

Lime Burning Tradition in a Field Kiln of the Jämtland Model in Sweden



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Abstract This study focuses on the local lime tradition in the region of Jämtland, in central Sweden. Local lime was used when building the medieval stone churches and since they are in a need of restoration there is subsequently a need for understanding the use of local lime. The geology of Jämtland contains several layers of limestone in the folded mountains. There is a broad spectrum ranging from pure Silurian limestone to clay containing Ordovician limestone, giving all kinds of lime from pure air lime to strong hydraulic lime. The preserved historic mortars have mostly been made with the hydraulic lime. Several old field kilns have been preserved in the forest landscape as prehistoric monuments, showing the model of the local lime burning tradition. This paper discusses the process of identifying the historic lime kiln constructions and their burning technique. It also describes the process of slaking this hydraulic binder in order to produce a lime mortar with workability and compatibility required from a restoration mortar. Newly-produced samples of lime mortar have been compared with historic ones in thin section microscope for further understanding.

Keywords Lime mortar · Slaked lime · Lime burning · Lime kiln
Workability

1 Introduction

Oviken old church in Jämtland, Sweden was constructed with local limestone and lime mortar during several centuries. Now that there is a need of restoring the church a discussion regarding the use of local lime took place. In order to restore

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with traditional materials and methods the general demand of authentic local lime binder has increased. The project was initiated by the Swedish Church, involving the local museum with a Conservation Officer and an Archeologist plus a research team from Gotland University and Gothenburg University specialized in lime burning and lime mortars.

This paper shows the process of producing local lime in a small scale for a single object; from analyzing the historic mortars, finding local limestone suitable for burning and slaking, inventory of field lime kilns, burning lime, slaking and mixing mortars. Similar projects have taken place in Sweden recently on Visby City Wall and Läckö Castle (Balksten and Thelin 2014; Mebus and Balksten 2015; Sandström Malinowski 2016).

Jämtland is a county in central Sweden where the Scandinavian mountains form the landscape. There is limestone originating from both the Ordovician and the Silurian period around the lake Storsjön. In the same village there have often been small quarries in more than one limestone layer with the effect that there are lime mortars with very different properties existing on the old stone churches.

The oldest stone buildings constructed with local lime are the churches of Hackås and Norderön from 1170–1180th. Field kilns were then used in Jämtland with continuity until the 1920s (Åsling 2000). There is a unique situation in Jämtland since several old field kilns from the 19th century still remains around in the forests, see Fig. 2. Several of them were built and never burned, for unknown reasons. 143 remaining lime kilns are registered as ancient monuments in the area (Fornminnesregistret). The positions of some of them are marked with yellow dots in Fig. 1.

2 Lime Burning Project of Oviken

The project started in Oviken old church with archive studies and analysis of the old mortars available at the church and its surrounding wall. The archives held information about the building history of the church and also about different materials that have been used during different restorations (Persson 2010).

The old mortar samples, as well as the newly-produced ones, were analyzed as thin sections with a Zeiss TM Polarization Microscope.

The remaining lime kilns in the area were studied and compared to other field kilns in Sweden. Local limestones were burned, first in a small lime kiln at Gothenburg University and then in a field kiln at Gotland University in order to locate a proper stone for burning in a field kiln of the local Jämtland type. A small field kiln with two fire passages was built with limestones from two quarries in May 2011, and burned during 80 h with birch wood (Persson 2012).

During a workshop in July 2011 the lime was slaked, mixed with sand and used as a mortar for restoring a part of the wall surrounding Oviken old church, see Fig. 3. Both dry slaking and wet slaking methods were used according to a method developed by Eriksson and used for Ordovician lime from south of Sweden

