Red pyterlite from Virolahti in southeastern Finland: a unique heritage stone with a classic rapakivi texture applied in historic and modern architecture

Härmä, Paavo; Selonen, Olavi

Published in:
Episodes

DOI:
10.18814/epiiugs/2023/023021

Published: 15/09/2023

Document Version
Final published version

by Paavo Härmä[1] and Olavi Selonen[2]*

Red pyterlite from Virolahti in southeastern Finland: a unique heritage stone with a classic rapakivi texture applied in historic and modern architecture

[1]Geological Survey of Finland, P.O. Box 96, FI-02151 Espoo, Finland; *Corresponding author, *E-mail: paavo.harma@gtk.fi*
[2]Åbo Akademi University, Faculty of Science and Engineering, Geology and Mineralogy, FI-20500 Turku, Finland

(Received: June 5, 2023; Revised accepted: August 1, 2023)

https://doi.org/10.18814/epiiugs/2023/023021

The red pyterlite of Virolahti is a rapakivi granite from the large Mesoproterozoic Wiborg rapakivi granite batholith of southeastern Finland, with the typical and exclusive appearance of the rapakivi texture and with good quality as a natural stone. The extraction of Virolahti pyterlite began on a large scale during the late 1700s for the construction of the city of St. Petersburg, Russia. During the 1700s and 1800s, the pyterlite was extensively used in St. Petersburg in applications such as building foundations, river embankments, street paving, fortress structures and decorative stone. The most famous objects constructed from the pyterlite are the monolith of the Alexander Column and the columns of St. Isaac's Cathedral. Virolahti pyterlite has been widely extracted in the Virolahti area, and a total of over one million cubic metres were exported to St. Petersburg. The pyterlite is an important part of history, as the objects in which the stone has been applied in St. Petersburg belong to a UNESCO World Heritage Site. Today, Virolahti pyterlite is extracted under the commercial name Carmen Red. The stone has been marketed and exported for use in several applications around the world, especially in countries of the Far East and Europe. Among the modern objects constructed using the pyterlite are numerous façades of skyscrapers, including the Central Daily Newspaper Building in Seoul, Korea, and the Arco Tower in Los Angeles, USA. The pyterlite area is still important in the natural stone market, and over a wider area than only Finland. Virolahti pyterlite meets all the criteria for designation as a Heritage Stone presented by the IUGS Subcommission on Heritage Stones. It has been applied in significant works (in a UNESCO World Heritage Site), used in large quantities in highly valuable architectural objects and quarried from 126 historical quarries. It is a focus of development for tourism infrastructure, has wide geographical use and a prolonged cultural history, and is still extracted from 11 present quarries, with global applications. Hence, we will later begin the procedure to propose Virolahti pyterlite as a candidate for designation as a Heritage Stone.

Introduction

Rapakivi granite is a special granite with a type location in the Wiborg rapakivi granite batholith of southeastern Finland. Because of its good properties as a natural stone, rapakivi granite has been used in construction in this area since the Middle Ages. The most commonly used type of rapakivi has been red pyterlite rapakivi granite from the municipality of Virolahti (Fig. 1).

The use of Virolahti pyterlite started on large scale at the end of the 1700s for the construction of the infrastructure of the city of St. Petersburg in Russia. A major part of the granite utilized in buildings and on streets and roads in St. Petersburg originated from old pyterlite quarries in Virolahti. The historical centre of St. Petersburg is inscribed on the list of UNESCO World Heritage Sites.

Today, the red pyterlite of Virolahti is extracted from several quarries for the world market for outdoor and indoor applications. The main market areas are China, Taiwan, Spain and Egypt. In addition, the pyterlite is sold in the domestic market of Finland.

Rapakivi granites are an important raw material for the Finnish natural stone industry, as they account for approximately 70% of all current granite production (Härmä, 2020). The main locus for extraction is the Wiborg rapakivi granite batholith, where wiborgite and pyterlite are the main rock types in production. These granites, exhibiting the unique and classic rapakivi texture, are used both internationally and domestically for all types of applications. The Wiborg batholith is globally an exclusive production area; extraction in the other rapakivi occurrences in the world is insignificant compared to Finnish production. Only granites from Finland with the classic rapakivi texture (*Baltic Brown*, *Carmen Red*, *Karelia Red*, and *Eagle Red*) can be found at the websites (for example, stonecontact.com, stoneadd.com and thestonecollection.com) as well as in Pivko (2003).

The geological and petrological features, historical quarries and the applications of Virolahti pyterlite were investigated with financing

