Geoarchaeology, bedrock surveys, and geochemical analysis

Tracing the provenance of medieval building stones

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Abstract

This study started from the premise that information about the provenance of building materials increases the understanding of construction activities and utilization of environment in the past. In this study, we analyzed 163 building stones from twelve medieval cellars in Turku (Finland) with a portable X-ray fluorescence spectrometer (pXRF) and compared the results with surveys and analysis of the local bedrock. According to the study, the majority of stones were quarried near the construction site. The only exceptions were limestones, which are not of local origin and could have been imported from the Baltic area or collected as glacial boulders on rocky beaches in the surroundings of Turku. Another major result is that stones of different kinds and from different areas were used in the same buildings and rooms. This indicates non-systematic quarrying, reuse of stones and challenges related to the acquisition of material despite the availability of local rocks.

Keywords: building archaeology, Finland, geology, the Middle Ages, pXRF, Turku

Introduction

When Turku was founded in the early 14th century, stone and brick were already known as building materials in this region. According to the present knowledge, bricks and stones were used for the first time in the latter part of the 13th century in the Bishop's Church locating in Koroinen at the distance of about 1.6 km from the present-day Turku Cathedral (Drake 1987; Koivunen 2003; Ratilainen 2016; Ratilainen et al. 2016). In Turku, stones and bricks were first used at the beginning of the 14th century in the construction of administrational and religious buildings, such as cathedral, castle and town hall (Drake 2003a: 129–33; 2003b: 137–8; Uotila 2003: 123–4).

In archaeological excavations, dozens of masonry buildings have been discovered in Turku. However, because of the lack of reliable datings, all buildings cannot be labelled medieval with certainty (e.g., Uotila 2003; 2005; 2007). In the early 18th century, the number of masonry houses in Turku was about 150, but in the Middle Ages the number was probably much smaller (Dahlström 1929: 204, 206; 1947: 20; Seppänen 2012: 670–1). The choice of building materials was influenced by the availability of the material and technical skills, building traditions and housing culture of the constructor. In Turku, the emergence of masonry buildings in the late 14th and in first part of the 15th century seems to relate to the immigration of German burghers and to close contacts with Hanse towns (Uotila 2003: 121–2; 2009: 44; Seppänen 2012: 671–8).

The medieval buildings in Turku have been analyzed and discussed in several studies, but the studies focused on building materials have been more limited (e.g. Uotila 2003; 2009; Seppänen 2012; Aalto 2016). Attention has mainly been paid to limestones, which are not of local origin and easy to detect. Otherwise, only the stones in one foundation have been analyzed more thoroughly. The stones in this construction were granite and gneiss / kinzigite found on the surrounding hills in Turku (Lindberg et al. 1994; Saloranta & Seppänen 2002: 32–3). Because of the availability of quarried stones, boulders and shingles of reasonable size on the shore zone near Turku, the general hypothesis has been that the stones used are of local origin and that the dimension stones were quarried from the surrounding environment (Seppänen 2012: 646). The main aim of this study was to test this hypothesis and to trace the origin of the quarried dimension stones used in the medieval Turku with geological investigations and scientific analyses.

In archeological excavations in the city of Turku, the documentation of constructions and building materials has improved in the course of the past decades but the documentation and analyses related to stones are still insufficient. All studies related to medieval buildings apart from the still standing Turku Castle and Cathedral are based on the preserved evidence from the lower parts and foundations of excavated buildings. Because of limited preservation, our knowledge about the building materials used in the upper floors is very limited. Therefore it is impossible to obtain a full picture of the use of different building materials in the Middle Ages in Turku.

Furthermore, most remains have either been demolished or covered after the excavations and are no longer available for analysis. Besides the castle and cathedral, medieval buildings are still visible for the public in the Aboa Vetus & Ars

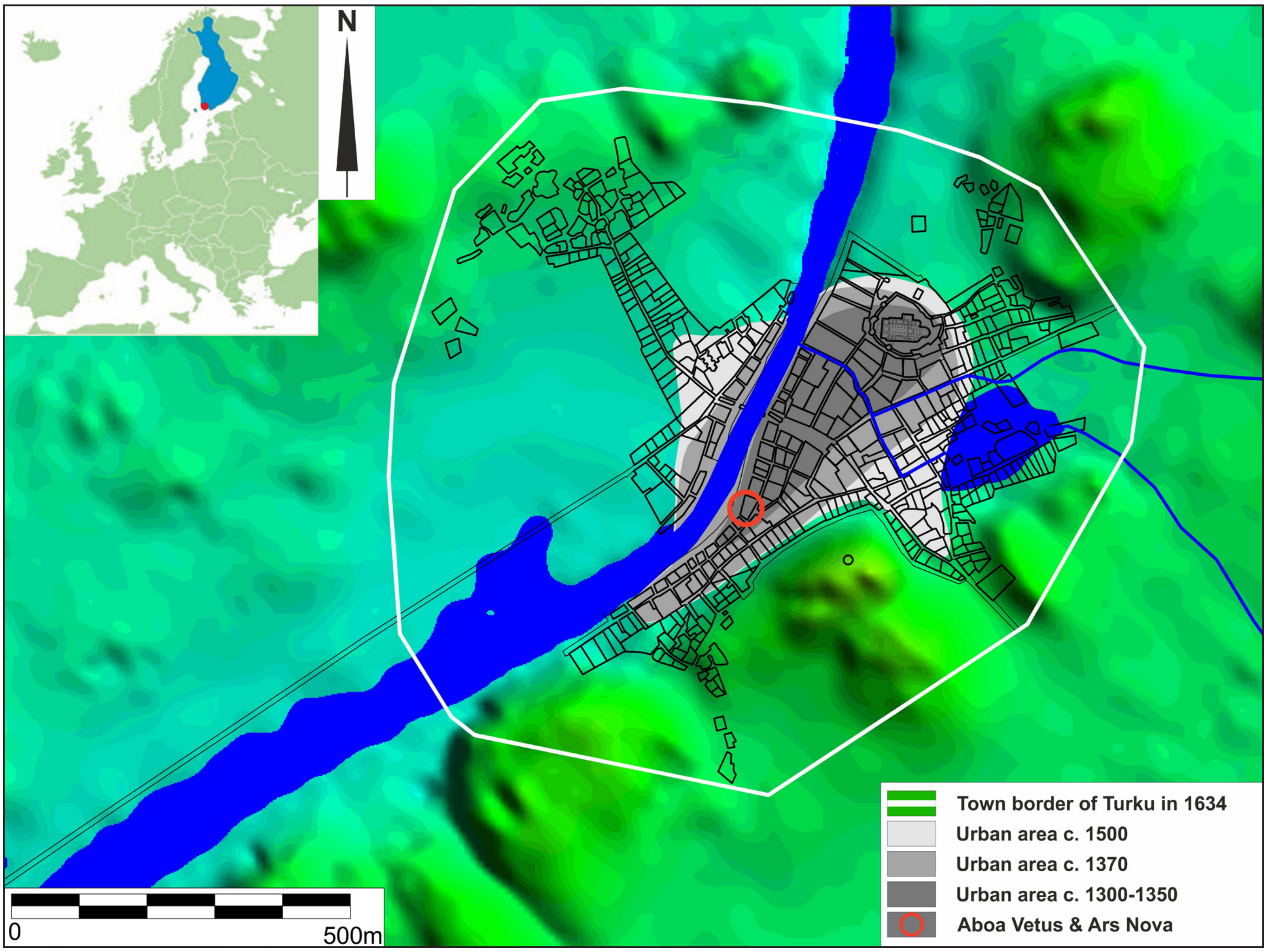

Figure 1. The map presents the town area of early modern Turku with interpretations about urban growth during the Middle Ages. The buildings investigated in this study in the present-day Aboa Vetus & Ars Nova museum located at the southwestern part of the medieval town. The figure contains data from the Elevation model 10 m of The National Land Survey of Finland.

Nova museum where the majority of the remains unearthed in the museum area is still *in situ* as part of the museum interior and exhibition. The largest excavations in this area were conducted in the 1920s and 1990s due to construction activities. The museum complex comprising both archaeological-historical museum Aboa Vetus and contemporary art museum Ars Nova was opened in 1995 (Sartes 2003) (Figure 1). Because of easy accessibility and availability of dated buildings, the study was focused on the remains in the museum. The remains are situated mainly in Aboa Vetus museum and therefore in this study only the name Aboa Vetus is used when referring to the remains in the museum complex.

Another aim of this study was to find evidence about medieval quarrying and quarries in Turku. The only preserved medieval written source referring to quarrying is a donation letter from 1329. In this letter, Turku Cathedral was donated a hill called Krakanes on the island of Kemiö in the vicinity of Turku. According to the letter, the hill had provided lime for the production of mortar (*pro fabrica montem cementi*) needed in masonry building (FMU 369; Seppänen 2012: 651–2).

The earliest information about a quarry in Turku comes from the mid 19th century and refers to Kakola Hill, where coarse grained and light gray coloured granite was quarried for the construction of a jailhouse. According to the place of provenance, this granite is also called kakolite. Today, kakolite is the most common dimension stone used in Turku. Besides Kakola, there were three quarries north of Turku in the 20th century: Räntämäki red granite quarry, Urusvuori (Räntämäki) monzodiorite quarry near Turku Airport and Kuninkoja granite quarry (Härme 1960: 56, 58; Lindberg et al. 1994; Karhunen 2004: 50). Geological bedrock maps, soil maps and historical maps do not reveal any evidence related to quarries in the Turku region.

There are no mentions in historical sources about medieval stonecutters in Turku. Probably, the stonecutters were addressed as masons or even as carpenters before the guild ordinances for professional stonecutters were established in the realm of Sweden in 1601. By 1571, there had been at least thirteen master masons in Turku while five of them were still active (Orviste 1989: 288). In the excavations, no evidence has been found referring to cutting and working of dimension stones on construction sites. This can indicate that the stones were cut near the quarry prior to transportation. The less likely explanation is that there was a specific place for cutting the dimension stones in the town area which has not been found (Seppänen 2012: 646).

The absence of cutting and working waste may also indicate effective reuse of dimension stones, which raises the question of the volume of quarrying activities in Turku. Because of the limited preservation, the quantity of the dimension stones used in medieval buildings cannot be counted, but according to the remains unearthed, the stones were mainly used in the lower parts of the buildings, on the floors and walls of cellars, while the upper parts were made of bricks of possibly even of wood. Furthermore, stones were used in fireplaces, wells and pavements, but the majority of these were probably loose cobbles and boulders collected from the surroundings of the town (Seppänen 2012).

Due to frequent and destructive fires in the Middle Ages, the use of stone and brick was promoted by statutes and recommendations. For example, in the early 15th century Reval, in the present-day Tallinn in Estonia, only brick and stone were permitted as building materials. The prevention of fires was not the only reason for promoting the use of stone and brick. The regulations also aimed at improving the sanitation and increasing the attractiveness of the town. The regulations were probably not equally strict in medieval Sweden although there were recommendations for using stone and brick, and on the other hand, also limitations concerning the use of timber (Johansen & von zur Mühlen 1973: 229; Söderlund 2001: 707; Seppänen 2012: 673–5).

In Turku, the increase in masonry buildings seems to coincide with the decline of good quality timber. Furthermore, the increase of masonry buildings was related to population growth, which is reflected in the expansion of the town area and in the intensification of the building stock. At the same time social and occupational stratification of the townspeople became more visible in Turku (Seppänen 2012: 623–7, 674). Consequently, the studies and analyses related to building materials do not only increase our knowledge about the supply and use of different materials in building activities, but may offer new insights into questions concerning possible professional specialization and organization of the society, as well as environmental changes in the city landscape.

Research material

Medieval buildings in Aboa Vetus

The majority of the medieval buildings in Aboa Vetus and Ars Nova were excavated in the mid 1990s during the building of the museum complex, but small-scale excavations have been carried out ever since. The oldest masonry building in this area is dated to the beginning of the 1390s, while the majority is dated to the fifteenth and sixteenth century. The buildings have a long history including several alterations, enlargements and reconstructions which can be detected in constructions, attachments and plasterings, although the dating of these changes remains problematic. Some of the buildings were deserted and demolished in mid-seventeenth century but parts of a few buildings were used until the early twentieth century.

Mainly the cellars of the buildings are preserved while the evidence of the upper parts is very limited. In general, the lowest parts of the walls were made of stones while the upper parts of the walls were made of bricks. The proportion of bricks to stones is surprisingly large. The limited number of stones and the contamination of surfaces caused by later activities affected the number of analyses in this study. The floors of the cellars were mainly paved with stones, but the time of paving remains unsure, while reconstructions are also possible. Furthermore, the floors were quite often made of cobbles, possibly collected from the surroundings, with no indications of quarrying activities (Sartes & Lehtonen 2007; Seppänen 2012: 692–5). The dating of the cellars is based on dendrochronological analyses of timber foundations and therefore they can be considered quite reliable (e.g. Zetterberg 2003; Sartes & Lehtonen 2007; Uotila 2007; 2009; Savolainen 2011; Aalto 2016).

Since the focus of this study was in the medieval buildings, only twelve cellars with reliable datings to medieval period were selected for analysis (Figure 2). A short description of each cellar is provided in the chapter Stone types and the provenance of building materials but the more detailed discussion about the buildings and building materials in this area remains beyond the frames of this article.

Bedrock outcrops in the Turku region

The main aim of this study was to test the pXRF method on building stones and to trace the provenance of medieval building stones in Aboa Vetus area by comparing the stones with the local bedrock. In recent years the complicated geology of the Turku region has been discussed in several studies (e.g. Väisänen et al. 1994; Väisänen & Hölttä 1999; Väisänen 2002; Helenius et al. 2004; Väisänen & Westerlund 2007; Nevalainen et al. 2014). The bedrock of the Turku region consists mainly of older supracrustal (volcanic and sedimentary) rocks and slightly younger plutonic (intrusive) rocks. plutonic (intrusive) rocks. They formed as a consequence of Svecofennian orogeny (the process of formation of mountains) which caused new magma to rise, anatexis (melting) of old bedrock, migmatization, metamorphosis and fluid transportation, which all mixed and changed the original element proportions of the bedrock. Supracrustal rocks (circa 1900 Ma) were originally sediments and eroded volcanogenic material that stratified to the bottom of the shallow sea. They metamorphosed in the heat

Figure 2. The map presents the location of cellars in Aboa Vetus and the number of analyzed stones per each cellar included in this study. All in all, 163 stones were analyzed from twelve cellars. The figure contains data from the excavation maps of the area.

and pressure of the later Svecofennian orogeny. Depending on the composition (mineralogy and chemistry) of the original sediments, they metamorphosed forming quartz feldspar gneiss, mica gneiss or amphibolite common in this region.

Metamorphosed supracrustal rocks are usually fine-grained, strongly foliated and dark-coloured because of the mafic mineralogy. In high temperature and pressure, sediments melted partially or totally (anatexis) and when cooling down they formed migmatites or sedimentary granites (S-type). Furthermore, high pressure and temperature caused the growing of the metamorphic porphyroblasts (large recrystallized mineral grains), usually of garnet and cordierite, which both are abundant in the rocks of southwest Finland. The plutonic rocks consist of older synorogenic (in the same time with orogeny) granitoids (in Turku area 1890–1870 Ma), granodiorites, diorites, tonalities, and younger late-orogenic (1840–1810 Ma) microcline granites. Granitic rocks are usually homogenous, of medium to coarse grain and of light colour. Granitoids have originally crystallized from magma deep in the earth's crust. They are mainly composed of quartz, plagioclase and alkali feldspar whose proportion defines the nomination of granitoids (Karhunen 2004; Kohonen & Rämö 2005).

