Unravelling the history of a complex millstone quarry landscape: Tolstadkvernberget, South Norway

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Tolstadkvernberget, located in the municipality of Vågå in South Norway, comprises numerous small and large millstone quarries that were worked from at least the early 15th century until the late 1800s. The largest quarries targeted garnet-mica schist in solid bedrock, whereas a large number of smaller quarries were worked on similar rock in giant loose boulders emplaced by glacial transport. Field mapping and air-borne LIDAR scanning, combined with detailed studies of tool marks, have led to a tentative model for the typological and spatial evolution of the quarry landscape through time. The oldest phase, possibly dating back to the High Middle Ages, was characterised by both direct carving of circular blanks on the quarry face and splitting of stone slabs that were subsequently shaped into millstones. From the early 16th century or before, excavation of bedrock quarries at depth was facilitated by fire-setting and, locally, working of underground drifts, possibly as a result of technology conveyed to the millstone quarries from neighbouring copper mines. In the mid-18th century, exploitation was concentrated in two quarries and later only one large pit (Storgruva); these were worked primarily by powder blasting of blocks that were further processed at work areas outside of the actual pit. The long, unbroken record of exploitation at Tolstadkvernberget provides important insight into a part of Norwegian millstone quarrying history that is poorly represented elsewhere.

Keywords: millstone quarry, Middle Ages, fire-setting, Vågå

Background

Tolstadkvernberget, located in the municipality of Vågå, central South Norway (Fig. 1), has long been recognised as one of the significant quarries in Norwegian millstone history (Brekken 1980, Teigum 2011). Much of the quarry landscape was subject to a preservation order in 1987, in compliance with the Norwegian Cultural Heritage Act, as an important cultural heritage site for ancient millstone production. Historical sources show that the quarries were already worked in 1426 and record apparently continuous activity until the end of the 19th century, a period of nearly 500 years or more (Brekken 1980, Teigum 2011).

Covering the apparent time gap between large-scale quarrying at Hyllestad and Salten in the Viking Age to the High Middle Ages1 and at Selbu in the Modern Period (Baug 2002, Heldal & Bloxam 2007, Grenne et al. 2008, Grenne et al. this volume), Tolstadkvernberget thus provides an important account of a period of Norwegian millstone quarrying that otherwise lies mostly in darkness, i.e. the time of low population following the Black Death in 1349–1350 until the population started to recover in the 16th century (Benedictow 2004).

The quarry landscape is also interesting in terms of location. Unlike the older Hyllestad and Salten millstone quarries, which were all close to the sea, easily accessible from nearby settlements and for ship transport to

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1 Periodisation refers to Nordic Middle Ages (Ekroll 2006:40–45): Early Middle Ages 1030–1240, High Middle Ages 1240–1350, Late Middle Ages 1350–1537.
a broad market area, Tolstadkvernberget was situated in the highlands of central South Norway, far from the sea (Fig. 1). The nearest harbour was at Sognefjorden in West Norway, a distance of about 130 km across the mountain pass of Sognefjellet. On the other hand, the significance of more local markets was probably greater than at Hyllestad and Salten, particularly in the farming regions of the North Gudbrandsdalen valley but also further south in the uplands of Southeast Norway. Convenient for quarrying, Tolstadkvernberget was located only 2‒3 km from relatively large farm settlements at Lalm, in gently sloping forest terrain at 400‒440 m.a.s.l. near the floor of the otherwise steep-sided Ottadalen valley, a significant advantage compared to the Selbu quarries of Central Norway (Fig. 1) that were located in a remote mountainous region, far from both settlements and harbours (Grenne et al. 2008).

In spite of local knowledge and the status of Tolstadkvernberget as a heritage site, it is primarily the well-exposed traces of the most recent quarrying that have been recognised, whereas the numerous remnants of past events have received far less attention. This is largely due to the fact that the old quarries are far less recognisable, firstly because the old quarrying methods, in general, left only shallow pits and secondly because the pits and waste heaps are more covered by vegetation. Moreover, traces of past activity tend to be wiped out by more recent quarrying and may be recognised only through careful study of the quarry walls.

The quarries have been mapped by the present authors as a part of the project The Norwegian Millstone Landscape, funded by the Norwegian Research Council. Our approach was similar to that applied by Grenne et al. (2008) for the Hyllestad and Selbu quarry landscapes (Fig. 1), described by Heldal (2009) in a more general context. Key observations in these studies included geological characteristics, quarry morphology, tool marks, abandoned roughouts, work areas, and shelters and paths related to quarrying activities. Map compilation is based on studies of exposed areas by handheld GPS, combined with airborne LIDAR scanning (a remote sensing technology that measures distance by illuminating a target with a laser and analysing the reflected light), which provided a detailed 3D topography of the ground surface. The LIDAR data were particularly significant for the interpretation of quarry outlines and volumes in a landscape highly covered by vegetation. Tolstadkvernberget is briefly mentioned in several written sources that, combined with the field observations, shed additional light on the quarrying history. Details of this documentation have been presented in a separate field report (Grenne & Meyer 2012).

