The Vehmaa rapakivi granite batholith in southwestern Finland – the production area for Balmoral Red granites

Olavi Selonen, Carl Ehlers, Hannu Luodes, Paavo Härmä, Fredrik Karell
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YHTEENVETO: Vehmaan rapakivigranititaittueleen rakennuskivet

Olavi Selonen
Åbo Akademi University
Department of natural sciences
Geology and Mineralogy
FI-20500 Turku, Finland
E-mail: olavi.selonen@abo.fi

Carl Ehlers
Åbo Akademi University
Department of natural sciences
Geology and Mineralogy
FI-20500 Turku, Finland
E-mail: carl.ehlers@abo.fi

Hannu Luodes†

Paavo Härmä
Geological Survey of Finland
FI-02151 Espoo, Finland
E-mail: paavo.harma@gtk.fi

Fredrik Karell
Geological Survey of Finland
FI-02151 Espoo, Finland
E-mail: fredrik.karell@gtk.fi


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Front cover: Balmoral Castle in the Scottish highlands. Photo: Olavi Selonen.

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1 INTRODUCTION

The Vehmaa rapakivi granite batholith in southwestern Finland is a traditional Finnish stone production area where the extraction of stone started 115 years ago (Vähäkangas 2000). The first rocks that came into industrial production were the even and fine-grained red granites (the Vehmaa granite) in the eastern part of the batholith in 1901. The extraction of the medium-grained red porphyritic granites (the Taivassalo granite) in the middle of the batholith commenced in 1905, and very soon after the beginning of the production the stones were successfully exported.

These “Balmoral Red” granites became the first voluminously used and globally acknowledged Finnish natural stone qualities. They had a central role in the development of the Finnish stone industry and internationally they defined the industry for decades. Still today, there is stable demand for the classic Balmoral granites at the international stone market. The Vehmaa batholith is, together with the Wiborg batholith in southeastern Finland, and the Kuru batholith in central Finland (see App. 1), the best known granite production area in Finland.

The geology of the Vehmaa batholith and its natural stones has over the years been the target for several studies, e.g. Kanerva (1928), Vehmaan kotiseutuyhdistys (1995), Selonen (1998), Selonen et al. (2000), Eklund & Shebanov (1999), Shebanov et al. (2000), Vähäkangas (2000), Mononen (2005), Selonen et al. (2005), Mononen (2006), Bergström (2009), Karell et al. (2009), Selonen et al. (2011), and Karell (2013). A geological map on the Vehmaa batholith with an explanation (Lindberg & Bergman 1993) is published by the Geological Survey of Finland. These studies are mostly published in special publications, not easily accessible for many readers. In this geotechnical report, we have compiled the currently available knowledge on the geology and on the natural stones of the Vehmaa batholith. Our aim is to provide the reader with the basic information on the batholith combined with a comprehensive list of literature for further reading. This compilation of data on the Vehmaa batholith has not previously been published. For this report, the batholith area was revisited by the first author in 2015.

2 RAPAKIVI GRANITES

The Finnish word “rapakivi” has been internationally adopted as a term for a specific type of granite. Already, centuries ago geologists in Finland observed red granites sharply cutting the structures of the surrounding deformed rocks. In some areas, the rock surface was strongly weathered, forming a gravel like surface which was called rapakivi (“crumbly stone”) by the local people. The name was noted in the literature already 1694 by the Swedish naturalist Urban Hjärne, but it was introduced and defined internationally by J.J. Sederholm 1891 (Sederholm 1891). Similar granites were later identified in several other areas, e.g. Sweden, the Baltic countries, Russia, Ukraine, North and South America, Africa, and Australia (Rämö & Haapala 2005, Müller 2007).

Rapakivi granites often occur as discordant anorogenic intrusions, cutting sharply through an older deformed metamorphic bedrock unaffected by ductile deformation. Most rapakivis are of Proterozoic (ca 1800-1000 Ma) age, but also Archaean (ca 2800 Ma) and Phanerozoic (400-50 Ma) rapakivi granites occur. Rapakivi granite magmatism is often bimodal, with associated diabases, gabbros, and anorthosites (including the strongly iridescent variety of labradorite, known as “spectrolite”).

Rapakivi granites are characterized by a homogeneous and non-foliated structure. The traditional wiborgite rapakivi texture comprises large round K-feldspar megacrysts (ovoids), surrounded by a plagioclase mantle. Granite types with K-feldspar ovoids lacking the plagioclase rim, are named pyterlite. Drop-like quartz crystals are commonly found in the granites. Different types of superficially crystallized porphyritic or even-grained granitic rocks of 1700-1500 Ma in age, with and without the classical rapakivi texture, crosscutting the surrounding older bedrock, also belong to the rapakivi granite suite (Rämö & Haapala 2005).
The mid-Proterozoic anorogenic rapakivi granites in Finland occur as four major batholiths (Åland, Laitila, Vehmaa, Wiborg) (Fig. 1) and several smaller stocks in southern Finland (Rämö & Haapala 2005). Natural stone production is located in two of the major batholiths: the Vehmaa batholith in the SW, and the Wiborg batholith in SE Finland (Selonen & Härmä 2003, Härmä et al. 2015). Finland is a world leader in the extraction of rapakivi granites; in other countries, rapakivi granites are exploited in very modest amounts.

Finnish rapakivi granites have been used in buildings and constructions since the middle of the 18th century, e.g. in St. Petersburg, Russia (e.g. Heldal & Selonen 2003a, Bulakh et al. 2011). A recent study indicates that the weathering of granite is restricted to a few millimetres depth at the stone surface and does not impact the strength or durability of the granite elements (Panova et al. 2014).

3 GEOLOGICAL OUTLINE

The Vehmaa batholith covers an area of approx. 700 km² on the Finnish geological map-sheet areas of 1041, 1042, and 1044 (Lindberg & Bergman 1993, Karhunen 2004, Väisänen 2004). It is located in the municipalities of Vehmaa, Taivassalo, and Uusikaupunki.

The batholith consists from the margins inwards of intrusions of pyterlite, coarse-grained porphyritic granite, and two types of medium-grained porphyritic granite, forming a concentric pattern (Kanerva 1928, Lindberg & Bergman 1993, Bergström 2009, Selonen et al. 2005) (Fig. 2 and Figs 3, 5, 6, 7). Small intrusions of porphyry aplite intrude the main rock types. An intrusion of even-grained granite forms a separate satellite stock at the eastern contact of the Vehmaa batholith (Kanerva 1928, Lindberg & Bergman 1993, Bergström 2009, Selonen et al. 2005) (Fig. 2). All granite types in the batholith are cut by aplite dykes.

Figure 1. Major rapakivi granite batholiths in Finland. Modified from Karell (2013).

Figure 2. Geological map of the Vehmaa batholith. Modified from Lindberg & Bergman (1993) and Selonen et al. (2005, 2011).