Analytical methods and instrumentation

Analysis of rocks using pXRF

The portable X-ray fluorescence spectrometer (hereafter pXRF) is an easy and fast device for analysing elements from solid materials. Laboratory analyses for the whole-rock geo-chemistry are usually done from a homogenized (melted, dissolved or pulverized) sample for best results. In stones, the element composition is not homogenous but divided to mineral grains. Consequently, it is easier to get more accurate results by analysing fine grained stones than coarse grained ones. A pXRF-measurement of coarse-grained stones (for example granites with abundant quartz) reveals the chemistry of mineral grains in that part, not the chemistry of the whole stone. Therefore, when analysing a coarse-grained stone one needs to take more than one measurement and calculate the average values of element contents to achieve more reliable information about the geochemistry of that specimen.

Depending on the consistency and region of the specimen, the repeatability or precision of pXRF measurements is usually excellent (often better than ± 10%). On the basis of ten replicate analyses, RSDs (relative standard deviation) for the major elements Fe, Ca, K, and Si has been reported to be less than 2.5 % and for Mn, Rb, Sr, Ti, Y, Zn, and Zr less than 5 %. For low abundance elements (such as Sb, Se and Sn) RSDs can be more than 20 % (Hall et al. 2014: 123). Tests made on obsidian and volcanic rocks have proved that a well-calibrated pXRF device can generate accurate data about elemental composition of rocks, and the conceptual validity of pXRF for provenance studies has also been demonstrated (Newlander et al. 2015). Furthermore, the parallel ICP-AES and pXRF analyses of soil samples have indicated the reliability of pXRF in elemental determination (Rouillon & Taylor 2016: 259–61).

One needs to be aware that the calibration of the pXRF-device and the application used for analysis affect results. In fundamental calibration, as used also in Mining Plus application of Olympus pXRF, the detected element counts and the analysis result of the single element is recorded as ppm (Thomsen 2007; Hall et al. 2013). Measuring or counting time (i.e. radiation time) is an important factor in pXRF analysing, too. For heavier elements the counting time can be from ten to fifteen seconds per beam, but even a few minutes per beam are needed when the intention is to reach as many elements as possible. However, no significant improvement has been recorded in precision and reliability of pXRF data when the counting time is more than 180 seconds (Olympus 2012; Newlander et al. 2015).

Abilities and limitations of the pXRF used in this study

In this study, the geochemical analyses were made with the Olympus Delta DP-6500 portable X-ray fluorescence spectrometer provided for us by the Department of Geography and Geology at the University of Turku. The instrument has a 4W X-ray tube with tantalum/gold-anode and a SDD (Silicon Drift Detector) -photodiode as the detector. The focusing area of radiation (i.e. the area of analysis) is 10 mm in diameter (circa 0.8 cm2). The penetration of radiation depends on the measured material so that for stones, ceramics and bricks it is from hundreds of micrometers to a few millimeters. During each analysis, two different radiation beams/modes are used with Mining Plus application (Innov-X 2005; Olympus 2011; 2016).

The device is capable of detecting the following elements: vanadium, chromium, iron, cobalt, nickel, copper, zinc, hafnium, tantalum, wolfram, arsenic, lead, bismuth, zirconium, molybdenum, silver, cadmium, tin, antimony, titanium, manganese, aluminium, silicon, phosphorus, sulphur, chlorine, potassium, and calcium. In this case study, it was impossible to use calcium analyses because the stones in the buildings were covered with mortar and plaster, which would have affected the measurements of this element. Unfortunately, the pXRF device at our disposal could not detect geologically important major elements properly. For example, light elements like magnesium and sodium could not be detected at all.

Because of the absence of important main element data of sodium and magnesium and unreliable silica content, it impossible to use pXRF analyses in conventional geochemical QAPF- or TAS-classification (Le Maitre 2002: 21–42). Therefore, the investigation of trace elements may yield better results than the study of major elements. In principle, the pXRF-device used in this study is able to analyze magnesium, but it would require rhodium as the anode material in the X-ray tube instead of tantalum/gold used in the device at our disposal. Unfortunately, the tantalum/gold anode also affects the measurements of aluminium and silicon causing questionable results. Phosphorous turned out to be problematic too, since the detection limit (LOD) for phosphorous was so high (500–700 ppm = 0.05–0.07 %) that most analyses remained under the lowest possible limit (Olympus 2011). The detection limits for different elements depend on the type of the instrument, X-ray tube material, the detector, used application, calibration, number of the beams, and beaming time. Therefore it is impossible to inform exact detection limits of the elements for each combination, but the closest limits of detection provided by the pXRF-device used in this study are presented in Table 1 (according to Olympus 2011).

Table 1. The detection limits for some elements when analyzed with the similar kind of an instrument than used in this study.

Olympus Delta Premium, 2-Beam, Mining plus, Ta/Au-tube, SDD-detector			
Element	Limit of detection	**Element**	Limit of detection
Mg	Not available	**Fe**	5 ppm
Al	max. 4.0 %	**Ni**	10–20 ppm
Si	max. 0.75 %	**Cu**	5–7 ppm
P	500–700 ppm	**Zn**	3–5 ppm
S	100–250 ppm	**As**	1–3 ppm
K	30–50 ppm	**Zr**	1 ppm
Ca	20–30 ppm	**Ag**	6–8 ppm
Ti	7–15 ppm	**Cd**	6–8 ppm
Cr	5–10 ppm	**Sn**	11–15 ppm
V	7–15 ppm	**Sb**	12–15 ppm
Mn	3–5 ppm	**Pb**	2–4 ppm

Because of the restrictions of the device and detected contamination on the stones, the available major elements for comparison and plotting in this study were potassium, aluminium, iron, titanium and manganese. Since many trace elements remained under the detection limits, the only usable trace elements were vanadium, nickel, zirconium, tin, antimony, lead and cadmium.

Measurements and analysis

Besides mortar and plaster, the medieval building stones in Aboa Vetus were contaminated by rust, metals and paint which inflect the element content of calcium, iron, manganese, copper, zinc, tin, lead, sodium and titanium. The possible contamination of building stones was evaluated before they were selected for analysis by comparing the analysis results to results from natural stones. As a consequence, a noticeable enrichment of some elements (especially calcium and iron) was detected in the building stones in Aboa Vetus. Since the contaminated stones were excluded from the study, the number of suitable stones for analysis remained limited in some contexts. Furthermore, clearly roundish loose stones were omitted since they cannot be directly connected with quarrying. There were also practical restrictions related to the analysis of stones in some contexts. For example, only the stones in the outer wall of cellar K94:10 were analyzed because the exhibition objects blocked the access to inner walls at that moment. On the other hand, the cellars K94:12, K94:11 and K94:9 were partly still unexcavated and therefore all stones were not visible. After the evaluation of stones and practical restrictions, the most representative stones were chosen for analysis

Table 2. The table presents the number of stone types in each cellar analyzed in this study. The locations of the cellars are presented in Figure 2. Number of available stones reveals the total number of suitable stones that could have been analyzed in this study. In average, 35 % of these were analyzed within the frames of this study.

Id	Cellar	Dating	Number of available stones	Number of analyses	% of stones analysed	Stones by type									Number of stone types/cellar
						1	2	3	4	5	6	7	8	9	
1	K92:6	1600–1650 (lower constructions can be medieval)	59	14	24	-	3	7	1	-	1	-	2	-	5
2	K92:3	1440s	46	14	54	6	3	-	2	-	1	-	-	2	5
3	K92:5	1293–1350 AD / 1440s	55	25	25	11	1	-	-	6	6	1	-	-	5
4	K93:4	1450s	8	4	50	1	1	-	-	-	-	-	-	2	3
5	K93:5	1450s	51	13	16	4	3	-	2	3	-	1	-	-	5
6	K93:3	1390s	23	8	57	1	1	4	2	-	-	-	-	-	4
7	K95:21	1390s	32	13	41	3	2	7	-	-	-	1	-	-	4
8	K94:7	1440s	63	9	14	1	1	6	-	1	-	-	-	-	4
9	K94:12	15th and 16th c.	38	26	66	7	6	3	8	1	-	-	1	-	6
10	K94:11	15th and 16th c.	33	25	79	12	3	1	3	3	-	-	3	-	6
11	K94:9	c. 1404–1410	20	7	35	-	4	-	-	-	-	3	-	-	2
12	K94:10	c. 1404–1410	35	5	14	-	3	-	-	-	1	1	-	-	3
		Total	463	163	35	46	31	28	18	14	9	7	6	4	52

so that at least one example of different stone types from each cellar was selected. All in all, the number of analyzed stones per cellar varied from eight to 63, which accounts for 14–75 % of all stones used in different cellars (Table 2).

The selected stones were analyzed from two points, which were washed with water and nylon brush. Thereafter, the measurements were taken from the cleaned and dry surface. Both points were measured/counted for 60 seconds per beam, two minutes in total. The average of the measurements was calculated by the pXRF-device, by the standard procedure set by the manufacturer (Olympus 2012: 115–24). The area of detection and analysing in the pXRF was large, 10 mm in diameter, which is more than the size of any single mineral grain in the analyzed stones.

In total, about 260 building stones were examined, documented and analyzed in Aboa Vetus. Forty analyses were excluded because the dating of the context was not confirmed medieval. Furthermore, fifteen analyses were dropped out from the final plotting since there were not equivalent stones for comparison (including the only amphibolite sample). Finally, after discarding the analyses of stones with possible contamination, 163 analyses from twelve cellars remained for plotting and comparison (Figure 2, Table 2).

Local bedrock outcrops were prospected by separating the bedrock outcrop shapefile from the Topographic Database of Finland and from the Terrain map in Turku map service. Bedrock outcrop polygon figures were overlaid with the pre-Quaternary geological map of Finland (Lindberg et al. 1994) and the selection of the outcrops for analysis was done by choosing as diverse rock types as possible. However, the analyzed outcrops do not represent all bedrock types in Turku, but rather the ones that were most accessible and therefore most likely suitable for quarrying in the Middle Ages.

The locations of the sampled and/or analyzed outcrops were marked as waypoints with Garmin Montana 680 GPS (Figure 3). All in all, 88 specimens from the outcrops were collected, photographed, examined, and analyzed. In addition, 16 analyses were made straight from the bedrock outcrop. Consequently, the number of bedrock analyses was 104 in total, but after excluding the analyses of rock types that were

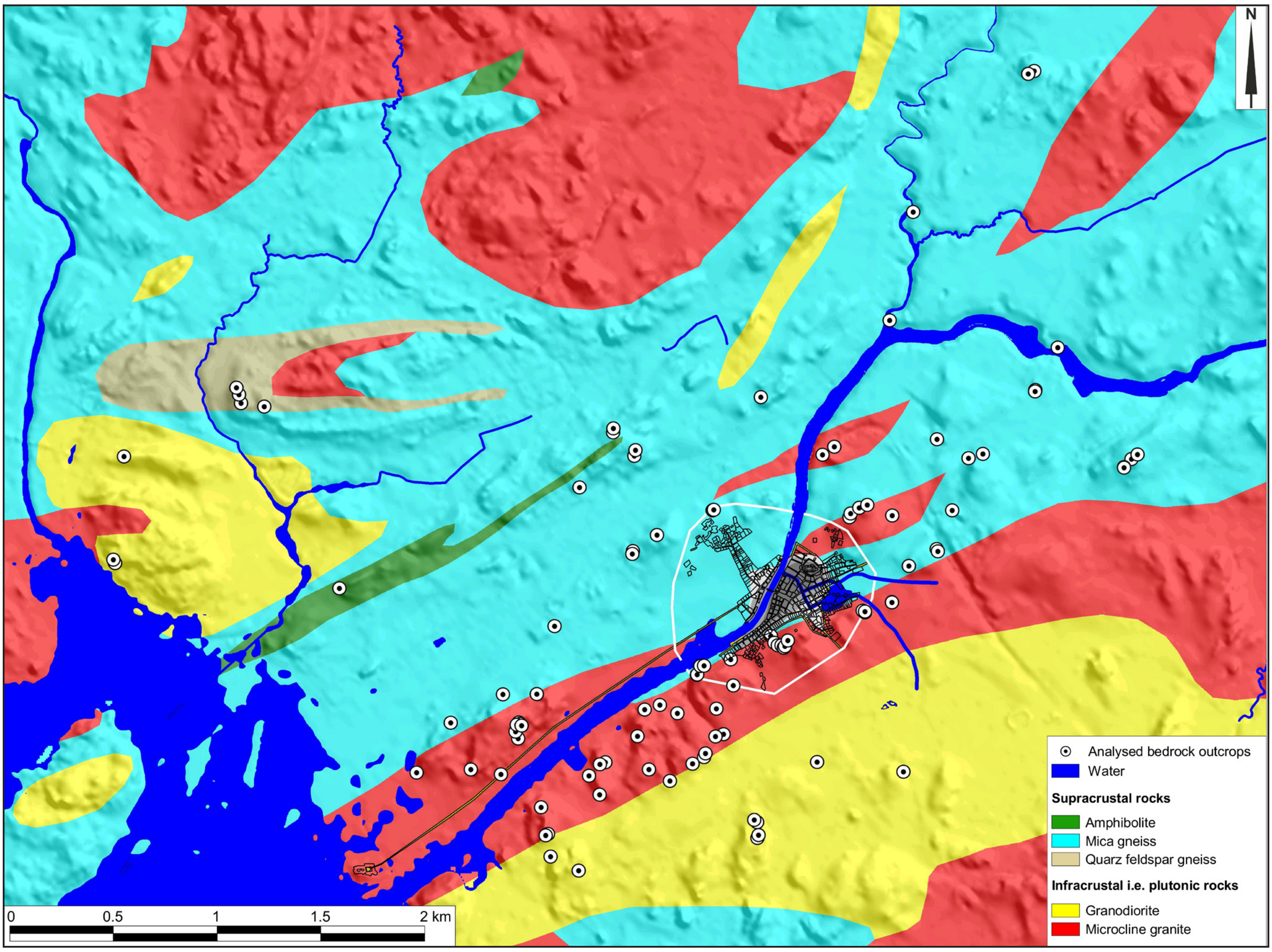

Figure 3. The map presents all analyzed bedrock outcrops. From 104 analyzed outcrops 89 were selected for comparison. The map is modified from the Geological map of Finland, pre-quaternary rocks 1:100 000 of Geological Survey of Finland. (Lindberg et al. 1994.) The figure contains data from Elevation model 10 m of The National Land Survey of Finland.

not used in the buildings (diorite, amphibolite, yellow coloured granite), 89 analyses were left for final geochemical plotting and comparison.

After some experimenting and consideration of element restrictions, plots K-Fe-Al, Zr-Pb-V, Al-Ti, K-Al, K-Fe, and K-Ti were selected for comparison. In practise, K-Fe-Al -plot was the only possible ternary major element plot and therefore all museum and outcrop analyses are plotted in K-Fe-Al-ternary diagrams (Figure 4). Zr-Pb-V-ternary plot gave the largest variation for the most abundant trace elements. Aluminium and titanium are regarded as stabile elements in stones and their ratio reflects the original composition of stones. Therefore, Al-Ti-plot was also used. K-Al, K-Fe, and K-Ti -plots were used for cross checking the other plots used in this study. Analyses were plotted a cellar by cellar and stone type by stone type. Major elements and trace elements were compared separately and data pre-processing was done with MS Excel. The conclusions of the provenances of dimension stones used in Aboa Vetus are based on the comprehensive examination and comparison of all analyses and evidence. Therefore the visual observation of geochemical plots is only one factor in the process of interpretation.

