UNFC and ornamental stone resources – Larvikite case study

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Introduction

The term 'Larvikite' is applied for a range of peculiar monzonitic rocks within the southern part of the Carboniferous-Permian Oslo Igneous Province (Figure 1). They have for more than a hundred years been appreciated as one of the world's most attractive ornamental stones, and at present, its production and use is more extensive than ever. The main reason for the continuous success of larvikite on the world market is the blue iridescence displayed on polished surfaces, which is caused by optical interference in microscopic lamellae within the ternary feldspars.

The name 'larvikite' was first applied by the geologist Waldemar Christopher Brøgger (1852–1940). The name has its origin in the small coastal town of Larvik, situated almost right in the centre of the main plutonic complex of larvikite.

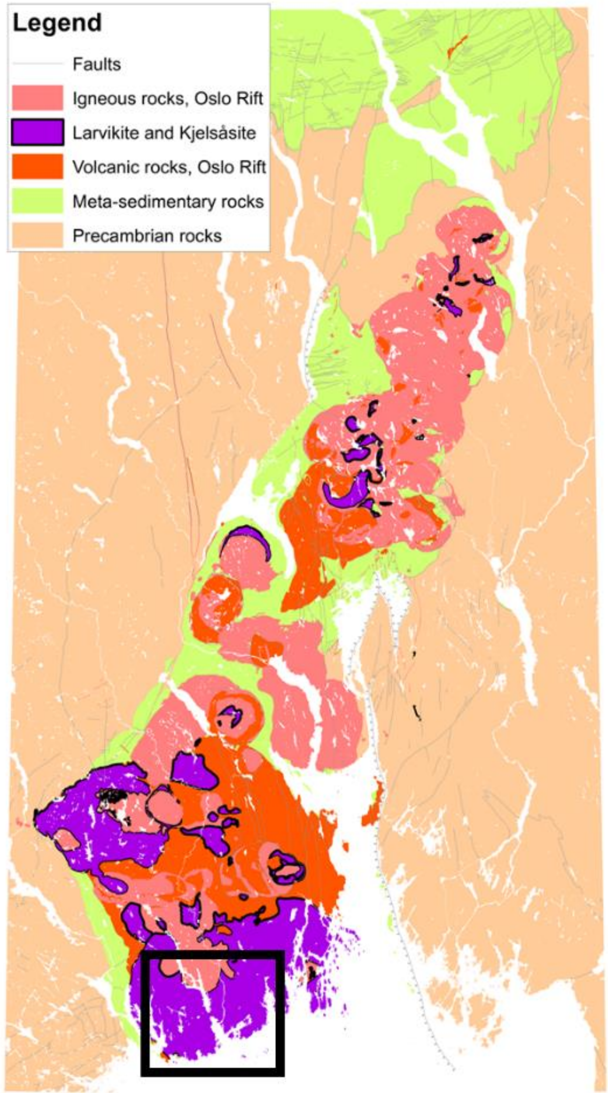

Figure 1. The Oslo rift and studied area (black rectangle).

The first recorded use of larvikite as dimension and ornamental stone dates back to the 12th century (Fig. 7). Many of the stone churches in the region are made of larvikite. It took several hundred years until larvikite again came on the agenda. In the 18th century, the Danish-Norwegian king initiated a hunt for ornamental stones – or 'beautiful marbles' – in Norway (Jansen & Heldal 2003). The iridescent larvikite was known to scholars at that time. However, the Napoleonic wars did put a preliminary end to such dreams, and modern period exploitation did not start until around 1820, remaining small scaled until the late 19th century (Børresen & Heldal 2009).

From about 1875 to 1895, Norway suffered an economic depression, which among other things led to a massive emigration, first of all to the USA. But this was also a time for exploring new opportunities, among those extraction and export of larvikite blocks. In 1886, larvikite won a gold medal at the world exhibition in Liverpool (Oxaal 1916). Since then, larvikite production for export has remained a significant industry in the area. The application of the stone all over the globe and the annual output of stone is comparable with other high-profiled stone quarry areas of the world, such as the Carrara marble.

Defining resources of larvikite

Primary larvikite production is mainly about extracting rectangular blocks of homogenous and high quality. The quality (and thus, market price) depends on the following factors:

- Technically homogenous rock (wide spacing of primary fractures and joints in the rock mass for achieving large blocks)
- Visually homogenous rock (little variations within the raw block)
- Type of larvikite (some gain higher market price than others)

A crude division of larvikite types are shown in Figure 2. More information can be found in Heldal et al. 1999, 2008, 2014 and Kjølle et al. 2003.