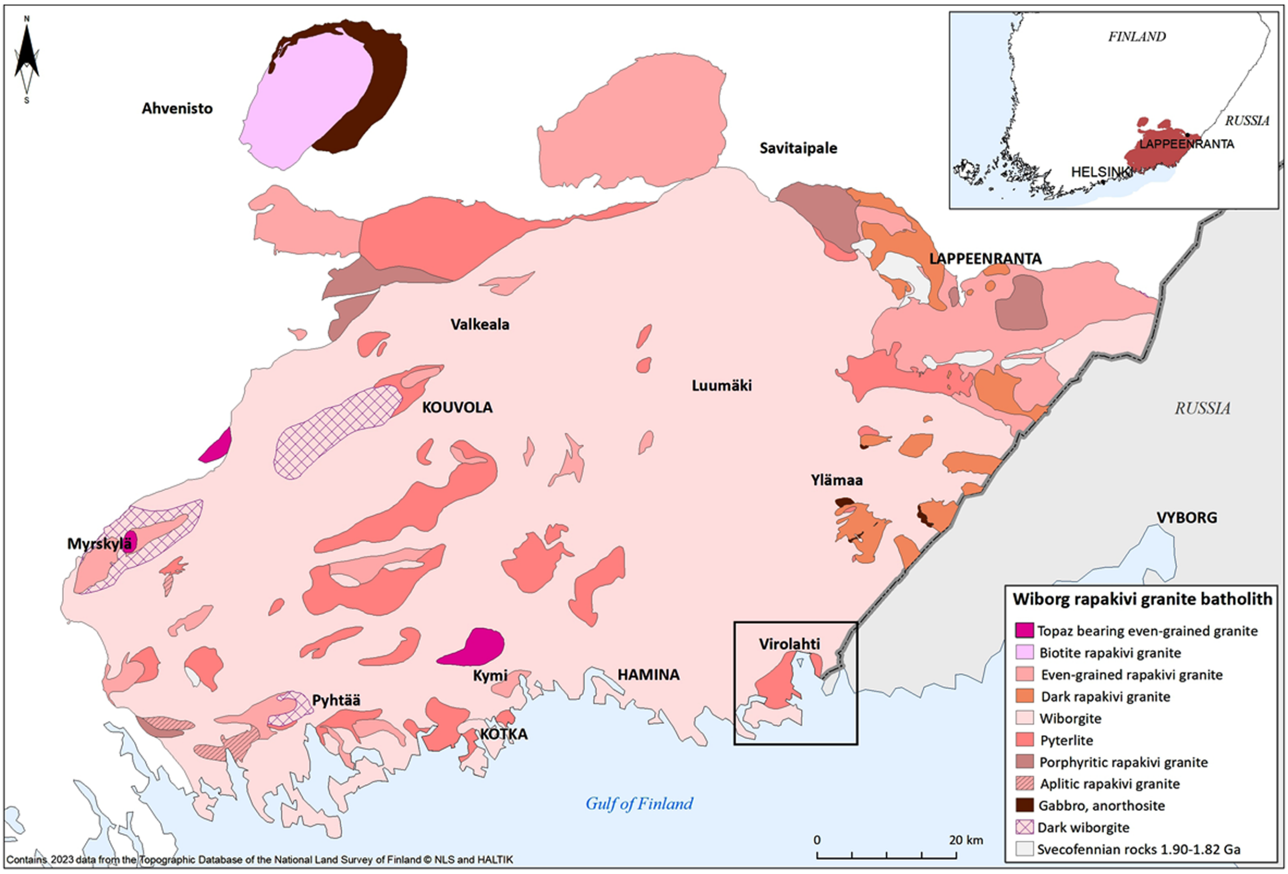

Figure 1. Lithological map of the Wiborg rapakivi granite batholith. Modified from Härmä et al. (2015) and Härmä (2020).

from the NaStA project (The history and future of natural stones in architecture – bridge between southeastern Finland and Russia). The aim of the project was to increase knowledge regarding the natural stones used in historical constructions and to demonstrate the uniqueness of rapakivi granites used in constructions and architectural monuments. The European Union partly funded the project through the ENI CBC Programme 2014–2020 between South-East Finland and Russia.

In this paper, we provide new information on the extraction and applications of Virolahti pyterlite based on the results of the NaStA project and we will later begin the procedure to propose Virolahti pyterlite as a candidate for designation as a Heritage Stone (see, e.g., Pereira, 2021, 2023).

Rapakivi Granites

The word "rapakivi" means "crumbly stone", a name given by local Finnish people to a distinct porphyritic granite, which in places could break down to gravel. The definition was first mentioned "scientifically" by Swedish physician and naturalist Urban Hjärne in his doctoral thesis in 1694 (Hjärne, 1694). The rock type was finally defined geologically by the prominent Finnish geologist J.J. Sederholm in 1891 (Sederholm, 1891), and the Finnish word "rapakivi" became an internationally adopted term. Following the definition of the classic Finnish rapakivi intrusions, similar types of granites have been found globally, for example in South and North America, Africa, Australia, Ukraine, Russia, the Baltic countries and Sweden (Rämö and Haapala, 2005).

Today, the rapakivi granites are defined as "A-type granites characterized by the presence, at least in the larger batholiths, of granite varieties showing the rapakivi texture" (e.g., Rämö and Haapala, 2005). Commonly, they occur as discordant anorogenic intrusions and sharply cut the older surrounding rocks. They have a non-foliated structure and do not appear to be influenced by later ductile deformation. The majority of rapakivi intrusions have ages of ca. 1800–1000 Ma (Proterozoic), but both older ca. 2800 Ma (Archaean) and younger 400–10 Ma (Phanerozoic) intrusions occur. Typically, rapakivi plutons are associated with early mafic intrusions with anorthosites, gabbros and diabases.

The traditional rapakivi texture (Sederholm, 1891) comprises large round K-feldspar megacrysts (ovoids) surrounded by a plagioclase mantle; this rock type is named "wiborgite". The granite type in which the K-feldspar ovoids lack a plagioclase rim is called "pyterlite". The rapakivi plutons commonly also include intrusion phases with granites lacking the classic texture. Typically, drop-like quartz crystals are found in all rapakivi granite varieties.

The Finnish rapakivi granites occur as four major batholiths (Wiborg, Laitila, Vehmaa, and Åland) and numerous smaller stocks in southern Finland (Rämö and Haapala, 2005). They form post-orogenic composite intrusions, comprising porphyritic and even-grained granites with or without the classical rapakivi texture (Rämö and Haapala, 2005). The age of the rapakivi intrusions is 1700–1500 Ma (Rämö and Haapala, 2005).

Geological Setting

The Wiborg rapakivi granite batholith occupies an area of approximately 18, 000 km^2 in southeastern Finland (Härmä, 2020) (Fig. 1), but also covers parts of northwestern Russia. The main granite types in the batholith are wiborgite, dark wiborgite, pyterlite, porphyritic rapakivi granite, even-grained rapakivi granite, dark rapakivi granite and aplitic rapakivi granite (Härmä, 2020). Wiborgite is the main rock type, covering approximately 75% of the batholith area, whilst pyterlite occupies 6% as localized intrusions (Härmä, 2020). The rest of the rapakivi varieties are found as smallish intrusions.

Virolahti pyterlite forms a distinct intrusion around Virolahti Bay in the southeastern part of the Wiborg batholith, having a size of 67.6 km^2 (Fig. 2). The pyterlite is homogeneous throughout the intrusion, with no inclusions. The contacts against the surrounding wiborgite are gradational. Towards the contact, the colour of the pyterlite becomes browner and the ovoids with a rim of plagioclase increase in number, but no change in the grain size can be observed. Detailed field work carried out in the NaStA project, including drilling in the Hämeenkylä area (Fig. 2), revealed that the pyterlite dips gently under the wiborgite: Virolahti pyterlite constitutes a subhorizontal sheet intrusion within the wiborgite. The age of the Virolahti pyterlite is 1,634.5 ± 3.0 Ma defined from the ovoid and 1,628.0 ± 2.5 Ma from the groundmass (Heinonen et al., 2016).

