Lime burning tradition in field kilns – a case study of the Jämtland tradition in Sweden

K. Balksten[1], C. Persson[2] & J. Eriksson[3]

1. *Department of Art History, Conservation, Campus Gotland, Uppsala University, SE-621 67 Visby, kristin.balksten@konstvet.uu.se*
2. *Department of Conservation, Gothenburg University, SE-405 30 Gothenburg*
3. *Department of Conservation, Gothenburg University, SE-405 30 Gothenburg*

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.

Key words: 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. 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.

Jämtland is a county in the middle part of 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 1920’s (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 figure 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 illustrated in figure 1.

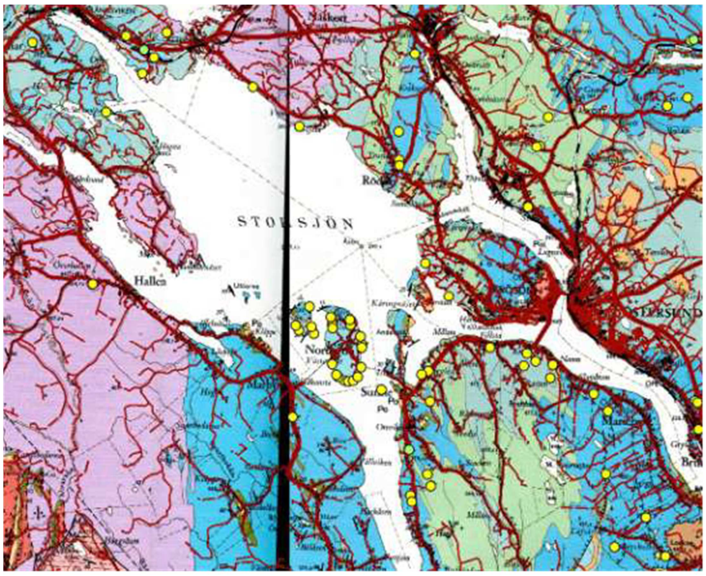

Figure 1: Bed-rock map of Jämtland combined with the remains of lime kilns found in Jämtland marked with yellow dots (SGU 1980/Fornminnesregistret, Persson 2012)

Figure 2: Illustration of a field kiln of Jämtland model (Åsling 2000). Unburned field kiln built in the late 19th century still standing in the forests of Åse. Now it is covered with moss but originally it was not covered.

2 Methods

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, where 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 local type. A small field kiln with two fire passages was built with limestones from two quarries in May 2011, and burned during 80 hours 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 figure 3. Both dry slaking and wet slaking methods were used. When being slaked, the burned limestone was placed inside in an oil drum (Eriksson 2012). When mixing mortars for test surfaces, an electric stirrer specialized for mortar were used. The mortars were then applied with a trowel and their surface texture was made as similar to the old 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 of the results.

Figure 3: Mortars are applied with a trowel onto the wall. Old mortars can be seen as the white and yellowish surfaces in the picture.

3 Materials

Old mortars from the area were analyzed 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. The mortars were most likely from the 15th to the 17th century. They were extremely fat (rich of lime) made from local hydraulic lime.

Figure 5: Old lime mortars in Oviken. The oldest mortars are extremely lime rich with a yellowish color.

Because of the complex geology in Jämtland and the formation of foulded 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 figure 6. 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 of lime kilns are preserved all over the landscape showing that most kind of Berge and Isö limestone have been burned at one time.

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 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 2 (Shaik et al 1989). The limestones in this study were taken from open quarries in Jämtland were such certain types of limestone were available; *Näversjöberg* north of Storsjön and *Marieby*, east of Oviken.

