From Hyllestad to Selbu: Norwegian millstone quarrying through 1300 years

Tor Grenne[1], Tom Heldal[1], Gurli B. Meyer[1] and Elizabeth G. Bloxam[2]

[1] Geological Survey of Norway (NGU), 7491 Trondheim, Norway.
[2] Institute of Archaeology, University College London, 31–34 Gordon Square, London WC1H 0PY, England, UK.
E-mail: tor.grenne@ngu.no

'Industrial-scale' millstone production in Norway dates back to at least AD 700. Recent detailed mapping in the Hyllestad and Selbu areas has identified extensive quarry landscapes, which together demonstrate the development in 'industrial scale' millstone production over a period of 13 centuries. Based on geological characteristics, traces of quarrying techniques and archaeological dating, it is possible to relate different stages within this history to technological development, population change, market demands and other influences from the surrounding society. Production at Hyllestad, which dominated the Norwegian millstone market from the pre-Viking Age, was based on carving of relatively soft but massive garnet-kyanite-muscovite schist directly from the bedrock in shallow quarries, a technique that was essentially similar to Iron Age soapstone extraction. A change to a more centralised and technologically advanced production in larger and deeper quarries occurred in the 12th century, possibly introduced by professional stonemasons connected to the establishment of monasteries and churches. A marked decline in activity at Hyllestad after the High Middle Ages was followed by the rise of millstone production at Selbu in the 16th century, based on wedging of more easily cleavable staurolite-biotite schist. It is likely that this dramatic change in market dominance was influenced by the partial collapse of social and trade structures following the Black Death and recurrent plague outbreaks throughout the late 14th and early 15th centuries, when the millstone trade was practically in ruins due to the small population size and the market was left open for 'newcomers' when population and trade recovered in the 16th century. Equally important was the increasing demand for larger and more durable millstones caused by the gradual change from querns to water mills and from farm mills to village mills and commercial trade mills, a demand that could readily be met by the geological conditions that existed in the Selbu area.

Grenne, T., Heldal, T., Meyer, G.B. and Bloxam, E.G. (2008) From Hyllestad to Selbu: Norwegian millstone quarrying through 1300 years. *In* Slagstad, T. (ed.) *Geology for Society*, Geological Survey of Norway Special Publication, **11**, pp. 47–66.

Introduction

Millstone quarries are distributed throughout Norway and each quarry area produced stones that had specific usage attributes. Through history, the significance of the different qualities—and hence the demand for millstones from the different areas—varied with developments in milling technology as well as regional and temporal changes in the grain types produced. In addition, the overall production of millstone was strongly related to population development, because grain has always been a fundamental part of our diet.

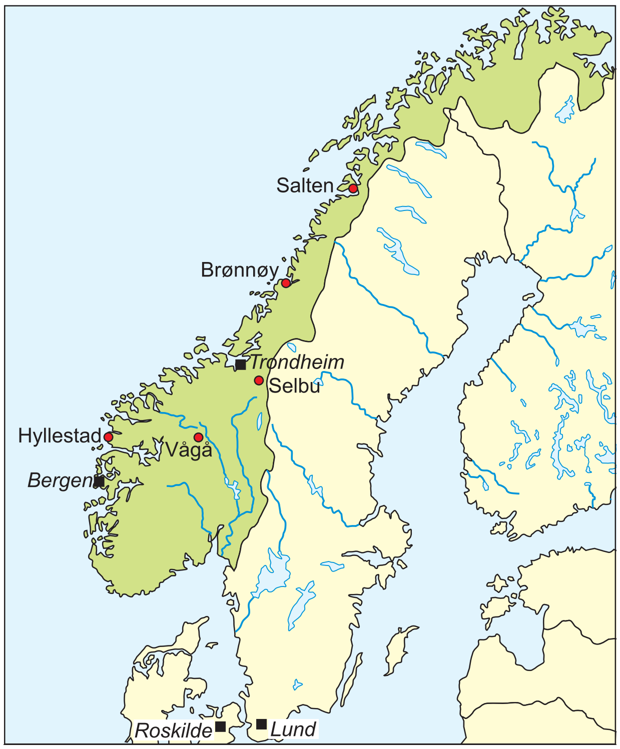

Figure 1. Locations of major millstone-quarry areas in Norway.

Also significant for millstone demand was technological development. In Scandinavia, the rotating hand querns gradually took over from the traditional saddle querns in the Roman and Germanic Iron Age[1], and by the beginning of the Viking Age hand querns were fairly standardised with a stone diameter of 35–60 cm and a thickness of 10–20 cm of the upper stone ('runner') (Carelli and Kresten 1997).

Several authors have addressed the question of when water mills were introduced in Norway (Statens Kornforretning 1934, Griegh 1960, Gulbrandsen 1969, Carelli and Kresten 1997, Baug 2002). Baug (2002) suggested that in Hyllestad the production of stones for water mills was established in the Early Middle Ages, which is also supported by archaeological records from Lejre, near Roskilde in Denmark (Carelli and Kresten 1997). However, according to Baug (2002) it is not unlikely that water millstones were produced in Hyllestad already in the late Viking Age. Note that in English literature the terms 'quern' and 'mill' generally refer to hand-driven and water-driven types, respectively. The Norwegian equivalent of the word quern—kvern—traditionally also included certain water-driven constructions, like those colloquially referred to as 'Norse Mills' ('kall-kvern' in Norwegian). For simplicity, in the following we will use 'mill' and 'millstone' both for hand-turned and for water-driven types. The size of the millstones in all types of early, essentially farm-based, water-driven mills was between 60 and 120 cm (Baug 2002), i.e., in general significantly larger than hand millstones.

Medieval laws and tax systems urged farmers to bring their grist to larger village mills, which led to a demand for larger and more durable millstones. Professional millers are first mentioned in King Magnus Lagabøte's (meaning Law Mender) Municipal Law of 1276 (see Grieg 1960). Commercial trade mills were established after the 18th century and gradually replaced most of the farm and village mills, further increasing the demand for large and durable millstones. More advanced industrialisation towards the end of the 19th century included artificial millstones and roller mills, and by the early 20th century production of natural millstones came to an end (Statens Kornforretning 1934).

Norwegian millstone-quarry landscapes

For more than one and a half millennia, good raw materials for the manufacturing of rotating millstones has been sought after and quarried in Norway, leaving traces in the landscape of one of the longest-lasting extractive industries in the country. Certain mica schists that had a knobbly surface due to the presence of garnet or staurolite porphyroblasts[2] proved to be of particularly good quality and resulted in huge quarry landscapes, each of them active for many centuries. Five such quarry landscapes stand out as particularly important production sites, including the two case studies presented in the present paper—the Hyllestad and the Selbu quarry landscapes (Figure 1).

Production in Hyllestad dates back at least to the 8th century (Germanic Iron Age) and peaked in the Early to High Middle Ages (12th to 14th century) (Baug 2002). The decline in production in Hyllestad was followed by a rise in production at Selbu in the 16th century (Friis 1632), after which time the

[1] Historical time periods according to Scandinavian subdivision; i.e., Pre-Roman Iron Age: 500 BC–AD 0; Roman Iron Age: AD 0–400; Germanic Iron Age: AD 400–800; Viking Age: AD 800–1050; Early Middle Ages: AD 1050–1200; High Middle Ages: AD 1200–1400; Late Middle Ages: AD 1400–1536.

[2] *Porphyroblast* is a geological term for a relatively large crystal that is surrounded by a finer-grained matrix, formed by recrystallisation of the rock during metamorphism.

Selbu millstones totally controlled the Norwegian market for nearly 400 years (Statens Kornforretning 1934). Together, these quarry landscapes provide insight into a continuous, more than 1300-year history of technological progress and the role of early industry in the developing community.

Even though millstone production has been a very important industry over a long period, research on the subject is limited. One reason may be the lack of historical sources connected to the stone-extraction industries in general, in contrast to the post-medieval mining of metal ore deposits. The only exception is Selbu, where there are significant amounts of written records from the 19th and early 20th century quarrying, some of which were collected and published by Rolseth (1947). This unique material from Selbu provides important insight into the later stages of millstone production. Due to the historical records, interest and knowledge of the site have been kept alive in the local community in Selbu. This knowledge was an essential argument for the archaeological excavations of old quarry settlements that were threatened by flooding from a planned power plant reservoir in the 1970s (Alsvik et al. 1981).

In Hyllestad, historical records are almost completely absent. However, interest in the site has gradually grown in the community over the last decades, resulting in several locally based books and brief accounts (e.g., Rønneseth 1977, Thue 2000, Waage 2005, see also reports from Hyllestadseminaret 2004 and 2005 at http://kvernstein.no/). Some knowledge of the latest quarrying was achieved through interviews with elderly people (see http://www.nrk.no/nyheter/distrikt/nrk_sogn_og_fjordane/fylkesleksikon/1682747.html) who still remembered the millstone production. Archaeological excavations carried out by Irene Baug in her M.Sc. work provided the first evidence of Viking Age quarrying (see Baug 2002).

Based on present knowledge, Selbu and Hyllestad were by far the largest of the Norwegian millstone producers, and in both areas their significance as cultural heritage sites has stimulated new research that is still in progress. In contrast, little research has been done on the other quarry landscapes. A limited archaeological rescue excavation was recently carried out in a quarry site at Saltdalen, giving early 11th century radiocarbon dates (Helberg 2007). The site has also been partially mapped by Titland (2003, see also http://www.saltdal.kommune.no/Kvernsteinsbruddene i Saltdal). For other sites shown in Figure 1, work is limited to short accounts, for example in annuals of local history groups (e.g., Brekken 1980, Sognnes 1980, Monssen 1997, Krokvik 1999).

Also, the use and distribution of millstones from different sources is largely unknown, and provenance studies of ancient millstones found in archaeological contexts throughout Norway remain to be done. One exception is a study carried out by Carelli and Kresten (1997) providing evidence for the extensive use of Hyllestad millstones in southwest Sweden and Denmark in the Viking Age and Middle Ages. Another exception is a governmental registration of all mills in Norway in 1919, which showed that at that time Selbu millstones were used in 89% of Norwegian mills (Statens Kornforretning 1934).

A study of millstones from the Iron Age farm at Ullandhaug near Stavanger (Figure 1), dating from AD 350 to 550, was carried out by Dahl (1986). Interestingly, rotating hand millstones found in the settlement seem to have been used contemporaneously with the 'old fashioned' saddle quern, and the site may represent the oldest use of rotating mills in Norway. Apparently, only gneiss and other local rocks were used (Dahl 1986), none of them resembling the rocks from the major millstone-production areas. A brief inspection of artefacts at the Archaeological museum in Stavanger by two of the present authors (TH and GBM) in January 2007, suggests that these millstones were made largely from local boulders. Thus, the millstones at Ullandhaug seem to represent the early precursor to the more standardised millstone production starting a few hundred years later.

Hyllestad

Previous research and historical sources

Millstone quarrying has made a significant impact on the landscape in Hyllestad and must have been an important part of the community's identity over hundreds of years. Nevertheless, this activity became absent in the collective memory of the community in an amazingly short period of time. Ottar Rønneseth (1968) 'rediscovered' the millstone quarries and understood their significance in the 1960s. After shipwrecks had been localised along the west coast of Norway with cargos of millstones from Hyllestad (Figure 2) (Hansen 1991), marine archaeology was carried out along Åfjorden in Hyllestad (Figure 3). This led to the discovery of several harbours where the stones had been loaded onto boats (Hansen 1997).

A provenance study by Carelli and Kresten (1997) demonstrated that Hyllestad millstones were widely distributed in settlements from the late Viking Age and early medieval times in Denmark and south Sweden. Specifically, they were

Figure 2. Hyllestad millstones found in a shipwreck. Whetstones (in the background) were placed in-between the millstone cargo for support during transport.

