

## DOCUMENTATION AND EVALUATION OF STONE DAMAGE ON MONUMENTS

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### Abstract

Comprehensive documentation is of vital importance in the field of stone monument preservation. The approach to the protection of stone monuments can be subdivided into anamnesis, diagnosis and therapy. According to established international directives, documentation is a necessary part of all three worksteps.

The particular objectives and items of documentation within the scope of anamnesis, diagnosis and therapy are presented. Evaluation and graphic documentation of stone deterioration is presented by means of examples referring to in-situ investigation of stone monuments in the framework of diagnosis.

**Keywords:** documentation, anamnesis, diagnosis, therapy, monument preservation

### 1. Introduction

Stone monuments represent a very important part of the world's cultural heritage. The great range of stone monuments includes historical and modern monuments, buildings and decorative stone structures, individual monuments and assembly of monuments constructed with dimension stones or carved from bedrock. Further differences concern dimension, style and utilization of the monuments. Many stone types have been used for monument construction. Due to their geological history, the stone types show significant differences in their properties.

All stone monuments are affected by stone deterioration, especially by weathering, which means physical disintegration or chemical decomposition is initiated and controlled by the interaction between stone and exogenic factors such as climate, biosphere or pollution. The increasing damage on stone monuments and the danger of irretrievable loss of cultural heritage has resulted in ever-increasing efforts world-wide for monument preservation.

A multidisciplinary cooperation is required for monument preservation. National and international guidelines, norms and conventions were established for the protection of monuments. According to these directives, documentation is of fundamental importance (e.g. Venice Charter 1964, Deutsches Nationalkomitee für Denkmalschutz 1982). Documentation here is to be understood as the thorough compilation, registration, processing, evaluation, storage and distribution of comprehensive information needed for effective and economic monument preservation.

Precise documentation has to address all available information about a monument and all types and results of investigation and work, ranging from the identification of a stone object to the quality control of preservation measures. Today, documentation plays an important role in education and project funding in the field of monument preservation. Modern computer technology represents an important tool for manifold steps of documentation.

The well-accepted approach to sustainable monument preservation comprises the steps of anamnesis, diagnosis and therapy (fig. 1). Documentation has to be involved in each of these three steps (VDI-Guideline No. 3798 - Part 1 / 1989; Part 2 / 1997, Part 3 / 1998).

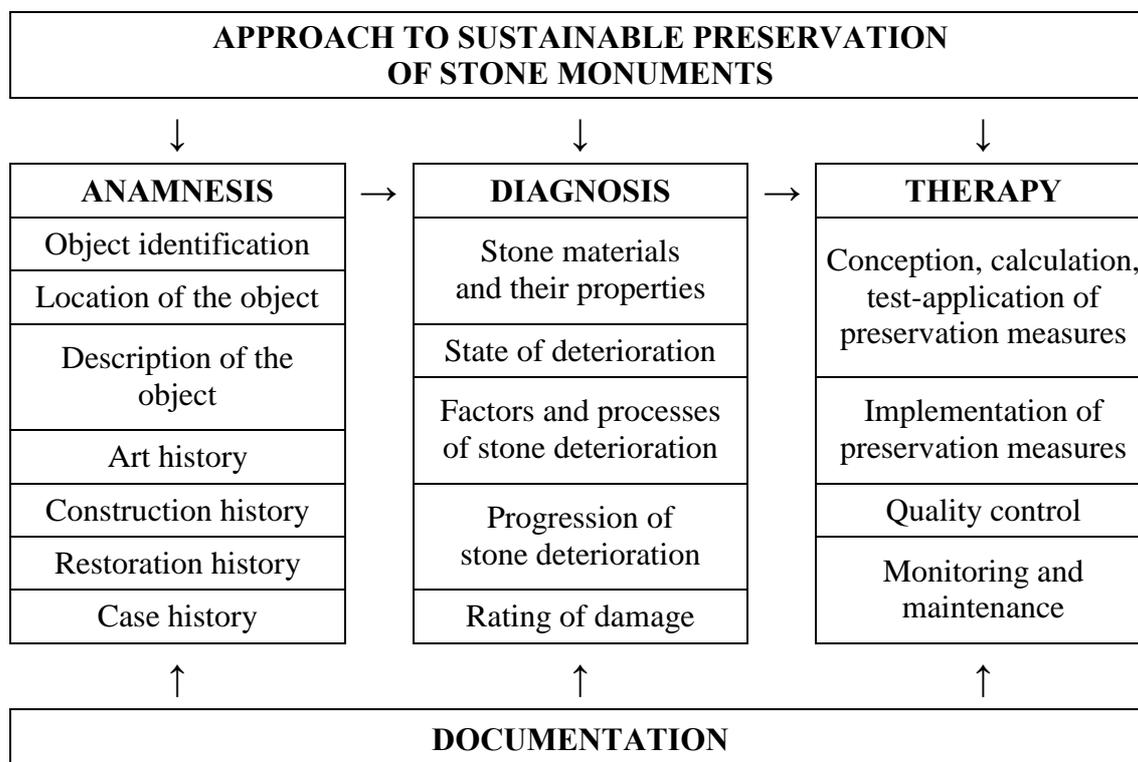


Fig. 1: Approach to monument preservation.

