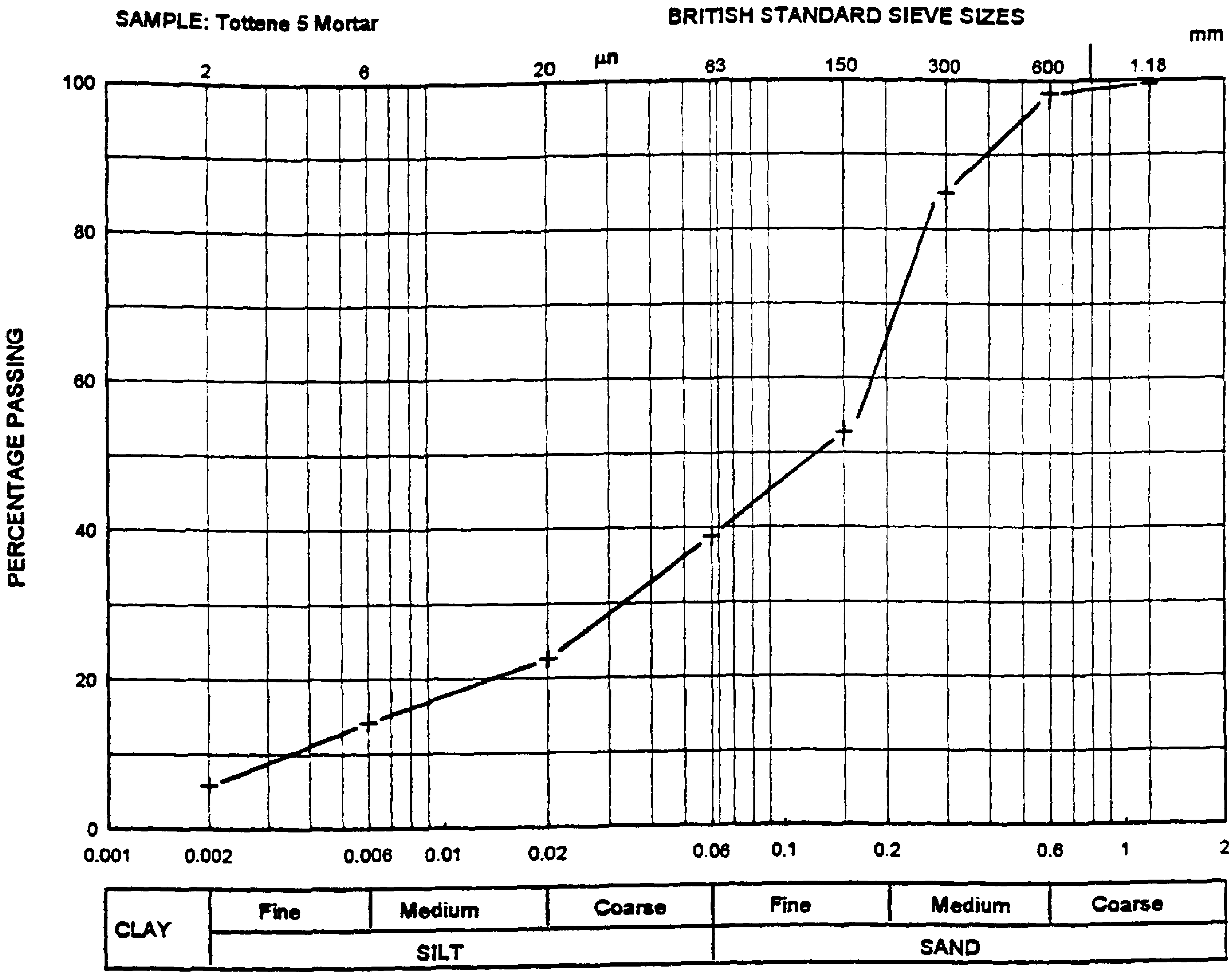


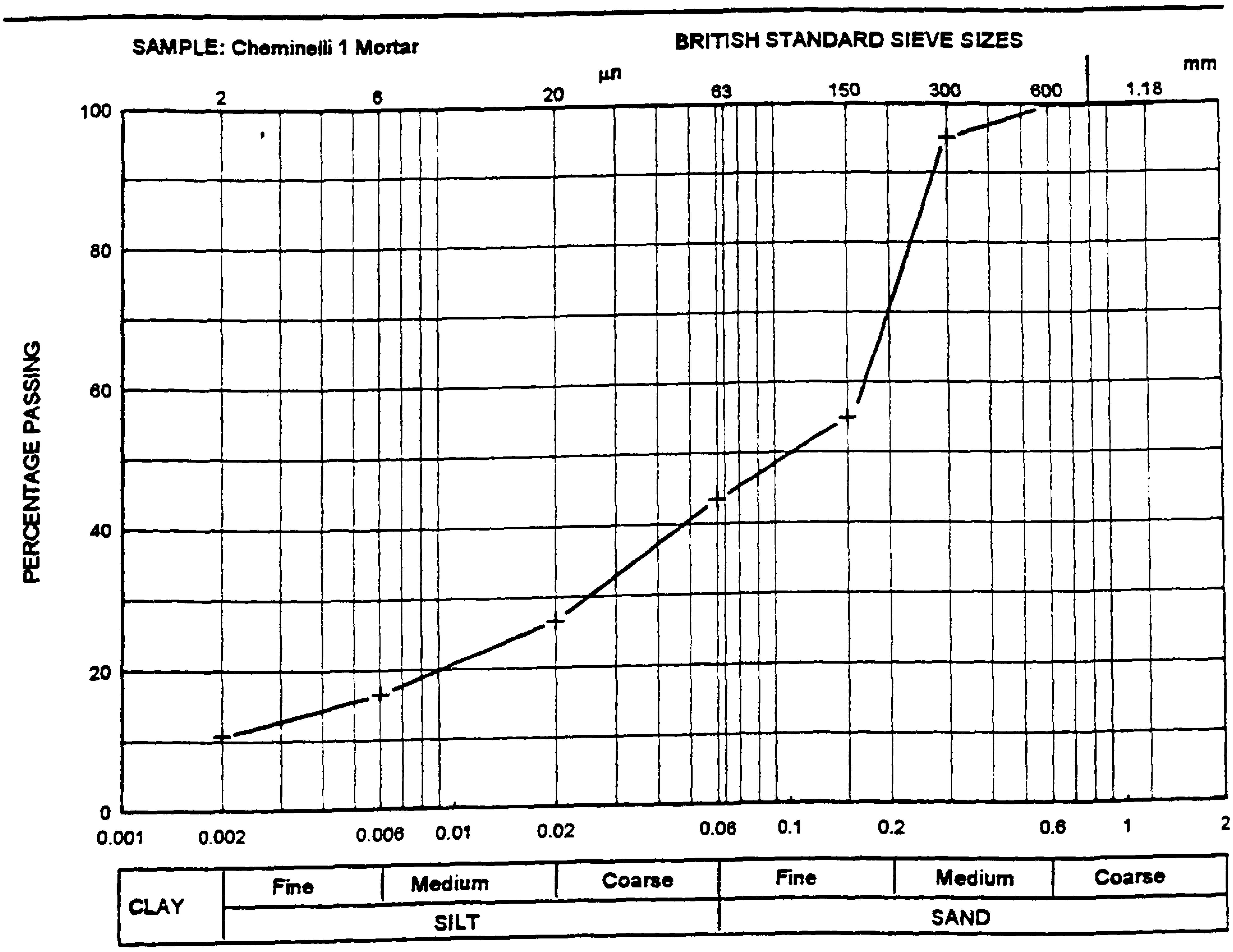


GRADING CURVE FROM SIEVING AND SEDIMENTATION RESULTS

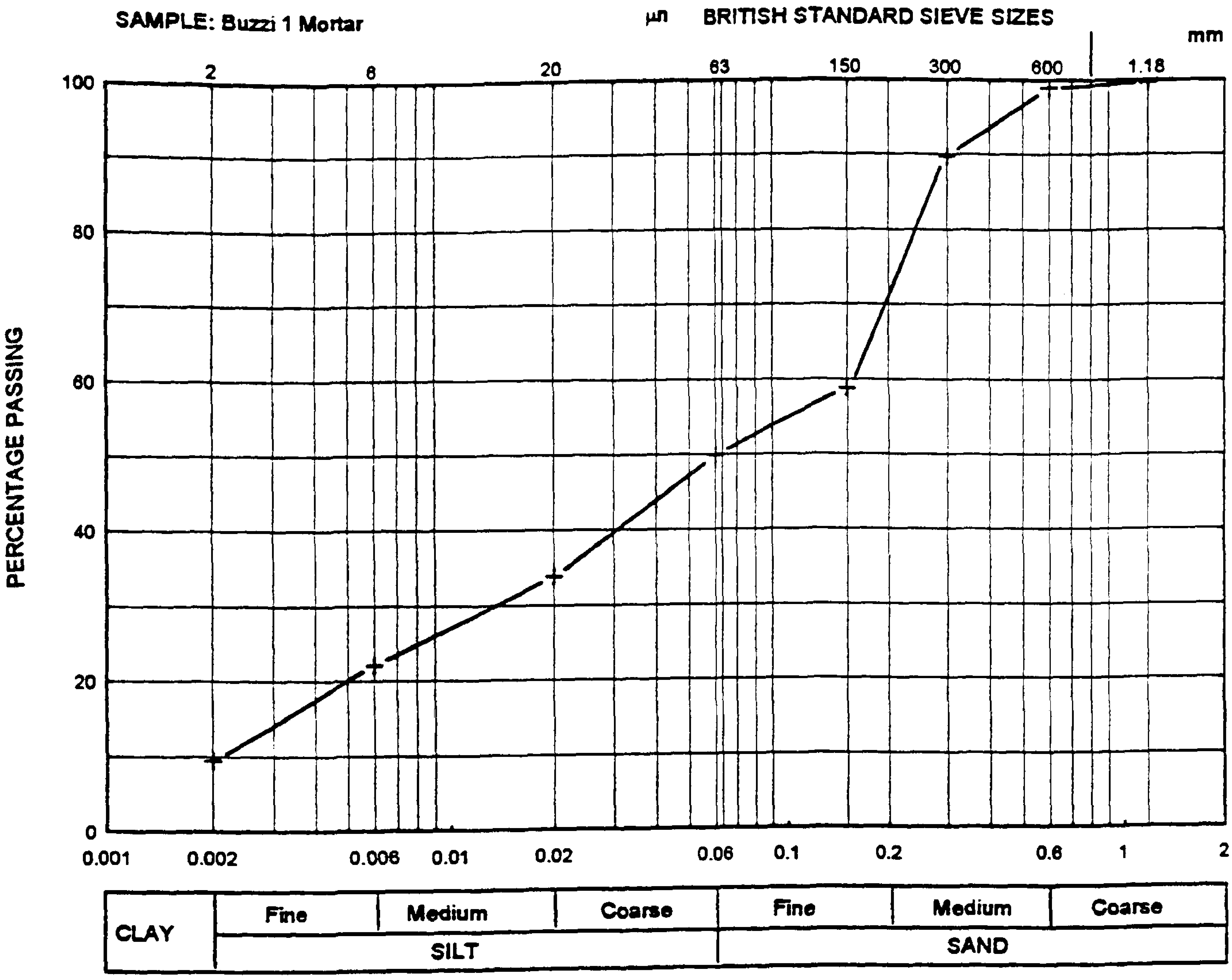
SAMPLE: Tottene 5 Mortar



SAMPLE: Chemineili 1 Mortar



GRADING CURVE FROM SIEVING AND SEDIMENTATION RESULTS



APPENDIX B: Liquid and Plastic Limits

PLASTIC AND LIQUID LIMITS

SAMPLE: Tottene 5 Adobe

Mass of sample: 178.59g Mass passing on 425μm sieve: 156.33g Percentage of clay: 19.5%

PLASTIC LIMIT

Test number	1	2	3	4	Average
Container no.	TO 1	TO 2	TO 3	TO 4	
Wet soil & container (g)	115.93	115.07	28.19	26.11	
Dry soil & container (g)	113.93	111.12	26.83	25.00	
Container (g)	98.93	91.74	18.96	18.77	
Dry soil (g)	14.67	19.38	7.97	6.23	
Moisture loss (g)	2.9	3.95	1.36	1.11	
MOISTURE CONTENT %	19.77	20.38	17.06	17.81	18.75

LIQUID LIMIT

Test Number	1	2	3	4
Cone penetration	14.9/ 15.1	18.0/17.9/18.2	23.0/22.2/22.2	25.9/25.3/25.3
Average penetration	15.0	18.03	22.47	25.5
Container no.	TO 1	TO 2	TO 3	TO 4
Wet soil & container (g)	36.712	35.710	39.339	37.562
Dry soil & container (g)	35.961	35.048	37.925	35.539
Mass container (g)	33.202	32.721	33.269	29.195
Mass dry soil (g)	2.759	2.327	4.656	6.344
Moisture loss (g)	0.751	0.662	1.414	2.023
MOISTURE CONTENT %	27.22	28.448	30.369	31.888

RESULTS

LL: 29.38 (determined graphically)

PL: 18.77

PI: 10.61

PLASTIC AND LIQUID LIMITS

SAMPLE: Lumke 1 Daub

Mass of sample: 224.4g Mass passing on 425μm sieve: 140.19g Percentage of clay: 5.4%

PLASTIC LIMIT

Test number	1	2	3	4	Average
Container no.	LU 1	LU 2	LU 3	LU 4	
Wet soil & container (g)	115.19	107.64	29.73	30.42	
Dry soil & container (g)	111.07	103.97	26.84	27.45	
Container (g)	99.20	93.25	18.68	19.15	
Dry soil (g)	11.87	10.72	8.16	8.3	
Moisture loss (g)	4.12	3.67	2.89	2.97	
MOISTURE CONTENT %	34.71	34.23	35.42	35.78	35.03

LIQUID LIMIT

Test Number	1	2	3	4
Cone penetration	15.3/15.7/15.6	16.7/17.5/16.5	22.1/22.7/22.3	25.2/25.2
Average penetration	15.53	16.9	22.36	25.2
Container no.	LU 1	LU 2	LU 3	LU 4
Wet soil & container (g)	38.351	36.536	38.170	40.665
Dry soil & container (g)	36.888	34.216	36.772	37.998
Mass container (g)	33.438	28.808	33.638	32.217
Mass dry soil (g)	3.45	5.408	3.134	5.781
Moisture loss (g)	1.463	2.32	1.398	2.667
MOISTURE CONTENT %	42.405	42.899	44.607	46.133

RESULTS

LL: 44.00 (determined graphically)

PL: 35.00

PI: 9.00

PLASTIC AND LIQUID LIMITS

SAMPLE: Wacholz 1 Daub

Mass of sample: 243.83 Mass passing on 425μm sieve: 151.05 Percentage of clay: 29.3%