The age of the Vehmaa batholith has been determined as 1573 ± 8 Ma (a monazite U-Pb age of the even-grained satellite granite) and as 1582 ± 4 Ma (a zircon U-Pb age of the pyterlite) (Lindberg & Bergman 1993). These ages are in agreement with the ages of the other rapakivi batholiths in SW Finland and are slightly younger than those of the Wiborg batholith in SE Finland.

The Vehmaa batholith has intruded the older, ca 1900-1830 Ma old deformed and metamorphosed host rocks, which include mica schists, quartz-feldspar gneisses, and hornblende gneisses, as well as tonalites and K-rich granites and migmatites (Lindberg & Bergman 1993, Ehlers et al., 1993, Selonen & Ehlers 1998a, Karhunen 2004, Väisänen 2004, Suominen et al. 2006, Väisänen et al. 2012). A number of small intrusions of rapakivi granite occur to the east of the Vehmaa batholith (Väisänen 2004). It is not known if these are related to the Vehmaa batholith.
4 GRANITES OF THE VEHEMAA BATHOLITH

4.1 Pyterlite

The most common granite type in the Vehmaa batholith is pyterlite, surrounding the other main granite varieties (Fig. 2). The pyterlite has a typical rapakivi texture (Fig. 3A), comprising potassium feldspar ovoids (2-5 cm in diameter), a few of which are coated with plagioclase rims.

The main minerals in the pyterlite are potassium feldspar, quartz, plagioclase, hornblende, and biotite (Lindberg & Bergman, 1993) (Table 1). Apatite, fluorite, zircon, and opaques are found in small amounts (Lindberg & Bergman, 1993). The colour of the pyterlite varies from brown to red, within small areas, and sometimes in one and the same outcrop.

Mafic and felsic igneous enclaves, and supracrustal xenoliths as well as composite aplite and pegmatite dykes (a few centimetres to ½ metre wide) and quartz veins occur in the pyterlite (Selonen et al. 2005).

The pyterlite is typically very sparsely fractured with an orthogonal fracture pattern (Selonen et al. 2011). The spacing of the vertical fractures is several metres (up to 10 metres in the northern parts of the batholith) (Fig. 4). The spacing of the horizontal fractures varies from one to several metres.

4.2 Coarse-grained porphyritic granite

The coarse-grained porphyritic granite (the Lokalahti granite) occurs as an intrusion within the pyterlite (Fig. 2). It contains large, mostly euhedral, potassium feldspar phenocrysts, 2-3 cm in length with scarce ovoids (Fig. 5).

The main minerals are potassium feldspar, quartz, plagioclase, and biotite (Lindberg & Bergman, 1993) (Table 1). Chlorite, fluorite, apatite, zircon, and opaques are accessory minerals (Lindberg & Bergman, 1993). The granite is cut by occasional aplite dykes. The colour of the coarse-grained porphyritic granite is pale red or red. In places a greenish tint can be seen in the rock, caused by light green plagioclases.

Table 1. Mean mineralogical compositions of the main granite types in the Vehmaa batholith. Compiled from Lindberg & Bergman (1993).

<table>
<thead>
<tr>
<th></th>
<th>Pyterlite</th>
<th>Coarse-grained porphyritic granite (Lokalahti granite)</th>
<th>Medium-grained porphyritic granite (Taivassalo granite)</th>
<th>Even-grained granite (Vehmaa granite)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium feldspar</td>
<td>43.7</td>
<td>45.7</td>
<td>35.5</td>
<td>42.8</td>
</tr>
<tr>
<td>Quartz</td>
<td>29.3</td>
<td>32.1</td>
<td>34.1</td>
<td>34.6</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>16.6</td>
<td>16.4</td>
<td>21.5</td>
<td>15.5</td>
</tr>
<tr>
<td>Biotite</td>
<td>3.6</td>
<td>4.7</td>
<td>5.7</td>
<td>4.0</td>
</tr>
<tr>
<td>Chlorite</td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
<td>1.0</td>
</tr>
<tr>
<td>Muscovite</td>
<td>-</td>
<td>-</td>
<td>0.8</td>
<td>1.5</td>
</tr>
<tr>
<td>Hornblende</td>
<td>5.2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fluorite</td>
<td>0.3</td>
<td>0.3</td>
<td>0.9</td>
<td>0.2</td>
</tr>
<tr>
<td>Apatite</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
<td>+</td>
</tr>
<tr>
<td>Zircon</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Opaques</td>
<td>0.3</td>
<td>0.1</td>
<td>0.6</td>
<td>0.1</td>
</tr>
<tr>
<td>Others</td>
<td>0.5</td>
<td>0.2</td>
<td>0.3</td>
<td>0.1</td>
</tr>
</tbody>
</table>
Figure 4. Sparse vertical fracturing in the pyterlite in the northern parts of the Vehmaa batholith. Length of the hammer handle is 63 cm. Photo: Olavi Selonen.


Figure 5. Coarse-grained porphyritic granite (the Lokalahti granite). Source: Rock collection of the K.H. Renlund foundation.

The coarse-grained porphyritic granite is sparsely fractured with an orthogonal fracture pattern (Selonen et al. 2011). The spacing of the vertical fractures is typically several metres. Sheeting occurs with intervals around two metres. Red colorization around some fractures occurs.

4.3 **Medium-grained porphyritic granites**

An area (7 km in length and 4.5 km in width) of medium-grained porphyritic granite (the Taivassalo granite) occupies the central parts of the Vehmaa batholith (Fig. 2). The granite body is composed of two petrologically very similar, but texturally different intrusions of granite; an inner granite (IG) and a surrounding outer granite (OG) (Selonen et al. 2005) (Figs 2, 3B, and 6). The granites are separated by a barely visible, gently outward dipping sinuous contact.

Both granites consist of potassium feldspar, quartz, plagioclase, and biotite with accessory chlorite, fluorite, apatite, zircon, muscovite, and opaques (Lindberg & Bergman 1993, Selonen et al. 2005) (Table 1). Potassium feldspar phenocrysts (≤ 2 cm in length) define the porphyritic texture of the granites. Occasionally, potassium feldspar ovoids are found.

The two granites have a slight difference in texture (Figs. 3B and 6). In the outer granite (OG), the potassium feldspar grains occur as clusters in a net-like texture, while in the inner granite (IG) the potassium feldspars are found mainly as separate, evenly distributed euhedral grains (Selonen et al. 2005). The colour of the granites is red with slight variations towards pale red.

Small mafic enclaves and lens-shaped or rounded aplitic felsic inclusions (< 50 cm in mean diameter) occur sometimes in the granites. Miarolitic cavities (with crystal growth) are in places found in the inner granite. Occasional magmatic flow-structures and mafic layer-like schlieren (“ladder dykes”, Karell et al. 2009) rich in biotite occur along the southeastern and southern margins of the outer granite.