## 2. Documentation within the scope of anamnesis

The anamnesis is to acquire, compile and evaluate all information, data and documents for the identification and description of stone monuments and for the portrayal of their history. In particular, it considers the following objectives:

- object identification: name, designation, owner, responsible authorities;
- location of the object: geographical and topographical location, geological conditions, building ground, exposure characteristics, surroundings in the course of time;
- description of the object: type, age, overall appearance, dimension, architectural style;
- art history: architectural composition, artistic elements, historical / cultural / artistic value of the object;
- construction history: phases of construction / rebuilding, construction techniques, type and provenance of building materials, craftwork, artwork;
- restoration history: concepts and chronology of previous restoration measures, techniques and materials applied for restoration;
- case history: utilization and function of the object in the course of time, natural or anthropogenic impacts, history of environmental conditions such as climate and pollution.

The items of documentation with respect to anamnesis are presented in table 1.

Table 1: Items of documentation within the scope of anamnesis

<b>Anamnesis</b>	<b>Items of documentation</b>	
	Archive work – compilation and evaluation of available documents	Drawings, plans, maps, photographs or other relevant illustrations
		Publications, reports, journals, newspapers, expertises, files, building logs, records, construction manuals, manufacturing manuals, supplier’s documents, accounts, static calculations etc.
	Collection and evaluation of oral information from people professionally involved with the object and from local people	
	Collection and evaluation of environmental data from authorities or institutions	
	Documentation of own observations, elaboration of new documents where necessary	

### 3. Documentation within the scope of diagnosis

The diagnosis uses the information provided by the anamnesis and it represents the basis for the decision and implementation of appropriate preservation measures. The overall aim of the diagnosis is the characterization, quantification, interpretation and rating of stone damage on the monuments. The methodological approach of diagnosis includes laboratory analysis and in-situ investigation. Diagnosis has to consider different scales of stone deterioration (tab. 2).

Table 2: Scales of stone deterioration (modified from Viles et al. 1997)

<b>Scales</b>		<b>Parameters</b>	<b>Investigation</b>	<b>Involved sciences</b>
Non-visible deterioration	Nanoscale < mm	Changes of stone properties	Laboratory analysis	Geosciences, material sciences, chemistry, physics, microbiology, ecology
Visible deterioration	Microscale mm to cm	Mass loss, micromorphology		
	Mesoscale cm to m	Deterioration phenomena	In-situ investigation	
	Macroscale - whole structures or monuments	Structural stability, aesthetic appearance		Structural engineering, architecture

Particular objectives of diagnosis are:

- stone materials and their properties: type and distribution of stone materials, stone working, surface structure, stone mounting, macroscopical characteristics, mineral composition, chemical composition, textural properties, porosity properties, hygric properties, thermal properties, mechanical properties, correlations between stone properties, stone quality;
- state of stone deterioration: stone alteration, physical disintegration, chemical decomposition, deterioration profiles, type and intensity of deterioration phenomena;
- factors and processes influencing stone deterioration: natural and anthropogenic factors, coaction of factors, interaction of processes, mechanisms of deterioration, threshold levels;
- progression of stone deterioration: stone properties in the course of deterioration, sequences of deterioration phenomena, rates of deterioration, models of stone deterioration, prognosis;
- rating of damage: degree of damage, distribution of damage, risk prognosis, need and urgency of intervention.

The items of documentation with respect to diagnosis are presented in table 3. In the following, some examples of documentation within the scope of damage diagnosis on stone monuments are presented.

The monument mapping method has been established as a non-destructive procedure for the precise registration, evaluation and documentation of lithotypes and deterioration phenomena (Fitzner & Heinrichs 2002). It can be applied to all stone types and to all kinds of stone objects. Modern computer programmes are used for the processing of information registered in the course of mapping. They use digital plans of stone monuments or structures. Digital plans and information files with planimetric data allow manifold options for the query, illustration, quantitative evaluation and transformation of information.

In many monuments different stone types were used, due to architectural, constructional or artistical considerations, or due to availability and workability of stone material. Rebuilding or stone replacement may have also resulted in additional stone types. The lithological mapping comprises the survey, identification, petrographical characterization and registration of all stone types. This is very important for the evaluation of damage in dependence upon stone types. Well-established petrographical schemes should be used for the description of stone types. The distribution of stone types is illustrated in maps and is evaluated quantitatively according to number or area of dimension stones (figs. 1, 2).

The objective and reproducible registration and documentation of deterioration phenomena (other terms: ,weathering forms‘, ,weathering features‘, ,weathering patterns‘, ,pathology‘) require precise classification (eg. Fitzner, Heinrichs & Kownatzki 1995, Fitzner & Heinrichs 2002, Fitzner & Heinrichs 2004, NORMAL 1/88 1990). It is recommended to also consider the intensity of deterioration phenomena. However, a standard intensity classification of deterioration phenomena is not suitable. The classification of intensities has to be adjusted to each monument or stone structure with respect to the apparent range of intensities. The deterioration phenomena and their intensities registered in the course of monument mapping are illustrated in maps (fig. 3). The quantitative evaluation addresses type, intensity and distribution of deterioration phenomena, and in addition their dependencies on stone types and monument characteristics such as architectural structure, orientation or other exposure characteristics.