All analyses and geochemical data are presented in detail (including GPS coordinates of all

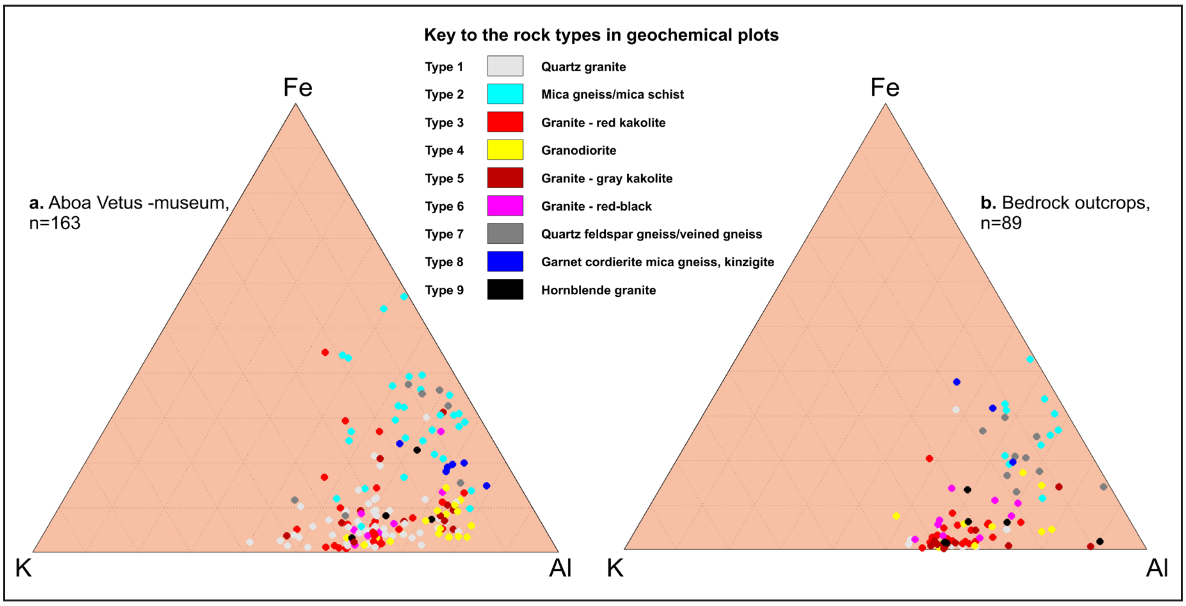

Figure 4. K-Fe-Al-ternary plots of a) all analyses made in Aboa Vetus and b) all outcrop analyses.

analyzed outcrops and location of analyzed building stones in Aboa Vetus) in the MSc thesis of Kinnunen (2018), which was prepared in tandem with this paper and repeats the information and results presented in this article. Hence, geochemical analyses and plotting made in this study can be reconstructed on the basis of available information, but mesoscopic geological comparison is based on personal inspection by Kinnunen with expertise in bedrock geology.

Classification of stones

In this study, geological mesoscopic classification is based on mineralogy on mineralogy, migmatization, colour, grain size and possible metamorphic structures of the stones. The stones analyzed were classified into nine different types according to geological nomination, structure, and appearance (Table 3, Figure 5). In Turku, the most common bedrock is microcline granite i.e. kakolite. In this research, kakolite granite was divided according to colour and appearance (i.e. visible mineralogy) to the following five types: quartz granite (type 1), red granite (type 3), gray granite (type 5), red–black granite (type 6) and special hornblende granite (type 9). The differences in their appearance are caused by variations of mineralogy.

Stone types in the Turku region are presented in the bedrock map in Figure 3 where *Microcline granite* includes stone types 1, 3, 5, 6 and 9 classified in this study. *Mica gneiss* includes both type 2 (mica gneiss) and type 8 (garnet cordierite mica gneiss/kinzigite) which is also common in interbeds in granites. *Amphibolite* has similar sedimentary origin than mica gneiss, but in more mafic sediment beds they metamorphosed to amphibolites and not to mica gneisses. *Granodiorite* contains type 4 (granodiorite) and *quartz feldspar gneiss* is like type 7 (quartz feldspar gneiss/veined gneiss), which is also commonly found in the migmatitic parts of granites.

Besides the classified nine stone types, two limestones were discovered in Aboa Vetus. The limestones are fine grained and homogenous with light greenish grey colour. There are no visible fossils or crawling tracks on the weathered surfaces. The limestones were analyzed but the

Table 3. The table presents the classified stone types in this study according to their representativeness in Aboa Vetus so that the most common one is presented first.

Type 1	**Quartz granite**	
	Main minerals	potassium feldspar and quartz (50:50)
	Appearance	salmon red, transparent glassy quartz
	Structure	coarse grained and homogenous
	Porphyroblasts	none
Type 2	**Mica gneiss/mica schist**	
	Main minerals	quartz, plagioclase and biotite
	Appearance	nearly black
	Structure	fine grained, homogenous and foliated, sometimes schistose
	Porphyroblasts	none
Type 3	**Granite/red kakolite**	
	Main minerals	quartz, plagioclase, potassium feldspar
	Appearance	red
	Structure	medium grained and homogenous
	Porphyroblasts	cordierite ± garnet
Type 4	**Granodiorite**	
	Main minerals	quartz, plagioclase, potassium feldspar, biotite and hornblende
	Appearance	light grey to reddish grey, dark mineral grains
	Structure	mainly medium grained and often clearly foliated
	Porphyroblasts	none
Type 5	**Granite/grey kakolite**	
	Main minerals	quartz, plagioclase, potassium feldspar
	Appearance	bone grey
	Structure	homogenous, medium- to coarse grained
	Porphyroblasts	cordierite ± garnet
Type 6	**Granite/red-black**	
	Main minerals	quartz, plagioclase, potassium feldspar and biotite
	Appearance	red-black
	Structure	medium grained and often clearly schistose
	Porphyroblasts	none
Type 7	**Quartz feldspar gneiss/veined gneiss**	
	Main minerals	quartz, plagioclase, potassium feldspar and biotite
	Appearance	paleosome streaky black and white, neosome granitic and light coloured
	Structure	thoroughly foliated and often folded
	Porphyroblasts	rare
Type 8	**Garnet cordierite mica gneiss/kinzigite**	
	Main minerals	plagioclase, quartz, biotite, potassium feldspar
	Appearance	paleosome black or dark grey, stripes of light coloured granitic neosome parallel to foliation
	Structure	fine to medium grained
	Porphyroblasts	garnet ± cordierite
Type 9	**Hornblende granite**	
	Main minerals	quartz, plagioclase, potassium feldspar, hornblende
	Appearance	salmon red–grey spotted by small black hornblende grains
	Structure	medium grained and homogenous
	Porphyroblasts	garnet ± cordierite

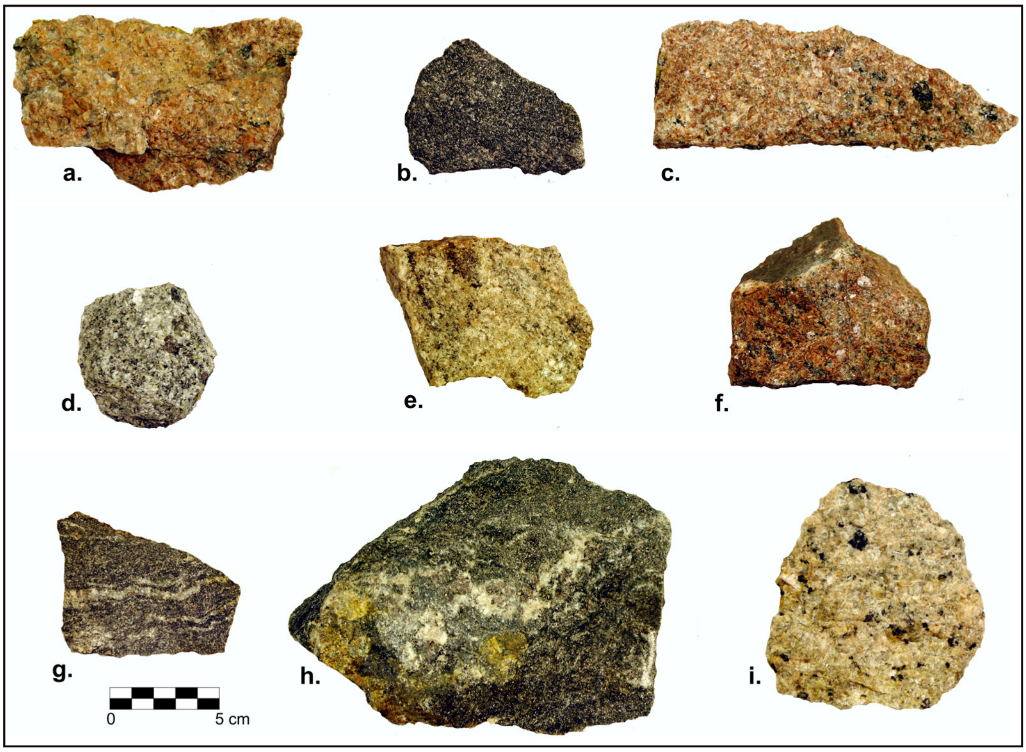

Figure 5. The most common stone types from Aboa Vetus and examined outcrops with coordinates in ETRS89-TM35FIN-projection (EPSG: 3067).
a) Type 1: quartz granite (sample 2016-1-38, Suikkila. N: 6712 322, E: 237 072),
b) Type 2: mica gneiss (sample 2016-2-9, Tuureporinkatu. N: 6711 509, E: 239 807),
c) Type 3: granite – red kakolite (sample 2016-1-23, Amiraalistonkatu. N: 6709 995, E: 238 213)
d) Type 4: granodiorite (sample 2016-2-4, Vesimiehenkatu. N: 6711 420, E-241 290),
e) Type 5: granite – grey kakolite (sample 2016-2-2, Halistenkoski. N: 6712 387, E: 242 006)
f) Type 6: granite – red-black (sample 2016-1-27, Mikaelinpuisto. N: 6710 853, E: 238 786),
g) Type 7: quartz feldspar gneiss/veined gneiss (sample 2016-1-21, Kalastajankatu. N: 6709 997, E: 237 877),
h) Type 8: garnet cordierite mica gneiss/kinzigite (sample 2015-20, Yliopistonmäki. N: 6711 471, E: 240 717),
i) Type 9: hornblende granite (sample 2015-17, Tuomaansilta. N: 6711 858, E: 240 584).
Photo: Jussi Kinnunen

analyses are not included in the geochemical plots because the nearest comparable limestone outcrops are in the bottom of Sea of Bothnia and on a few islands in the archipelago. In Turku region, Fennoscandian Cambrian limestones are commonly found on rocky beaches as loose stones. Imported limestones from Gotland and Estonia are younger, Ordovician to Silurian, and they usually contain detectable fossils (Magnusson et al. 1963: 276–83; Perens & Kala 2007: 16–7).

Stone types and the provenance of building materials

The following descriptions of the cellars included in this study provide information on stone types used in each cellar and an interpretation of the provenance of the building stones. If there is more than one place of provenance for a certain stone type, the most probable one is mentioned first. Exact information of the location of all analyzed stones can be found in the MA dissertation of Kinnunen (Kinnunen 2018: appendices 2 and 3) but in this article each cellar is presented with one photo only.

Cellar K92:6 is located in the entrance hall of Aboa Vetus & Ars Nova museum (Figures 2 and 6). The size of the cellar is circa 15 m². It was built on the remains of an older cellar and represents a slightly younger building phase than the adjacent cellar from the Middle Ages (see below K92:3). Judging from the bonding of the bricks in the upper parts of the southwest wall, the cellar was built after the Middle Ages. Furthermore, the dating of some of the bricks to the first part of the seventeeth century gives support to the time of construction suggested by the bonding. However, the lower parts of the cellar made of stones, as well as the stone floor, may originally belong to the antecedent cellar (Uotila 1995: 2–8; Sartes & Lehtonen 2007: 42–3, 198). Many stones used in the walls are covered with plaster and therefore were not suitable for pXRF analysis. All in all, fourteen stones were analyzed from the walls (Kinnunen 2018: Appendices 2, i–ii; 3, Figure 1) and they represent five different stone types originating from the eastern side of Aura River (Table 3 and Figure 7).

Cellar K92:3 is also located in the entrance hall of the museum (Figures 3 and 8). According to dendrochronological analysis, the cellar has been dated to the late 1440s. The inner walls of the cellar are made of stones, apart from the entrance which is made of bricks and leads to the adjacent staircase (K92:5). The outside and

Figure 6. Cellar K92:6 in the entrance hall of Aboa Vetus & Ars Nova. The upper part of the walls and the barrel vault ceiling was made of bricks. The floor is paved with cobblestones, which are mainly rounded loose stones with the diameter of about 10–20 cm. Photo: Markus Kivistö.

upper parts of the building are made of bricks as well, but the floor of the cellar is made of stones (Uotila 1995: 6–7; 2003: 130; Sartes & Lehtonen 2007: 40). The size of the cellar is about 27.5 m², but about two thirds of the southern part of the cellar is not accessible because of the walking bridge made above the cellar. In this study, fourteen stones were analyzed from three different walls of the northern part of the cellar (Kinnunen 2018: Appendices 2, iv–v; 3, Figure 2) and they represent five different stone types originating most likely from the eastern side of Aura River (Table 3, Figure 9).

Cellar K92:5 is a narrow staircase leading to the abovementioned cellar K92:3 in the entrance hall of the museum (Figures 2 and 10). The size of the staircase is 5.5 m x 1.2 m. The lower part of the staircase, as well as the stairs with seven steps leading to the cellar K92:3, are made of stones, but bricks have been used in the walls, too (Sartes & Lehtonen 2007: 40–2). Only one dendrochronological sample from the foundations of the staircase has been analyzed and it has given a much older dating to the staircase (1293–1350 AD) than to the adjacent cellar K92:3 (Uotila 2003: 130; Zetterberg 2003: 390; Sartes & Lehtonen 2007: Appendix 7, 1). However, it is very likely that the staircase and the cellar were built at the same time in the 1440s, since they both belong to the same building. In this study, 25 stones from all the walls of the staircase were analyzed (Kinnunen 2018: Appendices 2, ii–iv; 3, Figure 3) and they represent five different stone types, which originate most probably from the hills on the eastern side of Aura River (Figure 11, Table 3).