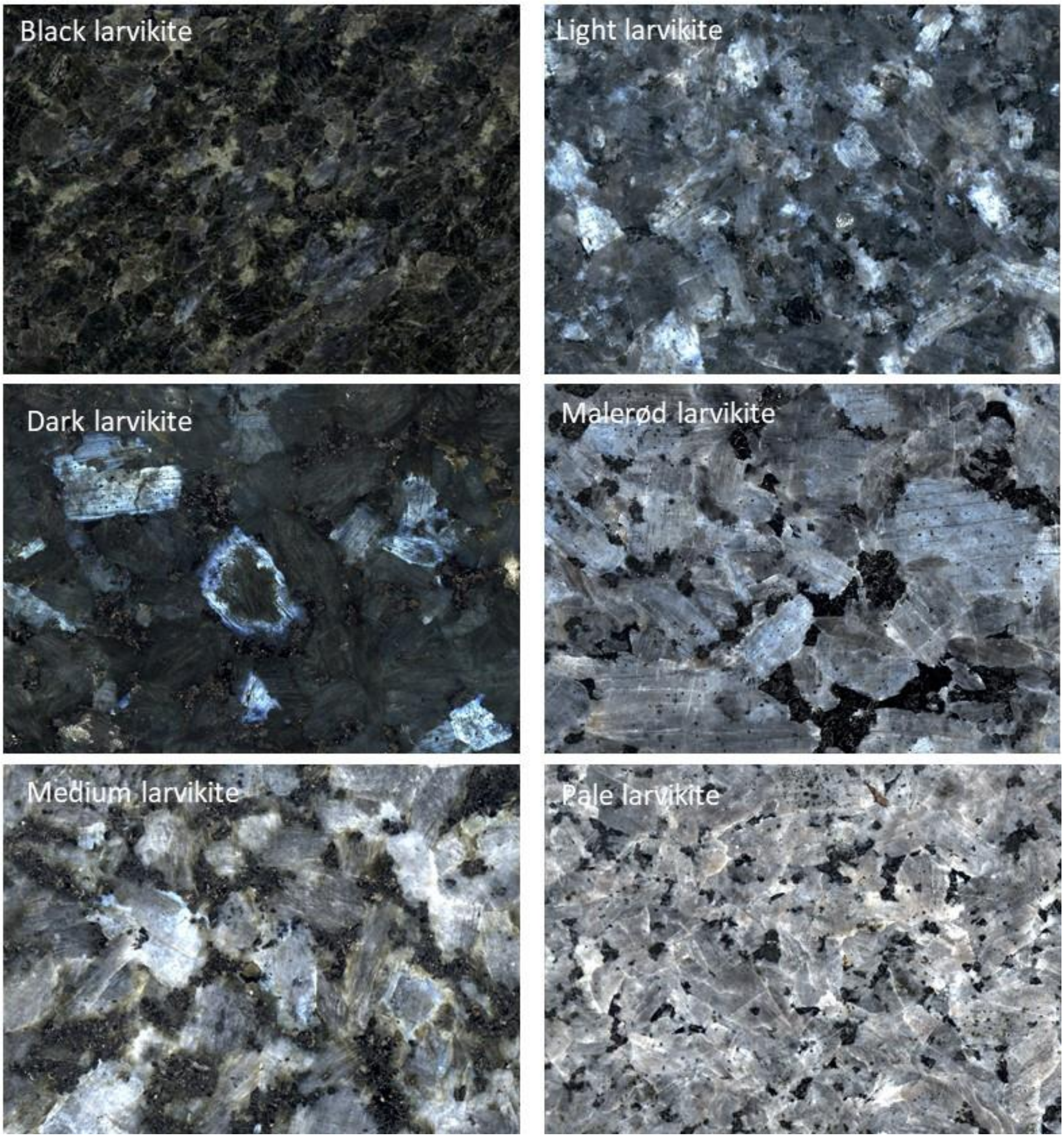

Figure 2. Six types of larvikite, as used in the further text and tables. Polished slabs, each approximately 15 cm wide. Black and pale larvikite are at present time not produced

Black larvikite: more fine-grained than the other types, dark colour with blue schiller. Mainly applied for outdoor applications. At the time of writing, there is no production, but regulations as a legal extraction site is still valid.

Dark larvikite: classic, dark larvikite with blue schiller that has been produced for almost 140 years, mostly known as "Emerald Pearl" (Figure 3). Several quarries and large production site in the eastern part of Larvik.

Figure 3. Larvikite often associates to exclusiveness and fashion.

Medium larvikite: Large grain larvikite medium grey, with blue schiller. There has most likely been production of this type since around 1900. Several large quarries in the area.

Light larvikite: mostly known as "Blue Pearl, light larvikite has been produced since the late 19th century. At present time, there are large production sites in the Tvedalen area, western Larvik.

Malerød larvikite: the "youngest" among the larvikite types in production, and also the northernmost. Clear blue larvikite with large grains known as "Royal Pearl".

Pale larvikite: this type has been produced in a very small degree, and there is no current production. The colour is paler than the other types, and the chiller is more silvery than blue. Until present time this type has been looked upon as difficult to sell in the market due to the weak colour.

Most of the municipality of Larvik is on top of larvikite rocks (Figure 4). However, only parts of that area contain larvikite resources of high enough technical quality to produce large blocks. This is mainly due to significant faults and fracture systems responsible for the uneven terrain in the municipality. The hypothesis behind resource mapping was that the area most resistant to erosion (hills) are the less fractured parts, whilst the valleys and depressions in between the most fractured parts.

The resource mapping, carried out between 1999 and 2003 (Heldal et al. 1999, Kjølle et al. 2003), aimed at map the distribution of the different types and identify the best areas for quarrying each of them. In addition to the technical quality (fracture spacing), characterization of colour, composition and homogeneity were carried out. The resulting resource map is shown in Figure 5.