PLASTIC LIMIT

Test number	1	2	3	4	Average
Container no.	WA 1	WA 2	WA 3	WA 4	
Wet soil & container (g)	40.83	37.14	42.05	42.43	
Dry soil & container (g)	39.26	35.81	40.27	40.44	
Container (g)	34.23	31.38	35.00	34.76	
Dry soil (g)	5.03	4.43	5.27	5.68	
Moisture loss (g)	1.57	1.33	1.78	1.99	
MOISTURE CONTENT %	31.21	30.02	33.77	35.03	32.50

LIQUID LIMIT

Test Number	1	2	3	4
Cone penetration	15.7/16.0	18.9/19.8/20.4	24.0/23.4/24.1	25.6/24.9/25.5
Average penetration	15.85	19.7	23.83	25.33
Container no.	WA 1	WA 2	WA 3	WA 4
Wet soil & container (g)	43.305	45.853	37.300	39.484
Dry soil & container (g)	40.285	41.801	34.473	36.369
Mass container (g)	34.825	34.983	30.024	31.646
Mass dry soil (g)	5.46	6.818	4.449	4.723
Moisture loss (g)	3.02	4.052	2.827	3.115
MOISTURE CONTENT %	55.311	59.430	63.542	65.953

RESULTS

LL: 60.30 (determined graphically)

PL: 32.50

PI: 27.80

PLASTIC AND LIQUID LIMITS

SAMPLE: Franz 1 Daub

Mass of sample: 224.4g Mass passing on 425μm sieve: 140.19 Percentage of clay: 29.8%

PLASTIC LIMIT

Test number	1	2	3	4	Average
Container no.	FRA 1	FRA 2	FRA 3	FRA 4	
Wet soil & container (g)	42.15	41.37	40.53	38.32	
Dry soil & container (g)	39.52	38.77	37.77	36.29	
Container (g)	33.41	33.01	31.90	31.79	
Dry soil (g)	6.11	5.76	5.87	4.5	
Moisture loss (g)	2.63	2.6	2.76	2.03	
MOISTURE CONTENT %	43.08	45.13	47.01	45.11	45.07

LIQUID LIMIT

Test Number	1	2	3	4
Cone penetration	15.6/16.4/16.2	19.5/19.2	21.8/22.3	25.1/24.3/25.0
Average penetration	16.06	19.35	22.05	24.8
Container no.	FRA 1	FRA 2	FRA 3	FRA 4
Wet soil & container (g)	20.629	22.462	19.901	19.857
Dry soil & container (g)	18.243	19.029	17.174	17.368
Mass container (g)	14.450	13.860	13.225	13.900
Mass dry soil (g)	3.793	5.169	3.949	3.468
Moisture loss (g)	2.386	3.433	2.727	2.489
MOISTURE CONTENT %	62.905	66.415	69.055	71.770

RESULTS

LL: 67.00 (determined graphically)

PL: 45.07

PI: 22.03

PLASTIC AND LIQUID LIMITS

SAMPLE: Tottene 5 Mortar

Mass of sample: 146.05g Mass passing on 425μm sieve: 136.64 Percentage of clay: 5.8%

PLASTIC LIMIT

Test number	1	2	3	4	Average
Container no.	TO 1	TO 2	TO 3	TO 4	
Wet soil & container (g)	39.96	40.7	43.47	40.96	
Dry soil & container (g)	38.71	39.52	41.96	39.39	
Container (g)	32.79	33.89	34.82	31.91	
Dry soil (g)	5.92	5.63	7.14	7.48	
Moisture loss (g)	1.25	1.18	1.51	1.57	
MOISTURE CONTENT %	21.11	20.95	21.14	20.98	21.04

LIQUID LIMIT

Test Number	1	2	3	4
Cone penetration	14.9/14.6	19.4/18.8/19.4	23.4/23.4	25.9/25.1/25.1
Average penetration	14.75	19.02	23.4	25.36
Container no.	TO 1	TO 2	TO 3	TO 4
Wet soil & container (g)	38.610	37.911	40.112	40.687
Dry soil & container (g)	37.774	37.076	38.980	39.372
Mass container (g)	34.376	33.857	34.757	34.544
Mass dry soil (g)	3.398	3.219	4.223	4.828
Moisture loss (g)	0.836	0.835	1.132	1.315
MOISTURE CONTENT %	24.602	25.939	26.805	27.236

RESULTS

LL: 26.00 (determined graphically)

PL: 21.04

PI: 4.96

PLASTIC AND LIQUID LIMITS

SAMPLE: Cheminelli 1 Mortar

Mass of sample: 126.06g Mass passing on 425μm sieve: 120.47g Percentage of clay: 10.7%

PLASTIC LIMIT

Test number	1	2	3	4	Average
Container no.	CHE 1	CHE 2	CHE 3	CHE 4	
Wet soil & container (g)	34.01	42.23	41.43	37.81	
Dry soil & container (g)	32.94	41.06	40.36	36.76	
Container (g)	27.01	34.06	34.45	31.03	
Dry soil (g)	5.93	6.46	5.91	5.73	
Moisture loss (g)	1.07	1.17	1.07	1.05	
MOISTURE CONTENT %	18.04	18.11	18.10	18.32	18.14

LIQUID LIMIT

Test Number	1	2	3	4
Cone penetration	17.3/18.2/17.6	21.6/22.0	24.9/25.6	25.6/25.1
Average penetration	15.03	17.36	21.8	25.25
Container no.	CHE 1	CHE 2	CHE 3	CHE 4
Wet soil & container (g)	38.891	37.863	41.201	43.575
Dry soil & container (g)	34.198	36.613	39.952	41.833
Mass container (g)	34.896	30.917	34.527	34.657
Mass dry soil (g)	3.302	5.696	5.425	7.176
Moisture loss (g)	0.693	1.25	1.249	1.744
MOISTURE CONTENT %	20.98	21.96	23.02	24.30

RESULTS

LL: 22.60 (determined graphically)

PL: 18.14

PI: 3.46

PLASTIC AND LIQUID LIMITS

SAMPLE: Buzzi 1 Mortar

Mass of sample: 118.51g Mass passing on 425μm sieve: 112.08g Percentage of clay: 9.5%

PLASTIC LIMIT

Test number	1	2	3	4	Average
Container no.	BU 1	BU 2	BU 3	BU 4	
Wet soil & container (g)	39.45	40.37	40.26	41.06	
Dry soil & container (g)	38.11	38.94	38.64	39.61	
Container (g)	32.23	32.74	31.66	33.46	
Dry soil (g)	5.88	6.2	6.98	6.15	
Moisture loss (g)	1.34	1.43	1.62	1.45	
MOISTURE CONTENT %	22.78	23.06	23.20	23.57	23.13

LIQUID LIMIT

Test Number	1	2	3	4
Cone penetration	15.8/15.4	19.4/19.0	23.6/22.7/22.6	25.1/25.4
Average penetration	15.6	19.2	22.96	25.25
Container no.	BU 1	BU 2	BU 3	BU 4
Wet soil & container (g)	37.455	38.262	37.471	39.982
Dry soil & container (g)	36.115	36.709	36.214	38.632
Mass container (g)	31.793	31.831	32.419	34.658
Mass dry soil (g)	4.322	4.878	3.795	3.974
Moisture loss (g)	1.34	1.553	1.257	1.35
MOISTURE CONTENT %	31.00	31.83	33.12	33.97

RESULTS

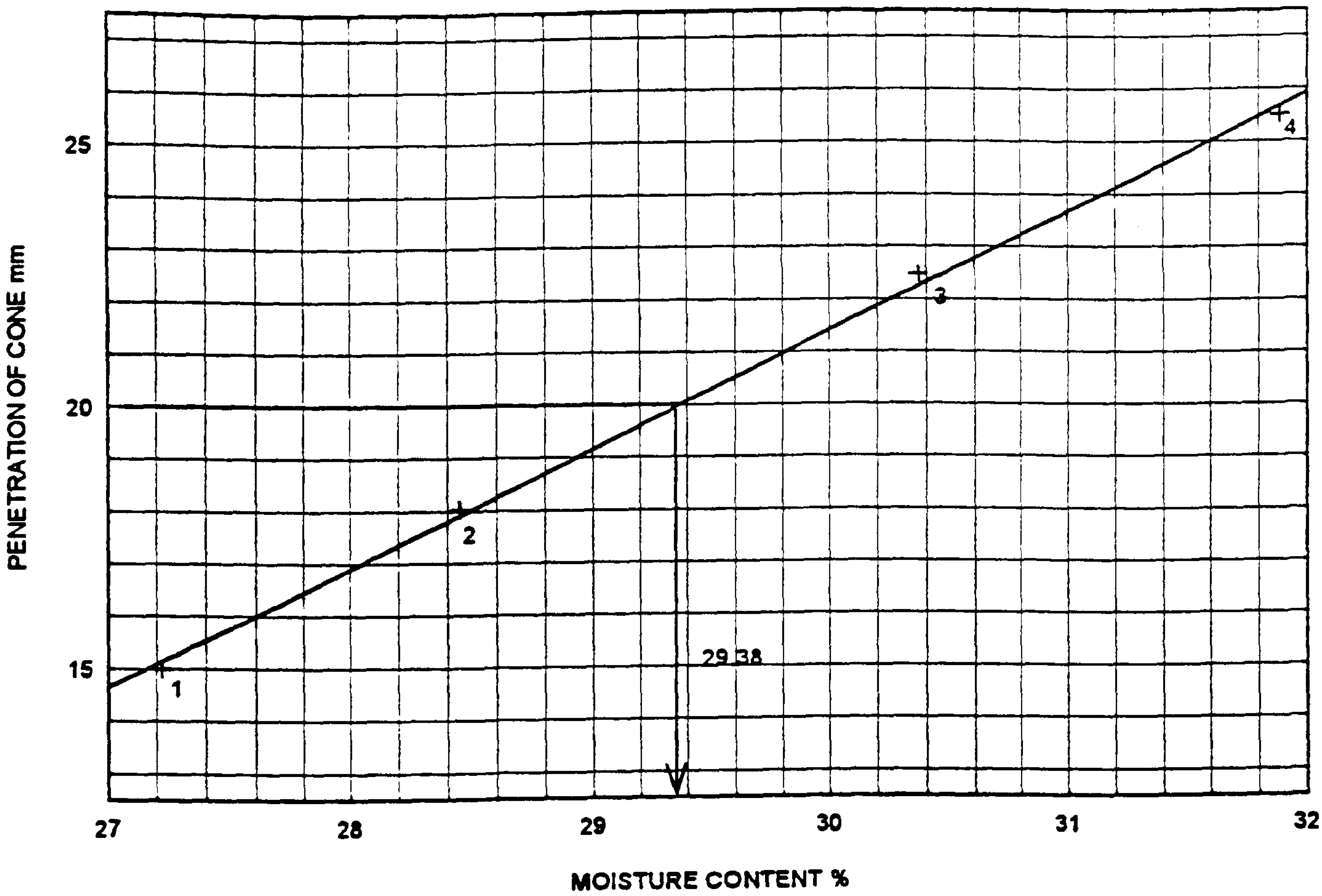
LL: 32.22 (determined graphically)

PL: 23.13

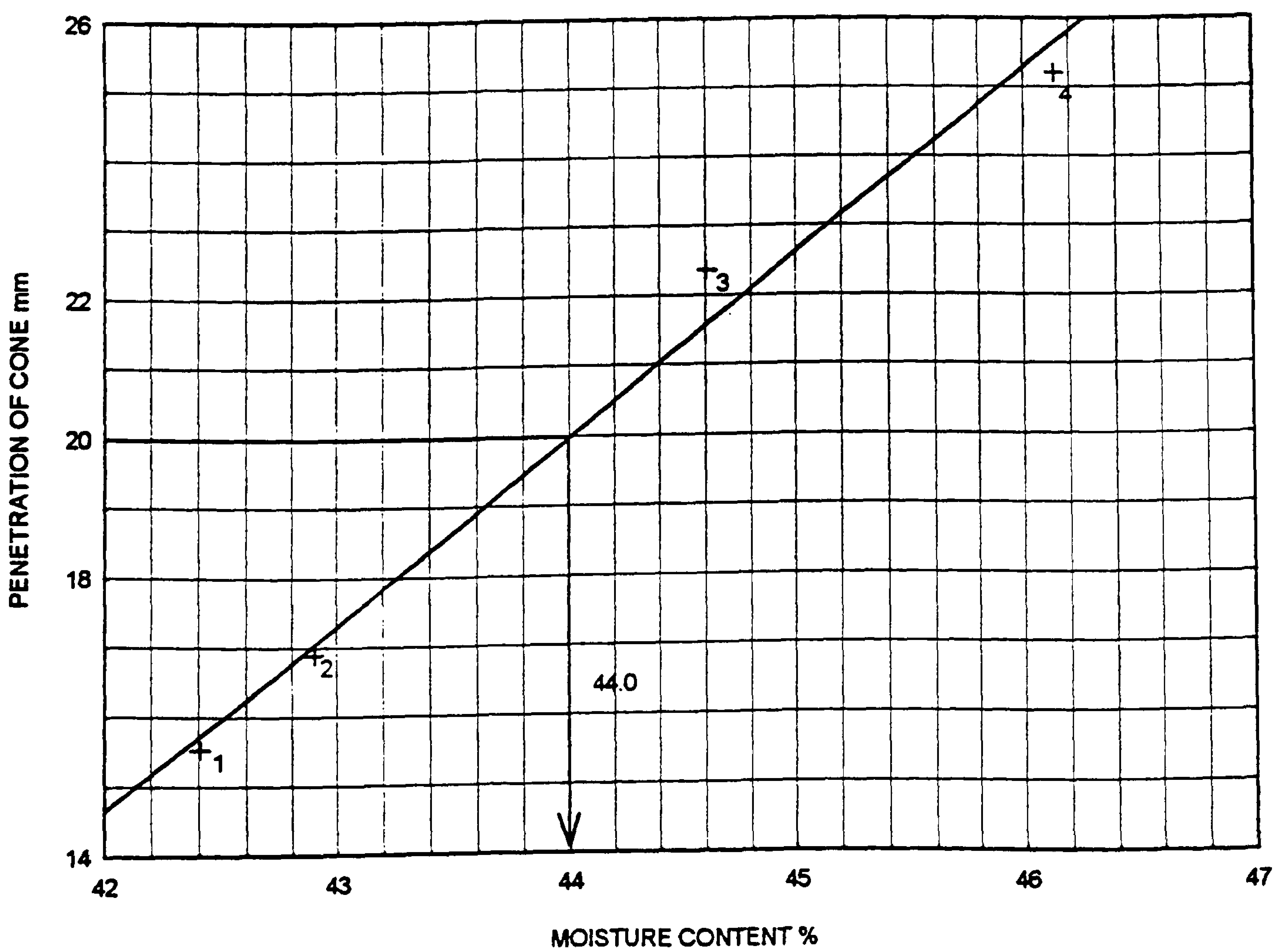
PI: 9.09

LIQUID LIMIT GRAPH (CONE TEST)