Cellar K93:4 locates inside Aboa Vetus and was first excavated already in the 1920s (Figures 2

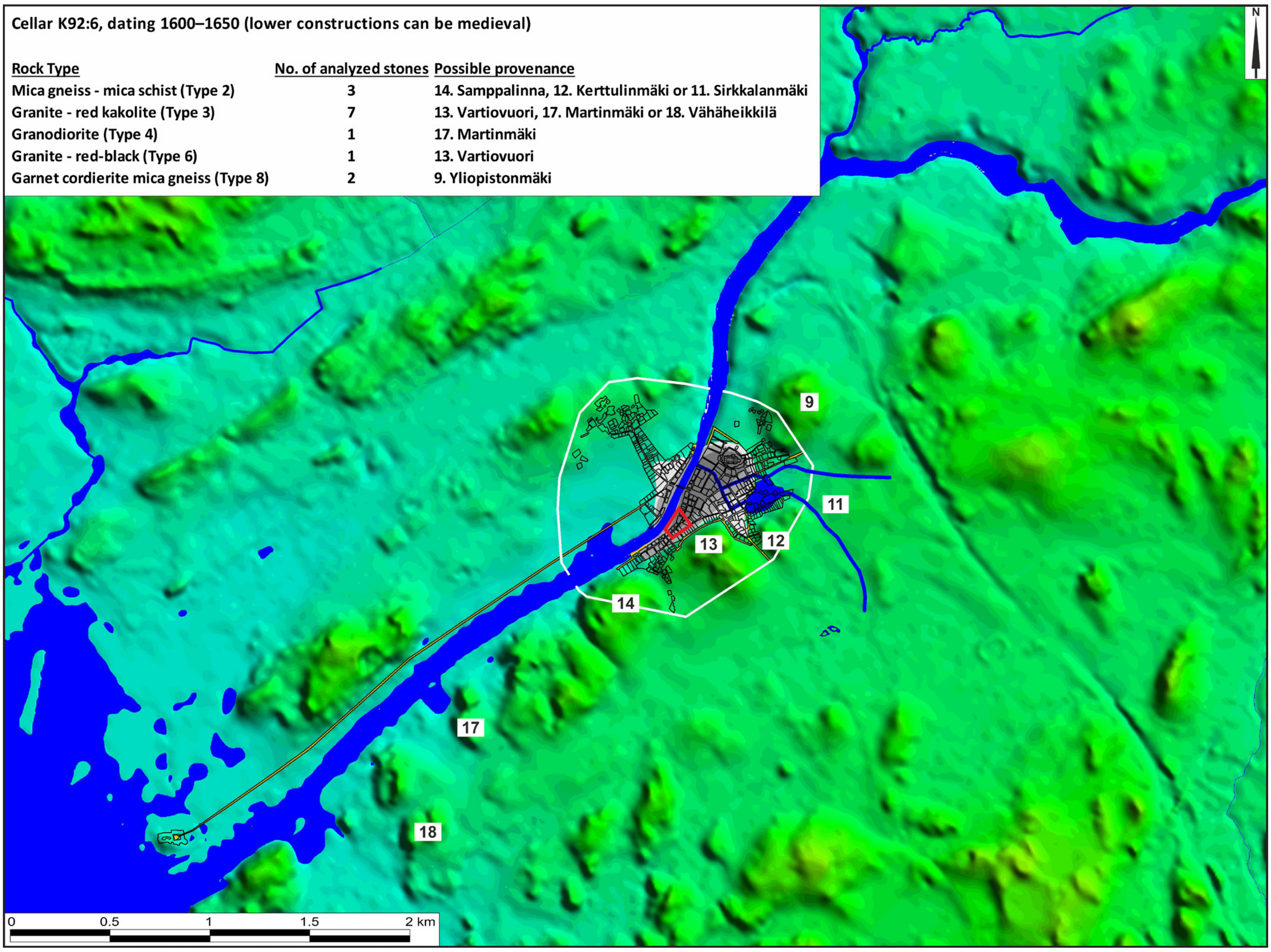

Figure 7. The possible provenance of the dimension stones used in cellar K92:6. The dominant stone type is red granite and all stones have been quarried from the eastern side of the river. The figure contains data from the Elevation model 10 m of National Land Survey of Finland.

Figure 8. Six stones were analyzed from the northern wall of the cellar K92:3. The big block at the bottom of wall is the only red-black granite (type 6) among the analyzed stones in this context. The floor is paved with cobblestones (diameter about 10–20 cm), which were not analyzed in this study. Photo: Markus Kivistö.

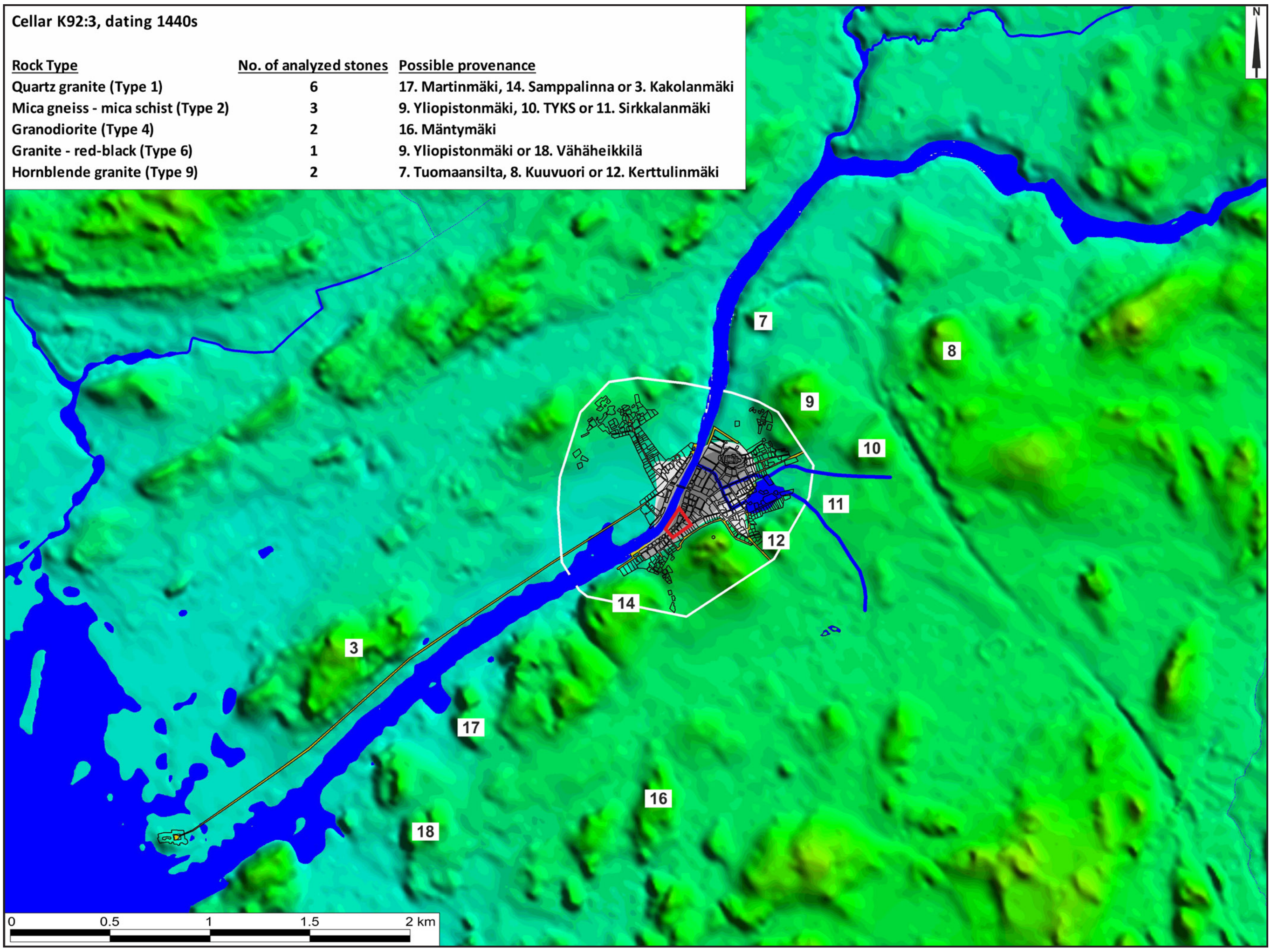

Figure 9. The stones used in cellar K92:3 were quarried from different hills on eastern part of the river. The figure contains data from the Elevation model 10 m of National Land Survey of Finland.

and 12). The size of the cellar is about 18.5 m^2. According to the dendrochronological dates, the cellar was built in the 1450s as an extension to the older building (Uotila 2007, 22, 25; 2009: 44). The cellar was used until the early 20th century. At the end of the 19th century, it was probably used as a part of a bathing house built in this area in 1874. Thereafter, the building was used as a cigarette factory until the 1920s when it was demolished and the cellars underneath were abandoned. In the course of the centuries the cellar has been renovated and reconstructed. For example, the floor was covered with concrete and the walls were plastered with cement mortar that is still covering major parts of the walls (Uotila 1995: 35–7; Sartes & Lehtonen 2007: 61–3). Apparently, three of the walls were made exclusively of bricks and only the lower part of the northeastern wall was made of stone. In this study, four stones were analyzed from this wall (Kinnunen 2018: Appendices 2, v; 3, Figure 4) and they represent three different stone types (Figure 13 and Table 3).

Cellar K93:5 locates next to cellar K93:4 and both cellars belong to the same building phase of a larger building complex (Figures 2 and 14). Both cellars were probably made during the 1450s. The size of this cellar is only 4.8 m^2. The lower parts of the walls are made of dimension stones, but the upper part of the walls, as well as the vaulted ceiling, are made of bricks. The walls are partly covered with plaster. In the excavations, no evidence of paving of the floor was found. The cellar was in use until the early 20th century and some renovations were

Figure 10. Cellar K92:5 is actually a narrow staircase leading to the adjacent cellar K92:3. The stairs are made of split stone blocks. Photo: Markus Kivistö.

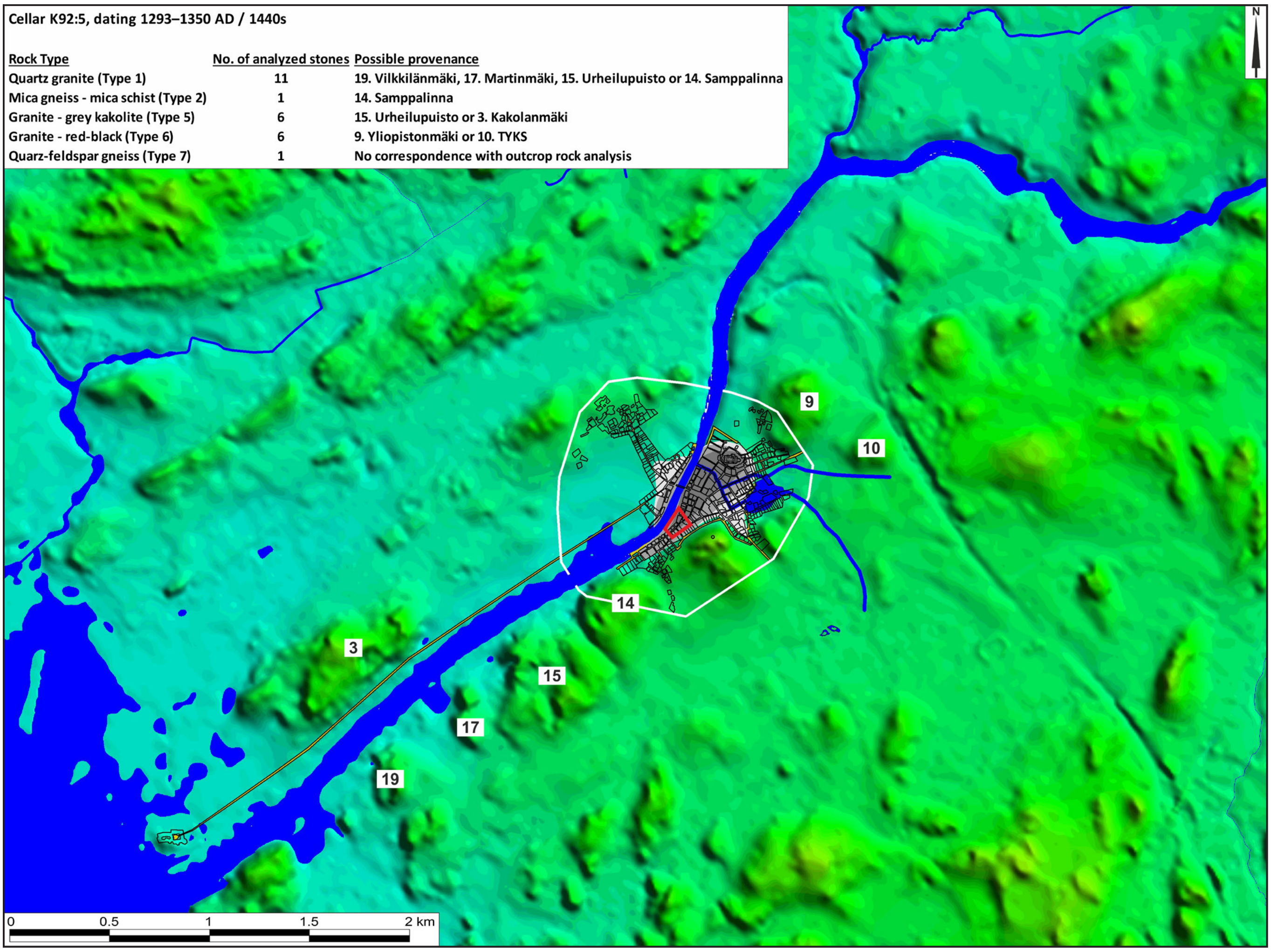

Figure 11. Granites and quartzs are the dominant stone types in cellar K92:5. The stones originate from the hills on the eastern side of Aura River. Gneiss with very low Al and Ti has no parallel in outcrop analyses. The figure contains data from the Elevation model 10 m of National Land Survey of Finland.

Figure 12. All analyzed stones can be found in the northeast corner of the cellar K93:4. The darkest stone on the left above the niche is mica gneiss – mica schist (type 2), the light-grey one next to it is quartz granite (type 2) and the one below it (above the opening) is hornblende granite (type 9). Photo: Markus Kivistö.

made in the course of the centuries here as well. The cellar was found partly demolished and some reconstruction work was carried out in the mid 1990s when the museum was under construction (Uotila 1995: 38–9; Sartes & Lehtonen 2007: 63–4; Uotila 2007: 22; 2009: 44). In this study, thirteen stones of cellar K93:5 were analyzed from three walls where dimension stones were most numerous (Kinnunen 2018: Appendices 2, vi–vii; 3, Figure 5). The stones represent five different stone types as stated in Figure 15 and Table 3.

