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PROBLEMS IN REOPENING MEDIEVAL STONE QUARRIES: A STUDY OF NORWEGIAN FAILURES

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Abstract

This paper explains why a recent attempt to reopen the small Klungen medieval soapstone quarry near Trondheim in Central Norway failed. The quarry was used for extracting building stone in the Middle Ages and in the 19th century and has not been in use since 1900. As in the 19th century, the main reason for trying to reopen the quarry again was to obtain stone for restoration purposes. The work undertaken included geological investigations and determination of primary rock quality, archaeological excavations and studies of old extraction techniques, as well as quarrying experiments using modern techniques (sawing). A comparison with earlier attempts to reopen old quarries nearby is also given in the paper. The main technical reason why the reopening attempt failed was because the stone quality was worse than expected. This case study may throw light on some of the general difficulties encountered when trying to reopen old, listed quarries and give some guidelines and ideas for working out sensible investigation strategies elsewhere.

Keyword: NORWAY, MEDIEVAL STONE QUARRIES

Background

Since 1952 the Restoration Workshop of Nidaros Cathedral has extracted soapstone at the Bubakk quarry near Kvikne (*fig. 1*), in the mountains some 140 km south of Trondheim (Storemyr 1997a). This quarry is the oldest known soapstone quarry in Norway, with traces of extraction of vessels dating back to the 5th century B.C (Skjølsvold 1969, Storemyr & Heldal, in print). All monuments and artefacts, including stone quarries, from before 1537 (the Reformation) are listed in Norway (see http://www.riksantikvaren.no), implying that the Workshop was granted exemption from preservation rules in order to extract stone for rebuilding and restoring the cathedral. During work at Kvikne, limited destruction of former traces of exploitation could not be avoided - a fact that led to conflict with cultural heritage authorities in the middle of the 1990s. The Workshop was subsequently charged with breaking preservation rules, but the case was dismissed because of the state of the evidence. However, the quarry was closed for further extraction of stone and it is still not certain whether it will be reopened.

The closing of the Bubakk quarry has led to serious stone supply problems for the Workshop, especially because a major restoration programme is about to begin at the choir of the cathedral. Moreover, as the Workshop has worked its own quarries through the Middle Ages and again from 1869 (Storemyr 1997 a), and considers the extraction of stone a vital part of the stone mason's craftsmanship, the closing of Bubakk could mean breaking a long and very valuable crafts tradition. Another problem is that good quality soapstone is not readily available on the commercial market.

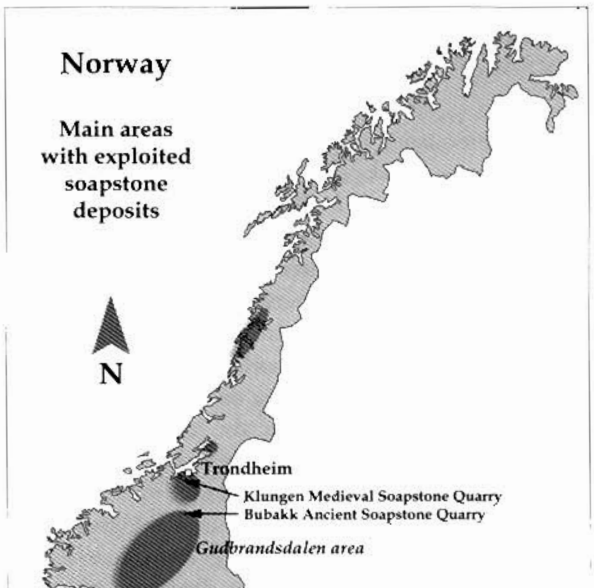

Fig. 1 – Map of Norway showing soapstone provinces and quarries mentioned in the text.

The Klungen project

Thus, in 1996-97 it was decided to explore the possibilities of reopening Klungen soapstone quarry, a medieval quarry situated close to Trondheim (*fig. 1*). Since the quarry is medieval and exhibits numerous traces of former extraction, the Workshop was faced with the same problems as at Bubakk: a listed quarry and the need to obtain exemption from preservation rules.

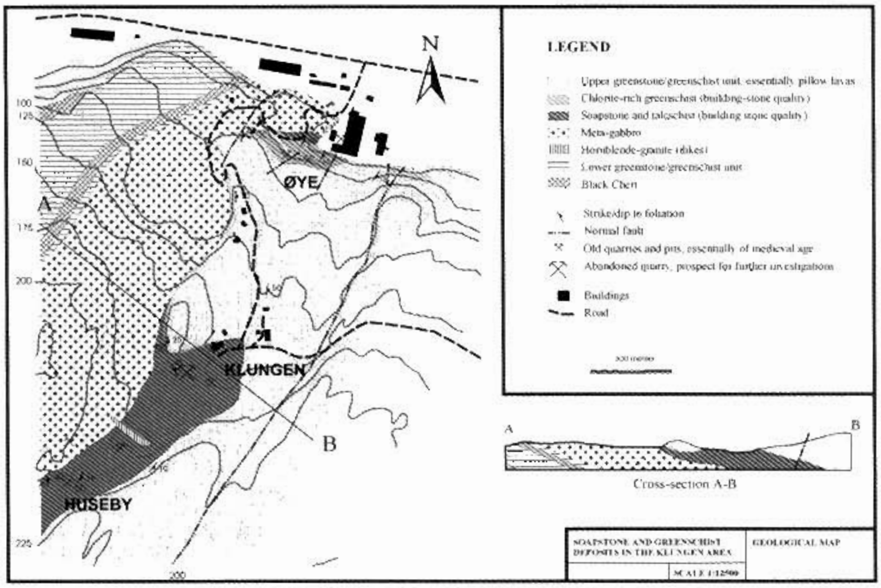

Fig. 2 – Geological map of the Klungen quarrying area. Mapping by Heldal & Storemyr 1996-97, cartography by Heldal.