SAMPLE: Tottene 5 Adobe

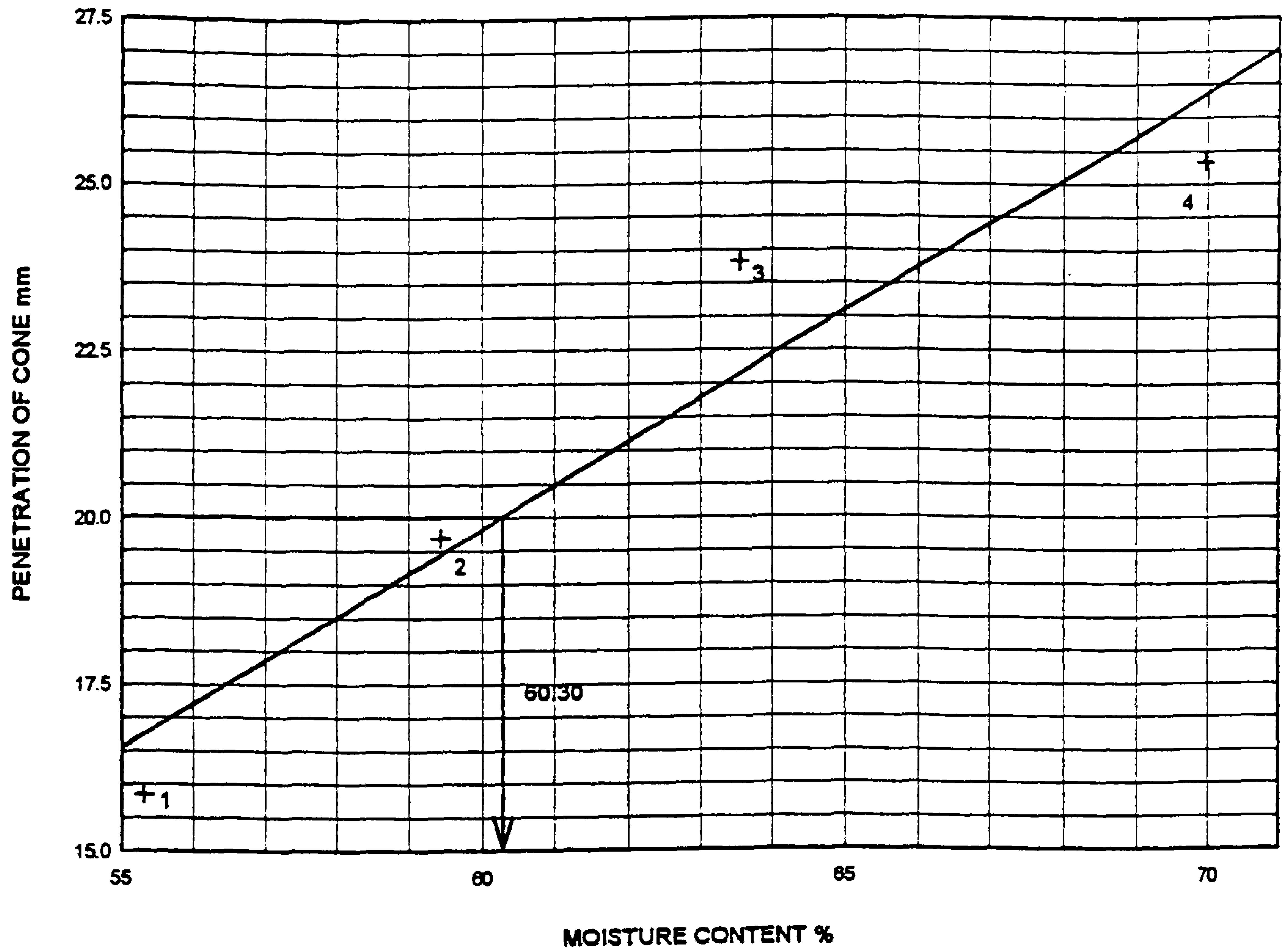


SAMPLE: Lumke 1 Daub

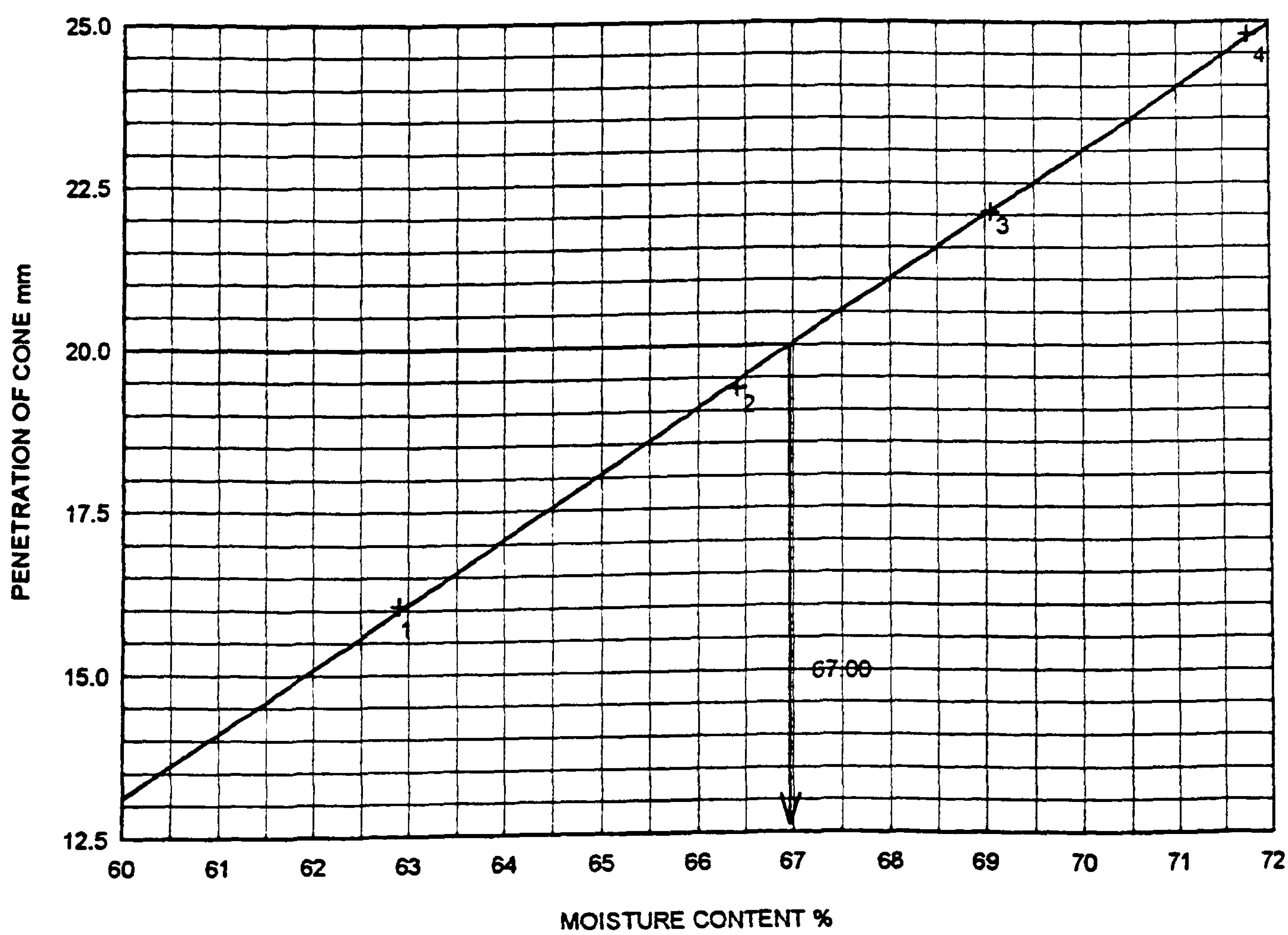


LIQUID LIMIT GRAPH (CONE TEST)

SAMPLE: Wacholz 1 Daub

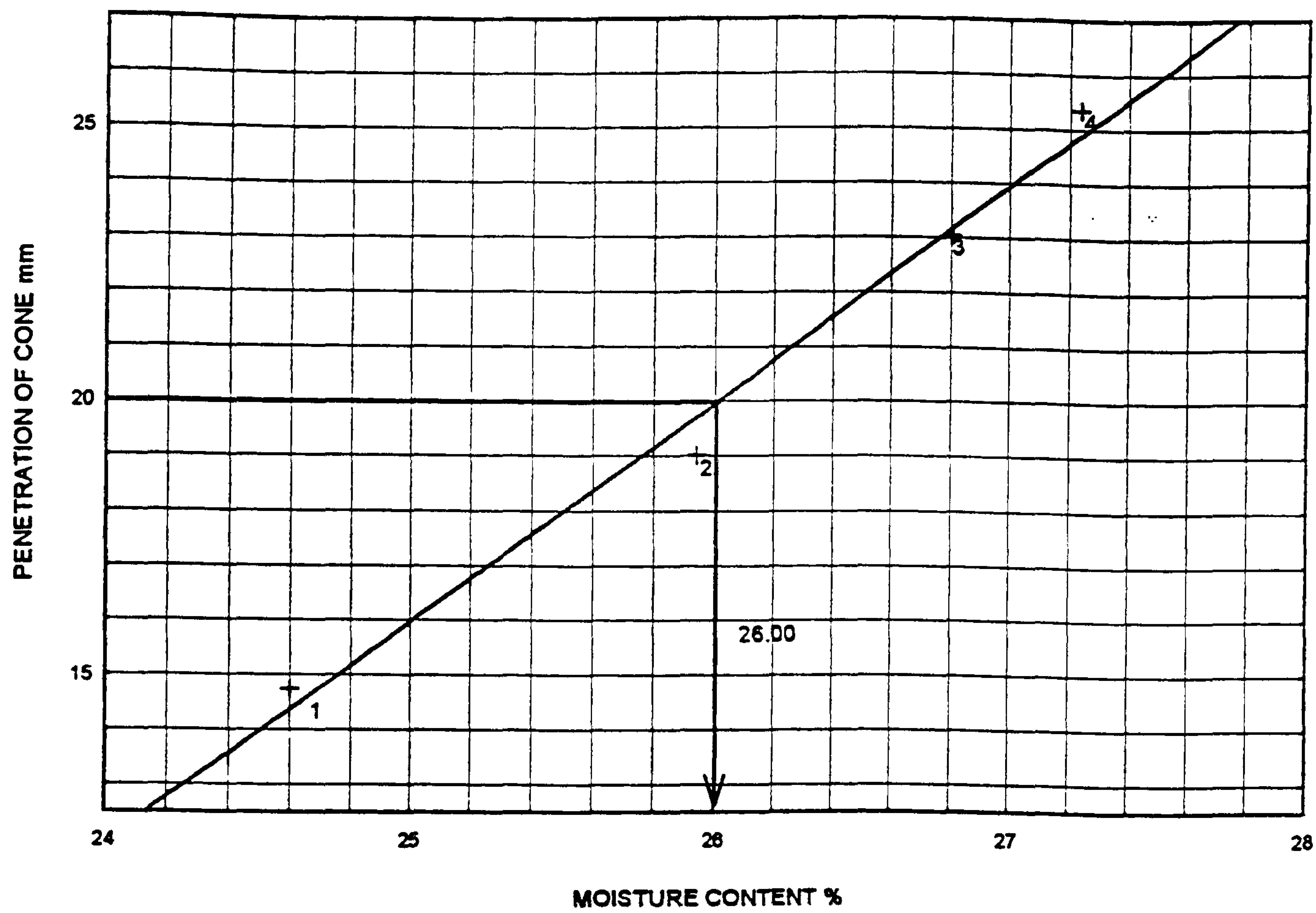


SAMPLE: Franz 1 Daub

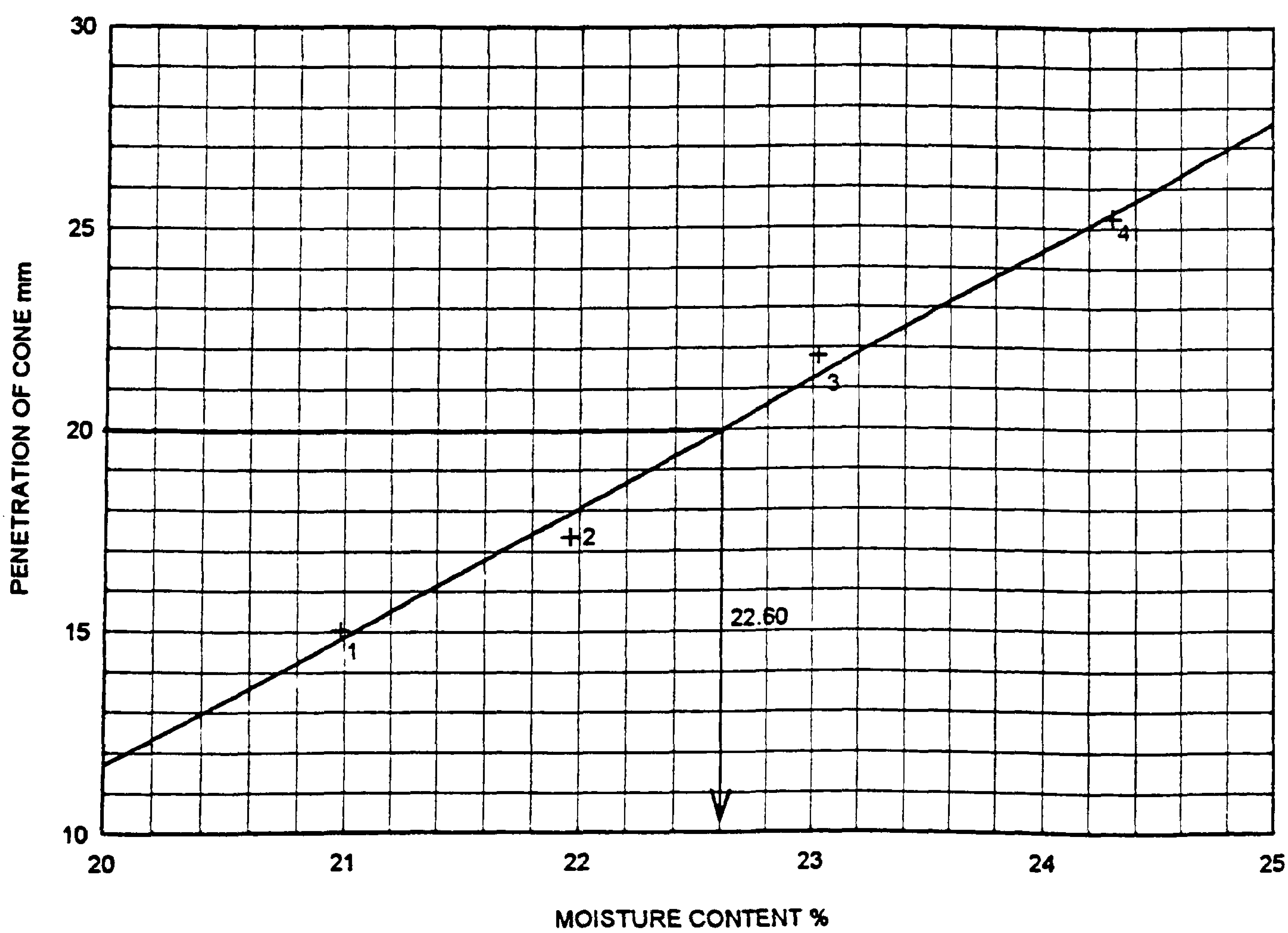


LIQUID LIMIT GRAPH (CONE TEST)