4.4 **Even-grained granite**

A coherent body of even-grained granite (4 km in width, 4.5 km in length) can be found at the eastern margin of the Vehmaa batholith as a satellite intrusion (Fig. 2). In geological descriptions this granite has been denoted as the Uhlu granite (e.g. Lindberg & Bergman 1993). In this report we use the nomination “Vehmaa granite”, which is commonly adopted within the stone sector.

The fine-grained, intensely red Vehmaa granite (Fig. 3C) has potassium feldspar, quartz, plagioclase, and biotite as the main minerals (Lindberg & Bergman, 1993) (Table 1). Occasional small intrusions and dykes of aplite, single small mafic inclusions as well as greisen-like veins occur in the granite. Furthermore, miarolitic cavities with
crystal growth are sometimes found. The marginal zones of the granite are characterized by biotite clusters and patches (Lindberg & Bergman 1993).

The fracturing of the Vehmaa granite is orthogonal or in places multi-directional (Selonen et al. 2011). The maximum spacing of the vertical fractures is 3-4 m. Reddish colouring around some fractures is observed. Other types of even-grained granites are found as separate small intrusions in the pyterlite.

4.5 Porphyry aplite

A porphyry aplite is mostly found around the margins of the Vehmaa batholith or in the marginal zones between the different types of granite (Lindberg & Bergman 1993) (Fig. 2). In places, the porphyry aplite can even be found outside the batholith in the host rock near the contact (Fig. 2). Also in the southern part of the Vehmaa satellite granite intrusion, a distinct area of porphyry aplite can be found (the Riittiö granite) (Fig. 2).

The porphyry aplite is a granite variety with unevenly distributed unmantled ovoids and feldspar phenocrysts in a fine or medium-grained matrix (Fig. 7). Grey and red types of porphyry aplite are reported (Bergström 2009). The fracture pattern of the porphyry aplite is dense and diagonal (<1 m spacing). The grey types seem to be less fractured than the red ones.

5 CONTACTS OF THE VEHMAA BATHOLITH

The Vehmaa batholith cuts sharply through the older metamorphosed bedrock. The contacts against the host rocks are mostly sharp with no or very minor brecciation (Lindberg & Bergman 1993, Selonen et al. 2005, Bergström 2009, Karell et al. 2009) (Fig. 8). Also, the contacts between the different granite intrusions within the batholith are sharp. In a few outcrops sparse individual fragments of pyterlite can be observed in the intruding coarse-grained porphyritic granite at the contact zone (Bergström 2009, Selonen et al. 2011).
Most of the contacts of the Vehmaa batholith and the contacts within the batholith dip gently or moderately outwards (Kanerva 1928, Lindberg & Bergman 1993, Selonen et al. 2005, Bergström 2009, Karell et al. 2009). At the southeastern contact zone of the batholith gently dipping grey porphyry dykes occur in the surrounding gneiss. The dykes dip gently away from the batholith and form an umbrella pattern (Bergström 2009, Karell et al. 2009).

The contact relations of the granite types observed on outcrops indicate that the relative ages for the major intrusions (from the oldest to the youngest) are: pyterlite, coarse-grained porphyritic granite, and the medium-grained porphyritic granites (Lindberg & Bergman 1993, Selonen et al. 2005, Bergström 2009). The satellite intrusion on the eastern contact of the batholith appears to be younger than the pyterlite (Lindberg & Bergman 1993, Selonen et al. 2005, Bergström 2009).

6 GEOPHYSICAL OBSERVATIONS

The Vehmaa batholith, and, especially the two intrusions of medium-grained porphyritic granite in the middle of the batholith, show distinct aeromagnetic patterns (Selonen et al. 2005, Karell et al. 2009, Selonen et al. 2011, Karell 2013) (Fig. 9). The difference in magnetic susceptibility between the two granites is caused by a higher magnetite content in the inner granite (Karell et al. 2009).

The anisotropy of magnetic susceptibility (AMS) can indicate internal structures within granitic intrusions such as magma flow or other structures related to the emplacement of magmas (Karell et al. 2009, Karell 2013). An AMS study in the Vehmaa batholith shows that magnetic fabrics (lineation and foliation) are well-developed in the inner granite (Karell et al. 2009). The outer granite is defined by poorly developed magnetic

Figure 9. Aeromagnetic map of the Vehmaa batholith. Modified from Karell (2013).
lineations, while the magnetic foliations are better developed (Karell et al. 2009).

7 INTRUSION OF THE GRANITES OF THE VEHMAA BATHOLITH

The AMS data with the magnetic fabric directions, the concentric structure of the batholith (with the relatively youngest granite varieties closer to the centre of the batholith) in combination with mainly outward dipping contacts, the general absence of breccia structures, and the gently outward dipping dykes along some of the outer granite contacts, implies a collapse-type succession of intrusions of relative small pulses of magma (Selonen et al. 2005, Bergström 2009, Karell et al. 2009, Selonen et al. 2011, Karell 2013) (Fig. 10).

Geochemical data (Karell et al. 2009) indicates that the outer (OG) porphyritic medium-grained granite is more fractionated than the inner granite (IG) and could have been intruded after the inner intrusion. This could imply that the collapses and related small intrusion pulses took place as single events at different times when blocks of older gneisses and volcanic rocks as well as earlier intrusions of granite progressively subsided downwards, causing intrusion of repeated pulses of subhorizontal sheet intrusions of granite.

The large rapakivi batholiths on Åland islands and southeastern Finland (Fig. 1) are associated with superficial volcanic rocks along their margins, and it is probable that most rapakivi batholiths can be considered as shallow crustal magma chambers, with or without associated volcanic activities. When a collapsing caldera develops by successive phases of eruption and cauldron subsidence, blocks of the overlying gneiss roof subside into the underlying magma chamber. Different fractioned magma pulses intrude as subhorizontal sheets, and finally build up the granite batholith (Selonen et al. 2005, Bergström 2009, Karell et al. 2009, Selonen et al. 2011, Karell 2013).

Figure 10. Intrusion mechanism for the Vehmaa batholith. See text for explanation. Modified from Selonen et al. (2011).

8 FRACTURE ZONES AND FRACTURES

The main fracture zones in and around the Vehmaa batholith appear as major topographical lows as well as straits and offings in the sea areas. The dominant direction of the major fracture zones is NW-SE, with a few zones with a direction of W-E or SW-NE (Lindberg & Bergman 1993) (Fig. 11). These fracture zones show no or only minor lateral offsets. Inside the batholith, these zones cut through all the rock types in the batholith.

The same three large scale fracture directions can be defined by the help of LiDAR data, topographical maps, and geophysical maps within the body of the medium-grained porphyritic granites in the middle of the Vehmaa batholith (Selonen et al. 2011) (Fig. 12).