As a consequence of the conflicts at Bubakk, the Workshop decided to undertake an «exemplary» project, in which cultural heritage authorities, local authorities and the land owner was invited to join at an early stage. The idea governing the project was that it ought to be possible to protect the most valuable parts of the quarry and at the same time undertake quarrying in less valuable parts. This would also mean that the tradition represented by the quarry (used for building the cathedral) could be revitalised. In other words, the idea defined the quarry as a «living museum», in which the public also ought to have access - to experience «old and new» extraction methods simultaneously. This idea was accepted with enthusiasm from the authorities, also because it would imply extensive archaeological excavations which could shed new light on medieval stone quarrying - a field which had not been investigated in depth in Norway before (LIDÉN 1974, EKROLL 1997). Except for Bubakk, which was excavated under archaeological supervision in the 1970s, the only excavations of stone quarries in Norway until this project were in fact very minor ones in a few Viking age soapstone vessel quarries (SKJØLSVOLD 1961, see also ØSTERÅS 1999).

Another reason for the positive feedback from the cultural heritage authorities was related to the fact that the Klungen quarry and several other medieval quarries nearby have been partially destroyed by modern activities (houses, industries, roads, farming etc., HELDAL & STOREMYR 1997). These activities have been undertaken without involving the cultural heritage authorities, probably mainly because the quarries have been practically unknown to the public before. This is unfortunately a very normal situation with regard to old stone quarries in Norway. Therefore, a project like the one proposed was looked upon as a new way of co-operating in order to find good solutions to the problem of managing these fragile monuments.

Before the archaeological excavations started, geological investigations were undertaken in order to confirm whether it was possible at all to extract more stone from the medieval quarry. The history of the quarry was also worked out. Below, these investigations will be presented first.

History of the quarry and quality of the stone

The Klungen quarry is only one of several medieval soapstone and chlorite schist (greenschist) quarries occurring in a c. 2 km long, small valley close to the mouth of River Gaula, c. 17 km south of Trondheim (*fig. 2*). All the quarries were used for Nidaros Cathedral and other medieval buildings in the region, and it seems that they were successively opened from c. 1050 A.D. The Black Death in 1350 probably marked the end of the medieval exploitation of the quarries (CARSTENS 1927, STOREMYR 1997a, 1997b).

After the Reformation (1537) some of the quarries may have been in very minor use for local purposes, but it was not until the late 1860s that they were actually reopened to be used for restoring Nidaros Cathedral. The Klungen quarry went into use for a short period in the 1880s, and in 1892 a new quarry was opened just beside the old one. The quarries were worked until c. 1900, delivering some 4-500 m^3 finished blocks to the restoration of the cathedral. The reason why the quarry was abandoned appears to have been that good quality soapstone could be obtained from larger quarries elsewhere (STOREMYR 1997a).

Following geological investigations in the 1960s, which concluded that the deposit was too difficult to work again (HULTIN 1967a, 1967b), the new Klungen quarry was covered with several metres of earth/clay in order to be used as farmland. The old quarry was left exposed, and over the years it became almost completely overgrown. A small pond also developed within the quarry (*fig. 3*). The reason why the deposit was considered too difficult to operate seems to have been the several metres of clay covering large parts of the area.

Fig. 3 – The overgrown Klungen quarry before archaeological excavations commenced. Photo: Storemyr 1992.

Another reason might have been the foliated nature of the stone, implying that it was considered difficult to obtain block sizes large enough for restoration purposes.

Foliation must have been of major concern also for the medieval quarrymen and stone masons. It seems that the stone was mainly used for decoration in the Middle Ages, but there are also examples of ashlars (*figs. 4, 5*). Many sculptures made from the stone are currently on display in the Cathedral Museum in the Archbishop's Palace in Trondheim. Some of the sculptures seem to have broken along foliation planes already by the time they were carved, and they appear to have been subsequently fixed with iron dowels (in lead). The reason why the stone nevertheless was used must be because of its deep blue colour and excellent workability (carving). From the quarrying campaigns in the late 19th century there are no reports of difficulties due to foliation, but in a survey report made in the 1920s (in the Workshop's archives) it is mentioned that the deposit is extremely foliated and difficult to operate.

As a consequence of these historical and geological facts, there were doubts within the Workshop about the feasibility of opening the quarry once more. However, since the soapstone is outstanding with regard to colour and carving properties, and since the medieval and 19th century quarrymen were able to extract stone from the deposit, it was decided to give it a try.