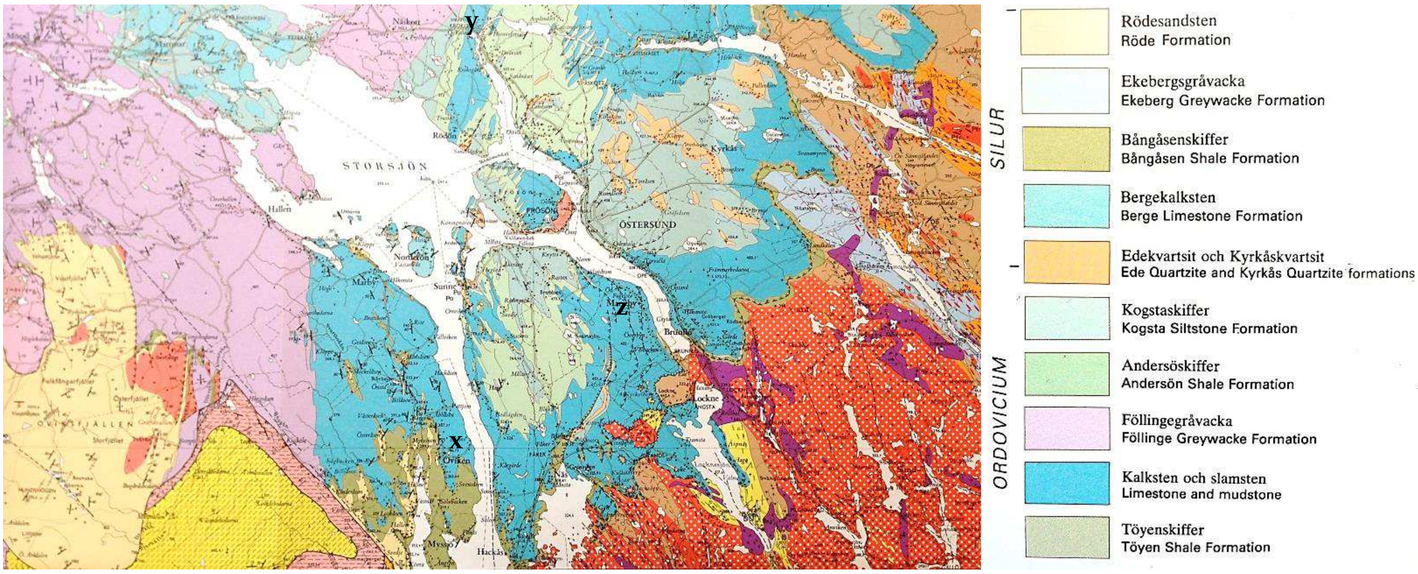

Figure 6: Part of the bed-rock map around Storsjön in Jämtland showing the complex geology of the region. Notice the blue and turquoise colors showing the presence of limestone. An x marks where Oviken church is situated, y marks Näversjöberg and z marks Marieby. (SGU 1980)

Table 1: Stratigraphic table of limestone from Jämtland (Shaik et al 1989). It shows the large variation of limestone such as the Silurian *Berge,* and the Ordovician *Furulund, Slandrom, Dalbyn, furudal, Folkeslunda, Seby, Segerstad*, *Holen*, *Isön*, *Lanna* and *Latorp.* (*Kalksten* is the Swedish word for limestone.)