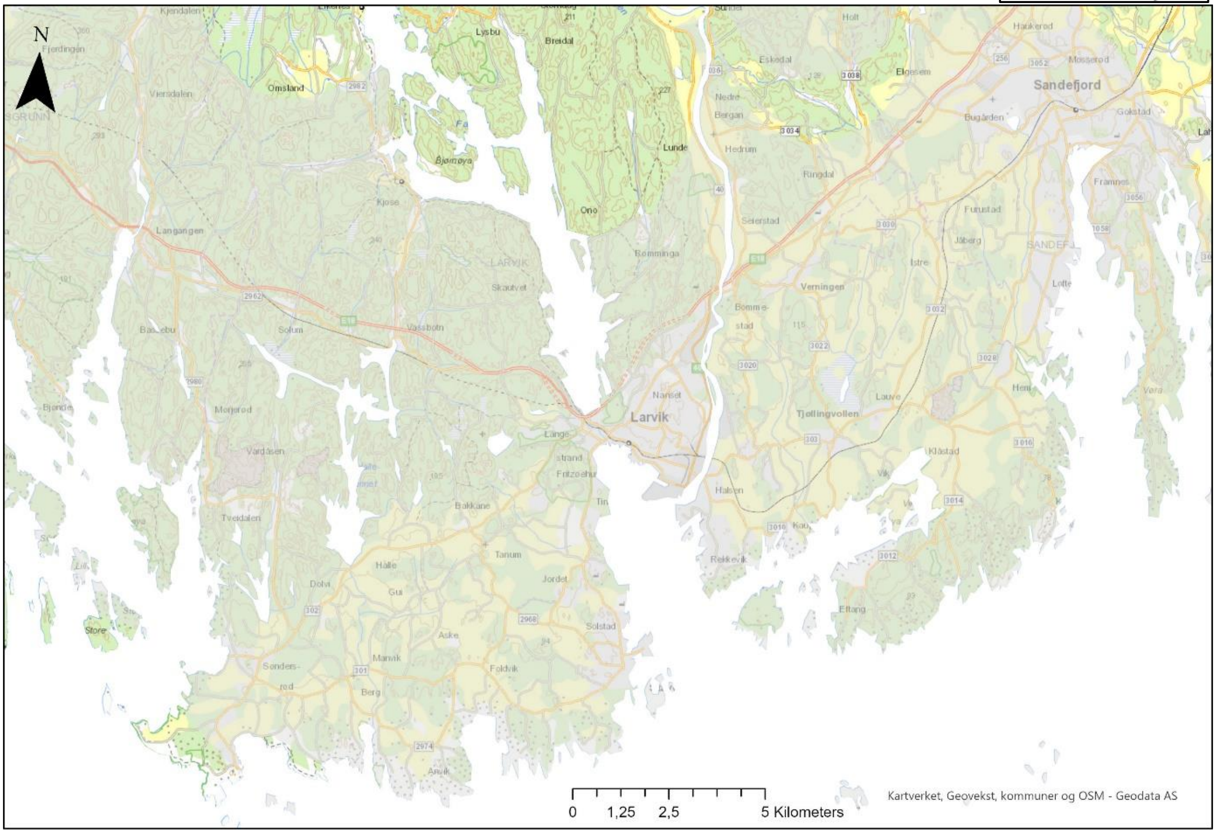

Figure 4. Map showing area covered by larvikite (shaded area)

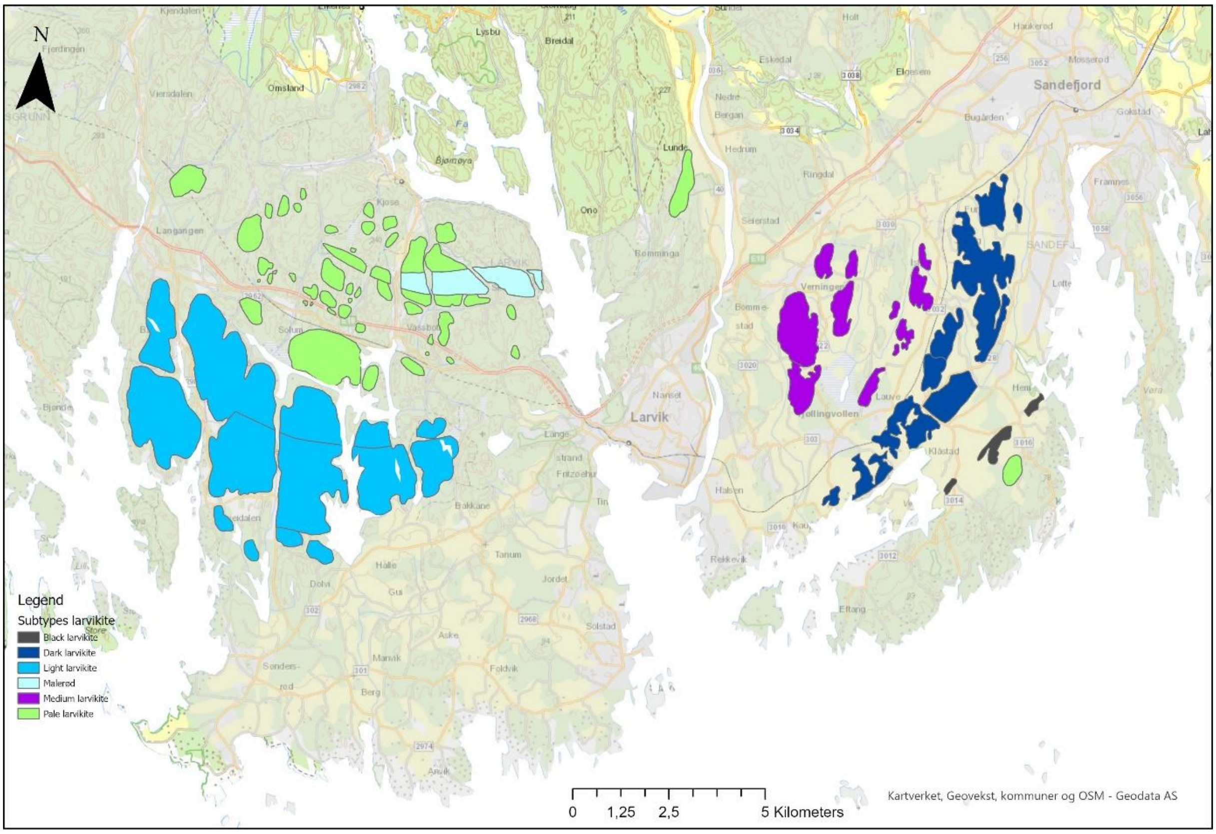

Figure 5. Map showing result of resource mapping and distribution of larvikite types