In outcrop scale a characteristic orthogonal fracture pattern can be observed in most of the granites of the Vehmaa batholith with two vertical fracture directions perpendicular to each other accompanied with well-developed sheeting (Fig. 13). According to Lindberg & Bergman (1993) the main direction of vertical fractures on outcrops is SW-NE (the direction perpendicular to that direction is NW-SE, which means that the fractures in outcrop scale have the same directions as the major zones). Typically, the coarse-grained rocks in the Vehmaa batholith are less fractured than the finer grained varieties.

The knowledge of fracture zones and fractures is important in several ways for exploration, site assessment, and quarrying of natural stone (e.g. Selonen et al. 2014, Luodes 2015). During exploration, it is useful to observe that the bedrock is typically fragmented into macroscopic blocks bordered by larger shear zones, fault zones and

Figure 11. The main fracture zones in the Vehmaa batholith. Modified from Lindberg & Bergman (1993).
Figure 12. The main fracture zones in the medium-grained porphyritic granite body. The measured direction of the present principal horizontal rock stress in two areas is indicated. LiDAR data as background. Modified from Mononen (2005) and Selonen et al. (2011).

fracture zones, which could have been repeatedly reactivated during the geological history (e.g. Mattila & Viola 2014). The rock areas between the zones remain sparsely fractured and intact and often indicate potential for natural stone resources. In evaluation of outcrops, besides the appearance of stone, the fracturing is the most important criterion for a rock suitable for natural stone. The spacing of fractures should allow extraction of large blocks (2-15 m³) for production. The regular and sparse orthogonal fracture pattern of many granites (without diagonal fracturing) is as such beneficial for production of the rectangular blocks. The existing fracture pattern could also be utilized in the quarrying process, e.g. using one vertical fracture direction as a free end when detaching the primary block.

9 TOPOGRAPHICAL FEATURES AND FORM OF THE ROCK OUTCROPS IN THE VEHMAA BATHOLITH

The present topography in the Vehmaa batholith is an expression of the pre-glacial structural features of the bedrock and the subsequent glacial erosion during the last ice age. The erosional force of the ice (glacial quarrying) exploited especially the pre-existing fracture zones in the same direction as the movement of the ice, i.e. the NW-SE direction, and the zones can now be seen as marked topographical lows.

The topographical features can used as a tool in practical exploration for natural stone, because the local topography mirrors the frequency and type of fracturing (soundness) of the bedrock and can be seen as an indicator of potential natural stone resources (Selonen et al. 2014). Two main types of topographic relief can be distinguished in the Vehmaa batholith (Selonen et al. 2011).
9.1 Terraced outcrops

Relatively high and large plateau-like terraced outcrops rise 25-30 metres over the surrounding area, appearing as distinct highs in the landscape (Selonen et al. 2011). This type of outcrops are often composed of sparsely fractured and massive granite with a regular pattern of fractures. The outcrops are associated with a well-developed sheeting, giving the outcrops a terraced shape (Fig. 14A). The terraced outcrops are often bordered by vertical fracture zones forming topographical lows, which can be seen, e.g. in the SW part of the medium-grained porphyritic granite body. This type of relief is a good indicator for prospect for natural stone (Selonen et al. 2014).

9.2 Low and flat outcrops

Relatively low and flat outcrops are only 5-10 m higher than the surrounding areas (Selonen et al. 2011) (Fig. 14B). These outcrops cover vast areas. The vertical fracturing is very widely spaced, but a dense sheeting and an intense subhorizontal penetrative micro fracturing, reaching down to several metres (partly peeled off by glacial erosion) can often be observed. This type of relief could imply potential for natural stone, but a superficial dense sheeting and micro fracturing must be always evaluated (Selonen et al. 2014).

Small (area less than a hectare) and relatively high outcrops are found in parts of the Vehmaa batholith. They are often too densely fractured to be suitable as natural stone (Selonen 1998).

10 BEDROCK STRESS FIELD

Fractures that we presently observe on outcrops (Fig. 13) have been formed in response to deformation after the rock has been solidified from molten rock material (magma). The main cause of deformation has been the prevailing stress field, paleostress, at given times after rock solidification, but the bedrock is still today under constant stress. This stress is mainly caused by plate tectonic forces, which means that the earth crust is composed of lithospheric plates which move in relation to each other. The movements causes stress (horizontal compression) within the plates. In Finland, the tectonic stress is due the extension along the mid-Atlantic ridge between the North American and Eurasian plates, causing a principal horizontal lithospheric stress in WNW-ESE direction in the Finnish bedrock (Mononen 2005).

Rock stress has been measured in two sites within the outer intrusion of the medium-grained porphyritic granite (Mononen 2005, 2006) (Fig. 12). The measurements were done by the Minifrac hydraulic fracturing system. The direction of the
The principal horizontal stress in the southeastern parts of the body is $170^\circ$ and in the northeastern parts $120^\circ$ (Mononen 2005, 2006) (Fig. 12), which is in accordance with other reported stress directions in Finland.

Directions of the local rock stress should be known in quarrying, because a high rock stress can, e.g. cause deformation (creep) of the lower parts of the horizontal sheets (Fig. 15), compress the drill holes (Mononen 2005, Selonen et al. 2012), and challenge the use of, e.g. diamond wire sawing (vertical sawing perpendicular to the main horizontal stress direction). With a proper knowledge of the rock stress directions, the quarry planning can be correctly executed and the correct preventive measures to manage the stress undertaken (e.g. placing slot drilling lines in suitable locations perpendicular to the main horizontal stress direction) (Mononen 2005).

11 NATURAL STONE PRODUCTION IN THE VEHMAA BATHOLITH

11.1 Vehmaa granite

The rocks of the Vehmaa batholith have been extracted since the end of the 19th century. Modern quarrying started in the even-grained Vehmaa granite around the village of Uhlu in 1901 (Vähäkangas 2000) (Fig. 16). The granite was commercially named “Balmoral Red” reportedly inspired by the Balmoral Castle in Scotland (Vähäkangas 2000) (see, cover photo). The granite has been quarried by several companies from a number of quarries throughout the granite body (Fig. 16). The export of the stone to many countries, e.g. to Scotland, commenced soon after the start of the quarrying (see, e.g. Brown (1949) for applications in Australia). The granite has been used for all applications both outdoors and indoors, and especially for monuments (see, App. 4.).

Today, the Vehmaa granite is commercially known as “Balmoral Red fine-grained” (Fig. 3C) and can be quarried in three licenced areas (Fig. 16). The granite is in use in Finland, but also exported, e.g. to Italy, France, and the Far-East countries.