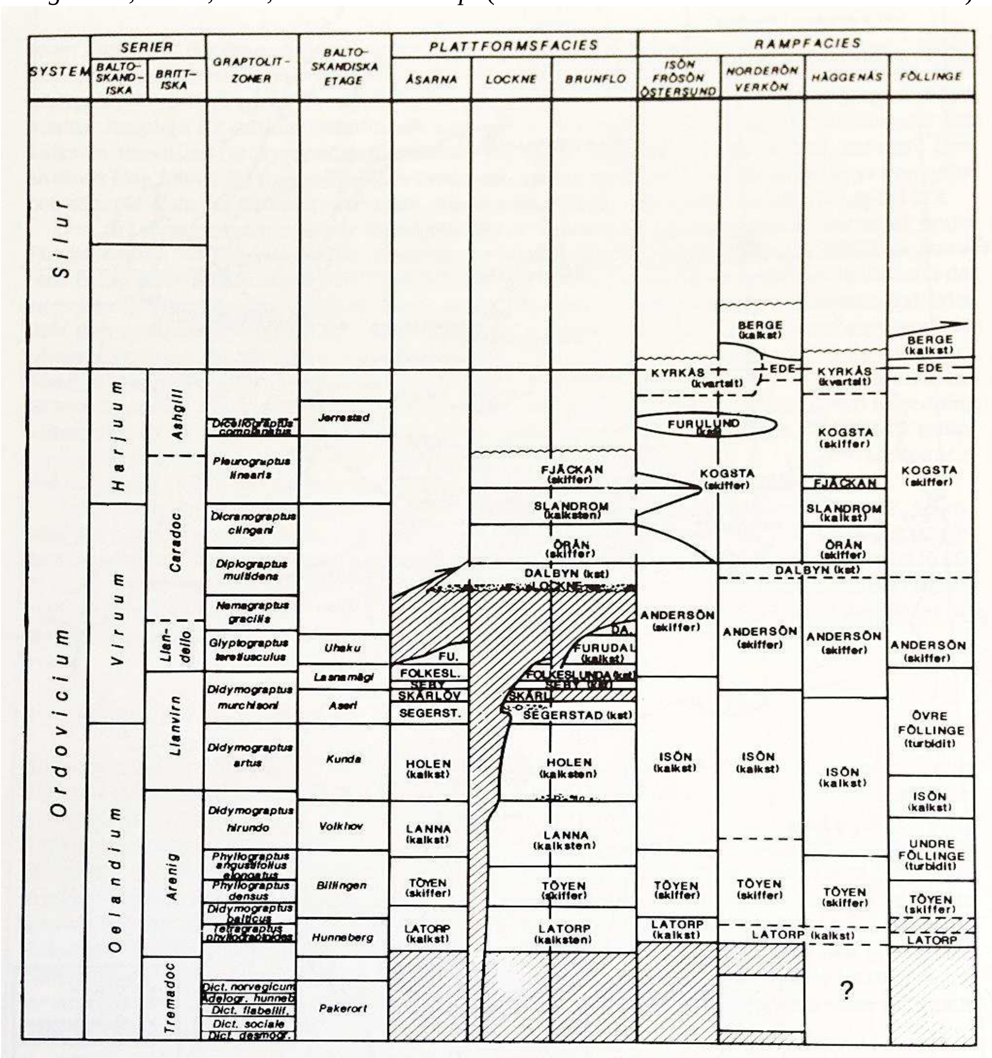

Table 2: Chemical composition in the Isö limestone of Oviken.
Samples taken from the early Ordovician layer (Shaik et al 1989).

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

4 Results and discussion

Analysis showed that the old mortar samples from Oviken and Sunne were composed of hydraulic lime 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, Mebus 2012). Such extremely fat mortars were used all over Sweden until the mortar tradition of the 18th century took over (Pasch 1824). Thin sections are made from soft yellow colored lime mortar samples which are extremely hard and fat, see figure 7. They both contain hydraulic components, reference material can be found in Johansson (2006) in analysis made by Jan-Erik Lindqvist and Torbjörn Seir.

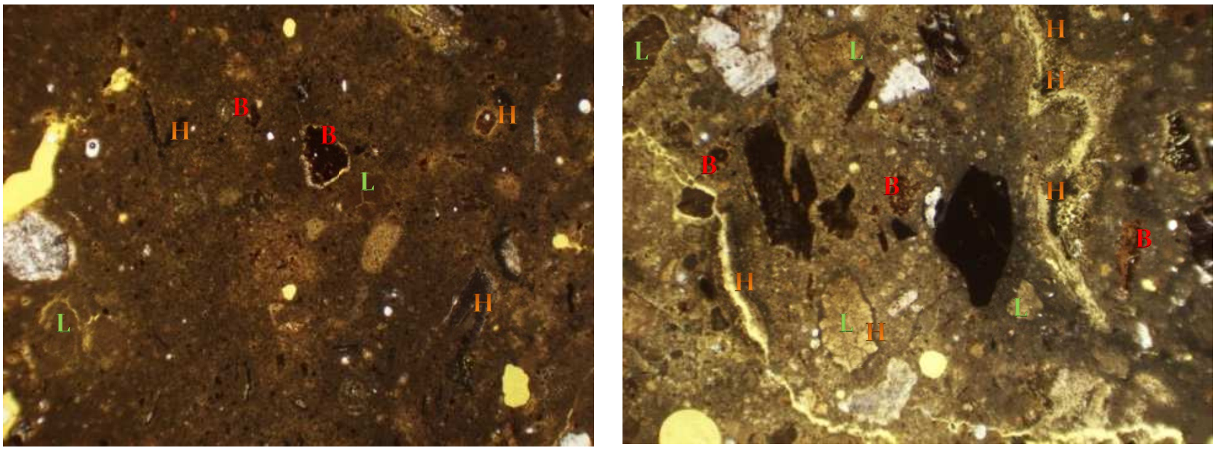

Figure 7: Examples of thin sections made from old lime mortar samples from the old church wall in Oviken (see figure 5) and the church ruin in Sunne, Jämtland. The shown width of each image is equivalent to 4.5 mm. Both of the analyzed mortars are extremely rich of lime, showing almost no sand particles at all. The lime is not pure $CaCO_3$, it contains some other elements, or impurities, showing that the lime contains some hydraulic components, some are marked with L (lime lump), H (hydraulic lime) and B (burned clay minerals).