The resource and the quarry landscape

Like virtually all medieval millstone quarries in Norway, Tolstadkvernberget exploited a particular type of mica schist, with scattered crystals of garnet set in a light greyish matrix composed essentially of

Fig. 1. Location of the Tolstadkvernberget quarries (red dots) at Lalm (Vågå). Contour intervals 20 metres. Topographic base: series M711 1:50,000 map sheet 1718 IV Otta, © The Norwegian Mapping Authority. Inset map shows other significant millstone quarries in Norway referred to in the text.
muscovite (white mica) and quartz. The grinding properties of these rocks are a result of the contrast between the hard garnet crystals and the soft micaceous matrix. This tends to maintain a rugged and efficient grinding surface even as it wears down, because the hard garnets are more resistant than the matrix.

The Tolstadkvernberget schists belong to a geological unit generally referred to as the Heidal Group, a sequence of folded and metamorphosed sedimentary and igneous rocks of supposedly Precambrian age (Sturt & Ramsay 1999). Containing garnet crystals that commonly range from one to five millimetres in size and muscovite ranging from fine to coarse grained, the millstone schists have a relatively heterogeneous appearance; they also commonly have different 1–10 cm thick bands containing variable proportions of visible hornblende, calcite, biotite and quartz (Grenne & Meyer 2012).

Geological mapping shows that the exploited garnet-mica schist is restricted to a 20–40 metre thick meta-sedimentary unit that has been folded into an isoclinal, nearly east-west trending structure (Fig. 2). This millstone quarry zone is divided into 2–4 subunits of exploitable garnet-mica schist, each of them typically 5–10 metres thick, separated by somewhat thinner subunits of other schists. The hinge of the large fold structure defines the western end of the quarry landscape, while the two north-dipping limbs delineate two nearly parallel belts of quarries that approach each other towards the fold hinge. To the east, the millstone quarry zone disappears under a cover of gravel and sand.

The part of the quarry landscape that is based on bedrock resources is thus confined to an area of some 300 by 130 metres, most of which is within the established heritage site. In addition, the present mapping has revealed a large number of relatively small millstone quarries hitherto not recognised, stretching east-southeast from the main quarry (Fig. 2). These small quarries were based on the exploitation of similar garnet-mica schist in giant loose boulders found in a moraine; quarrying here generally used up the original resource and left only shallow pits surrounded by low spoil heaps, where millstone production is revealed only by the mass of fragmented and carved waste rock and occasional observations of roughouts (Grenne & Meyer 2012). The areal distribution of these quarries indicates that the boulders were derived from the bedrock units around the main quarries and emplaced in their present position by glacial transport downstream along the valley at the end of the ice age some 10,000 years ago, thus representing a typical boulder train. This particular part of the quarry landscape covers an area of ca. 800 by 100 metres, the largest of the quarried boulders are near their bedrock source to the west-northwest.

**Quarry typology**

Three different types of quarrying have been identified at Tolstadkvernberget, each of them leaving characteristic sets of tool marks and quarry morphologies.
These are: 1) Wide and relatively deep quarries in solid bedrock, worked primarily by powder blasting of blocks or slabs; 2) Less discernible, shallow quarries in solid bedrock, worked by both direct carving and manual slab splitting; 3) Quarries worked primarily by direct carving on loose giant boulders. The basic principles of powder blasting, manual slab splitting and direct carving in Norwegian millstone quarrying have been outlined elsewhere (e.g. Heldal & Bloxam 2007, Grenne et al. 2008, Grenne et al. this volume) and will be described only briefly here.

Essentially, direct carving aimed to produce a more or less finished millstone blank by carving a circular channel directly on the quarry face, before the blank was loosened with the help of a chisel along its base. This was the predominant technique of the Viking Age and much of the Middle Ages, such as at Hyllestad in western Norway (Fig. 1) (Heldal & Bloxam 2007). Slab splitting, by contrast, was based on carving millstone blanks from large, appropriately thick stone slabs that had been loosened from the quarry face either by the so-called pointillé technique (by chiseling a straight line of small, shallow pits across the surface until the rock splits) or by wedging, techniques that were used in the important Selbu quarries in central Norway at least from the 16th century onwards (Grenne et al. 2008) and at Salten in North Norway (Fig. 1) apparently as early as the 13th century (Grenne et al. this volume). Finally, powder blasting was essentially a gradual development of the manual slab splitting technique, seen especially in the 18th to early 20th century at Selbu, whereby slabs or large blocks were loosened with the aid of gunpowder (Grenne & Meyer 2009).