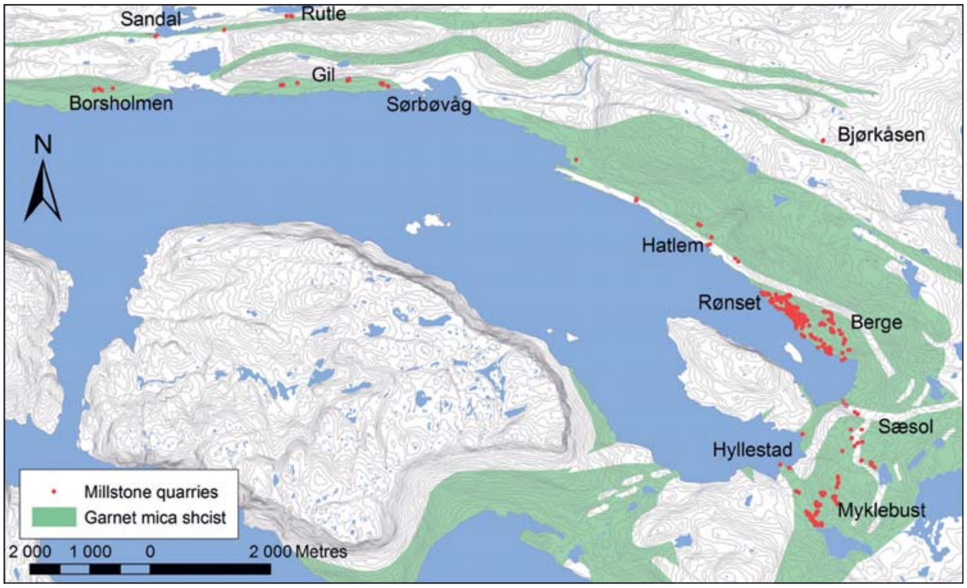

Figure 3. Map of the Hyllestad area showing distribution of quarries and names of the quarry landscapes.

predominant among the early medieval millstones used in the town of Lund in southern Sweden (Danish until 1658). Excavations in Hyllestad suggest that the earliest quarrying dates back to at least AD 700, with a peak between the 12th and 14th century and only minor extractions thereafter (Baug 2002).

At some stage after the Middle Ages, the production techniques changed from carving the millstones directly from the bedrock, to using wedges and, later, black powder for the primary extraction of blocks. Quarries near Rønset (Figure 4), where powder was evidently used, were abandoned in 1750 (Rønneseth 1968) and denote that blasting techniques were introduced already in the first half of the 18th century. Quarrying with powder continued in Hyllestad until 1930, when the last millstone was made.

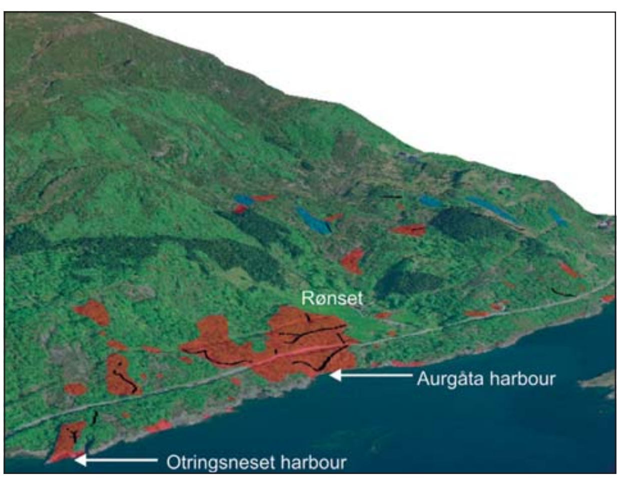

Figure 4. Perspective model of the Rønset quarry area, Hyllestad (Rønset farm is seen in the centre of the image). Red colour: quarries where millstones have been carved directly from bedrock, blue colour: quarries where blasting was applied for primary extraction. Black lines are ancient quarry roads and tracks.

One of the important milestones in Hyllestad millstone production was the introduction of water mills in Norway. Baug (2002) dates the first production of water millstones (60 to 120 cm in diameter) to around AD 1100. Before that, only hand millstones (35 to 60 cm) were produced. However, production of hand millstones continued also after water mills were introduced and probably remained an important product for a long time.

Not only millstones were produced in Hyllestad in the Middle Ages, but also several of the large stone crosses from the 11th century found at various locations along the west coast of Norway (Baug 2002). The schist from Hyllestad was also used for grave slabs and a range of domestic purposes. Traces of such non-millstone production are seen in several of the millstone quarries (Figure 5).

Since 1995, efforts in the local community along with multidisciplinary research (see Heldal and Bloxam 2007 and reports from Hyllestadseminaret 2004 and 2005 at http://kvernstein.no/) have contributed in re-establishing Hyllestad as a 'millstone community' and an outdoor museum ('The Millstone Park'), and several successful educational and promotional activities have put the site on the tourist map.

The quarry landscape

The quarry landscape is named after the municipality of Hyllestad, situated in the western part of Sogn og Fjordane county. Most of the quarries are found on the slopes above the fjord Åfjorden, less than 1 km from the sea (Figure 3) (Heldal and Bloxam 2007). Approximately 300 individual quarries and 70 trial extractions have been recorded in the survey. The highest concentrations of quarries are found in the southern part of the area, at Myklebust, Rønset and Berge. In these areas, numerous quarries occur side by side and even on top of each other. They are connected by roads and tracks to several harbours where the

Figure 5. Carved quarry face, Hyllestad, after extraction of large rectangular slabs, probably grave-slabs.

Figure 6. Example of prospecting site, Hyllestad, with traces after trial extraction of hand millstones.

millstones were loaded onto ships. Outside these core areas, only small and scattered millstone quarries are found. In addition to the numerous quarries, there are many prospecting sites showing evidence of limited test carving (Figure 6).

The *Myklebust area* is the southernmost and perhaps largest production site. All the quarries display evidence of carving of millstones directly from the bedrock. In the lowland around the Millstone Park there are numerous quarries worked only for hand millstones, together with deeper quarries where both hand millstones and water millstones were extracted. Similar quarry landscapes are probably buried under recent buildings and constructions of the Hyllestad community. Radiocarbon dating of charcoal from a quarry in the Millstone Park indicates that production took place from the Viking Age to the Late Middle Ages (Baug 2002). Further uphill on the northern side of the valley there are also numerous deep quarries.

Just to the north of the Myklebust area, a group of small and scattered quarries are situated on top of a hilly plateau near the *Sæsol farm* (Figure 3). Most of these quarries produced only hand millstones. One of them gave a calibrated radiocarbon date of AD 715–890, thus being one of the oldest recorded quarries in Hyllestad (Baug 2002). A few attempts at millstone production with powder blasting in later stages never developed to anything sizeable. In the northern part of the Sæsol area, along the Stigedalen valley, the mica schists and quarries can be followed down towards the fjord where ancient harbour facilities have been found.

The *Berge area*, north of Sæsol, contains some traces of early quarrying activity (assumed Viking Age and Middle Ages, Heldal and Bloxam 2007), particularly along the fjord. Further uphill, there are large quarries from the later period situated in a harder variety of the mica schist. The number of quarries increases towards the north in the *Rønset area* (Figure 4), which is the largest and most significant quarry area along with the Myklebust area. Numerous quarries partly overlap each other and display intensive quarrying during several periods, particularly the Viking Age and Middle Ages (Baug 2002, Heldal and Bloxam 2007). There are also some quarry pits in scree. These pits may represent remains of a very early phase of quarrying, exploiting single blocks of suitable size for the production of hand millstones only.

North of Rønset, there are several small quarry areas scattered over a wide area. Most significant is the *Sørbøvåg* quarries, the majority of which are covered by agricultural land. Several small and more remote quarries are situated at *Gil*, *Borsholmen*, *Sandal* and *Rutle*, all of them probably dating from the Middle Ages (Heldal and Bloxam 2007).

Geology and millstone characteristics

In Hyllestad, millstone quarrying has targeted a specific variety of garnet-kyanite mica schist within the *Hyllestad complex*, a unit of high-pressure metasedimentary rocks (Chauvet et al. 1992) along Åfjorden in Hyllestad. The Hyllestad complex is correlated with other aluminous pelitic units within the Lower or Middle Allochthon of the Norwegian Caledonides (Chauvet and Dallmeyer 1992, Tillung 1999). The main metamorphic assemblage and cleavage[3] of the rocks were formed during the Scandian orogeny at crustal depths of ca. 50 km (Hacker et al. 2003). Subsequently, the complex underwent deformation and retrograde metamorphism at lower pressures and temperatures during late-orogenic extension along the Nordfjord–Sogn Detachment Zone (Hacker et al. 2003).

The Hyllestad millstone schist is composed predominantly of coarse-grained aggregates of muscovite alternating with quartz-rich laminae, garnet porphyroblasts ranging from 2 to 8 mm, and kyanite porphyroblasts up to 2 cm long (Figures 7 and

[3] *Cleavage* is used in this paper as a general term for the rock properties resulting from a foliated or schistose texture with planar or near-planar arrangement of mica (muscovite or biotite).

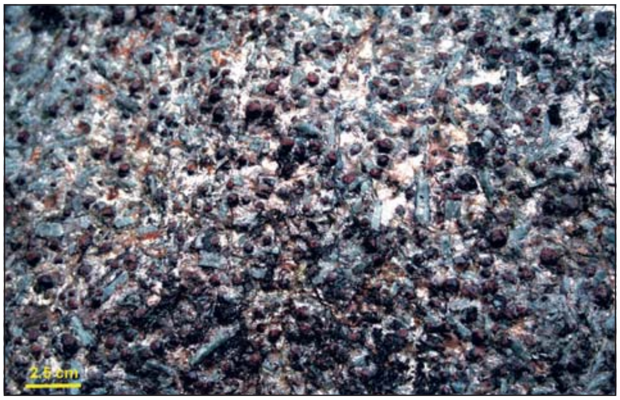

Figure 7. Close-up of weathered surface of garnet-kyanite-muscovite schist (coarse-grained variety) from the Hyllestad millstone quarries.

8). Minor amounts of staurolite and retrograde chloritoid are also common. The presence of kyanite is generally considered a diagnostic feature of the Hyllestad millstones (Carelli and Kresten 1997, Baug 2002). Clearly, the size and distribution of garnet were important measures of quality, and there are many examples of quarrying that ended when it reached garnet-poor zones or zones with garnet that was too large. The zones of optimal quality apparently represent strongly folded layers and display very complex distribution patterns, embedded in heterogeneous mica schist with layers of quartzite, semipelite and ferruginous schist.

Roughly speaking, two subtypes of good-quality mica schist are recognised. In most of the area the schist is highly micaceous and 'soft', containing large flakes of mica in a quartz-poor matrix (Figure 8a). This subtype was the target for quarrying when millstones were carved directly from the bedrock (see below), particularly in the Myklebust area where it is very abundant. In the eastern part of the area, especially between Rønset and Sæsol, the schist is more quartz-rich and contains smaller amounts and finer flakes of mica (Figure 8b). This subtype appears much harder to carve and seems to have been exploited only in later periods, when wedging and blasting became the primary extraction techniques.

It is likely that this selective quarrying was partly a consequence of the harder mica schist being more suitable for blasting, but there may also be quality measures linked to this change of source. The garnet in the mica-rich schist bears signs of strong deformation, such as rounding, cracking and chloritisation (Figures 8a, c). Thus, they are poorly attached to the enveloping, large mica aggregates of the matrix. In contrast, garnet in the quartz-rich schist is less cracked and more euhedral. It is likely that this difference was significant for the grinding properties and durability of the millstones, because the garnet of the 'soft' variety might loosen from the millstone. Yet, the mica-rich schist was easier to carve and was preferred until the use of black powder made it equally easy to quarry the quartz-rich schist.