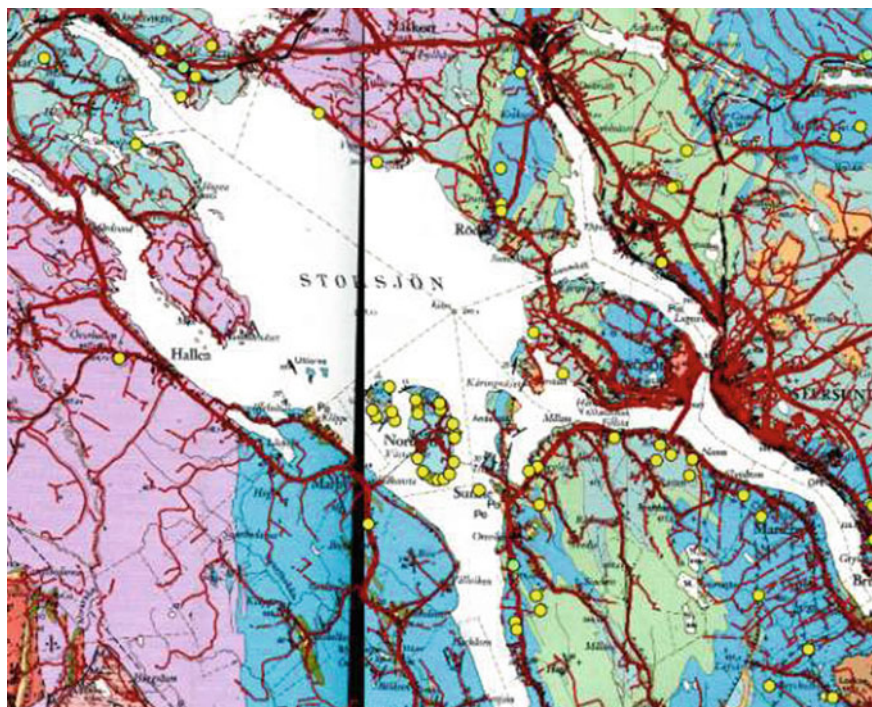


Fig. 1 Bed-rock map of Jämtland combined with the remains of lime kilns found in Jämtland marked with yellow dots (SGU 1980/Formminnesregistret, Persson 2012) (Color figure online)



Fig. 2 **i** Illustration of a field kiln of Jämtland model (Åsling 2000). **ii** Unburned field kiln built in the late 19th century still standing in the forests of Åse. Now it is covered with moss but originally the stones were visible and not covered. **iii** Lime kiln from Havsnäs Jämtland in the 1920s

(Eriksson 2015). When being slaked, the burned limestone was placed inside in an oil drum (Eriksson et al. 2012), see Fig. 9, giving the effect that the lime is slaked under a small pressure. When mixing mortars for test surfaces, an electric stirrer specialized for mortar were used. The mortars were then applied being pressed or thrown with a trowel; the more fat mortars had to be pressed while the more lean mortars could be thrown. Their surface texture was made as similar to the old



Fig. 3 Mortars are applied with a trowel onto the wall. Old mortars can be distinguished by color and texture, here as the white and yellowish surfaces in the picture

surfaces as possible. The workability of the mortars was the most essential property in the study and the discussion and dialog between the masons and scientists was essential when evaluating the results.

3 Limestone and Mortars of Jämtland

Old mortars from the area were analyzed by thin sections in order to show different parameters such as type of lime, type of sand and mixing ratio between lime and sand. The mortars came from Oviken old church and its surrounding wall and from Sunne church ruin, nearby. The mortars were most likely from the 15th to the 17th century, due to where they were found in and on the walls. They were extremely fat (rich of lime) made from lean lime (Balksten and Lindqvist 2016), from local lime stone found nearby the buildings. The lime stone in the area is un-pure and gives what today is defined as hydraulic lime [Shaikh et al. (1989)].

Because of the complex geology in Jämtland and the formation of folded mountains the limestone layers are found in many different small deposits in the area around Storsjön as well as in the mountains. The limestone existing in Jämtland is of many different characters; from the early and middle part of the Ordovician period and from the oldest part of the Silurian period, see Fig. 5. There are all kinds of limestones ranging from almost pure limestone (98% CaCO_3) that gives air lime mortar to limestone containing clay minerals (more than 85% CaCO_3) giving strong hydraulic mortar. The stone from the Silurian period is called Berge limestone and consist of more CaCO_3 than other limestone in the area. The stone from the Ordovician period studied in this project is called Isö limestone and often consists of approx. 90% CaCO_3 . Ancient remains and ruins of historic lime kilns are preserved in the forests (Fornminnesregistret) and can be found all over the landscape showing that most kind of Berge and Isö limestone have been burned at one time. A stratigraphic table of limestone from Jämtland (Shaikh et al. 1989) shows the large variation of limestone available such as the Silurian *Berge*, and the



Fig. 4 Old lime mortars in Oviken. The oldest mortars from 17th century are extremely lime rich (20:1 lime/sand by volume) with a yellowish color. What occurs as sand particles to us might be just impurities from the limestone and the slaking process (Balksten and Lindqvist 2016). To reproduce such mortars we need to experiment more with slaking and storing of the specific lime. The surface has traces of lime wash and aging

