TAMPERE UNIVERSITY
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QUARTZ DUST EXPOSURE

The example of rock crushing quarries

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Bachelor's thesis
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ABSTRACT

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RYBINA SVETLANA:
Quartz Dust Exposure
The example of rock crushing quarries

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This Bachelor's Thesis was commissioned by a Finnish company Destia Ltd regarding quartz dust exposure on rock crushing quarries. Expectation of possible tightening of regulations created the necessity to measure dust amounts and analyse quartz dust concentration in the area of two quarries, also to evaluate exposure of workers and estimate if Destia is ready for the coming limitations.

The sampling was done in two rock crushing quarries: Syrjänsalo in Ylöjärvi and Pitkäkallio in Lempäälä near Tampere (Finland). Duration of each measurement was three working days. Data was collected with ELPI (Electrical Low Pressure Impactor) and used for particle size distribution analysis and workers' 8 hours TWA exposure evaluation. PM10 Impactor was applied to calculate the average dust mass concentration in the air, also dust collected with PM10 Impactor was used for mineralogical composition analysis with X-ray diffraction method. Device DustTrak was used for construction of dust distribution maps.

One of the most important findings is the detection of quartz in dust samples. It was found that working machines in the quarry influence the amount of PM10 particles in the air greatly. Average dust concentrations lay within the allowed range, however, maximum values of dust concentration detected might pose danger to human health in cases of prolonged exposure. In the scope of this work, it was impossible to evaluate the exact amounts of quartz dust in samples, that is why part of the results is estimated based on petrographic analysis provided by Destia Ltd.

From the results it can be concluded that even in the worst-case scenario 8 hours TWA exposure to quartz dust is not exceeding the established values, however, in case of Binding Occupational Exposure Limit establishment extra measures have to be taken in order to avoid exceedance of limits. It was noticed that dust spreading depends on wind direction and speed, temperature, humidity of air, amount of working crushing units. To find a clearer dependence of these factors further research is needed. In the studied case, at least, it can be safely said that dust is not spreading far beyond quarries borders. It is not easy to make any firm conclusions about quartz dust behavior since it was not possible to detect its mass content in samples. One interesting fact was noticed, the amount of quartz dust released from solid material is not proportional to the quartz content in this material and under certain weather conditions can be much less. This fact tells that more research and experiments have to be conducted in order to understand the behavior of airborne quartz dust.

Key words: quartz dust, dust exposure, rock crushing

CONTENTS

ABBREVIATIONS AND TERMS

BOEL	Binding Occupational Exposure Limit
C_m	Mass concentration, g/m^3
C_n	Number concentration, 1/cm^3
ELPI	Electrical Low Pressure Impactor
m	mass, g
n	number of particles
NEPSI	European Network for Silica
OEL	Occupational Exposure Limits
p	pressure, kPa
PM	Particulate matter
RH	Relative humidity, %
SCOEL	Scientific Committee for Occupational Exposure Limits
SiO_2	Silicon dioxide (silica)
TWA	Time Weighted Average
UEPG	European Aggregates Association
V	Volume, m^3
v_{wind}	Wind speed, m/s
XRD	X-ray diffraction

1 THEORY

Dust are fine particles of matter with organic or mineral origin. It can get into humans' respiratory system, stay in lungs and subsequently cause health problems. Dust is classified according to grain size. Three most commonly distinguished groups are: inhalable, thoracic and respirable. Inhalable – the mass fraction of total airborne particles, which is inhaled through nose or mouth. Thoracic – fraction that can penetrate beyond the larynx and enter airways of the lung. Respirable – fraction of inhaled particles penetrating unciliated airways, beyond the terminal bronchioles into gas-exchange region of the lungs (Brown, 2013). Also, airborne particles are characterized according to their diameter: PM10 – particles with diameter less than 10 μm, PM2.5 - diameter less than 2,5 μm, and PM1 - diameter less than 1 μm (Lilja, 2013). Respirable dust fraction is the one that causes the biggest concern, since prolonged exposure leads to dust accumulation and may result in irreversible health effects (NEPSI, 2006).

In many cases dust is created by human activities and there are a lot of examples when hazardous dust is produced at workplace: mineral dust from the extraction and process of minerals; metallic dust; chemical dust; flour, cotton and tea production; molds and spores; etc. (WHO, 1999). There are such indicators as mass concentration (formula 1) and number concentration (formula 2), which can be used for determination of air quality in environment or at work place

$$C_m = \frac{m}{V} \tag{1}$$

where C_m, m, and V are respectively mass concentration (g/m^3), mass of particles (g) and volume of air (m^3)

$$C_n = \frac{n}{V} \tag{2}$$

where C_n, n, V are respectively number concentration (1/cm^3), number of particles and volume of air (cm^3).

Even though body's natural defense mechanisms can eliminate much of respirable dust inhaled, in occupational hygiene it is important to prevent, eliminate or reduce occupational health risks related to dust (NEPSI, 2006).

1.1 Crystalline silica, quartz

Silica, or silicon dioxide with chemical formula SiO_2, is one of the most abundant inorganic materials. It exists in various forms, which can be crystalline and non-crystalline. According to NEPSI crystalline silica makes approximately 12% of the Earth crust. It is hard, chemically inert and has a high melting point. These qualities are valuable for various industrial uses. The most common form of crystalline silica is quartz, it is found nearly in all types of rock.