Table 3: Items of documentation within the scope of diagnosis

		<b>Items of documentation</b>
<b>Diagnosis</b>	Description of the diagnostical concept	Description of all methods applied during the course of diagnosis including their aims, appropriation / suitability, modes of evaluation, success
		Description and graphic documentation of the investigation areas - location, dimension, orientation, exposure characteristics, reasons for selection
		Description and graphic documentation of sampling - materials, type and dimension of samples, places of sampling, reasons for selection
	Evaluation of results	Stone materials and their properties - classification schemes, data sets, files, diagrams, photographs, lithological maps with quantitative evaluation
		State of stone deterioration - characterization of deterioration according to change of stone properties, classification of deterioration phenomena considering type and intensity, data sets, files, diagrams, photographs, maps of deterioration phenomena with quantitative evaluation
		Factors and processes of stone deterioration - qualitative or quantitative / direct or inferable information, data sets, files, diagrams
		Progression of stone deterioration - modes of assessment / quantification, rating of accuracy / validity / transferability, data sets, files, diagrams
		Rating of damage - considerations / schemes for the rating of damage and for the appraisal of need and urgency of preservation measures, maps of damage with quantitative evaluation, data sets, files, diagrams

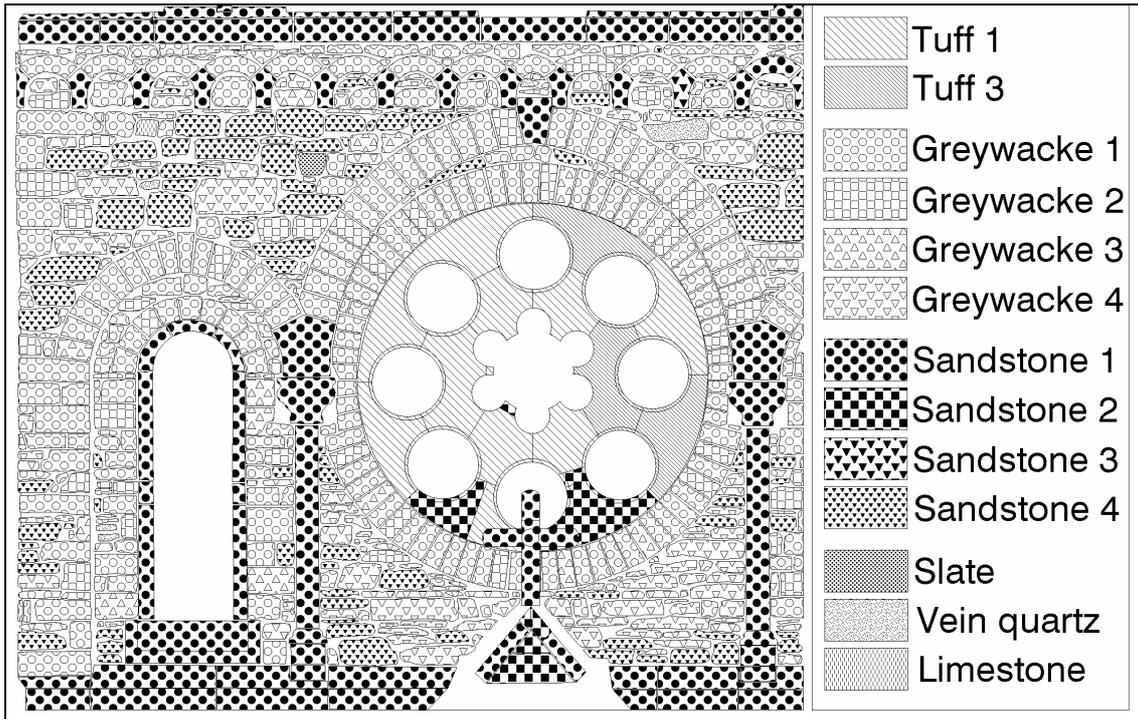


Figure 1: Lithological map. St. Lambertus Church – Monschau-Kalterherberg / Germany. SW tower / part of the west façade.

