Nidaros Domkirkes Restaureringsarbeider

The Restoration Workshop of Nidaros Cathedral

REPORT

Andreas Franz & Per Storemyr

Conservation of Mural Paintings in the Regalia Room, Archbishop's Palace, Trondheim, Norway 1999-2005

Emergency Conservation of the West Wall and Scientific Investigations 2000

NDR 1/2001

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R e p o r t

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This report is part of a "work-in-progress" CD-ROM with the title: *Conservation of Mural Paintings in the Regalia Room, Archbishop's Palace, Trondheim, Norway 1999-2005*. The CD also contains additional images from the conservation campaign, as well as earlier reports from the work with the Regalia Room (NDR reports no. 9901 and no. 0001)

Abstract

Following the comprehensive scientific investigations of the 17th century mural (lime/secco) paintings in the Regalia room, Archbishop's Palace (Trondheim, Norway) in 1998-1999, this report describes the first emergency conservation of the west wall in the room in 2000. Scientific investigations supplementing earlier work are also included in the report.

The emergency conservation was carried out using lime-based materials only. It included: 1) Removal of gypsum repairs from 1966. 2) Impregnation of the painted surface with lime water. 3) Re-fixation of exfoliating limewash and paint (injection). 4) Re-fixation of mortar in hollow areas (injection). 5) Closing of cracks and gaps with lime mortar.

Scientific investigations included following up of crack measurements and climate monitoring, as well as studies on salt weathering. The relationship between indoor climate and salt crystallisation/dissolution is not yet properly understood, and a discussion of how to deal with this problem is included in the report. A plan for further conservation work is also included.

It can be concluded that the murals paintings in the room are in a semi-stable condition at the moment, and that the greatest risks are related to possible future water leaks from the west gable wall and unwanted release of water from the sprinkler system on the loft.

Preface

Supported by the EC Raphaël Programme under the project "European Heritage Laboratories / Nidaros Cathedral Restoration", this work has been a co-operation between Atelier Andreas Franz (CH) and The Restoration Workshop of Nidaros Cathedral. The emergency conservation campaign was undertaken over four weeks in June 2000. The report is part of a "work-in-progress" documentation (on CD-ROM) of the conservation work in the Regalia room.

Thanks to Professor Jon Solem at the Museum of Natural History and Archaeology in Trondheim who kindly determined the "bug" found in the room in 2000. Also thanks to colleagues in the Workshop for scaffolding work and practical help whenever it was necessary.

Zürich in January 2000
Per Storemyr and Andreas Franz

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1 Introduction

The so-called Regalia room in the north wing of the Archbishop's Palace in Trondheim exhibits perhaps the finest example of secular mural paintings in Norway. Covering all the walls and the barrel vault of a medieval room in the palace, the renaissance murals were painted in the early 17th century. The current name, the Regalia room, derives from its use as a storeroom for the Norwegian crown regalia in a short period after 1826.

Although the paint has faded and there are many other damages, the murals are generally in relatively good shape. The great exception is the west wall, which has been in a very bad condition for a long period of time, even after having been extensively restored in the 1960s. Thus, as the damages are critical, and reappearing after the last restoration, the conservation project was started on the west wall in 1998-99. The plan is to continue work on the other walls, implying that the whole project will be be continued at least until 2005

Since repeated surveys of the west wall have shown that the weathering is very active and that there are no simple causes of the decay, the conservation project was designed as an *applied research* study, and not only a short-term investigation in order to draw up a practical conservation plan. The main objective is thus to lay a sound basis for long-term protection, maintenance and conservation, including necessary follow-up work of a scientific nature. In this respect the project follows the idea of *sustainable care of monuments*, and the work is carried out as small, "reversible" steps. A further aim of the project is to use and refine state-of-the-art graphical digital documentation methods.

Studies on art history, building history, stratigraphy of plaster, whitewash and paint, as well as weathering were carried out before the emergency conservation of the west wall, described in this report, started in June 2001 (Odén 1999, Franz & Storemyr 2000).

The emergency conservation was carried out according to the plan presented in Storemyr & Franz (2000:54ff), which in a modified form was accepted by the Norwegian cultural heritage authorities (Directorate for Cultural Heritage, *Riksantikvaren*) in the spring of 2000.

The work in 2000 did not only include emergency conservation, but also a range of scientific analyses. Thus, the content of this report is as follows:

- Experiments with mortars for the work
- Emergency conservation of the west wall
- Building archaeology - new findings
- Monitoring and observations of cracks
- Monitoring of indoor climate
- Weathering phenomena - new findings

2 Experiments with mortars for the work

In order to find the most appropriate material for the emergency conservation, several mixtures of lime mortar to be used for for injection and filling of cracks and gaps were tested. We mostly used stored, wet slaked lime from Rødvig (Denmark, see appendix 3), but also some dispersed hydrated lime provided by Deffner & Johann (Germany).

2.1 Experiments with dispersed hydrated lime

Over the past few years *Fachhochschule Köln* has experimented with a "new" type of lime mortar called "dispersed hydrated lime" (Jägers 2000, see also http://www.restauratoren.de/mitteilungen2_00/fortbildung-weisskalkhyd.html or see appendix 1). Generally, this type of mortar is produced by mixing hydrated lime, water and aggregates with special mixers at high speed, up to 20-30.000 RPM, thus producing a very fine-grained lime, which carbonates more rapidly and shows less shrinkage fissures than normal lime. Made in the right way, the mortar is also praised for its ability to flow and for not letting the aggregates settle rapidly.

These features make the mortar potentially useful as an injection agent for fixing scales, exfoliations and hollow areas in stone, plaster and mural paintings. There are some drawbacks, though. First, upon carbonatisation the mortar becomes much harder than normal lime mortar, a feature rarely appreciated in conservation work, which usually deals with rather soft historic materials. Second, in order to be able to make large quantities, the commercial producers mix the mortar with dispersing agents, probably methyl cellulose and acrylic acid (the producers don't normally give accurate information). Third, according to our experience, the rapid carbonatisation makes it difficult to use the same mortar mix for longer periods of time (some hours, a day), which may be a problem in practical work.

We nevertheless decided to try the mortar, and obtained a ready-to-use injection mix from Deffner & Johann (http://www.deffner-johann.de/calxnova.htm, see also appendix 2). This mix has been tested on some very few spots on the west wall (se map in chapter 3). These test spots will be evaluated later. The reason why we did not carry out more extensive tests, was because experiments with other mortar mixes produced very good results, especially related to the ability to flow (for injection mortars) and to the low amount of shrinkage fissures.

2.2 Experiments with stored, wet slaked lime

Inspired by the fact that mixed (dispersed) lime may have some useful properties, especially as injection mortars, our experiments aimed at revealing whether mixing (in contrast to stirring) normal wet slaked lime mortar would produce good results.

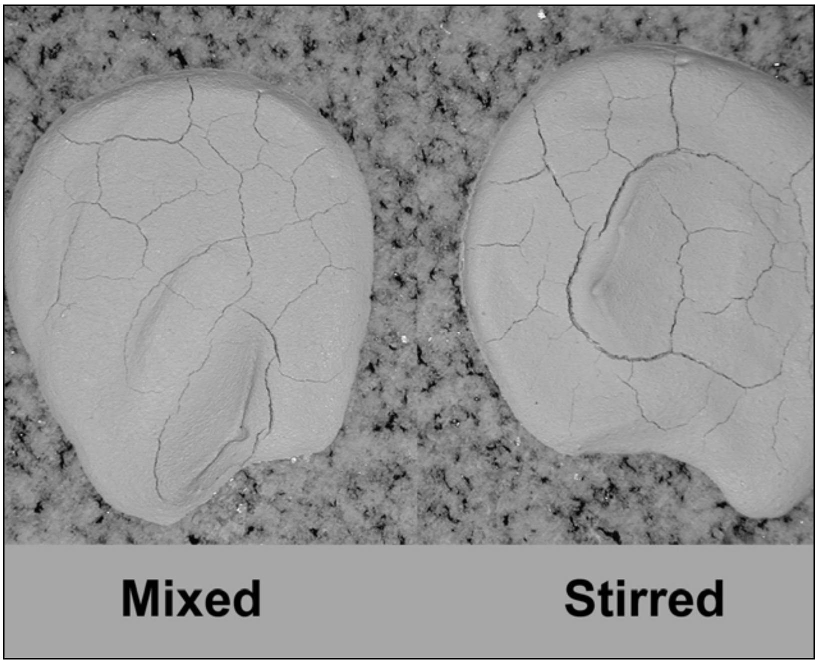
We prepared several mortar mixes (see table on next page) and let small quantities harden on a roughly worked slab of Trondhjemite (a type of granite).

Prescription of test injection mortars. Stored, wet slaked lime from Rødvig, Denmark (appendix 3). One series was mixed with a hand mixer at 12.000 RPM, another was stirred using spatulas (volume parts)

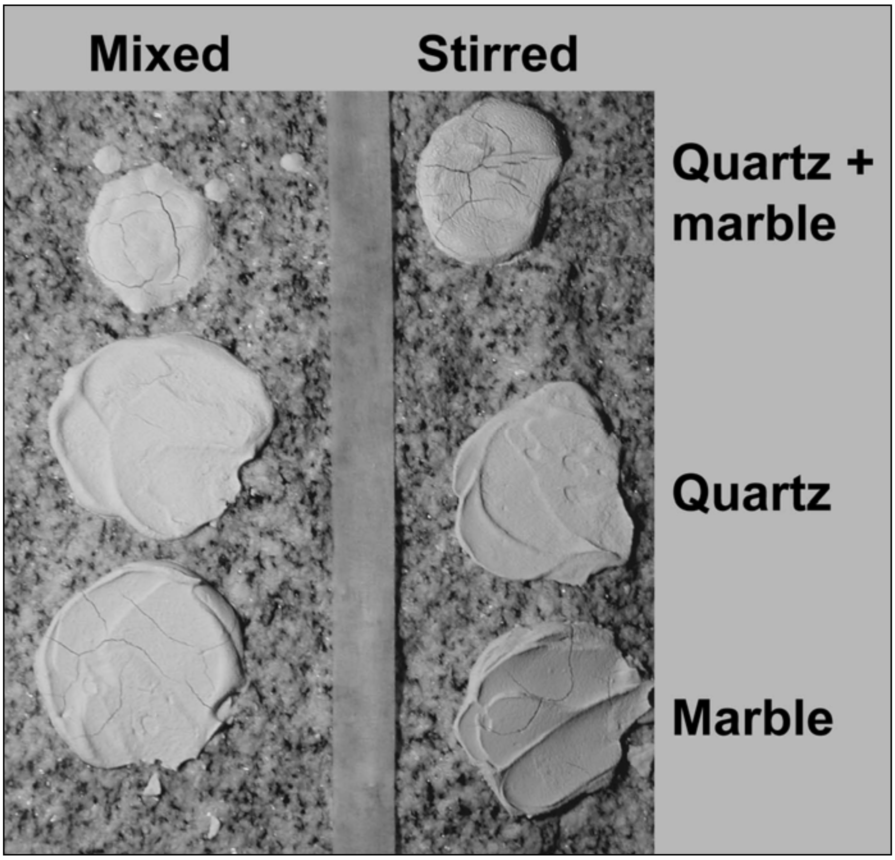
Type	Wet slaked lime	Quartz powder	Marble powder	Water
1	1 part	3 parts (0-300 µm)	1 part (0-300 µm)	1 part
2	1 part	4 parts (0-300 µm)	-	1 part
3	1 part	-	4 parts (0-300 µm)	1 part

The results of the experiments can be summarised like this:

- When mixing the mortars at 12.000 RPM the amount of shrinkage fissures somewhat decreases.
- The added aggregates have a very significant effect on the development of shrinkage fissures. Mixtures with marble powder showed distinctive crack patterns, *whereas mixtures with quartz powder hardly developed any cracks at all*. When using quartz and marble powder together, distinctive crack patterns also developed. We cannot explain the the fact that marble has such a great effect on the crack development, and this would be a very interesting field for further research.
- Mixed lime flows significantly better than stirred lime and does not as easily block injection needles. This must be due to the finer grain size of the mixed mortars



Mixed (at 12.000 RPM) and stirred (with spatulas) pure lime *after one day of hardening. The mixed lime show somewhat less cracks than stirred*



Mortar mixes 1, 2 and 3 (see table on previous page) after 2 days of hardening. Note that the mortars with quartz have no cracks at all