Dust containing quartz is of special control in occupational hygiene and environment. The European Commission's Scientific Committee for Occupational Exposure Limits (SCOEL) states, that free respirable crystalline silica may be a reason for a disease called silicosis. Silicosis is characterized by irreversible scarring and inflammation of upper lobes of lungs. There are studies showing that the relative lung cancer risk is higher for people who suffers from silicosis (NEPSI, 2016).

Quartz concentration in different rock types and materials may vary a lot. Table 1 represents some of these numbers for materials commonly used in industries.

TABLE 1. Quartz concentration in various materials (NEPSI public data values 2010)

Material	**Quartz concentration**
Sand	*>90%*
Granit	*20 – 40%*
Clay	*5 – 50%*
Slate	*<40%*
Ironstone	*7 – 15%*
Limestone	*<1%*
Cement dust	*1%*
Concrete	*30-40%*

In many materials quartz concentration is quite high, proceeding these materials is very likely to produce crystalline silica dust. Examples of such processes include: mining, quarrying, construction works, manufacture of glass and ceramics, rubber manufacturing, any process using blasting.

Clear threshold for silicosis development cannot be identified, that is why any reduction of exposure will reduce the risk of this disease (NEPSI, 2006).

1.2 Unions NEPSI and UEPG

Industries take actions to control quartz dust exposure. People are aware of danger that poses quartz dust and other forms of respirable crystalline silica. A special union was formed in order to raise public awareness about respirable crystalline silica, create guidance for reduction of occupational risks, protect workers and report on progress of implementation of good practices. The name of union is NEPSI and it stands for European network for Silica. It was formed by Employee and Employer European sectoral associations, who signed «Agreement on Workers' Health Protection Through the Good Handling and Use of Crystalline Silica and Products Containing it» on 25th of April in 2006. Apart from agreement in 24 languages, which includes Good Practice Guide, Dust Monitoring Protocol, Health Surveillance Protocol for Silicosis and some other documents, NEPSI provides illustrative videos for good hygiene at work place and Occupational Exposure Limits (OEL) for crystalline silica in European countries. NEPSI Council duties regarding issues related to silica include: follow-up of the application and implementation of the agreement; adaptation of the Good Practices; communication with third parties; drafting of summary reports and executive summaries every two years and other.

One of the European industry sectors associations who signed the agreement is UEPG – European Aggregates Association. Currently, aggregates sector is the largest non-energy extractive industry (UEPG, 2017). Aggregates are granular materials used for construction purposes. They can be sand, gravel, crushed rocks or recycled materials from demolished buildings, for example. Very often aggregates are produced from natural sources extracted from quarries and gravel pits and in some countries from sea-dredged materials. Figure 1 below represents sources of aggregates.

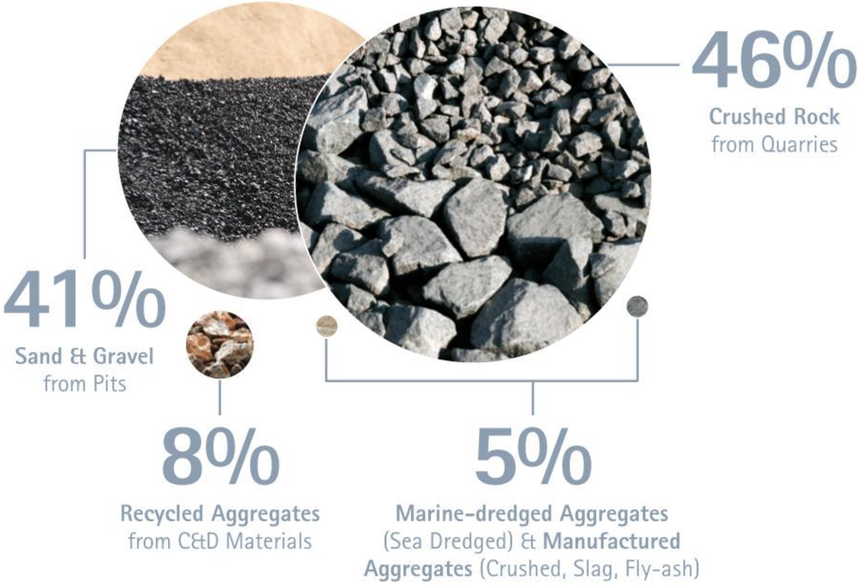


FIGURE 1. Sources of aggregates (UEPG, 2017 http://www.uepg.eu/what-are-aggregates)

The diagram on figure 1 shows that the biggest share of aggregates is coming from crushed rock mined in quarries.

UEPG has a sustainable vision of aggregate industry and one of its duties is representing environmental policy and health and safety information to the members of this association in 26 countries (UEPG, 2017). Finnish Infra Constructors Association belongs to UEPG and one of the members of Infra in Finland is a company Destia Oy.