11.2 Taivassalo granite

The quarrying of the medium-grained Taivassalo granite commenced in 1905 in the Helsinki village along the shoreline in the western part of the granite body (Vähäkangas 2000) (Fig. 17). The first quarries were established in the OG type, resembling closely the Vehmaa granite, except for a slightly coarser grain size. This granite type became commercially attractive, and additional quarries were later opened along the southern border of the granite body (Fig. 17). The IG type remained commercially less interesting. The Taivassalo granite was sold under the name of “Balmoral Red” together with the Vehmaa granite and was exported extensively. For a period of time, a rare light red variety of the granite was marketed under the commercial name of Järppilä Rosa. The Taivassalo granite has been utilized in a number of applications; facing stone, interior decorations, monuments, environmental stone etc. (see, App. 4.).
Figure 16. Location of all quarry sites in the Vehmaa granite. Open square = licenced quarry, square with slash = abandoned quarry. See also Vehmaan Kotiseutuyhdistys (1995).


Figure 17. Location of all quarry sites in the Taivassalo granite. Open square = licenced quarry, square with slash = abandoned quarry.

Today, the Taivassalo granite is commercially known as “Balmoral Red coarse-grained” (Fig. 3B). There are six licenced areas for quarrying, mainly in the outer granite variety (OG) (Figs 17 and 18). The granite is used domestically and exported, e.g. to Italy, Poland, France, and the Far-East countries.

11.3 Pyterlite

During the 1970’s, brown pyterlite was quarried in the Kiimkallio area in the northern part of the batholith (Fig. 2). The stone has been used, e.g. for the annex of the Finnish Parliament House in Helsinki, built in 1978 (see, App. 4). Later, the brown pyterlite has been quarried under the commercial names of “Antique Brown” in the village of Puotila (Fig. 2), and “Mustangi” in the Hyövelä village (Fig. 2). Today, all these quarries are closed.

Presently, there is one licenced quarry area for brown pyterlite in the Vehmaa batholith, located in the village of Marjus in the southeastern part of the batholith (Figs. 2 and 3A). Commercial name of the stone is “Esko Brown”. It has been used in many applications mostly in Finland, but also abroad as facing stone (see, App. 4).

11.4 Geotechnical features of the Balmoral Red granites

The physical properties of the Balmoral Red granites (Table 2) indicate high durability and good resistance to weather and wear. Hence, they have been used for all purposes both indoors and outdoors, and no durability problems have been reported, including the oldest installations of the material.

Figure 18. Hydraulic splitting of semi-finished block in the Taivassalo granite. Photo: Carl Ehlers.

The high durability of the granites is defined by the typical silicate mineral composition (Table 1) with the absence of sulphides and only a few soft minerals (such as biotite) in combination with the homogeneity of the rock, the general microscopic soundness, and the relatively fine grain size. The homogeneity of the rapakivi granites with no preferred mineral orientation implies that the durability properties are isotropic, i.e. fairly equal in all directions of the stone. The comparatively fine grain size together with the high content of quartz (hardness) gives the stones good ability to accept glossy polishing. The granites are unweathered, the fracturing is mainly orthogonal, and the cleavability is good (Table 2). For geotechnical features of natural stones in general, see Siegesmund & Snethlake (2014).

### Geotechnical Control of Natural Stone Deposits in the Vehmaa Batholith

All natural stone deposits are located in sites and areas where a combination of geological conditions are favourable for formation of an isotropic and structurally sound rock (e.g. Selonen 1998, Luodes et al. 2000, Selonen et al. 2000, Carvalho et al. 2008, Heldal et al. 2008, Arponen et al. 2009, Selonen et al. 2011, Selonen et al. 2012, Cárdenes et al. 2014, Selonen et al. 2014). Geological factors like the metamorphic grade in the area, the magmatic intrusion history, and the brittle deformation history can control the location of deposits. Several geological features, interacting both on regional and local scale are required in

<table>
<thead>
<tr>
<th>Colour variations</th>
<th>Balmoral Red coarse-grained</th>
<th>Balmoral Red fine-grained</th>
<th>Esko Brown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polishability</td>
<td>Small</td>
<td>Good</td>
<td>Fair</td>
</tr>
<tr>
<td>Resistance to weather</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Durability</td>
<td>High</td>
<td>Orthogonal</td>
<td>High</td>
</tr>
<tr>
<td>Fracturing</td>
<td>Orthogonal</td>
<td>Orthogonal, occasionally diagonal</td>
<td>Orthogonal</td>
</tr>
<tr>
<td>Cleavability</td>
<td>Good</td>
<td>Very good</td>
<td>Fair</td>
</tr>
<tr>
<td>Weathering</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Availability</td>
<td>Good</td>
<td>Good</td>
<td>Quarried on demand</td>
</tr>
<tr>
<td>Surface treatments</td>
<td>Polished, matt, shot blasted, flamed, bush hammered, split</td>
<td>Polished, matt, flamed, bush hammered, split</td>
<td>Polished, matt, shot blasted, flamed, bush hammered, split</td>
</tr>
<tr>
<td>Water absorption (%)</td>
<td>EN 13755 0.12</td>
<td>0.09</td>
<td>0.14</td>
</tr>
<tr>
<td>Apparent Density (kg/m³), EN 1936</td>
<td>2640</td>
<td>2630</td>
<td>2680</td>
</tr>
<tr>
<td>Flexural strength (MPa), EN 12372</td>
<td>13.4</td>
<td>14.3</td>
<td>12</td>
</tr>
<tr>
<td>Frost resistance, change of flexural strength* (%)</td>
<td>EN 12371 -3.7</td>
<td>-1.4</td>
<td>6.7</td>
</tr>
<tr>
<td>Compressive strength (MPa), EN 1926</td>
<td>171</td>
<td>207</td>
<td>176</td>
</tr>
<tr>
<td>Abrasion resistance (mm³), EN 14157</td>
<td>17</td>
<td>16</td>
<td>17</td>
</tr>
<tr>
<td>Breaking load at dowel hole (N), EN 13364</td>
<td>2350</td>
<td>2500</td>
<td>2450</td>
</tr>
</tbody>
</table>

*after 48 cycles
order to produce a rock of economically viable quality.

Being homogeneous and sparsely fractured rocks the rapakivi granites have generally a high general potential for natural stone. In the Vehmaa batholith all the granite types are well-suited for natural stone, except for the porphyry aplite which is too densely fractured for production (Selonen & Ehlers 1998b, Selonen et al. 2011) (see, App. 2). Still, the deposits are concentrated only in the outer Taivassalo granite and in the Vehmaa granite (Selonen et al. 2011), because only these granite intrusions have had a commercially interesting colour and appearance. The location of the economically useful natural stone deposits with bright-coloured stone qualities are confined to distinct intrusion phases that can be identified by a thorough geological study of the intrusion history of the batholith (Selonen et al. 2011).

The knowledge of the geological controls on localization of natural stone deposits is important as it can be applied in the exploration for natural stone (Selonen et al. 2011, Selonen et al. 2014). Geological environments with potential for deposits can be pre-determined and the information can be used in creating geological exploration models for efficient prospecting.