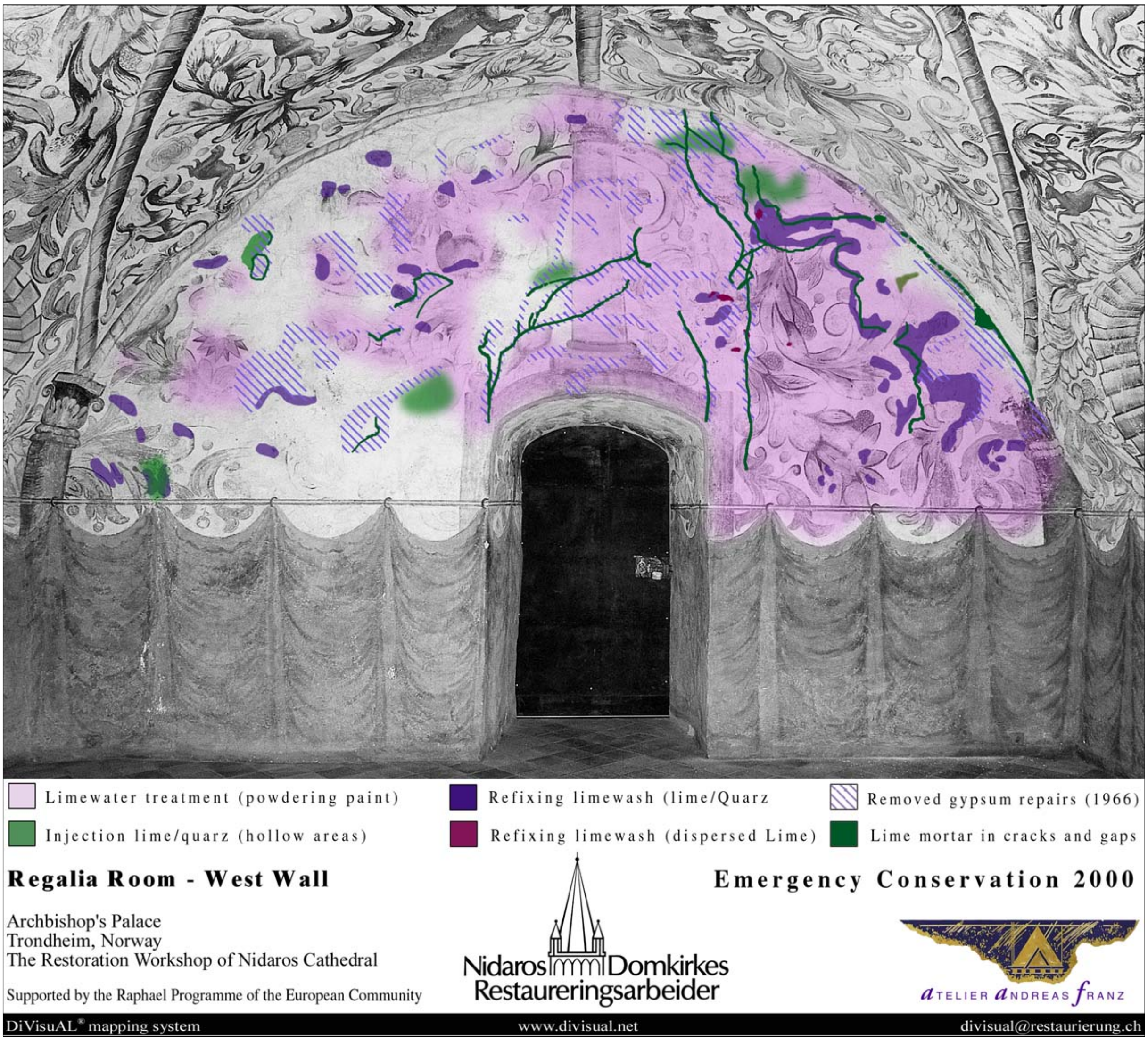
Summarised, mixing lime based injection mortars with quartz as aggregate has a very positive effct on shrinkage and flow. We therefore decided to use such mortars for the emergency conservation of the west wall.

3 Emergency conservation of the west wall

The emergency conservation was carried out according to the plan presented in Storemyr & Franz (2000:54ff), which in a modified form was accepted by the cultural heritage authorities (Directorate for Cultural Heritage, *Riksantikvaren*) in the spring of 2000. The modified plan involved the following steps:

- Removal of gypsum repairs from 1966
- Impregnation of the painted surface with lime water
- Re-fixation of exfoliating limewash and paint (injection)
- Re-fixation of mortar in hollow areas (injection)
- Closing of cracks and fissures

We decided to "stay in the system" and therefore all measures were carried out using lime only. The maps below shows the location of measures carried out. All pictures taken during the campaign can be found on attached CD.



Map of measures carried out during the emergency conservation in June 2000

3.1 REMOVAL OF GYPSUM REPAIRS FROM 1966

The first measure undertaken was the removal of the extensive gypsum repairs from 1966. These repairs covered most cracks and were often "smeared" over the surface without any apparent reason. Below some of these surfaces we could find older painted layers in quite good condition. The reason might be that salts tend to crystallise on the surface, thus not causing paint at a lower level to disintegrate/powder. Gypsum was also used for fixing loose plaster and limewash in 1966. At several places the repairs were heavily weathered (exfoliation, spalling), perhaps due to thermal/hygric dilatation and/or salt crystallisation (cf. Franz & Storemyr 2000:35ff). It also seems that some gypsum repairs, especially the thick ones, were affecting adjacent plaster and limewash in a negative way by giving rise to fissures. This can be explained by the different thermal (and hygric) behaviour of gypsum and lime.

We removed all the loose and exfoliated gypsum repairs, as well as many of those apparently affecting adjacent plaster and lime negatively. We also removed most gypsum in cracks. The work was undertaken mechanically using various sized scalpels only. Gypsum was not, or only partly, removed at places where it covered large areas and apparently did not give rise to any damage (especially in the lower part of Q1).

Removal of gypsum repair mortar from 1966 (in Q2)

Removal of gypsum repairs "smeared" over the surface in Q1

3.2 IMPREGNATION OF THE SURFACE WITH LIME WATER

Before undertaking further measures, we considered it necessary to treat areas in which powdering of paint was observed (Q1, Q2, and Q4; Q1 being the upper left quadrant and Q4 the lower right one, see fig. in appendix 6). Since the aim of the conservation is to keep the actual appearance of the murals (although all loose parts to be re-fixed), we did not make a difference between “original” painting and “over-paintings”.

There are several ways to treat powdering of paint on murals, but since we wanted to "stay in the system", impregnation by limewater was chosen as the best option. Another option, impregnation by ethyl silicate, was considered very problematic, not least since other measures on the wall was to be undertaken by lime mortar. Lime mortar will introduce water to the wall, which negatively influences the hardening of ethyl silicate.

Spraying limewater on the wall in order to consolidate the surface (in Q2). Note also the extensive cracks, which appeared after the removal of gypsum repairs from 1966

Consolidation by limewater sprayed on murals has been employed by conservators for a long time, although, given the low solubility of calcium hydroxide (1,7 g/l at 20ºC), many are sceptical about its effect as a consolidating agent. Recent research have, however, shown that limewater can be effective on mural paintings, but that crystallisation/carbonation is a very lengthy process (Brajer & Kalsbeek 1999). In some cases a consolidating effect has first been observed some 80 days after treatment. There are, moreover, potential hazards of the limewater method. These are especially related to dissolution and recrystallisation of soluble salts present in walls (due to the amount of water introduced) and destruction of organic binding media (due to the alkalinity of sodium hydroxide) (ibid.).

Potential areas for limewater treatment on the west wall of the Regalia room had no, or extremely small amounts of, organic binders (Franz & Storemyr 2000:20ff). However, the amount of salts in masonry, plasters and limewash was very significant (ibid.:35ff). Thus, the employment of limewater must clearly be regarded as a risky operation. Considering the heavy loss of pigments on the wall and the loose nature of the surface, we believe that we chose the lesser of two evils. Intial tests with limewater vs. ethyl silicate in 2000 also showed that the limewater method had some potential in the Regalia room (ibid.:55).

The treatment was carried out by spraying limewater on areas marked on the map (see above). The actual areas were wetted until the point where water *almost* started running down the wall, and then repeated after a while until a remarkable decrease in water absorption occurred. It was still carried out a few more times until almost no water was absorbed by the surface. A total of 35 cycles of impregnation was in this way carried out over a period of more than one week, bringing all together 17 litres of limewater into the wall (c. 2,2 l/m^2). This seems like a very small amount compared to what was achived during a test in Avnsø church in Denmark. Brajer & Kalsbeek (1999) reports that as much as 25 l/m^2 was applied over a 10 day period in this case. It might be that the masonry material in the latter case was more porous, thereby taking up more water, than the dense granite and greenstone that can be found in the walls of the Regalia room.

In the weeks after the application we carefully observed the wall, looking for new salt efflorescences, but we were (luckily!) not able to see any new salts as a result of the treatment. A further discussion of the behaviour of salts can be found in chapter 7. Since we cannot expect the limewater treatment to be fully effective before several months have passed, a careful study of the results of the treatment will be carried out in 2001.

3.3 RE-FIXATION OF EXFOLIATING LIMEWASH AND PAINT

On the uppermost parts of the wall, especially on the so-called "chimney plaster" in Q2, intensive exfoliation of limewash and paint can be found. One reason seems to be that the limewash/paint from 1826 was applied on a very dry plaster. Another reason is the fact that large hollow areas and an extensive crack-pattern exists in these part (ibid.:35ff).

The re-fixation process was carried out with lime and fine aggregates only (see prescription in

Injecting lime behind limewash

chapter 3.6). The lime mortar was applied using thin injection needles. Before injection the spot was pre-moistened with limewater (as used for impregnation; see above). After full absorption of the limewater the injection was performed and the flakes of limewash and paint were placed on the appropriate spot using slight pressure (manually with the hand). Very fine gaps between mortar and limewash were re-fixed using a thin soup of lime without any aggregates.

It was often difficult to inject lime behind the very fragile flakes of limewash. Sometimes flakes broke and had to be re-fixed, and sometimes it was impossible to fill areas we wanted to fill due to too narrow spaces between limewash and underlying plaster. But generally we were able to improve the situation drastically, and time will show if the lime will keep the flakes in place.

3.4 FILLING OF HOLLOW AREAS

Apparently unstable and potentially dangerous hollow areas were filled with lime mortar with fine quartz-sand using injection needles (see prescription in chapter 3.6). Again, all places to be filled were pre-moistened with limewater in order to avoid shrinkage fissures in the new lime mortar.

We did not fill as many hollow areas as described in the conservation plan (ibid.:54). This was because we wanted to observe the behaviour of the actually filled areas before continuing the conservation in 2001.

Shortly after filling some of the hollow areas, strong salt crystallisation (mirabilite) could be observed close to injection holes at one place in the upper left part of Q1 and one place in the lower right corner of Q1. We brushed away this salt, and it never recrystallised afterwards.

This salt crystallisation is discussed further in chapter 7.

Upper right part of Q1. After removing a large gypsum repair hollow areas around were filled with lime mortar, which was also use to close the gaps around the "open" area. Salt crystal-lisation were observed after the work, but after being brushed away they did not return.

3.5 CLOSING OF CRACKS AND GAPS

In order to stabilise the plasters along the edges of cracks, they were filled using "regular" lime mortar (see prescription in chapter 3.6). According to the tests made in advance (see chapter 2), lime mortar with quartz sand was the best material for this purpose (few shrinkage fissures).

The same mortar was also used for closing many gaps on the wall, especially where the plasters had completely disappeared and masonry stones could be seen.

Closing of cracks and gaps with lime mortar in Q2. Right: Final closing of crack. Left: temporary closing of edges and corners (Q2).

3.6 MATERIAL PRESCRIPTIONS

All mortars, except with regard to tests with dispersed lime (see chapter 2), were prepared using stored, wet slaked lime from Rødvig, Denmark (see appendix 3). Since tests showed that the use of quartz aggregates only, as well as mixing at 12.000 RPM, produced the best mortars, all were prepared in this way (se also chapter 2).

Prescription of mortars used for injecting hollow areas, re-fixing loose limewash and filling cracks and gaps (all mixed at 12.000 RPM, volume parts)

Type	Wet slaked lime	Quartz sand	Sand grading	Water
Injection mortar	1 part	3 parts fine	0-300 µm	1 part
Injection lime	1 part			10 parts
Repair mortar regular	1 part	3 parts fine 2 parts coarse	0-300 µm 0-1 mm	-
Repair mortar fine	1 part	4 parts fine 1 part coarse	0-300 µm 0-1 mm	-

4 Building archaeology - new findings in 2000

During the stratigraphical investigations of the west wall in 2000 (Franz & Storemyr 2000:15ff) we discovered that a lot of cement had been used for repairs in 1966, but we did not observe a gray injection mortar, possibly from the same time. This injection mortar, as well as a gray intermediate paint already observed in 1999, will be reported below.