Destia offers wide range of infrastructure services and aggregates production is one of them. There are about 300 extraction areas around Finland, which belong to the company. In its actions Destia fulfils environmental obligations of ISO14001 Environmental Management System (Destia, 2016). Many operations disturb natural environment, for instance, blasting, crushing and transporting of rocks and gravel releases fine quartz dust into atmosphere and as environmentally responsible company, Destia is doing its best to decrease consequences of their actions for environment and people, also follows regulations and laws.

1.3 Regulations

Knowledge about carcinogenicity of respirable crystalline silica creates necessity in adaption of laws on regulation of exposure limits. Directive 2004/37/EC of the European Parliament and The Council of 29 April 2004 on the protection of workers from the risks related to exposure to carcinogens or mutagens at work sets requirements, which guarantee better standard of health and safety and protects workers from risks related to carcinogens and mutagens at work. During autumn 2017 it was expected that some changes would be made in the Directive concerning respirable crystalline silica in particular. The Directive introduces in its Annex I “work involving exposure to respirable crystalline silica dust generated by a work process” and sets a Binding Occupational Exposure Limit Value (BOEL) of 100 µg/m^3 for respirable crystalline silica (NEPSI, 2017). In plenary session of the European Parliament on the 25th of October 2017 the Directive was approved. However, the amended version of the Directive 2004/37/EC (Directive (EU) 2107/2398 of the European Parliament and the Council) was signed on the 12th December 2017 and there is no information about binding exposure limit for respirable crystalline silica. It sets limit of 100 µg/m^3 measured or calculated in relation of a reference period of eight hours. Basically, it means, that during a work day of 8 hours a short-term exposure to respirable crystalline silica dust can be higher than this value. At the same time Article 18a of the Directive states that «The Commission shall, as part of the next evaluation of the implementation of this Directive … also evaluate the need to modify the limit value for respirable crystalline silica dust. The Commission shall propose, where appropriate, necessary amendments and modifications related to that substance». It is highly likely that in the next couple of years exposure limits will be tightened and for all industries it is better to keep exposures below current requirements to be safe and ready for possible changes. Moreover, one of the statements of the Directive says that «the precautionary principle should be applied in the protection of workers' health». Exposure to carcinogens and mutagens must be prevented, if it is not technically possible, then it should be done in a closed system, amount of people exposed should be minimized and consequences of exposure should be eliminated (Directive 2004/37/EC).

On a European level limit value is established at 100 µg/m^3 during 8 hours working day. On a national level a country can establish own value, which cannot exceed the one establishing on European level. In Finland occupational exposure limit for 8 hours TWA (time weighted average) to respirable dust is 50 µg/m^3 for silica (50 µg/m^3 for quartz; 50

μg/m^3 for cristobalite and 50 μg/m^3 for tridymite – these are different forms of SiO_2) (NEPSI, 2014). Finnish limit value is 2 times lower than permissible European exposure limit.

2 AIMS

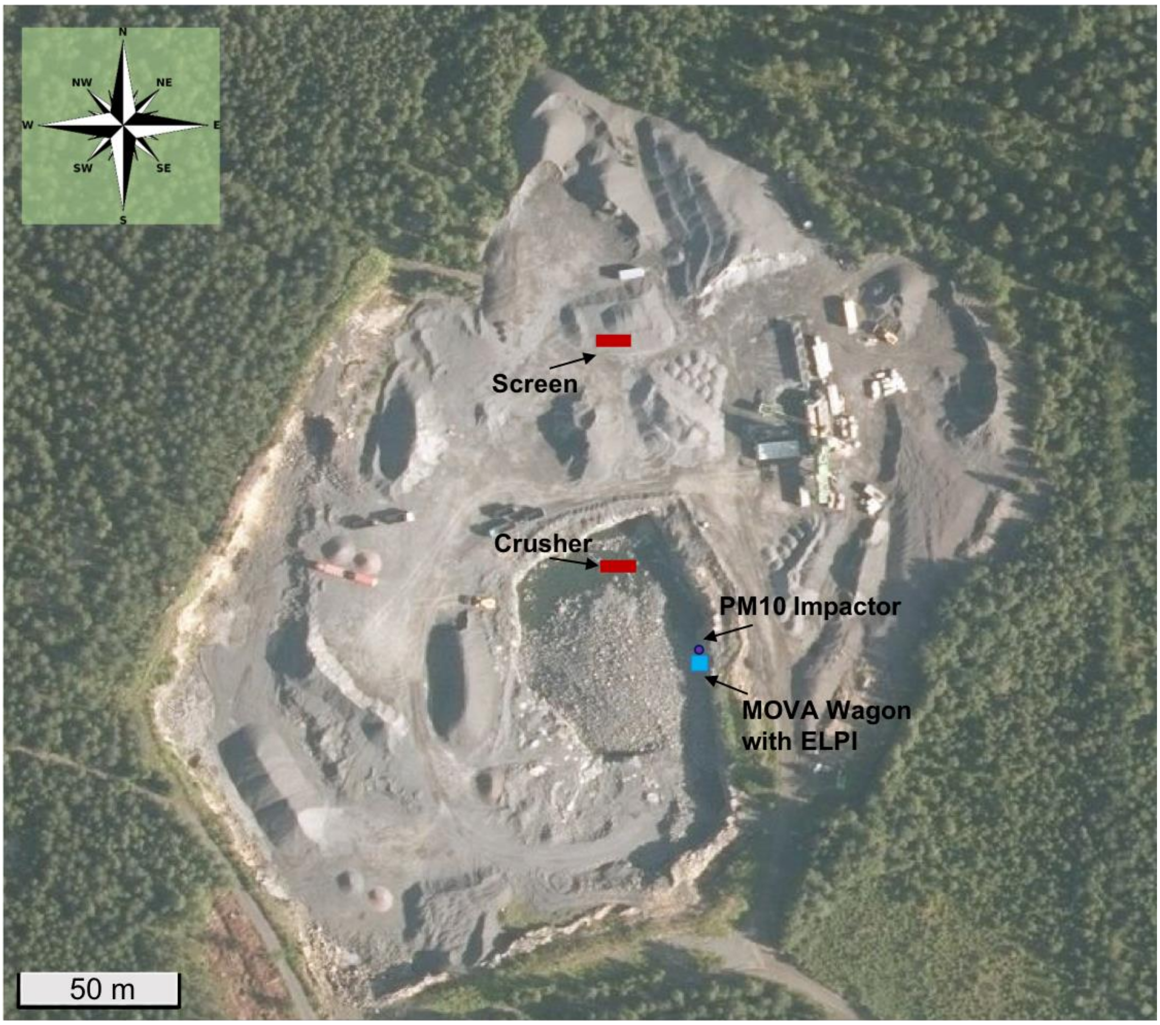
This thesis work is done for a Finnish company «Destia Ltd» whose services include production of aggregates, which in its turn requires crushing of rock and as a result creates quartz dust.

