Abstract

This paper describes an attempt at reopening Klungen medieval soapstone quarry near Trondheim in Central Norway. In the project the quarry was considered a resource not only for building material, but also for knowledge and research and for the general public; a kind of a "living museum". The project has included extensive geological investigations, archaeological excavations, extraction experiments and preliminary work on presenting the quarry to the public. From the perspective of stone extraction and obtaining material for the further restoration of Nidaros Cathedral, the attempt has (so far) been unsuccessful, mainly because the stone is extremely foliated and difficult to work, and because the extraction experiments probably were ill-suited. On the other hand, the project has given new knowledge about medieval quarrying techniques, archaeological excavation methodology and how to co-operate in order to manage an old, listed quarry. The latter issue is important in a country like Norway where old quarries have often been neglected and poorly managed, in spite of being automatically protected by law as historic monuments.

Background

Since 1952 the Restoration Workshop of Nidaros Cathedral has extracted soapstone at the Bubakk quarry near Kvikne, in the mountains some 140 km south of Trondheim (Storemyr 1997a). This quarry is the oldest known soapstone quarry in Norway, with traces of exploitation for vessels dating back to the 5th century BC (Skjølsvold 1969, Storemyr & Heldal, in print). All monuments and artifacts, including stone quarries, from before 1537 (the Reformation) are listed in Norway (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
The 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 (Storemyr & Lunde 1998). Moreover, as the Workshop has worked its own quarries through the Middle Ages and again from 1869 (Storemyr 1997a), 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 at the commercial market.

![Figure 2: The overgrown medieval Klungen quarry before excavations](image)

**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. 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.

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, partly because it would imply extensive archaeological excavations which could shed new light on medieval stone quarrying - a field which have not been investigated in depth in Norway before (cf. 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., see 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 cooperating 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 as far as possible. Below, these investigations will be described 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, 17 km south of Trondheim. 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 AD. 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. This quarry was worked until c. 1899. The reason why the quarry was abandoned appears to have been that good quality soapstone could be obtained in 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. 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. 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. 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 (Storemyr et. al. 2000).

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. Klungen and the other quarries appear to be situated within a metamorphic ophiolite fragment formed some 500 million years ago. Today the soapstone deposit at Klungen appears as a 10-20 m thick "plate" between greenstone and gabbro with weak fall towards east. Generally, there are two types of soapstone in the deposit; one carbonate-rich, rather soft type, and one carbonate-poor, harder type. Both types are foliated due to deformation and folding, but more massive types also occur (Heldal & Storemyr 1997).

Following these investigations it was decided to undertake a detailed geological study by diamond drilling 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).

Figure 3: Images of medieval Klungen soapstone from Nidaros Cathedral. Above: Corbel head damaged along foliation plane (from the Octagon, c. 1200). Right: Beautifully carved corbel head (Octagon, c. 1200). Below: Ashlars from the choir (c. 1220) with characteristic veins of carbonate minerals. The corbels are presently in the museum in the Archbishop's Palace in Trondheim. Photo corbels Jørn Adde.
The results of the drilling 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 at the cathedral. 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. 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

![Figure 5: Sketch map showing the extent of the archaeological excavations and other activities in Klungen 1998-99.](image)
short period in the 1880s, this implied that there were small 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; most of the marks of picks and chisels that appeared on the walls of the quarry seemed to stem from the operations in the 1880s because they were all too often accompanied by drill holes (probably manual drilling). A well-preserved iron pick found on the floor of the quarry also appeared to be of relatively recent age. The pick will, if possible, be dated by C14 (Berg 1998, 1999).

The excavations also confirmed earlier measurements with "Georadar" (Heldal & Storemyr 1997), indicating that the largest waste dump from the quarrying was situated below the dirt road to the east of the quarry. Before investigations began it was thought that the road was situated on solid rock.

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 so limited traces of former excavation 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 were 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 were more or less in accordance with results from the diamond drilling programme (see above).