Methodology

The aim of this case study is to explore the application of UNFC (see description of method in UNFC main document for mineral resources and guidance for use in the Nordic countries) on the larvikite resources within one municipality. We have viewed this from the perspective of public entities, such as municipalities, regional authorities or geological surveys, as a tool for UNFC resource based management.

The first part of the case study uses disclosed data, published by authorities. The geological map, combined with published resource mapping and spatial management information makes the base of the study. However, voluntarily disclosed data from the larvikite producer Lundhs AS are used in calculations of "ore grade".

In this part, we have made some choices:

- Larvikite resources have been considered "exploitable" down to sea level. This is not completely accurate, since there are already quarries extracting stone below sea level. We have chosen to make this limitation due to the yet unknown variability of technical property variations among larvikites that can influence maximum depth of extraction, along with the geological uncertainty of resource quality at depth.
- The municipality of Larvik has made a quite detailed regulation plan for larvikite resources. Some areas are designated to larvikite exploitation in the short or medium long term; these, we consider to be open for quarrying projects without land-use conflicts. Other areas are designated to possible future exploitation. These areas we consider to be of low land-use conflict. The rest of the outcropping areas of defined resources of larvikite, we consider to be high-conflict areas, or areas were future larvikite production is not likely to happen.
- We have used a "direct evidence" method for evaluating the resources. This means, that we have used the obtained levels of knowledge within the area as the best possible, disclosed knowledge platform. For instance, the maximum certainty of resource calculations from disclosed data is G2, since we do not have access to internal company information.
- Using a probabilistic method could give a statistical more viable distribution of G1 to G4. However, in this case, it would most likely be based on decreasing certainty surface to depth. Since this approach has little evidence in the quarry areas, and since there are several other factors controlling exploitability changes on a lateral axis (of which we have limited data), we decided to use only deterministic method.

In the last part of the study, we have used data from the company Lundhs, disclosed for this work.

Evaluation of data and calculating volumes

The total area situated in larvikite (Figure 4) may be classified as G4. We have not made calculations of volumes, since the amount of larvikite resources with observed, higher confidence is significant.

The resource mapping creating the areas shown in Figure 5 did result in an assessment of resources, although with a rather low level of confidence, down to sea level. These volumes (from terrain surface down to sea level) are classified as G3.

By computing a tin-model (Figure 6) covering the area with larvikite resources, volumes could be calculated by applying "polygon volume" tool in ArcGIS Pro, when z-value of polygons equal 0. This resulted in a set of volumes for each polygon – *gross volumes* (Figure 7).