Petrographic Features of Virolahti Pyterlite

The colour of the fresh surface of Virolahti pyterlite is red. The rock has a rapakivi texture with densely dispersed K-feldspar megacrysts (ovoids) (Fig. 3). The ovoids lack a plagioclase rim and generally measure 2–4 cm in diameter. The large K-feldspar megacrysts are surrounded by smaller mineral grains, mostly of quartz and plagioclase. The grain size of the matrix (the grains between the large K-feldspar ovoids) is less than 10 mm. A few sporadic angular megacrysts of K-feldspar are also found. The texture of Virolahti pyterlite is homogeneous and the rock itself is massive without orientation.

The main minerals of Virolahti pyterlite are quartz, K-feldspar, plagioclase and biotite (Table 1). Plagioclase is partly altered to sericite. K-feldspar contains abundant elongated plagioclase inclusions. According to the mineral composition and texture, the formal petrographic name of the rock is *rapakivi granite* (*pyterlite*).

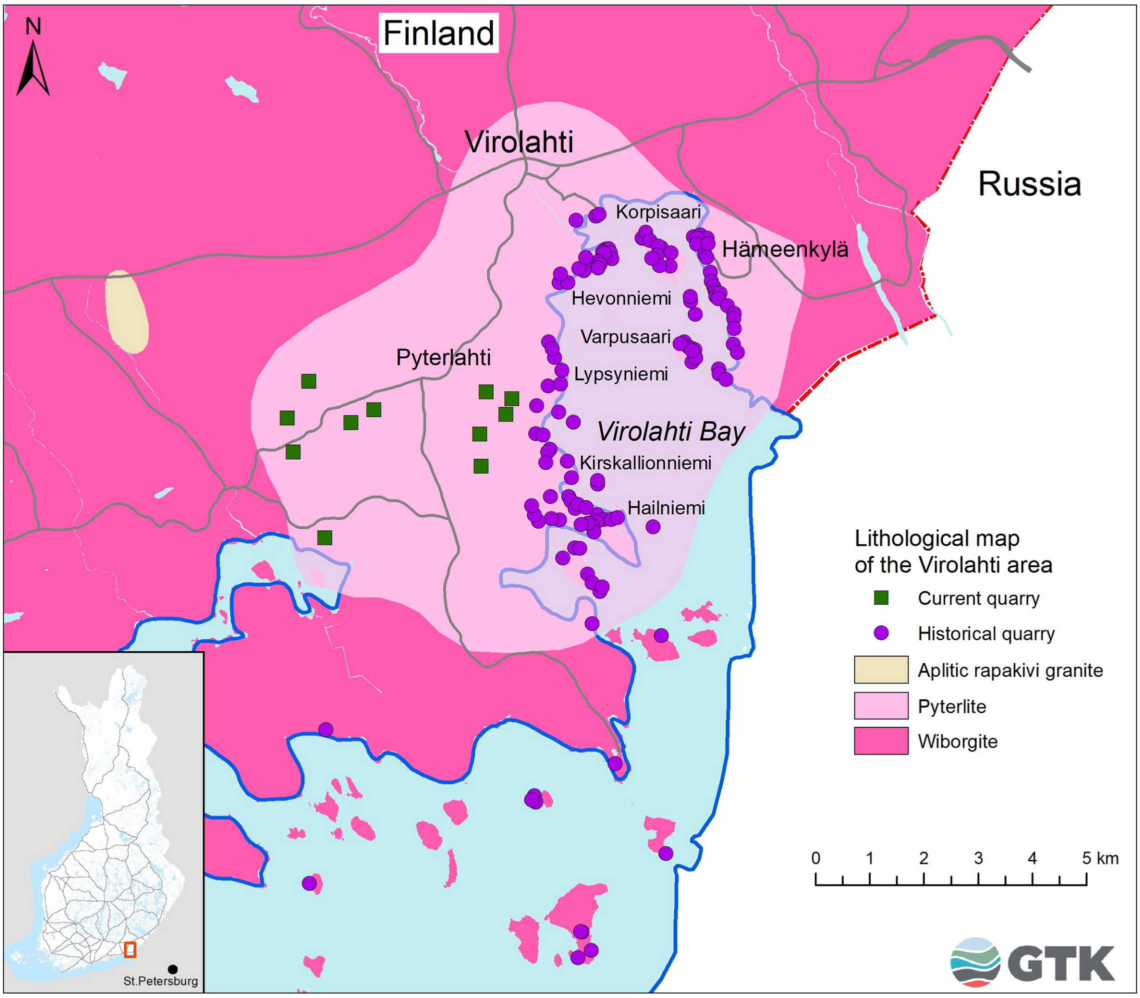

Figure 2. Lithological map of the Virolahti area, with historical and current quarries for red Virolahti pyterlite. Blue-coloured areas are sea and lakes.

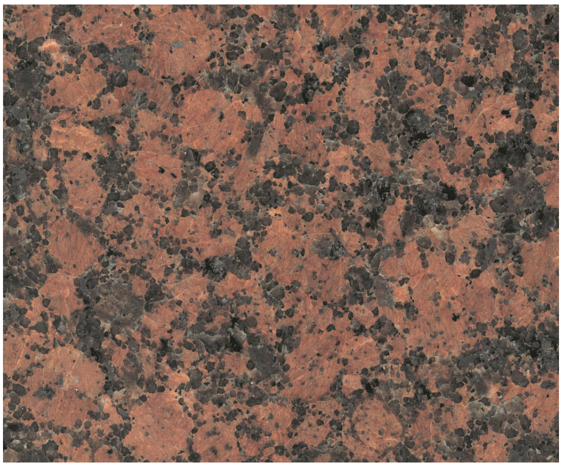

Figure 3. Virolahti pyterlite, with the classic rapakivi texture. K-feldspar ovoids measure 1–3 cm in diameter. Photo: Geological Survey of Finland, GTK.