The geological investigations

Geological mapping and registration of all former traces of exploitation in the whole 2 km long valley were undertaken in 1996-97 (*fig. 2*). Klungen and the other quarries are situated within a metamorphic ophiolite fragment (detached ocean floor crust) formed some 500 million years ago. Today the soapstone deposit at Klungen occurs as a 10-20 m thick «slab» between greenstone and gabbro, dipping weakly towards east. Generally, there are two types of soapstone in the deposit. One predominantly consist of the minerals talc, chlorite and carbonate (frequently as veins), and is considered to be soft and good to carve. The other type is harder, contains less talc and carbonate and some amounts of serpentine and amphibole. Both types are foliated due to deformation and folding, but more massive types also occur (HELDAL & STOREMYR 1997).

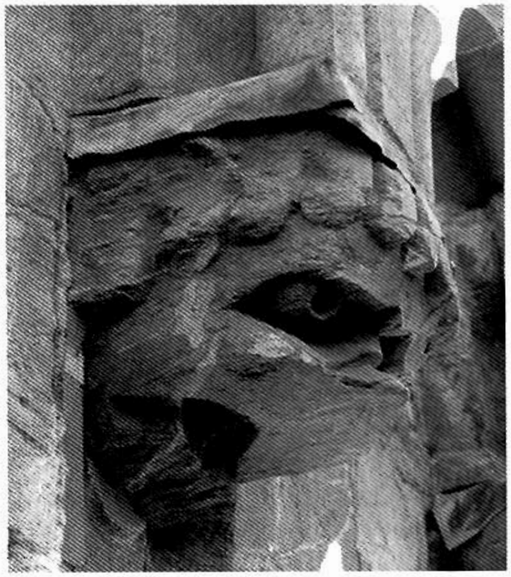

Fig. 5
Medieval head made of Klungen stone at Nidaros Cathedral. Note that the lower part is broken along a foliation plane. Photo: Storemyr 2000.

Fig. 4 – Klungen-like stone at Nidaros Cathedral. Note dark oxidised veins of carbonate minerals. Photo: Storemyr 2000.

Following these investigations it was decided to undertake a detailed geological study by diamond drilling of the deposit around the old Klungen quarry in 1998. This part was selected because it is the most accessible in the area (farmland and a dirt road). Moreover, most of the other old quarries in the valley showed more extensive traces of medieval stone extraction than what could be seen on the surface at Klungen. This meant that possible new quarrying would be least damaging here (HELDAL *et al*. 1998).

The results of the drilling campaign were unfortunately rather disappointing because the most massive (»best») stone occurred in the lowermost and rather inaccessible part of the deposit, whereas the higher parts often were extremely foliated and cracked. Nevertheless, in quite a few areas it appeared, in spite of a high frequency of core fractures (more than 7 pr. metre), that it would be possible to extract relatively thin blocks large enough for restoration purposes. It should be noted that it is quite impossible to *quantitatively* transfer the frequency of core fractures to the actual nature of the foliation - only test quarrying can give a proper answer (HELDAL *et al*. 1998). Such test quarrying was undertaken after the archaeological excavations.

The archaeological excavations

The excavations, which were concentrated to the areas east and south-east of the old quarry, as well as within the quarry itself, started in the autumn of 1998 and were continued in the summer of 1999 (*fig. 6*). Since large parts of the area were covered with up to 5 metres of a compact layer of clay (see also HELDAL & STOREMYR 1997), it was impossible to undertake the work without excavators. Most of the clay originated from the efforts to create better farmland around the quarries in the late 1960s (see above). Adding that the old quarry was operated in a short period in the 1880s, this implied that there were limited chances of finding layers within or around the quarry that had remained completely untouched since the Middle Ages (BERG 1998, 1999).

Generally, the first season of excavation consisted in emptying the pond and using larger and smaller excavators in order to remove the clay. This was done under careful archaeological supervision in which all steps were documented by drawings and photos. Subsequently, the barren rock and rock with traces of quarrying were manually cleaned and washed with water provided by the local fire brigade (BERG 1998, 1999).

The most interesting discovery during the first season was a relatively large shaft-like pit (10 m wide and 5 m deep) where the former pond had been. This pit showed numerous traces of quarrying, some of which appeared to be medieval. Otherwise there were unfortunately very few traces of indisputable medieval extraction marks; most of the marks of picks and chisels that appeared on the walls of the quarry seemed to stem from the operations in the late 19th century because they were all too often accompanied by drill holes (manual drilling). A well-preserved iron pick found on the floor of the quarry (*fig. 8*) also appeared to be of relatively recent age (BERG 1998, 1999).

Fig. 7 – Iron wedge found during the excavations (2,5 kg., 8 cm wide). Photo: P.E. Fredriksen.

The first phase of the excavations more or less determined the extent of the old Klungen quarry. This meant that it was possible for the cultural heritage authorities to draw up borders between «valuable» and «less valuable» parts of the quarry. The south-east area had such limited traces of former quarrying that a go-ahead was given for further quarrying, while in the rest of the quarry further operations were banned.