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 (mostly 19th century) quarrying operations could be studied in great detail. Moreover, several tools were found on the floor, of which the most interesting was a heavy wedge 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 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: 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. This will be discussed at the end of the paper.

Figure 6: View of the quarry after excavations and test quarrying (cut rock face)
Interpretation of extraction marks

The uncovered walls and floors of the quarry showed several types of extraction marks (see also Heldal & Storemyr 1997 and Berg 1999):

- Irregular, thin lines from pointed picks or chisels. These may be of medieval origin.
- More regular and longer lines, probably mostly from pointed chisels. Since such marks may appear in connection with drill holes, it is probable that they are from the 1880s.
- Drill holes. Such holes are more or less confined to the south wall of the quarry. It seems that they have been used to "blast away" (with gunpowder) rock layers of relatively poor quality (much cracks).
- Holes for wedging blocks out along foliation planes

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 telling 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.

The general extraction technique appears to be very similar to what has been observed in quarries of soft stone (sandstone, limestone etc.) all over 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 are chiseled or picked out around the desired block perpendicular to the bedding or foliation planes and the block is subsequently loosened by wedging it out at the bottom (see figure 10). The technique appears to have been used both in the Middle Ages and in the 19th century (see also Storemyr 1996).
There are many variations of this general extraction technique at Klungen. For example, since the rock is intersected by numerous cracks, the quarrymen have also taken advantage of these in order to limit the amount of chiseling.

It has not yet been possible to interpret the actual age of the various extraction marks. However, it seems that the more regular marks (rather long lines) of pointed chisels or picks stem from operations in the 1880s. This is because the marks sometimes are associated with drill holes. It is highly unlikely that drilling was in use in the Middle Ages at Klungen.

The test quarrying

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, use of a little gunpowder and wedging. The aim was to quickly obtain some material for further dressing and carving tests. During the test 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.

Thus, in the next experiment it was decided to quickly advance 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). 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 20-30 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 distinctive that it was impossible to use the blocks for further working. Only very small objects could be made from the stone. To our knowledge, the only explanation of this behaviour of the stone must be release of remanent stress in the rock. This phenomenon has not yet been interpreted in depth, and it has never before been encountered in Norwegian soapstone deposits. However, experience from other natural stone deposits seems to indicate that when cutting relatively large rock masses, there is a risk of releasing remanent stress too quickly, meaning that "extra" cracks and fissures develop. In other words: the stress is not released through natural cleavage, foliation and cracks only (Heldal, pers. comm. 2000).

As a preliminary conclusion it may be stated that the Klungen deposit is more difficult to work than initially was thought. However, it still is a fact that both medieval and 19th century quarrymen and stonemasons were able to utilise this resource of beautiful and easily carved material. Therefore, it may be suggested that their way of extracting the stone - manually and rather slow - is the only way also today. It is perhaps to be expected that remanent stress will
be more gradually released, predominantly following natural planes of weakness, when using the traditional methods (see also Storemyr et.al. 2000).

It should be mentioned that many smaller objects (heads, bowls etc.) measuring perhaps up to 20x20x20 cm already have been carved from the Klungen stone that was extracted. 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 egdes can be easily made without worrying about whether they will keep or not.

Figure 11: Survey by the ridge that was cut by diamond wire. The apparently best stone was found in the middle.

Figure 12: The best block after a couple of days: All the minute fissures (dark) developed after the block was quarried and are explained by release of remanent stress.
Concluding remarks and further work

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 for use at the cathedral. However, it appears to be difficult to get professional stone masons interested in such labour-intensive work. Moreover, 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). Another example of the use of old labour-intensive techniques in modern restoration work is the great effort world wide to produce lime mortars in the traditional way. Generally, such experiments are not only aimed at producing suitable, compatible materials, but also at learning more about traditional techniques. In the author's opinion, this aim should be considered important if the Klungen project is continued.

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 medieval stone working and excavation methodology, has been very valuable; not least when considering all the other old quarries in Norway that need investigations, protection and management. What remains to be done in Klungen for the public is especially related to signs and posters telling the quarry's story, as well as somewhat better securing of pits and cliffs.

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