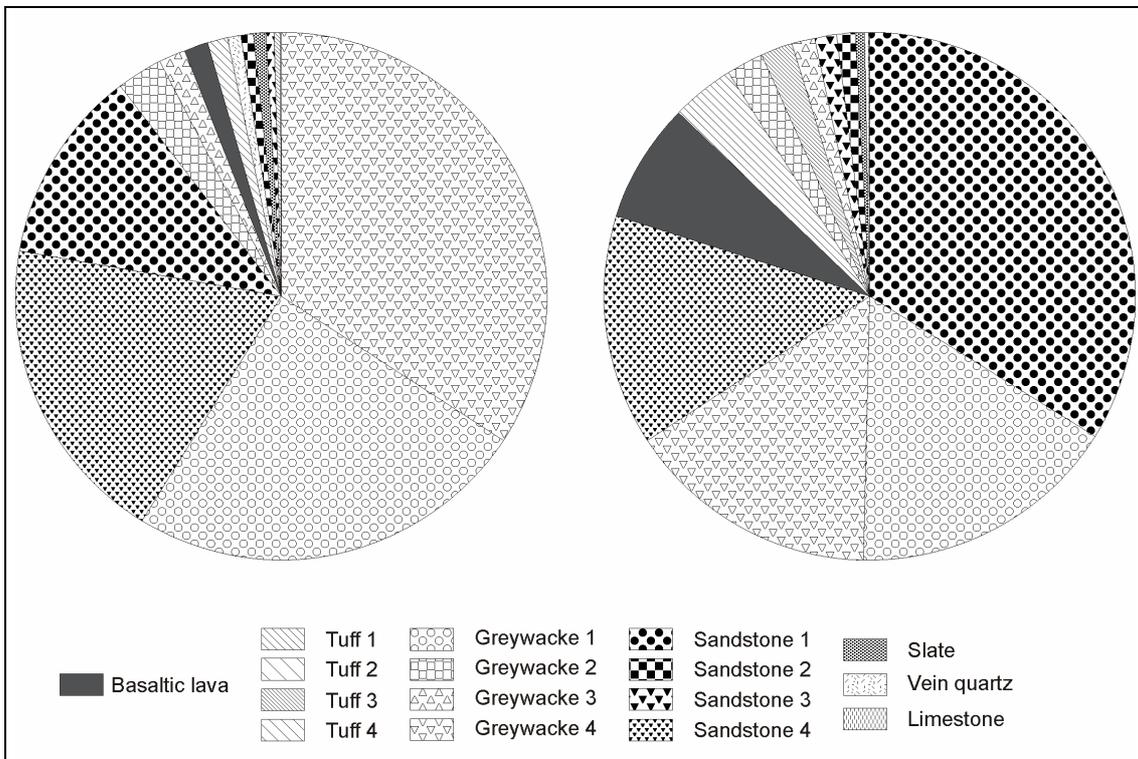


Figure 2: Quantitative evaluation of lithotypes according to number of dimension stones (left) and area of dimension stones (right) in %. St. Lambertus Church – Monschau-Kalterherberg / Germany. West façade.