4.1 INJECTION MORTAR

The injection mortar can especially be found in the lower right corner of Q1 and in the lower part of Q2. Although we have not seen it at other places, it is to be assumed that its use was more widespread. The mortar has apparently been used to fill hollow areas below plasters, and there are some clearly distinguisable holes in which the mortar must have been injected (see picture to the right). These holes were earlier incorrectly classified as strongly weathering aggregates (ibid.:42).

Holes for injection mortar (Q2)

The mortars are medium to loosely bound and at places very soft and disintegrated. We classified the mortar as a weathered cement injection, but were not sure whether it could be a peculiar lime mortar. Since it was impossible for us to distinguish possible lime from other components in the very fine grained mortar by microscopy, we made a quick XRD in order to check for calcite. This analysis showed that there is no lime in the mortar whatsoever. We can thus rule out that it is a lime mortar, but in a cement one would also have expected some lime (calcite). This means that we are either dealing with a particular cement or with a different kind of mortar (cement paste cannot be accurately determined by XRD).

Minerals in the mortar included (in decreasing order with regard to content): Quartz, chlorite, mica, albite, amphibole and anorthite, as well as *possible* trace amounts of montmorillonite/illite and quite a lot of the salts sodium nitrate and halite. The high amount of phyllosilicate minerals (chlorite and mica) is astonishing - one would not have expected these minerals as main components in an injection mortar, at least not if the mortar was applied as late as in 1966. We therefore have to ask whether this is some kind of a clay mortar, used for injection purposes at a far earlier date than 1966. In this connection we should also note that a mortar with similar colour was found in the former niche in the

NW-corner in 1999. This mortar was definitely not from 1966. Another question is whther this mortar can give some cluses to the high salt load on the west wall?

Since a main aim of the next conservation campaign is to fill in hollow areas, the injection mortar will have to carefully analysed before the campaign starts in the summer of 2001.

Gray injection mortar behind plaster in Q1

4.2 Gray intermediate paint layer

Discovered in 1999, but not reported in our previous report, a gray, intermediate paint layer was found to be quite extensive. It appears that it it was applied above the original limewash from 1616, especially in the right corner of Q2. Perhaps it was applied in the intermediate, somewhat difficult-to-understand-period between 1672 and 1826. We did not analyse this layer properly in 2000, and further work will be undertaken later.

Gray, intermediate paint layer (in the middle of the picture)

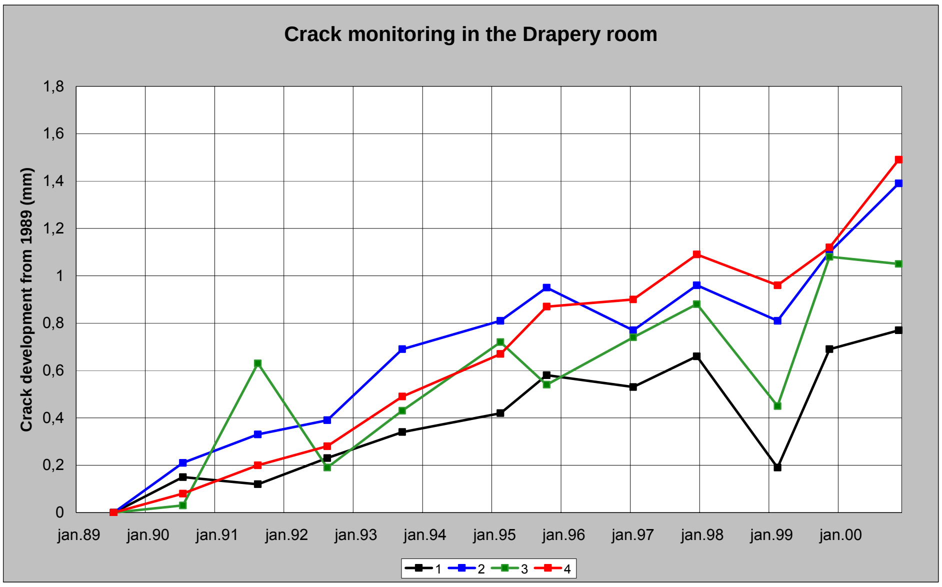
5 Monitoring and observation of cracks

The cracks in the north wing of the Archbishop's Palace were mapped in 2000 and reported and interpreted in Franz & Storemyr (2000:29f). Since then the cracks have been measures once more, in November 2000. Moreover, after removing the gypsum repairs from 1966 on the west wall, it became much easier to observe the extent of the cracks on this wall.

5.1 Monitoring and comparison of state 1992-2000

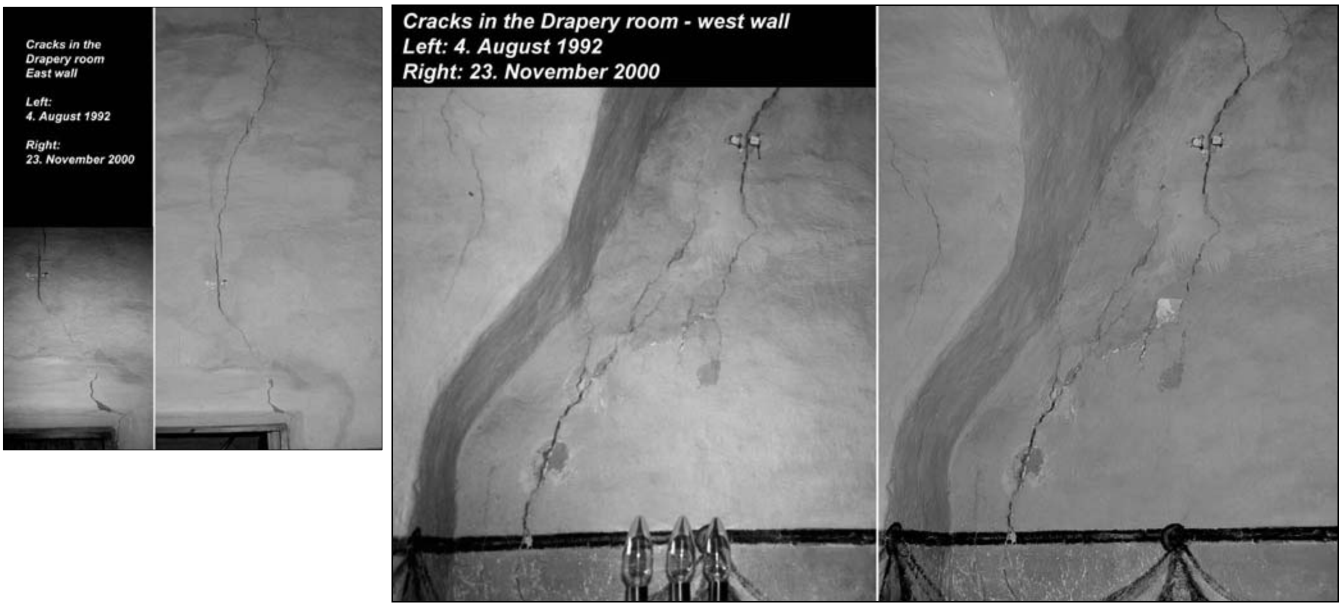
The new measurements show that the longitudinal (east-west) cracks generally widened little from 1999 to 2000. Maximum values were measured in the Drapery room close to the Regalia room, where the widening between November 1999 and November 2000 was in the order of 0,3 mm. This must be regarded as somewhat serious, especially since it seems clear that the widening does not represent seasonal variations.

No further attempts at interpreting the crack development has been made in 2000, and the planned structural analysis of the whole west wing has not commenced yet. Such an analysis is planned in 2001-2002.



Crack monitoring in the Drapey room 1989-2000. No. 1-2 are measuring points on the west wall, and 3-4 on the east wall. The drop in the winter of 1999 was probably caused by heavy rain (see Franz & Storemyr 2000).

After finding photos of the cracks in the Drapery room taken i 1992, we have undertaken a comparison with the state in 2000 (see photos on next page). It is impossible to observe any widening of the cracks on the photos, but it seems that no *new* cracks have developed over these 8-9 years. It is on the other hand clear that a few flakes of exfoliating plaster and whitewash close to the cracks have been lost in the period (both on the west and east wall). This corresponds to what we have observed in the Regalia room (east and west wall).



Cracks in the Drapery room. Comparison of state in 1992 and 2000 on the west wall (large photo, measuring points 1-2) and east wall (small photo, measuring points 3-4). Photos: Øystein Ekroll (1992) and Per Storemyr (2000)

5.2 CRACKS AFTER GYPSUM REMOVAL

The removal of gypsum repairs from 1966 on the west wall in the Regalia room made it much easier to se the extent of the cracks. Although looking dramatic, we believe that the cracks are quite stable at the moment, and at least not widening more than cracks in the Drapery room. Since most of the cracks were closed by lime mortar repairs in 2000, it will be easier to follow possible widening in the future. We also plan to establish measuring points on the wall.

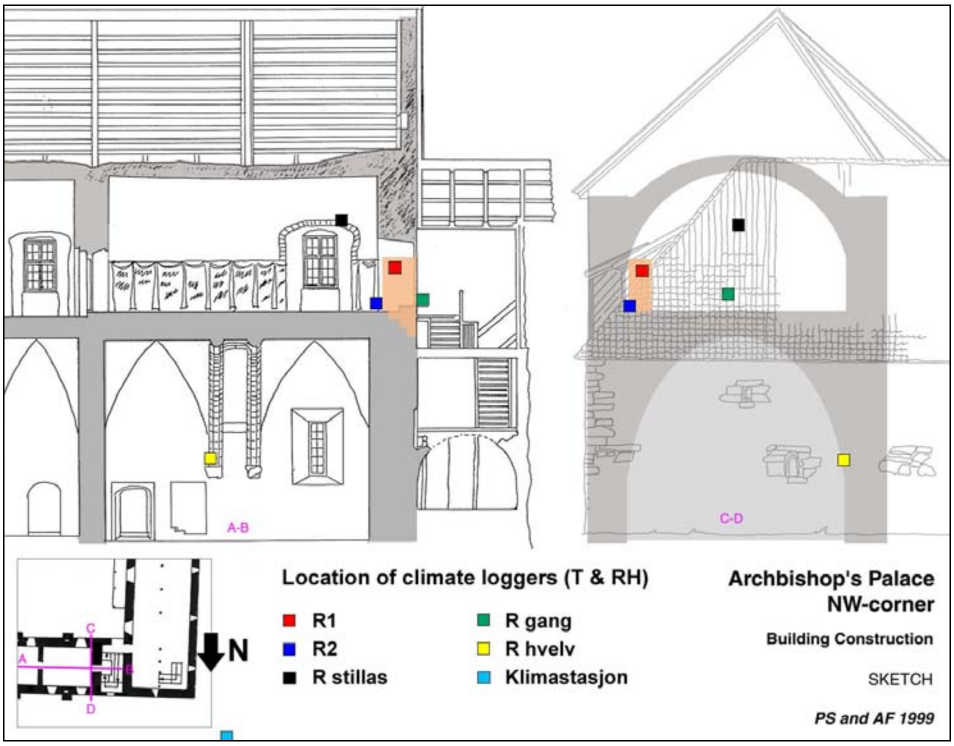
Cracks on the west wall (Q1) after removal of gypsum repairs from 1966. The cracks were closed with lime mortar in 2000

6 Monitoring of indoor climate

Monitoring and interpretation of indoor climate in the Regalia room has been undertaken since 1996 and is reported in Franz & Storemyr (2000:31ff). In 2000 the monitoring was continued and several new indoor monitoring stations were established in June 2000. An exterior monitoring station was also established. As of December 2000, the monitoring stations are (see also figure below):

- **R1 -** On floor level in the NW-corner of the Regalia room (since 1996)
- **R2 -** In the wall, in the closed niche in the NW-corner (since June 2000)
- **R stillas -** On the scaffolding in the Regalia room (since June 2000)
- **R gang -** Outside the door on the west wall (staircase) (since June 2000)
- **R hvelv -** in the vaulted room below the Regalia room (since Dec. 2000)
- **Klimastasjon -** Exterior monitoring station close to the Cathedral (west front) (Since Dec. 1999).