In addition to the mineralogy, structural features such as folding, shear zones and brittle fractures have been important for the location and productivity of the quarries. For example, a small group of quarries just north of the Myklebust area are small and scattered due to the structural complexity; only small 'pockets' of proper schist have escaped the intense folding and shearing that was detrimental to millstone quality. In general, areas displaying little folding of the cleavage planes and wide spacing of brittle fractures were favourable for obtaining large blocks with uniform and straight cleavage planes.

In some areas, widely spaced brittle fractures define natural limits for extraction areas within individual quarries. Locally, a low inclination of the cleavage plane made it feasible to establish deep, efficient quarries in the hillside, such as in the northern part of the Myklebust area. In the southern part of the Hyllestad area, the primary cleavage is partly overprinted by subhorizontal shear zones (Figure 8c) probably related to late-orogenic extension (Chauvet et al. 1992, Hacker et al. 2003). Locally, this provided an alternative orientation for millstone extraction (Figure 9), but it could also cause high waste ratios due to cracking along either the primary or the secondary cleavage.

Quarrying primarily targeted areas where the combined geological conditions were most favourable for extraction. This can partly explain the large concentration of quarrying activity at Rønset and Myklebust. However, the near absence of exploitation in qualitatively similar areas further north (Heldal and Bloxam 2007) also points at other mechanisms, i.e., land use and ownership, as the driving force for quarrying.

Selbu

Historical records

The earliest reference to millstone quarrying in Selbu is a travelogue from 1591–1592 by the clergyman Peder Claussøn Friis, who claimed that in this area there were *"produced millstones of better quality than anywhere else in the kingdom and that the stones were widely distributed in the country"* (Friis 1632). This implies that the Selbu millstones were already well established on the market and that the production history may be extended back to at least the middle of the 16th century.

The first reference to black powder used in the Selbu quarries is from 1734 (Haarstad 1972), about 60 years after it was introduced in the Røros copper mines some 70 km to the south. The millstone quarries are also mentioned in an account of a journey through the area in 1773 by the historian Gerhard Schøning (1778), who noted that quarrying took place after the farm work season was finished by the end of September until close to Christmas. Court records show that quarrying rights were heritable and often held by different farms (Haarstad 1972). An indication of production rates is known from a statement signed by 286 farmers and peasants that had quarrying rights in the year 1800, when it was agreed that annual production must be limited to an equivalent of three medium-size millstone pairs

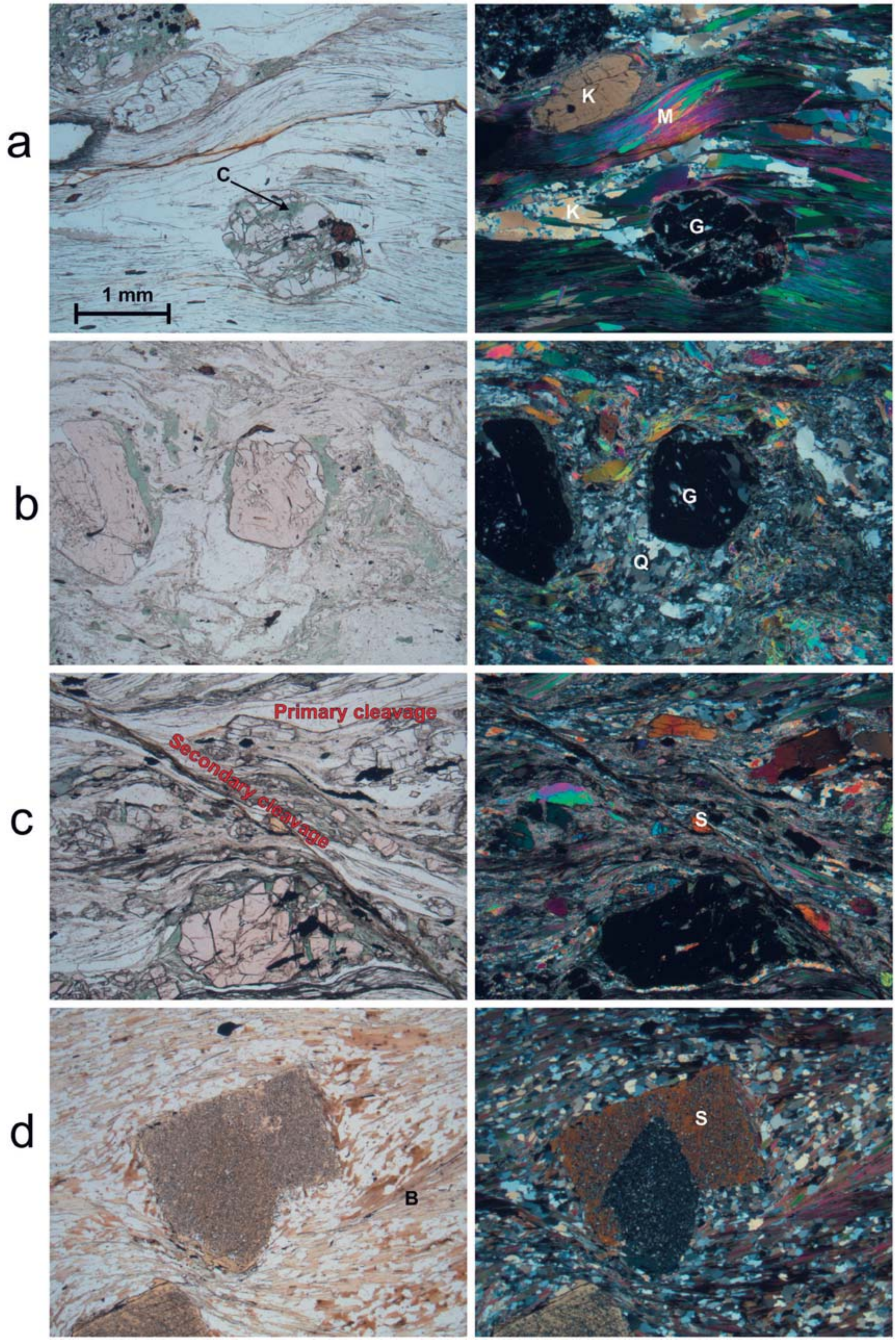

Figure 8. Photomicrographs, plane-polarised light (left) and cross-polarised light (right). (a) Mica-rich, 'soft' type millstone, Hyllestad, showing coarse-grained muscovite aggregates and rounded/cracked garnet porphyroblasts that are partly altered to chlorite. (b) Quartz-rich, harder type of Hyllestad millstone schist containing more euhedral garnet and finer-grained matrix with less mica. (c) Primary and secondary cleavage in Hyllestad millstone schist. (d) Selbu millstone schist displaying euhedral staurolite porphyroblasts set in a fine-grained biotite-quartz matrix. K: kyanite, M: muscovite, G: garnet, C: chlorite, Q: quartz, S: staurolite, B: biotite. Scale bar in (a) applies to all the photomicrographs.

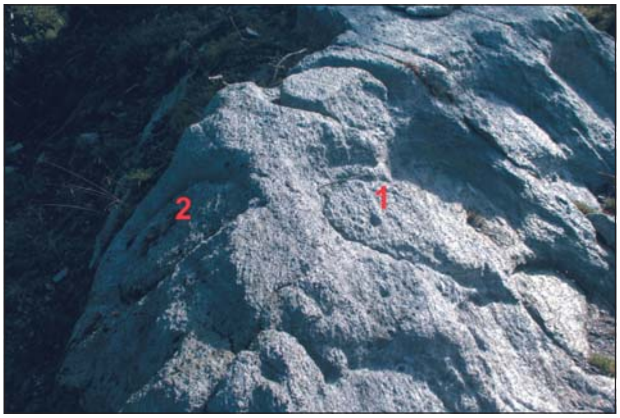

Figure 9. Two directions of splitting of millstones, Hyllestad. 1) Splitting along the primary cleavage. 2) Splitting along the secondary cleavage.

for farmers and one pair for peasants. A comprehensive report on technical and economic aspects of the millstone production was written by the Commissioner of Mines, H.C. Strøm, who investigated the quarries in 1817 (Strøm 1820).

A change from small-scale quarrying to increased industrialisation is seen after the 1840s, just after the onset of the Industrial Revolution in urban parts of Norway. The change was partly incited by the central authorities (Department of the Interior) due to a need for more organised and efficient operations of the important millstone production. The Selbu merchant Frederik Birch took a leading role in this development when he bought up major parts of several quarries and introduced new equipment and techniques. Much of the documentation from this period, including records of stories told by quarrymen, was compiled by Rolseth (1947) some 30 years after the last quarry closed down. According to these records, the quarrying period generally stretched from autumn through to March, and the millstones were horse-sledged to the village, usually in April (Rolseth 1947).

Records of production rates exist for certain periods and were regular after 1867, when an official millstone register was established. A report from the County Governor for 1846–1850 indicates that about 250 quarrymen provided a total of 600 millstone pairs annually (Adresseavisen, 15 March 1856), but the true yield was considered to be higher than that declared by the quarry proprietors. The last decades of the century saw a gradual decline in production, ranging approximately from 225 millstone pairs (1869) to 80 (1883), due to competition from imported German millstones and increasing use of artificial millstones and roller mills. Quarrying came to a complete end in 1914.

According to the geologist and geographer Amund Helland, millstone quarrying in Selbu was highly peculiar compared to mining and stone extraction elsewhere in Norway (Helland 1901). This was not only by virtue of the remote location and extremely difficult working conditions, but also the quarrying terminology and law practice that had developed over the centuries that was distinctly different from official mining legislation.

The quarry landscape

The Selbu area has about 1000 large and small quarries situated along a relatively narrow, ca. 30 km long 'millstone zone' (Figure 10). The majority of quarries were located in a remote mountainous terrain above the tree line, far from harbours and more than 15 km from the nearest road or permanent settlement. Quarries, traces of working techniques and remains of cabins and other infrastructure are well preserved and can easily be studied in this barren landscape. Combined with

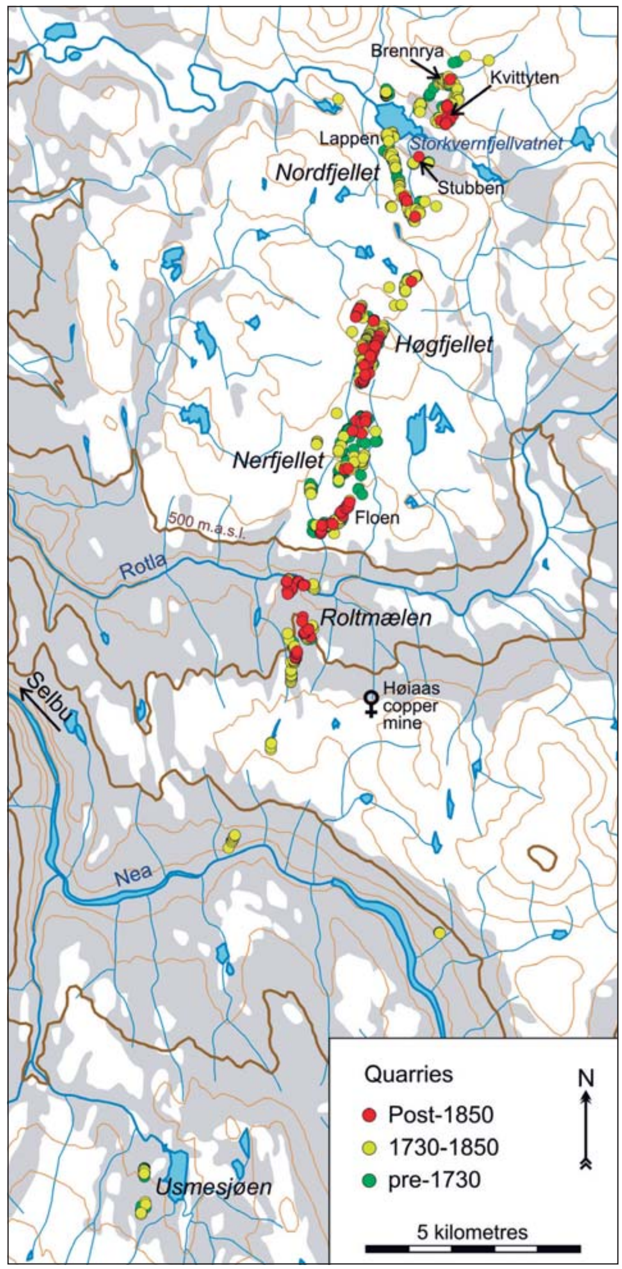

Figure 10. Selbu map showing the distribution of quarries from different periods and names of the quarry landscapes. Contour interval 100 m.

historical sources on major new developments in the quarrying activity, such as the initial use of powder, the shift from only autumn-season to full winter-season work, and documented technological achievements during the later 'industrialised' period, our recent field studies have served to distinguish different periods in the quarrying history. The millstone zone can be subdivided into five main quarry landscapes, from north to south: the Nordfjellet, Høgfjellet, Nerfjellet, Roltmælen, and Usmesjøen areas (Figure 10); the first three are by far the most important.