Cellar K93:3 (Figures 2 and 16) locates next to the abovementioned cellar K93:4 and is closely connected to the adjacent cellar K93:2 (not analyzed in this study). In the late Middle Ages,

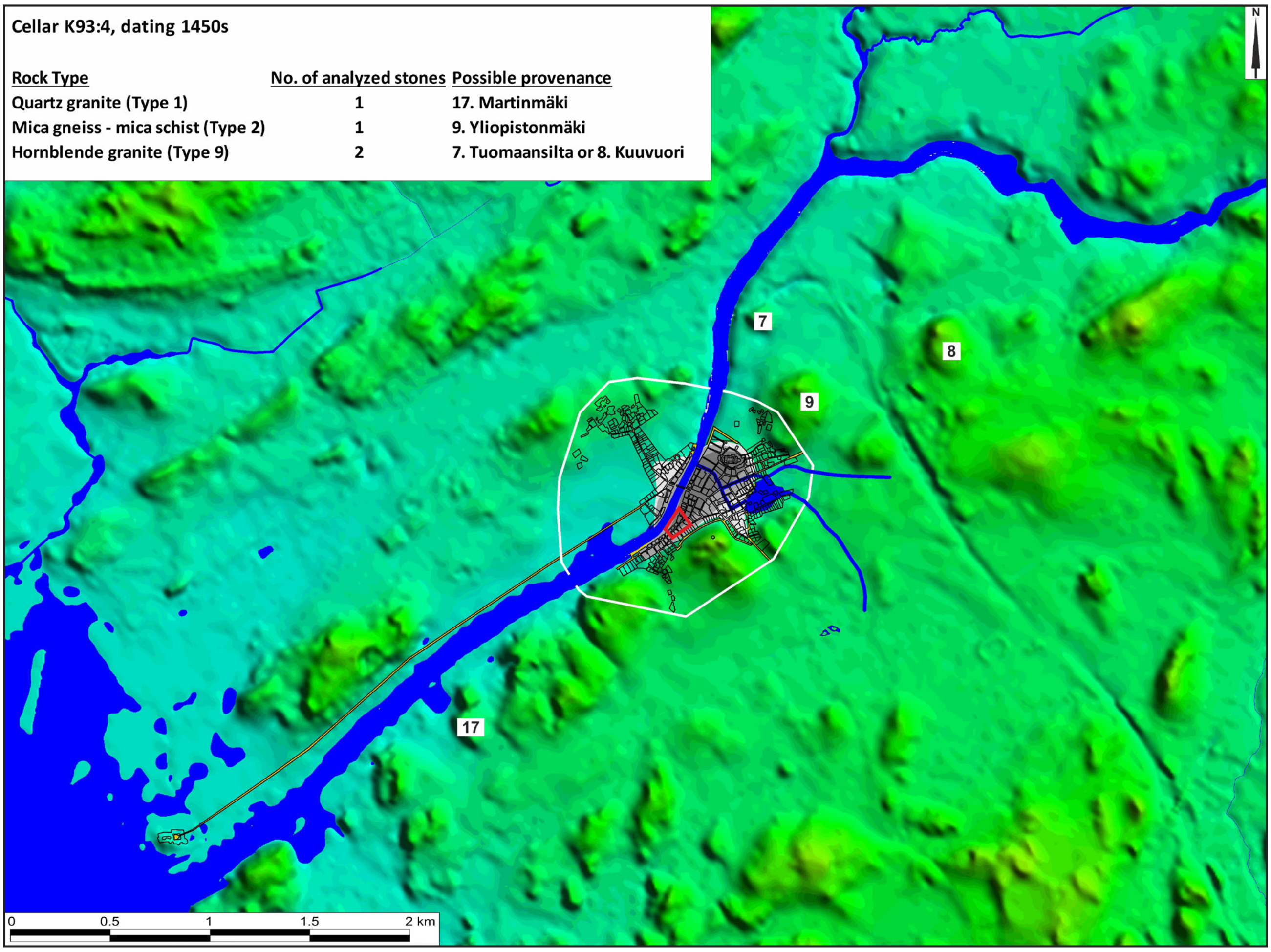

Figure 13. The dimension stones used in cellar K93:4 originate most probably from three hills locating north-east of the medieval town. Hornblende granite (type 9) is quite unique and it is most probably from Tuomaansilta (7) or Kuuvuori (8) where this stone type can be found. The figure contains data from the Elevation model 10 m of National Land Survey of Finland.

Figure 14. Cellar K93:5 was mainly made of bricks but stones were used in the northeastern wall and in the lower parts of the cellar. In this study, eight stones of this wall were analyzed. The dark grey one in the middle on top is the only quartz-feldspar gneiss (type 7) in this cellar. Photo: Markus Kivistö.

all these cellars belonged to the same building complex. This cellar represents the oldest part of the building and has been dated to the 1390s (Uotila 2007: 22; 2009: 44). The size of the cellar is circa 12.3 m^2 with the maximum height of 2.15 m. The northwestern wall is mainly made of stones, but otherwise the walls are mostly made of bricks so that stones have been used in the corners and in the lower parts the walls. The vaulted ceiling is made of bricks. Also this cellar was in use until the early 20th century as a part of a bathing house. In the course of the centuries, the original floor made of cobblestones was covered with concrete and the walls were covered with plaster. Furthermore, an old entrance was replaced with a new one (Uotila 1995: 30–4; Sartes & Lehtonen 2007: 60–1). Eight stones were analyzed from two walls visible in Figure 16 (Kinnunen 2018: Appendices 2, v–vi; 3, Figure 6). The analyzed stones represent four different stone types (Figure 17 and Table 3).

Cellar K95:21 locates next to the abovementioned cellar K93:5 (Figure 2), but probably the cellars belong to different buildings and represent different construction phases. The size of the cellar is only 7.4 m^2. The walls of the cellar are mainly made of big dimension stones. Also the vaulted ceiling is made of stones and the floor of the cellar is made of small cobblestones (Figure 18). Compared to the size of the cellar, the doorstone is very big, 1 m x 1 m. The cellar belongs to the building complex that has been dated to the 1390s, but it has a long history reaching until the 19th century (Sartes & Lehtonen 2007: 85–6; 2009: 44). In this study, thirteen stones from the walls and a large step stone were analyzed (Kinnunen 2018: Appendices 2, vii–viii; 3, Figure 7). The stones in this cellar represent four different stone types (Figure 19 and Table 3).

Cellar K94:7 locates in the westernmost corner of Aboa Vetus (Figures 2 and 20). According to dendrochronological analysis, the cellar was constructed in the 1440s. At the end of the 19th century, it was still in use as a part of a bathing house on site. Despite the long use-history including renovations, it is one of the most well preserved cellars in the museum, with a maximum height of approximately four meters. It is also one of the biggest cellars with an area of about 55 m^2. Stones in the lower parts of the cellar belong possibly to the original construction phase from the Middle Ages. The western wall of the cellar is mainly made of stones, which have been covered with plaster in a later phase. The floor is made of cobblestones and the vaulted ceiling is made of bricks (Sartes & Lehtonen

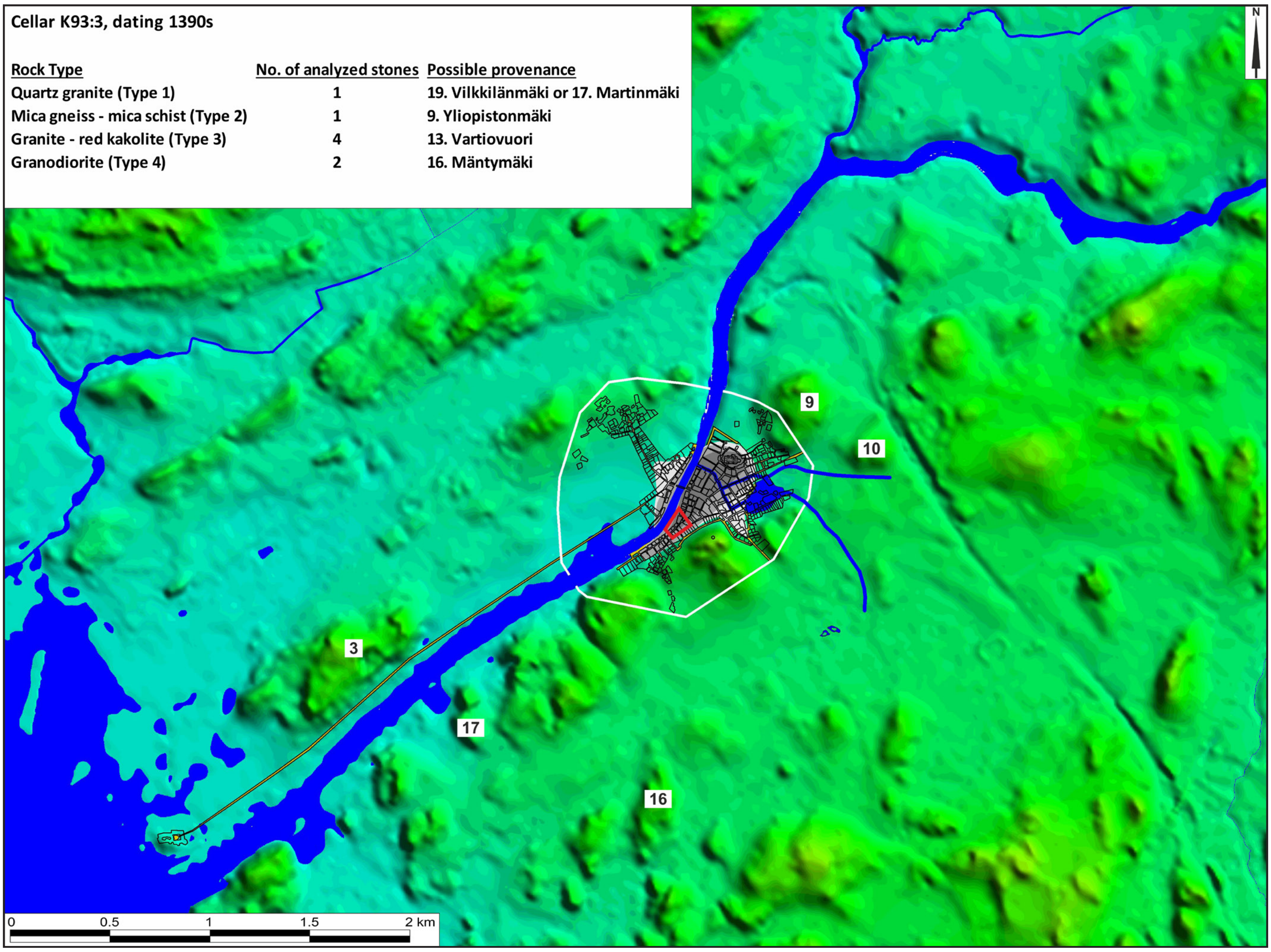

Figure 15. The dimension stones analyzed from the cellar K93:5 originated most probably from four hills outside the medieval town area. The figure contains data from the Elevation model 10 m of National Land Survey of Finland.

Figure 16. The cellar K93:3 was mainly made of bricks, but some stones were used in the northwestern (front) and northeastern (right) walls from where eight stones were analyzed and they represent all four stone types used in this cellar. Photo: Markus Kivistö.

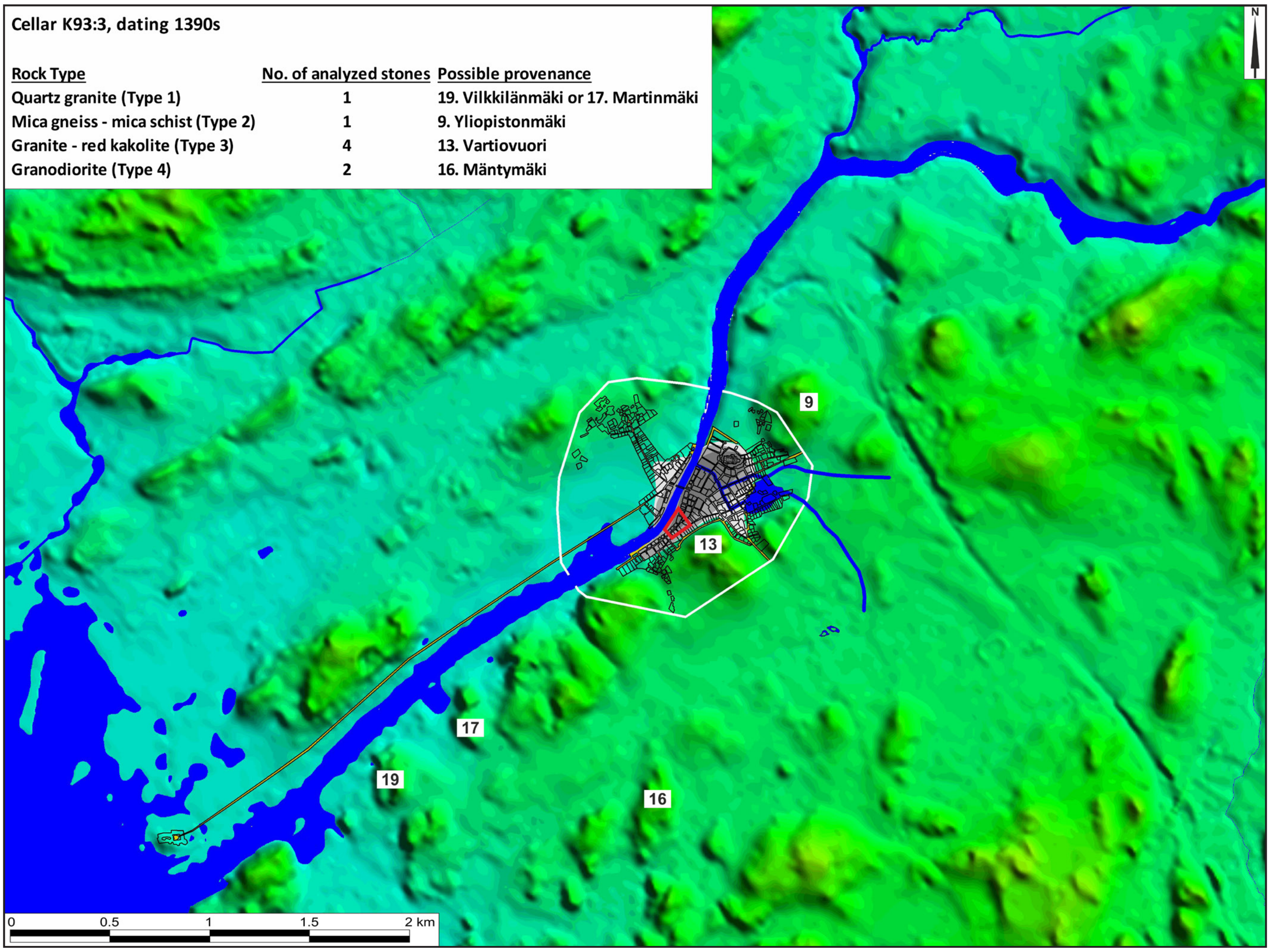

Figure 17. In cellar K93:3 four stone types were used. The dominant stone type is red granite originating from the adjacent Vartiovuori Hill (13). Other stones originated from others hills on the eastern side of Aura River. The figure contains data from the Elevation model 10 m of National Land Survey of Finland.

Figure 18. Cellar K95:21 was mainly made of dimension stones. The analyzed step stone can be seen in front of the back wall. Photo: Markus Kivistö.

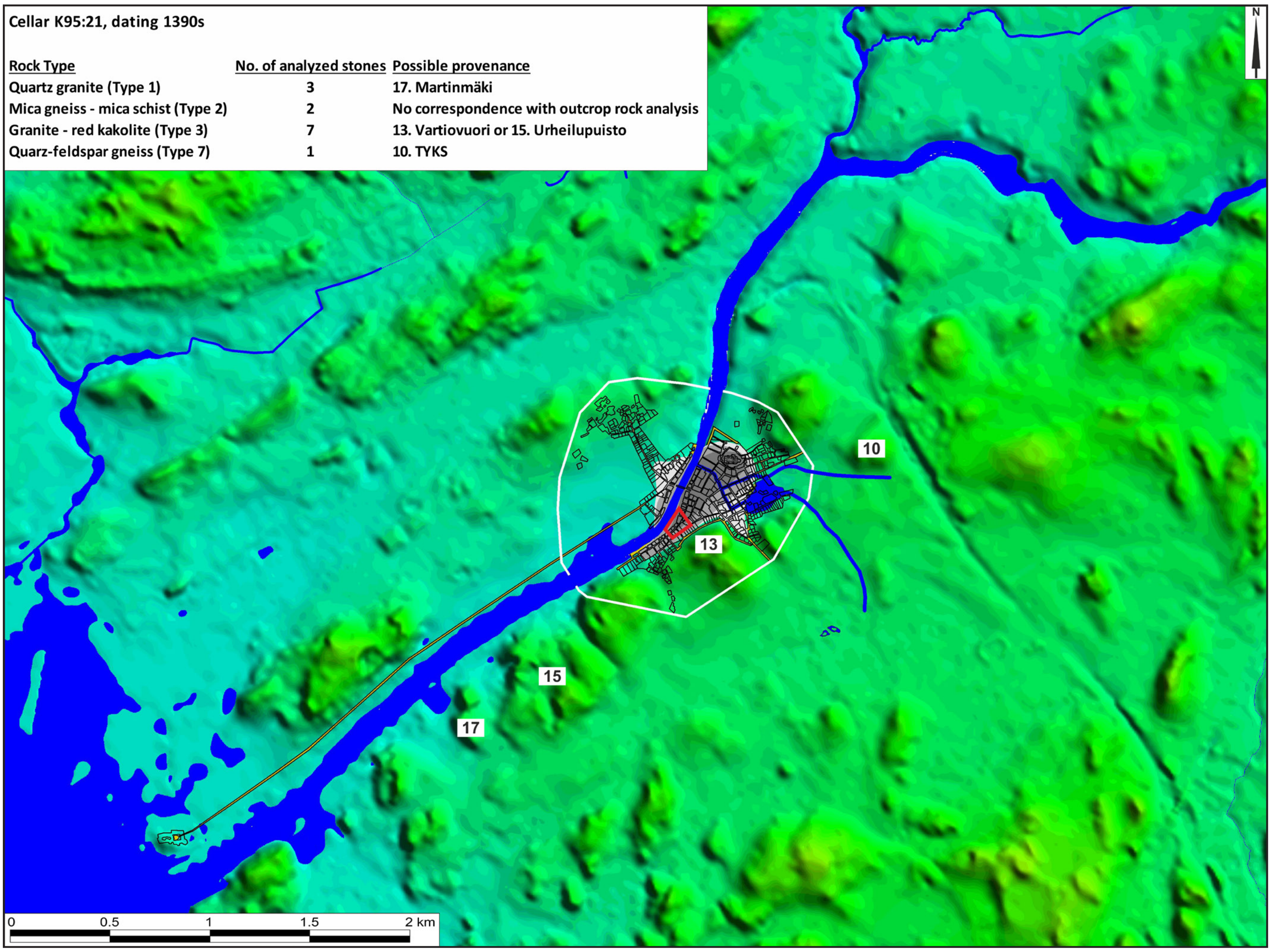

Figure 19. In cellar K95:21, the dominant stone type is red granite originating most probably from the adjacent Vartiovuori Hill (13). The other stones originated from the other hills on the eastern side of Aura River. Analyzed mica gneisses differ slightly from the analyzed outcrops due to the abundant amount of TiO2. However, the possible provenance can be located to the University hospital area (TYKS, 10). The figure contains data from the Elevation model 10 m of National Land Survey of Finland.