13 LEFTOVER STONES

Quarrying of granite produces rock material, which cannot be directly used as primary products of the quarry (Romu 2014). The bedrock can be too densely fractured in parts of the quarry or the appearance of the stone too heterogeneous for production. The leftover material is stored in the quarry area for later use.

The granitic leftover is composed of the same rock as the primary product and is an inert material (Luodes et al. 2011). Its technical quality is the same as that of the production stones (Luodes et al. 2012). The granite leftover does not contain ore metals (e.g. sulphides), and because of its siliceous composition no leaching occur. The stored granitic leftover blocks pose no risk to the environment or to the human health (Heikkinen et al. 2007, Luodes et al. 2012).

The granite leftover is mostly used in aggregate production (concrete production, road constructions**, as foundations of buildings etc.), in environmental construction (rubble walls, road embankments, yards and parks etc.), water construction (armourstone and other harbour structures, water treatment dams etc.), and in industrial production of quartz and feldspar (Romu 2014).

We estimate that the production of granite over decades has generated 15-16 M tons of leftover stone at the quarries in the Vehmaa batholith. Several studies have been conducted on that material and they all show that the technical quality of the leftover (Table 3) enables the use of it in all the applications mentioned above (Sunnitteluveskus 1993, GeoUnion 1996, Selonen & Ramsay 2002, Vuorinen 2002, Luodes et al. 2012). The main product for the leftover stone from Vehmaa batholith has so far been rock aggregate from the Uhlu quarry (with periods of production when all the leftover material from the production was used) (Fig. 19A). The leftover has also been used for water constructions, armourstones, noise barriers, playgrounds, environmental constructions, gabions etc. (Figs 19B and 19C). Some of the leftover blocks are suited for, e.g. monument design as such (Fig. 19D).

The main challenge for use of the leftover stone from the Vehmaa batholith is the high cost for transport. The distance to the major cities in the area is today still too long for economical use of the leftover material. See also Aatos (2003), Heldal & Selonen (2003b), Räisänen et al. (2007) and Alexandrova (2014).

** It is worth noting that aggregate made from granitic leftover can be utilized in addition to use as bound base course in roads, also in asphalt in built-up areas (speed limit less than 60 km/h) with low traffic impact (average daily traffic of, e.g. 500-2500 vehicles) (Vuorinen 2002).
Table 3. Aggregate properties of leftover stones in the Vehmaa batholith. NBM = Nordic Ball Mill (%), PLI = Point Load Index (MPa), FL = Flakiness (%), SIT = Swedish Impact Test (%), LA = Los Angeles value. See also Table 1. Adopted from Vuorinen (2002), except for the LA value for Balmoral Red fine-grained which is from GeoUnion (1996).

<table>
<thead>
<tr>
<th></th>
<th>NBM</th>
<th>PLI</th>
<th>FL</th>
<th>SIT</th>
<th>LA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balmoral Red coarse-grained</td>
<td>19.0</td>
<td>7.0</td>
<td>13</td>
<td>33.8</td>
<td>35.5</td>
</tr>
<tr>
<td>Balmoral Red fine-grained</td>
<td>19.6</td>
<td>8.4</td>
<td>9</td>
<td>30.0</td>
<td>35.6</td>
</tr>
</tbody>
</table>


14 LANDSCAPING AND AFTER-USE OF QUARRIES

A visible effect of granite extraction is alteration of landscape. With good quarry planning and proper landscaping the impact can be managed (Romu 2014). In landscaping, safety for human health and environment is the main issue (Romu 2014). When extraction has ceased all hazardous and inappropriate materials (buildings, machinery, scrap etc.) are removed from the quarry area. Previously removed topsoil is used for reforestation. Blocks of leftover stone are used as barriers to prevent access to the abandoned quarry (Fig. 20).

When the landscaping operations are approved by the authorities, the quarry is free for after-use. Granite quarries have unique features that are not found in ore mines or in aggregate quarries. These include stable vertical quarry faces and stable horizontal quarry benches, piles of leftover stone, and a water pond at the quarry. These features can be utilized as key elements in creating an after-use; they also imply physical safety and good slope stability of the quarry (Lintukangas & Suihkonen 2010, Lintukangas et al. 2012).

There are several ways to bring new life to an old quarry (Lintukangas & Suihkonen 2010, Lintukangas et al. 2012). Options include, e.g. forestry, freshwater reservoirs, crab and fishing ponds, and recreational (leisure, climbing, swimming, scuba diving, amphitheatre, nature), or industrial areas. The quarry can also be turned into a geological or scientific-historical sight, giving information on the natural history of the area or cultural heritage of the stone industry. Furthermore, the xerothermic surfaces of old quarries create habitats for, e.g. bees and butterflies; the abandoned quarry areas can provide new environments for the endangered species. Selected options from the Vehmaa batholith can be seen in Figure 21.

15 CONCLUDING REMARKS

The quarrying of granite in the Vehmaa batholith started in 1901. Balmoral Red granites became an essential material for the Finnish stone industry. Today, the granites can be seen in many buildings as facing material and interior stone all over the world. The stones also constitute a central part of our built stone heritage in Finland. They have a steady demand in the present international market place for natural stone.

The geotechnical properties of the Balmoral Red granites are excellent, with high durability and good resistance to weather and wear. The granites have been used in many applications, ranging from building projects to interior decoration, tiles and monuments with no reported durability problems. They have a long service life and minimal needs for maintenance, contributing to a sustainable way of construction. The known reserves of Balmoral Red granites are sufficient for decades to come, including material for restoration and replacement.

Figure 20. Utilization of leftover blocks in inhibiting the admittance to a landscaped quarry in the Vehmaa batholith. Photo: Olavi Selonen.


ACKNOWLEDGEMENTS

This report is dedicated to the memory of our co-author geologist Mr Hannu Luodes, remembering the pleasant cooperation over the past 25 years. Mr Erkka Lehto (formerly Palin Granit Oy, Baltic Granit Oy, and Lehdon Kiviiliike Oy) and Mr Ismo Kainu (formerly Finska Stenindustri Ab, Granicon Oy, and Sinocraft Oy) gave invaluable information on quarrying of stone in the Vehmaa batholith (Erkka especially for the Kiimkallio area). Managing director Mr Mikko Paljakka (Loimaan Kivi Oy) provided information on the references of Balmoral Red and Esko Brown. Their contributions are highly appreciated.

Geologists Mr Heikki Pirinen (GTK, Kuopio) and Mr Risto Varritainen (GTK, Rovaniemii) are thanked for technical help during making the report. Ms Kirsti Keskiisaari (GTK, Espoo) and Mr Harri Kuvonen (GTK, Espoo) are acknowledged for preparing maps and figures. Finally, we thank the Finnish Natural Stone Association for the possibility to publish this report.