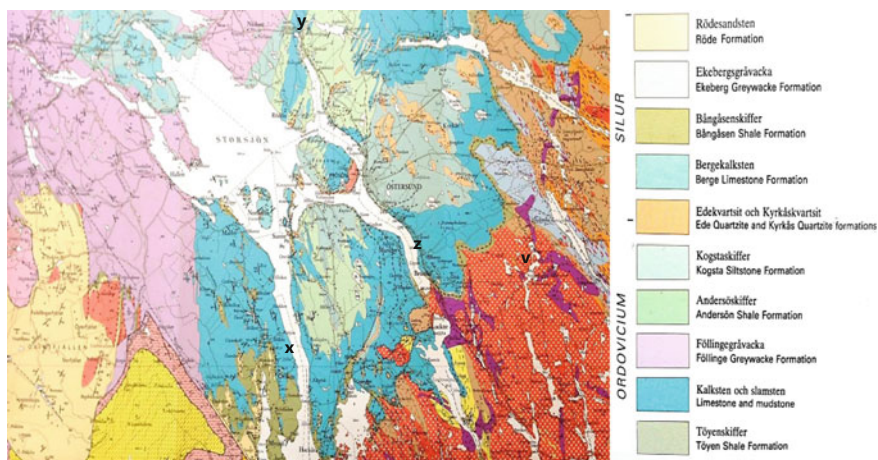


Fig. 5 Part of the bed-rock map around Storsjön in Jämtland showing the complex geology of the region. Notice the blue and turquoise colors showing the presence of limestone. The letter **v** marks Sunne church, **x** marks Oviken church, **y** marks Näversjöberg and **z** marks Mariaby (Sveriges geologiska undersökning 1980)

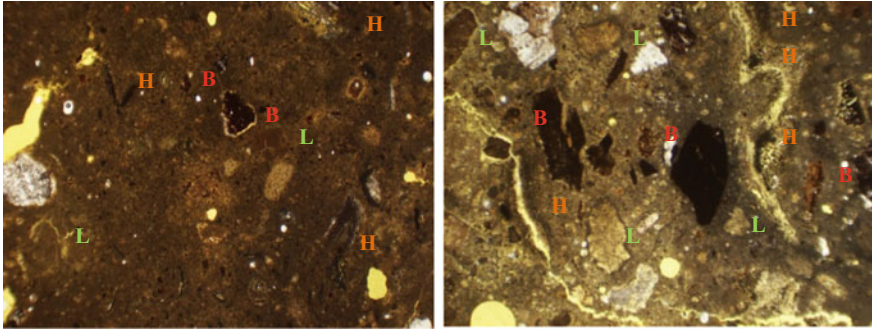


Fig. 6 Examples of thin sections made from old lime mortar samples from the old church wall in Oviken (see Fig. 4) and the church ruin in Sunne, Jämtland. The shown width of each image is equivalent to 4.5 mm. Both of the analyzed mortars are extremely rich in lime, showing almost no sand particles at all. The binder is not pure CaCO_3 , it contains some other elements, or impurities. The thin sections show that the lime contains some darker hydraulic components, marked with H, lime lumps L and burned clay minerals B



Fig. 7 Field kiln built in 2011. It has two fire places, like some of the kilns found in the region had



Fig. 8 Lime kiln during the first, second and third day. On the third day the flames started to become blue all over the top of the kiln, giving a signal that the lime was burned long enough

Ordovician *Furulund*, *Slandrom*, *Dalbyn*, *Furudal*, *Folkeslunda*, *Seby*, *Segerstad*, *Holen*, *Isö*, *Länna* and *Latorp*.

The limestones burned in this project were chosen for several different reasons. The types of limestone available in the surroundings of Oviken were the interesting



Fig. 9 Lime slaking under pressure in an oil drum

ones to study. It is the Isö limestone from the Ordovician period that exists in the Oviken region. Analysis of limestone samples from the surroundings of Oviken shows a CaCO_3 content of 79–92%, the samples also contains clay minerals, see Table 1 (Shaikh et al. 1989). The limestones in this study were taken from open quarries in use where such certain types of limestone were available; *Näversjöberg* north of Storsjön and *Marieby*, east of Oviken.