2007: 67–71; Uotila 2009: 44). In this study, nine stones in total were analyzed, including stones from all walls (Kinnunen 2018: Appendices 2, viii–ix; 3, Figure 8). The stones represent four different stone types (Figure 21 and Table 3).

Cellar K94:12 belongs to a larger building complex made in the 15th or 16th century (Figure 2). The size of the cellar is about 14.4 m² (Uotila 2009: 4). The walls are mainly made of dimension stones (Figure 22) apart from the brick entrance on the south-east wall leading to the adjacent staircase (K94:11). The floor is made of stones of various sizes, but the vaulted ceiling was made of bricks (Sartes & Lehtonen 2007: 82–3). In this study, 26 stones were analyzed from the walls and from the step stones of the cellar (Kinnunen 2018: Appendices 2, xi–xiii; 3, Figure 9). These stones represent six different stone types (Figure 23 and Table 3). A couple of stones, including a limestone used on the floor, did not have corresponding outcrops, which suggests a practise of using loose stones or possible transportation of single stones.

Cellar K94:11 is a narrow staircase leading to the abovementioned cellar K94:12 (Figures 2 and 24). They both belong to the same building phase and have been dated to the 15th and 16th centuries. The length of the staircase is about 5.5 m and it consists of six stone steps and a narrow doorstone in the upper part of the staircase. The size of the doorstone connecting the cellars K94:11 and K94:12 is 76 cm x 60 cm. The width of the staircase is about 1.5 m. The lower part of the northeast wall is made of large stones (the biggest being 2.2 m x 1.2 m), but the upper parts of the walls are made of bricks. The floor is made of small stones (Sartes & Lehtonen 2007: 80–1). In this study, seventeen stones from three walls and eight stones from the staircase and floor were analyzed, 25 stones in total (Kinnunen 2018: Appendices 2, ix–xi; 3, Figure 10). The stones represent six stone types (Figure 25 and Table 3).

Cellar K94:9 locates next to cellar K94:12 and the staircase K94:11 mentioned above. It belongs to the biggest building in the museum area, to which are included also cellar K94:10 presented below and staircase K94:8 not analyzed in this study (Figures 2 and 26). The size of the building is about 150 m². Cellar K94:9 is the larger of two cellars separated from each other by an inner wall made of bricks. Otherwise, the walls are mainly made of stones

Figure 20. In cellar K94:7, dimension stones were mainly used in the lower parts of the walls. In the photo, you can see the western wall from where four stones were analyzed. All stones are red granite (type 3) quarried from the adjacent Vartiovuori Hill. Photo: Markus Kivistö.

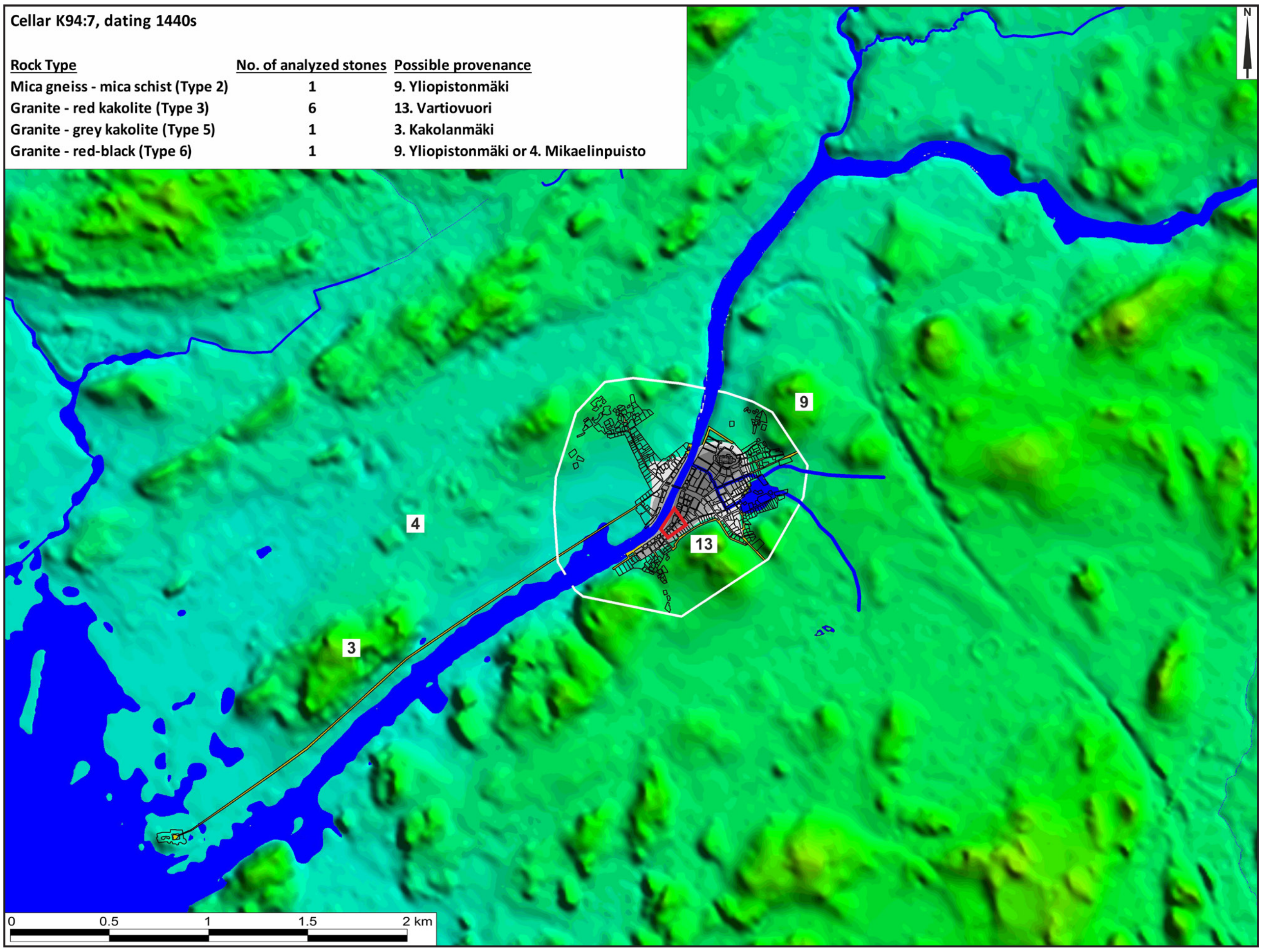

Figure 21. The dominant stone in the cellar K94:7 is red granite which was quarried from adjacent Vartiovuori Hill (13). A few stones originate from other hills around the city. The figure contains data from the Elevation model 10 m of National Land Survey of Finland.

and the floor is mainly made of cobblestones with a few larger stones in between. The size of the cellar (floor area) is about 40 m². The building complex has been dated to the early 15th century (ca. 1404–1410 AD) and it was used until the mid 17th century (Uotila 2003: 127; 2007: 22; Sartes & Lehtonen 2007: 74–5, 199–200; Uotila 2009: 44; Lehtonen & Aalto 2012: 6, 19–25; Aalto 2016: 8, 21–5). In this study, seven stones from two walls were analyzed (Kinnunen 2018: Appendices 2, xiii–xiv; 3, Figure 3) and they represent two different stone types (Figure 27 and Table 3).

Cellar K94:10 belongs to the same building complex than the abovementioned cellar K94:9 and the staircase K94:8 leading to this cellar (Figures

Figure 22. Some stones of notable sizes have been used in the south-west wall of cellar K94:12. From this wall nine stones were analyzed and they all can be seen in this picture. Three gray stones framing the niche are gradiorite (type 4), which is the most often used stone type is this cellar. The reddish one on the foot of the wall is quartz granite (type 1) and the big block below the niche is mica gneiss – mica schist (type 6) that are also frequently used in this cellar. Photo: Markus Kivistö.

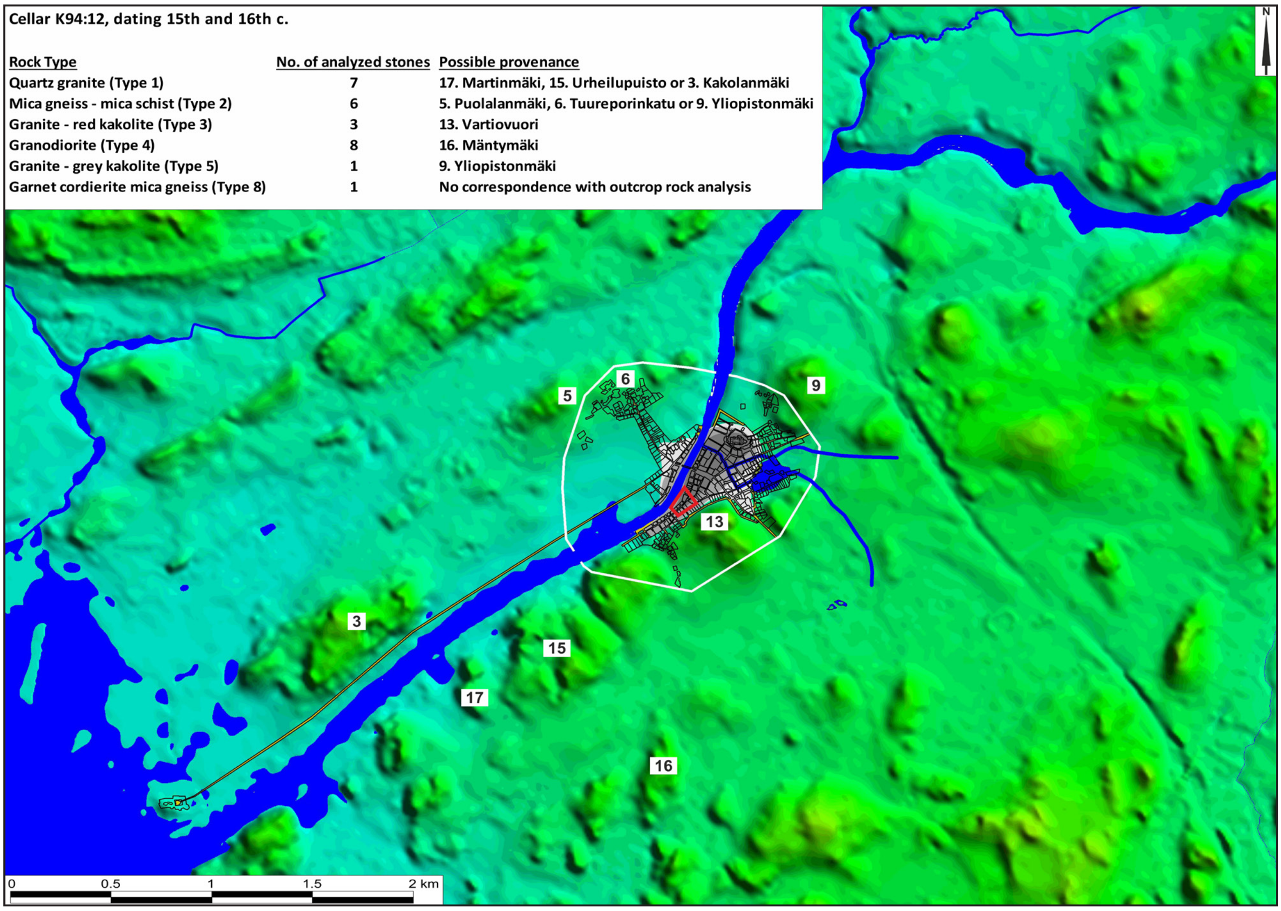

Figure 23. Granodiorite, quartz granite and mica gneiss are the dominant stone types in cellar K94:12. Garnet cordierite mica gneiss did not have correspondence with outcrop analyses, but most probably it originates from Yliopistonmäki Hill like the same stone type used in the adjacent cellar K94:11, too. The stones used in the cellar K94:12 originate most likely from the hills on the eastern side of Aura River. The figure contains data from the Elevation model 10 m of National Land Survey of Finland.

2 and 28). According to dendrochronological analyses, the cellar was built around 1410 AD. The size of the cellar is about 33.8 m^2. The remaining walls (apart from the inner wall separating the cellars K94:10 and K94:9) are mainly made of dimension stones, but bricks have also been used especially in the southwestern wall and in the entrance leading to the staircase. Also the floor of the cellar is made of stones, as well as the vaulted ceiling, which had later been repaired with bricks and does not exist anymore. Probably, the inner walls of the first floor were also made of dimension stones (Uotila 2003: 127; Sartes & Lehtonen 2007: 75–80; Aalto 2016: 25–7). In this study, five stones were analyzed from the outer wall of the cellar (Figure 28; Kinnunen

Figure 24. The stairs of cellar K94:11 are mainly made of quartz granite (type 1). The stepstone at the entrance leading to cellar K94:12 (on left) is mica gneiss – mica schist (type 2). The big block on the right side of the corridor is garnet cordierite mica gneiss (/kintzigite, type 8) which is is one of the biggest stones (1.2 m x 2.2 m) in the whole museum area. Photo: Markus Kivistö.