Aim of the work is to measure dust amounts and analyze quartz dust concentration in the area of two quarries, where the stone crushing work is done, also estimate exposure of workers. Another goal is to create a simple tool, which could be used for assessing the risks of quartz dust spreading into environment.

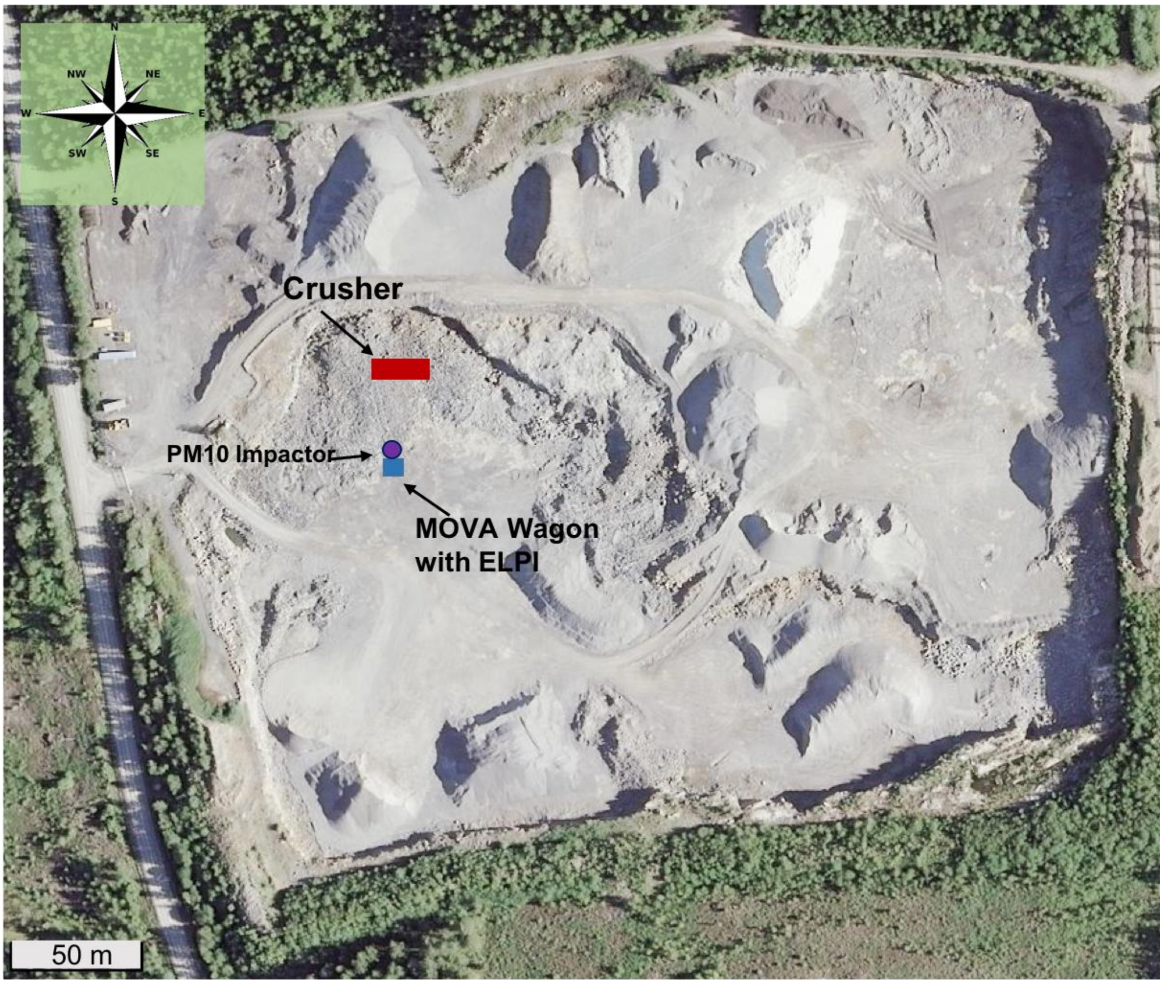
3 METHODS

3.1 Sampling and equipment

Two rock crushing sites were chosen for sampling. Pictures 1 and 2 represent Syrjänsalo in Ylöjärvi and Pitkäkallio in Lempäälä respectively. Pictures were taken in 2016, because of continuous extraction works the landscape of areas is changing a little bit all the time.