The most remote landscape, *Nordfjellet*, comprises several quarry areas around the lake Storkvernfjellvatnet, many of which show evidence of activity through all periods of quarrying history. *Kvittyten* and *Stubben* are young, large quarries surrounded by clusters of small, old quarries. Kvittyten is the largest single quarry of the Selbu area, measuring ca. 30 x 30 m with a depth of more than 15 m. Both quarries have remains of large cabins typical of the late period, built for 10–15 quarrymen and located close to the quarry in places where the snow would drift away. By contrast, the areas of *Brennrya* and *Lappen* (Figure 10) are dominated by older, small quarries where associated cabins were located mostly close to running water in places sheltered from the wind. Altogether, ca. 100 cabin ruins of this type have been found around the lake Storkvernfjellvatnet; each cabin was apparently meant for only two or three men and commonly built side by side (Alsvik et al. 1981). Trial excavations of six ruins by Alsvik et al. (1981) indicated that they were used after AD 1700.

Høgfjellet comprises several quarry areas that are internally fairly homogeneous with respect to morphology and quarrying history, while local overlapping relationships provide evidence of relative chronologies. An eastern zone displays almost only young (post-1850) and large workings that merge to form a more than 400 m long and 10 m wide trench-like quarry (Figure 11) with associated remains of large cabins. A few tens of metres to the west is an array of smaller, intermediate-age quarries with related intermediate-size house ruins, and 200 m farther west another series of intermediate-age to relatively young quarries. To the southwest is an area of numerous small, old quarries together with remains of small cabins and primitive shelters (Figure 12). An intermediate-age quarry area is located to the northwest, almost on the top of the mountain Høgfjellet in extremely barren and exposed terrain.

The *Nerfjellet* landscape shows traces of old activity variably preserved among scattered quarries of later age. Much of the area is relatively flat bog-land and the old quarries are typically filled with water (Figure 13). The majority of quarries are found in three separate zones that are oriented SW–NE in an *en echelon* manner. The southern area (*Floen*) is largest in terms of production, including several trench-like quarries of relatively late age that are 40–110 m long and 5–15 m wide.

Roltmælen is a group of relatively small quarry areas stretching southwards from the river Rotla. Most of the workings are intermediate in age, but there are also a number of relatively small, young quarries. The *Usmesjøen* landscape south of the Nea valley is comparable to Roltmælen, except that little or no evidence exists for late activity. According to B. Flakne (in Rolseth 1947), the quarrying at Usmesjøen took place mainly in the 18th century.

Figure 11. Northeastern part of the Høgfjellet quarry landscape, Selbu, viewed towards the north. The most recent (post-1850) activity produced a deep, trench-like, continuous array of quarries (right), with waste and working areas irregularly spread on the right side. An earlier quarrying phase in the same zone is represented by large, flat-topped working areas and waste piles on the opposite (left) side of the trench. Farther left is an array of even older and smaller quarries with associated small, flat-topped working areas on their left side. A restored cabin from the most recent quarrying activity is seen in the background.

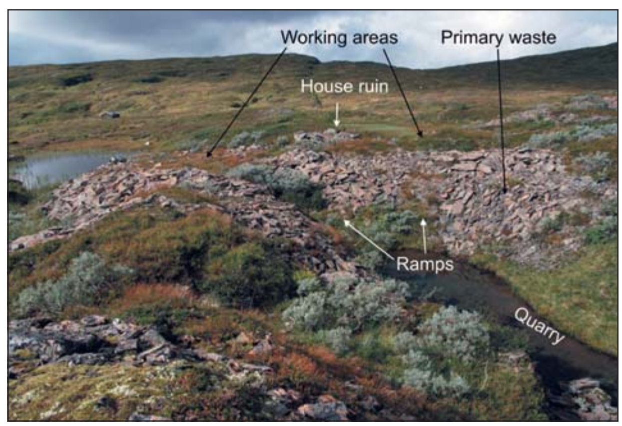

Figure 12. Area with small, old quarries in the southwestern part of the Høgfjellet quarry landscape, Selbu, viewed towards the west. The shallow, water-filled quarry in the foreground is partly filled with primary waste rock. Gently inclined ramps lead from the quarry to flat-topped working areas. A small house ruin is situated on an old part of the working area.

Geology and millstone characteristics

The Selbu millstone quarries are located in the eastern part of the Gula Complex, a medium- to high-grade metamorphic unit within the Trondheim Nappe Complex of the Norwegian Caledonides (Wolff 1989, Hacker and Gans 2005). This part

Figure 13. Water-filled old quarries typical of the Nerfjellet quarry landscape, Selbu, surrounded along their edges by waste heaps that are completely overgrown.

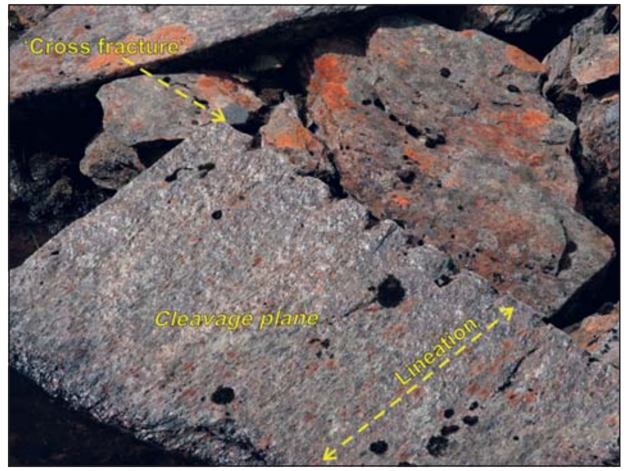

Figure 14. Close-up of slab from a quarry in the northwestern part of Høgfjellet, Selbu, showing a cleavage plane with lineation marked by a characteristically undulating surface. The slab was loosened along the primary cleavage using chisels and pick-axe (note tool marks) on a free 'cross-fracture' plane marked on the photo. The left side of the slab was broken along the lineation as discussed in the text.

of the Gula Complex is characterised by metasedimentary rocks, including calcareous metasandstone, calc-silicate schist, thin marble layers, and semipelitic biotite schist with varying proportions of garnet and staurolite (Olesen et al. 1973).

The 'millstone zone' is characterised by relatively homogeneous staurolite-biotite schist with a thickness of several metres, in some cases up to 20 m. Local heterogeneities include irregular bodies of milky quartz and boudins of variably skarnified marble layers. Staurolite typically forms euhedral porphyroblasts that are mostly 2–5 mm across, in a fine-grained (< 1 mm) matrix of biotite and quartz (Figure 8d). The staurolite is commonly twinned with crosses at 60°, and is strongly poikiloblastic with very fine-grained inclusions of quartz. Garnet is generally a subordinate or minor phase, forming < 1 mm euhedral porphyroblasts of clear, brownish-red almandine; garnet-biotite schist without staurolite has been observed in only two small quarries. Kyanite is a common, but minor, constituent, and small amounts of sillimanite and andalusite are found in places.

The rocks are affected by polyphase deformation, with two phases of early isoclinal folding superimposed by later open folding, which in some areas resulted in a complex pattern of several subparallel millstone zones. They typically display a primary cleavage striking approximately N–S with steep westerly dips, and a secondary cleavage striking SSE–NNW with moderate westerly dips. The two cleavage planes are defined by characteristically sigmoid-shaped biotite aggregates that probably represent an S–C tectonic fabric. The intersection of the cleavage planes defines a lineation that plunges SSW and is recognised on the surface of split millstone slabs as a 5–10 mm-scale undulation of the matrix biotite (Figure 14).

The tectonic fabric is variably developed, resulting in different cleavage and lineation characteristics that were significant for quarrying. Most of the quarries display a well-developed primary cleavage that facilitated easy wedging and production of millstones with a cleavage-parallel grinding surface. Also, thin but extensive fractures across the cleavage were important for quarrying (Figure 15). These 'cross-fractures' are oriented E–W with moderate to steep northerly dips and are spaced at intervals of less than one metre to tens of metres.

On weathered and worn rock surfaces the staurolite and garnet stick out from the softer and less resistant micaceous matrix, leading to a characteristic knobbly surface (Figure 16). The quarrymen distinguished between millstone varieties with 'ståltyt' ('steel knobbles') and 'bruntyt' ('brown knobbles'), which were the old terms for staurolite and garnet, respectively. In places, staurolite is variably replaced by a fine-grained aggregate of muscovite, especially along rims of the porphyroblasts, and this retrograde metamorphism may be accompanied by partial chloritisation of the matrix biotite. The whitish mica aggregates were referred to as 'kvit-tyt' ('white knobbles') and were considered to have a detrimental effect on the millstone quality. Also the size and distribution of staurolite and garnet were important for quality, and different varieties were demanded by different markets to suit the various requirements for grinding properties (Rolseth 1947). According to the Commissioner of Mines, H.C. Strøm (1820), the hard porphyroblasts in the softer matrix allowed a simple 'sharpening' of the millstone using only sand for roughing of worn grinding surfaces.

Also the cleavage characteristics were significant for grinding properties. Rolseth (1947) claims that millstones with the grinding surface oblique to the cleavage plane were highly valued, supposedly due to their better grinding or 'self-sharpening' properties. Such millstones (called 'tvihaus' in the old quarrying terminology) were produced if the secondary cleavage was well developed; however, extensive production was restricted by the high risk of failure along the secondary cleavage during wedging.

Quarrying techniques

In both Selbu and Hyllestad, the millstones were formed by carving and hewing using picks or hammer and chisel, and the same basic principle was used throughout the history of millstone extraction. The main difference is seen in the primary production of blocks from the bedrock and in the size and shape of the final millstones. In the following, we distinguish between four extraction techniques: loose-block quarrying, carving of millstones directly from the bedrock, wedging of slabs from the bedrock, and blasting combined with wedging.

Loose-block quarrying

A few quarries in Hyllestad show evidence of quarrying based on the collection of suitable loose blocks for making hand millstones. The quarries appear as circular depressions in scree deposits, enveloped by piles of unusable talus blocks, broken millstones and waste from carving. This type of ad hoc exploitation is an anomaly compared to the other quarries, suggesting quarrying for local domestic use rather than manufacturing of standardised millstones for trade. Although it cannot be ruled out that such exploitation may have occurred during different stages of the production history in the area, there is a possibility that these quarries are the remains of the earliest millstone quarrying activity in Hyllestad.