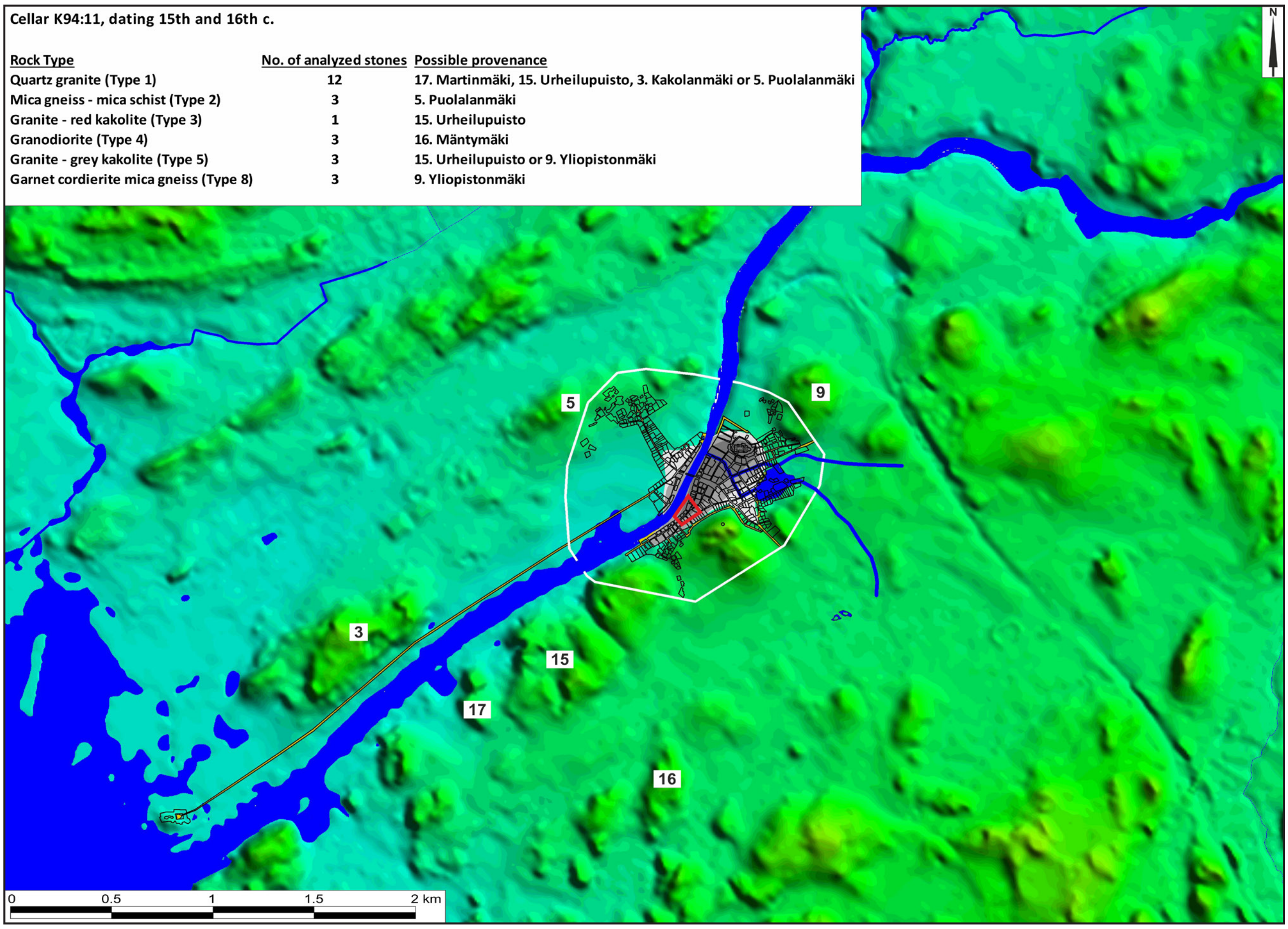

Figure 25. Quartz granite (type 1) is clearly the most dominant stone type in cellar K94:11 used both in the stairs and in the walls. The large garnet cordierite mica gneiss block visible in figure 24 is most probably from Yliopistonmäki Hill. All stones originate most probably from the hills on the eastern side of Aura River. The figure contains data from the Elevation model 10 m of National Land Survey of Finland.

Figure 26. The southwest wall of cellar K94:9 with two arched recesses. The stones visible in the eastern recess on the left are all mica gneiss – mica schist (type 2). ¬At the time of this study, archaeological excavations in this cellar were still going on. Photo: Markus Kivistö.

2018: Appendices 2, xiv; 3, Figure 12), and they represent three different stone types (Table 2 and Figure 29).

Discussion of the results

The analyses demonstrate that in Turku building stones have been quarried from local bedrock since the end of the 14th century. In the studied cellars, kakolite-group granites were used most often (62 % of all analyzed stones) and the most common stone type was quartz granite (28 % of all stones). Mica gneiss / mica schist, kinzigite and quartz-feldspar gneiss together constitute 27 % of all stones analyzed in this study (Table 4). These stones split easily along the foliation and therefore are easier to quarry and work than hard granite. In Turku region, mica gneiss bedrock is located in valleys and depressions usually covered with quaternary deposits and therefore it was unreachable in the Middle Ages. However, mica gneiss interbeds (from one to tens of meters thick) can be found on the hill-

Table 4. The prevalence of different rock types and the use of different stone types can be estimated according to the number of analyses made in this study.

Stone type	Stone name	Number of analyses from Aboa Vetus	Number of analyses from outcrops	Total
1	Quartz granite	46	10	56
2	Mica gneiss	31	11	42
3	Granite – red kakolite	28	20	48
4	Granodiorite	18	10	28
5	Granite – grey kakolite	14	11	25
6	Granite – red-black	9	9	18
7	Quartz feldspar gneiss	7	9	16
8	Kinzigite	6	3	9
9	Hornblende granite	4	6	10
	Analyses in total	163	89	252

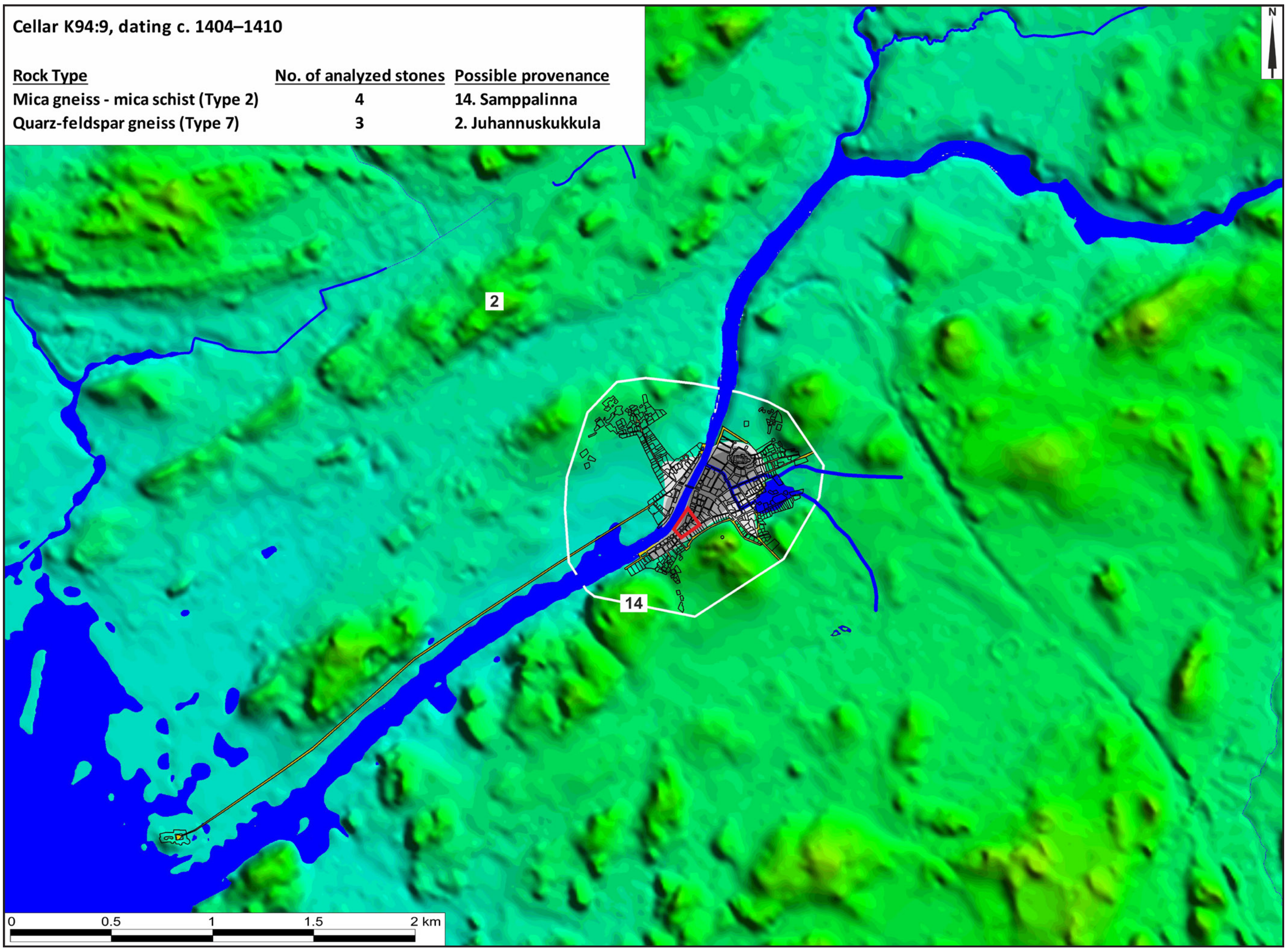

Figure 27. The analyzed stones in cellar K94:9 represent two different stone types. Mica gneisses (type 2) are abundant in vanadine and the similar kind of stone is found from Samppalinna Hill (14). Apparently, all mica gneiss stones originate from the same quarry. Quartz-feldspar gneiss is probably from Juhannuskukkula Hill (2) north of the town. The figure contains data from the Elevation model 10 m of National Land Survey of Finland.

sides between granite layers. Therefore it may have been easy to quarry mica gneiss interbeds together with granite. The remaining 11 % of the analyzed building stones were granodiorite, which is clearly distinguishable from other stones. The closest area with granodiorite deposits is located at a distance of 0.5 km south of medieval Turku. A few single limestones suggest some stones were transported from the Baltic area, but otherwise there is no evidence of long-distance transportation of stone material in the Middle Ages in Turku.

The hills on the eastern side of the Aura River were used for the acquisition of stones throughout the Middle Ages. The town was founded on the eastern side of the river at the beginning of the 14th century and although the urban area expanded on the western side of the river at the end of the 14th century, the heart of the medieval town with most handsome and significant buildings remained on the eastern side. It was not until in the latter part of the 16th century when the role of the western side of the river was transformed and it was inhabited by people with good status and wealth (Nikula 1987: 105–9; Seppänen 2011: 479–80; 2012: 941–6; 2016: 94–6). On the basis of this study, the first evidence of stone material acquisition from the western side of the river can be dated to the end of the Middle Ages, when mica gneiss from Puolalanmäki was used to build cellars K94:11 and K94:12. In

Figure 28. Even the largest stones in the northeast wall of the cellar K94:10 are round shaped suggesting that they can be loose stones (cf. K94:12). Therefore, only five stones from this wall were analyzed. The stones on the left below belong to a well that was not analyzed in this study. Photo: Markus Kivistö.

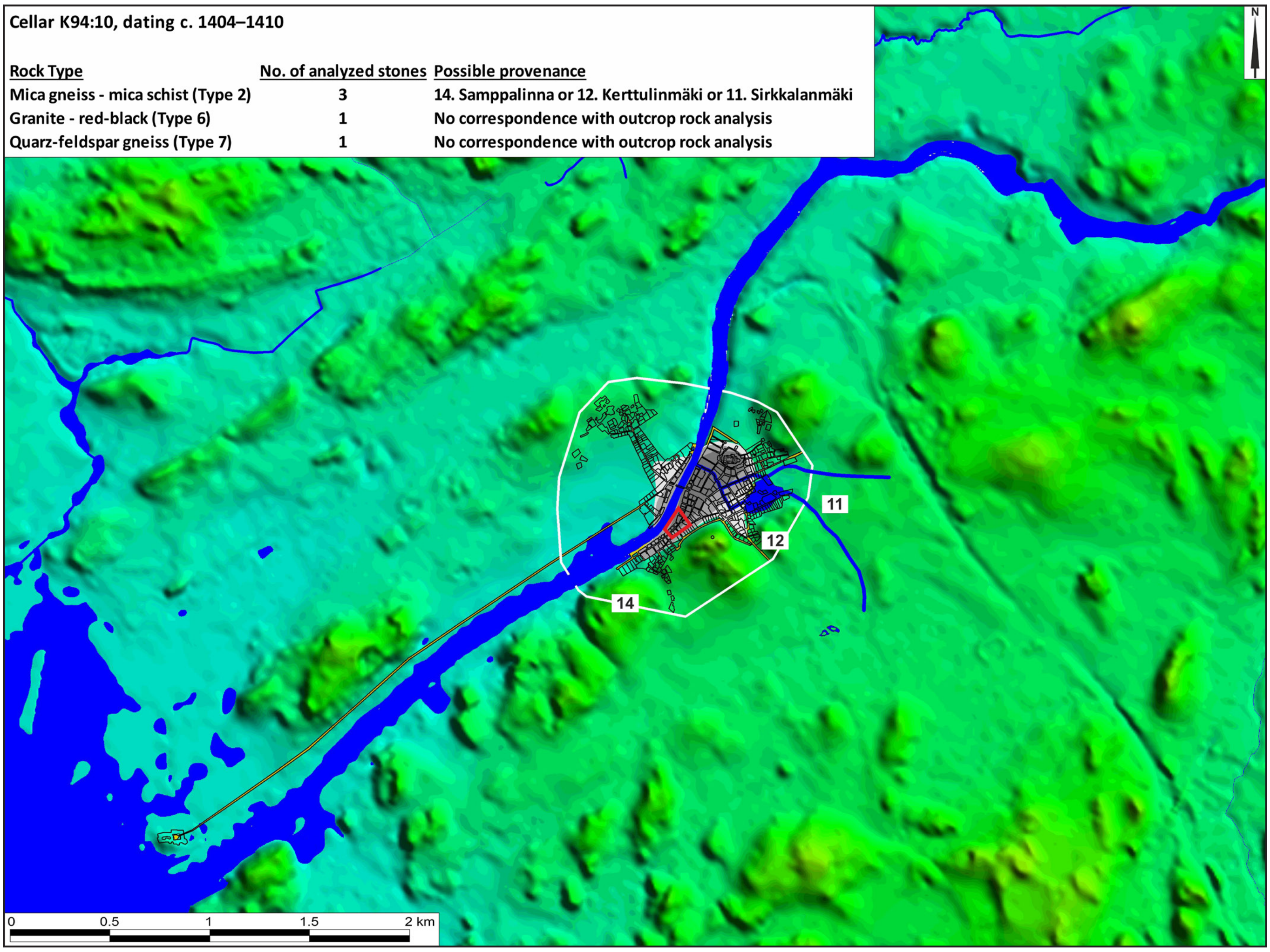

Figure 29. All mica gneiss stones (type 2) used in cellar K94:10 are most probably from Samppalinna Hill (14) locating close to the building site, but the provenance of red-black granite (type 6) and quartz-feldspar gneiss (type 7) cannot be defined. The figure contains data from the Elevation model 10 m of National Land Survey of Finland.

these cellars also granodiorite was used, which indicates that for some reason the stone material in this case was acquired from a more distant location outside the medieval city. The first bridge across the river was constructed in 1414 (REA 349), which facilitated the transportation and traffic across the river. According to this study, no transportation of stones across the river took place prior to the construction of the bridge. However, we need to remember that the utilization of the hills on the western side of the river may prove to have been more active in the late Middle Ages if the masonry buildings excavated on that side are also studied. On the basis of this study, however, we can make the conclusion that in medieval Turku building stones were acquired close by and preferably from the same side of the river (Figure 30).