PICTURE 1. Quarry Syrjänsalo in Ylöjärvi (https://kartta.paikkatietoikkuna.fi/)



PICTURE 2. Quarry Pitkäkallio in Lempäälä (https://kartta.paikkatietoikkuna.fi/)

Red rectangle on the pictures indicates position of the rock crushing machine, and also position of a screen on picture 1 (it is used for different stone fractions separation and acts as a dust source), blue square stands for wagon with ELPI, violet circle represents position of PM10 impactor. More detailed measurement plan with sequence of actions and dates can be found in Appendix 1.

Table 2 summarizes information about equipment, type of aggregate under production and weather conditions during sampling.

TABLE 2. Additional information about crushing works and sampling.

	Syrjänsalo			Pitkäkallio		
Equipment	3 crusher units, 1-2 loaders, excavator, screen			2 crusher units, 1-2 loaders, excavator, trucks transporting aggregates		
Produced material	0-8 mm and 8-16 mm			0-32 mm		
Water spreading	NO			NO		
Weather conditions (measured on place)	**Date (dd.mm.yy)**	***t* (C°)**	**RH (%)**	**Date (dd.mm.yy)**	***t* (C°)**	**RH (%)**
	10.04.18	6	25	17.04.18	5,5	85
	11.04.18	9	22	18.04.18	15	45
	12.04.18	14	17,5	19.04.18	6	90
	13.04.81	14,6	18,5	20.04.18	17	46

3.1.1 PM10 Impactor

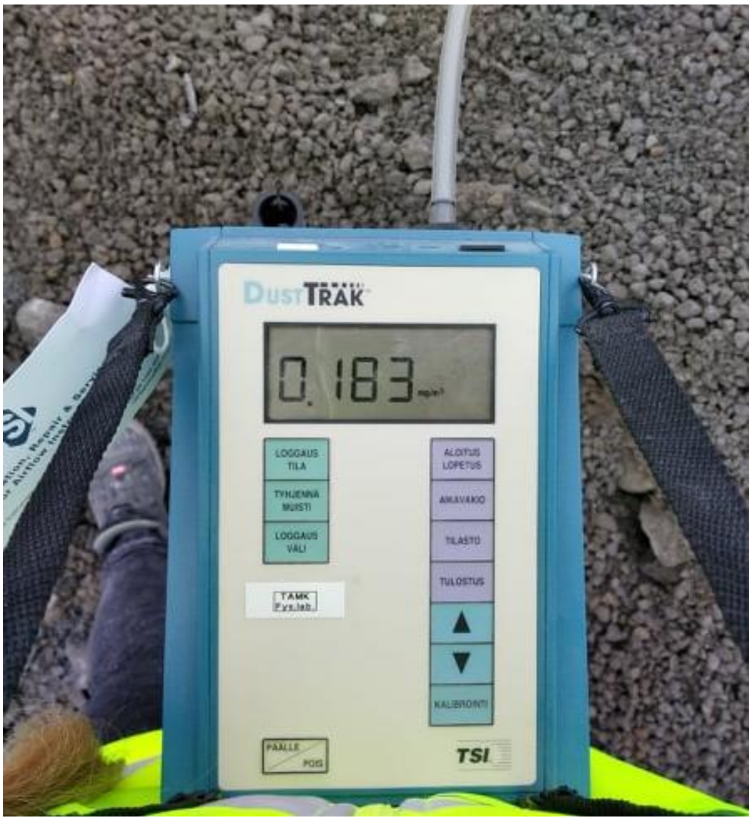
One of the devices used during this work was PM10 Impactor. It is a good tool to measure mass concentrations of fine particles in the air (picture 3).

PICTURE 3. PM10 Impactor (manufacturer - Dekati)

The device is collecting different grain size particles on filters and later on it is possible to make analysis of mineralogical composition. PM10 impactor is relatively easy to use. 3 aluminum plates are installed and covered with special spray. The pump with adjustable flow rate is attached. For this work the flow rate of 20 lpm (liters per minute) was used. The pump needs electricity source and for that purpose it was placed inside of the wagon. At each sampling area PM10 impactor was left working for 3 days in order to collect enough dust for analysis.