In the Selbu area, this type of exploitation is very limited, probably due to the near absence of talus containing appropriate rocks. Carving of millstones from small erratic blocks is observed locally along the stream Rensbekken, near Brennrya in the most remote quarry landscape (Nordfjellet, Figure 10), but the age is unknown.

Direct carving

Direct carving from bedrock is used in the majority of the Hyllestad quarries. After making a circular groove on the primary cleavage surface (or more rarely on the secondary cleavage) outlining the shape of the millstone, a channel was carved by a pick or a pointed chisel (Figure 17). The millstone was loosened along its base by striking a pointed chisel repeatedly along its perimeter until a crack was created parallel to the cleavage plane. Smoothing of surfaces and carving of the centre hole ('eye') in the millstone was carried out in the quarry, while final fitting of the millstone pair was probably carried out at the site where it was used (Hansen 1991, Baug 2002). This view is supported by cargos of unfinished millstones found in shipwrecks and in medieval contexts in the city of Bergen.

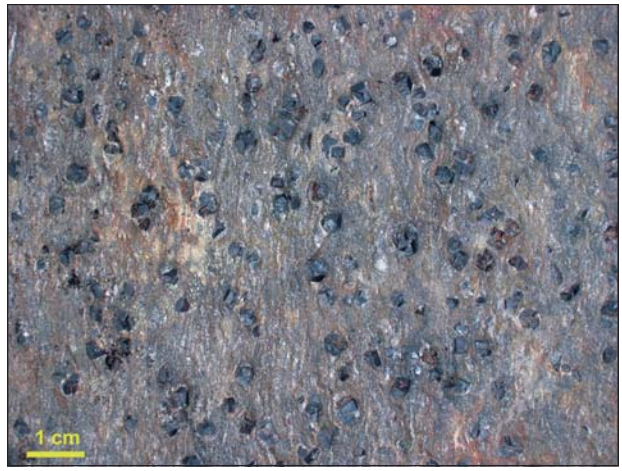

Figure 16. Close-up of weathered surface of typical staurolite-biotite schist from the Selbu millstone quarries.

Even though the basic principle of this extraction technique seems to remain the same from the earliest known quarries in Hyllestad throughout the Middle Ages, there are some important differences between the quarries that have chronological implications (Figure 18). In many of the quarries, extraction took place one layer at a time, leaving laterally consistent quarry

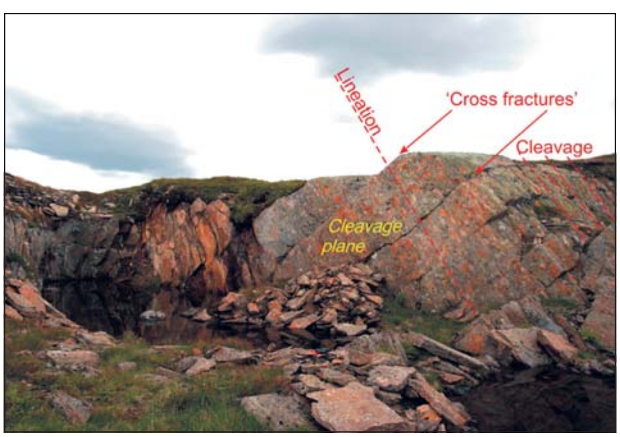

Figure 15. Intermediate-age quarry in the Høgfjellet area, viewed towards the north-east. See text for the significance of cleavage planes, lineation and cross fractures for quarrying.

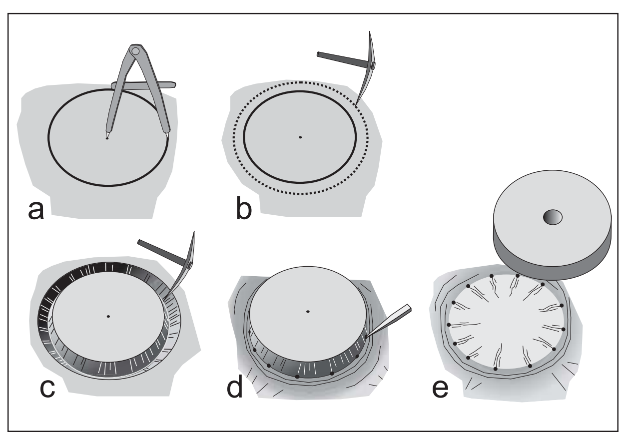

Figure 17. Schematic illustration of millstone carving directly from the bedrock. (a) Measuring and making circular groove; (b–c) carving of channel around the planned millstone; (d) splitting the millstone from the bedrock with a pointed chisel; (e) loosening of millstone with carved centre hole.

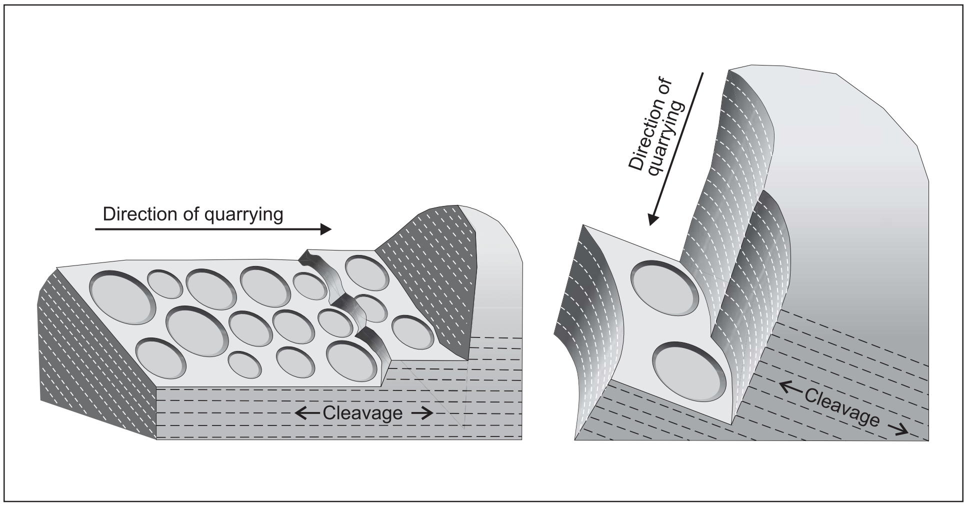

Figure 18. Schematic illustration of the two subtypes of quarries worked by carving directly from the bedrock in Hyllestad. Left: quarrying layer by layer along the cleavage plane. Right: 'coin pile' quarry involving deep extraction.

Figure 19. Shallow quarry established in layers along the cleavage plane, Sæsol area, Hyllestad.

Figure 20. Typical marks after extraction of hand millstones by carving directly from the bedrock, Myklebust area, Hyllestad.

floors along the cleavage plane with the circular marks from millstone extraction occurring side by side (Figure 19). Some of the oldest dated quarries display such morphology, such as one at Sæsol from the pre-Viking to Viking Period (Baug 2002). This first subtype of direct-carving quarries, which produced predominantly hand millstones (Figure 20), is widely distributed throughout the Hyllestad area.

A second subtype of carved quarries is characterised by deeper extraction in taller steps. The millstones were quarried in piles, each one under another ('coin piles' as described by Baug 2002), leaving tall quarry faces perpendicular to the cleavage (Figure 21). The change in extraction method towards deeper (and more efficient?) quarries seems to be associated with the period after water millstones were introduced in Norway, which most likely happened at about AD 1100 (Baug 2002).

The second subtype of carved quarries is confined to only two quarry areas, namely Rønset and Myklebust (Figure 3). Thus, the development in quarrying in Hyllestad seems to have moved from widely distributed quarries of the first subtype during the Viking Age and Early Middle Ages, to more concentrated extraction in deeper and more efficient quarries at some stage in the 12th century. Some quarries display an early phase of layer-wise quarrying of hand millstones (first subtype), and a later phase with deeper quarrying of water millstones and hand millstones. At Otringsneset (Figure 3), such multi-period quarrying is confirmed by radiocarbon dating (Baug 2002).

Pre-powder wedging

In contrast to Hyllestad, practically all primary extraction in Selbu was done by wedging or chiselling along the cleavage plane. The most primitive and least labour-intensive technique depended heavily on the presence of a well-developed cleavage, combined with one or more free faces and fractures or other weak structures that facilitated easy loosening of slabs. Examples of this are seen on the west side of small hillocks or narrow, E–W-oriented 'whaleback' ridges, where slabs of appropriate

Figure 21. Deep extraction of millstones on top of each other, Hyllestad. Unfinished water millstone is seen at the bottom.

thickness (10–20 cm) were loosened along the west-dipping cleavage plane (Figure 22).

More extensively worked pre-powder quarries can be up to 20 m wide and more than 30 m long, but the majority are significantly smaller. Their depth rarely exceeds 2 m. The exact shape and size is often difficult to estimate, because in many cases the quarries are highly overgrown and filled with water and are not easily discernable from the undisturbed landscape. Moreover, much of the waste was disposed of in previously worked parts of many quarries (Figure 12), leaving quarry landscapes characterised by innumerable small pits and waste mounds that together may comprise one coherent quarry. There are no existing records of extraction methods in these old quarries, however, on the basis of quarry morphology and a limited number of exposed quarry walls the following quarrying pattern emerges:

Slabs were loosened along the steeply west-dipping cleavage by splitting with iron or possibly wooden wedges. Some of the pre-powder quarries reveal 10 x 6 cm wide and up to 19 cm deep wedge holes at 50 cm intervals (Figure 23). The size of the wedge holes and wide depressions hewn around each hole may indicate the use of wooden wedges. This would be consistent with Rolseth's (1947) reference to findings of wedges made of juniper in an old water-filled quarry when it was reopened in 1818. In other quarries, narrow channels, a few centimetres deep and wide, were hewn to weaken the rock along appropriate cleavage planes, usually combined with hewing of small holes at close intervals for the subsequent use of chisels or iron wedges.

The presence of appropriately spaced north-dipping 'cross fractures' (cf., Figure 15) was apparently crucial, providing a practically free surface on the lower south side of each slab. Loosening of the lower north side of the slabs was controlled by the minimal mechanical strength in a plane across the slab and parallel to the south-plunging lineation fabric (Figure 24), commonly referred to as 'grain' in dimension-stone quarrying terminology. The structurally controlled working of slabs in most cases facilitated quarrying from west to east, followed by a stepwise extension and deepening of the quarry southwards along the millstone zone. A common reflection of this technique is a triangular or trapezoidal quarry morphology.

Figure 22. Primitive extraction of millstone slabs from the Brennrya area in the Nordfjellet quarry landscape, Selbu. Three slabs are variably loosened from a small cliff by cutting grooves along the primary cleavage.

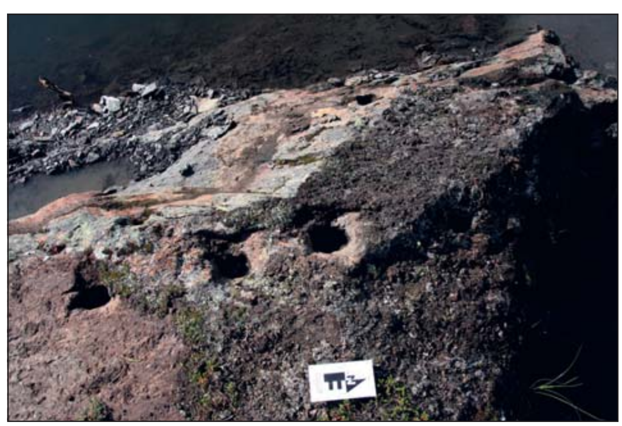

Figure 23. Large and deep wedge holes with shallow depressions around each hole, possibly for the use of wooden wedges. Pre-powder quarry in the Nerfjellet quarry landscape, Selbu.