### Quarries worked by powder blasting

By far the most noticeable of the Tolstadkvernberget quarries is referred to as Storgruva (literally “The Big Mine”) in local tradition. Located on the southern limb of the fold structure, it extends over the total thickness of the millstone quarry zone and covers an area of some 40 by 35 metres (Fig. 3). The quarry walls are steep and
up to 10 metres high. The total volume is calculated at ca. 7000 m$^3$ based on 3D modelling of LIDAR data. Geological mapping shows that this quarrying was not very selective and included large quantities of unusable schists that crop out as units up to 5–6 metres thick between the exploitable garnet-mica schist.

Remnant drill holes reveal that hand drilling and powder blasting were used to loosen blocks that were subsequently carved to millstones (Fig. 4), but there are also sporadic traces of direct carving on the quarry face. Towards the north, the gently sloping terrain is covered with large waste heaps stretching up to 60 metres out from the pit (Fig. 3). The heaps have characteristically flat, terrace-like top surfaces covered with a lot of fine debris, and steep sides with discarded blocks and coarse rock waste. These terraces define several separate levels that represent different stages of quarry development. The low-lying terraces are consistently younger and were connected to the pit through dry-walled passages ca. 2 metres wide, cutting the slightly older waste heaps (Fig. 5). A comparable quarry, here referred to as Vestgruva, is found some 30–60 metres to the west (Fig. 3). A shallower pit and the existence of only one recognisable waste heap terrace suggest a shorter life span but otherwise similar working approach.

Typologically, the waste heaps at Storgruva and Vestgruva are similar to those of millstone quarries from the late 18th through to the early 20th century in the Selbu area (Grenne & Meyer 2009); blocks or slabs for millstone production, along with coarse rock waste, were transported out from the pit in wheelbarrows or by other means, and further processing took place at the flat work area on top of the waste heap (Fig. 6).

**Quarries worked by direct carving and manual slab splitting**

In contrast to blasting technology, manual extraction targeted the usable garnet-mica schist more specifically. Given that the intervening useless schists were avoided, these quarries are generally much narrower (Fig. 7), typically 5–10 metres wide; they are also generally shallower, typically 3–5 metres deep. Hence, many are hardly perceptible in the forested and moss-covered landscape, especially where millstone extraction is
limited to small cliffs that protrude only a metre or two from the surrounding terrain, with little or no associated pit (Fig. 8). Nevertheless, this is by far the most prevalent quarry type at Tolstadkvernberget. It is the only type in the northern limb of the fold structure, and it is also the predominant type in the southern limb where these quarries are found on the sides of, and between, the more noticeable quarries worked by blasting (Fig. 3).

Typologically, the quarries are characterised by pits that strictly follow the valuable garnet-mica schist units to depth, with traces of carving on the south quarry face and commonly overhanging contacts with

Fig. 6. Typological characteristics of quarries worked by powder blasting. Large blocks loosened using gunpowder were transported out from the pit along with coarse rock waste, and the millstones were carved on the flat work area on top of the waste heap.

Fig. 7. Bedrock quarry worked by direct carving, with overhang towards other schist on the north side (right) and direct carving (not seen on picture) on the footwall quarry face (left). Ca. 10 metres west-northwest of Vestgruva (see Fig. 3).

Fig. 8. Traces of limited direct carving on a small bedrock cliff. Ca. 50 metres northwest of Vestgruva (see Fig. 3).
unusable schists on the north side of the pit (Fig. 9) (Grenne & Meyer 2012). Moreover, waste heaps typically form a relatively narrow, more or less continuous mound enclosing the rim of the pit (Fig. 10), in marked contrast to the extensive terrace-like waste heaps of quarries worked by powder blasting. In some places, a low, rough drywall structure made of piled quarry waste, with fine debris on the top, is found close to the rim of the pit, similar to structures interpreted as workbenches at the Salten millstone quarries (Grenne et al. this volume). A natural cave on the edge of one of the pits may have been a primitive smithy, with a dry-walled fireplace and sides.

Tool marks on the quarry face reveal that direct carving was important and in some quarries apparently the only extraction technique (Fig. 11). The procedure was essentially similar to that previously identified at Hyllestad, where the circular blanks were carved side by side along layers of the cleavage plane (Heldal & Bloxam 2007). Channels were carved on the quarry face along circular outlines that were probably made with a pair of compasses like those described at Selbu (Fig. 1) (Grenne et al. 2008). Along the base of the channel, densely spaced pits, a few centimetres deep, were directed inwards on the perimeter of the millstone blank. Similar to the pointillé technique (Waekens et al. 1990), the stone was loosened along the base by hammering a pointed chisel into the pits.