Technical Properties of Virolahti Pyterlite

The mineral composition of Virolahti pyterlite indicates that the rock is durable and resistant to deterioration: it is composed of hard silicate minerals such as quartz and feldspar, whereas soft biotite is found in minor amounts (Table 1). The general microscopic soundness and the homogeneity of the rock further contribute to its durability. No dark-coloured ferromagnesian minerals or sulphides were found in the microscopic study, indicating that the colour of the pyterlite remains constant over time.

No preferred mineral orientation was observed in the thin section or in the macroscopic sample. This, together with the mineralogical homogeneity of the rock, provides the isotropic durability properties of the pyterlite. Technical tests carried out according to EN standards demonstrated that the resistance of the pyterlite to mechanical and physical wear fulfils the national and international requirements (Table 2).

Table 1. Mineral composition of Virolahti pyterlite (Carmen Red). The mineral composition was determined using a polarization microscope from a polished thin section. 1000-point count

Mineral	Vol% (1)	Average grain size (mm)	Habit	Shape	Boundaries	Distribution	Orientation	Remarks
Quartz	42.1	3.0	Anhedral	Anisometric	Partly definable	Homogeneous	Isotropic	
K-feldspar	42	6.5	Anhedral	Anisometric	Partly definable	Homogeneous	Isotropic	Elongated plagioclase inclusions
Plagioclase	12.8	2.5	Subhedral	Anisometric	Partly definable	Homogeneous	Isotropic	Altered to sericite in places
Biotite	3.1	2.5	Subhedral	Flaky	Partly definable	Homogeneous	Isotropic	Occasionally zircon inclusions
Zircon	<0.1	0.06	Euhedral	Isometric	Definable	Inside biotite grains	Isotropic	

Table 2. Technical properties of Virolahti pyterlite (Carmen Red). Based on Härmä & Selonen (2018) and Härmä (2020)

Rock type	Pyterlite
Main minerals	Quartz, K-feldspar, plagioclase, biotite
Colour/appearance	Red/unoriented
Colour variations	Small
Suitability	All uses, outdoors and indoors
Polishability	Good
Resistance to weather	Good
Durability	High
Fracturing	Orthogonal
Cleavability	Modest
Weathering	None
Availability	Good
Surface treatments	Polished, honed, shot blasted, caress, waterjet, flamed, bush hammered, split
Water absorption (%), EN 13755	0.10
Apparent density (kg/m^3), EN 1936	2630
Flexural strength (MPa), EN 12372	11.7/11.8*
Frost resistance, change in flexural strength (%) EN 12371	0.0**
Compressive strength (MPa), EN 1926	132/143**
Abrasion resistance (mm), EN 14157	15
Breaking load at dowel hole (N), EN 13364	1700

*After 56 freeze/thaw cycles (1% NaCl)
**After 48 freeze/thaw cycles

The high content of quartz gives Virolahti pyterlite a good ability to accept excellent polishing, as well as a good ability to take a flamed finish. Other surface treatments for the granite include split, bush hammered, shot blasted, caressed, waterjet and honed finishes.

The cleavability of the coarse-grained pyterlite of Virolahti is only modest, indicating challenges in producing, for example, small paving stones (cubes).

Historical Uses of Virolahti Pyterlite

The exploitation of the red pyterlite of Virolahti dates to the Middle Ages, when the rock was used locally in the construction of churches (Luodes et al., 2022). The rock was also quarried during the 1600s for fortifications in Narva and Tallinn in the current Estonia, by the Baltic Sea (Härmä and Selonen, 2018). However, the large-scale extraction of the pyterlite started during the late 1700s for the construction of the city of St. Petersburg in Russia.

General Aspects of the Historical Use of Virolahti Pyterlite

The city of St. Petersburg was founded in 1703 by Emperor Peter I, commonly known as Peter the Great (reign 1682–1725), on a lowland in the estuary of the Neva River in the Gulf of Finland (e.g., Bulakh et al., 2010). As no hard rocks were available in the close vicinity, the infrastructure of the city was built with rapakivi granite, and mainly with Virolahti pyterlite (Bulakh et al., 2010). It was during the time of Empress Catherine the Great (reign 1762–1796) that the use of Virolahti pyterlite started on a large scale.

The total amount of stone exported from the Virolahti area for the construction of St. Petersburg was over one million cubic metres (Kaukiainen, 2016). This vast quantity of stone was used in the following applications: 1. foundations and stairs of buildings, 2. embankments, walls, bridges and railings of rivers, 3. paving of streets, 4. fortress structures and 5. decorative stone (Kaukiainen, 2016).

Foundations and Stairs of Buildings

The need for natural stone for foundations and stairs rapidly increased as the city of St. Petersburg developed. Around 1760, there were less than 500 brick buildings in St. Petersburg, and most of these had limestone foundations (Kaukiainen, 2016). By 1795, approximately a thousand new brick houses had been built, mainly with a granite foundation. In addition, new wooden houses were also generally built on a granite basement. Between 1795 and 1915, the population of St. Petersburg increased tenfold, and the number of residential buildings increased in the same proportion. Hence, tens of thousands of granite foundations were built (Kaukiainen, 2016).

Embankments, Walls, Bridges and Railings of Rivers

The systematic lining of the riverbanks of the Neva River with seafront streets and stonewalls in granite (Fig. 4) commenced when Catherine the Great ascended the throne (Kaukiainen, 2016). The first major works were the Hermitage Bridge over the Winter Canal in 1763–1766 and the Palace Embankment during 1763–1767, designed by architect T. Nasonov (Bulakh et al., 2010). This marked the beginning of a decades-long process during which the banks of the adjacent Rivers Moika and Fontanka were also encased with granite embankments. The construction of the river embankments continued without interruption until the First World War (Kaukiainen, 2016).

Figure 4. The embankments of the Neva River are constructed from Virolahti pyterlite. Photo: Paavo Härmä.

Paving of Streets

The third application that required a substantial amount of stone was the thoroughfares and the squares of St. Petersburg, which were paved from the second half of the 1700s partly with cobblestones and partly with squared granite slabs (Kaukiainen, 2016). The sidewalks were typically covered with stone slabs.