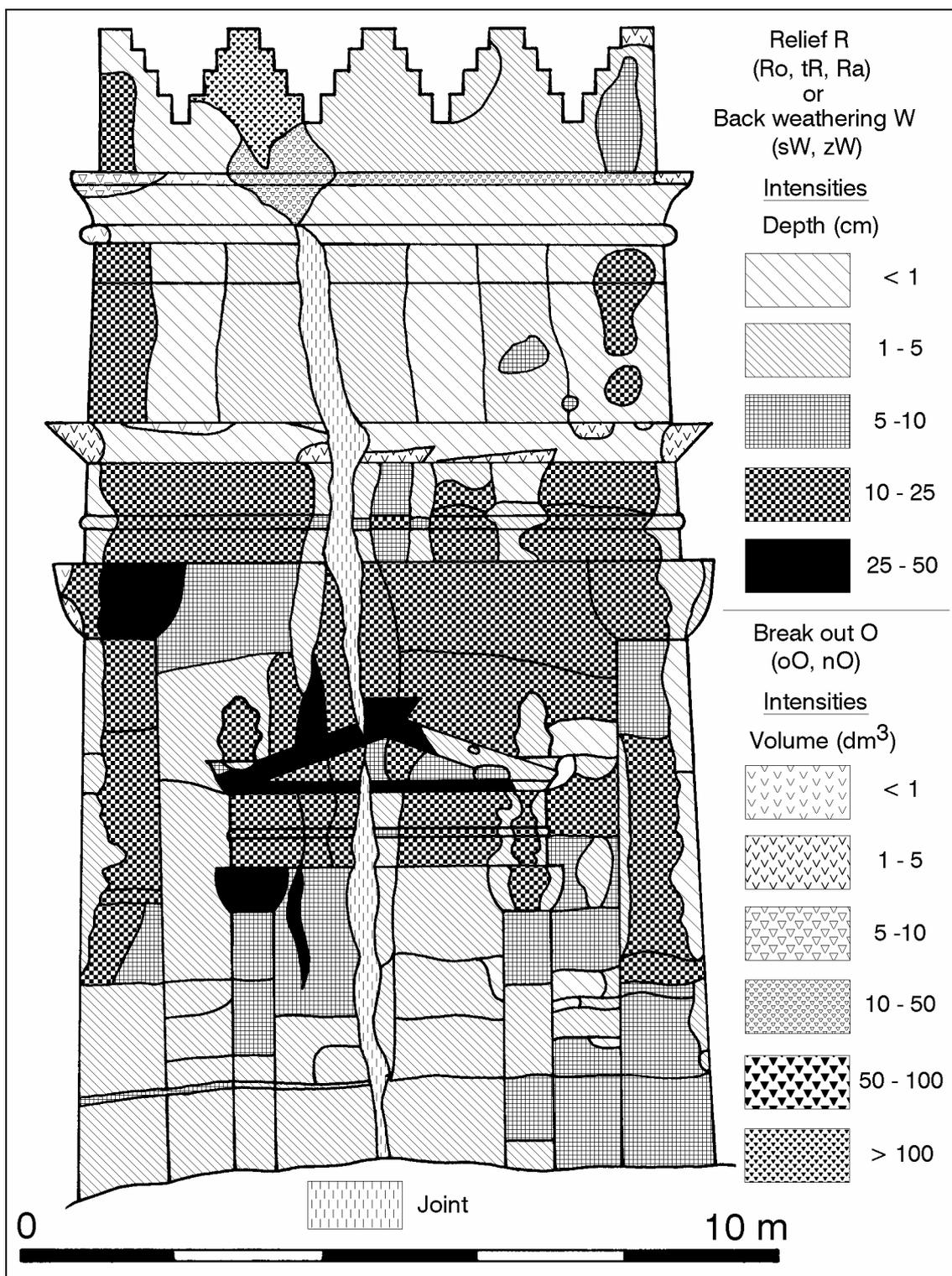


Figure 3: Map of weathering forms characterizing loss of stone material. Tomb No. 70 carved from sedimentary bedrock in the middle of the 1<sup>st</sup> century - Petra / Jordan.

Information on the development and progression of stone deterioration is an important concern of scientific damage diagnosis. Referential archive documents with information on the state of stone deterioration in the past can allow to characterize and quantify stone deterioration over the course of time.

However, due to the lack of such documents in most cases, alternative steps of evaluation have to be found, which allow the assessment of development and progression of stone deterioration from information on the recent state of deterioration. The determination of average weathering rates is suitable for a first estimation of weathering progression. It is based on the mapping and evaluation of weathering forms characterizing loss of stone material. Average weathering rates quantify the extent of stone surface recession per time unit and they are calculated from the hitherto total extent of stone surface recession and the age of the monument at the time of investigation. Average weathering rates can be determined and illustrated for all particular areas of a stone monument or can address the entirety of a stone monument or structure (figs. 4, 5). They can be used for weathering prognosis, taking into account that they describe a continuously linear weathering progression as per calculation mode.

Since linearity of weathering progression may not be realistic, further attempts are necessary to approach real weathering progression. Based on the systematic evaluation of weathering forms – considering all types, intensities and combinations of weathering forms characterizing loss of stone material, deposits on the stone surface, and current detachment of stone material - Heinrichs (in press) deduced for rock-cut monuments in Petra / Jordan statistical successions of weathering forms depending on stone type. The findings were used for the calculation of weathering progression factors. This was the basis for the determination of weathering progression curves which quantify the recession of the stone surface over time. The weathering progression curves obtained for the most important stone types revealed a continuous acceleration of weathering progression, approximating a linear weathering progression only in very advanced phases of weathering. The extrapolation of the results allowed quantitative weathering prognosis, since it was considered to be close to reality (fig. 6).



Figure 4: Tomb No. 634 (right) carved from sedimentary bedrock in the 1<sup>st</sup> century - Petra / Jordan.