Analysis by thin sections showed that the old mortar samples from Oviken and Sunne were composed of lime containing hydraulic components and a very small amount of sand. These types of mortars, made from local lime with high lime content, are characteristic for the medieval lime mortar tradition of Sweden (Johansson 2006; Balksten 2010; Balksten and Mebus 2012). Such extremely fat mortars were used all over Sweden until the mortar tradition of the late 18th century

Table 1 Chemical composition (79–92% CaCO_3) in the Isö limestone of Oviken

Sample nr	85082	85083	85084
SiO_2	3.9	12.3	4.4
Al_2O_3	1.02	3.80	1.28
TiO_2	0.08	0.22	0.04
Fe_2O_3	1.35	1.87	0.86
MnO	0.27	0.16	0.23
CaO	51.0	43.6	50.3
MgO	0.45	0.69	0.48
K_2O	0.29	1.06	0.37
Na_2O	0.05	0.06	0.03
P_2O_5	0.08	0.06	0.14
CO_2	40.5	34.9	40.4
F	0.01	0.02	0.02
S	0.46	0.49	0.01
Sum	99.46	99.23	98.56

Samples taken from the early Ordovician layer (Shaikh et al. 1989)

took over (Pasch 1826). Thin sections are made from soft yellow colored lime mortar samples which are extremely hard and fat, see Fig. 6. They both contain hydraulic reactions; reference material can be found in Johansson (2006) in analysis made by Jan-Erik Lindqvist and Torbjörn Seir and in Ingham (2011).

The lime kiln built in this project was made with a mix of limestone from both Näversjöberg and Marieby. Since the reconstruction of the historical proportions of the kiln was the essential task, the stones were arranged in size-order rather than separated in different types of limestone. The lime kiln was placed in a small slope, built with two fire passages. It was then burned with birch wood during 72 h. The temperature in the field kiln was expected to stay at approximately 800–1000 °C but the temperature was not measured. The expected temperature is based on the experience of highly skilled craftsmen and practical knowledge from the burning field kilns and small lime kilns in Sweden during 20th century where temperature have been measured with traditional methods such as looking at the color of a piece of iron that is inserted into the kiln. Figures 7 and 8 show the kiln during building and burning. For illustrations on how to build a field kiln of the type, Bernerman (2015) is recommended.

The lime was slaked using two different slaking methods; wet slaking with a small surplus of water and dry slaking with the amount of water that the stone would absorb when it was soaked in water for some seconds. The time was decided by the size of the stones, the absorption capacity was tested for each type of limestone. A stone was placed in water for a short time (10–20 s) until it ceases to bubble. It was then divided in two pieces, making it possible to see if the water had reached the center of the stone. The search for the right consistency of the lime defined the amount of water that was used during the slaking process.

The lime that was slaked was tested in situ with the aim to get stiff lime putty from the wet slaking method and dry lime powder from the dry slaking method. Some of the participants in the study had very long practical experience of lime slaking in leading the slaking process to produce lime with good workability. The lime must not be too stiff or too wet, it should be easy to mix with sand and it shouldn't need too much sand in order to make a mortar, according to the analysis of the old mortar samples from the church. Because of the fact that the lime was difficult to slake, hot water (80 °C) was used in the slaking process of wet slaking in order to make it start faster and to be able to control that the slaking was completed. Many years of testing has shown that unslaked particles become more frequent in wet slaking if cold water is used for limestone that is difficult to slake. For the dry slaking cold water was used. The lime was slaked inside an oil drum under small pressure (made by placing heavy stones on top of the lid) to avoid unslaked particles, see Fig. 9. These slaking methods have been developed during many years of lime slaking of a similar Ordovician limestone in Västergötland, in Sweden at Gothenburg University (Eriksson et al. 2012). By slaking the lime under pressure it can be used faster without risking unslaked particles that will be slaked after being used. Both types of quick lime are extremely sensitive when it comes to adding too

much water during the wet slaking process, giving mortars with inconsistent and hard-worked qualities when it comes to workability. The amount of water used in wet slaking for similar kinds of limestone is known to cause extended time for the hardening process followed by lower resistance to degradation (Pasch 1826). Traditional wet slaking in Sweden (Sjöbladh and Engeström 1750) means using a larger surplus of water to slake the lime in the open atmosphere to achieve lime putty. In this project this technique was only tried on a few individual stones, but since the limestones of Marieby and Näversjöberg proved to be difficult to slake, the method of slaking under pressure developed by Eriksson (2015) was instead applied, see Fig. 9.

The lime was then used to prepare mortar together with local sand with a particle size of 0–3 mm in different mixing ratios. The sand was chosen from a quarry nearby, looking as similar as possible concerning color, shape and size distribution, compared to the content of old sand in the historic mortars. Several test-surfaces were made on the wall surrounding the cemetery in order to find a consistency with good workability, mixing ratio and structure similar to the old preserved mortar samples.