Fortress Structures

The fortresses of St. Petersburg, especially on the Island of Kronstadt outside the city in the Gulf of Finland, became a very important target of use for Virolahti pyterlite in the 19^{th} century (Kaukiainen, 2016). On Kronstadt, the main fortress (Kronslott) was rebuilt with granite in the 18^{th} century, but in the early 19^{th} century, other constructions were still traditional earthworks. Between 1828 and 1913, all the structures of the Kronstadt Fortress area were renewed and built with granite, including breakwaters and piers (Kaukiainen, 2016).

Decorative Stone

Decorative stones made from Virolahti pyterlite, such as columns, were used in prestigious objects (Bulakh et al., 2010; Kaukiainen, 2016; Lahermo, 2017). The first of these applications were the columns in St. Michael's (Engineers') Castle and in Kazan Cathedral, while the most famous were the Alexander Column and the columns of St. Isaac's Cathedral (see, Chapter 6.2).

The extraction of Virolahti pyterlite for the construction of St. Petersburg ended by the First World War and the Russian Revolution (Kaukiainen, 2016).

Specific Objects Built Using Virolahti Pyterlite in Historical St. Petersburg

Virolahti pyterlite has been used in several buildings and monuments in historical St. Petersburg. In the following, based on the results of the NaStA project, Hirn (1963), Bulakh et al. (2010) and Lahermo (2017), we present a selection of specific objects in which the pyterlite has been applied.

The building for the Academy of Arts on Vasilyevsky Island (No. 17 University Embankment), in the delta of the Neva River, was designed by architect Antonio Rinaldi during 1764–1768. The brick-structured basement is faced with blocks of red Virolahti pyterlite combined with light grey-coloured wiborgite rapakivi blocks.

The Peter and Paul Fortress (1779–1787) on Zayachy Island, in the Neva River, was designed by architect Antonio Rinaldi. The cladding of the fortress is made of Virolahti pyterlite.

The Marble Palace building (No. 5/1, Millionnaya Street) was designed by architect Antonio Rinaldi in 1768–1785. The ground floor of the building is dressed in pyterlite from Virolahti.

The building for the St. Petersburg Academy of Sciences on Vasilyevsky Island (No. 5 University Embankment) was designed by architect Giacomo Quarenghi during 1783–1789. The stylobate with a staircase is made from red Virolahti pyterlite.

St. Michael's (Engineers') Castle by the Summer Garden (No. 2 Sadovaya Street) was designed by architects Vincenzo Brenna and Vasily Bazhenov in 1797–1800 for Emperor Paul I (reign 1796–1801). The staircases leading up to the four entrances in the courtyard are made of red Virolahti pyterlite, as are the twelve columns by the stairs. Following the completion of this object, similar red pyterlite columns were included in the interior decoration of several churches in St. Petersburg during the rule of Emperor Paul I.

Kazan Cathedral (or the Cathedral of Our Lady of Kazan), in Kazan Square (No. 2 Kazan Square Street), is a cathedral of the Russian Orthodox Church. It was designed by architect Andrey Voronikhin in 1801–1811. Several of the rapakivi columns in the main nave of the church are made of pyterlite from Virolahti (Fig. 5A).

The walls of the Spit (Strelka) at the eastern end of Vasilyevsky Island in the Neva River are clad with red Virolahti pyterlite combined with light grey-coloured wiborgite rapakivi (1804–1810) on the order of Emperor Alexander I.

The Stock Exchange House (No. 4 Exchange Square) was designed by architect Jean-François Thomas de Thomon during 1805–1810, located on the Spit. The stairs and brick-structured stylobate are faced with red Virolahti pyterlite combined with grey wiborgite rapakivi: the

Figure 5. A. Several of the columns in the main nave inside Kazan Cathedral have been constructed from red pyterlite of Virolahti. Photo: Heikki Pirinen. B. The two lower courses of walls lining the stairs on the Spit (Strelka) at the eastern end of Vasilyevsky Island are realized in Virolahti pyterlite. Photo: Paavo Härmä. C. The 11 lower steps of stairs on the Spit (Strelka) are made from red Virolahti pyterlite and the remaining upper ones from grey wiborgite rapakivi. Photo: Paavo Härmä. D. Virolahti pyterlite has been applied as 112 monolithic columns in St. Isaac's Cathedral (1818–1858). Photo: Paavo Härmä.

lower two courses of stylobate were made from red Virolahti pyterlite and the two upper ones from grey wiborgite rapakivi (Fig. 5B). In the granite staircase, the upper steps are of grey rapakivi, whereas the lower ones are of red Virolahti pyterlite (Fig. 5C).

St. Isaac's Cathedral (1818–1858) in St. Isaac's Square was initially an orthodox cathedral but was later turned into a museum. It was designed by architect Auguste de Montferrand. The cathedral is the fourth largest dome church in the world and can accommodate approximately 15,000 people. In addition to rapakivi granite, several other rock types have been used in the church. Virolahti pyterlite has been applied as 112 monolithic columns in the building. The largest columns (114 tonnes in weight, 17 metres in height, 1.85 metres in diameter) are found at the four entrances on the ground level. Smaller columns are located in the rotunda, in the bell towers and on the façade (Fig. 5D). The columns have a polished finish.

The Alexander Column (1829–1834), located at the centre of Palace Square, was designed by architect Auguste de Montferrand (Fig. 6). The column consists of a monolith of red pyterlite extracted from the Hevonniemi quarry in Pyterlahti (see, Chapters 6.4 and 6.5). It was cut out of a single 30-metre-long block at the quarry. The block was roughly dressed at the quarry and then transported to St. Petersburg, where the final dressing and polishing was carried out. The 700-ton monolith has a diameter of approx. 3.5 metres and a height of 25.6 metres and is the tallest monolith in the world. The column stands on its own weight on a pedestal made of pyterlite from Virolahti. At the top of the column, there is a sculpture depicting an angel holding a cross.

The General Staff Building in Palace Square (No. 6/8 Palace Square Street) was designed by architect Carlo Rossi in 1819–1829. The high plinth and portals of the building are realized in Virolahti pyterlite.

Figure 6. The monolith and the pedestal of the Alexander Column (1829–1834) are made of red pyterlite of Virolahti. Photo: Paavo Härmä.

The buildings for the Senate and Synod, located in Senate Square (No. 1–3 Senate Square), were designed by architect Carlo Rossi in 1829–1834. The foundation, staircase and the kerbstones bordering the ramps are made from red Virolahti pyterlite. Carlo Rossi designed some other classical buildings in St. Petersburg, and a typical feature of these buildings is the abundant use of pyterlite from Virolahti.