Thus, in the second phase (1999) the character of the excavations changed to become more traditional removal of overburden in order to gain access to the selected new area for test quarrying. However, also in this phase of the work careful archaeological supervision was undertaken. The work consisted in removing several thousands of cubic metres of compact clay to the south of the old quarry, as well as between the old quarry and the new quarry (1890s) that was backfilled with clay in the 1960s (see above). Gradually, it appeared that the area between the new and the old quarry consisted of stone which was too hard and too fractured to be of any interest for the Workshop. This stone also had quite a lot of fibrous serpentine and tremolite that could be *potentially* dangerous (asbestos). Close to the old quarry, however, a small ridge with seemingly excellent – although quite foliated – stone turned up. This distribution of rock types was more or less in accordance with results from the diamond drilling programme.

The second phase also consisted in further investigations of the old quarry itself. The floor of the quarry was manually cleaned and washed, which implied that old extraction marks could be studied in great detail. Moreover, several tools were found on the floor, of which the most interesting was a heavy wedge (*fig. 7*) used to split the rock along foliation planes (BERG 1999).

The removal of overburden demanded a strict policy of where to deposit these huge masses of clay. Such a policy was worked out in co-operation with the land owner. It consisted in

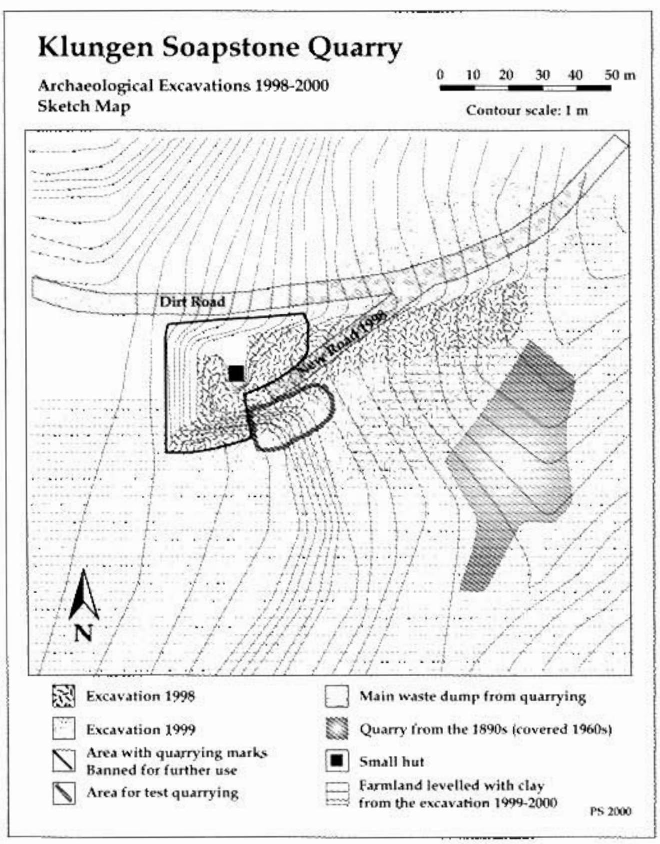

Fig. 6 – Sketch map showing the extent of the archaeological excavations at Klungen. Cartography: Storemyr & Heldal 1999-2000.

Fig. 8 – Iron pick found during the excavations (29 cm long) Photo: P.E. Fredriksen.

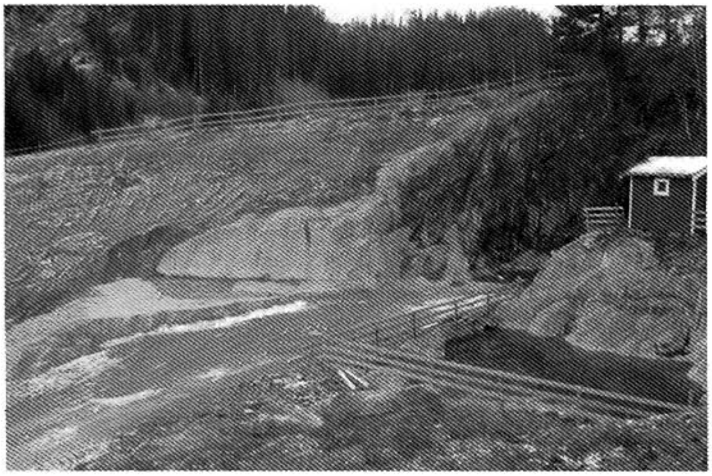

Fig. 9 – View of Klungen soapstone quarry after excavations and test quarrying (plain wall). Note the water-filled pond, which is a 5 m deep shaft-like pit. Photo: Storemyr 1999.

using the clay for levelling the farmland around the quarry, a process that also partially altered the drainage in the area. Hence, new ditches had to be dug and new drainpipes laid down. In effect, the loss of farmland due to the excavations was rather limited.

After securing potentially dangerous pits and cliffs with fences, the overall result of the excavation was satisfying for all parties involved (*fig. 9*). The workshop got access to apparently good quality rock for test quarrying; the cultural heritage authorities got a nicely presented medieval/19th century quarry; and the land owner did not lose too much farmland. However, more work will have to be done in the quarry, especially related to the presentation for the public.