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 hours. 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. Figure 8 and 9 show the kiln during building and burning.

Figure 8: Field kiln built in 2011. It has two fire places, like some of the kilns found in the region had.

Figure 9: 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.

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 figure 10. These slaking methods have been developed during many years of lime slaking of a similar stone 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 (Sjöbladh, Engeström 1750) with a larger surplus of water in the open atmosphere have not been used for more than some single stones when testing since those limestones proved to be difficult to slake.

Figure 10: Lime slaking under pressure in an oil drum. The limestone is put in a steel basket with holes and dipped in water for 18 seconds 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 but also from old descriptions regarding how to slake lime.

Figure 11: 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.

The lime was then used together with local sand with a particle size of 0-3 mm in different mixing ratios. The sand was chosen as similar as possible to the old sand existing in the historic mortars. Several test-surfaces were made on the wall surrounding the church in order to find a consistency with good workability, mixing ratio and structure similar to the old preserved mortar samples.

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 "non fat 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 and not 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 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 3 a comparison between the two types of lime is presented. All mixing ratios are presented in volume between lime: sand. The local sand needed a lot of lime in order to give what felt as lime rich mortars.

TABLE 3: A comparison between the slaked lime of Marieby and Näversjöberg

Marieby wet-slaked	Marieby dry-slaked	Näversjöberg wet-slaked	Näversjöberg dry-slaked
A yellowish lime, in color very similar to the original mortars of Oviken. Mixing ratio 1:1 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. 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. 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.	Same color as wet-slaked. It was not as sticky as the wet-slaked lime. Mixing ratio 1:1 gave a mortar impossible to work with so from the start more lime had to be added. 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.	A brownish lime, darker than the Marieby lime. This lime gave more fat mortars than the Marieby lime. 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. 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. Otherwise the mortar would roll off the wall immediately.	The dry-slaked Näversjöberg lime is very similar to the wet-slaked Näversjöberg lime in the mortars. 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.

The analysis as well as the practical tests show two very different types of lime after burning, slaking and hardening, see figure 11. The Näversjöberg lime proved to be more hydraulic than the Marieby lime even though both kinds are made from the Isö limestone. In a region such as Jämtland where there have been lime kilns 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 to a 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 smoothened 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 – it became clear when looking at some surfaces that did not harden properly.

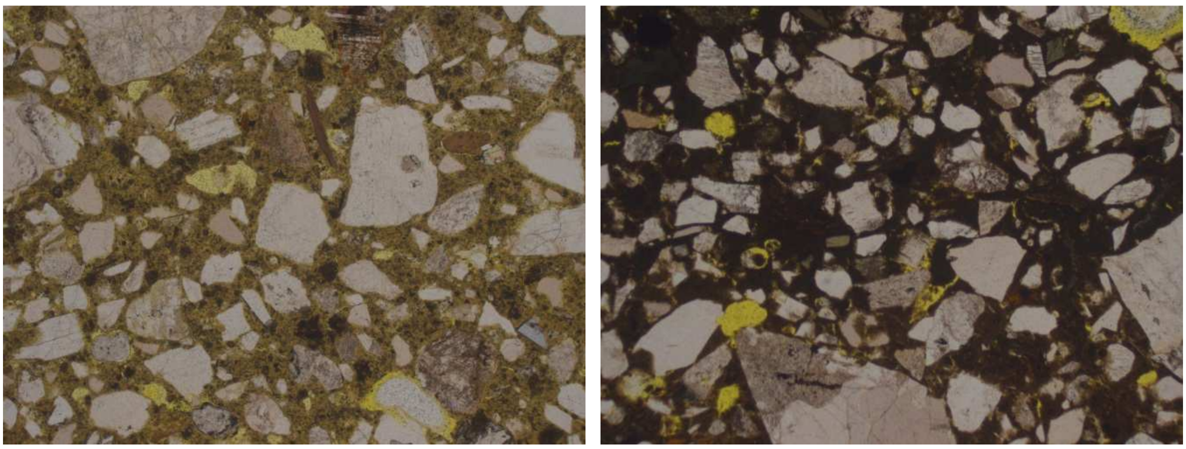

Figure 11: Thin section of mortar samples made from dry slaked Marieby lime 1:1 and dry slaked Näversjöberg lime 1:1 to sand 0-3 mm. The shown width of the samples are 2.6 mm. A polarization Microscope, Zeiss TM, was used.