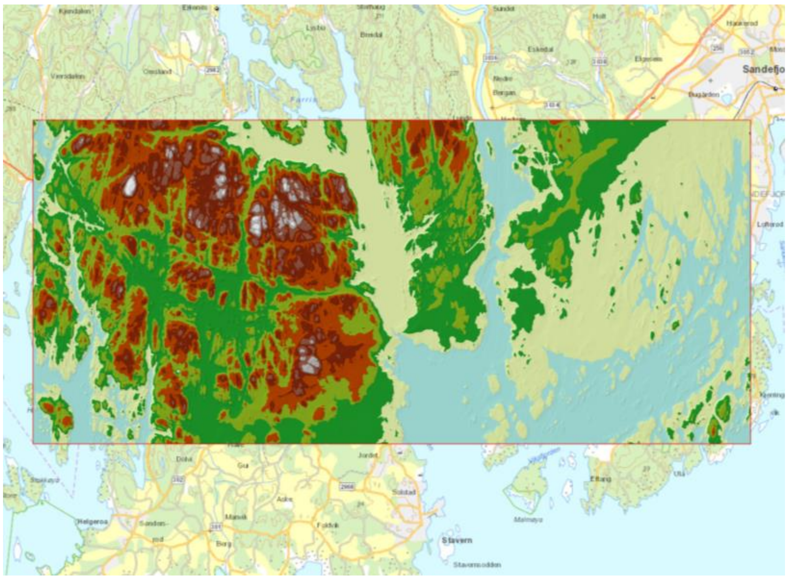

Figure 6. Tin-surface 10x10 metres made from dtm-model

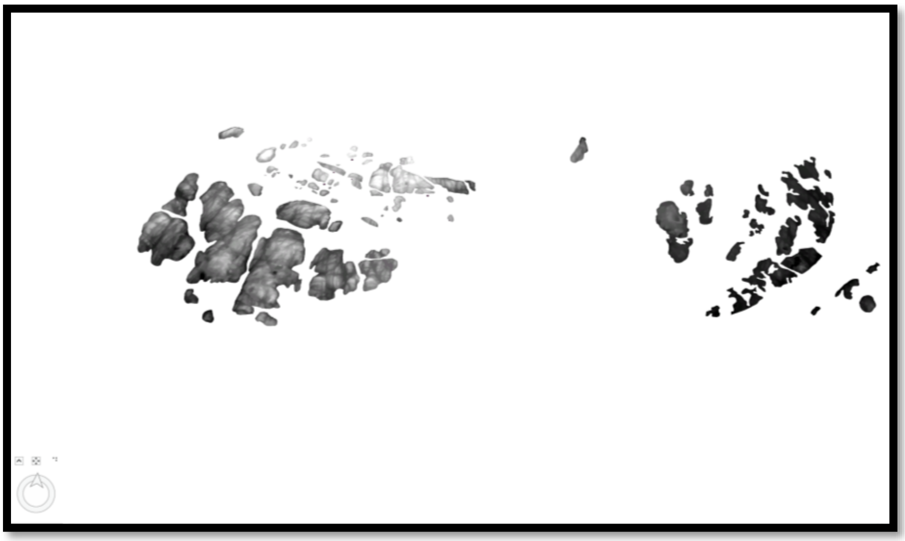

Figure 7. 3D-view of larvikite resource volumes calculated as volume between terrain surface and sea level

The *gross volume* for all the mapped potential resources is approximately 11 billion tons. However, the *gross volume* does not reflect a real situation, where volumes are decreased due to (inevitable) top layers, fracture zones and other parts not suitable for production. Viewing layout of the quarries in the area through history, at least 50% of *gross volume* will less likely be produced. We have used a conservative approach – reducing gross volume to 1/3 – the *reduced gross volume*.

Of the rock that actually will be produced, only a fraction will be sold as commercial blocks on the ornamental stone market. In the larvik area, this fraction is between 5 and 14 % (Lundhs, production figures) depending on the type of larvikite. The *net volume* will therefore be between 5 and 14 % of the *reduced gross volume*.

Thus, the formula for calculating will be:

Net volume = (*gross volume*/3) x (0,05 – 0,14)

Calculating E, F and G axes

As mentioned, the mapped resource areas can be classified at least as G3 (Figure 8). We have anticipated that the knowledge of the resource on a company scale is better in the active quarry areas; companies use core-drilling and consultants, and although this information is classified, we think it is valid to use G2 for resources within such areas (Figure 9).

This brings us to the E and F axes.

In the Larvik municipality, the geological mapping was fed into land-use planning, resulting in a priority of resource areas: some were discarded as non-negotiable no-exploitation areas, where other land-use interests have higher priority than stone production. These, we classify as E3 and F4. However, a significant part of the resource areas was considered to be “of future interest for larvikite production”, i.e. *awareness zones*. Although they are not secured for future larvikite production, it is likely or probable that they will in the future. Future larvikite production in such areas is negotiable. We have classified those areas as E2-F2.2.

The areas designated to larvikite production through concession (Norwegian mining act) and/or regulations according to the Norwegian Plan- and Building Act are classified as E1.1. and F1.1.

In one case (black larvikite) quarrying was recently stopped. Whether it will start again or not is an open question, but the quarry area remains regulated to such activities so far. We propose E1.1 and F2.2 for this particular area.

The proposed UNFC classification for the total larvikite resources is shown in Table 1.