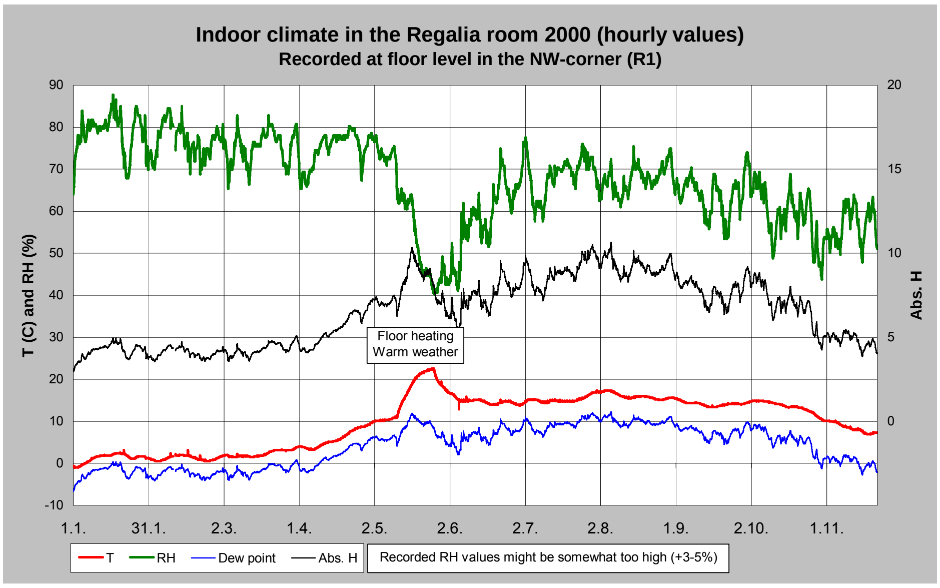
On all these stations T and RH are monitored every hour with different Tinytag devices. Most diagrams from the monitoring campaign (since 1999) can be found in Appendix 1, whereas the most important diagrams are shown below.

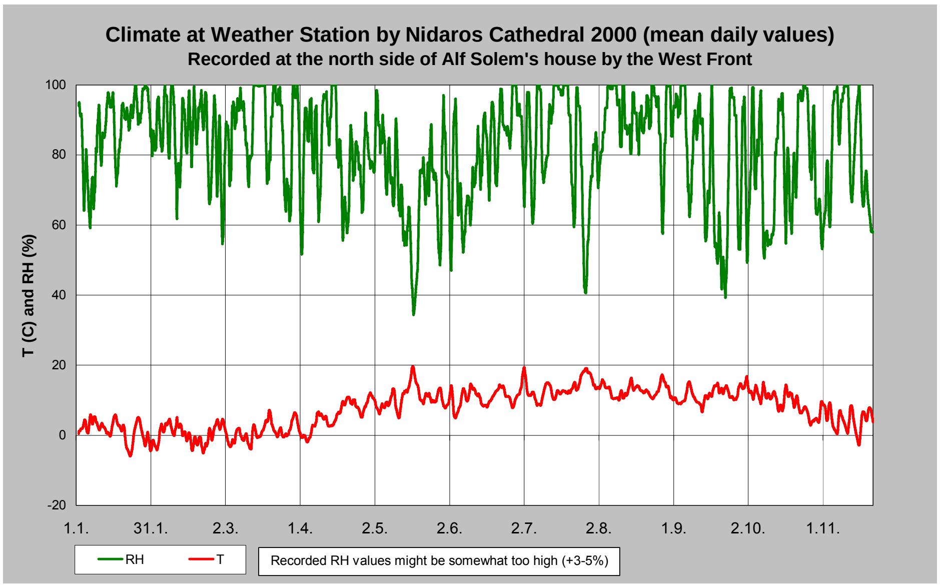


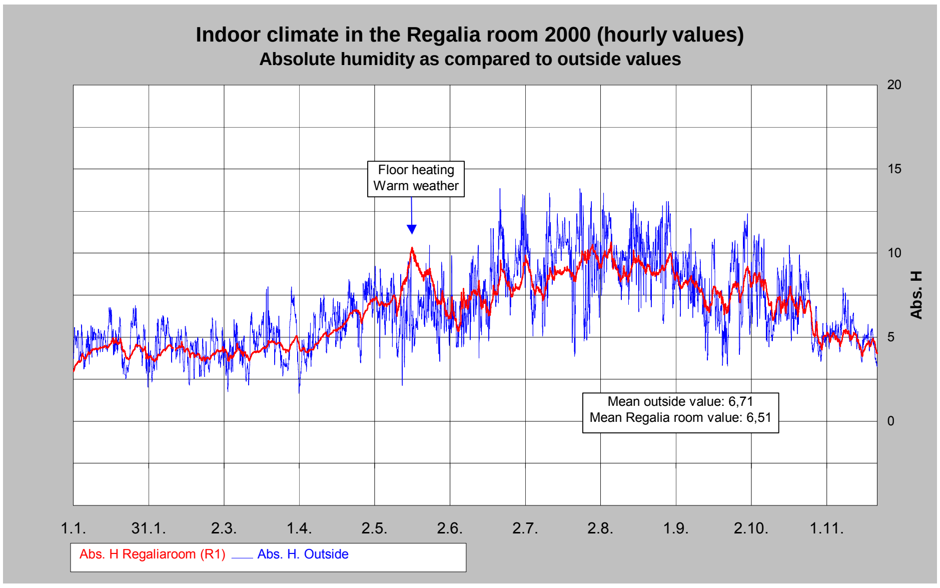
Location of climate stations (climate loggers) related to the Regalia room

6.1 INDOOR CLIMATE IN THE REGALIA ROOM IN 2000

The indoor climate in the Regalia room in 2000 shows a couple of interesting features. First, the winter climate was relatively humid (70-85% RH), which corresponds to a mild exterior weather with few very cold days. Second, the temperature rose sharply in May (from 10 to 22ºC within two weeks), with a







Indoor climate in the Regalia room 2000 (top) as compared to the outside weather (middle). The bottom image compares absolute humidity inside and outside (g/kg air).

corresponding drastic decrease in RH (75-40%). This unusual event occurred because the floor heating in the room was turned on accidentally for some two weeks. The drastic rise of T and drop in RH also reflect a warm and dry outside weather in May. Third, the summer climate in the room was cool and humid (15C, 60-75% RH), whereas the autumn brought about exceptionally dry weather, implying that the RH dropped to 50-65%. For a general description of the 2000 weather, see http://www.dnmi.no/klima/veret_i_2000/veret_i_2000.html

Although probably not good for the murals, the accidental floor heating event was of particular interest for us. Earlier we believed that the floor heating (installed in the 1960s) was out of order, but we now know that it can be used for slight warming of the room if necessary in the future. However, a heat regulation mechanism will have to be installed in order to be able to control such a possible heating properly.

Earlier we also believed that the room was continously becoming a little more humid from year to year, after the closing of the exterior repair work on the west gable wall in 1995. We thought so because the west wall was covered by scaffoldings between 1992 and 1995, implying that the wall had time to dry out. After removing the scaffoldings the wall became heavily exposed to rain. However, it seems that the repaired (plastered and whitewashed) wall until now is able to prevent moisture from entering the masonry. This can be seen by comparing the average absolute humidity outside and inside. The values are almost identical (6,71 g/kg air outside and 6,51 g/kg air inside in 2000), *probably* implying that the masonry of the west wall does not act as an *extra* source of moisture to the room. *This again implies that most moisture enters the room through the half-doorways*. If this situation is to stay the same in the future, regular repair work on the west gable wall is absolutely necessary.

In the autumn of 1999 curtains were put up in the room, preventing much of the low winter sunshine to reach the murals on the west wall. From the climate monitoring we can see that this has indeed reduced short and drastic drops in RH in the winter time. Less dramatic drops still occur, and this is due to the fact that the curtains are not completely "black".

6.2 CLIMATE AT STATIONS CLOSE TO THE REGALIA ROOM

From the recordings at the newly installed (June 2000) climate stations close to the Regalia room, a couple of interesting features can be seen (appendix 4).

First, the monitoring in the middle of the Regalia room (R stillas) shows that the RH is slightly lower than in the NW-corner of the room (R1). This may be due to the fact that the measuring devices in the corner are located on floor level, but also because the devices may give somewhat inaccurate values (+3-5% RH) (see also Franz & Storemyr 2000:33). We have therefore installed new devices in the corner.

Second, the monitoring within the wall in the NW-corner (R2) shows that the "wall climate", as expected, is generally identical to the room climate. However, on a couple of hot summer days the RH rose dramatically, which can probably be explained by warm air from the staircase entering the cool masonry giving rise to condensation. Since there are reinforced concrete with *rusting* iron in the wall (Franz & Storemyr 2000:42f), we now that condensation can take place within the wall. Condensation has, on the other hand, never been observed on the murals in the Regalia room over the last 5 years.

Third, the monitoring in the unheated staircase just outside the west doorway shows that the RH is a little more turbulent here than in the Regalia room (T was not recorded - technical failure). This indicates that the staircase, as expected, is more directly affected by the outside weather than the Regalia room.

6.3 STABILISING THE REGALIA ROOM CLIMATE

The reason why the Regalia room still has a rather turbulent climate (RH varies normally between 45 and 85%), and only a little less turbulent than the staircase outside, can be explained by the fact that the west door cannot be closed properly. This again means that the exterior weather is not buffered as much as would be possible with a better door.

The rather direct relationship between the outside weather and the climate in the room can especially be "felt" on days with westerly winds when the draught in the room is severe. During the conservation work in June 2000 we could also confirm that the cracks on the west wall contributes to the draught: It was possible to feel the wind coming through the cracks and temperature mesurements close to the cracks showed rapid variations dependent on the draught (+/-3ºC). We cannot explain exactly from where the wind entered the cracks, but since they are now sealed with lime mortar, we believe that this particular problem is - at least temporarily - solved.

It is not easy to say what is the "perfect" indoor climate for the murals in the Regalia room. However, we believe that it would be better for the murals if the climate did not show the relatively large variation in RH that can be seen today. Therefore, we have decided to undertake a large-scale experiment, in which the purpose is to "cut" the RH-extremes in the room. We hope to be able to achieve this by:

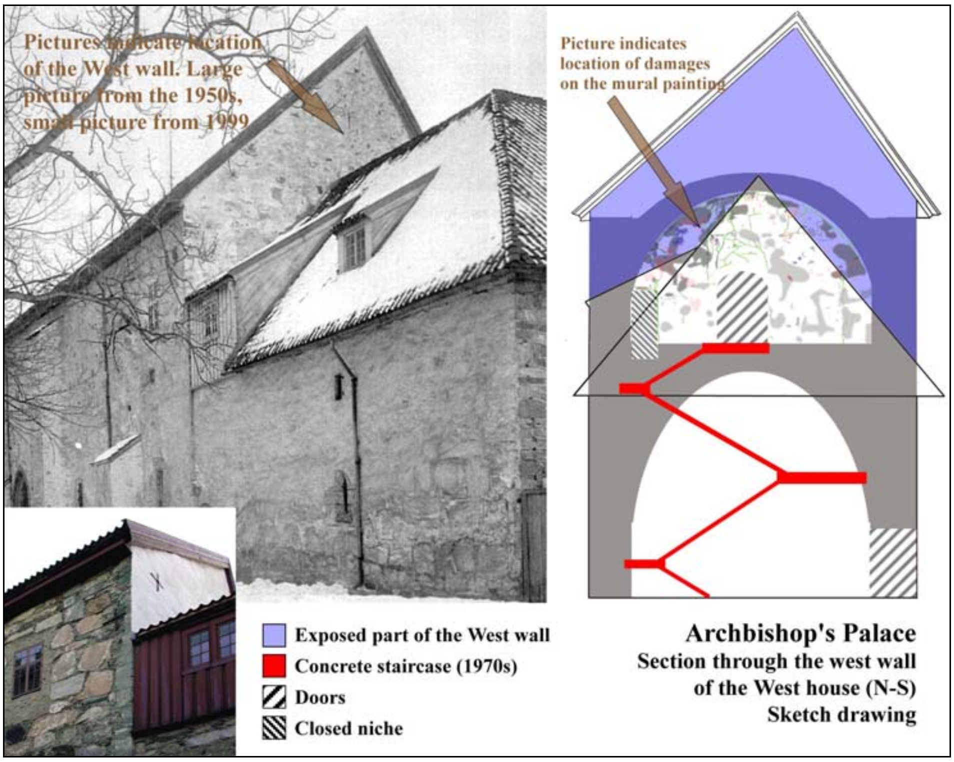
- Installation of an extra air-tight west door in order to avoid draughts
- Installation of a wooden floor in order to buffer the room climate as much as possible.