Although direct carving was evidently common in these quarries, it is obvious that it was not the only technique. Some quarry faces only have sporadic remnants of circular channels on an otherwise smooth cleavage surface. In such cases, the extraction technique is inferred to be similar to that of the Selbu quarries in the 16th to early 18th century, where stone slabs of an appropriate thickness for millstones were split along the cleavage plane (Grenne & Meyer 2009). Poor exposure at Tolstadkvernberget makes it difficult to decide whether the splitting was done by means of wedges or pointillé picking; however, it is quite possible that both methods were used as at Selbu. Similar extraction of thin slabs using mostly pointillé picking already took place in the 13th century at Salten (Grenne et al. this volume).

Two peculiarities of relatively deep quarries of this type deserve particular mention. In one place, a narrow adit was driven eight metres horizontally from the lower terrain into the deep part of the quarry (Fig. 12). The adit is only about one metre high and was probably opened up primarily to drain water from the more than six-metre deep pit. The deep part of the shaft-like quarry was worked as a lateral drift of a few metres. Furthermore, parts of the roof and walls of the adit have a red, apparently burnt surface, partly covered with soot (Fig. 13). Rock waste on the floor and along the sides is a mixture of thin fragments and fine, silt-sized rock debris with abundant pieces of charcoal.

Similar burnt surfaces and fine debris mixed with charcoal are also found elsewhere at Tolstadkvernberget, specifically under the overhang of relatively deep
Quarries of this typology. Considered together, these are features that indicate the use of fire-setting (e.g. Willies & Weisgerber 2000). Using fire to sink shafts or drive steep trenches is difficult because heat tends to rise and it is therefore generally assumed that the fire had to be covered as a measure to direct heat downwards. Nine $^{14}$C ages of charcoal samples (all identified as pine) from the adit and three other quarries (Table 1) are interpreted to reflect the use of fire-setting in the period from ca. 1520 at least to 1670 (Grenne & Meyer 2012). The use of fire-setting and the presence of underground workings both seem to be unique to Tolstadkvernberget in Norwegian millstone quarrying.

Quarries on giant loose boulders

About sixty quarries worked on boulders have been identified in the area stretching east-southeast from the bedrock quarries (Fig. 2). The actual pits vary from 2 m$^3$ to more than 60 m$^3$ and are up to 3 metres deep (Fig. 14). Many are so deep that they must have been from boulders that were largely buried in the...
surrounding till, whereas others were probably from boulders lying more or less on the surface. In nearly all cases, the boulder itself has been completely used up and the only evidence of quarrying is the heaps of waste from millstone carving. The waste typically forms a narrow, continuous mound that encloses the rim of the pit, similar to the bedrock quarries worked by direct carving and manual slab splitting.

Four of these sites still have large remains of the original boulder with traces of millstone carving. Direct carving is the only recognisable extraction technique. It is reasonable to assume that carving started on boulder surfaces above the surrounding terrain (Fig. 15), before enclosing moraine material had to be removed to gain access to buried parts of the boulder (Fig. 16).

### History and landscape evolution

#### Early quarrying

Written historical sources provide clear evidence that millstones were produced at Tolstadkvernberget as early as 1426, when the millstone quarry is specifically mentioned in a document regarding payment for ground rent related to the farm Tolstad, one of the oldest settlements in the district (Teigum 2011). Local tradition has it that quarrying started much earlier, but this is not documented by historical or archaeological data.

Through to the late 17th century, the large Tolstad farm with the quarries was subject to changing ownership. In 1463, it was sold to Alv Knutsson, member of...
the State Council and the wealthiest private landowner in Norway. The property was acquired by the king in 1586 and mortgaged to the Amsterdam trading dynasty Johan Marselis in 1661, before it was ultimately bought by the tenant farmer Pål Tolstad in 1685. Documents from this period show that quarrying was a privilege of the Tolstad farm and, to some extent, the neighbouring farm Hammer (Håmår). However, other farmers in the Vågå district were granted the rights to quarry millstones on the condition that every third stone was given to the landowner (Teigum 2011:52). This tradition continued after the Tolstad farm was bought by the leaseholder Pål Tolstad in 1685. Several 17th century court cases involving the owner and local farmers concerning quarrying rights indicate that millstone production was quite extensive, and that it was a profitable year-round activity.