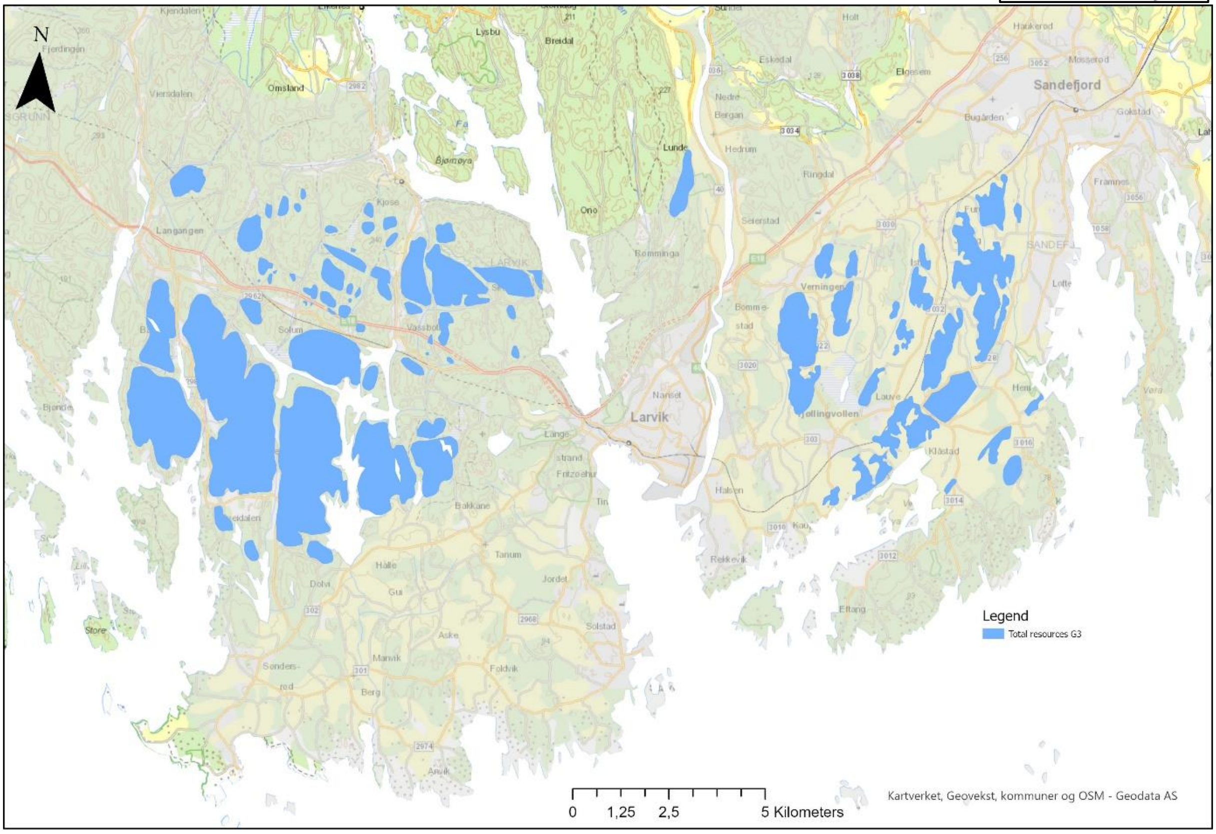

Figure 8. Map showing all defined potential resources - G3

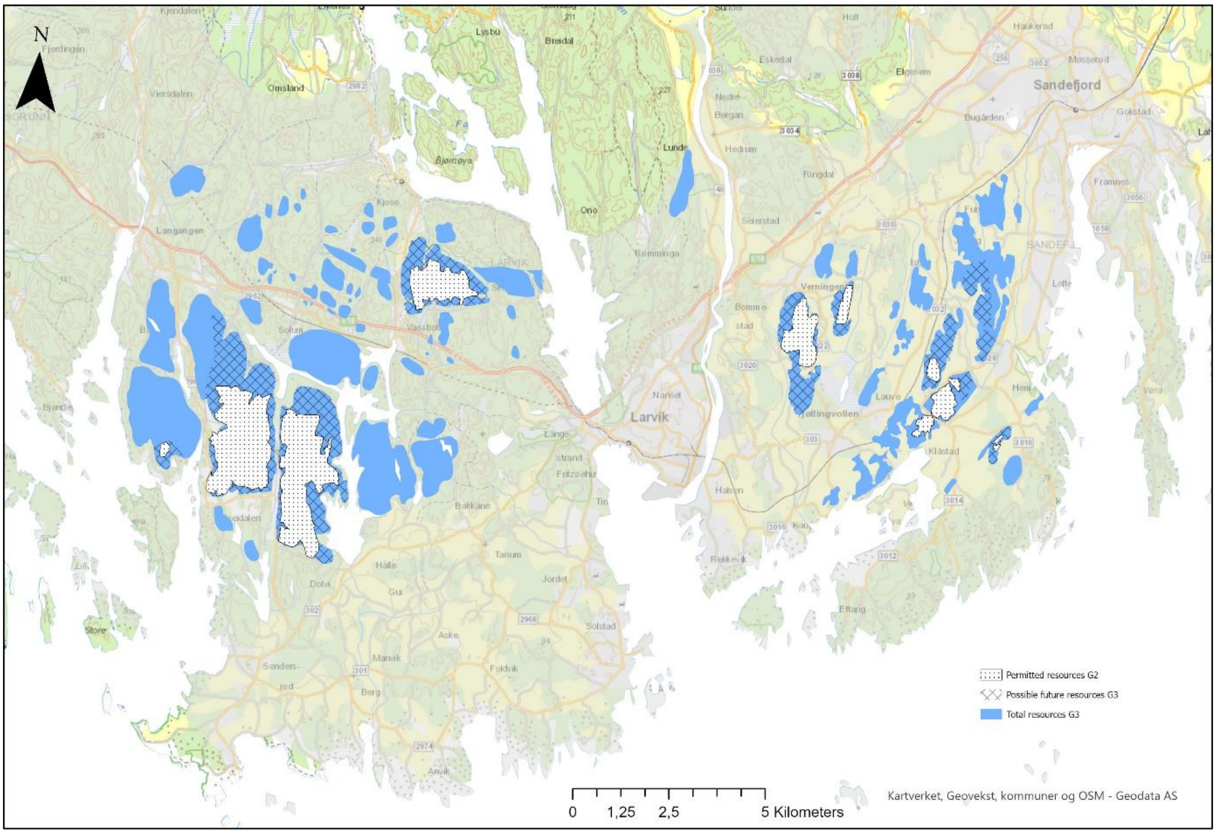

Figure 9. Map showing all resources, awareness zones (cross hatched) and mining permission areas (white with dots).

*Table 1. Proposed UNFC classification of total larvikite and broken down to the six subtypes, net volumes. *For the Malerød subtype, reduced gross volume is lower than the other ones, due to that this specific awareness zone covered more unproductive areas than the others.*

	E	F	G	Sales t	Non-sales t
Larvikite total	1.1	1.1	2	63 729 961	835 609 094
	1.1	2.2	2	97 411	
	2	2.2	3	36 702 836	
	3.2	4	3	122 331 950	
Black larvikite	1.1	2.2	2	97 411	876 702
	2	2.2	3	347 325	
	3.2	4	3	239 536	
Dark larvikite	1.1	1.1	2	2 315 187	20 836 682
	2	2.2	3	5 142 412	
	3.2	4	3	11 489 056	
Medium larvikite	1.1	1.1	2	7 641 772	7 641 772
	2	2.2	3	6 917 749	
	3.2	4	3	6 374 882	
Light larvikite	1.1	1.1	2	32 317 362	614 029 881
	2	2.2	3	23 447 861	
	3.2	4	3	43 009 366	
Malerød larvikite*	1.1	1.1	2	21 455 640	193 100 760
	2	2.2	3	847 489	
	3.2	4	3	5 478 327	
Pale larvikite	3.2	4	3	55 740 783	

Breaking down to subtypes of larvikite

As mentioned previously in this report, the larvikite resources do not define one single quality. There are at least six subtypes, each acting like different products in a demanding market. Thus, a breakdown of the generic UNFC classification to the six subtypes and even more, can be of great value for future land use management (Table 1).