Interpretation of toolmarks at Klungen

The general extraction technique (*figs. 10, 11*) appears to be very similar to what has been observed in soft-stone quarries (sandstone, limestone etc.) throughout the world; from the Old Kingdom in Egypt to 19th century Europe - and in many other Norwegian soapstone quarries. The technique takes advantage of the weak bedding planes of the rock (in our case the foliation planes): Thinner or thicker grooves/channels (usually 10-15 cm wide) were chiselled or picked out perpendicular to the foliation planes around the desired block (measuring up to 1 × 1 × 0,4 m), which was subsequently loosened by wedging along foliation planes. The technique appears to have been used both in the Middle Ages and in the 19th century at Klungen.

There are many variations of this general extraction technique. For example, since the rock is intersected by numerous cracks, the quarrymen have also taken advantage of these in order to limit the hard labour of making grooves.

The actual toolmarks to be observed on the quarry faces at Klungen today include (*figs. 10, 11*):

A. Irregular, thin, short (c. 5 cm) and rather straight lines from pointed picks or chisels (*fig. 11A*). These are rather scarce, confined to the upper (older) quarry faces and might be of medieval origin. Such toolmarks are very common in the nearby Öye quarry (see below).

B. Regular, slightly curved, long lines (10-20 cm) (*fig. 11B*). These are particularly observed on the south quarry face parallel to the axis of the quarry (the «long side»), and might originate from either pointed or flat picks. They can probably be dated to the extraction campaign in the 19th century, since they frequently are associated with drill holes. These toolmarks have very much in common with slightly curved tool-

Fig. 10 – View of the Klungen quarry after excavations. Note extraction marks. Photo: Storemyr 1999.

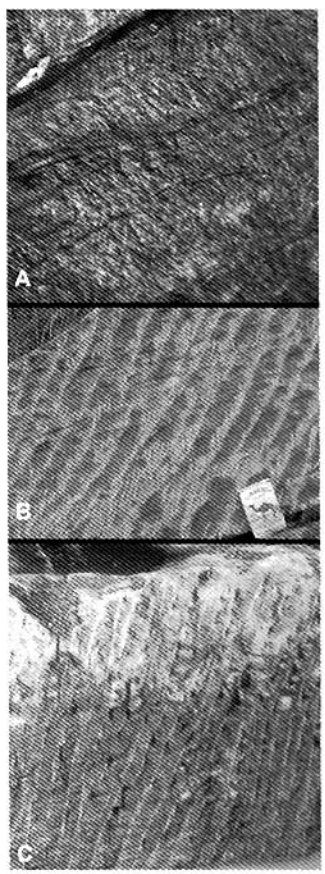

Fig. 11 – Various types of extraction marks at Klungen: A) Irregular medieval marks. B) Slightly curved 19th century marks. C) Straight 19th century marks. The scale is approximately the same for each photo (height: 40-50 cm). Photos: Storemyr 2000.

marks/lines in ancient quarries throughout the world (see e.g. Bessac 1996, especially 197ff).

C. Straight, almost vertical, long lines (10-20 cm) (*fig. 11C*). These are abundant and can especially be found along grooves perpendicular to the axis of the quarry (the «short side»). They are always confined to the lower (younger) levels of the quarry. We have unfortunately not been able to interpret how these lines were formed.

D. Holes for wedging out blocks along foliation planes.

E. Drill holes. Such holes are more or less confined to the south face of the quarry. It seems that they have been used to «blast away» (with gunpowder) rock layers of relatively poor quality (many cracks) in the 19th century. It is highly unlikely that drilling was in use in the Middle Ages at Klungen.

In addition, several loose blocks found during the excavation showed marks of sawing. This was to be expected, because there are reports from the 19TH century confirming that Klungen stone is very easy to saw (HELLAND 1893). It has, however, not yet been confirmed whether the stone was sawed in the Middle Ages.

If our interpretation of the age of the toolmarks is correct, the question arises why the 19th century toolmarks are much more regular than the medieval ones. This question has not yet been resolved, also because we have not been able to interpret how the long vertical toolmarks were formed. However, the general difference might of course simply be related to a difference in quarrying tradition and use of tools. In this connection it should be remembered that the excellent medieval stone working tradition was more or less completely lost in Norway when soft-stone quarrying resumed in the middle of the 19th century (cf. STOREMYR & HELDAL, in print).

Reopening attempts and toolmarks in the Öye quarry

Close to the Klungen quarry the much larger Öye chlorite schist quarry can be found (*fig. 2*). This quarry was heavily used for local building purposes in the Middle Ages and several attempts to reopen the quarry were undertaken in the late 19th and early 20th century (STOREMYR 1996, 1997, STOREMYR & HELDAL 1997). Toolmarks from the reopening attempts are somewhat easier to interpret than at Klungen and the quarry might therefore shed some more light on the extraction principles.

The Öye deposit is an almost horizontal, 2-5 m thick phyllonitic chlorite schist developed along the same thrust zoneas Klungen. Quarrying was undertaken along steep cliffs and partly below overhanging rock (*fig. 12*). The stone is extremely foliated, but was nevertheless used with success both for ashlar and sculpture in the Middle Ages (STOREMYR 1996, 1997).