SAMPLE: Tottene 5 Mortar

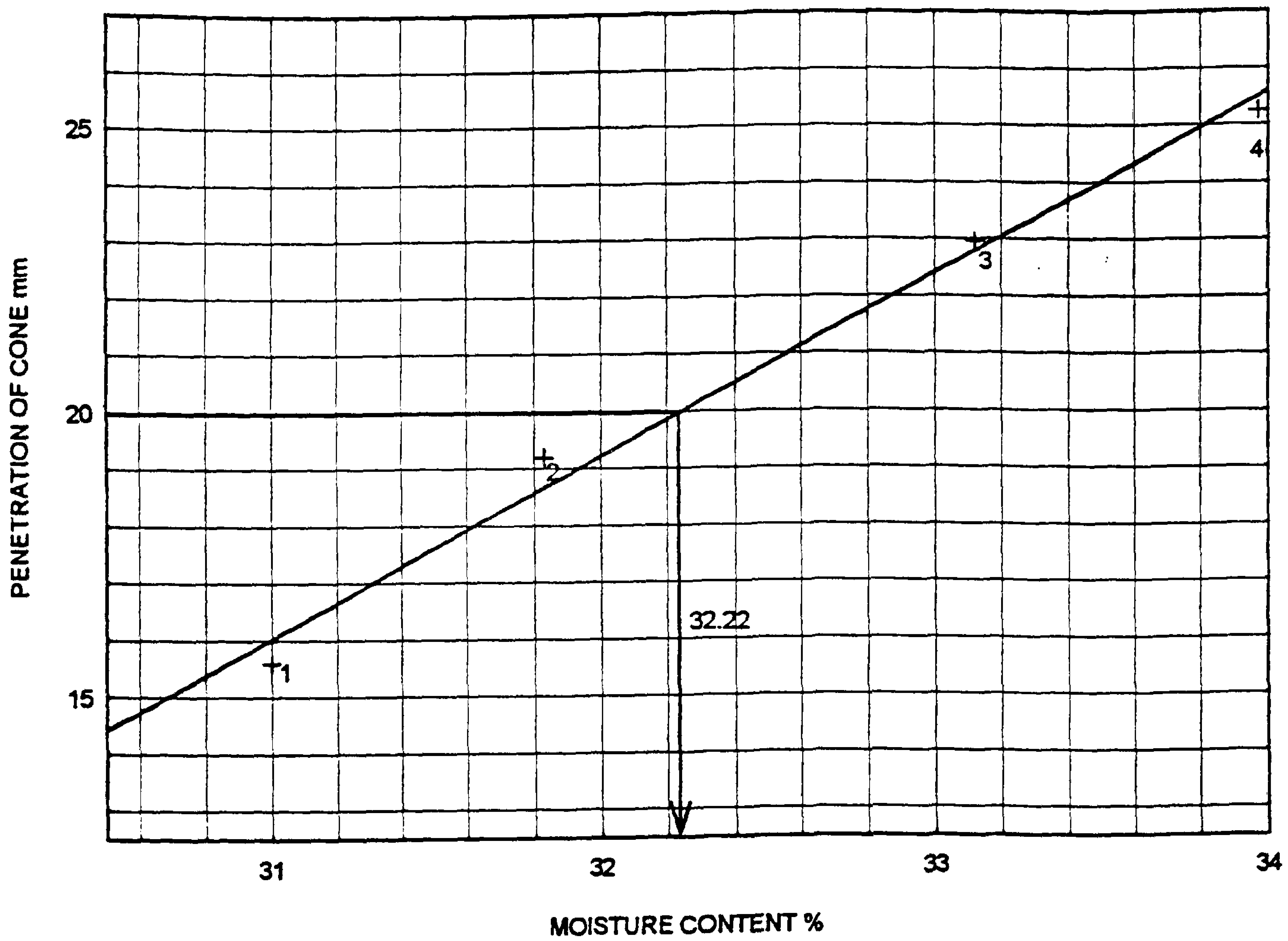


SAMPLE: Cheminelli 1 Mortar



LIQUID LIMIT GRAPH (CONE TEST)

SAMPLE: Buzzi 1 Mortar



APPENDIX C: Organic Matter

DETERMINATION OF ORGANIC MATTER

SAMPLE	LOSS IGNITION (%)
Reincke 8 Plaster	2.8
Cheminelli Mortar	3.0
Wacholz 2 Plaster	3.9
Tottene 5 Adobe	4.4
Franz 3 Render	4.5
Lumke 2 Render	5.9
Tottene 5 Mortar	5.9
Buzzi 1 Mortar	7.2
Wacholz 1 Daub	11.2
Lumke 1 Daub	12.9
Franz 1 Daub	13.6
Fiedler 3 Undercoat	39.1

APPENDIX D: Thin Sections

OPTICAL MICROSCOPY OBSERVATION OF THIN SECTIONS

SAMPLE: Franz 3 Render

COARSE FRACTION: The texture is totally dominated by sand size material.

FINE FRACTION: It is a thin earth matrix, probably less than 10% by weight. The clay is not clean.

ARRANGEMENT OF COARSE AND FINE FRACTION: It is a loose material, bridges of matrix linking the grains.

SAMPLE: Lumke 2 Render

COARSE FRACTION: The texture is mainly sand size material. The mineralogy is variable and complex; soil and possible metamorphic material (bits of rock) and rather weathered material.

FINE FRACTION: It is a thin earth matrix, probably less than 10 % by weight. The clay is not clean, but is mixed with fine charcoal and organic matter.

ARRANGEMENT OF COARSE AND FINE FRACTION: It is a loose material, bridges of matrix linking the grains.

SAMPLE: Tottene 1 Render

COARSE FRACTION: The texture is a medium size sand material. The grains are more round in shape. Coarse crystals of calcium carbonate are evident.

FINE FRACTION: It is a thin matrix of calcitic nature, but not pure (areas of yellow colour).

ARRANGEMENT OF COARSE AND FINE FRACTION: The grains are coated by the matrix, but it is a loose material.
Obs: The limewash is very dense. (dark)

SAMPLE: Buzzi 2 Render

COARSE FRACTION: The texture is more medium size sand and very fine sand material. The sand is mainly of quite angular shape and few are round.

FINE FRACTION: It is pale brown, impure calcitic matrix. The lime matrix is mixed with inclusions of silt size particles.

ARRANGEMENT OF COARSE AND FINE FRACTION: The grains are coated by the matrix.

OPTICAL MICROSCOPY OBSERVATION OF THIN SECTIONS

SAMPLE: Fiedler 1 Render

COARSE FRACTION: The texture ranges from coarse to fine sand material. The mineralogy is mainly quartz sand and ocasionally secondary minerals.

FINE FRACTION: It is a pale brown colour, slightly impure calcitic matrix. Ocasionally there are bits of clay and some silt size material.

ARRANGEMENT OF COARSE AND FINE FRACTION: The grains are coated by the matrix.

SAMPLE: Fiedler 8 Render

COARSE FRACTION: The texture is coarse to fine sand material. The mineralogy is mainly quartz sand.

FINE FRACTION: It is an impure calcitic matrix. It is a pale brown matrix probably resulting from the effect of organic material dung, flacks of charcoal or other organic matter. It is a very dense binding material.

ARRANGEMENT OF COARSE AND FINE FRACTION: The grains are well coated by the matrix.

SAMPLE: Wacholz 2 Plaster

COARSE FRACTION: The texture is mainly coarse sand size material. The mineralogy is mainly quartz but also bits of rocks. A fibre fragment is visible.

FINE FRACTION: It is a thin earth matrix, probably less than 10% by weight.

ARRANGEMENT OF COARSE AND FINE FRACTION: Not homogeneous. There are areas where the grains are bridged by the matrix or coated by the matrix.

SAMPLE: Wacholz 3 plaster (examination of the lime- sand undercoat)

COARSE FRACTION: The texture is a very coarse sand size material. The mineralogy is mainly quartz.

FINE FRACTION: It is a calcitic matrix, but it is cloudy. It may contain impurities or the lime may be partially carbonated.

ARRANGEMENT OF COARSE AND FINE FRACTION: The grains are coated by the matrix.

OPTICAL MICROSCOPY OBSERVATION OF THIN SECTIONS

SAMPLE: Reincke 8 Plaster

COARSE FRACTION: The texture is coarse to fine sand material. The grains are mainly quartz and few feldspar. There is evidence of a fragment of high birefringence which may be a re- use of a building material. The sand is rather angular.

FINE FRACTION: It is a thin earth matrix. The colour is a strong brown with fine organic materials which are not birefringent. The clay percentage is probably not more than 5% by weight. Optically there is no evidence of any calcium carbonate.

ARRANGEMENT OF COARSE AND FINE FRACTION: Not homogeneous. There are areas of where the grains are bridged by the matrix or coated by the matrix.

Obs/ stratigraphy: 1st plaster and multilayers of silt limewash and limewash; 2nd plaster and multilayers of silt limewash and limewash.

SAMPLE: Havenstein 1 Plaster

COARSE FRACTION: The texture is coarse to fine sand material. The mineralogy is quartz, feldspar and lots of mica. There are also inclusions of calcium carbonate.

FINE FRACTION: It is a thin matrix which nature is not lime rich. There are a lot of dark inclusions, organic inclusions of some kind.

ARRANGEMENT OF COARSE AND FINE FRACTION: The matrix is not homogeneous. There are areas of impure coating and then a very pure coating. The grains are loosely embedded by the matrix.

SAMPLE: Poffo 4 Ceiling Plaster

COARSE FRACTION: The texture is coarse and medium sand material. Coarse crystals of calcium carbonate are evident.

FINE FRACTION: The matrix is not homogeneous. There are patches dominated by earthen material and in contrast there are areas of an impure calcitic matrix.

ARRANGEMENT OF COARSE AND FINE FRACTION: The grains are coated by the matrix.

SAMPLE: Buzzi 3 Plaster

COARSE FRACTION: The texture is coarse to fine sand material. The mineralogy is mainly quartz sand. Lumps of calcium carbonate (chalky lime) are distributed in the matrix which presents cracks.

FINE FRACTION: The matrix is a pale brown to grey colour. It is a dense binding material. The proportion is estimated at 20 to 40% by weight. It includes areas of rich birefringent fabric and areas of organic matter likely to be dung or charcoal and silt size inclusions.

ARRANGEMENT OF COARSE AND FINE FRACTION: The grains are embedded in the matrix.

OPTICAL MICROSCOPY OBSERVATION OF THIN SECTIONS

SAMPLE: Fiedler 4 Ceiling Plaster

COARSE FRACTION: The texture is a very fine sand material. The mineralogy is mainly quartz.

FINE FRACTION: It is a white/ grey quite pure calcitic matrix.

ARRANGEMENT OF COARSE AND FINE FRACTION: The grains are embedded in the matrix.

SAMPLE: Fiedler 2 Plaster

COARSE FRACTION: The texture is from coarse to fine sand material. The mineralogy is mainly quartz sand and ocasionally secondary minerals.

FINE FRACTION: It is a pale brown, slightly impure calcitic matrix with ocasional bits of clay.

ARRANGEMENT OF COARSE AND FINE FRACTION: The grains are coated by the matrix.

SAMPLE: Fiedler 3 (two plaster coats: lime/fibre undercoat and earth coat limewashed)

COARSE FRACTION: The earth coat has a sand size texture with lumps of clay soil (weathered minerals). The lime undercoat has only fibres in the coarse fraction. These are likely to be from animal source (dung).

FINE FRACTION: The earth coat is a more pure clay matrix, probably 15% by weight. The undercoat is a very pale grey matrix of calcitic nature bonding the fibres.

ARRANGEMENT OF COARSE AND FINE FRACTION: The grains of the earth coat are coated by the matrix. The fibres from the undercoat are completely embedded in the matrix.

SAMPLE: Reincke 1 Pointing Mortar (reflected light observation)

COARSE FRACTION: It is a fine sand texture.

FINE FRACTION: It is a white and dense matrix likely to be calcitic nature.

ARRANGEMENT OF COARSE AND FINE FRACTION: The grains are embedded in the matrix.

OPTICAL MICROSCOPY OBSERVATION OF THIN SECTIONS

SAMPLE: Thurow 3 Pointing Mortar (reflected ligh observation)

COARSE FRACTION: The texture is coarse to fine sand material with angular grains.

FINE FRACTION: It is a white and dense matrix likely to be calcitic nature.

ARRANGEMENT OF COARSE AND FINE FRACTION: The grains are embedded in the matrix.

SAMPLE: Havenstein 2 Pointing Mortar (reflected light observation)

COARSE FRACTION: The texture is coarse to fine sand material with angular grains.

FINE FRACTION: It is a white and dense matrix likely to be calcitic nature.

ARRANGEMENT OF COARSE AND FINE FRACTION: The grains are embedded in the matrix.

SAMPLE: Zimath 3 Pointing Mortar

COARSE FRACTION: The texture is coarse to fine sand material with angular grains. The mineralogy is mainly quartz sand.

FINE FRACTION: It is a white/ grey material, pure and totally carbonated matrix of calcitic nature.

ARRANGEMENT OF COARSE AND FINE FRACTION: The grains are completely embedded in the matrix.

SAMPLE: Poffo 1 Pointing Mortar

COARSE FRACTION: The texture is coarse to fine sand material. The mineralogy is mainly quartz.

FINE FRACTION: It is a pure and totally carbonated calcitic matrix.

ARRANGEMENT OF COARSE AND FINE FRACTION: The grains are embedded in the matrix.