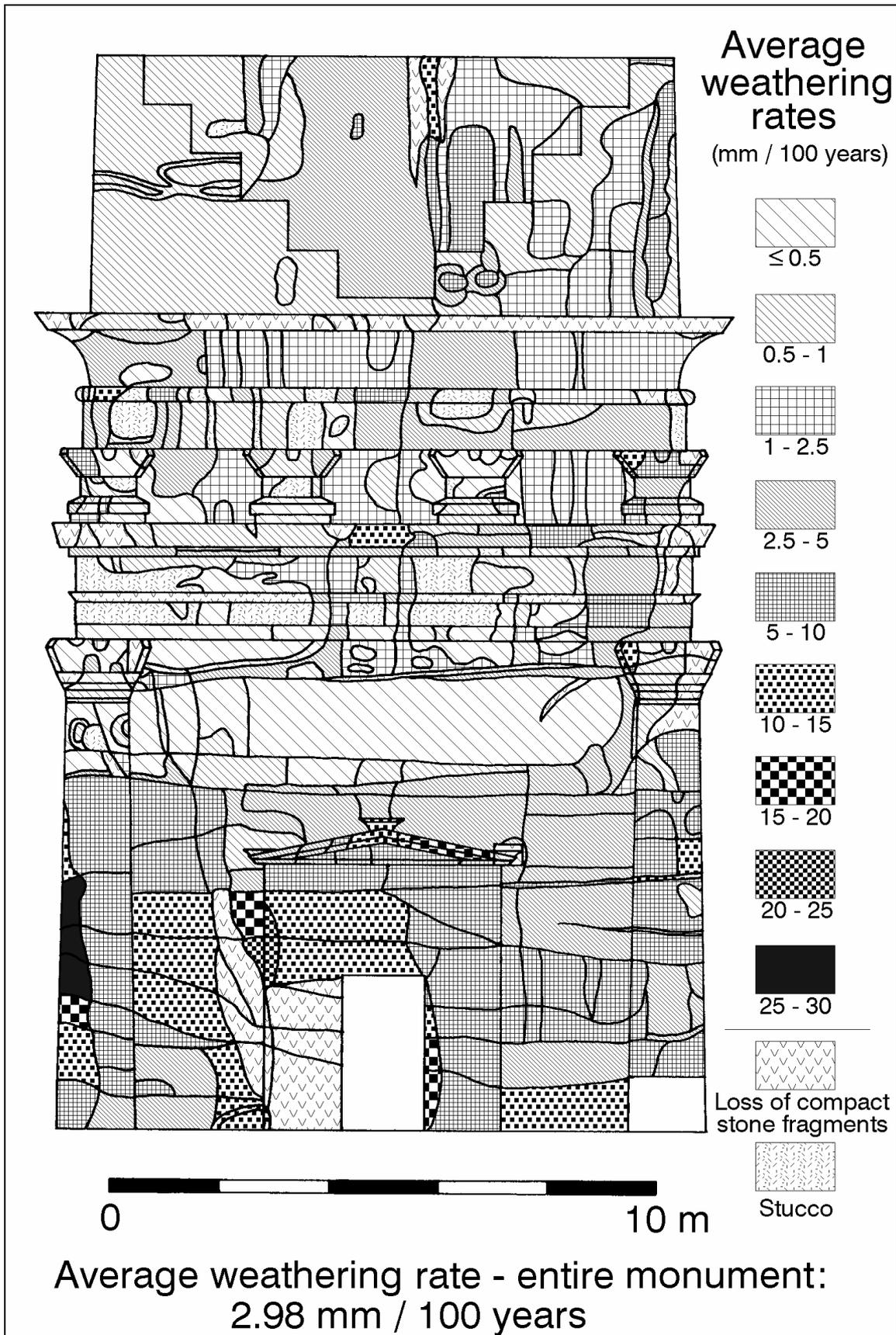


Figure 5: Average weathering rates. Tomb No. 634 - Petra / Jordan.

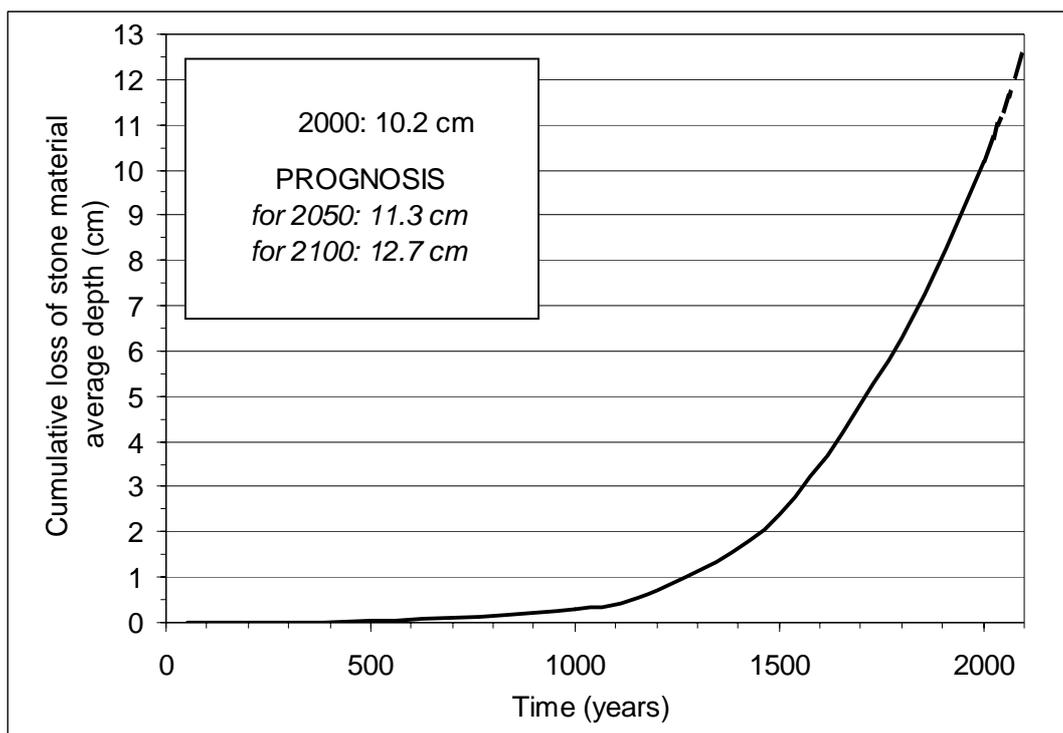


Figure 6: Weathering progression and prognosis. Tomb No. 9 – Petra / Jordan, carved from sedimentary bedrock in the 1<sup>st</sup> century.

Based on the results and documents obtained from monument mapping, complementary studies and sampling for the characterization and quantification of stone deterioration can be well directed.

In-situ measurements can provide important quantitative information on stone materials and their state of deterioration. Preferably, non-destructive measuring methods should be applied. Ultrasonic measurements represent a very suitable method for the quantification of stone deterioration and also for the detection of preimminent stone damage. In particular, the transmission mode can be applied successfully to decorative stone structures such as sculptures, columns, balustrades or slabs. An example is shown in figures 7 and 8. In figure 8 the decrease of ultrasonic velocities (transition from white to black) corresponds to the increasing degree of stone deterioration.