After rather unsuccessful attempts to reopen the greenschist quarry in 1869, 1885 and 1892, the Restoration Workshop of Nidaros Cathedral tried once more in 1913 (STOREMYR 1996), maybe because a well-known geologist had praised the stone and foreseen a rationally operated quarry some years earlier (HELLAND 1893). The description of the 1913 «experiment» is symptomatic for a time when industrial quarrying techniques were about to replace traditional, manual methods:

The stone was so schistose that it was impossible to extract it by using gunpowder. One had to carve channels from existing corners and use a wedge to split the stone horizontally - like «the old» {medieval} craftsmen did. To use the stone for mouldings is going to be impossible, but it may be suitable for ashlars (Source: Documents in the Workshop archive, translated from Norwegian).

The experiment was terminated after a week or so – maybe it was too laborious to use the traditional methods? When the next experiment was carried out in 1934 (*fig. 13*), pneumatic equipment was used to drill closely spaced holes (channelling). The campaign was, however, once more terminated after a couple of weeks, even though a «completely rational operation» had been anticipated for the years to come (Source: Documents in the Workshop archive).

Fig. 12 – Overview of the Öye chlorite schist quarry. The quarry is situated along steep, overhanging rock. Photo: Storemyr 1993.

In addition to problems connected with the use of gunpowder, main reasons why the campaigns in 1913 and 1934 failed seem to have been the large difficulties encountered when dressing the stone, and that more easily workable soapstone could be obtained elsewhere. Masons who have tried to work the greenschist maintain that it «always» tends to delaminate when faces perpendicular to the foliation planes are to be dressed – and that the stone is difficult to saw. Hence, except for a few ashlars, nothing was produced from the stone after nearly 70 years of infrequent experimentation – an enormous contrast to what was achieved during a similar time-span in the Middle Ages (*fig. 14*).

The general extraction techniques (*fig. 15*) at Öye both in the Middle Ages an around 1900 are the same as at Klungen (except for the channelling campaign in 1934). The type and age

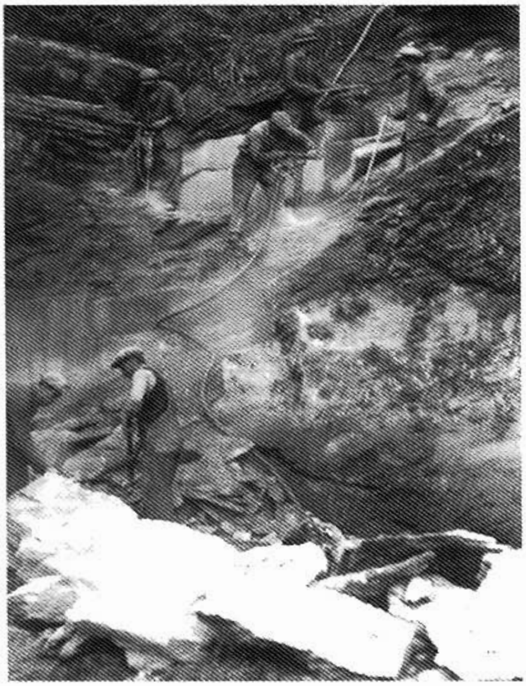

Fig. 13 – Manual channelling using pneumatic equipment in the Öye quarry in 1934. Photo: The Restoration Workshop of Nidaros Cathedral.

Fig. 14 – Early Romanesque capital showing beautifully carved Öye chlorite schist. Photo: The Restoration Workshop of Nidaros Cathedral.

of the toolmarks are also more or less the same, except that the long, slightly curved lines (*fig. 11B*) do not appear. The irregular marks (*fig. 11A*) can be found on the upper (older) levels, whereas the straight, vertical, hard-to-interpret lines (*fig. 11C*) are mostly occurring on the lower (younger) levels in the quarry - often together with short manual drill holes. It therefore seems quite certain that the straight lines were formed during campaigns like the one in 1913. Another difference between the medieval and modern extraction techniques at Öye is that most remaining corners from medieval block extraction are strongly curved, whereas the modern ones are straight. Together with the fact that the medieval toolmarks are short and irregular (*fig. 13*), this perhaps indicates that the medieval tools were smaller and less «heavy» than the modern ones?

The test quarrying at Klungen

As can be seen from the discussions above, we knew quite a lot about stone quality, former extraction techniques and potential difficulties before the test quarrying at Klungen began. The test quarrying was undertaken as two different experiments; one in the autumn of 1998 and another, much larger experiment, in the autumn of 1999.

In the first experiment only 5-6 m^3 was extracted by drilling and wedging. The aim was to quickly obtain some material for dressing and carving tests. During the tests it was soon realised that the stone was a very difficult one to quarry. Potential blocks that looked rather homogeneous before quarrying, «deteriorated» to a heap of smaller and larger stones during the extraction process or afterwards. This behaviour was explained by all the cracks appearing in the superficial part of the deposit. Mainly due to frost, the uppermost 1-2 metres (or more) of Norwegian natural stone deposits are usually rather cracked. In addition, it could easily be confirmed that the problem with foliation was going to become serious indeed.

Fig. 15 – Extraction marks in the Öye quarry, probably dating from the late 19th century. Photo: Storemyr 1998.

However, it was also confirmed that the small pieces of massive stone obtained were extremely well-suited for delicate carving.