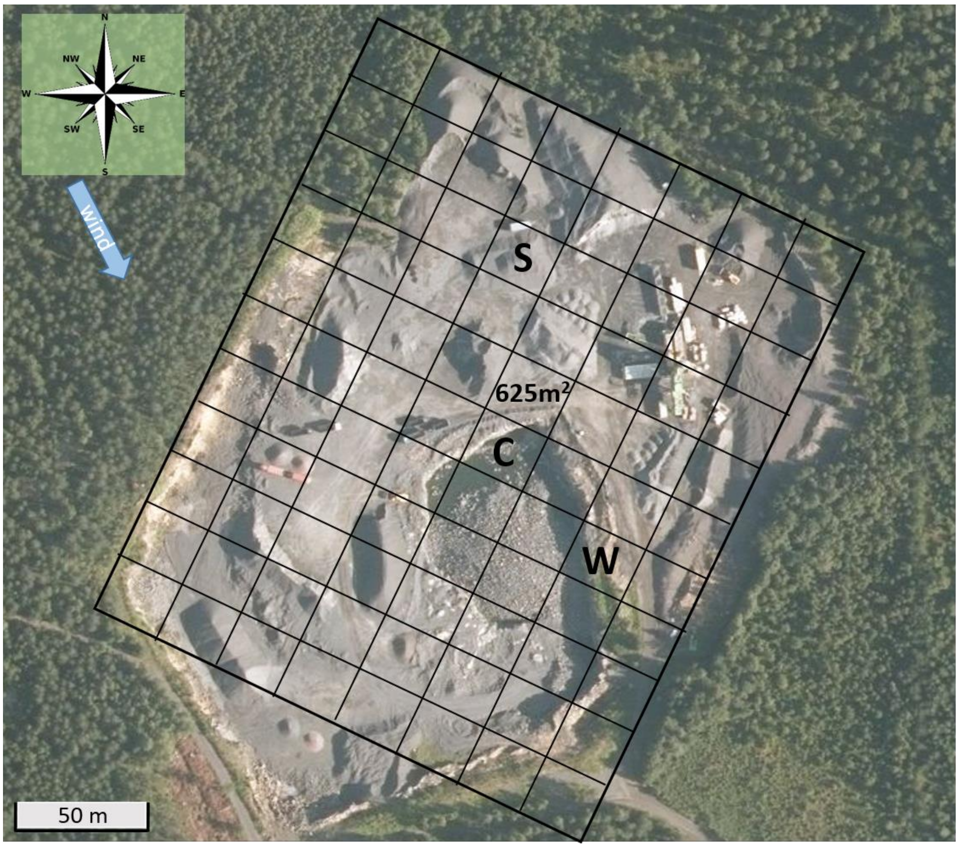
3.1.2 DustTrak

For fine particles measurements DustTrak Aerosol Monitor Model 8520 was used as well. It is shown on picture 4.



PICTURE 4. DustTrak Aerosol Monitor Model 8520 (manufacturer - TSI)

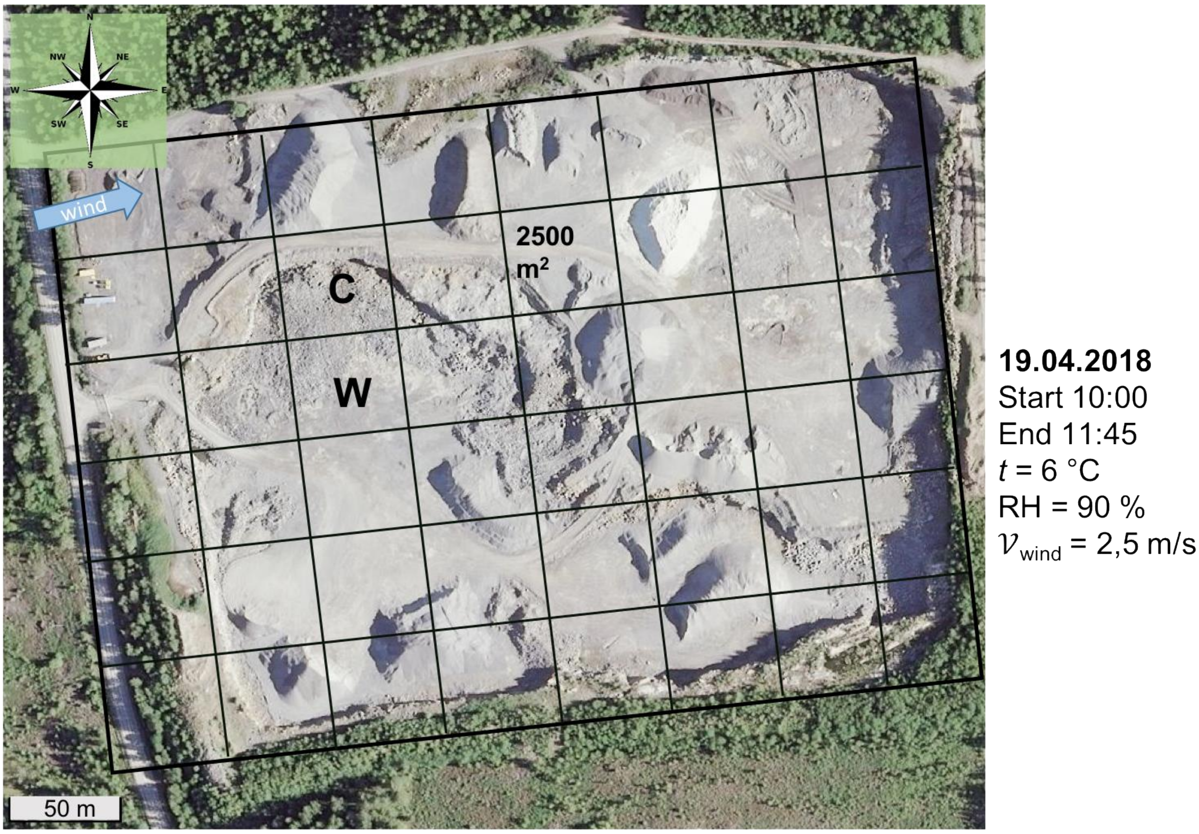
TSI DustTrak Aerosol Monitor Model 8520 is one of the devices, which can detect and measure particulate matter mass concentrations in the air. The particle size range of the DustTrak monitor is 0,1 to 10,0 microns. It is designed in such way to match the requirements of health-based aerosol sampling (Lilja, 2017). DustTrak was used to see how dust spreads with distance attenuation from the crushing machine. Before measurement sampling areas were divided into squares (pictures 5 and 6).