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YHTEENVETO: VEHMAAN RAPAKIVIGRAANIITTIALUEEN RAKENNUSKIVET

Johdanto


Vehmaan graniittialueen tärkeimmät yleispiirteet


Vehmaan graniittialueen yleispiirteitä


Vehmaan graniittialueen geologiasta ja rakennuskivistä

Vehmaan graniittialueen yleispiirteitä

Vehmaan graniittialueen yleispiirteitä


Vehmaan graniittialueen geologiasta ja rakennuskivistä

Vehmaan graniittialueen yleispiirteitä

Vehmaan graniittialueen yleispiirteitä

Vehmaan graniittialueen yleispiirteitä

Vehmaan graniittialueen yleispiirteitä

Vehmaan graniittialueen yleispiirteitä
Pyterliitillä on tyyppillinen rapakiven rakenne; siinä esiintyy pyöreitä kalimaasälpähajarakeita eli ovoideja (2-5 cm halkaisijaltaan), joita paikoin kehys- tää plagioklaasireunus (Kuva 3A). Pyterliitin päämineraalit ovat kalimaasäläpä, kvartsi, plagioklaasi, särivälke ja biotiitti, lisäksi tavataan fluoritit, apatitit ja zirkonia sekä opaakkeja (Taulukko 1).


Lokalahden graniitti


nöllisesti rakoille kalliopaljastumat ovat topografialtaan usein korkeakohojen ja terassimaisia (Kuva 14A). Vaakarakojen välillä on keskimäärin noin kaksi metriä, mutta voi olla kalliopintaosissa tiheämpä. Pystyrakojen välillä on puolestaan noin kolme metriä. Rakojen lähisyysdissä tavataan paikoin punertavaa värísäyvää. Rakoilun tyyppisissä tai tiheydessä ei ole havaittu eroavaisuuksia sisemmän ja ulomman granititri-eriteuvaisuukseilla.

Taivassalon granitissa havaitaan paikoin kalliopintaan, yleisesti rakoille kalliopaljastumisia (Kuva 14A). Vaakarakojen väli on keskimäärin noin kaksi metriä, mutta voi olla kallion pintaosissa tiheämpi. Paikoin porfyyriapliittia tavataan jopa granititri-eriteuvaisuuteen leikkaöljyn ympäröiviä kivilajeja (Kuva 2). Myös Vehmaan granitiin eteläosassa esiintyy erillinen porfyyriapliittiin muodostuma (Riittiön graniti) (Kuva 2).

Porfyyriapliitit

Porfyyriapliittia esiintyy usein eri granititri-eriteuvaisuuksesta tai koko granititri-eriteuvaisuudesta tai vanhempaa kallioperää vastena (Kuva 2). Paikoin porfyyriapliittia tavataan jopa granititri-eriteuvaisuuteen leikkaöljyn ympäröiviä kivilajeja (Kuva 2). Myös Vehmaan granitiin eteläosassa esiintyy erillinen porfyyriapliitit muodostuma (Riittiön graniti) (Kuva 2).

Porfyyriapliitti on pieni- tai keskirakenteinen. Siinä esiintyy säännöttömiä kalimaasälpiä- ja plagioklaasihajarakeita (Kuva 7). Porfyyriapliitit ovat harvinaisia kallioperää vasten (Kuva 2). Myös Vehmaan granitiin eteläosassa esiintyy erillinen porfyyriapliitit muodostuma (Riittiön graniti) (Kuva 2).

Vehmaan graniitti

Vehmaan granititri-eriteuvaisuudessa esiintyy yhtenäinen, noin 4 km leveä ja noin 4,5 km pitkä muodostuma tasarakeista granitit (Kuva 2). Geologisessa kirjallisuudessa granititista käytetään nimitystä Uhlun graniti. Vehmaan graniti, koska kivi tunnetaan rakennuskivialalla yleisesti sillä nimellä.

Vehmaan granititri-eriteuvaisuus esiintyy tyypillisesti harmaasta punaiseen. Harmaat tyypit vaikuttavat olevan harvemmin rakoilleita kuin punaiset muunnokset.

Kivilajien rakennuskiviominaisuuksia esitetään liitteessä 2.

Rakennuskiven tuotanto

Vehmaan granitti

Tänä päivänä Vehmaan graniitin kaupallinen nimi on ”Balmoral Red fine-grained” eli Vehmaan punainen (Kuva 3C). Louhintaluvut ovat voimassa kolmella alueella (Kuva 16). Kiveä käytetään kotimaassa ja viedään esim. Italiaan, Ranskaan ja Kauko-Idän maihin.

Taivassalon graniitti


Pyterliitti


Ruskeassa pyterliitissä on tänä päivänä louhintaluvut voimassa yhdelä alueella, joka sijaitsee Taivassalon Marjustenrannassa (Kuva 2). Kiven kaupallinen nimi on ”Esko Brown” eli Taivassalon ruskea (Kuva 3A). Kiveä on käytetty mm. oopperatalon julkisivussa Helsingissä, Vantaan kirjastotalon rakennuksessa ja Paraisten kaupungintalossa sekä viety ulkomaille.

Liitteessä 5 esitetään Vehmaan graniittialueen rakennusvärien käyttökohteita.

Balmoral Red -graniittien geoteknisä ominaisuuksia


Balmoral Red -graniittien hyvät kestävyysominaisuudet ovat seurausta mm. niiden mineraalikoostumuksesta (Taulukko 1), homogeenisuudesta ja raekoosta. Kittovue on koostunut myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suuresti myös suurest...
Sivukivet

Rakennuskiven louhinnassa syntyy tuotantoon sopimattomina ns. sivukiveä, joka joudutaan varastomaan louhimoiden läheisyyteen. Sivukivi ei täytä tuotteleelle asetettuja korkeita laatuvastuuksia. Se voi olla ulkonäöllisesti vaihtelevaa tai kooltaan liian pientä.

Granitiitten sivukivi on materiaalina inerttiä eli pysyvää ja koostuu samasta kiviaineksesta kuin varsinaisen tuotantokivikin. Se on mekaanisilta ja fysikaalisilta ominaisuuksiltaan hyvin samankaltainen varsinaisen tuotantokiven kanssa. Se ei sisällä malmimineraaleja, ja johtuen tyypillisestä silikaattisesta mineraalikoostumuksesta liukene mistä ei tapahdu. Sen varastoinnista tai itse sivukivilohkareista ei aiheudu haittaa ympäristölle tai ihmisen terveydelle.

Sivukiven käyttökohteina voivat olla esim. kiiviaineskäyttö, ympäristöraakentamisen kohteet, tien- ja radan rakentaminen, vesi- ja sataman rakentaminen, patojen verhoilu, hiekoitus, betonin valmistus sekä teollisuusmineraalien raaka-aine (kvartsi, maasälpä). Sivukiviä hyödynnetään myös louhimon elinkaaren aikana ottamisalueen teiden, varasto- ja lastausalueiden rakentamiseen.