Scientific rating of stone damage is an important objective of the approach to sustainable monument preservation. For example, damage categories and damage indices have been introduced for the rating of weathering damage (Fitzner & Heinrichs 2002, Fitzner et al. 2002, Fitzner et al. in press). Subsequent to the registration, quantitative evaluation and illustration of weathering forms, damage categories are used for the rating of the weathering forms with respect to degree of damage. This is based on correlation schemes in which all weathering forms are related to defined damage categories. Damage categories are illustrated in maps and they are used as indicators of the need and urgency of preservation measures (fig. 9). Damage indices are applied for the conclusive quantification and rating of weathering damage. Their calculation is based on the quantitative evaluation of the damage categories. Damage indices reveal the overall need and urgency of preservation measures for stone monuments or individual stone structures.



Figure 7: Ultrasonic measurements. Lion horoscope, Nemrut Dag / Turkey.

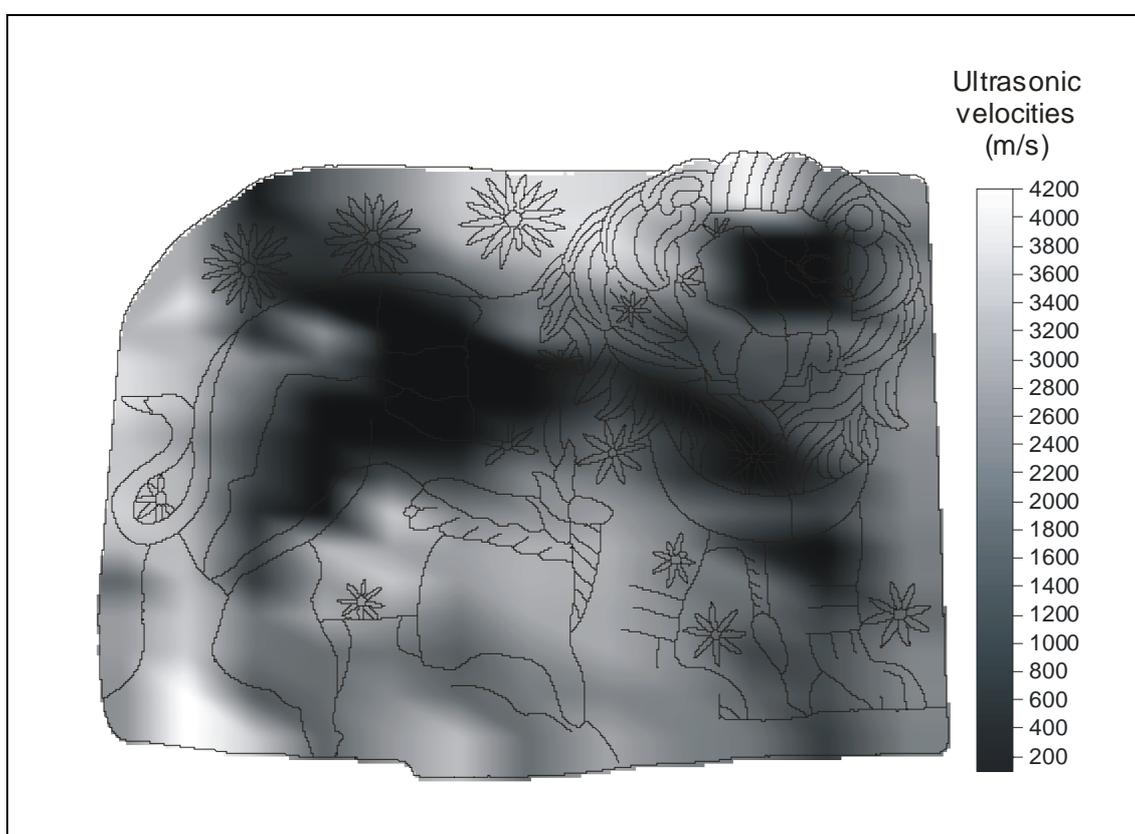


Figure 8: Ultrasonic velocities. Lion horoscope, Nemrut Dag / Turkey.