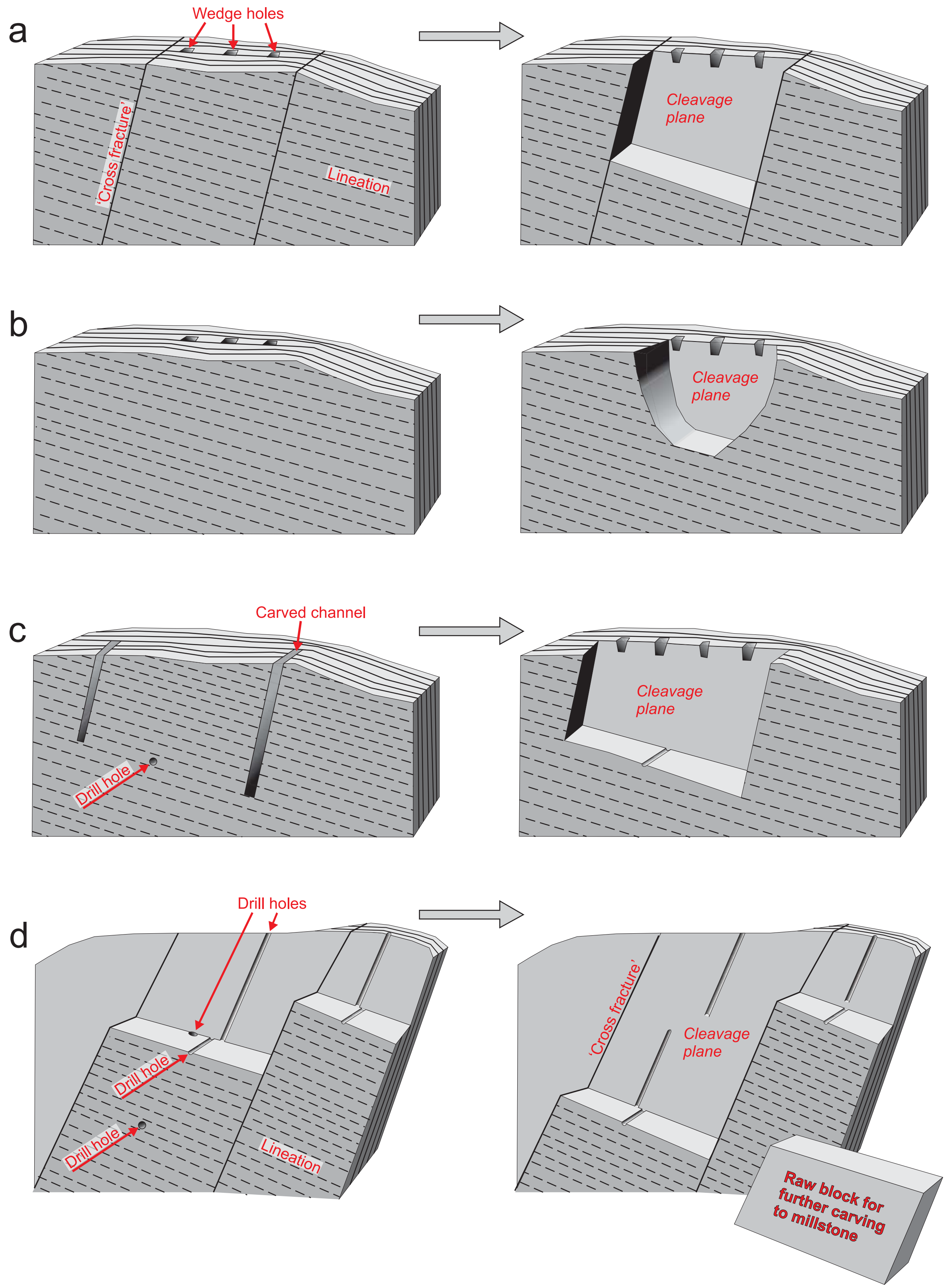

Figure 24. Schematic illustration of quarrying in the Selbu area. (a) Pre-powder wedging of slabs along the cleavage, using 'cross fracture' for loosening the millstone slabs. (b) Pre-powder wedging of slabs along the cleavage in rare cases where cross fractures are absent. (c) Wedging of slabs along the cleavage combined with drilling/blasting across the cleavage; carving of 10–20 cm deep V-shaped channels on the cleavage plane in the absence of cross fractures. (d) Drilling/blasting both across and along the cleavage plane with extraction of thick blocks that were subsequently split into slabs.

The primary waste from slab extraction was thrown out to form a mound along the edge of the pit, or was left behind in previously worked parts of the quarry (Figure 12). Suitable slabs were mostly removed from the quarry along a gently inclined ramp up to a wide, semicircular, flat-topped working area (Figure 12) where the actual millstone hewing took place.

In Hyllestad, we have observed only one quarry in which primary blocks have been extracted from the bedrock by the use of wedging alone. Here, the cleavage is slightly inclined and favourable for wedging along the cleavage planes at small steps in the surface. Small grooves in the split surface suggest that wedging was done by flat, thin chisels.

Blasting

In Selbu, the adoption of black powder for quarrying, apparently from the early 18th century onwards, led to a progressive development rather than a sudden changeover in techniques. This is reflected in a gradual change in quarry morphology and tool marks, from relatively small quarries similar to those of the pre-powder period with evidence of only limited blasting, to large quarries (Figure 25) with very abundant drill holes from the latest period of millstone production. Parallel with this change to larger and deeper quarries was a gradual adoption of more advanced technical equipment for transportation of rock slabs and for emptying the seasonally water-filled quarries (Rolseth 1947).

Throughout this period, quarrying was based on easy splitting of slabs or thicker blocks along cleavage planes, coupled with loosening along the steeply north-dipping ‘cross fractures’ like in the pre-powder period (Figure 24). In a few quarries, especially in the Rotla–Flora area (Figure 10), an absence of appropriately spaced cross fractures was compensated by carving 10–20 cm-deep V-shaped channels along the cleavage plane. Initially, powder was only used to break the base of the slabs across the primary cleavage (Figure 24), while wedging was still used for splitting along the cleavage plane. In later times, longer holes were drilled both along and across the cleavage plane (Figure 24) to produce blocks that were subsequently split into slabs with a thickness suitable for millstone hewing. Splitting of blocks was based on chiselling or wedging with iron tools (Figure 26), essentially similar to pre-powder techniques, except in the relatively young ‘industrialised’ quarries where arrays of short drill holes were used for wedging.

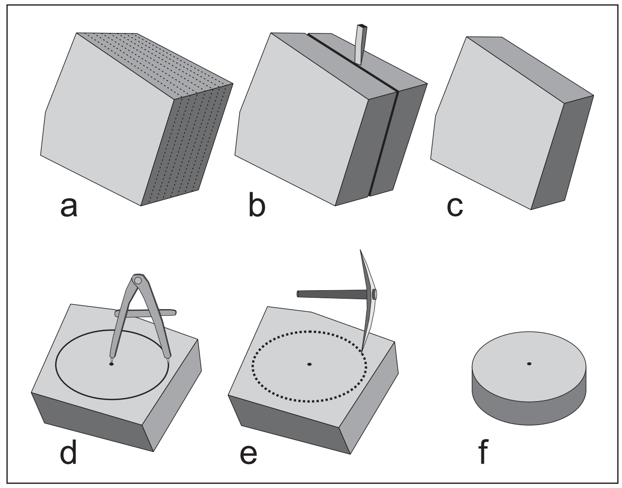

Figure 26. Schematic illustration of block splitting and carving of millstone in the Selbu quarries. (a–c) Splitting of a thick block into several slabs with a thickness appropriate for millstone hewing. (d–f) Marking and hewing of millstone from slab. Note that stages (a–c) are relevant only for the extraction of thick blocks in the latest quarries. See text for explanation.

Figure 25. Westerly view of the large Raudhammeren quarry, from the latest period of quarrying in Selbu. Note the cross fractures that were appropriately spaced for production of large blocks. An open adit enters the quarry from near the lake. On top of the irregular waste heaps and working areas on the quarry margin, one can see three remains of timber capstans used to lift waste and blocks. An area with much older, pre-powder quarries is seen in the background to the right of the lake.

Hewing was also similar to the old technique, except for a general increase in millstone diameter from mostly ca. 50–100 cm in pre-powder quarries to ca. 80–140 cm in young quarries and a parallel increase in thickness of the lower stone from 10–12 cm to 12–20 cm and occasionally up to 33 cm (these ranges are based on remnants of flawed millstones left behind in the quarry areas and may not be truly representative of the production). If necessary, the split cleavage plane was trimmed by carving of parallel grooves, probably by a chisel or a pickaxe, before the intervening ridges were chopped off, as described by Strøm (1820). A metal-pointed compass was used to mark the millstone perimeter at an appropriate diameter (Figure 26), and the vertical sides of the stone were carved through the slab with a pickaxe or a chisel (Figure 27).

The topside of the runner (upper) stone was typically trimmed to a bell-shaped, double-curved, form (Figure 28) that seems to be characteristic of the Selbu millstones. The centre hole of the upper stone was occasionally carved at the quarry site, but in most cases this was part of the final preparation that was done after the stones had been carried to the village of Selbu (Rolseth 1947).

As long as quarrying was limited to the autumn season, working areas had a flat-topped semicircular shape like in the pre-powder quarries, although they grew significantly larger because

Figure 27. Marks after a compass used to outline a planned millstone in Selbu. Carving of the millstone side was finished almost through the slab before it continued along the rest of the compass markings.

Figure 28. Characteristically bell-shaped upper millstone ('runner') from the blasting period in Selbu. Behind the millstone there are several slabs that were placed edgeways on the working area, ready for millstone hewing.

Figure 29. Entrance of a Selbu quarry worked through the winter, showing primary waste that was sledged on the snow and disposed along ridges extending out from the quarry. Nordfjellet quarry landscape.

of all the primary waste that had to be removed from the deep pits. Only in the relatively late quarries, which were worked also during the winter, did the working area and waste heaps change significantly. In some of these quarries, the coarse primary waste created by blasting was sledged on the snow and was disposed of along ridges extending out from the quarry (Figure 29, see also Figure 11). Elsewhere, man-driven timber capstans were used to lift the coarse waste and the blocks for production, leaving disorderly-shaped waste heaps and intervening working areas along the quarry margins. The deepest and most industrialised quarries from this period were established in sloping terrain where the construction of open adits allowed efficient water drainage as well as transport of waste and blocks in wagons.

In Hyllestad, only 18 of the known quarries were worked by powder blasting. The majority are located in the Berge–Rønset area, while a few small quarries are found at Sæsol, Hatlem and Bjørkåsen. Black powder was detonated in short drill holes, and well-fitted blocks were worked to millstones. This type of quarrying probably never achieved the efficiency seen in Selbu due to more folding of the cleavage planes, poorer splitting properties and a less favourable relationship between cleavage and topography.

Hyllestad vs. Selbu—the significance of geology

The suitability of rocks to be used for grain milling depends on a range of factors. Hardness is required for durability and to avoid excessive rock powder in the flour. According to the Norwegian Commissioner of Mines, H.C. Strøm (1820), millstone qualities were also strongly dependent on their ability to maintain good grinding properties without frequent roughening of the grinding surfaces. On this basis, Strøm divided millstones into three quality categories:

(1) Millstones that required no surface dressing. This type included the vesicular basalts from Mayen in Germany. Millstone types with apparently similar properties were the porous, but tough siliceous gritstones from Derbyshire in England and the world-famous siliceous limestone from La Ferté-sous-Jouarre in France.