Arvioimme, että vuosikymmeniä pitkää tuotantoa on tuottanut 15-16 milj. tonnin sivukivivarastot Vehmaan granittoalueen louhimoille. Sivukiven käyttön tehostamisesta on alueella tehty useita erilisiä selvityksiä. Tehdyt tutkimukset osoittivat, että alueen sivukivet soveltuvat parhaiten vesialustuksen rakentamiseen sekä teollisuusmineraalien alkutosien tai sukelluspaikkojen rakentamiseen. Sivukiven käyttö on kevyt ja rentoiluinen elinympäristö, jota voidaan käyttää muun muassa avonavutöissä, avolin ja urheilutiloissa.

Louhimoiden jälkikäyttö


Esimerkkejä Vehmaan granittoalueen vanhojen louhimoiden jälkikäytöstä esitetään Kuvassa 21.
APPENDICES

Appendix. 1. Licensed areas for natural stone extraction in Finland and the main natural stone companies operating within the Vehmaa batholith.

NATURAL STONES
Quarries in Finland 2015

Lithology
- Caledonian tectonic units
- Mainly Neo- and Mesoproterozoic sediments
- Mesoproterozoic rapakivi granites
- Paleoproterozoic igneous rocks
- Paleoproterozoic schists
- Archean rocks

Stone types
- Red granite
- Brown granite
- Grey granite
- Green granite
- Black granite
- Multicoloured granite
- Schist
- Marble
- Soapstone

Palin Granit Oy www.palinggranit.com
Finska Stenindustri Ab www.finskastone.fi
SKT-Granit Oy (Vientikivi Finland Oy) www.sktgranit.fi
Lännen-Graniti Oy www.lannengraniti.fi
Kivipalvelu Eikka Lahti Oy kivipalvelulahti.mobisites.fi
JJ Granitetti Ay www.jj-graniitti.fi
Granikka Oy www.granikka.com
### Appendix

2. The main geological properties of the granite types of the Vehmaa batholith in assessment for natural stone suitability. Based on this study, Selonen & Ehlers (1998b), and Selonen et al. (2011). See also App. 3.

<table>
<thead>
<tr>
<th>Granite type</th>
<th>Fracturing</th>
<th>Colour</th>
<th>Inconsistencies in appearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyterlite</td>
<td>-Orthogonal fracture pattern.</td>
<td>-Brown colour with variations towards red.</td>
<td>-Mafic and felsic igneous enclaves, supracrustal xenoliths, composite aplite and pegmatite dykes, quartz veins.</td>
</tr>
<tr>
<td></td>
<td>-Up to 10 metres spacing of vertical fractures.</td>
<td>-Greenish pyterlite occurs.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-Spacing of horizontal fractures from one to several metres.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lokalahti granite</td>
<td>-Orthogonal fracture pattern.</td>
<td>-Pale red colour with slight variations.</td>
<td>-Red colorization around some fractures.</td>
</tr>
<tr>
<td></td>
<td>-Spacing of vertical fractures typically several metres.</td>
<td></td>
<td>-Occasional aplite dykes.</td>
</tr>
<tr>
<td></td>
<td>-Sheeting interval around two metres.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taivassalo granite</td>
<td>-Orthogonal fracture pattern.</td>
<td>-Red colour with slight variations towards pale red.</td>
<td>-Red colorization around some fractures.</td>
</tr>
<tr>
<td></td>
<td>-Spacing of vertical fractures in average around three metres.</td>
<td></td>
<td>-Occasional aplitic inclusions (“spots”), small mafic enclaves, and schlieren structures (“black smoke”).</td>
</tr>
<tr>
<td></td>
<td>-Horizontal fracture spacing in average around two metres, but can become denser closer to the surface.</td>
<td></td>
<td>-Occasional miorolitic cavities (with crystal growth) in the IG.</td>
</tr>
<tr>
<td></td>
<td>-No difference in fracturing style or fracture density between IG and OG.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehmaa granite</td>
<td>-Orthogonal fracture pattern, in places diagonal fracturing.</td>
<td>-Intense red colour with slight variations.</td>
<td>-Red colorization around some fractures.</td>
</tr>
<tr>
<td></td>
<td>-Maximum spacing of vertical fractures 3-4 m.</td>
<td></td>
<td>-Occasional small intrusions and dykes of aplite, single small mafic inclusions, greisen-like veins as well as miorolitic cavities with crystal growth.</td>
</tr>
<tr>
<td>Porphyry aplite</td>
<td>-Dense and diagonal fracture pattern (&lt;1 m spacing).</td>
<td>-Red or grey colour.</td>
<td></td>
</tr>
</tbody>
</table>
Appendix. 3. Requirements for suitable natural stone. Modified from Romu (2014).

**Geological requirements**
- colour and appearance of stone (one-coloured/multi-coloured)
- soundness of bedrock (block size 2-15 m³)
- size of the prospect
- mineralogy

**Technical requirements**
- physical properties (e.g. density, water absorption)
- mechanical properties (e.g. durability properties)
- production technical (quarrying/processing)

**Infrastructural requirements**
- legislation
- location of the prospect in relation environment (noise, dust, vibration, waters)
- transport connections
- availability of labour

**Commercial requirements**
- interesting appearance and colour
- price and fashion
- product selection
- market and competition
Appendix. A selection of applications where the stones from the Vehmaa batholith have been used.

**Balmoral Red Fine-Grained**

1. Pyynikki water tower, Tampere, Finland. 1929. Photo: Olavi Selonen.
22. Aleksis Kivi monument pedestal, Helsinki, Finland. 1939. Photo: Olavi Selonen.

**Balmoral Red Coarse-Grained**

23. Memorial park, Asgabat, Turkmenistan. 2015. Photo: Silkar Ltd.
35. Monuments, Mänrysoonkatu 4, Lappeenranta, Finland. Photo: Olavi Selonen.
42. Park, Uusikaupunki, Finland. Photo: Olavi Selonen.
47. Street paving, Hämeenkatu 4, Tampere, Finland. 2015. Photo: Olavi Selonen.

JÄRPPILÄ ROSA


ESKO BROWN

54. Shiroyama building, Tokyo, Japan. Photo: Palin Granit Oy.

KIIMKALLIO PYTERLITE

BALMORAL RED FINE-GRAINED
BALMORAL RED COARSE-GRAINED
JÄRPPIlä ROSA

51.

52.

53.

ESKO BROWN

54.

55.
The Vehmaa granite has been widely used as monumental stone. In 1933 a single piece of stone, weighing 60 ton (480 x 440 x 140 cm) was quarried by Lehdon Kiviliike in the Tummamäki quarry as raw material for the memorial to the Latvian national poet Rainis. The stone was later transported to Latvia, where the final carving of the monument was carried out. Upper photo: Lehdon Kiviliike Oy, 1933. Lower photo: Olavi Selonen, 2015.