The first quarrying at Tolstadkvernberget must have started on resources that were easily accessible and required the least effort to exploit. Based on field evidence, it is likely that these were the many exposed cliffs protruding from the otherwise covered terrain. Such cliffs with usable garnet-mica schist were found in solid bedrock as well as in giant loose boulders, and both types were equally easy to exploit as long as quarrying could take place above the surrounding ground level. In both cases, millstone blanks could be easily extracted directly from the bare rock surface, either by direct carving or by manual slab splitting, and there was no need to dig deep pits or remove barren rock and gravel.

As noted above, field data suggest that the slab splitting method may have been used contemporaneously with direct carving right from the beginning in quarries worked on solid bedrock. The few localities showing only direct carving are too small and insufficient to prove an initial period of direct carving only. Our data also indicate that water millstones were produced at the same time as hand querns in all quarry types at Tolstadkvernberget, including the relatively old extraction sites. At Hyllestad, the first documented production of water millstones (diameter 60–120 cm) is from the 10th century (Baug 2002, Baug 2013:334), but hand querns continued to be by far the most important product through the Middle Ages. In the Salten district, hand quernstones from direct carving were apparently the sole products in quarries worked at some time between 1020 and 1270. Here, additional slab splitting and carving of water millstones seemingly became important in the 13th century, certainly...
before the Black Death in 1349–1350 (Grenne et al. this volume).

The above indicates that quarrying at Tolstadkvernberget commenced later than the Early Middle Ages, when hand querns were still by far the main product in leading millstone quarries such as at Hyllestad and Salten (Heldal & Bloxam 2007, Grenne et al. this volume). Moreover, the possibly combined use of slab splitting and direct carving is comparable to that documented at Salten in the 13th through to at least the early 15th century (Grenne et al. this volume). The mention of Tolstadkvernberget in a 1426 document (Teigum 2011:49) fits with this time interval, but it does not reveal how long activity had been underway at that time. It is reasonable to speculate, however, that quarrying goes back to before the mid-14th century, because the Black Death and recurrent plague outbreaks through to at least the 15th century led to very low population (Benedictow 2004), a context unfavourable for establishing significant quarrying activities in a new area.

The intermediate stage: the introduction of fire-setting

At some stage, the easily available resources – cliffs and boulders above ground – were used up and
continued activity required quarrying at depth. This was relatively undemanding in the case of giant loose boulders, where surrounding moraine material could be removed to gain access to exploitable subterranean rock surfaces (Fig. 16). In contrast, quarrying of solid bedrock at depth required far more effort. Here, it was necessary to remove a certain amount of barren rock on the hanging-wall side of (above) the exploitable garnet-mica schist, before quarrying could continue at depth. This was because the traditional extraction techniques required a free surface on the cleavage plane. Such work would be extremely time-consuming by manual means but could be undertaken more efficiently by driving a narrow, steeply inclined trench along the upper contact of the garnet-mica schist through fire-setting (Fig. 17a), followed by working the newly exposed quarry faces at depth (Fig. 17b) (Grenne & Meyer 2012).

At this stage, there is clear field evidence that the extraction methods of direct carving and manual slab splitting were used contemporaneously. The former technique produced a more or less finished millstone right in the actual pit, and the moderate amounts of rock waste could be easily discarded along the rim of the pit, which formed the characteristic continuous waste mounds. Manual slab splitting, on the other hand, required further processing comparable to methods used in the Selbu quarries (Grenne et al. 2008); after a slab of appropriate thickness was loosened from the

Fig. 17. Schematic illustration of fire-setting (upper illustration) followed by working of newly exposed quarry faces at depth (lower illustration). Millstones were worked partly by carving directly on the quarry wall, partly by slab splitting. A workbench for processing stone slabs and finishing millstones is illustrated in the background, typically located near the rim of the pit. See text for further explanation.
quarry face, a pair of compasses was used to outline the desired size, before the millstone was carved with a pick or with a chisel and hammer. At least some of this processing took place on the low drywall structure interpreted as a workbench just outside the pit (Fig. 17). Like at Salten (Grenne et al. this volume), we assume that the workbench provided a stable surface that facilitated carving and served to reduce breakage of the slabs.

The use of fire-setting at Tolstadkvernberget is corroborated by court documents mentioning the transport of “wood for firing in the [Tolstadkvernberget] quarry” (Teigum 2011:55). The original documents (Ivar Teigum, pers. comm.) show that wood for fire-setting was used back in 1648 and was still used by the time of the court proceedings in 1698. Our 14C ages indicate that fire-setting was already in use by ca. 1520. The quarrying in this period must have had a large impact on landscape evolution; not only was it a phase of extensive activity spread over numerous small and medium-sized quarries (Fig. 18), it is also likely that the surroundings were completely deforested due to the demand for firewood.