(2) Millstones where intermittent grinding with sand was sufficient. Strøm (1820) claimed that the Selbu millstones belonged to this group; it is also likely that Hyllestad millstones would be included, in view of their similar mixture of hard porphyroblasts in a softer micaceous matrix.

(3) Millstones that required periodical hewing of furrows to maintain the cutting surface. In this category, Strøm (1820) included various granites and sandstones.

In Norway, focus was put on porphyroblastic mica schist already in the early days of standardised production of millstones. Obviously, the occurrence of evenly distributed porphyroblasts of hard minerals in a softer matrix must have been a well-known measure of quality. Nevertheless, there were differences between the Norwegian millstone mica schists that may have been significant for their grinding and maintenance properties.

It is noteworthy that the garnet porphyroblasts in Hyllestad, particularly in the micaceous and 'soft' schist variety, are commonly cracked, altered and rounded, and enveloped by mica aggregates so that they would be expected to easily fall out. The Selbu schist is strikingly different. Here, staurolite porphyroblasts are euhedral and commonly twinned, the matrix is finer grained and the mica is more evenly distributed. Furthermore, the porphyroblasts are more firmly attached to the matrix due to abundant intergrowths and less post-porphyroblast deformation. Consequently, the Selbu millstones may have been more durable and had better grinding properties than the soft variety of the Hyllestad schist.

While the differences in mineralogy and texture may have contributed to Selbu's total dominance in the market during the latest periods of Norwegian millstone production, production feasibility must also have been significant. Clearly, Hyllestad had a great advantage in terms of accessibility and transport by virtue of a mild climate and proximity to harbours and permanent settlements, in contrast to the very remote Selbu area with its tough climate during most of the year. Other millstone-quarry sites in Norway, such as Salten, Brønnøy and Vågå, also held this logistical advantage (Figure 1), and may alone explain why there was apparently no production in Selbu in the early days of Norwegian millstone quarrying. In spite of this, Selbu took over and dominated the market by the end of the 16th century or somewhat earlier, even if there is nothing to suggest that the Selbu quarry areas had become comparatively more favourable from a logistical point of view.

The Selbu millstone lithology must have been known already in the Middle Ages, because the mountainous regions of central Norway had long been extensively used and explored by hunters, shepherds and travellers. Moreover, extensive exploitation of usable rocks, such as soapstone for the production of pots, already took place in the Pre-Roman Iron Age and the Viking Age in equally remote areas across the region (e.g., Skjølsvold 1969). Thus, it is unlikely that the shift in market dominance resulted from a late discovery of the millstone resources in Selbu.

Nor is it likely that the shift in market dominance was provoked by different suitability for blasting. Certainly, the combination of cleavage, lineation and 'cross fractures' in Selbu was ideal for extracting rectangular blocks with minimum effort, in contrast to Hyllestad where geological structures were less favourable for blasting and gave much more unpredictable results with a higher proportion of waste. However, while this may have strengthened Selbu's dominance in the period characterised by blasting, it does not explain why Selbu took over already in the 16th century, well before powder was introduced in millstone quarrying.

A possible clue to the enigma may be found in different geological conditions of significance for quarrying. In the early days of millstone quarrying, the main prerequisite from a quarrying point of view was that the rocks were easy to carve. In Hyllestad, the type of mica schist targeted in the carving periods is relatively soft due to a high content of mica and was thus feasible for carving. While the Selbu rocks may have been equally easy to carve and apparently gave more durable millstones, their main advantage over Hyllestad was a much better cleavability. Combined with the abundant 'cross fractures' that were in many areas appropriately spaced for the preferred millstone dimensions, this obviously was in favour of Selbu when the markets demanded larger millstones in response to the shift from hand mills to gradually larger water mills. With this in mind, it is interesting to note that when the production techniques in Hyllestad shifted towards blasting, a different quality of schist was targeted, namely a more quartz-rich type with euhedral garnet and finer-grained mica. This development may have been forced by better blasting properties in the harder, quartz-rich variety, but it may also represent an attempt at adapting to new market demands for larger and mechanically stronger millstones like those produced in Selbu.

Millstone-quarrying development and society

The Hyllestad schist seems to have been in the game almost as long as organised millstone production has taken place in Norway. Around AD 700, carving of millstones directly from bedrock took place even in more remote parts of the Hyllestad quarry landscape (Baug 2002). This is only 200–300 years after the first significant evidence of rotating hand mills used in Norway (i.e., Ullandhaug Iron Age farm), where non-standardised millstones were apparently produced from suitable local stones. Thus, it is likely that the early, standardised production in Hyllestad represents some of the earliest organised millstone quarrying.

The early quarrying technique applied in Hyllestad is represented mostly in small but numerous quarries that are widely distributed across the area. This might indicate a decentralised organisation of production. The carving technique was basically similar to that used for the contemporaneous extensive extraction of soapstone for various types of pots and cooking vessels, the latter having roots in comparable quarrying techniques in the Early Iron Age. The quarrying remained largely unchanged until production of water millstones began in the early 12th century (Baug 2002). At this stage, the quarries turned deeper and larger, and at the same time the activity was apparently concentrated in the Rønset and Myklebust areas. Both the technique itself and the concentration of the activity indicate a more centrally organised quarrying.

The shift in quarrying technique may be partly explained by increased efficiency, i.e., larger work force and higher output per square metre in the deeper quarries. However, it is also noteworthy that the shift temporally coincides with a widespread exploitation of building stone for the construction of churches and monasteries. The medieval quarrying of building stone represents an important introduction of new methods of

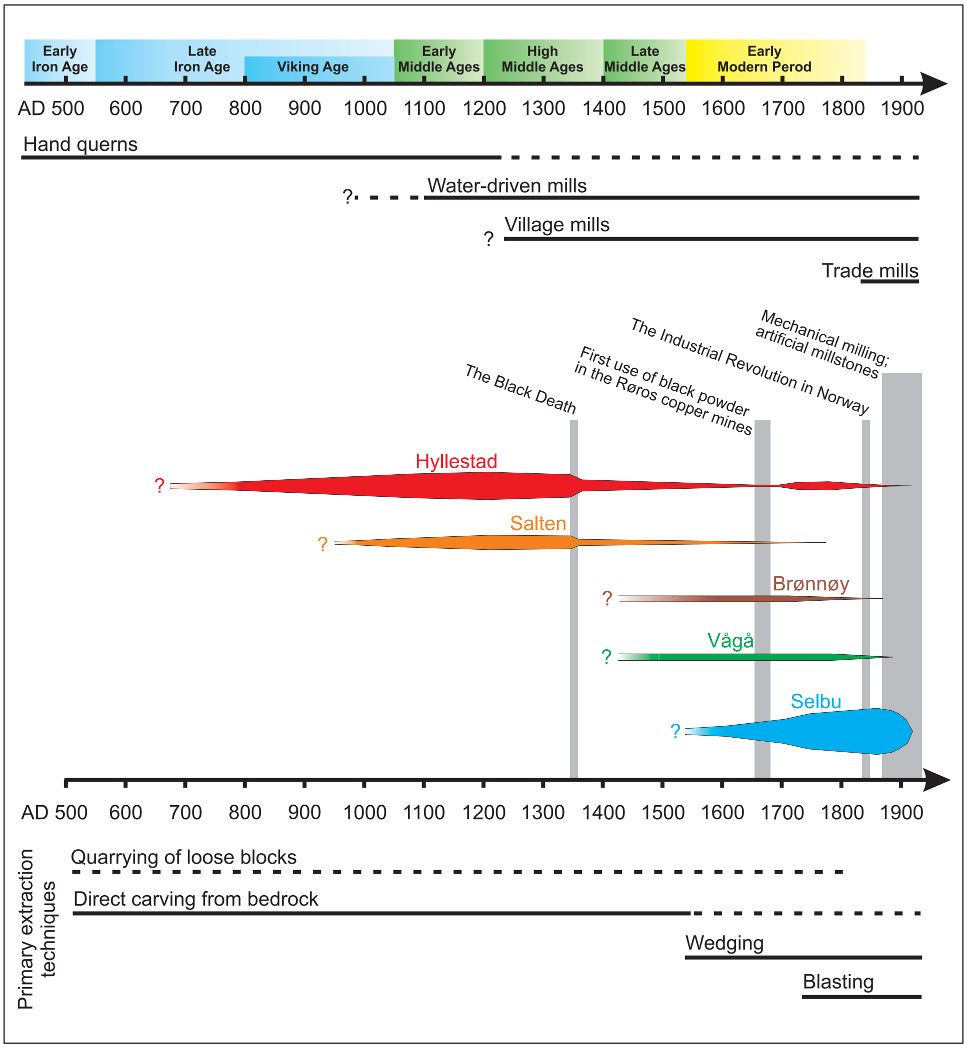

Figure 30. Time line showing the development of the major millstone-quarry areas, together with related technological and historical events in Norway. See discussion in the text for details. Figure based on data from Baug (2002), Berg (1998), Brekken (1980), Carelli and Kresten (1997), Friis (1632), Grieg (1960), Gulbrandsen (1969), Helberg (2007), Krokvik (1999), Monssen (1997), Rolseth (1947), Schøning (1778), Sognnes (1980), Statens Kornforretning (1934), Trones (2003) and Tønnesson (1997).

extraction, aided by foreign stonemasons (Storemyr and Heldal 2002). The planning and organisation of the later medieval millstone quarries in Hyllestad bear strong similarities to some of the large building-stone quarries and may have been inspired from this activity. This specifically applies to deep extraction in tall steps. We know that the Munkeliv Abbey took over land in Hyllestad at about the early 12th century (Baug 2002), including some of the most important millstone-quarry areas. As the monasteries were important users of building stone and may have been directly involved in the exploitation of such quarries themselves, it is reasonable to assume that the knowledge of building-stone production had some impact also on millstone-quarry technology and organisation.

The production of water millstones and hand millstones during the Middle Ages represents the peak of the Hyllestad millstone industry, both with respect to volume and distribution of the products (Carelli and Kresten 1997, Baug 2002). This period was followed by a decline in quarrying activity during the Late Middle Ages. Post-medieval quarrying techniques parallel those of the Selbu area, but production never reached the previous levels and was negligible compared to Selbu (Figure 30).

A major shift in primary extraction technique came with the use of wedging in Selbu, apparently in the 16th century, followed by further development of wedging combined with blasting techniques. At least in Selbu, blasting led to highly efficient quarrying, but the question remains as to why the principal change in extraction method, from primary carving to wedging, occurred well before powder was introduced in quarrying early in the 18th century.

Laws and taxes urged farmers to bring their grist to larger village mills already from medieval times. Together with the general technological development, this led to a demand for larger and more durable millstones. Although it is likely that the coinciding shifts in quarrying techniques and quarry areas were at least to some extent influenced by the increasing usage of large millstones, which were easier to produce in Selbu due to different geological conditions, as discussed above, additional factors may have served to strengthen the development. The

Selbu quarries are located in a mountainous region far from permanent settlements and harbours, and in traditional ways of thinking production took place 'against all odds'. On the other hand, the Selbu quarries were closer to important grain producing areas in central and eastern Norway, which may have been a driving force for building market power. Such a scenario is particularly relevant for the rise of Selbu quarrying in the 16th century, when the Norwegian population started to increase after the catastrophic decline following the Black Death in 1349–50 and recurrent serious outbreaks of the plague until the first half of the 15th century (Figure 30). Even if the old quarrying skills were not necessarily lost, the small population through this period may have reduced or practically ruined the trade of millstone that was previously dominated by Hyllestad, leaving the market open for new entrepreneurs when population and trade recovered.