By these measures, to be implemented in the winter of 2001, we hope to reduce the highest RH values from c. 85% down to, say, 70-75% and increase the lowest values from 45 to 55-60%. It should be strongly underlined that these measures will be completely reversible. They should at this stage only be looked upon as an experiment to be carried out for a couple of years, combined with climate monitoring and observations of the behaviour of the murals, especially related to salt crystallisation (see section about weathering below).

We have not yet drawn up the exact experimental programme, but in the first year (2001) we have decided to leave the new west door closed all the time. Later, it may be possible to experiment with "intelligent" ventilation using this new door and also put slight floor heating into use if it seems necessary (in the winter). It should also be considered to make the exterior door to the staircase more air-tight (see picture below). If good results are achived after having carried out such experiments, one may discuss similar, more permanent measures for the future.

At last it should be pointed out that the condition of the murals on the west wall is extremely dependent on the state of the exterior gable wall. When this wall is in order (no water leaks), large-scale damages will not develop, as in the past (Franz & Storemyr 2000:45f). This means that regular maintenance of the exterior wall is of utmost importance. And if this is not enough, one has to think in terms of installing an extra protective wall.

Another thing to be pointed out is that since most of the murals on the west wall is not exposed to the outside, there is not a great temperature gradient through the wall at the moment. This is important to bear in mind when in the next section discussing the weathering caused by salt crystallisation.



Section through the west wall showing which parts of the wall that are directly exposed to rain, as well as location of staircase and doors.

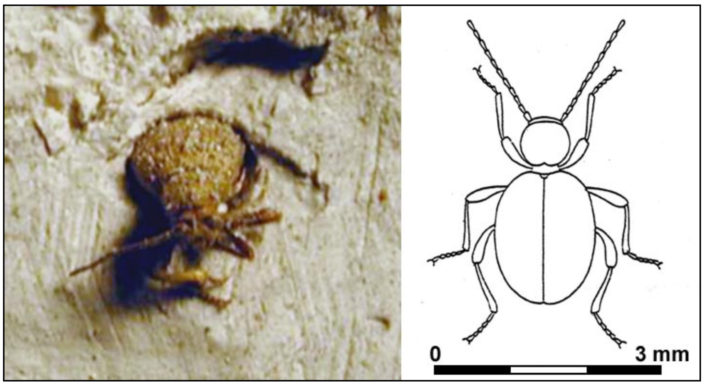
The doors to the staircase (right), the Regalia room (middle) and the closed niche in the NW-corner of the Regalia room (all pictures taken in the staircase).

7 Weathering - new findings in 2000

Weathering phenomena on the west wall and at other parts related to the Regalia room is described and interpreted in Franz & Storemyr (2000). In this section new findings will be reported.

7.1 Determination of "The Bug": A brass beetle

During the investigations in 1999, a particular dead beetle was observed on the west wall (see picture below). At that time it was supposed that the beetle could be connected to so-called flour beetles which had earlier ben found in the vaulted room below the Regalia room (Franz & Storemyr 2000:41f).



Brass beetle (Niptus hololeucus) *in the Regalia room.*
Drawing after Statens Institutt for Folkehelse,
RM 1989, nr. 100

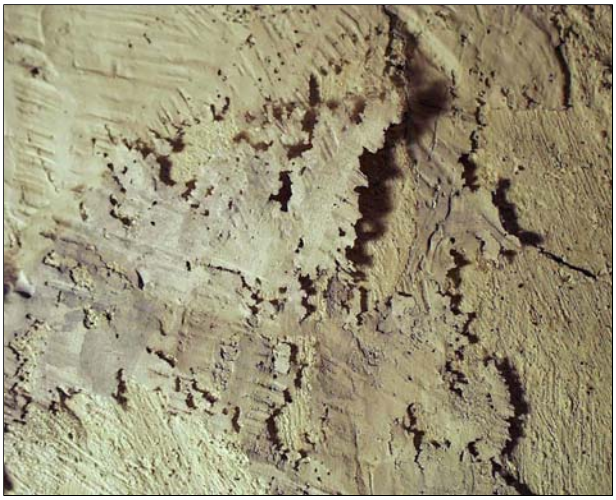
Before the emergency conservation commenced in 2000, several more beetles were found on the floor close to the west wall. Some were alive, and some might have fallen from the wall or the openings between the wall and the vault. One was taken to professor in zoology, Jon Solem at the Museum of Natural History and Archaeology in Trondheim, who immediately determined it as a brass beetle (*Niptus hololeucus*), which belongs to a family of "theft beetles".

According to an information leaflet from the National Institute of Public Health in Norway (see appendix 5), the brass beetle arrived in Norway in the late 19th century. It develops over a period of some 120 days and the mature beetle normally lives some 80-120 days. It is a quite common beetle, particularly to be found in old houses and store rooms with abundant dead biological material. The beetle is however omnivorous and can also feed on textiles, tapestries and glue, for example. There is no simple way of getting rid of the beetle, but careful cleaning usually helps.

As can be seen, the brass beetle in the Regalia room is not necessarily connected with the earlier found "flour beetle" in the vaulted room below. This beetle was supposed to have entered the room when it was earlier used a store room for flour and other foodstuffs. According to professor Solem the brass beetle is so common that a particular reason for its appearance in the Regalia room is not needed. He also maintains that the warm weather (as well as the accidental floor heating) in May 2000 may have made the beetle especially active then.

At the moment we don't know why and where the brass beetle enters the Regalia room. One possibility is that it comes from the loft, through the openings between the west wall and the vault, but this has not been confirmed yet. It has neither been confirmed whether the beetle is damaging for the murals. We don't think so, given the few beetles that have been found and the fact that there is not much "food" on the walls of the room. However, on the loft there might be abundant food (dead birds, insects etc.), implying that it should be cleaned soon.

7.2 DRAUGHT THROUGH CRACKS IN THE WEST WALL



Exfoliating gypsum repair from 1966 (photo from 1999)

As mentioned in the section about indoor climate, strong draughts were observed through cracks in the west wall (after removal of gypsum repairs from 1966). A question that arises is whether this draught has had any influence on the weathering of the wall. One possibility is that draughts (with associated rapid fall and rise of temperature) have contributed to thermal expansion and contraction in the gypsum repairs that were used to seal most cracks in 1966. As reported in Franz & Storemyr (2000:39f), these gypsum repairs were in very bad condition before they were removed in June 2000 (see picture above). However, this suggestion has by no means been confirmed. Moreover, as the cracks are now sealed by lime mortar, we will have to observe the development over a longer period of time in order to find out whether these new sealings will weather faster than other parts of the wall.

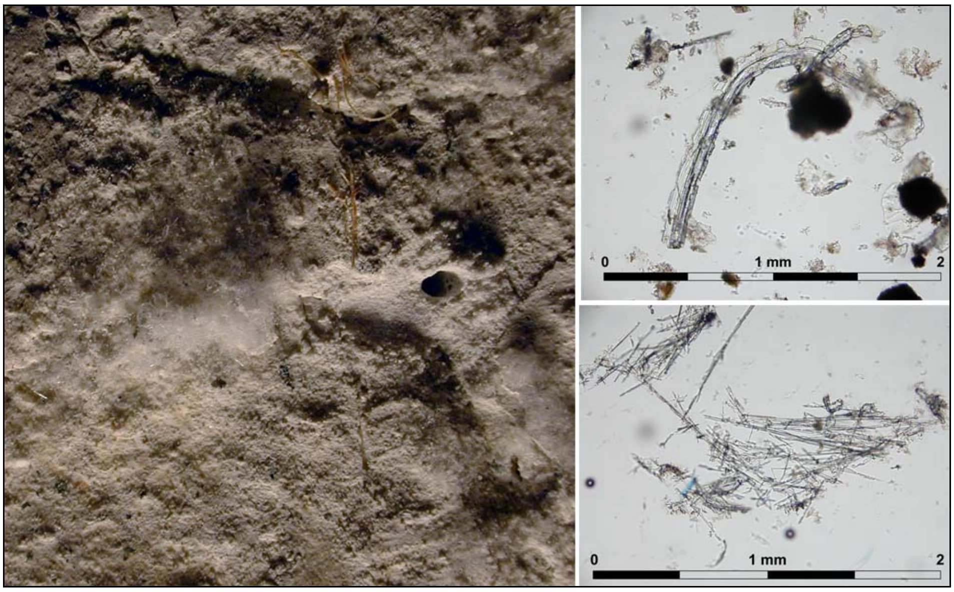
7.3 OBSERVATIONS OF BEHAVIOUR OF SALTS

In connection with the emergency conservation in June 2000, large parts of the west wall were sprayed with lime water (see chapter 3.2). This gave us the opportunity to observe the behaviour of salts on the wall before and after it was moistened. All salt analyses done in 2000 can be found in appendix 6.

As reported in Franz & Storemyr (2000:35ff), one problem with observing salts on the west wall is that, although analyses show large amounts of for instance sodium nitrate and halite whiskers, the salts cannot be seen properly. This is due to their small size and also because they often occur on a whitish substrate of limewash, implying that their "glassy" nature make them almost disappear to the naked eye

Taking these difficulties into consideration, we could still observe that the salts did *not re-crystallise rapidly* after the moistening of the wall: We carefully brushed away much sodium nitrate (sample RE050600/6) with a soft brush on a spot in Q2 (close to observation spot O.1 mentioned below), moistened the wall, and carefully brushed the same spot one day later (RH was 50-55%). No or very few salts could be found at that time (sample RE080600/1). Further observations with side light the following days and weeks did not reveal more salts. It might of course be that re-crystallisation of sodium nitrate is such a slow process that it will take months for the salt to re-appear. Therefore, we have established observation spots for salts (se below). Another possibility is that the evaporation front after limewater treatment never reached the surface of the wall, implying that the salts crystallised within the plaster or elsewhere. In this connection it should be remembered that there cannot be a strong temperature gradient in the wall, since most of it is not exposed to the outside climate.

During the emergency conservation in June 2000, we also used lime mortar as an injection material for fixing scales etc. (see chapter 3.4). This implied that much moisture entered the wall at specific locations. At two such locations, both in Q1, mirabilite (hydrated sodium sulphate) appeared very soon (some hours) after injection (se picture below).



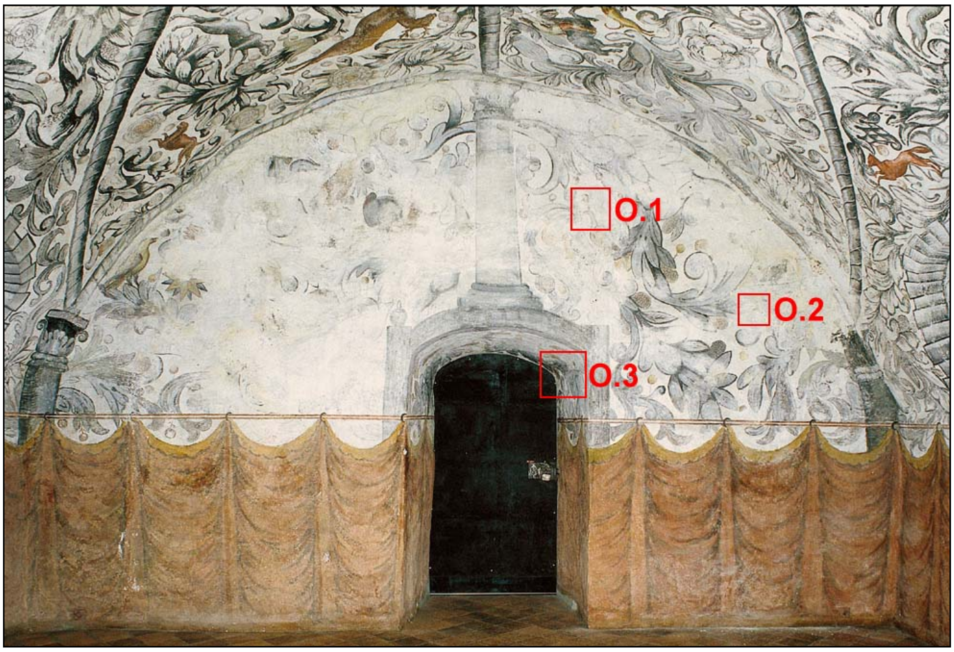
Needles and whiskers of mirabilite formed soon after injecting lime mortar for consolidation purposes in Q1. Left: Cotton-like surface deposits of mirabilite. Right: Microphotos of needles (below) and whiskers (above). Microphotos taken in normal light.