According to this study, it is possible to divide medieval quarrying areas in Turku into the following five groups (Figure 31):

Urheilupuisto, Samppalinna, Vartiovuori, and Kerttulinmäki have a similar geological setting with red granite as the main bedrock type. Red granite was quarried from Vartiovuori Hill also in later times. Also the softer mica gneiss interbeds are common in this area. According to our study, stones from this area were used throughout the Middle Ages in Turku.

Martinmäki, Vähäheikkilä, Vilkkilänmäki, and Kakolanmäki are mainly labeled as belonging to the kakolite area with coarse kakolite granites (quartz granite, grey granite and red-black granite) as the most common bedrock type. Geochemically it is impossible to distinguish the provenance more precisely, but it is very likely that Kakolanmäki Hill was not quarried on a large scale in the Middle Ages to meet the needs in the town area. However, kakolite from Kakolanmäki Hill could have been quarried for the construction of Turku Castle in the Middle Ages, but this should be investigated with material analysis of the castle.

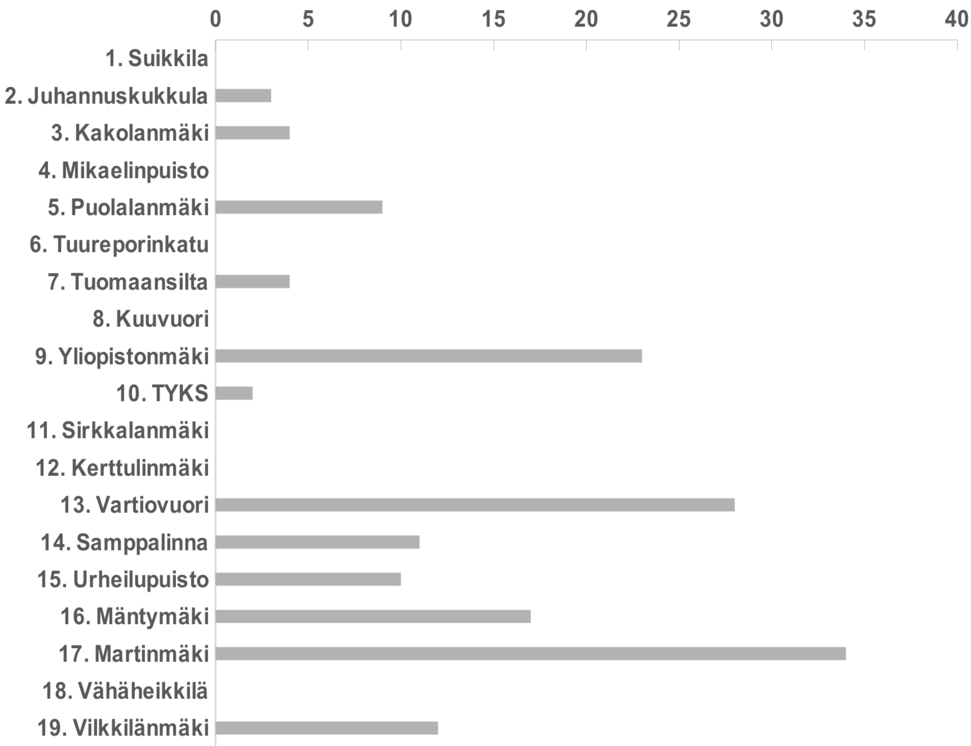

Figure 30. The number of analyzed building stones per hill demonstrating that the utilization of the hills on eastern part of the river (7–19) was much more active than the utilization of the hills on the eastern side of the river during the Middle Ages in Turku. On the basis of this study, the majority of building stones were acquired from the same side of the river.

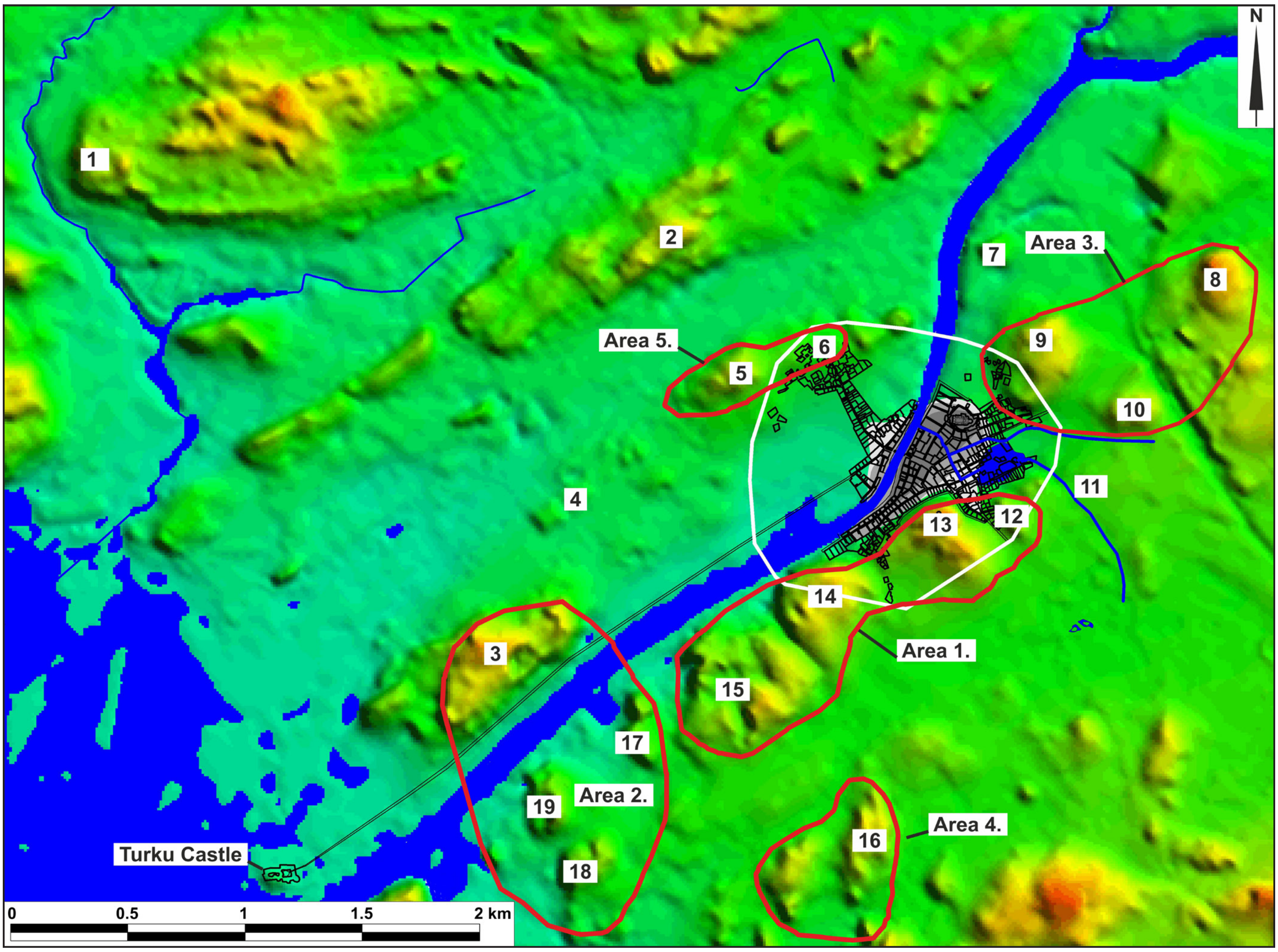

Figure 31. The hills that were possibly used for minor scale quarrying in the medieval Turku: 1. Suikkila, 2. Juhannuskukkula, 3. Kakolanmäki, 4. Mikaelinpuisto, 5. Puolalanmäki, 6. Tuureporinkatu, 7. Tuomaansilta, 8. Kuuvuori, 9. Yliopistonmäki, 10. Turku University Hospital (TYKS), 11. Sirkkalanmäki, 12. Kerttulinmäki, 13. Vartiovuori, 14. Samppalinna, 15. Urheilupuisto, 16. Mäntymäki, 17. Martinmäki, 18. Vähäheikkilä, and 19. Vilkkilänmäki. The possible quarrying areas discussed above (1–5) are circled with red. Water level + 2.65 m as in circa 1300 AD. The figure contains data from the Elevation model 2 m of National Land Survey of Finland.

Yliopistonmäki, TYKS, and Kuuvuori form an area where the main bedrock is granite (gray, hornblende, black red) commonly featuring dark mafic minerals. Granite forms wide lenses (hundreds of meters in diameter) in mica gneiss deposits. Mica gneiss, mica schist and especially garnet bearing kinzigite have commonly interbedded in granite, and also migmatites (including both granite and mica gneiss) are frequently found. Furthermore, the bedrock of these hills contains guartz-feldspar gneiss in minor quantities. All these hills were used for quarrying in the Middle Ages in Turku.

Mäntymäki is the closest possible place of origin for granodiorite first used in the 1390s (cellar K93:3).

Puolalanmäki and Tuureporinkatu form a mica gneiss area. Dark and fine grained mica gneiss was probably used at the end of the 15th century or at the beginning of the 16th century. Mica geiss dimension stones of notable sizes (cellars K94:11 and K94:12) originate possibly from the Puolalanmäki Hill, where the mica gneiss differs from strongly foliated and striped migmatitic gneisses interbedded with granites.

All in all, the number of stones used in masonry buildings seems to have been surprisingly low in Turku. Usually only the lowest parts of the walls were made of stones, and in many cellars brick was commonly used in the walls. This

Hill	Cellar	K92:6	K92:3	K92:5	K93:4	K93:5	K93:3	K95:21	K94:7
1	Suikkila								
2	Juhannuskukkula								
3	Kakolanmäki					3			1
4	Mikaelinpuisto								
5	Puolalanmäki								
6	Tuureporinkatu								
7	Tuomaansilta		2		2				
8	Kuuvuori								
9	Yliopistonmäki	2	1+3	6	1	3	1		1+1
10	TYKS					1		1	
11	Sirkkalanmäki								
12	Kerttulinmäki								
13	Vartiovuori	7+1					4	7	6
14	Samppalinna	3		1					
15	Urheilupuisto			6					
16	Mäntymäki		2			2	2		
17	Martinmäki	1	6		1	4		3	
18	Vähäheikkilä								
19	Vilkkilänmäki			11			1		

Table 5. The table presents the possible provenance of building stones used in different cellars. Plus sign indicates different stone types, which could have been acquired from the same hill.

may suggest favouring bricks over stones when possible. In each cellar, from two to six different stone types were used, and in total the number of different stone types in all of the analyzed twelve cellars was 52 (Table 3). The stones originate from different parts of Turku (Table 5 and Figure 31), and consequently there is no evidence of systematic quarrying from one area only. Possibly all easily available and suitable stones (including loose stones) have been used for building, since the bedrock in Turku is mostly difficult to quarry and hard to work. It is also possible that prehistoric stone cairns in this region were consumed as building stones. Although the Turku region was intensively inhabited in late prehistoric times, no cairns exist in this area, while the closest are found in the archipelago. The variability of stone types in single constructions, also suggests active reuse of materials.

It seems that after splitting the stones from bedrock, further finishing was not carried out, which also can be seen as an indication of the difficulties of working the hard stones. Therefore, it is perhaps slightly misleading to speak about dimension stones in this context. On the other hand, possible evidence of medieval stone splitting and working may have been destroyed or covered by later activities. During the fieldwork made for this study, dozens of clear drilling marks were detected in the bedrock outcrops, especially on the Vartiovuori Hill, indicating extensive quarrying activities. The marks on the hill, however, cannot be dated to the Middle Ages. Evidence of medieval stone working can be found in the northern façade of Turku Cathedral, where at least six large stones have clear drilling marks. The façade has been dated to the 1430s (Drake 2011), but the provenance of the stones has so far not been analyzed.

Since all available stone types from each cellar were included in this study, it seems that the variety of stone types used in different cellars was at the largest at the end of the 14^{th} century and in the 16^{th} century (Table 3 and Figure 32). The implementation of masonry technique took place at the end of the 14^{th} century and the large variety

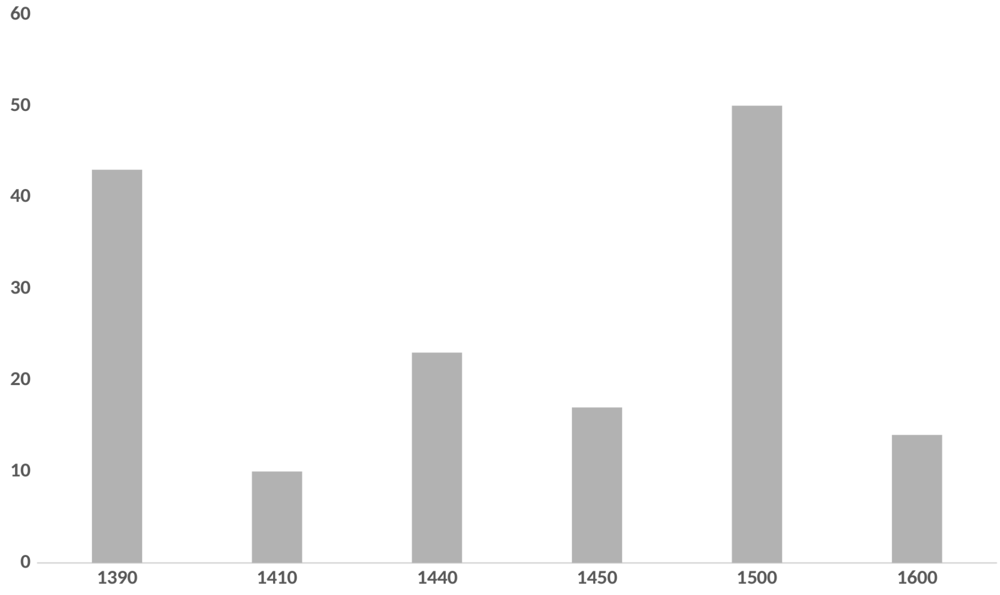

Figure 32. The number of analyzed building stones per constructions in different periods.

of stone types used in the oldest buildings may be related to problems in acquisition of stones and to limited skills and knowhow of the use of the local bedrock. This supports the idea that the builders of the first masonry buildings came from abroad.

In the 15th century, the variety of stones was more limited, which may indicate a more systematic use of local bedrock, increased understanding of the resources available, and organized acquisition of the material. This coincides with the boom in masonry building, the erection of new religious buildings and guildhalls, and the large-scale renovations in the town hall, cathedral, castle and Dominican convent (Seppänen 2012: 660–75; Niukkanen et al. 2014: 72, 74–5, 78–9, 81, 83, 86–8, 93–4; Seppänen 2016: 83–4). In the 16th century, the variety of different stone types seems to have increased. This can possibly be connected to destruction of old masonry buildings by fires (especially the one in 1546) and other wreckage in the early 16th century including measures catalyzed by the reformation, and active reuse of old material for repair work and new buildings (e.g. Seppänen 2016). However, in order to confirm these hypotheses, more systematic analyses of masonry buildings are needed from different periods and parts of the town.

Concluding remarks

The main aim of this study was to test the suitability of pXRF in analysing and tracing the provenance of building stones in Turku. Considering the limitations of the device, material, method and sampling, the results of the study are encouraging and provide a good basis for further discussions and studies related to the acquisition of stone materials and use of the environment in the past. The previous hypothesis suggesting local provenance of stone materials proved to be right, but in addition a much more detailed picture of the acquisition and use of stones was achieved by using this method.

The main problem limiting further research on building stones in Turku is the lack of available research material. This is caused by the fact that masonry constructions have in most cases either been demolished or covered without analyses of the material. Excavated masonry buildings have been filled and covered after documentation also in very recent past. If we want to get information of building stone provenance, the analyses of the stone material must be conducted while the excavations are on-going and while material is still available.

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