12.04.2018
Start 12:00
End 15:00
t = 14 °C
RH = 17,5 %
v_{wind} = 0,6 m/s

PICTURE 5. Division into sampling points in Syrjänsalo quarry in Ylöjärvi + weather conditions during sampling. C = crusher, S = screen, W = wagon (https://kartta.paikkatietoikkuna.fi/)

In total there were 88 sampling points in Syrjänsalo, the area of one square is 625 m^2. Letter «C» is showing square with crushing machine, letter «S» means screen and letter «W» stands for position of the wagon.



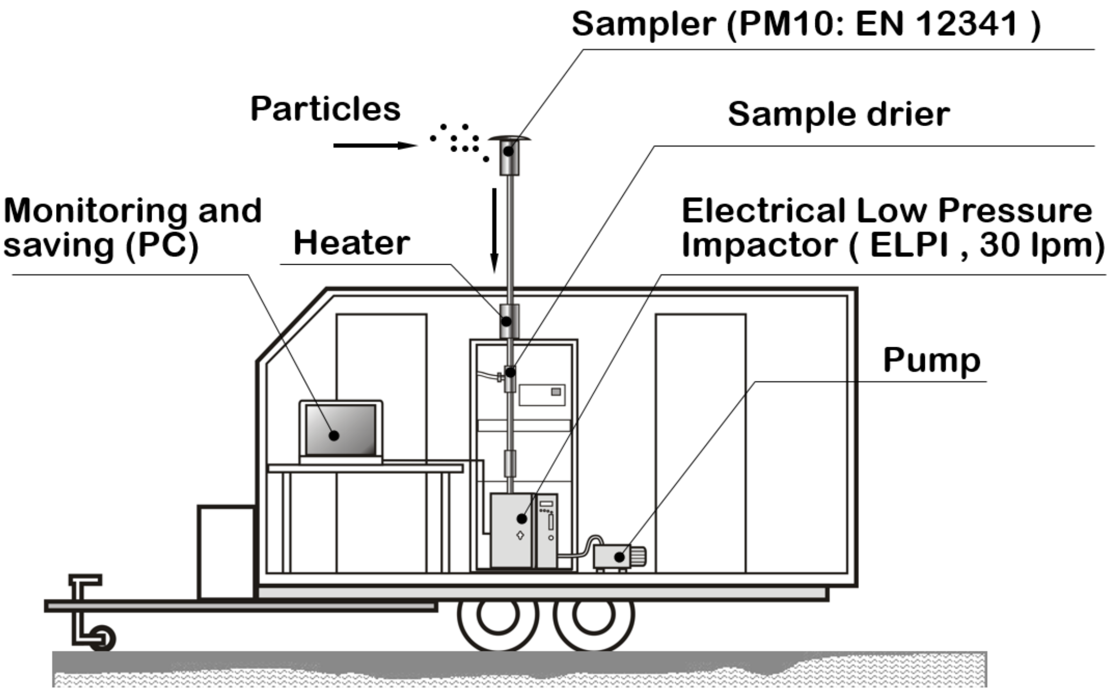
PICTURE 6. Division into sampling points in Pitkäkallio quarry in Lempäälä + weather conditions during sampling. C = crusher, W = wagon (https://kartta.paikkatietoikkuna.fi/)

There were 48 sampling points in Pitkäkallio with area 2500 m^2 each. Positions of crusher and wagon are shown on the map in a similar way as on picture 5. Wind speed information was taken from «Weather Underground» web pages, link can be found in references.

At each sampling point particles were measured for 1 minute with 10 seconds interval and average mass concentration for this time period was used to make colour maps representing dust spreading. In appendix 2 original data sheet can be found.

3.1.3 ELPI

One more device used for this work was Electrical Low Pressure Impactor (ELPI). There is a schematic representation of ELPI installed into MOVA wagon on picture 7.