It seems reasonable to explain the formation of mirabilite as being connected with salts from cement repairs. Especially at one location, in the lower, right corner of Q1, there was clearly a lot of injection material. It is on the other hand not yet clear what this injection material really is (see chapter 4.1).

Becoming very concerned by this rapid and, at places, massive formation of mirabilite, we carefulle brushed away all that was visible to the naked eye after the wall was reasonably dry. And - luckily - the salts have not returned at any location afterwards (last observed in December 2000). This is very interesting, because it shows that formation of sodium sulphate needs quite a lot of moisture, and that it does not form "by itself" under the prevailing climatic conditions in the Regalia room. This is also in accordance with earlier observations (Franz & Storemyr 2000:49f), which indicated that sodium sulphate found on several spots must have formed as mirabilite when the wall was considerably moister than today (water leaks). This mirabilite must have subsequently dehydrated to form the "stable" thenardite, which we can see today.

7.4 Establishment of observation spots for salts

In order to be able to follow the behaviour of the hard-to-see salts on the west wall, three observation spots were established in June 2000. The spots chosen are located on the photo below. Samples were taken from all spots before the wall was moistened with lime water.



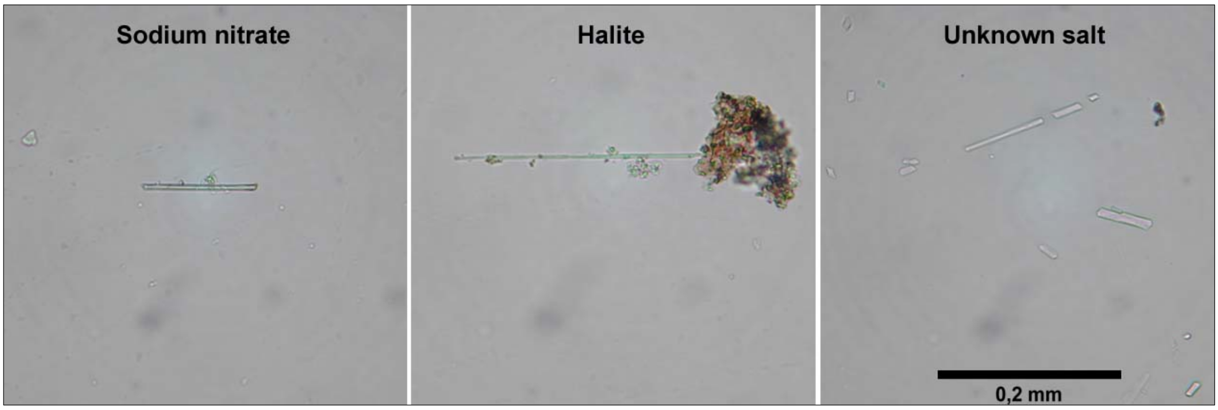
Location of observation spots for salts on the west wall

Observation spot O.1

This spot is located in the upper left corner of Q2. In this area much sodium nitrate, as well as some chloride and sulphate were found during the investigations in 2000 (Franz & Storemyr 2000:48). Since it is almost impossible to see the salts on the whitish limewash with the naked eye, a tiny spot on a dark aggregate grain in the whitewash/mortar was chosen as reference. On this aggregate grain it was possible to see small salt needles, which under the microscope turned out to be sodium nitrate and halite (se photos on the next page). An additional salt with very low relief was also detected. This salt remains undetermined, but according to the optical properties it might be aphthitalite, which is a sodium-potassium sulphate.

After spraying the wall with limewater during the emergency conservation, further observations were undertaken, but no salts were detected. Observations throughout the summer and fall neither revealed new salts forming on the test spot.

Observation spot O.1 on a dark aggregate grain. Note the tiny, white salt needle in the middle. Width of field c. 10 mm

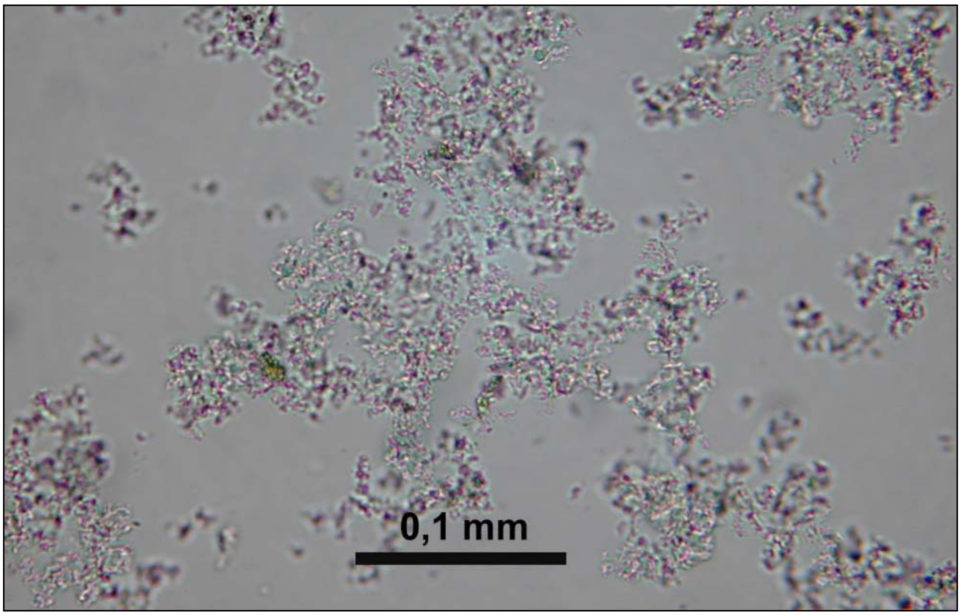


Microphotos of salts found on observation spot O.1.Left: Needle of sodium nitrate. Middle: Needle of halite.Right: Unknown salt (possibly aphthitalite).Pictures taken in normal light.The scale to the right applies to all three microphotos. Sample taken/analysed 2. June 2000

Observation spot O.2

This spot is located in a "hole" in the limewash/mortar, on granite in Q2. There are much powdery efflorescences of thenardite both on the spot itself and below adjacent scales of mortar and limewash. After spraying the wall with limewater in June 2000 all the salts went into solution, and when the last observation was made in December 2000, they had not re-appeared. It should be noted that the spot is now covered with a very thin layer of lime mortar.

Observation spot O.2. Powdery efflorescences of thenardite.
Width of field c. 5 cm.

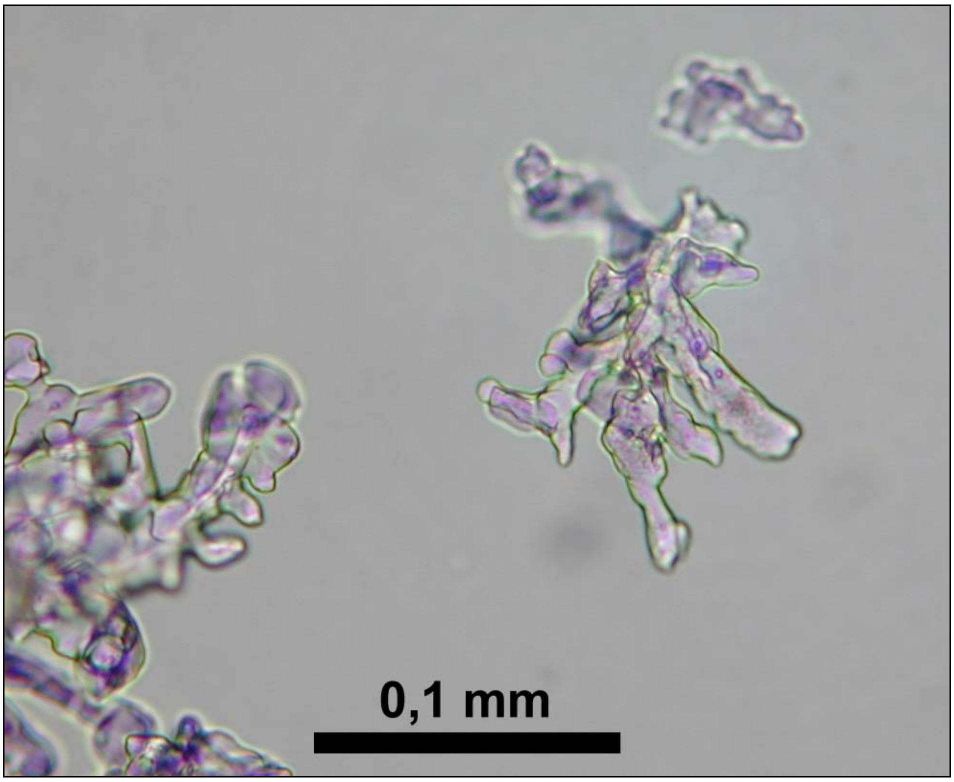


Microphoto of thenardite in O.2. The dehydrated morphology indicates that the salt formed from mirabilite. Sample taken/analysed 2. June 2000

Observation spot O.3

This spot is located within the "vault" of the door opening, and is the only place on the wall that has got epsomite as the main salt species. Epsomite occurs in its "normal" way, as "skeleton-like" whiskers with rounded edges. This area was not sprayed with lime water, and no morphological changes has been observed during the fall of 2000.

Powdery efflorescences and whiskers of epsomite in O.3. Width of field c. 5 cm



Microphoto of epsomite in O.3. Sample taken/analysed 2. June 2000

8 Concluding remarks - a small risk analysis

It is clear that more time is needed in order to be able to properly evaluate the success of the emergency conservation on the west wall of the Regalia room. Given the fact that after the work there are no loosely bound limewash- and paint flakes on the wall, we think however that the situation is relatively stable at the moment.

Although we have not been able to observe salt crystallisation by sodium nitrate and halite (the most common salts), it is also clear that these hard-too-see and difficult-to-understand salts are part of the most important, but seemingly less active weathering processes at the moment. The behaviour of the salts is dependent on the indoor and outdoor climate, which represent factors that are neither properly understood yet. What we do know is that the indoor climate basically is a modified outdoor climate only, and that the changes in relative humidity are quite extreme (40-85%), which is normal at this high latitude. This means that, theoretically, the indoor relative humidity lays in a range in which crystallisation and dissolution of sodium nitrate and halite can take place.

Thus, in the future we should aim at a better understanding of the relationship between the behaviour of the salts and the climate. This is of vital importance in order to be able to design the least harmful indoor climate. A start has been made in 2000-2001 by the establishment of test spots for salt crystallisation and the planned (temporary and reversible) installation of a better door and a wooden floor. In this way we will be able to undertake realistic experiments with the indoor climate.

Simple salt crystallisation experiments in the laboratory may also give important clues to the relationship between salts and climate. It is for instance possible to obtain realistic, salt-laden samples in the niche at the rear of the wall (NW-corner) and let these samples undergo changes in temperature and relative humidity. In this way we might be able to discover under which conditions the salts crystallise and re-dissolve. Such experiments should be carried out as soon as possible.

Still, the greatest risk for the mural paintings on west wall is the fact that the outside gable wall is heavily exposed to the weather. If water leaks become active, we can expect strong weathering events to occur. An indication of how such weathering might take place was the massive formation of sodium sulphate upon injecting moist mortars to the wall during the emergency conservation. But this event also showed us that these salts (sodium sulphates) are only active as long as moisture is provided to the wall.

Another great risk is the sprinkler system on the loft above the Regalia room. If unwanted release of water from this system occur, we can expect weathering events similar to the one described above.

These considerations indicate that the *murals in the Regalia room are in a semi-stable condition at the moment*. And this again means that the theme of a most important discussion in the future should be how to deal with the greatest risks.

9 Proposal for further work

Following the conservation concept (Franz & Storemyr 2000:51ff), a preliminary plan for further research and conservation measures in the Regalia room has been worked out:

2001	Experiments in order to adapt the indoor climate (preventive conservation measures and visitor control). Further conservation work on the west wall. Development of simple web-site: "Live conservation of the Regalia room".
2002	Mapping of the other parts of the Regalia room. Refinement of conservation methods
2003	Beginning of the conservation of the other parts
2004	Continuation of conservation work
2005	Closing of the of the work and publication (web and book)

Climate and other monitoring work will be undertaken throughout the project period, as will measures aimed making the building "safer" from the view of the mural paintings (reducing risks). Further studies on the actual sources of salts, as well as paint technology are also planned.