Larvikite is a geological resource carrying longevity. It has been on the world market for nearly 140 years, and will likely be present for the next hundreds of years. In thousands of buildings, monuments and other constructions worldwide, larvikite is an important component. Thus, it is important to secure long-term production of larvikite.

From our figures, light larvikite resources may reach 500 years into the future within regulated areas (E1.1, F1.1). This may be seen as a “well done” management policy from the authorities. Dark larvikite, however, within regulated quarry areas, last approximately 45 years with the present production rate[1]. On the other hand, “awareness zones” (E2, F2.2) may stretch this another 100 years.

The breakdown of figures shown here is an example of how UNFC can be applied in several levels, from national to municipality and company scale. Using the UNFC in such ways will provide tools for long term planning of land use and resource exploitation. If resources are expected to run out in a foreseeable future, authorities can be motivated to make “awareness zones” that can be developed to future production areas.

The issue of “non-sales” – a resource stock model

We have analysed the larvikite production in the light of primary production of raw blocks. However, an increasing amount of the non-sales are being transformed to other commercial products. Larvikite not suitable for natural stone raw blocks can be applied for coastal protection blocks (armour stone), aggregate, dry-wall stone and even agricultural additives (Figure 10). It is important to note that the company owning the concession only produce raw blocks, while a cluster of other companies feed their business models on the non-sales from that company.

One way of studying the non-sales is by viewing it as a contemporary and future stock of products, aligned with the resource estimates described above. This is shown in *Table 2*. Note that we have only calculated this in the permission areas.

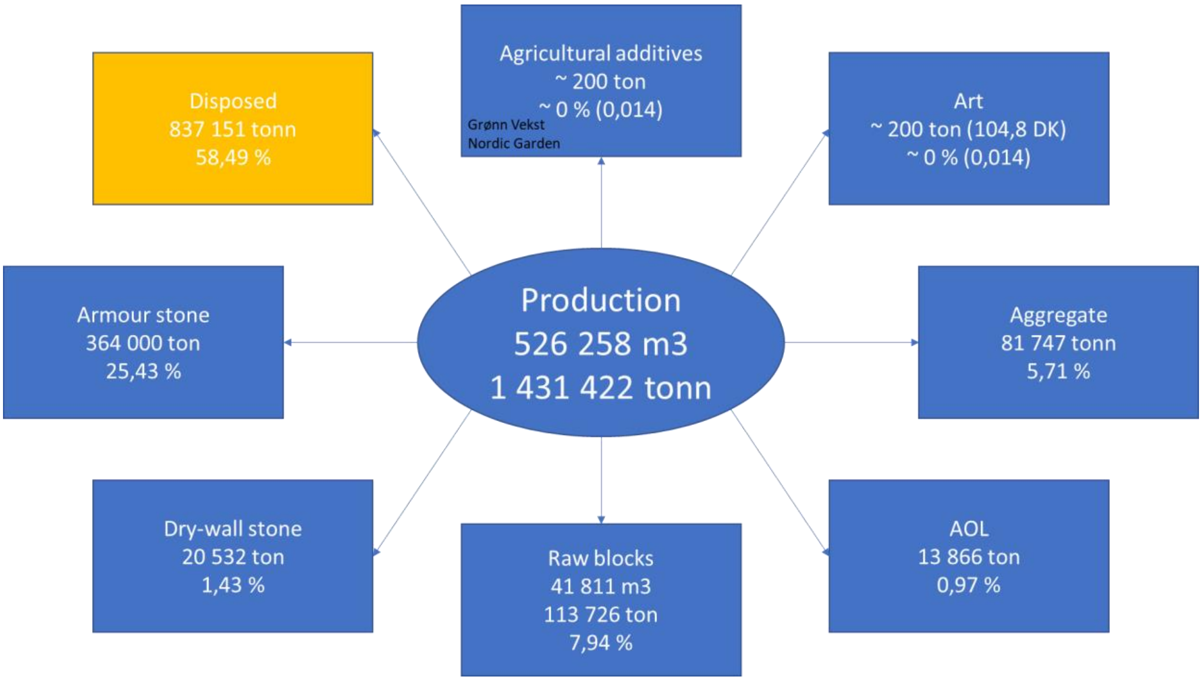

Figure 10. Additional use of larvikite in one company owning many quarries, figures from 2018

[1] Roughly in line with industrial calculations in that area

Table 2. Stock model UNFC for calculating use of non-sales. Based on figures from Lundhs.

	E	F	G	Non-sales t	Dry-wall stone t	Armour stone t	Aggregate t	Other t	Left t
Larvikite total	1.1	1.1	2	835 609 094	26 798 987	329 637 094	187 697 870	926 075	291 475 144
	1.1	2.2	2						
	2	2.2	3						
	3.2	4	3						
Black larvikite	1.1	2.2	2	876 702					
	2	2.2	3						
	3.2	4	3						
Dark larvikite	1.1	1.1	2	20 836 682			5 324 930	926 075	14 585 677
	2	2.2	3						
	3.2	4	3						
Medium larvikite	1.1	1.1	2	7 641 772	1 528 354				6 113 417
	2	2.2	3						
	3.2	4	3						
Light larvikite	1.1	1.1	2	614 029 881	14 542 813	329 637 094			269 849 974
	2	2.2	3						
	3.2	4	3						
Malerød larvikite	1.1	1.1	2	193 100 760	10 727 820		182 372 940		0
	2	2.2	3						
	3.2	4	3						

The issue of “non-sales” – a resource flow model

Another way of reviewing non-sales is by using a material flow model. Since the “biproducts” of larvikite raw block production totally depends on the latter (no raw block production – no biproducts) a flow model may be more appropriate to apply. Moreover, trends (of reducing waste) may come more clearly forward.