In Norwegian copper and silver mines, fire-setting was extensively used from the first half of the 17th century until the mid-19th century and it is very likely that the technique was also applied in the Middle Ages. Copper mines existed in central and southern Norway from the early 14th century or before and were probably influenced by mining expertise from Sweden, where fire-setting was an established technique already in the 14th century at the large Falun mine, and by Cistercian monks who were known as skilled craftsmen and specialised in metallurgy (e.g. Stenvik 2013:91–92). A large number of copper mines and showings, some of which show clear evidence of fire-setting, are found within a radius of 2 to 15 kilometres from Tolstadkvernberget (Geological Survey of Norway, mineral resource database). Although none of these have a documented history farther back than 1624, it is reasonable to believe that copper mining in the district started much earlier, not least because a probable copper mine located in the Fron district (apparently at Espedalen, ca. 38 kilometres south of Tolstadkvernberget) is mentioned in a document from 1342 (Blom 1991, Stenvik 2013:92). This opens the possibility that fire-setting technology was conveyed to the millstone quarries from neighbouring copper mines.

The late period and the decline
The next significant step in landscape evolution apparently took place with the introduction of blasting techniques in millstone quarrying. In the important Selbu quarries, the first reference to black powder is from 1734 (Haarstad 1972) and we know that by the mid-19th century blasting had taken over as the predominant technique (Grenne et al. 2008). At Hyllestad, blasting techniques were introduced before 1750 (Ronneseth 1968) but the exact timing is unknown. Powder was already used to some extent by the end of the 17th century in large copper mines such as at Roros; however, even in such metal mines led by professional mine officials, fire-setting remained the main technique at least until the early 18th century (Berg 2004). On this basis, it is reasonable to assume that powder blasting may have become significant at Tolstadkvernberget towards the mid-18th century.

The powder blasting stage is characterised by a concentration of the activity into only two large quarries: Storgruva and Vestgruva (Fig. 18). Both quarries include large quantities of barren rock between three or four units of exploitable garnet-mica schist (Fig. 3). Together with the larger amount of waste from slab-based carving as compared to direct carving in general and from blasting as compared to manual working in particular, this created vast amounts of coarse rock waste that was disposed of on sloping terrain to the north. The characteristic flat-topped, terrace-like shape of the waste heaps and the wide, dry-walled, entrances to the pits resulted partly from a need for more efficient transport of this enormous quantity of coarse rock waste and large stone slabs. The shape of these terraces was further accentuated by their use as work areas for carving millstones, which left significant amounts of fine rock debris.

Both Storgruva and Vestgruva were apparently worked in the early days of powder blasting. At some stage, Vestgruva was abandoned and all quarrying was focussed on Storgruva. These later phases are reflected in the topographically lower waste terraces at Storgruva (Fig. 3 and 18), which were formed successively with the gradual deepening of the quarry and the consequent need for new, deeper entrances for stone transport and water drainage.

Significantly, the large size of these pits and associated waste heaps is not a simple reflection of their importance in terms of production. Firstly, the more recent waste heaps obviously include older rock waste that had to be removed when modern quarrying expanded over a wider area. Secondly, it is obvious that the blasting technique in itself created far more waste than the previously used manual methods because of the rougher handling that tended to make more cracks.
in the rock slabs. Thirdly, by the time black powder was introduced, a large proportion of the apparent pit volume had already been mined out by earlier, manual, quarrying. This is seen partly from the general map pattern, where old quarries worked by direct carving and manual slab splitting appear to be cut by Storgruva and Vestgruva (Fig. 3), partly from occasional traces of old quarrying that have remained intact along the rims of the younger pits (Grenne & Meyer 2012). Field evidence shows that some precursor pits of Storgruva were at least six metres deep. Lastly, like typologically similar quarries elsewhere at Tolstadkvernberget, the precursor pits of Storgruva and Vestgruva targeted only the exploitable garnet-mica schist, implying that

Fig. 18. Model depicting inferred landscape evolution at Tolstadkvernberget. Upper) late 17th century; lower) late 19th century. Grey shades represent quarry pits, brownish colours are waste heaps, and greenish shades represent pristine terrain. The representation is based on mapping data coupled with a 3D terrain model from LIDAR scanning; view towards south-southwest, terrain shading based on light direction from the east-northeast.
several parallel, narrow quarries were separated by intervening barren units all the way to the original terrain surface. All this unproductive material had to be removed by blasting as the quarries were deepened in later periods, yet quarrying was still profitable thanks to the improved efficiency of black powder blasting as compared to manual working.