Another aspect of the Selbu quarries is its location in the important copper province of central Norway. New mining technology was introduced to Norway in the 16th century when the Danish–Norwegian King Christian III (Norwegian reign 1536–59) summoned Saxonian mine officials to help with copper exploration and mining. The first direct evidence of copper mining in Selbu is from 1713, when the Høiaas mine ('Gammelgruva') was opened for production and was worked intermittently until 1764 (Rolseth 1945). The mine was located only a few kilometres from the millstone zone (Figure 10), and many of the farmers involved in millstone quarrying were also periodically involved in mining. Thus, it is likely that knowledge of mining technology disseminated to the millstone quarries earlier and faster than in Hyllestad. Moreover, historical records indicate that copper exploration in the region began already in the 16th century (Rolseth 1945). A letter from Archbishop Erik Walkendorf of Nidaros, written in 1516, refers to copper findings by Swedish miners at a distance from Trondheim that fits with the Høiaas mine in Selbu or ores in the Meråker area just to the north. This implies that the area may have benefited from the influence of new mining technology at a very early stage after the late-medieval recession.

Concluding remarks

The Hyllestad and Selbu quarry areas define huge 'industrial landscapes', which are testament to acquisition of stone resources over hundreds of years. Starting at least 1300 years ago, large-scale millstone production in Hyllestad saw a gradual development of technology from ancient hewing techniques, similar to those used for soapstone extraction since the Early Iron Age, to the more centralised and technologically advanced exploitation that may have been initially introduced by professional stonemasons related to the establishment of monasteries during the early 12th century. The decline in millstone production in Hyllestad after the High Middle Ages and the rise of Selbu as the dominant producer from the 16th century, coincided with a major technological shift to wedging, later combined with blasting, as the primary extraction technique (Figure 30).

It is likely that such a dramatic change in market dominance was significantly influenced by the breakdown of social and trade structures following the Black Death and recurrent plague outbreaks through the late 14th and early 15th century, leaving the market open for 'newcomers' when population and trade was recovering in the 16th century. Yet equally important was the increasing demand for larger millstones caused by the gradual change from hand querns to water mills, and from farm mills to village mills (Figure 30). These changes in demand favoured the geological conditions in Selbu, the properties of which consequently necessitated different extraction techniques.

Geological surveys are obviously crucial in multidisciplinary studies of such landscapes. For instance, knowledge of the exploitation of geological resources through history provides insight into developments in stone-working skills and the transfer of technology across regions, which again adds important information about social contexts. Moreover, geological studies of ancient quarries are essential in provenance studies of archaeological stone artefacts, which is a powerful tool in the understanding of trade routes and relations between countries and regions.

The knowledge gained from this study opens new challenges and possibilities. On the one hand, it points to the need for heritage management systems capable of dealing with ancient industrial landscapes, and on the other, it is significant for the historical identity of local communities and is essential in the development of geotourism. The Hyllestad and Selbu quarry landscapes are extensive and well preserved and clearly have a potential for arousing interest on an international scale as 'windows' into mankind's utilisation of geological resources.

Acknowledgements

We are grateful to Irene Baug, Torbjørn Løland, Finn B. Førsund and Bjarne Akse for sharing their knowledge of the Hyllestad area, and to Ola A. Hårstad, Knut Stomsvik and Rut Langbrekke Nilsen for discussions on various aspects of the Selbu quarries. Ane Engvik is thanked for valuable comments on the structural and metamorphic geology. The enthusiasm and interest of the Hyllestad and Selbu municipalities have been crucial for the implementation of the studies and is greatly acknowledged. Thanks are also extended to Leif Furuhaug (NGU) for help with mapping and preparation of figures, and to Astrid Waage (Hyllestad), Per Morten Storhaug and Sverre Selboe (Selbu) for logistical support. Øystein J. Jansen and Peter Kresten are thanked for their thorough and constructive reviews of the manuscript. The present paper is a result of ongoing multidisciplinary research in Hyllestad and Selbu, funded by NGU, the Directorate for Cultural Heritage, the Directorate for Nature Management, the Sør-Trøndelag County Council and the Hyllestad municipality.

References

Alsvik, E., Sognnes, K. and Stalsberg, A. (1981) Kulturhistoriske undersøkelser ved Store Kvernfjellvatn, Selbu, Sør-Trøndelag 1978. Det Kongelige Norske Videnskabers Selskab, Museet. *Rapport Arkeologisk serie 1981*, Trondheim, 146 pp.

Baug, I. (2002) Kvernsteinsbrota i Hyllestad. Arkeologiske punktundersøkingar i steinbrotsområdet i Hyllestad i Sogn og Fjordane. *Norsk Bergverksmuseums skriftserie*, **22**, 113 pp.

Berg, B.I. (1998) *Gruveteknikk ved Kongsberg Sølvverk 1623–1914*. Centre for technology and society, Norwegian University of science and technology, Norway, *Report 37*, 586 pp.

Brekken, J. (1980) Tolstadkvernberget og andre kvernsteinbrot i Vågå og Sel. *Årbok for Gudbrandsdalen 1980*, pp. 78–83.

Carelli, P. and Kresten, P. (1997) Give us this day our daily bread. A study of Late Viking Age and Medieval Quernstones in South Scandinavia. *Acta Archaeologica*, **68**, 109–137.

Chauvet, A. and Dallmeyer, R.D. (1992) $^{40}Ar/^{39}Ar$ mineral dates related to the Devonian extension in the southwestern Scandinavian Caledonides. *Tectonophysics*, **210**, 155–177.

Chauvet, A., Kienast, J.R., Pinardon, J.L. and Brunel, M. (1992) Petrological constraints and PT path of Devonian collapse tectonics within the Scandinavian mountain belt (Western Gneiss Region, Norway). *Journal of the Geological Society, London*, **149**, 383–400.

Dahl, J.M. (1986) Kvernsteinene på Ullandhaug. *Frá haug ok heiðni*, **1**, 4–7.

Friis, P.C. (1632) *Norriges oc Omliggende Øers sandfærdige Beskriffuelse*, København, 185 pp.

Grieg, S. (1960) Kvernkall og mølle. *Volund, Norsk Teknisk Museums tidsskrift 1960*, 9–45.

Gulbrandsen, G. (1969) Kornmaling gjennom tiderne. *Volund, Norsk Teknisk Museums tidsskrift 1968*, 9–156.

Haarstad, K. (1972) *Selbu i fortid og nåtid*, Volume 1. Aktietrykkeriet in Trondheim, 405 pp.

Hacker, B.R. and Gans, B.G. (2005) Continental collisions and the creation of ultrahigh-pressure terranes: Petrology and thermochronology of nappes in the central Scandinavian Caledonides. *GSA Bulletin*, **117**, 117–134.

Hacker, B.R., Andersen, T.B., Root, D.B, Mehl, L., Mattinson, J.M. and Wooden, J.L. (2003) Exhumation of high-pressure rocks beneath the Solund Basin, Western Gneiss Region of Norway. *Journal of Metamorphic Geology*, **21**, 613–629.

Hansen, A.M. (1991) Kverna som maler på havets bunn. Et kvernsteinsfunn i Alverstraumen, Lindås i Hordaland. *Sjøfartshistorisk årbok 1991*, pp. 195–215.

Hansen, A.M. (1997) Maritime perspektiv på kvernsteinsproduksjonen i Hyllestad. Arkeologi og kystkultur, 25 and 26 October 1997, Sunnmøre Museum, Ålesund, Proceedings, Sørheim, H. (ed.), pp. 58–63.

Helberg, B.H. (2007) Rapport vedrørende overvåking av inngrep i kvernsteinsbrudd i damområdet for Saksenvik kraftverk, Saksenvik i Saltdal Kommune, Nordland. *Unpublished report*, Tromsø, 9 pp.

Heldal, T. and Bloxam, E.G. (2007) Kartlegging og karakterisering av kvernsteinsbruddene i Hyllestad. *NGU Rapport 2007.079*, 120 pp.

Helland, A. (1901) *Bergverksdrift og Stenbrydning i Norge*. John Griegs Forlag, Bergen, 116 pp.

Krokvik, O. (1999) Kvernsteindrift. *Blad av Brønnøy Historie 1999*, 26–30.

Monssen, J.D. (1997) Kvernfloget. *Saltdalsboka*, Saltdal kommune, pp. 17–18.

Olesen, N.Ø., Hansen, E.S., Kristensen, L.H. and Thyrsted, T. (1973) A preliminary account on the geology of the Selbu–Tydal Area, the Trondheim Region, Central Norwegian Caledonides. *Leidse Geologische Mededelingen*, **49**, 259–276.

Rolseth, P.O. (1945) *Selbo Kobberverk*. Selbu og Tydals Historielag, 188 pp.

Rolseth, P.O. (1947) *Kvernfjellet*. Selbu og Tydals Historielag, 275 pp.

Rønneseth, O. (1968) Das Zentrum der ältesten Mühlsteinindustrie in Norwegen. *In* Haarnagel, C.W. and Raddatz, K. (eds.) *Studien zur europäischen Vor- und Frühgeschichte*, Karl Wachholtz Verlag, Neumünster, pp. 241–252.

Rønneseth, O. (1977) Kvernsteinsbrota ved Åfjorden, *Sogeskrift frå Hyllestad*, hefte 2.

Schøning, G. (1778) *Reise giennem en deel af Norge 1773–1775*. Det Kongelige Norske Videnskabers Selskab i Trondheim i anledning af dets 150-Aars Jubilæum, 1920. Trondhjem, A/S Adresseavisens bogtrykkeri, 333 pp.

Skjølsvold, A. (1969) Et keltertids klebersteinsbrudd fra Kvikne. *Viking*, **33**, 201–238.

Sognnes, K. (1980) Kvernsteinsdrifta i Monsholet. *Årbok for Helgeland 1980*, 171–176.

Statens Kornforretning (1934) *Norske mylnor og kvernar*. Bind I–II, H. Aschehoug and Co., Oslo, 556 pp.

Storemyr, P. and Heldal. T. (2002) Soapstone production through Norwegian history: geology, properties, quarrying and use. *In* Herrman, J.J., Herz, N. and Newman, R. (eds.) *Asmosia 5—Interdisciplinary studies on ancient stone*. Proceedings of the Fifth International Conference of the Association for the Study of Marble and Other Stones in Antiquity, Museum of Fine Arts, June 1998, Boston, Archetype Publications, London, pp. 359–369.

Strøm, H.C. (1820) Beretning om Qværnsteensbruddene i Sælboe. *Budstikken*, issue 59–66.

Thue, J.B. (2000) Livets steinar: produksjon og eksport av kvernstein frå Hyllestad i mellomalderen. *Skald*, Leikanger, 79 pp.

Tillung, M. (1999) *Structural and metamorphic development of the Hyllestad-Lifjorden Area, Western Norway*. Cand. Scient. thesis, University of Bergen, 264 pp.

Titland, H.P. (2003) Kvernsteinsbruddene i Saltdal. *Saltdalsboka 2002/2003*, Saltdal kommune, pp. 35–43.

Trones, J.I. (2003) Om bergverksdrift fra middelalderen og muligens tidligere. *Saltdalsboka 2002/2003*, Saltdal kommune, pp. 44–47.

Tønnesson, K. (1997) *Spor i tid. Norge før 1850*. H. Aschehoug and Co. (W. Nygaard), Oslo, 223 pp.

Waage, A. (2005) Kvernsteinsdrifta i Hyllestad–eit nyoppdaga kapitel av norsk bergverkssoge. *Fortidsvern*, **30**, 28–29.

Wolff, F.C. (1989) Trondheim, bedrock geology map, scale 1:250,000, *Norges geologiske undersøkelse*.