9.1 Work plan for 2001

- Evaluation of measures carried out during the emergency conservation in 2000 (especially limewater impregnation, fixing of limewash and paint, and filling of hollow ares).
- Analyses of the gray injection mortar (see chapter 4.1).
- Further conservation work on the west wall, especially related to stabilising hollow areas.
- Cleaning of the loft above the Regalia room. Controlling exterior masonry and roofs. Discussing how to deal with the greatest risks: water leaks from the gable wall and unwanted release of water from the sprinkler system on the loft.
- Start on *in-situ* experiments on stabilising the indoor climate (especially installing extra air-tight door and a wooden floor - reversible measures to be undertaken in the winter of 2001). Such experiments will be followed by drawing up a plan for visitor control measures.
- Laboratory experiments on salt crystallisation (revealing when the hard-to see salts dissolve and crystallise (samples taken from the niche at the rear of the wall).
- Planning of structural analysis of the north wing.

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Appendix 1: Information about dispersed lime

From: http://www.restauratoren.de/mitteilungen2_00/fortbildung-weisskalkhyd.html

DRV - Mitteilungen 2/00

Fortbildung: Tagungsbericht

Dispergiertes Weisskalkhydrat

Am 14. 4. 2000 fand in Köln eine Tagung des Bundesverbandes der Deutschen Diplomrestauratoren (bdr) in Zusammenarbeit mit der Fachhochschule Köln, Fachbereich Konservierung und Restaurierung statt. Die Referenten stellten Arbeiten vor, die sich mit dispergiertem Weisskalkhydrat beschäftigten. Der Eingrenzung auf dieses eine Thema verdankte die Veranstaltung eine besondere Intensität, die durch das gleichzeitige Erscheinen eines Bandes mit der Sammlung der Vortragstexte unterstrichen wurde.

Seit über fünf Jahren beschäftigen sich Restauratoren meistenfalls im Rahmen von Diplomarbeiten sehr praxisorientiert mit diesem Mittel. Es handelt sich dabei um Weisskalkhydrat, das durch Dispergieren eine höhere Reaktivität und ein verbessertes Abbindeverhalten erhält. Anschaulich gesprochen werden die Kalkhydratkonglomerate in kleinere Teile zerschlagen und damit die Oberfläche, an der die Reaktionen stattfinden, vergrößert. Weiterhin können die Eigenschaften einer Masse aus dispergiertem Weisskalkhydrat und Füllstoffen in einem großen Umfang beeinflusst werden, weil aufgrund eines hohen Füllstoffanteils der spezifische Einfluss unterschiedlicher Füllstoffe ausgeprägter ist, als dies bei üblichen Kalkmassen der Fall ist. Es können nicht nur Mörtel und Hinterfüllmassen, sondern auch Steinergänzungsmassen, Spachtelmassen und Schlämmen sowie Anstrichstoffe hergestellt werden. Die Vergrößerung der Reaktivität und die vollständigere Carbonatisierung des Kalkhydrates verleihen den abgebundenen Massen physiko-mechanische Eigenschaften, die den Einsatz auch dort möglich machen, wo bislang auf zement- oder kunststoffgebundene Mittel zurückgegriffen werden musste.

Die Schwierigkeit bei der eigenen Herstellung solcher Mittel ist nunmehr durch die fabrikatorische Erzeugung von dispergiertem Weisskalkhydrat durch die Firma Alligator umgangen. Die industrielle Fertigung verspricht eine Qualitätssicherung auf hohem Niveau, erschwert jedoch auch die individuelle Einstellung der Eigenschaften. So sind bislang nur drei Produkte erhältlich: das dipergierte Weisskalkhydrat selbst und ein Injektionsmörtel, beides mit dem Namen CalXnova bei der Firma Deffner und Johann zu beziehen, sowie ein nach Wunsch auch pigmentierter Anstrichstoff. Die Firma Alligator produziert und vertreibt diesen Anstrichstoff zur Zeit jedoch nur nach Beratung durch Herrn Dipl. Restaurator (FH) Rochus Strotmann, Virchowstraße 8, 50935 Köln, Tel. 0221/433133, Fax 0221/4305327, E-mail: werkstatt@restaurierung-online.de.

Nach meiner persönlichen Beurteilung haben die Anstrichstoffe durch die Modifizierung den lebendigen Charakter eines Kalkanstriches verloren. Den Injektionsmörtel jedoch habe ich bereits schätzen gelernt. Eine größere Nachfrage könnte zukünftig auch die Bereitstellung von Injektionsmörteln mit verschiedenen Eigenschaften ermöglichen.

Ich kann die theoretische und praktische Bekanntschaft mit diesem Mittel nur empfehlen.

Das Buch zum Mittel:

Jägers, Elisabeth (Hrg.):
Dispergiertes Weisskalkhydrat für die Restaurierung und Denkmalpflege,
Altes Bindemittel – Neue Möglichkeiten.
Michael Imhof Verlag, Petersberg 2000.

Björn Scheewe

Appendix 2: Prescription of dispersed hydrated lime

From: http://www.deffner-johann.de/calxnova.htm

calXnova: dhl* -Hinterfüll- und Injektionsmörtel auf Basis von dispergiertem Weißkalkhydrat (Pat. angem.)

* dhl = dispersed hydrated lime

Produktbeschreibung:

Dispergiertes Weißkalkhydrat ist ein rein karbonatisch abbindendes Bindemittel für Mörtel, Steinergänzungsmassen, Schlämmen, Injektionsmassen und zur Putzfestigung.

Injektionsmassen auf Basis von dispergiertem Weißkalkhydrat sind gebrauchsfertige, fließfähige Suspensionen aus dispergiertem Weißkalkhydrat undFüllstoffen. Sie sind sedimentationsstabil und bilden in Hohlräumen eine homogene, kapillarüberbrückende Zone.

Sie eignen sich sowohl für den Einsatz in der Steinkonservierung, wie auch in der Konservierung von Wandmalerei und Putz und zeichnen sich durch sehr gute Verarbeitbarkeit, geringe Schrumpfung und hohes haftvermögen aus.

Sie binden ausschließlich karbonatisch ab, enthalten also keine zusätzlichen Bindemittel. Dabei ist die Spanne der physikomechanischen Eigenschaften so groß, daß die Injektionsmassen auf jedes Objekt und jede Anforderung individuell einzustellen sind.

Zusammensetzung:
Die Injektionsmassen bestehen aus dispergiertem Weißkalkhydrat, Marmormehlen oder Quarzmehlen, Anmachwasser und Dispergierhilfsmitteln (< 0,4 M.-%).

Eigenschaften:
Durch die aufgrund der durch das Dispergieren stark vergrößerten Oberfläche des Weißkalkhydrates karbonatisieren Kalkmassen auf der Basis von dispergiertem Weißkalkhydrat erheblich schneller und vollständiger, als herkömmliche Kalkmassen auf der Basis von Sumpfkalk oder Weißkalkhydrat.
Dies zeigt sich sowohl in erhöhten mechanischen Werten, wie auch in einer sehr guten Beständigkeit gegenüber Frost-Tauwechseln oder Salzsprengtests.
Gleichzeitig sind die dispergierten Kalkmassen in der Lage, selbst in dünnsten Schichten noch auszureagieren. Das ermöglicht den Einsatz von Kalkmassen in Gebieten, die bislang kunstharzgebundenen, bzw. kunstharzmodifizierten Systemen vorbehalten waren. So können fließfähige Injektionsmörtel in dünnste Hohlräume appliziert werden, ohne die Effiktivität zu unterbinden.

Physikalische Eigenschaften:
Druckfestigkeit ßD: 3,0 - 10,5 N/mm2
Oberflächenhaftzugfestigkeit ß HZ: 0,1 - 0,45 N/mm2
Wasseraufnahme 24 h (Gew.-%): 12- 25
Schrumpfung (Vol.-%): 0 - 0,6
Frost-Tauwechselverluste nach 15 FT: 3 - 15 Gew. -%
Verluste nach Salzsprengtest (DIN) 10 Zyklen: 15 - 38 Gew.-%
E-Modul: 1.500 - 3.000 N/mm2

Produktdaten:
Fest-Flüssigverhältnis (Gew.): 2,75:1 (Gew.-Teile)
Bindemittel-Zuschlagverhältnis (Vol.): 1:4
Dichte: ca. 2,6 g/ccm
Viskosität: 1.500 - 4.000 mPas
Spez. Oberfläche (berechnet): 240 - 270 cm2/g
Gesamtporenvolumen: 0,25 - 0,27 cm3/g

Verarbeitung:
Zur Injektion von Hohlräumen wird nach dem Vornässen mit entmineralisierten Wasser die Injektionsmasse mittels Packer oder Injektionsbesteck eingebracht.
Je nach Stärke des Hohlraumes können die Füllstoffe angepasst und die Injektionsmassen entweder unverdünnt oder bis 5 Gew.-% mit Wasser verdünnt angewendet werden.
Ein Nachnässen der injizierten Bereiche ist nicht erforderlich.

Appendix 3: Stored wet slaked lime

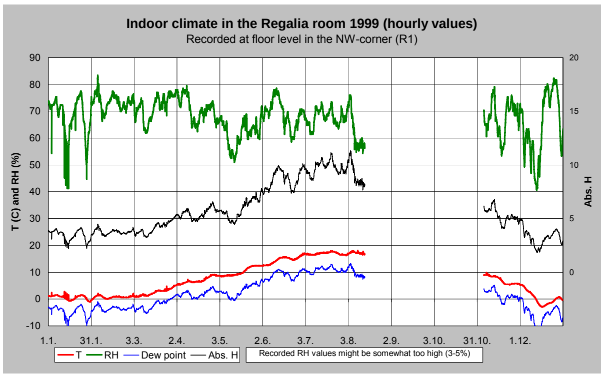
Stored (min. 2 years) Rødvig wet slaked lime was provided from:

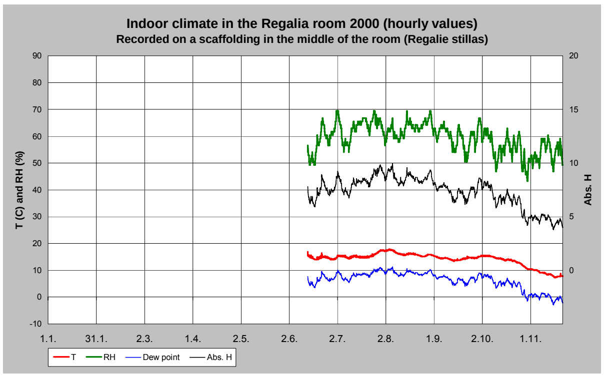
Skandinavisk Jurakalk A/S
Kronhøjvej 10
DK-4660 Store-Heddinge
Tlf. ++45-53 70 30 00

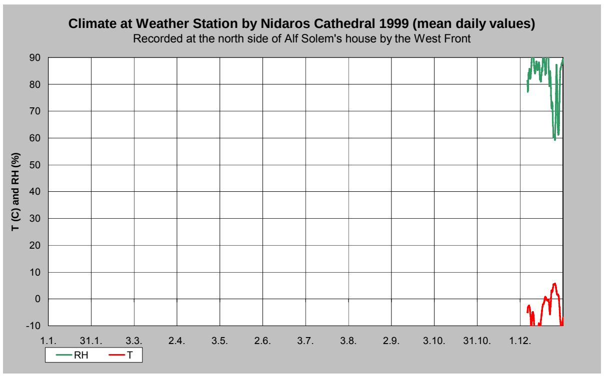
See also leaflet:

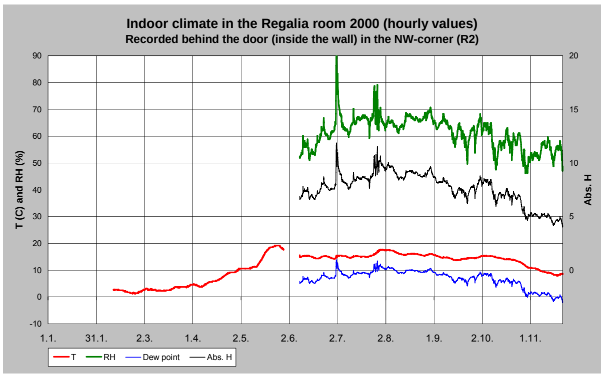
Bygningsbevaring - Blad om materialer til vedligeholdelse og renovering av bl.a. fredede og andre bevaringsværdige bygninger. Published by Skandinavisk Jurakalk, 3rd ed., 1995

Appendix 4: Climate recordings 1999-2000

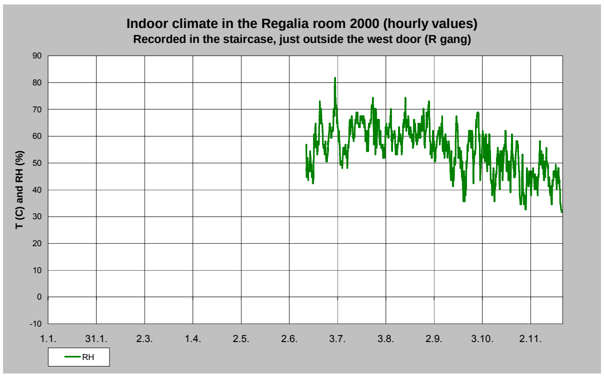








The 1999 recordings shown above has been included here because in the report from the work in 1999 (Franz & Storemyr 2000), the 1999-recordings were not complete.