The House of Laval is situated next to the Senate and Synod buildings (No. 4 Angliyskaya Naberezhnaya Street). It was designed by architect Jean-François Thomas de Thomon in 1806–1809. The balconies and the decorative lions by the entrance are made from Virolahti pyterlite.

The Narva Triumphal Arch, in Stachek Square (No. 1 Stachek Square), was designed by architect Vasili Stasov and was inaugurated in 1833. The high foundation and the entrance staircase are realized in Virolahti pyterlite.

The building of the New Hermitage Museum, in Palace Square (No. 35 Millionnaya Street), was designed by architect Leo von Klenzen and was constructed during 1839–1852. The foundation and the stairs of the building are made from Virolahti pyterlite. In the vestibule, there are sixteen columns in Virolahti pyterlite. In addition, in some of the interior rooms, Virolahti pyterlite columns can be found.

The monument to Emperor Nicholas I, in St Isaac's Square, was designed by architect Auguste de Montferrand and sculptor Pjotr Klodt and was made in 1856–1859. The foundation of the monument is constructed from red Virolahti pyterlite (lowest course) combined with other rock types above it. This is one of the most famous statues with a pedestal in Virolahti pyterlite, which has also been applied in decorative pedestals for several other monuments in St. Petersburg.

Use of Virolahti Pyterlite in St. Petersburg after the First World War and the Russian Revolution

The First World War and the Russian Revolution ended the extraction of Virolahti pyterlite for the construction of St. Petersburg. However, the pyterlite was recycled from old buildings and used in St. Petersburg after 1917, for instance, in the monument "To Fighters of the Revolution" in the centre of the Field of Mars, designed by architect Lev Rudnev in 1917–1919, and as a high foundation wall of the Bolshoy Dom administrative building, No. 4 Liteyniy Avenue, designed by architect Noi Trockiy during 1931–1932 (Bulakh et al., 2010).

Since the collapse of the Soviet Union, the city of St. Petersburg has been extensively reformed and restored. The main stone material of historical St. Petersburg, rapakivi granite, has only been used in a few cases. An example is the metro station Vasileostrovskaya (No. 29A Sredniy Prospect Street), where part of the floor and the interior design of a restaurant were made using *Carmen Red* granite from Virolahti in 1996 (Bulakh et al., 2020).

Historical Quarries for Virolahti Pyterlite

The historical quarries for Virolahti pyterlite are located both on the islands and along the coastline of Virolahti Bay (Fig. 2). Based on the results of the NaStA project, altogether 126 historical quarry sites have been identified around the Bay. The size of the quarries varies from 0.0021 to 5.2 hectares.

The colour of the fresh surface of Virolahti pyterlite in these quarries is usually red, but it is especially deep and evenly red in the middle of the Virolahti pyterlite area, i.e., in the area between Hämeenkylä, Hevonniemi, Lypsyniemi and Hailniemi, including the islands of Korpisaari and Varpusaari (Fig. 2). The texture of the pyterlite is also homogeneous in the same area.

The quarries with the largest surface area are located in Hämeenkylä, Korpisaari, Hevonniemi (Huvisaari), Lypsyniemi, Kirskallionniemi and Hailniemi (Fig. 2). The number and size of the quarries decrease towards the south and towards the contacts of the pyterlite intrusion. Therefore, homogeneous red pyterlite was probably the main target in old quarrying and selection based on quality was carried out.

The dimensions of the subvertical fractures have been utilized in historical quarrying. For example, in the Hevonniemi quarry (Fig. 7A), from which the famous monolith of the Alexander Column was extracted, the spacing of the SE–NW-oriented fractures is sparse, measured as tens of metres on outcrop (see, Chapter 8). Hence, elongated stone blocks could be quarried perpendicular to the SE–NW-oriented fractures, utilizing the SW–NE-oriented fractures that exist more densely in this quarry as sides of the quarried blocks.

The spacing of the subhorizontal fractures on the outcrop surface of Virolahti pyterlite is usually in the order of 1–1.5 m. However, the spacing can be sparser, from 2–5 m, in deeper parts of the outcrops. This spacing has been too sparse for the drilling equipment of the time, and V-shaped grooves have been carved in horizontal positions between the subhorizontal fractures to loosen stone blocks. Occasionally, the extraction has failed while utilizing these grooves, as seen in Figure 7B. In addition, there are still numerous semifinished products left in the historical quarries, which are stacked in high piles (Fig. 7C).

Related Historical Issues: The ancient Hevonniemi Quarry Area as a Tourist Attraction

The historical Hevonniemi quarry, from which the material for the Alexander Column and the columns in St. Isaac's Cathedral was extracted, was developed as a tourist attraction by the municipality of Virolahti in 2019–2022.

A new 700-metre-long walking path has been created through the quarry area. The security of visitors has been ensured by building stairs and railings in hazardous locations. Along the path, there are several viewing points looking over the quarry site (Fig. 7D) with information boards on the quarrying, processing and transportation of stone. Benches made of wood with legs in Virolahti pyterlite have been erected along the path. In addition, a mobile application and web pages, as well as introductory videos, have been compiled (The Story of Stone video, 2022).

Contemporary Use of Virolahti Pyterlite

After the end of extraction for the construction of St. Petersburg, the red pyterlite of Virolahti was quarried on a small scale for domes-

Figure 7. A The historical Hevonniemi quarry for Virolahti pyterlite, which the famous column of Alexander I was extracted from. Photo: Paavo Härmä. B. A subhorizontal V-shaped groove carved in Virolahti pyterlite. Photo: Paavo Härmä. C. Semifinished blocks of Virolahti pyterlite stacked in piles in a historical quarry on the island of Korpisaari. Photo: Paavo Härmä. D. A tourist route with information signs has been constructed through the area of the Hevonniemi historical quarry. Photo: Paavo Härmä.

tic use. The quarrying grew to a large scale during the 1970s and has continued without interruption until today. The commercial designation for the pyterlite is *Carmen Red* (other commercial names include *Karelia Red* and *Baltic Red*, depending on the quarrying company).