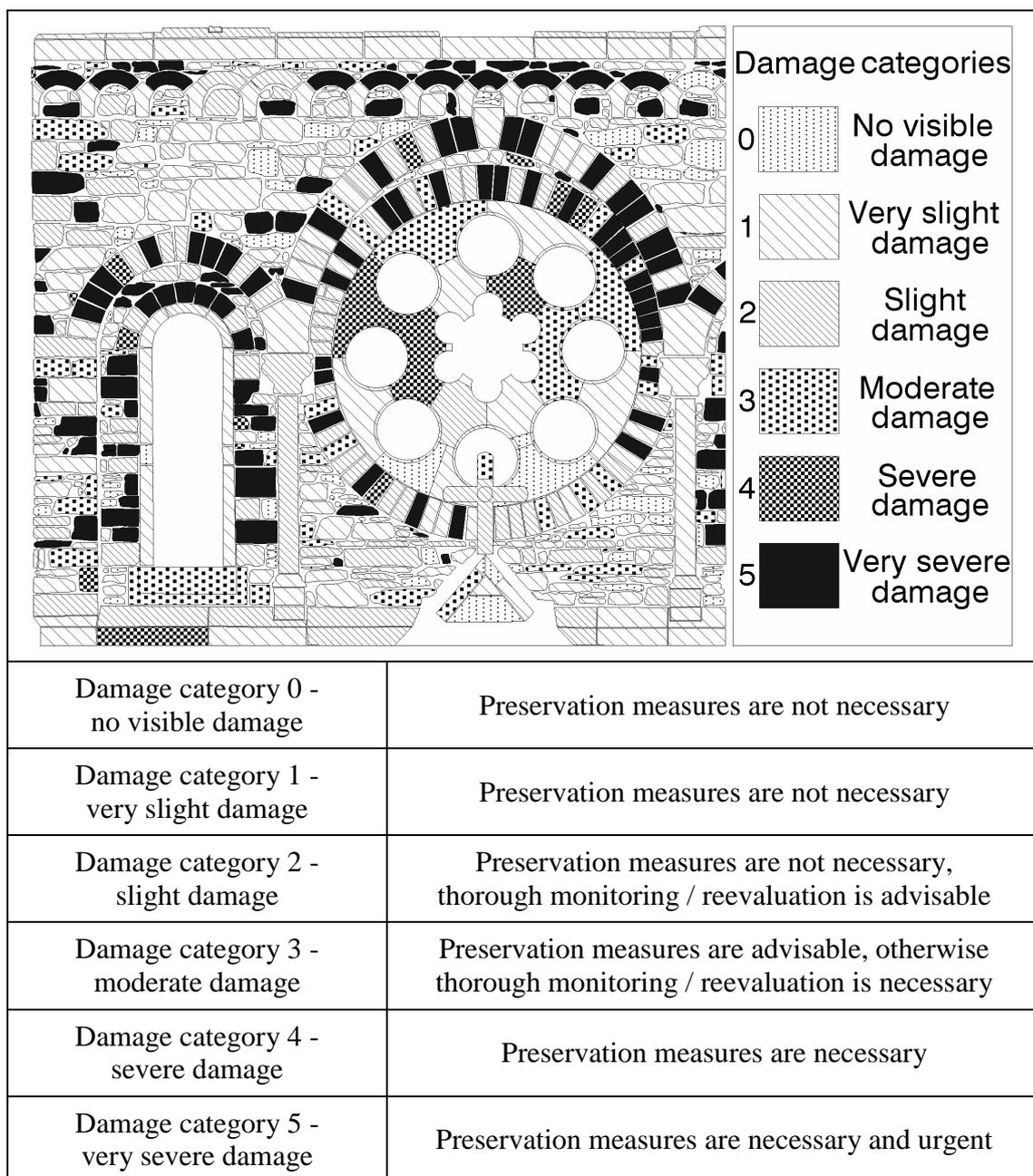


Figure 9: Map of damage categories with rating of need and urgency of preservation measures. St. Lambertus Church – Monschau-Kalterherberg / Germany. SW tower / part of the west façade.

#### 4. Documentation within the scope of therapy

The results of diagnosis are the basis for the deduction of therapeutical steps in accordance with the directives governing monument preservation. The therapeutical activities can be of remedial or preventive character. They can be addressed to maintenance, repair, rehabilitation, conservation, restoration, renovation, replacement, relocation, reconstruction or rebuilding of monuments or structures (Petzet 1999). Particular phases of therapy are:

- conception, calculation and test-application of preservation measures: decision of necessary and proper preservation measures, including selection of best techniques and materials and considering acceptable technical efforts and expenditure,

thorough test-application of techniques and tests of materials selected for monument preservation to clarify the expected effectiveness;

- implementation of preservation measures: implementation of all individual therapeutical steps following a defined working plan and time schedule;
- quality control of preservation measures: reevaluation of the monument condition, comparison of the conditions before and after the therapeutical steps, critical rating of the success of the preservation measures, amendments;
- monitoring, maintenance: regular re-evaluation at suitable intervals by means of standard procedures which ensure that any changes can be identified and quantified as function of time, initiation and implementation of occasional or constant maintenance works.

The documentation is to ensure the thorough and proper understanding of all therapeutical actions ranging from their decision up to their long-term control and the maintenance of monuments. The items of documentation with respect to therapy are presented in table 4.

Table 4: Items of documentation within the scope of therapy

<b>Therapy</b>	<b>Items of documentation</b>	
	Conception, calculation and test application of preservation measures	Preservation plan and its justification, involved authorities / institutions, responsibility, cost estimation, selection of techniques and materials, procedures and results of test applications and material tests, prognosis of the effectiveness of the intended interventions, plans, maps, data sets, files, reports
	Implementation of preservation measures	Working plan, description of all actions, description of techniques and materials, dates / periods of implementation, implementing institutions / companies, costs, maps, photographs, data sets, files, reports
	Quality control of preservation measures	Dates / periods of quality control, procedures and results of quality control, involved institutions / companies, recommendations for future control, maps, photographs, data sets, files, reports
	Monitoring, maintenance	Intervals of monitoring, monitoring concept, responsibility, procedures and results of monitoring, dates / periods and types of maintenance works, involved institutions / companies, maps, photographs, data sets, files, reports

All considerations, works, results, costs and participants in the course of anamnesis, diagnosis and therapy are to be precisely documented and should be summarized in a final documentation which should be stored properly.

This will ensure the thorough understanding of a stone monument ranging from its history and cultural significance to all interventions for its preservation. At the same time this documentation represents an excellent basis for all future activity. There is much effort to guide comprehensive documentation by means of data bases or expert systems.

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