PHOTOMICROGRAPHS OF SELECTED THIN SECTIONS

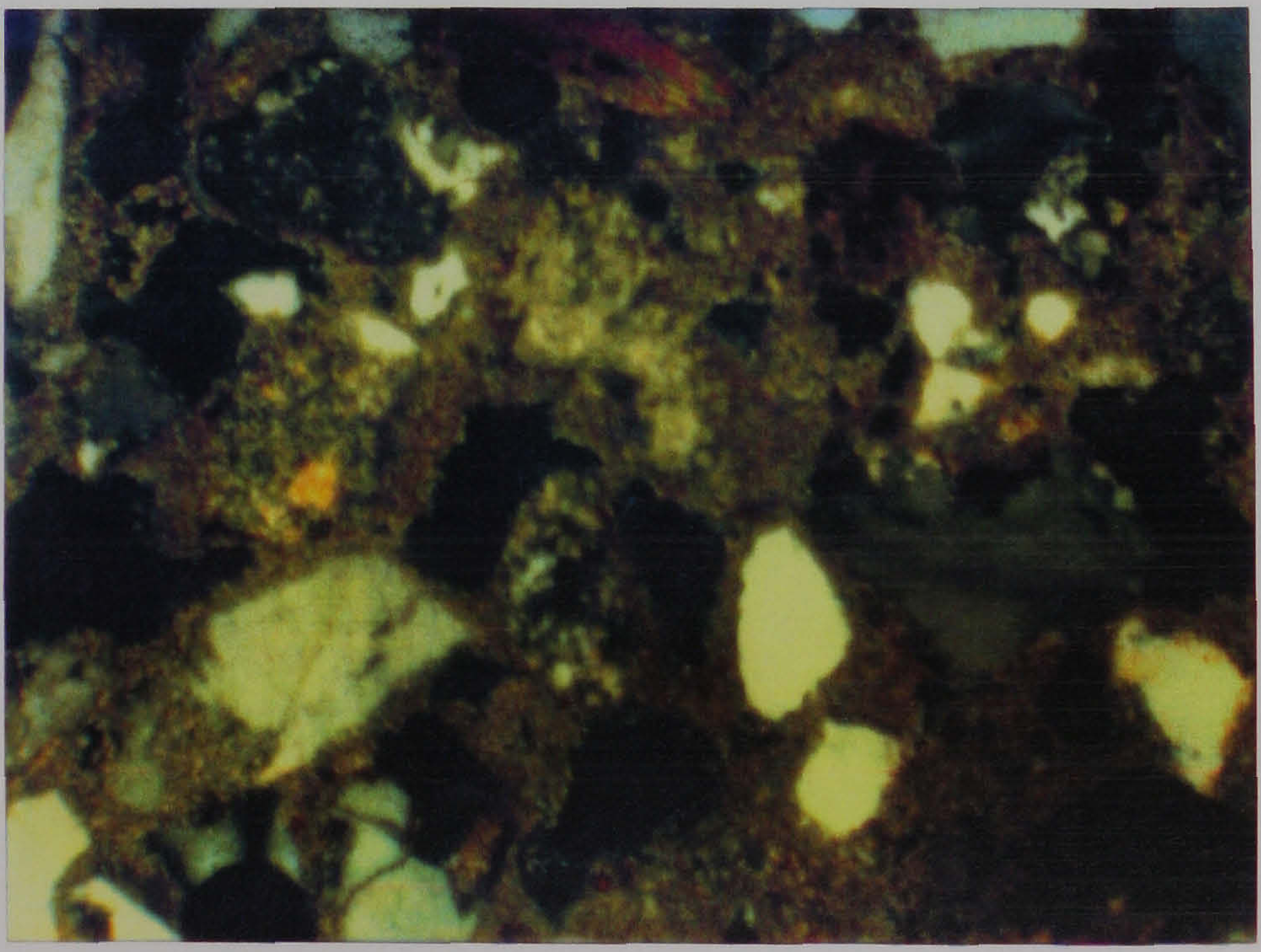
(Bar = 0,5mm) ____________________

SAMPLE:

Franz 3 Render

SAMPLE:

Tottene 1 Render

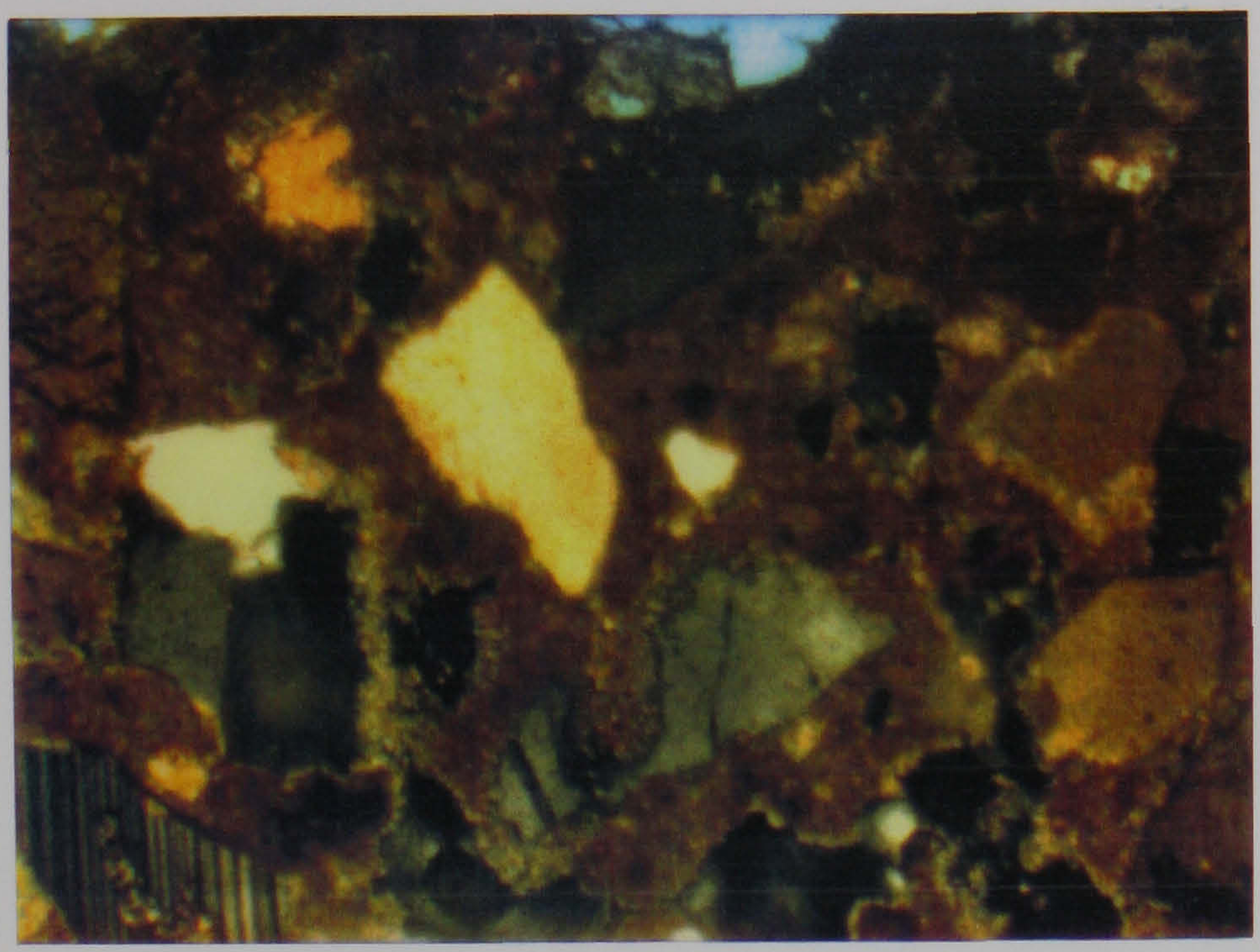


PHOTOMICROGRAPHS OF SELECTED THIN SECTIONS

(Bar = 0,5mm) ____________

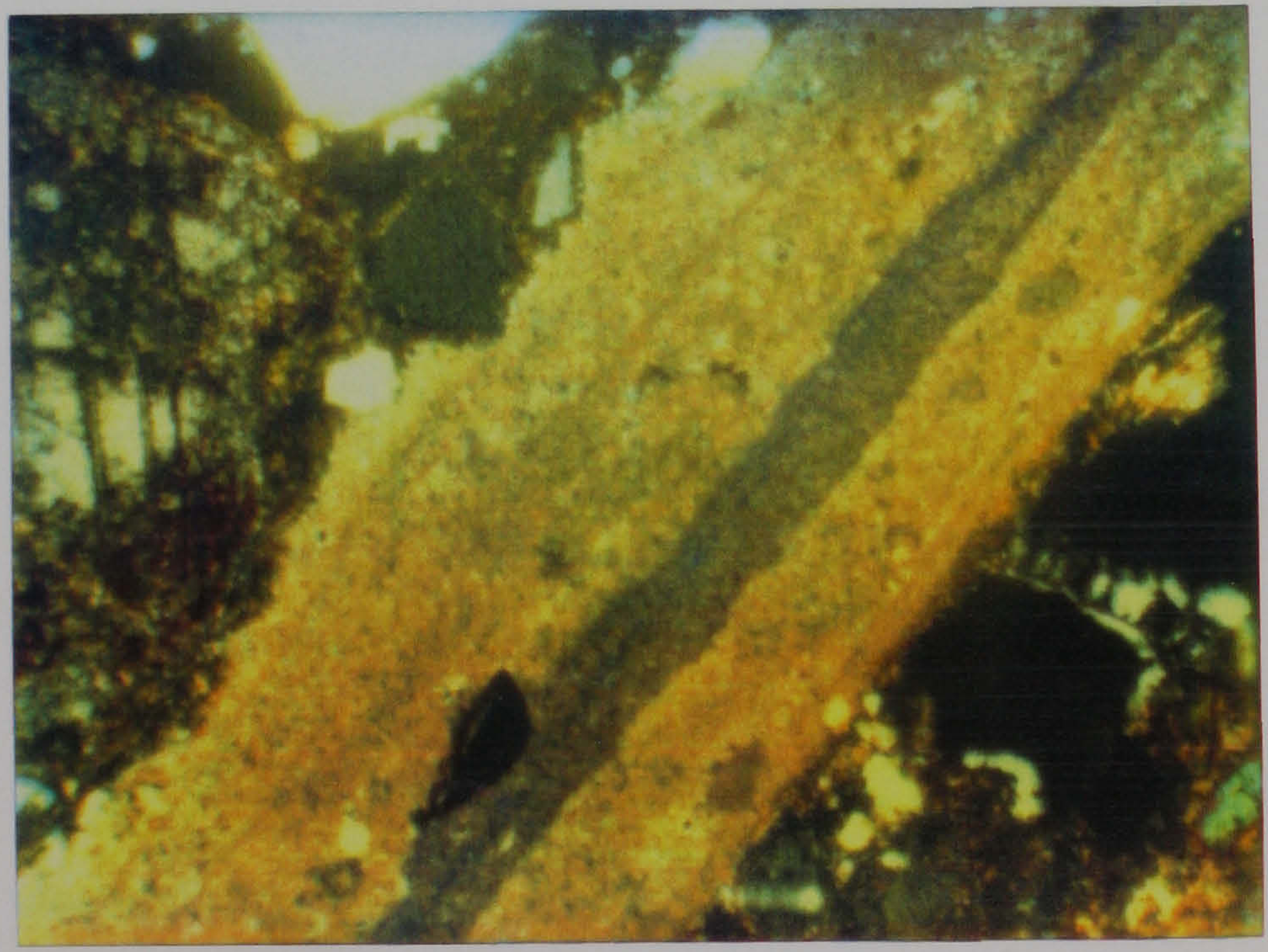
SAMPLE:

Fiedler 8 Render



SAMPLE:

Reincke 8 Plaster

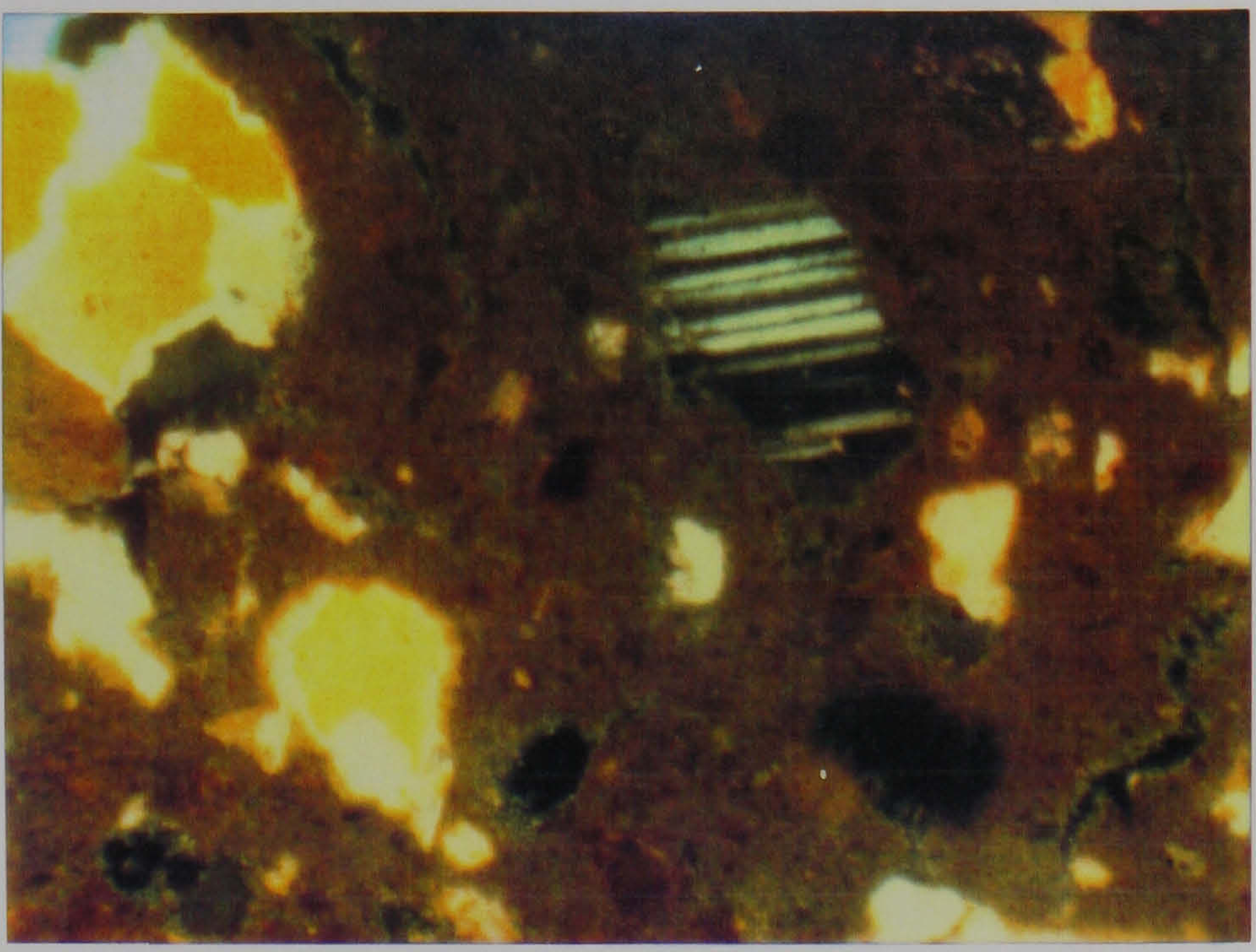


PHOTOMICROGRAPHS OF SELECTED THIN SECTIONS

(Bar = 0,5mm) ____________

SAMPLE:

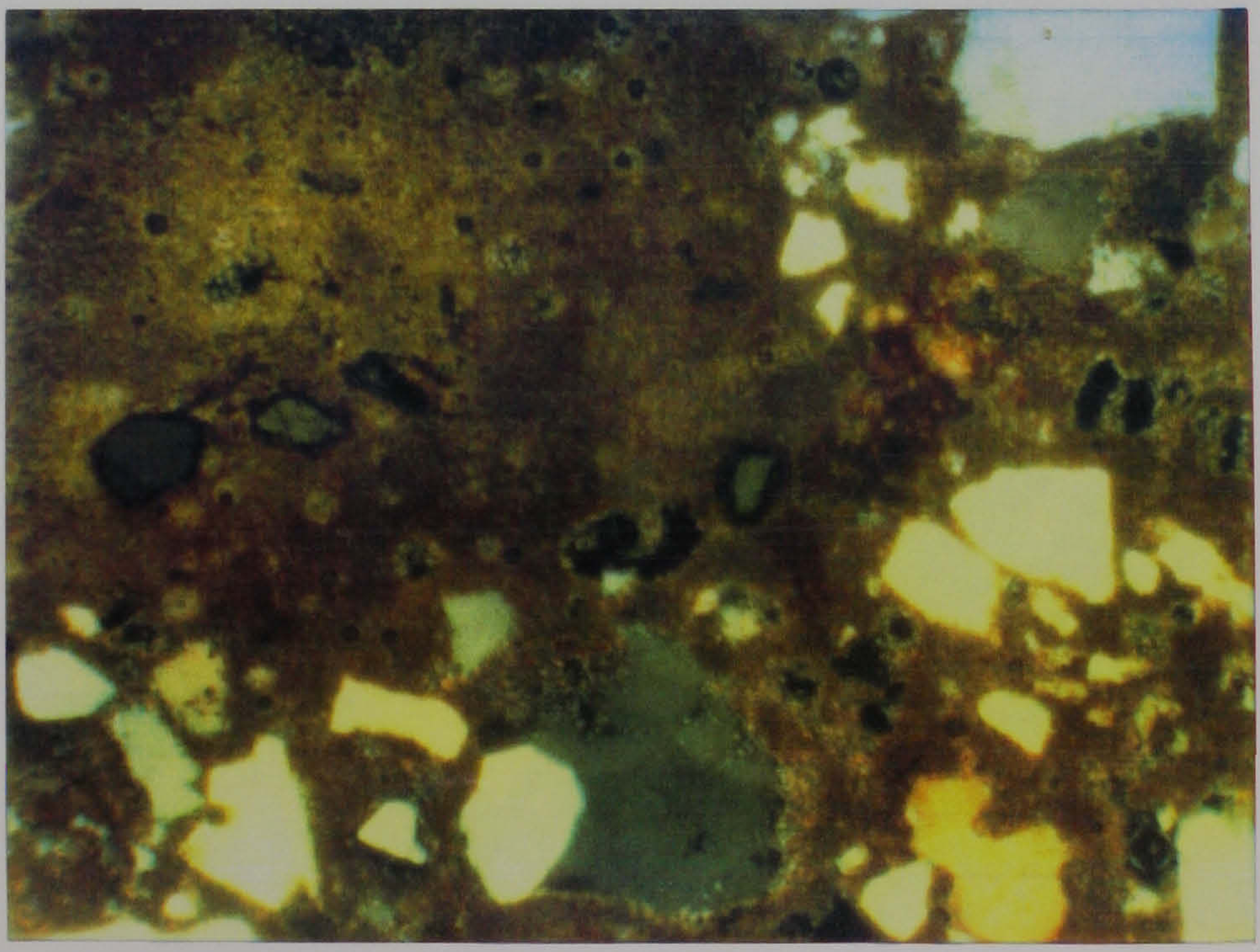
Buzzi 3 Plaster



SAMPLE:

Fiedler 4

Ceiling Plaster



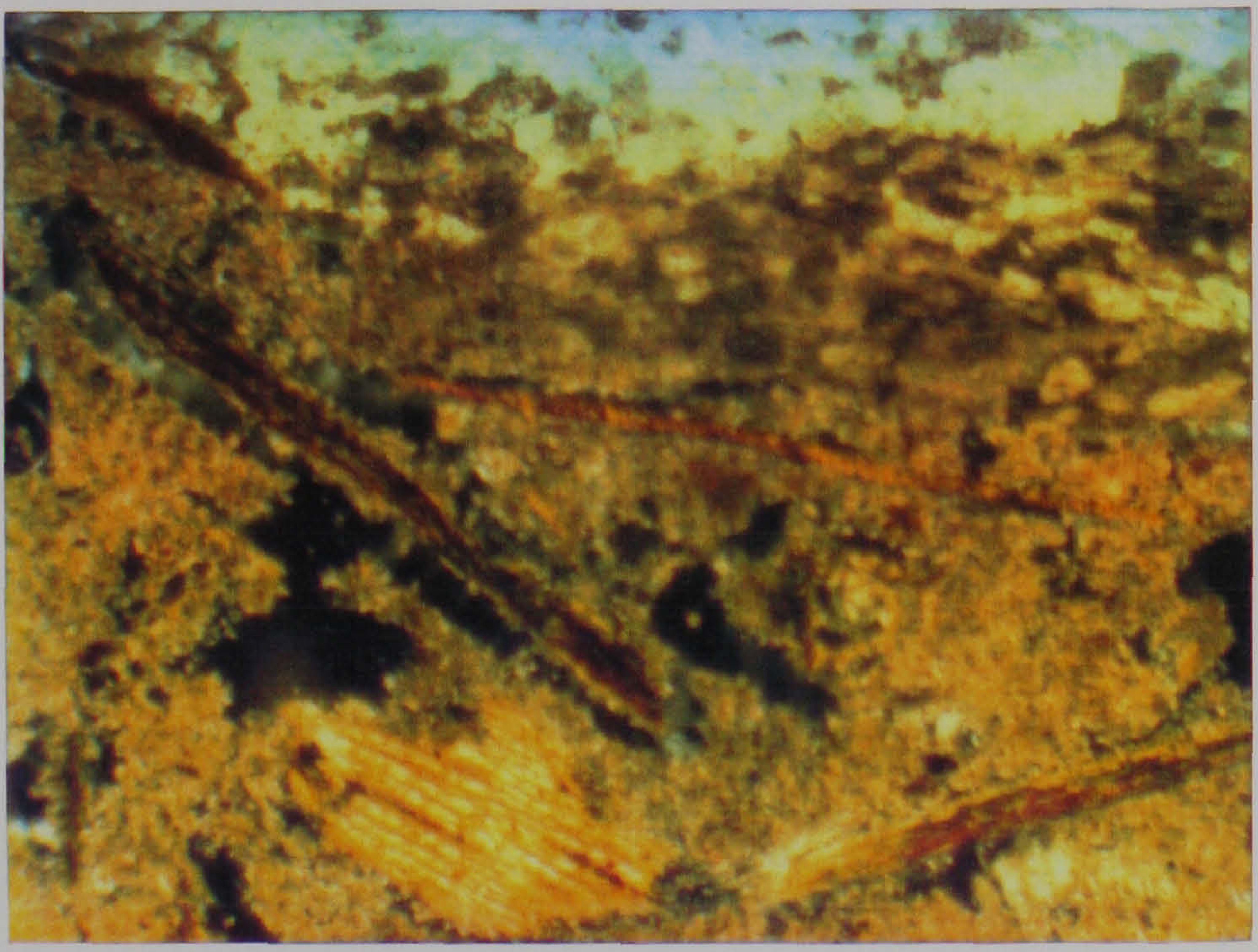
PHOTOMICROGRAPHS OF SELECTED THIN SECTIONS

(Bar = 0,5mm) ____________________

SAMPLE:

Fiedler 3 Plaster/

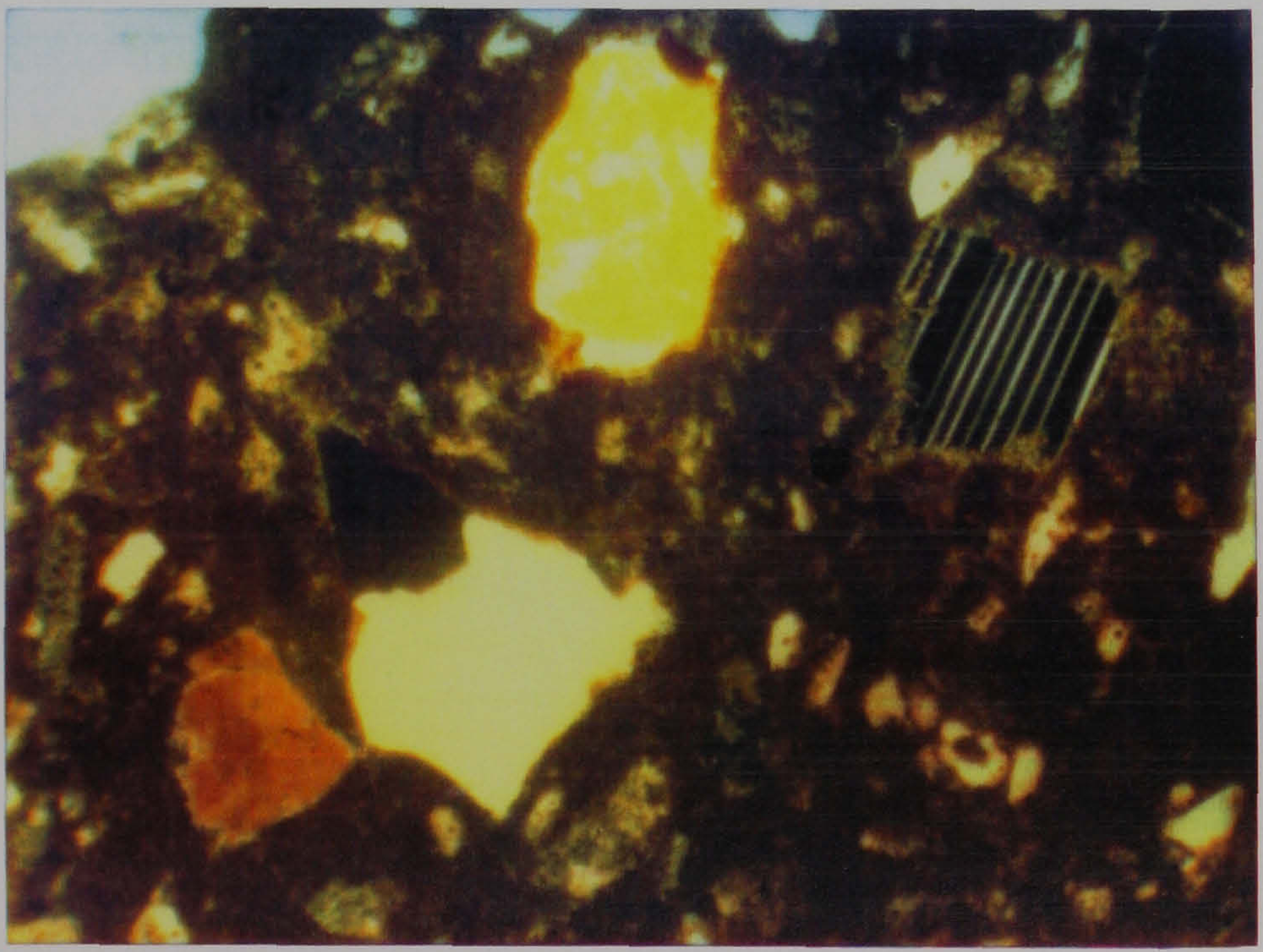
Undercoat



SAMPLE:

Zimath 3

Pointing Mortar



APPENDIX E: Calcium Carbonate and Particle Size of Aggregates

DETERMINATION OF CALCIUM CARBONATE CONTENT

SAMPLE: Havenstein 1

Sub- sample	Weight (g)	Titre (ml)	HCL (ml)	$CaCO_3$ %
HA 1	1.082	32.5	50	8.095
HA 2	1.090	32.4	50	8.081
HA 3	1.056	32.9	50	8.057

Average = 8.078

SAMPLE: Fiedler 2

Sub- sample	Weight (g)	Titre (ml)	HCL (ml)	$CaCO_3$ %
FI 1	1.151	23.9	50	11.338
FI 2	1.155	24.0	50	11.267
FI 3	1.148	23.7	50	11.466

Average = 11.357

SAMPLE: Poffo 4

Sub- sample	Weight (g)	Titre (ml)	HCL (ml)	$CaCO_3$ %
PO 1	0.338	41.0	50	11.609
PO 2	0.390	41.0	50	11.55
PO 3	0.412	40.8	50	11.176

Average = 11.445

SAMPLE: Buzzi 2

Sub- sample	Weight (g)	Titre (ml)	HCL (ml)	$CaCO_3$ %
BU 1	1.418	14.0	50	12.689
BU 2	1.440	14.0	50	12.512
BU 3	1.439	14.1	50	12.486

Average = 12.563

DETERMINATION OF CALCIUM CARBONATE CONTENT

SAMPLE: Tottene 1

Sub- sample	Weight (g)	Titre (ml)	HCL (ml)	$CaCO_3$ %
TO 1	1.370	15.1	50	12.750
TO 2	1.384	14.6	50	12.802
TO 3	1.341	15.7	50	12.802

Average = 12.785

SAMPLE: Fiedler 1

Sub- sample	Weight (g)	Titre (ml)	HCL (ml)	$CaCO_3$ %
FI 1	1.502	8.6	50	13.795
FI 2	1.562	7.0	50	13.778
FI 3	1.512	7.1	50	14.20

Average = 13.92

SAMPLE: Wacholz 3/ undercoat

Sub- sample	Weight (g)	Titre (ml)	HCL (ml)	$CaCO_3$ %
WA 1	1.038	20.7	50	14.128
WA 2	1.097	19.5	50	13.914
WA 3	1.067	19.9	50	14.119

Average = 14.054

SAMPLE: Fiedler 8

Sub- sample	Weight (g)	Titre (ml)	HCL (ml)	$CaCO_3$ %
FI 1	1.068	7.6	50	19.87
FI 2	1.104	6.5	50	19.721
FI 3	1.073	7.4	50	19.871