The limestone was put in a steel basket with holes and dipped in water for 18 s until it ceases to bubble. In the wet-slaking method hot water is placed in the drum in which the burned lime is poured into. When dry-slaking, the basket is put inside the empty drum. In both cases a lid is placed on top and a stone is placed on top of the lid in order to create a pressure, which minimizes the loss of energy. This method was created both from practical research and experience by Eriksson (2012), Eriksson et al. (2015).

The workability of the lime mortars was different from lime that the craftsmen, who came from other regions in Sweden, were used to. Even a very lime rich mortar didn't give the impression to be a very fat mortar. In the 19th century those kinds of lime were defined as "lean lime" rather than hydraulic lime (Pasch 1826; Henström 1869) even though their chemical composition suggests that they will give hydraulic lime. When occurring as wet slaked they could be stored for a few days but not more than two weeks. They were what the Swedish mason call "short" meaning they were not smooth nor gluing to the underlying surface. They were all quite difficult to work with. The surface had to be worked with light hand with a trowel, not with a wooden board. Otherwise the lime was "bleeding" to the surface and a lime film was too easily created. They were also extremely sensitive for time and consistency of the mortars when the surface could be worked on. All test mortars had to dry out and become stiff before they were worked on, otherwise they would not harden properly to become durable. In Table 2 a comparison between the two types of lime is presented. All mixing ratios are presented in volume between lime and sand. The local sand needed a lot of lime in order to give what felt as lime rich mortar.

The analysis as well as the practical tests show two very different types of lime after burning, slaking and hardening, see Fig. 10. As always it is essential that the

Table 2 A comparison between the slaked lime of Marieby and Näversjöberg

Marieby wet-slaked	Marieby dry-slaked	Näversjöberg wet-slaked	Näversjöberg dry-slaked
<p>A yellowish lime, in color very similar to the original mortars of Oviken</p> <p>Mixing ratio 1:1 by volume felt like it was mainly sand. The mortar needed more lime in order to be able to work with. It was difficult to apply by throwing the mortar with a trowel since it was in one way sticky and attached to the trowel too much but in another way not sticky when attaching to the underlying wall</p> <p>Tests with mixing ratio 2:1 or 1.5:1 proved to work much better but in order to work the surface it was essential to wait for the mortars to set and not to use any pressure on the tools since the lime then would end up as a lime film on the surface</p> <p>Also 10:1 and 20:1 were tested of this kind of lime since analyses of old lime mortars showed such an extreme mixing ratio. Both were possible to work with but since they cracked a lot as they dried out it was essential to wait for the cracks to appear before working the surface with a light hand</p>	<p>Same color as wet-slaked</p> <p>It was not as sticky as the wet-slaked lime.</p> <p>Mixing ratio 1:1 gave a mortar impossible to work with so from the start more lime had to be added.</p> <p>Mixing ratio 1.5:1 gave a mortar that proved to be easier to apply. It was not possible to work the surface with any wooden tools. Steel trowels had to be used for working the surface when the mortar had set and one had to be very light on the hand to avoid a lime film on the surface</p>	<p>A brownish lime, darker than the Marieby lime</p> <p>This lime gave more fat mortars than the Marieby lime.</p> <p>Mixing ratio 1:1 was possible to work with. It could not be described as sticky but it hardened faster when applied to the wall. Already after a day it became very hard</p> <p>To make a good adhesion between the wall and the mortar, stiff mortar was brushed into the surface of the stone before a layer of mortar was thrown on. Without this procedure the mortar would roll off the wall immediately</p>	<p>The dry-slaked Näversjöberg lime is very similar to the wet-slaked Näversjöberg lime in the mortars</p> <p>It also needed the ground layer for adhesion, it hardened fast once applied to the wall. When working the surface one had to be very light on hand in order to avoid a lime film on the surface</p>



Fig. 10 Burned limestone from Marieby; dry-slaked Näversjöberg lime in a special constructed steel basket; wet-slaked Marieby lime. The lime from Näversjöberg is almost a bit purple-grey when it is slaked compared to lime from Marieby that is yellow-brown (Color figure online)

craftsmen are experienced with fat lime mortars and comfortable with waiting on the setting time for each kind of mortar before working the surface. The Näversjöberg lime tended to act more hydraulic than the Marieby lime even though both kinds are made from the Isö limestone. The mixing ratio were frequently discussed and even small samples were made with 20:1 and 10:1 mortars in order to find out if it was possible to reproduce such fat mortars. However a later study of historic lime putty found in year 2014 (Balksten and Lindqvist 2016) taught us that slaking and storing of lean lime can have the effect that part of the binder transform into a function as aggregates as they partly harden. As we used a modern developed slaking technique to create a well slaked lime under small pressure, possibly we got a binder more active and fat, with a minimum of lime lumps, compared to the binder used in the original mortars we found and analyzed. If so, it can describe why we did not manage to create 20:1 mortars with good workability of the lime produced in this project. This question could be an object for further research and help us give an increased understanding for historic mortars.