In the next experiment it was decided to advance quickly to a deeper part of the deposit in order to obtain blocks that could hardly be affected by superficial frost weathering (cracking). Taking advantage of the small ridge that had been uncovered during the excavations, a diamond wire saw was applied for sawing away part of the ridge by one vertical and one horizontal cut (a total of c. 20 m^3 was thus extracted). The use of a wire saw was considered the least harmful method of obtaining material. Naturally, the rock mass was then divided in many larger blocks that were subsequently handled by a large tractor. After the blocks were sorted out, it appeared that many were quite homogeneous and definitely suitable for further working, especially those originating from the «core» of the ridge. Several blocks were subsequently transported to the Workshop in Trondheim where they were cut to suitable sizes. The blocks exhibited cracks along foliation planes, but these planes were usually situated some 20-40 cm apart, implying that it would have been no problem to seek out suitable material for use at the cathedral.

Surprisingly, after a couple of days, even the best blocks developed minute fissures between the main foliation planes and partly also perpendicular to these planes. Later, the fissures became so distinct that it was impossible to use the blocks for further working (*fig. 16*). Only very small objects could be made from the stone.

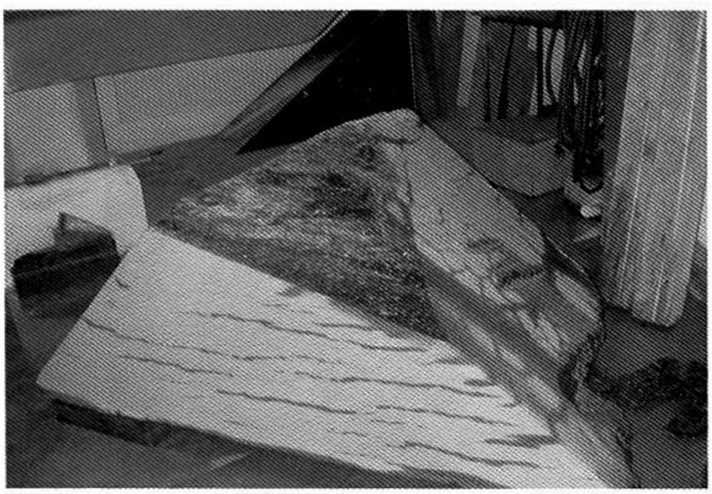

Fig. 16 – Quarried block of Klungen soapstone brought to the Workshop in Trondheim. Note the extensive cracks both parallel to (front) and perpendicular to (side) foliation planes. The stone has been wetted to show the cracks more clearly. Photo: Storemyr 1999.

To our knowledge there are two possible explanations of this behaviour:

- Shrinking due to drying (evaporation/release of the «quarry sap»)
- Release of remanent stress in the rock

With regard to shrinking, it was observed that cracks appeared both in blocks left exposed to the humid weather and in blocks placed in room climate. Moreover, the widening of the cracks came to a halt after a few days. Together, this probably means that we can rule out shrinking as the primary explanation. Since evaporation of the «quarry sap» is a very lengthy process (months), one would have expected the cracks to widen over a longer period of time or that new cracks turned up.

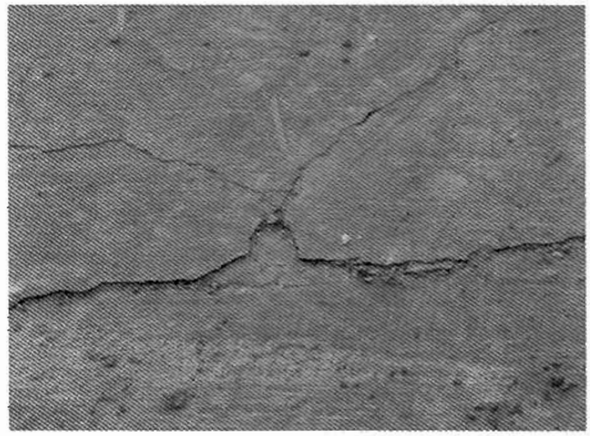

Fig. 17 – Crack in sawed surface at Klungen. Note the marked level difference between either side of the crack. This is indicative of release of remanent stress. Width of field: ca. 10 cm. Photo: Storemyr 2000.

The possibility of cracks developing due to release of remanent stress was further investigated by observing what happened in the quarry itself. After some time it became clear that initially very thin fissures in the cut rock faces widened. A marked level difference (some mm) between either side of many cracks also developed (*fig. 17*). According to professor in rock engineering, Arne Myrvang at the Norwegian University of Science and Technology (pers. comm. 2000), this behaviour is typical when release of remanent stress in rock masses takes place. It can be observed in many stone quarries – and especially in mines and tunnels – throughout the world. However, we have never before encountered this phenomenon in soapstone quarries. As a conclusion, we have to state that the cracks, which developed in the extracted blocks, most likely originate from release of remanent stress.

If we had known that the rock at Klungen exhibits relatively strong remanent stress, for example by measuring the stress in drillholes made during the geological investigations, we could have designed the quarrying experiment in another way. It could perhaps have been possible to carve larger channels or grooves in order to release the stress in a controlled way. This was recently done in a marble quarry in Northern Norway (Arne Myrvang, pers. comm. 2000), and should be considered if further work are to be unde rtaken at Klungen.