5 Conclusions

It is not too difficult to produce local lime if there is a known history of the lime burning techniques developed for every region and its conditions. It is also not a big process to burn limestone if a field kiln can be used but it requires some people with experience of burning lime. The difficulties in this project started with finding a proper stone that could provide a lime mortar with similar qualities as the original mortar in the need for a restoration, 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 20th century. 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. 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 1940’s only the pure lime compatible for lime-cement mortars became the ones that was burned (Balksten, 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 materials and methods.

6 References

Balksten, K (2005) Kalkputs – Porstrukturens betydelse för beständighet. *[Lime render – The importance of pore structure for durability.]* Licentiate Thesis, Göteborg: Chalmers Tekniska Högskola. ISSN 1652-943X.

Balksten, K (2007) Traditional lime mortar and plaster – Reconstruction with emphasis on durability. Göteborg: Chalmers. Doctorate Thesis. ISBN 978-91-7291-990-7.

Balksten, K. (2010) Understanding historic mortar and their variations – a condition for performing restorations with traditional materials, Proceedings of Historical Mortar Conference HMC-2010, Prag, Tjeckien.

Balksten, K. and Mebus, U. red. (2012) Bruk av ruiner. Kulturarv, konstruktion, kalkbruk, komfort och kalsonger. *[The use of ruins.]* Visby: Fornsalens förlag. ISBN 9789188036841.

Eriksson, J. et al (2012) Erfarenheter av bränning och släckning av Kinnekullekalksten. *[Experiences of burning and slaking limestone of Kinnekulle.]* Mariestad: Hantverkslaboratoriet, Göteborgs Universitet. ISBN 9789197938259

Fornminnesregistret, www.raa.se/cms/fornsok, 2011-05-26

Henström, A. (1869) Praktisk handbok i lantbyggnadskonsten. *[Practical hand book for buildings for peasants.]* Örebro: Beijer.

Johansson, S. (2006) Hydrauliskt kalkbruk: produktion och användning i Sverige vid byggande från medeltid till nutid. *[Hydraulic lime mortar: production and use in Sweden in buildings from middle age to our time.]* Doctorate Thesis. Göteborg: Chalmers. ISBN 91-7291-822-5

Pasch, G. (1826) Årsberättelser om vetenskapernas framsteg, afgifne af kongl. Ventenskaps-academiens embetsmän d.31 mars 1827. *[Annual stories about scientific progress.]* Stockholm: P.A. Norstedt & söner.

Persson, C. (2010) Ovikens gamla kyrka – Förundersökning av putsen på kyrkan och bogårdsmuren. *[Oviken old church – Investigation of render on the church and its surrounding wall.]* Östersund: Jamtli. Rapport-Jamtli 2010:5. ISSN 1654-2045.

Persson, C (2012) Jämtländs byggnadskalk – Erfarenheter från ett kunskapsuppbyggnadsprojekt. *[Building lime of Jämtland – Experiences from en knowledge project.]* Östersund: Jamtli. Rapport-Jamtli 2012:46. ISSN 1654-2045.

Shaikh, N A et al (1989) Kalksten och dolomit i Sverige. Del 1 Norra Sverige. *[Limestone and Dolomite in Sweden. Part 1 Northern part of Sweden.]* Sveriges Geologiska Undersökningar. Rapporter och meddelanden nr 54. Uppsala: SGU. ISBN 91-7158-457-9.

Sjöbladh, C.G., Engeström, J (1750) Beskrifning, huru kalk skal tilredas ifrån thes första Bränning och til then warder färdig til sitt bruk. *[Description how lime shall be produced from burning until it becomes mortar.]* Original ur Calle Brobäcks Gotlandicasamling, Maj 2007.

Sveriges geologiska undersökning (1980). Berggrundskarta över Jämtlands län. *[Bed-Rock map of Jämtland.]* Uppsala: SGU

Åsling, N. G. (2000) Kalk och kalkbruk i jämtländska bygder. *[Lime and lime mortar in the Jämtland region.]* Alsens hembygdsförening.