The right column shows recordings from 2000.

Appendix 5: Information about brass beetle (in Norwegian)

RM 1989 **Nr. 100**

STATENS INSTITUTT FOR FOLKEHELSE

Seksjon for medisinsk entomologi

Geitmyrsveien 75, 0462 Oslo 4

MESSINGBILLEN - *Niptus hololeucus*

Messingbillen tilhører familien tyvbiller, Ptinidae. Det er en 3,0-4,5 mm lang bille med messinggul-brun farge. Kroppen er delt i to kuleformede deler ved en innsnørning bak forbrystet. Kroppen er kledd med hår. Ben og antenner er lange. Lårene er tykkere mot spissen.

Larven er forholdsvis tykk, gulhvit med brunt hode. Den ligger krumbøyd på utviklingsstedet og kryper lite omkring. Før forpuppningen spinner den seg inn i en rund kokong.

BIOLOGI: Messingbillen sprer seg ved å gå eller ved transport med infiserte varer, som larve eller voksen. Messingbillen er aktiv i den mørke delen av døgnet. Dens utbredelse er innen den tempererte sone. Billen spredte seg fra Sør-Russland til Europa i 1840-1870 og ble funnet i Norge første gang i 1875.

Hunnen legger vanligvis 20-50 egg, maksimum 220, i løpet av en eggleggingsperiode på 3-5 uker. Eggantallet øker ved tilgang på drikkevann. Utviklingstiden fra egget er lagt til voksen er normalt 6-7 måneder.

Utviklingstiden er ved 20ºC og 70% relativ luftfuktighet:

Egg 14 døgn.

Larver 75 døgn.

Pupper 15 døgn + en hvileperiode i kokongen på 18 døgn.

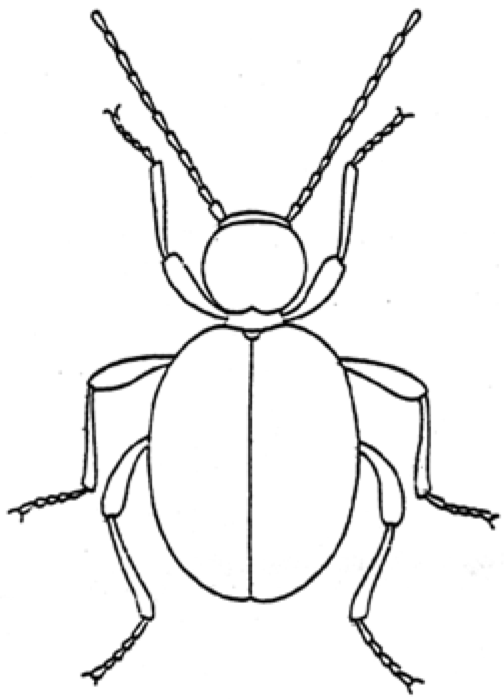
Total utviklingstid er 121 døgn.

De voksne billene kan leve lenge, 250 døgn er rapportert, men 80-120 døgn er vanlig. Messingbillen har vanligvis en generasjon om året. Utviklingen går ved 25C hurtigere, men stor dødelighet tyder på at denne temperaturen ligger nær den øvre grense for hva arten kan tåle. Den tåler lave temperaturer godt og er i aktivitet ved 0ºC. Messingbillen opptrer vanligst i gamle hus og i lagerbygninger med dårlig renhold. Larvene lever av kornvarer, vegetabilsk avfall, rester av døde mus, rotter og fugler, i fuglereir av gråpurv, stær, kaier mm., døde insekter som f.eks. treborende insekter og vepsebol i hus, eller i tilknytning til matvarerester.

Ved undersøkelser i Sverige har 90% av messingbillerapportene kommet etter reparasjoner av gamle bygninger. Dette forklares ved at biller og larver lever i veggfyllinger, gulvfyllinger og andre lukkete hulrom hvor det samler seg organisk avfall og døde insekter. Ved reparasjoner kan billene forstyrres og de søker ut gjennom de nye åpningene som er laget. Kjellere er også et sted hvor messingbillene kan trives. Messingbiller kan påtreffes hele året, men de fleste funn er fra høsten, oktober til desember.

ØKONOMISK BETYDNING: Messingbillen har vanligvis liten økonomisk betydning, men kan virke sjenerende. Larvene kan forekomme i mel- og kornlager Særlig i sprekker, i gulv- og veggfyllinger og på steder hvor rengjering er vanskelig og mel- og kornrester blir liggende lenge. Formeringen er langsom i forhold til andre komskadedyr. De voksne billene er registrert som alvorligere skadedyr i spesielle tilfeller ved at de har gnagd på tekstiler, pels, lær, tørre planter, bøker, garn og syntetiske fiber m.m. Den kan gnage på ting uten næringsverdi. Spesielt plagsomme og tallrike kan de bli i gamle lagerbygninger hvor en tidligere har lagret næringsstoffer som mel, korn, o.l., og siden har tatt lokalene i bruk tit lagring av papir, tekstiler, embalasje for næringsmidler o.a.

Bekjempelse. Det kan være vanskelig å bekjempe messingbillen p.g.a. skjulte utviklingsplasser for larvene. Utviklingsstedene børbør oppspores, rengjeres og eventuelt behandles med et insektmiddel.

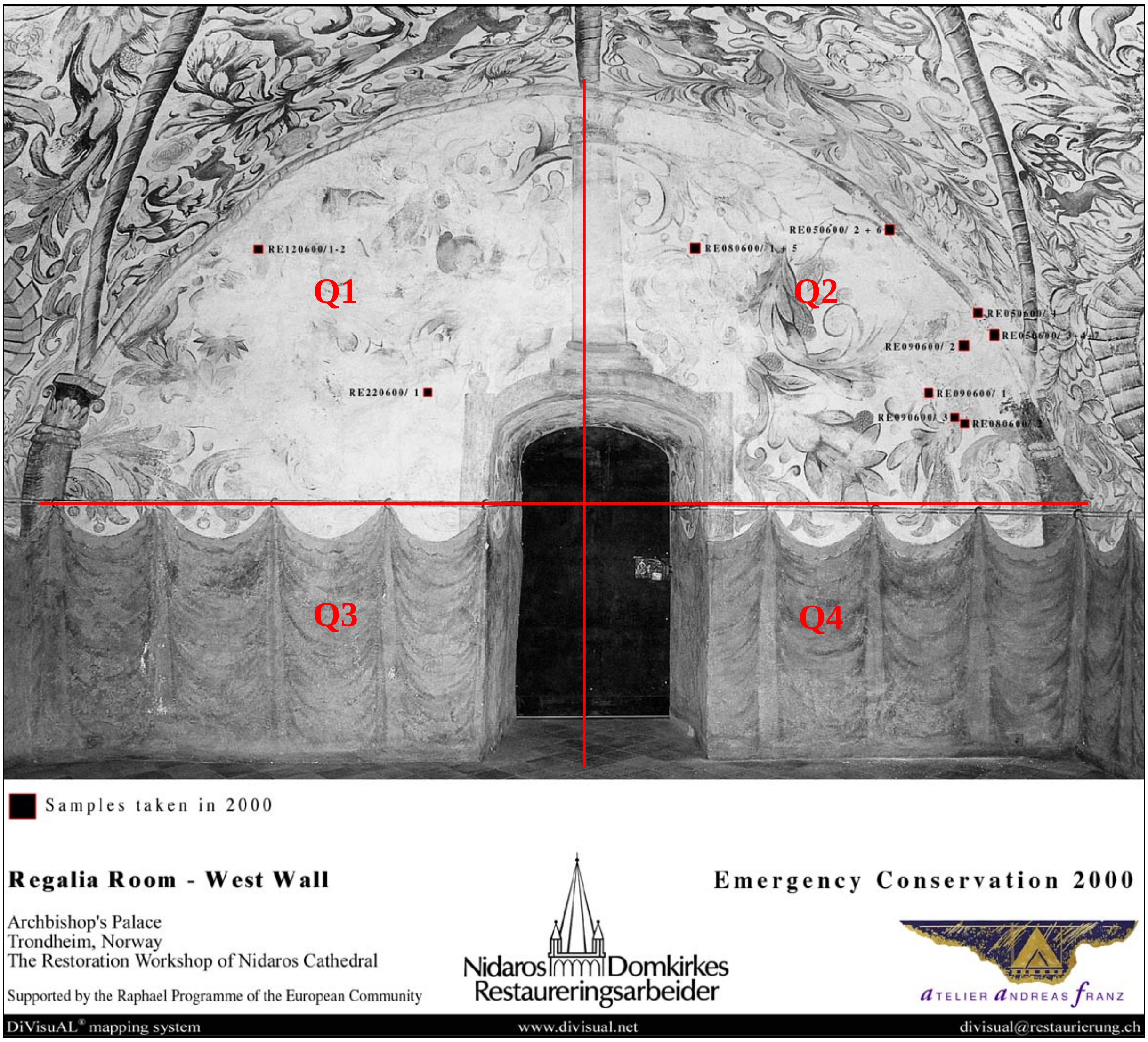


Appendix 6: Material analyses June 2000

Analysed by microscopy by Per Storemyr, June 2000
Location: Q1-Q4: Quadrant 1 (upper S) to Quadrant 4 (lower N) on the west wall
For accurate location; see map on next page.

Sample no.	Location	Description/analyses
RE050600/1	Q2	Mortar sample from the very weathered part close to the vault (N.a.)
RE050600/2	Q2	Salt; powdery efflorescences on stone (plaster weathered away). powder.***Thenardite*** *with dehydrated morphology*
RE050600/3	Q2	Mortar sample (N.a.)
RE050600/4	Q2	Salt and lime powder, looks like a weathered limewash. ***Calcite*** *and much* ***thenardite*** *(dehydrated) + small amounts of* ***unknown salts*** *(probably sulphate). Conclusion: It is a weathered limewash*
RE050600/5	Q2	Powder brushed from wall beside test spot for salts (O.1): *Large amounts of thick whiskers and crusts of* ***sodium nitrate****.*
RE050600/6	Q2	Salt; powdery efflorescences on stone (plaster weathered away). powder.*Thenardite with dehydrated morphology*
RE050600/7	Q2	Mortar and "dust" from crack between wall and vault (N.a.)
RE080600/1	Q2	Powder brushed from the wall by test spot for salts (O.1) one day after the wall was sprayed with lime water (same spot as RE050600/5): *Small amounts of* ***sodium nitrate*** *- difficult to say if the large amounts found on 5.6. was brushed away then or if the salt has gone in solution by the lime water spray. No or very small signs of dissolution of single grains. But there were other very thin needles and grains of salts, so small that it was not possible to analyse properly.*
RE080600/2	Q2	Powder of green/gray injection mortar from 1966. *Check with XRD (done by NGU, file no. 20010033 (doc & xls):* *Quartz (much)* *Chlorite (medium)* *Mica (little)* *Plagioclase (little)* *Amphibole (little)* *Sodium nitrate (little)* *Halite (little)* *Traces of clay minerals????* *NO lime (calcite)*
RE090600/1	Q2	Limewash. *Mostly* ***lime****, a few* ***sodium nitrate*** *grains*
RE090600/2	Q2	Salt efflorescences in a small depression in the limewash. *Large* ***halite*** *whiskers and crystals.*
RE090600/3	Q2	Gray, probably intermediate paint/limewash layer. *Mostly* ***lime****, a few* ***sodium nitrate*** *grains*
RE120600/1	Q1	Salt efflorescences after injection of lime mortar. ***Mirabilite***

RE120600/2	Q1	Salt efflorescences after injection of lime mortar. ***Mirabilite***
RE220600/1	Q1	Salt efflorescences after injection of lime mortar. ***Mirabilite***



Samples taken for material analyses in 2000. Q1-Q4 means the quadrants of the wall, which are referred to in this report