Commercially, the current *Carmen Red* is defined as deep red, porphyritic, coarse-grained, non-foliated granite with individual, relatively large, usually round K-feldspar grains, ranging from 20 to 50 mm in diameter (Fig. 3). The colour variations of the granite are small; occasional shades of pale red occur.

The *Carmen Red* granite with its rapakivi texture is a unique material and only produced in Finland. No similar natural stone qualities are found on the current natural stone market.

Carmen Red granite is suited, for example, for exterior and interior design, monuments, and street slabs, as well as for environmental constructions. Due to the large block size obtained, the granite is also well suited for large projects. The granite has been applied globally, with the main market areas being China, Taiwan, Spain and Egypt.

Current Quarries for Virolahti Pyterlite

Today, the pyterlite can be quarried from eleven licenced quarry areas in the Virolahti area (Figs. 2 and 8). They are situated in the same pyterlite intrusion as the historical ones, but located further west (Fig. 2).

Current Applications of Virolahti Pyterlite

Virolahti pyterlite (*Carmen Red*) has been applied in Europe and the USA, as well as in countries of the Far East. Below, we present a selection of objects based on the results of the NaStA project and Mesimäki (2006).

Figure 8. Virolahti pyterlite (Carmen Red) can be quarried today from eleven licenced quarry areas. Photo: Paavo Härmä.

- The First Interstate Bank of California, San Diego, California, USA. 1982. Façade.
- The Wilshire Court Plaza, Los Angeles, USA. 1982. Façade.
- The Marathon Oil Tower, Houston, Texas, USA. 1985. Façade, polished.
- The 7th World Trade Center, New York City, USA. 1986. Façade, flamed.
- The Touhou Seimei Building, Seoul, Korea. 1986. Façade.
- The Central Daily Newspaper Building, Seoul, Korea. 1986. Façade. (Fig. 9A).
- The Korea Trade Centre, Seoul, Korea. 1986. Façade.
- The Travellers Express Tower, St. Louis Park, Minnesota, USA. 1987. Façade. (Fig. 9B).
- The SYP Bank building, Oulu, Finland. 1985. Façade. (Fig. 10A).

Figure 9. Current applications of Virolahti pyterlite (Carmen Red). A. The façade of the Central Daily Newspaper Building, Seoul, Korea (1986). Photo: Finska Stenindustri Ab. B. The façade the Travellers Express Tower, St. Louis Park, Minnesota, USA (1987). Photo: Finska Stenindustri Ab.

Figure 10. Current applications of Virolahti pyterlite (Carmen Red). A. The façade of the SYP bank building, Oulu, Finland (1985). Photo: Olavi Selonen. B. The façade of Lurgi House, Frankfurt-am-Main, Germany (1989). Photo: Finska Stenindustri Ab. C. The façade of the building at Kaibygg 1, Ager Brygge, Oslo, Norway (1989). Photo: Olavi Selonen. D. The Pro Patria monument, Valkeala, Finland (2007). Photo: Paavo Härmä.

- The Water Side Tower, Norfolk, Virginia, USA. 1988. Façade.
- The Phoenix Plaza, Phoenix, Arizona, USA. 1988. Façade.
- The La Jolla Village the plaza, San Diego, USA. 1987–1988. Façade.
- The Lurgi House, Frankfurt-am-Main, Germany. 1989. Façade, flamed. (Fig. 10B)
- The Arco Tower, Los Angeles, USA. 1989. Façade.
- The Malayan Credit House, Singapore. 1989. Façade.
- The Center West Building, Los Angeles, USA. 1989. Façade, flamed, polished.
- The Kaibygg 1 building, Aker Brygge, Oslo, Norway. 1989. Façade, flamed. (Fig. 10C).
- The Landesarbeitsamt Saarbrücken, Saarbrücken, Germany. 1990. Façade, flamed.
- The Goethe University, Frankfurt, Germany. 1992. Façade, floor, flamed.
- The office building Biozentrum, Frankfurt, Germany. 1993. Outdoor walls, flamed
- The office building Sherman Oaks, California, USA. 1993. Part of façade, polished.
- The Pro Patria monument, Valkeala, Finland. 2007. (Fig. 10D).
- The environmental construction, Eiranranta, Helsinki, Finland. 2009.

Vulnerability and Maintenance of Supply

Virolahti pyterlite (*Carmen Red*) is an established stone quality on the global market for natural stone with a constant demand. Each permit for the eleven licenced quarry areas in Virolahti allows the extraction of a substantial amount of rock (50,000–70,000 m^3/a), ensuring that the reserves of the present quarries are good.

The future potential for natural stone of outcrops in the Virolahti pyterlite intrusion has recently been assessed by Härmä (2020). The macroscopic fracture pattern of Virolahti pyterlite on outcrops is typically orthogonal (Härmä, 2020). The fractures may be both closed and open. The general spacing of the fracturing is sparse (Fig. 11). The spacing of the parallel subvertical fractures is commonly 3–5 m, but

Figure 11. Sparse fracturing in a prospect of Virolahti pyterlite. The space between the subvertical fractures is over 20 metres. Photo: Paavo Härmä.

can in some outcrops even be up to 40 m. The space between the sub-horizontal fractures on the outcrop surface is usually in order of 1–1.5 m. However, the spacing can be sparser, from 2–5 m, in deeper parts of the outcrops. Thus, the pyterlite is well suited for the extraction of natural stone, yielding large block sizes. The colour of the pyterlite is persistently red. Sporadic variations towards pale red or brownish red are found. The rapakivi texture is constant, with marginal variation in the size of the ovoids. Virolahti pyterlite has a good potential for natural stone, indicating a good supply of the stone in the future.

Conclusions

The red pyterlite of Virolahti is a rapakivi granite from the large Mesoproterozoic Wiborg rapakivi granite batholith of southeastern Finland with the typical and unique appearance of the rapakivi texture and with good quality as a natural stone.

The extraction of Virolahti pyterlite began on a large scale during the late 1700s for the construction of the city of St. Petersburg in Russia. During the 1700s and 1800s, the pyterlite was extensively used in St. Petersburg in applications such as the foundations of buildings, embankments of rivers, paving of streets, fortress structures and decorative stone. The most precious objects constructed from the pyterlite are the monolith of the Alexander Column and the columns of St. Isaac's Cathedral. Virolahti pyterlite has been extracted from 126 quarries in the Virolahti area, and over one million cubic metres were exported to St. Petersburg. The pyterlite is a part of a special history, as the objects for which the stone has been utilised in St. Petersburg belong to a UNESCO World Heritage Site.