Table 3 and Figure 11 show Lundh’s annual primary production in different larvikite types and non-sales for 2018 and estimate for 2020. Note that only E1 and F1 figures are displayed.

Table 3. Annual production and non-sales 2018 and estimate for 2020.

2018	Annual primary production t	Block yield %	Primary blocks t	Dry-wall stone t	Armour stone t	Aggregate t	Other t	Disposed t
Dark larvikite	352 566	0,12	42 308			81 747	13 866	214 645
Medium larvikite	195 528	0,14	26 460	17 709				151 359
Light larvikite	710 973	0,06	42 658	16 045	363 980			288 290
Malerød larvikite 2018	175 318	0,095	16 655	6 500				152 163
Total	1 434 385	0,09	128 082	40 254	363 980	81 747	13 866	806 456

Estimate 2020	Annual primary production t	Block yield	Primary blocks	Dry-wall stone	Armour stone	Aggregate	Other	Disposed
Dark larvikite	352 566	0,12	42 308			81 747	13 866	214 645
Medium larvikite	195 528	0,14	26 460	17 709				151 359
Light larvikite	710 973	0,06	42 658	16 045	363 980			288 290
Malerød larvikite 2020	175 318	0,095	16 655	6 500		151 943		220
Total	1 434 385	0,09	128 082	40 254	363 980	233 690	13 866	654 513

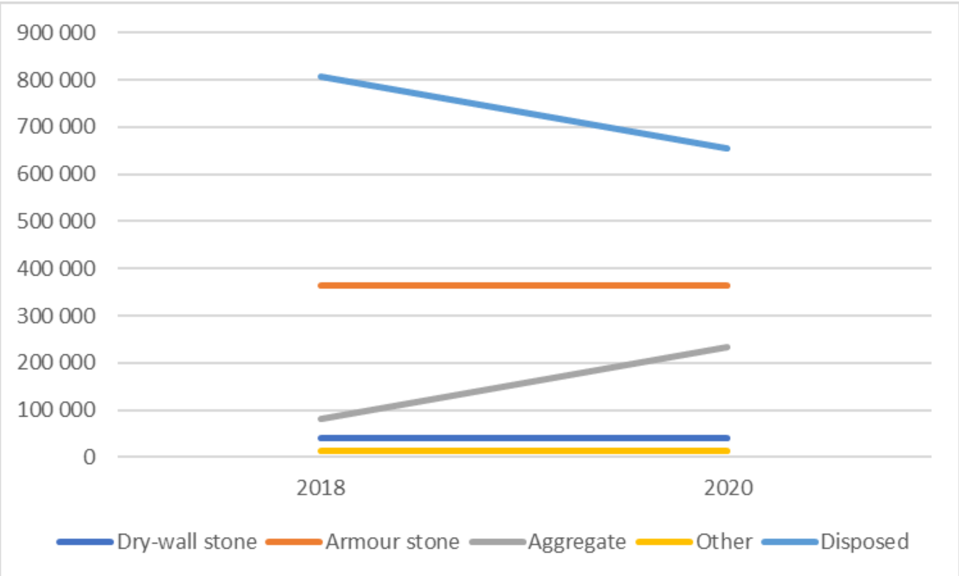

Figure 11. Graphic illustration of Table 3, showing increasing use for aggregate and decreasing disposals.

Challenges

In this case study, we did not start from scratch, but had good data available.

Geological resource mapping was carried out previously and available, identifying some qualities (G3) from poorer qualities (G4). G2 was assigned to all the active production and dedicated areas, of which, there may be several areas more correctly classified as G1; but since that information is not reported from companies, we have few possibilities of establishing such figures.

The Larvik Municipality have made significant work in their land-use planning, identifying dedicated short term extraction areas, longer term extraction areas and awareness areas for the future. This was crucial for establishing the E-axis. Dedicated and regulated areas are E1, whilst the awareness zones are E2. The remaining land on larvikite in the municipality must be regarded as E3. The work carried out by the municipality include the evaluation of many land use interests in the area, roughly identifying 1) no conflict areas where exploitation is supposed to take place, 2) low conflict areas where exploitation may be considered, and 3) high conflict areas where it is not likely to produce larvikite.

The weakest part of the case study is the F-axis. We do not have detailed figures or other information about industrial projects in the area, such information is not disclosed in Norway. However, we have assumed that the dedicated production areas have ongoing projects for expanding quarries or establishing new ones, and that low conflict zones may be open for possible new exploration.

On the one hand, UNFC may provide a good tool for resource management. And, in the case of Larvik, lack of detailed information about every project and industrial activity may not be a hinder for using UNFC in long-term planning, given that industrial data, although not-reported, have provided input to the land-use planning in the municipality.

In Norway, mineral producing enterprises owning mining concessions, are obliged to deliver annual reports of production and waste disposal to the government. They are not obliged to report resource assessments, and when other enterprises make their value chains on the non-sales, there are no reporting obligations at all. This makes it difficult to monitor the sustainability of the resource exploitation.

The application of UNFC may provide a solution to such issues, given that it is applied on non-sales in addition to sales.

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