In a region such as Jämtland where there have been limekilns in so many different deposits of limestone it is extremely difficult to find limestone giving exactly the same properties as the original mortars locally used. Adding the fact that old mortars are extremely different from mortars in modern mortar tradition concerning mixing ratio, there are other difficulties finding restoration mortars that are very similar to the historic ones since modern craftsmen are unsure of how to deal with fat lime mortars.

The tested mixes were extremely sensitive for too high water content, both when it came to applying the mortar and especially when it came to working the surface structure. All the tested lime mortars would easily bleed lime towards the surface if worked on before they had become stiff. Shrinking cracks occurring in the drying phase had to become visible before the render could be smoothed with a steel trowel with a light hand. The test surfaces showed that it is essential not to be in a hurry when building a render since every layer must be able to harden before another layer can be applied, and every layer must be worked on after it has set (Fig. 11).

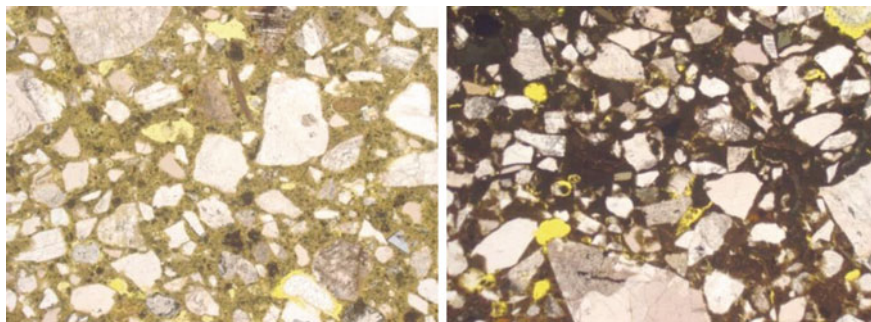


Fig. 11 Thin section of mortar samples made from dry slaked Marieby lime 1:1 and dry slaked Näversjöberg lime 1:1 to sand 0–3 mm. The shown width of the images is equivalent to 2.6 mm. A polarization Microscope, Zeiss TM, was used

4 Conclusions

To produce local lime in Jämtland was not too difficult since there is a known history and ancient ruins of the lime kilns developed for this certain region and its conditions concerning limestone and firewood. If there are a few people available with lime burning experience, as we have for instance due to the continuous lime production of Gotland (Mebus and Balksten 2015), the process of producing lime in a field kiln is rather simple. The difficulties in this project started with finding a proper stone that could provide a lime mortar with similar qualities as the original mortar of Oviken; firstly since Jämtland is a very difficult region with complex geology but also since most kinds of limestone have been used for burning historically. Many generations have developed their technique from local conditions during centuries and most of their knowledge was lost during the mid-20th century if not earlier. Today the knowledge must be recaptured and all the details from choosing stone, setting a lime kiln, burning technique and burning time, slaking technique and storing of slaked lime, sand quality, mixing ratio, mortar mixing technique to application method and surface working method have to be tested in order to find a proper restoration mortar for each type of masonry with remaining original mortars (Balksten 2005, 2007). Adding that the restoration mortar should have good workability as well as a long durability it requires a large quantity of tests and time for evaluation.

All types of lime produced in the project had interesting qualities and could give mortars with acceptable workability and color and structure similar to the old mortars. But it takes time to get used to how they work and how to control them in practice. In Sweden many impure limestones were burned historically (Johansson 2006) but in the 1940s only the pure lime compatible for lime-cement mortars became the ones that was burned (Balksten and Mebus 2012). This change has mediated the loss of knowledge among several generations of masons. Subsequently, our generation must learn to control mortars with properties far from

what they are used to if we want to restore our historic buildings with traditional and authentic materials and methods. As researchers and craftsmen nowadays work side by side in Sweden the conditions are rather optimistic.

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