Written sources show that the powder blasting phase, at least from the late 1700s, was actually a period of decline in millstone production at Tolstadkvernberget. The main reason was probably competition from the huge quarries at Selbu, which grew to become Norway’s dominating millstone producer from as early as the 16th century onwards (Grenne et al. 2008). A report from County Governor Christian Sommerfelt in 1790 (Teigum 2011:56) tells that Tolstadkvernberget produced millstones that were “considered to be of lower quality than comparable stones from Selbu, which are used all over [the region] Oplandet”. A 1789 petition from the owner Pål Tolstad to remit payment of land tax related to the quarries, reportedly because the quarries would be valueless in the future, was another reflection of the decline. In the 19th century, anyone could get permission to quarry millstones on the condition that every fourth stone was given to the landowner (Brekken 1980). From the 1830s onwards, many people had seasonal winter work at Tolstadkvernberget as a result of a rapidly increasing population and consequent unemployment. Regular quarrying ended about 1870, but more occasional extraction of millstones continued until ca. 1890 (Brekken 1980).

Continuity of traditional techniques
A noteworthy feature of the late stages is traces of direct carving in deep parts of Storgruva (Grenne & Meyer 2012), demonstrating that the traditional technique was kept alive to some extent throughout the powder blasting years. A documented representative of this activity was a man called Ole Jørgensen, a tenant who lived not far from Tolstadkvernberget until he moved to North Norway in 1842 (Grenne & Meyer 2011). When he established his own millstone quarry at Svelshamna a few years later, he only used direct carving and left carving traces virtually identical to those at depth in Storgruva. Interestingly, Ola Jørgensen was referred to as a qvernhugger (millstone quarryman) in official documents already before he started working at Svelshamna. Therefore, he must have brought the skills with him, and it is very likely that at least some of his previous experience was at Tolstadkvernberget (Grenne & Meyer 2011).

The persistence of direct carving, albeit secondary, through a period of more than a century of efficient blasting, is remarkable, not least in view of technological development at other significant Norwegian millstone quarries working comparable schists. The Selbu quarries, for example, do not have a single documented example of direct carving in their long history (Grenne & Meyer 2009). The same question applies to the continued existence of direct carving concomitant with manual slab splitting in early quarries at Tolstadkvernberget, long after the Selbu quarries were successfully established with slab splitting as the sole technique in the 16th century, and even longer after slab splitting became the principal method at Salten in about the 13th century (Grenne et al. this volume). The question remains open, but possible explanations include differences in geological properties that made splitting more favourable elsewhere. Tradition may also have played a significant role; the Tolstadkvernberget quarrymen would naturally lean on the old skills and traditions established over centuries in the millstone quarries, and on essentially similar techniques applied in numerous soapstone vessel quarries in the district from at least medieval times until the 19th century.

The Tolstadkvernberget millstones
Information about the actual millstones produced is obtained from measurements of circular channels on quarry faces and from spoiled blanks left in the work areas (Grenne & Meyer 2012). Direct carving on giant loose boulders has left only few traces that are still visible; the limited data indicate mostly hand querns (<60 cm) and fewer water millstones, the latter ranging from 70 to 94 cm.

The bedrock quarries that were worked also by manual slab splitting are more problematic in terms of identifying millstone type, because millstones produced from previously split slabs leave few traces of the final product. Spoiled blanks may certainly be found on waste heaps, but at Tolstadkvernberget, this would have required extensive removal of vegetation. Based on general considerations discussed elsewhere (Grenne et al. 2008) we assume that slab splitting was partly used to produce larger millstones than could easily be made by direct carving. That larger millstones
were indeed produced in significant numbers in this type of quarry is also indicated by 17th century court documents referring to stones with a diameter of 9 and 10 qtr (Brekkjen 1980:79–80, Ivar Teigum, pers. comm.), which we assume to be quarters of the old Norse ell measure called stikke-alen (ca. 55.3 cm) that was the standard length unit in contemporaneous quarries at Selbu (Grenne & Meyer 2009). This would imply that stones of ca. 125 and 140 cm were quite common at Tolstadkvernberget in this period. Observed traces of millstones in these quarries, however, are limited to circular channels from direct carving of hand querns, and water millstones mostly less than 90 cm. Hand querns of about 55–56 cm are particularly abundant and also suggest that the stikke-alen was a standard measure (Grenne & Meyer 2012). Teigum (2011) indicates that the production largely went to the local market and perhaps the upland district of Southeast Norway, but that some stones were obviously sold outside the region. For example, there are records of large millstones commissioned by Kongens Mølle (The King’s Mill) at Nedre Foss in Christiania (present-day Oslo) in 1656 (Ivar Teigum, pers. comm.) and by the same mill – by then acquired by the merchant family Grüner – in 1688 (Teigum 2011:47).