Average = 19.821

DETERMINATION OF CALCIUM CARBONATE CONTENT

SAMPLE: Buzzi 3

Sub- sample	Weight (g)	Titre (ml)	HCL (ml)	$CaCO_3$ %
BU 1	1.094	6.5	50	19.901
BU 2	1.048	8.0	50	20.058
BU 3	1.057	7.7	50	20.029

Average = 19.996

SAMPLE: Fiedler 4

Sub- sample	Weight (g)	Titre (ml)	HCL (ml)	$CaCO_3$ %
FI 1	1.191	26.9	100	30.719
F2 2	1.250	23.2	100	30.751
FI 3	1.218	24.1	100	31.189

Average = 30.886

SAMPLE: Reincke 1

Sub- sample	Weight (g)	Titre (ml)	HCL (ml)	$CaCO_3$ %
RE 1	0.260	31.3	50	53.998
RE 2	0.250	32.2	50	35.636
FI 3	0.254	31.9	50	35.665

Average = 35.766

SAMPLE: Havenstein 2

Sub- sample	Weight (g)	Titre (ml)	HCL (ml)	$CaCO_3$ %
HA 1	0.362	23.3	50	36.915
HA 2	0.312	27.0	50	36.896
HA 3	0.333	25.8	50	36.373

Average = 36.728

DETERMINATION OF CALCIUM CARBONATE CONTENT

SAMPLE: Thurow 3

Sub- sample	Weight (g)	Titre (ml)	HCL (ml)	$CaCO_3$ %
THU 1	0.754	42.1	100	38.434
THU 2	0.734	43.1	100	38.799
THU 3	0.711	46.5	100	37.661

Average = 38.298

SAMPLE: Poffo 1

Sub- sample	Weight (g)	Titre (ml)	HCL (ml)	$CaCO_3$ %
PO 1	0.743	42.0	100	39.070
PO 2	0.744	42.4	100	38.748
PO 3	0.720	44.3	100	38.719

Average = 38.846

SAMPLE: Zimath 3

Sub- sample	Weight (g)	Titre (ml)	HCL (ml)	$CaCO_3$ %
ZI 1	0.748	16.0	100	56.206
ZI 2	0.727	18.7	100	55.971
ZI 3	0.573	36.0	100	55.902

Average = 56.026

SAMPLE: Fiedler 3

Sub- sample	Weight (g)	Titre (ml)	HCL (ml)	$CaCO_3$ %
FI 1	0.261	19.5	50	58.487
FI 2	0.237	22.1	50	58.920
FI 3	0.237	22.1	50	58.920

Average = 58.775

DETERMINATION OF PARTICLE SIZE OF AGGREGATE

SAMPLE: Havenstein 1

Weight sample(W): 21.168g

Weight aggregate (W1): 19.404g

Weight aggregate retained on all sieves (W2): 19.313g

BS sieves	Weight retained (g)	% of mass retained	% of mass finer than
1.18mm	3.939	20.4	79.6
600μm	5.479	28.37	51.23
300μm	3.924	20.32	30.91
150μm	3.365	17.42	13.49
90μm	1.395	7.22	6.27
63μm	0.724	3.75	2.52
<63μm	0.487	2.52	

SAMPLE: Tottene 1

Weight sample(W): 25.443

Weight aggregate (W1): 21.997

Weight aggregate retained on all sieves (W2): 21.925

BS sieves	Weight retained (g)	% of mass retained	% of mass finer than
1.18mm	0.338	1.54	98.46
600μm	2.678	12.21	86.26
300μm	7.206	32.87	53.38
150μm	7.685	35.05	17.85
90μm	2.309	10.53	7.32
63μm	1.207	5.5	1.82
<63μm	0.502	2.29	

DETERMINATION OF PARTICLE SIZE OF AGGREGATE

SAMPLE: Fiedler 1

Weight sample(W): 20.021g

Weight aggregate (W1): 16.404g

Weight aggregate retained on all sieves (W2): 16.35g

BS sieves	Weight retained (g)	% of mass retained	% of mass finer than
1.18mm	0.907	5.5	94.5
600μm	5.365	32.8	61.17
300μm	5.870	35.9	25.8
150μm	2.562	15.67	10.13
90μm	0.914	5.59	4.54
63μm	0.540	3.3	1.24
<63μm	0.192	1.17	

SAMPLE: Buzzi 3

Weight sample(W): 23.783g

Weight aggregate (W1): 18.102g

Weight aggregate retained on all sieves (W2): 17.975

BS sieves	Weight retained (g)	% of mass retained	% of mass finer than
1.18mm	5.852	32.5	67.5
600μm	5.018	27.9	39.6
300μm	3.397	18.89	20.71
150μm	2.171	12.07	8.64
90μm	0.958	5.33	3.31
63μm	0.377	2.1	1.21
<63μm	0.202	1.12	

DETERMINATION OF PARTICLE SIZE OF AGGREGATE

SAMPLE: Fiedler 4

Weight sample(W): 15.672g

Weight aggregate (W1): 10.493g

Weight aggregate retained on all sieves (W2): 10.454g

BS sieves	Weight retained (g)	% of mass retained	% of mass finer than
1.18mm	0.417	4	96
600μm	1.237	11.83	84.17
300μm	2.520	24.1	60.07
150μm	3.405	32.57	27.5
90μm	1.883	18	9.5
63μm	0.857	8.2	1.3
<63μm	0.135	1.3	

SAMPLE: Thurow 3

Weight sample(W): 9.946g

Weight aggregate (W1): 5.82g

Weight aggregate retained on all sieves (W2): 5.798g

BS sieves	Weight retained (g)	% of mass retained	% of mass finer than
1.18mm	1.385	23.89	76.11
600μm	2.293	39.55	36.56
300μm	1.296	22.35	14.21
150μm	0.465	8.02	6.19
90μm	0.211	3.64	2.55
63μm	0.078	1.35	1.2
<63μm	0.07	1.2	

DETERMINATION OF PARTICLE SIZE OF AGGREGATE

SAMPLE: Zimath 4

Weight sample(W): 17.10g

Weight aggregate (W1): 8.123g

Weight aggregate retained on all sieves (W2): 8.034g

BS sieves	Weight retained (g)	% of mass retained	% of mass finer than
1.18mm	1.281	15.94	84.06
600μm	3.167	39.42	44.64
300μm	2.095	26.08	18.56
150μm	0.875	10.89	7.67
90μm	0.402	5	2.67
63μm	0.107	1.33	1.34
<63μm	0.107	1.33	

APPENDIX F: Cross Sections

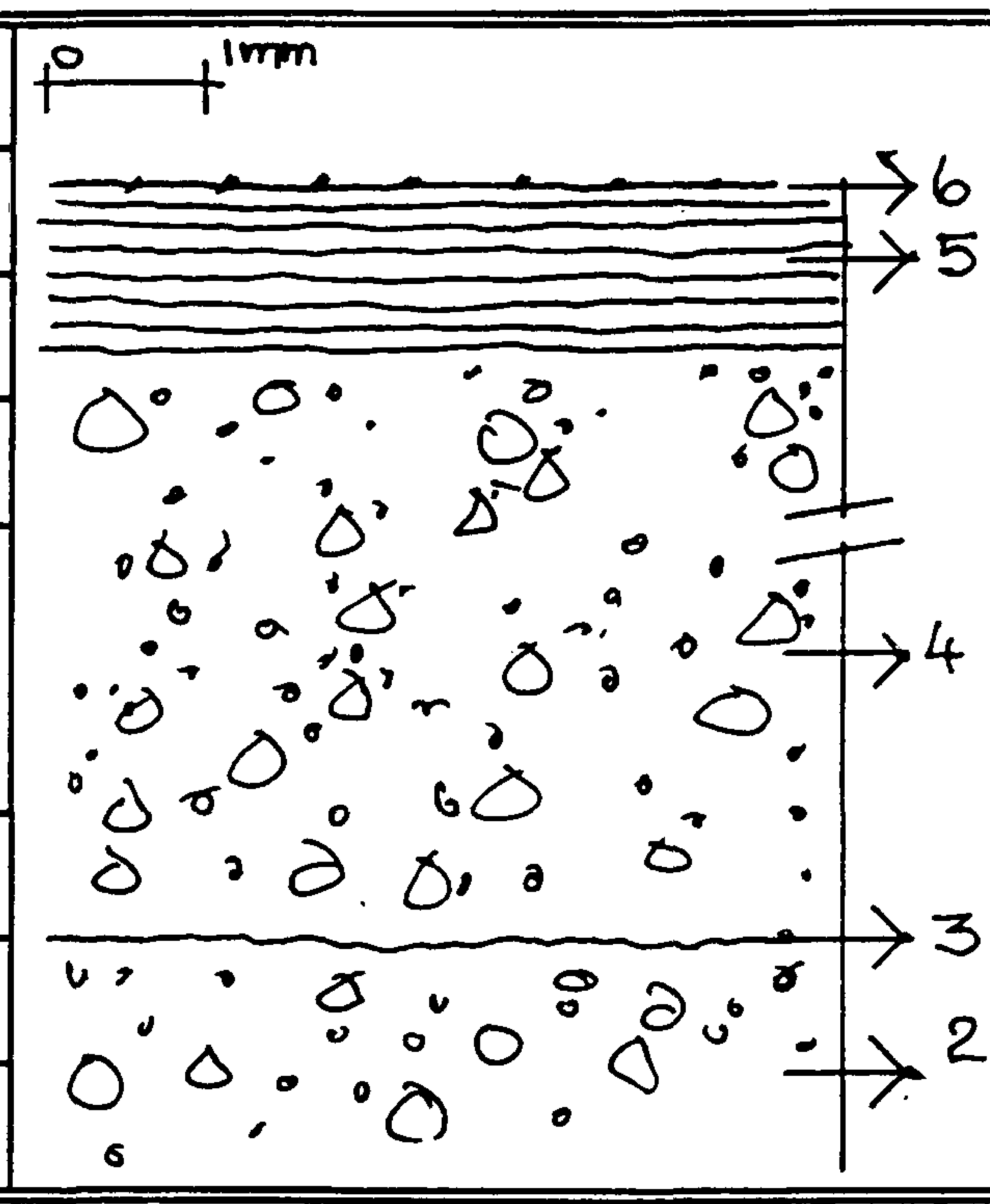
REFLECTED LIGHT MICROSCOPY OBSERVATION OF CROSS SECTIONS

SAMPLE: Wacholz 2

Description of Layers

Description of Layers
1. Wall support: daub
2. 1st Plaster substrate: earth (approx.1.5cm)
3. Very thin white layer
4. 2nd plaster substrate: earth (approx. 0.7cm)
5. Layers of limewash presenting differences in colour: white, ochre and light pink. (5/6 layers more than 1mm)
6. Stencilling: light olive (5Y 6/2)

Drawing of the Cross Section

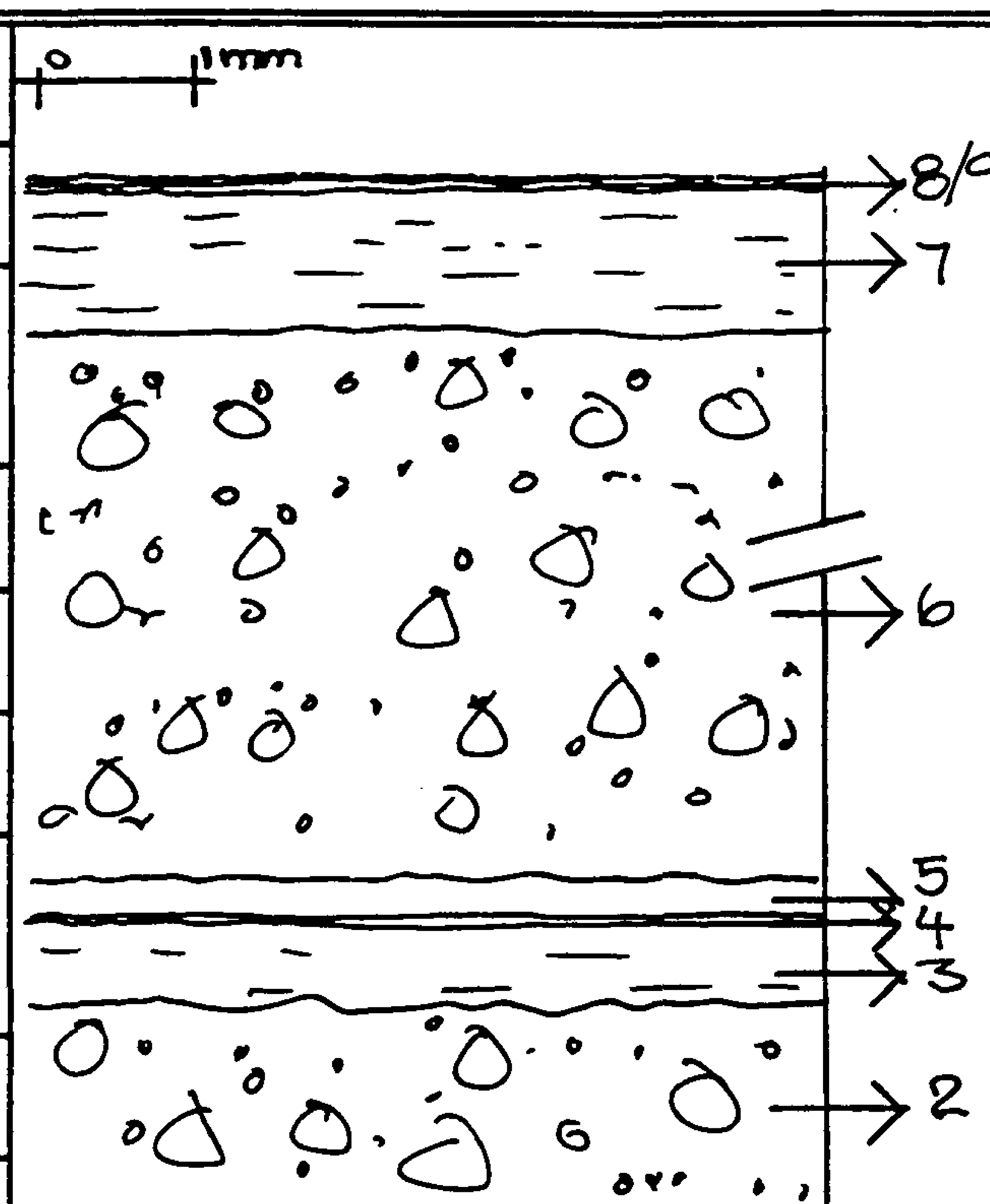


SAMPLE: Reincke 8

Description of Layers

Description of Layers
1. Wall support: brick
2. 1st plaster substrate: earth (approx.1.5cm)
3. Thick white limewash or multilayers (approx. 0,5 mm)
4. Thin blue (2 or 3 layers)
5. Thick white limwash
6. 2nd plaster substrate: earth (approx. 0.7cm)
7. Thick white limewash or multilayers of dark white. (approx. 0,8mm)
8. Ochre colour (3/4 layers)
9. White limewash.