Today, Virolahti pyterlite is extracted under the commercial name *Carmen Red* from eleven licenced quarries. The stone has been marketed and exported for use in several applications around the world, particularly in countries of the Far East and Europe. Modern objects constructed from the pyterlite include several façades of buildings (skyscrapers), including the Central Daily Newspaper Building in Seoul, Korea, and the Arco Tower in Los Angeles, USA. The pyterlite area is still important for natural stone production and over a wider area than only in Finland.

Virolahti pyterlite fulfils all the criteria for designation as a Heritage Stone presented by the IUGS Subcommission on Heritage Stone. Virolahti pyterlite:

- has been utilized in significant works (in a UNESCO World Heritage Site)
- has been used in large quantities in highly valuable architectural objects
- has been quarried from 126 historical quarries
- is a focus for the development of tourism infrastructure
- has wide geographical use and an extensive cultural history
- is still extracted from 11 quarries, with global applications.

Hence, we will later begin the procedure to propose Virolahti pyterlite as a candidate for designation as a Heritage Stone.

Acknowledgements

This study was carried out as a part of the NaStA project, which was partly funded by the ENI CBC Programme 2014–2020 between South-East Finland and Russia [Grant: 1803095-KS1528]. The company, Finska Stenindustri Ab kindly provided photographs of current applications of *Carmen Red* granite. Dr Roy Siddall is thanked for the language revision.

References

Bulakh, A.G., Abakumova, N.B., and Romanovsky, J.V., 2010, St Petersburg – A History in Stone. University Press, St Petersburg, Russia, 173 p.

Bulakh, A., Härmä, P., Panova, E., and Selonen, O., 2020, Rapakivi granite in the architecture of St Petersburg: a potential Global Heritage Stone from Finland and Russia. Geological Society, London, Special Publications, v. 486, pp. 67–76. doi:10.1144/SP486-2018-5

Härmä, P., Selonen, O., and Luodes, H., 2015, The Wiborg granite batholith - the main production area for granite in Finland. In: Lollino, G., et al. (eds.), Engineering Geology for Society and Territory, v. 5, pp. 259–262.

Härmä, P., and Selonen, O., 2018, Natural stones of the Wiborg rapakivi granite batholith in southeastern Finland. Geotechnical report 10. The Finnish Natural Stone Association, Helsinki, Finland, 34 p.

Härmä, P., 2020, Natural stone exploration in the classic Wiborg rapakivi granite batholith of southeastern Finland – new insights from integration of lithological, geophysical and structural data. Monograph: Academic dissertation. Geological Survey of Finland, Bulletin, v. 411, 90 p.

Heinonen, A., Mänttäri, I., Rämö, O. T., Andersen, T., and Larjamo, K., 2016, A priori evidence for zircon antecryst entrainment in Proterozoic megacrystic granites. Geology, v. 44, pp. 227–230.

Hirn, S., 1963, Strövtåg i Österled. Kulturhistoriska studier. Bidrag till kännedom av Finlands natur och folk 108. Finska Vetenskaps-Societeten, Helsingfors, Finland, 279 p. (In Swedish).

Hjärne, U., 1694, En kort Anledning till Åtskillige Malm och Bergarters, Mineraliers etc. efterspöriande och angifvande. Stockholm, 34 p. (In Swedish).

Kaukiainen, Y., 2016, Punaiset pilarit. Suomalainen graniitti tsaarien Pietarissa. Suomalaisen Kirjallisuuden Seura, Helsinki, Finland, 154 p. (In Finnish).

Lahermo, P., 2017, Suomalainen kivi vanhan Pietarin rakennuksissa ja monumenteissa. Omakustanne, 236 p. (In Finnish).

Luodes, N., Laxström, H., Härmä, P., and Selonen, O., 2022, A guide to natural stone in churches and nearby monuments in South-East Finland. GTK Open File Work Report 41/2022, 63 p.

Mesimäki, P., 2006, Luonnonkivikäsikirja. [Natural Stone Handbook]. The Finnish Natural Stone Association, Helsinki, Finland. (In Finnish).

Pereira, D., 2021, Final report of IGCP-637: a Project Linking Researchers and Heritage Stones from around the World. Episodes, v. 44, p. 75-80. doi:10.18814/epiiugs/2020/020086

Pereira, D., 2023, The Value of Natural Stones to Gain in the Cultural and Geological Diversity of Our Global Heritage. Heritage, v. 6, p. 4542-4556. doi:10.3390/heritage6060241

Pivko, D., 2003, Natural stones in Earth`s history. Acta Geologica Universitatis Comenianae, Nr. 58, 73 – 86.

Rämö, O.T. and Haapala, I., 2005, Rapakivi granites. In: Lehtinen, M., Nurmi, P.A. and Rämö, O.T. (eds.) Precambrian Geology of Finland – Key to the Evolution of the Fennoscandian Shield, Elsevier B.V. Amsterdam, Netherlands, pp. 533–562.

Sederholm, J.J., 1891, Über die finnländischen Rapakiwigesteine. Tschermaks Mineralogisch-Petrographische Mitteilungen, v.12, pp. 1–31 (In German).

The Story of Stone video, 2022, https://www.youtube.com/watch?v=hfSKwnpEcPE. [accessed 5th June 2023].

PhD Olavi Selonen (on the left) and PhD Paavo Härmä (on the right) in a natural stone processing plant. Photo: Pekka Jauhiainen.

Paavo Härmä is Senior Scientist in the Energy and Construction Solutions unit at the Geological Survey of Finland (GTK). He has worked on natural stone exploration, crushed rock aggregate inventory and bedrock geology mapping in numerous different projects since 1991. His current research interests have been focused on natural stone exploration in the rapakivi granite area of southeastern Finland.

Olavi Selonen is associate professor (docent) in natural stone geology in the field of geology and mineralogy at the Åbo Akademi University and has worked with natural stone since 1989 both in research and in private natural stone companies.