Quarries worked by powder blasting display only a limited number of measurable blanks left on the waste heaps. The few examples found indicate that relatively small water millstones (up to ca. 90 cm) were by far the most abundant (Grenne & Meyer 2012). This is in accordance with a report from County Governor Christian Sommerfelt in 1790 (Teigum 2011:56), which
denotes that the quarry produced “small millstones that are sold to neighbouring settlements”.

Even if LIDAR data and 3D modelling allow a reliable appraisal of total rock volumes quarried at Tolstadkvernberget, the production of millstones can only be roughly estimated due to several uncertainties, including production loss due to breakage during extraction and carving and the relatively heterogeneous nature of the garnet-mica schist with unknown proportions of unusable material. Based on an approach similar to that of Heldal & Bloxam (2007) and Grenne et al. (this volume) in which breakage loss is thought to be around 90 % depending on extraction method, also taking into account the volumes removed in the late, powder blasting period at Storgruva and Vestgruva, Grenne & Meyer (2012) suggested that production in the pre-powder period may have been somewhat in excess of 10,000 millstone pairs, calculated as 55 cm hand quern equivalents. Similarly, the later powder blasting period is estimated at a production on the order of 1000 pairs of water millstones (equivalent to 90 cm stones).

These production figures, albeit conjectural, indicate that Tolstadkvernberget was a significant quarry area for millstone production from a Norwegian perspective. Although production was far lower than at the medieval quarries of Hyllestad (Heldal & Bloxam 2007) and Salten (Grenne et al. this volume), and only a fraction of the volumes produced largely in the Modern Period at the Selbu quarries (Grenne & Meyer 2009), Tolstadkvernberget may still have played a major role in the millstone market of the Southeast Norwegian...
upland, particularly in the period from the heydays of Hyllestad in the High Middle Ages until Selbu took over and completely dominated the Norwegian market in the Modern Period.

Conclusions

Millstone production based on garnet-mica schist at Tolstadkvernberget goes back to at least 1426 and lasted until the late 19th century, a period of about 500 years or more. Over this period of time, landscape evolution was not a simple function of the amount of stone quarried, it was also greatly affected by technological developments and changing quarrying methods from the Middle Ages through to the Modern Period (Fig. 19). Significantly, the quarries give important insights into the development of stone extraction over a period that is poorly represented in other quarries in Norway.

What appear today as the most prominent landscape features are not representative of the history as a whole. Storgruva and Vestgruva, products of the late phase of activity from the mid-18th century, are large and deep quarries with huge waste heaps that stand out from the surroundings; however, these features represent a period of decline at Tolstadkvernberget, with decreasing production as a result of market competition from the large millstone quarries at Selbu. This phase was characterised, essentially, by the quarrying of large blocks by powder blasting, followed by carving of mainly water millstones at work areas outside the actual pit. Drilling and blasting made it easy to work at depth and to remove barren rock between the separate units of exploitable garnet-mica schist. This was a highly efficient way of removing large quantities of rock; however, the degree of exploitation was low since a large proportion of the rock was unsuitable for millstone carving and was discarded.

The heydays of Tolstadkvernberget were further back in history. In those times, work was distributed over a large number of relatively small and shallow quarries. Other quarrying methods, including a focussed quarrying of only the valuable units of garnet-mica schist, produced less waste and a different type of quarry landscape, where both pits and waste heaps are less noticeable. Much of the production came from the carving of circular blanks directly on the quarry face, similar to early medieval techniques at Hyllestad and Salten; apparently this method was used contemporaneously with manual splitting of stone slabs that were further processed at designated work areas on the rim of the actual pit. The techniques and products, yielding both water millstones and relatively large hand querns, are remarkably similar to those widely applied at Salten after the Early Middle Ages, possibly reflecting an unbroken history of millstone quarrying since the early 14th century or before.

While the earliest quarrying could take advantage of many easily available resources in cliffs and giant loose boulders protruding from the surrounding terrain, later production required deeper excavations and more effort was needed to access exploitable garnet-mica schist. This was achieved by removal of moraine material around loose boulders and, in the case of quarries in solid bedrock, fire-setting and rare underground workings. Both 14C data and historical sources indicate that fire-setting was applied from at least the first half of the 16th century until powder blasting gradually took over in the 1700s.

Traditional direct carving was used at Tolstadkvernberget long after slab splitting was employed as the only technique in the millstone quarries at Selbu, and carving continued to be used to some extent even through the late phase of powder blasting. This apparent paradox could be the result of different geological characteristics, less favourable for splitting large slabs at Tolstadkvernberget. It may also relate to the endurance of craft skills inherited through a continuous tradition from medieval quarrying techniques.

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