Drawing of the Cross Section



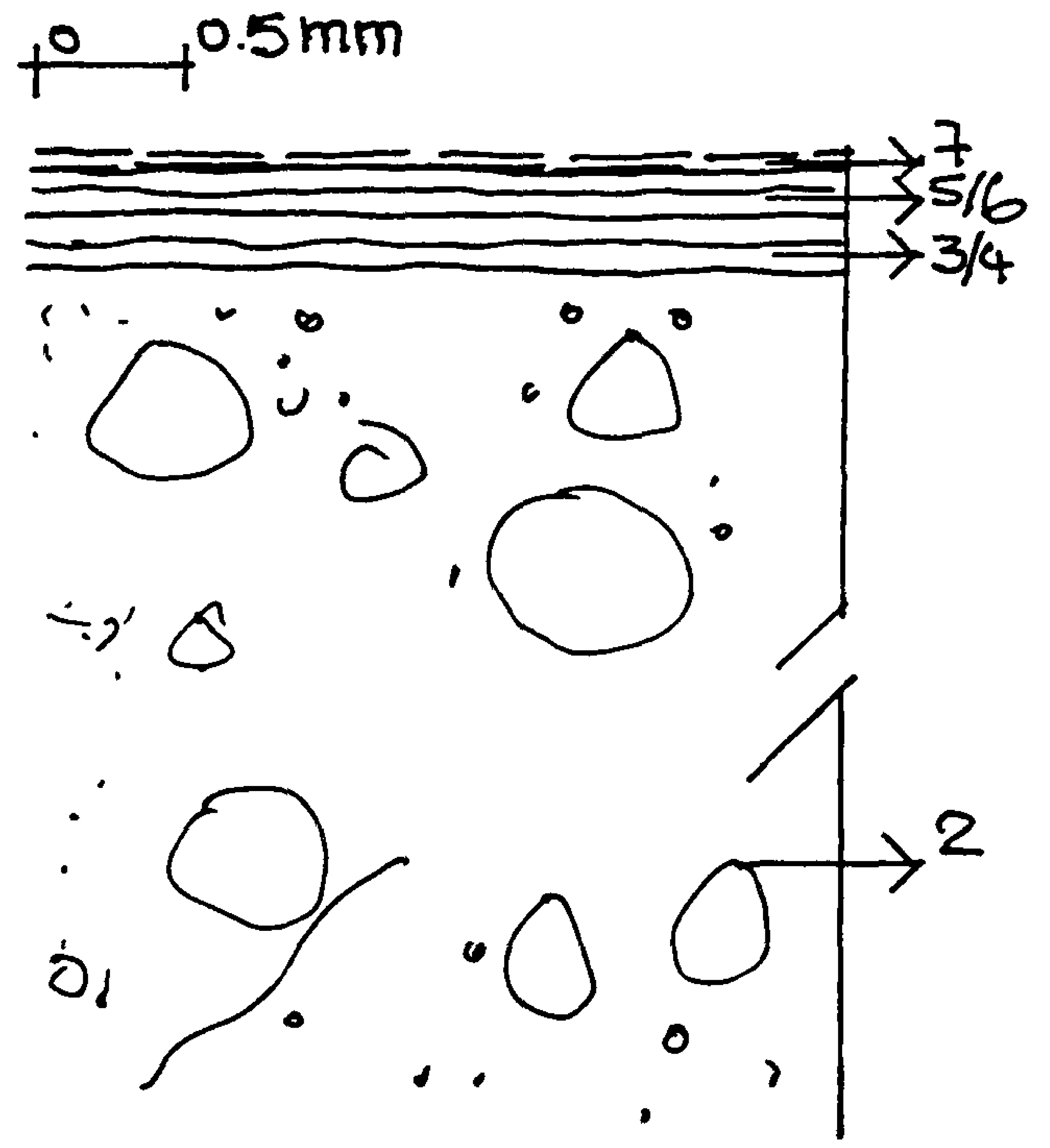
REFLECTED LIGHT MICROSCOPY OBSERVATION OF CROSS SECTIONS

SAMPLE: Buzzi 3

Description of Layers

Description of Layers
1. Wall support: solid brick
2. Plaster substrate: lime-sand (approx. 1cm)
3. Light ochre limewash
4. Ochre limewash
5. Green layer
6. Dark green layer
7. Red layer interrupted

Drawing of the Cross Section

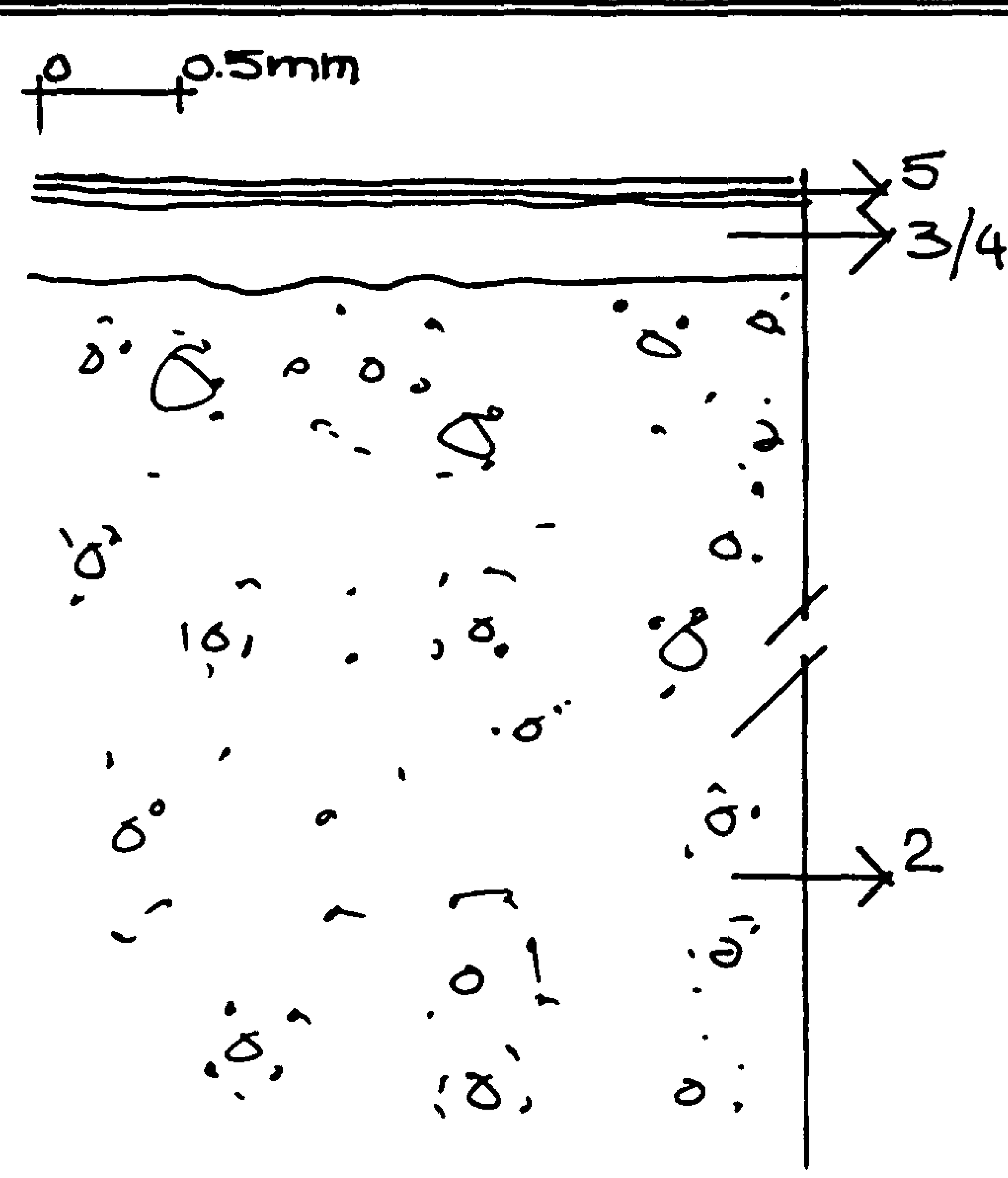


SAMPLE: Fiedler 4

Description of Layers

Description of Layers
1. Ceiling support: daub
2. Plaster substrate: lime- sand (approx. 0.7cm)
3. White limewash (approx. 0,5mm)
4. Darker White limewash
5. Olive grey layer

Drawing of the Cross Section

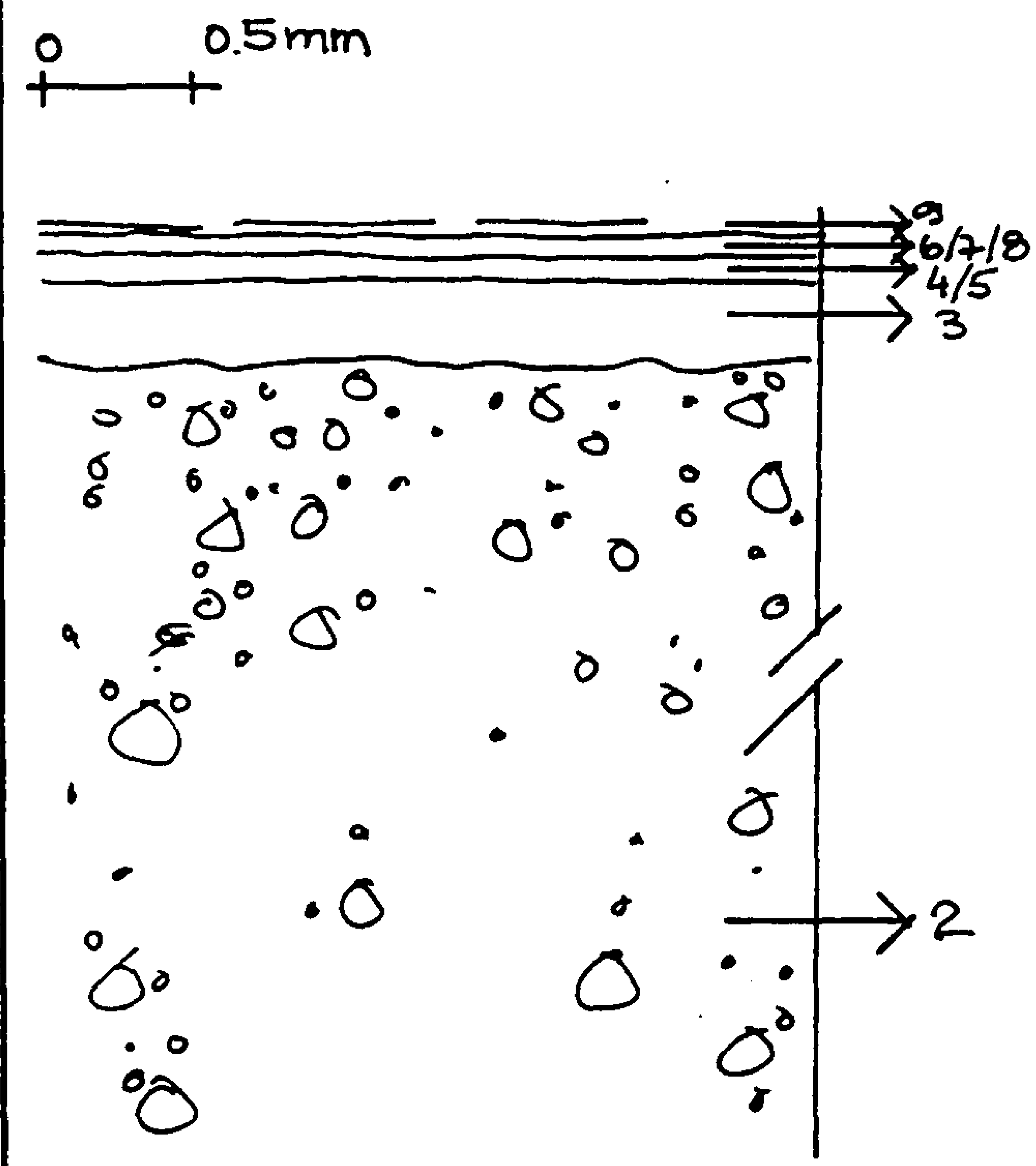


REFLECTED LIGHT MICROSCOPY OBSERVATION OF CROSS SECTIONS

SAMPLE: Fiedler 2

Description of Layers
1. Wall support: brick panel
2. Plaster substrate: lime- soil (approx. 1cm)
3. Thick limewash light ochre (approx. 0,5mm)
4. Dark ochre layer
5. Light ochre layer
6. Green layer
7. Thin green layer
8. Thin dark green layer (different gloss)
9. Interrupted white

Drawing of the Cross Section



APPENDIX G: Pigments

SEM/ EDAX ELEMENTAL ANALYSIS OF PIGMENTS

SAMPLE: Fiedler 4 / green colour - light olive grey (5Y 6/2)

ELEMENTS: Ca - large peack; Si, Fe, Al, S - small amounts

SAMPLE: Fiedler 2 / green colour- 10Y 3/4

ELEMENTS: Ca - large peack; Zn, Al, Si, S, Ba, Fe - small amounts

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SAMPLE: Wacholz 2/ green colour - olive grey (5Y 5/2) - motifs of stencilling

ELEMENTS: Ca, Si - large peack; Al, K- small amounts; Fe - very small amount

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SAMPLE: Reincke 8/ blue colour - 6.25 PB 3/12

ELEMENTS: Ca - large peack; Si, Al, S - small amount

SAMPLE: Fiedler 2 - ochre colour- 10Y 3/4 or 2.5 GY 3/4

ELEMENTS: Ca - large peack; Al, Si - small amount; Cu (probably)

SAMPLE: Buzzi 3 - red colour- dusky red (10R 3/3)

ELEMENTS: Ca - large peack; Al, Si, S- small amount; Fe- very small amount

---

SAMPLE: Wacholz 2/ 'white' colour - pinkish white 7.5YR 5/6

ELEMENTS: Ca - large peack ; Si - small amount

SAMPLE: Tottene 1/ ochre colour - brownish yellow 10YR 6/8

ELEMENTS: Ca - large peack; Al, Si- medium pick; Fe- very small amount; K (possible)

SAMPLE: Wacholz 2 / 'white' colour- redish yellow (7.5 YR 6/6)

ELEMENTS: Ca - large peack; Si, Al - small amount; Fe - very small amount

APPENDIX H: Oil

MICROCHEMICAL TEST FOR OIL DETECTION

SAMPLE RESULT: Wacholz 2 positive

SAMPLE RESULT: Fiedler 4 negative

SAMPLE RESULT: Fiedler 1 negative

SAMPLE RESULT: Reincke 8 negative

SAMPLE RESULT: Franz 3 negative

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