Some questions still remain: Why were the medieval stoneworkers able to obtain good material in both the Öye and

Klungen quarries? Are there other reasons than the «pure» technical ones for the failures to reopen the quarries? These questions can perhaps best be answered in an indirect way, by discussing technological and other changes in the 20th century.

Discussion

Studying the available historical documentation concerning the Öye quarry, one gets the impression that the quarry could have been developed further if the Workshop really had needed the stone. However, at the time (1913, 1934 etc.) other, easier-to-operate quarries were also worked by the Workshop and these quarries delivered rather good stone to large-scale reconstruction work at the cathedral. Öye chlorite schist seems to have been wanted primarily due to its deep green colour - to create «life» in otherwise dull grey walls (STOREMYR 1996, 1997).

Moreover, in the first half of the 20th century industrial extraction techniques were about to replace or supplement traditional manual methods. The first glimpse of how this influenced quarrying undertaken by the Workshop is the 1913 documentation from Öye (see above). Drilling and blasting was concluded to be a wrong extraction method, and one had to turn to the *old* methods in order to obtain crack-free blocks. This probably means that *carving* building stone out of solid rock already by then, only 15 years after working with such methods at Klungen, was generally looked upon as rather old-fashioned and inefficient. And although manual channelling using pneumatic equipment is about as labour-intensive as carving out blocks, we nevertheless see that the modern method was preferred in 1934.

Due to the difficult topography at Öye (cliffs and much overburden), it is hard to imagine efficient *small-scale* modern or «industrial» extraction in the quarry. Utilising the quarry for modern block production, for example in the 1930s, would probably have involved long-term investments and large-scale operations, perhaps even underground quarrying. Such capital-intensive operations were (and still are) far beyond the capabilities of the Workshop alone - one would have needed an industrial partner. This again would have demanded a commercial *market* for the stone, which in the first half of the 20th century simply was not there.

Thus, to use the stone for restoration purposes *alone* over a longer period of time would have demanded a return to very selective, labour-intensive, more or less manual extraction methods - probably very much like in the Middle Ages. This would also have enabled the stone workers to really get to know this foliated and difficult stone – and perhaps made them capable of producing more than simple ashlars from the stone. The fashion of the time was simply not for this type of manual work. Today we can be happy about the direction history took – an industrial operation would have destroyed most of the archaeological remains in the quarry!

With regard to the recent attempt at reopening the Klungen quarry, one can, to a certain extent, use similar arguments. We have seen that the quarry is extremely foliated and cracked and in addition exhibiting remanent stress breaking the stone apart.

For further works at Klungen there seems to be two different options - either to involve in a large-scale, industrial-like operation or to return to «medieval» extraction methods.

The first option would involve removing huge masses of overburden, making large grooves for controlled release of remanent stress and using some kind of sawing to extract blocks. It would be a capital-intensive, very risky operation, not least because the stone might still be too foliated to be offered on the commercial market. Without an industrial partner aiming at commercial production, it is financially impossible for the Workshop alone to engage in such an industrial operation. Another problem is of course whether the cultural heritage authorities will allow such an industry in the middle of a medieval stone quarrying area.

The second option is more viable for the Workshop. However, it would imply lengthy experimentation with extraction techniques in order to get to know the stone properly. One may perhaps also suggest that the traditional extraction methods – manual and rather slow – will release remanent stress more gradually, predominantly along natural planes of weakness, implying that «extra» cracks are less likely to develop?

It should of course be mentioned that many *small* objects (heads, bowls etc.) measuring perhaps up to 20 × 20 × 20 cm have already been carved from Klungen stone extracted in 1999. According to the stone masons and carvers, the stone is really magnificent to work. It is very soft, but at the same time firm, implying that fine edges can be easily made without worrying about whether they will keep or not.

Concluding remarks

From the perspective of stone extraction and obtaining material for the restoration of Nidaros Cathedral, the attempt at reopening the Klungen soapstone quarry has (so far) been unsuccessful. Any attempt at continuing the project ought to involve imitating the traditional manual work with picks and chisels in order to try to obtain suitable blocks. Such an experiment would not only mean carving out a block or two, but rather to get to know the stone through a longer period of work in the quarry, and in this way be able to find the most effective way of producing enough suitable blocks for the further restoration work at the cathedral. In this connection it should be mentioned that similar experiments recently have been undertaken elsewhere, for example related to restoration work at Maya ruins in Guatemala (WOOD & TITMUS 1997).

From other perspectives the Klungen project was quite successful. Through the co-operation that was developed between the Workshop, the cultural heritage authorities, archaeologists and the land owner, it was shown that potential new use of a listed quarry does not have to lead to conflict. In the Klungen project the quarry was considered a resource not only for building material, but also for knowledge and research and for the general public. It has not yet been possible to create a «living museum» of the quarry, but hundreds of local people have visited the quarry alone or through guided tours with lectures.

Moreover, the knowledge gained from the project, with regard to both old stone working techniques and archaeological excavation methodology, has been very valuable; not least when considering all the other old quarries in Norway in need of investigation, protection and management.

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