PICTURE 7. MOVA wagon with Electrical Low Pressure Impactor and other devices inside (TAMK internal MOVA project 2007-2011)

It is meant to detect small particles in the air. Functioning principle can be shortly described in a following way:

- Particle goes through charger cloud and gets positively charged
- Charged particles flow through 12 stages of impactor
- Electrical current created by collection of charged particles is measured
- Information from sensors is analyzed by computer program and conclusions about concentrations, mass and number distributions are made with the help of Excel calculation sheets developed by Dekati company (Lilja, 2017).

All the data collected by ELPI can be checked for a specific day and time interval, also information about fine particles is gained in real time. However, in this work data from ELPI is used to find out maximum dust concentration observed during sampling period, to estimate TWA exposure for 8 working hours and to see particles size and mass distribution during different time of sampling period.

3.1.4 Wagon

PM10 impactor and ELPI are able to work only with connection to electricity source. Also, it is required to avoid unfavorable weather conditions like heavy rain or negative temperatures for pumps and fragile electronics of device. That is why to each sampling place TAMK's MOVA wagon was brought (picture 8).

PICTURE 8. MOVA Wagon

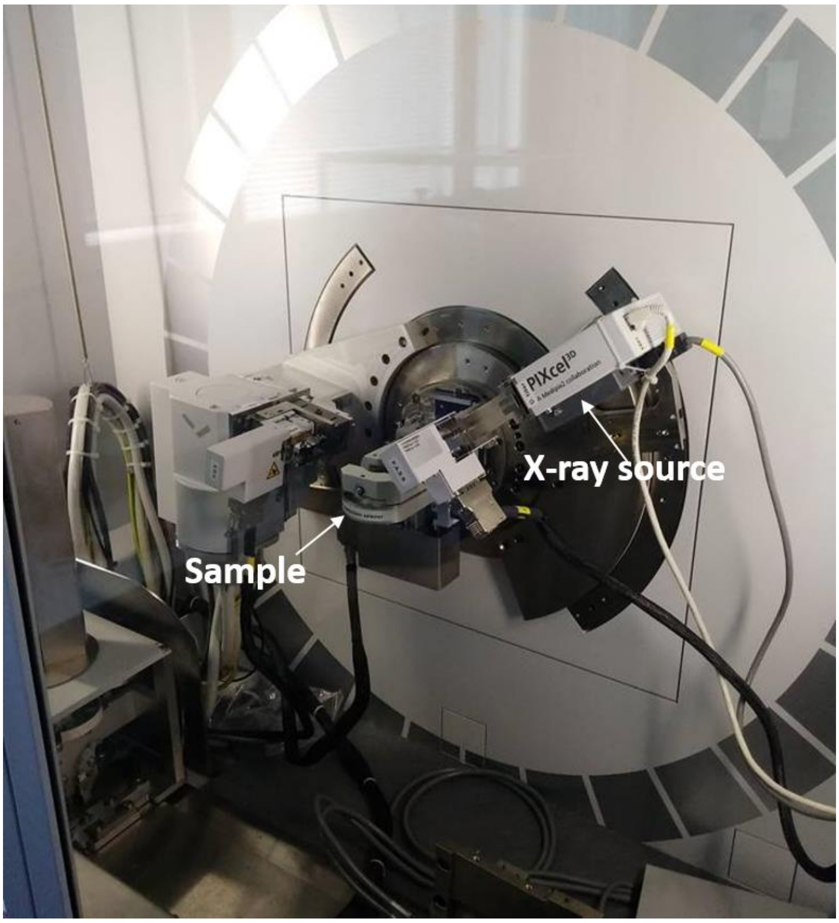
ELPI device is installed inside and wagon is modified in a way to make measurements easier. Schematic representation of wagon insides was shown before on picture 7.

3.2 Analysis

Results received from DustTrak, ELPI and PM10 impactor give information about dust concentrations in the air, however, in this work there is interest in amount of quartz dust and separate analysis is needed. PM10 impactor was collecting dust during the whole sampling period and with the help of Tampere University of Technology (TUT) geologist - Pirjo Kuula, X-ray diffraction analysis was made.

3.2.1 X-ray diffraction

X-ray diffraction is an analytical technique for identification and qualitative determination of the various crystalline forms of compounds presented in powdered and solid samples (Dutrow, 2018). On picture 9 the apparatus in TUT laboratory, which was used for the tests is represented.



PICTURE 9. Equipment for X-ray diffraction

4 RESULTS

4.1 DustTrak results

The collected data was systematized and analysed. As was told before, area of the quarry was divided into squares, at each point 6 values were taken with 10 seconds interval and then average was calculated and used for colour mapping. Table 3 represents dust mass concentrations measured in Syrjänsalo and table 4 shows situation for Pitkäkallio. Pink colour of the square indicates that dust source was located at that point, light blue – the wagon with ELPI and PM 10 impactor, «NA» stands for «not available» since some points were impossible to reach.

TABLE 3. Grid map of dust concentrations in Syrjänsalo (each square is 25m x 25m; pink = crusher and screen position; blue = ELPI and PM10 impactor; NA = not available)

Mass concentration (μg/m^3)

4	6	NA	NA	22	3	3	3
4	9	14	7	6	4	3	3
4	10	15	6127	8850	4	8	3
11	39	136	3090	1487	7	8	7
15	52	189	553	458	321	16	NA
11	21	76	NA	4227	60	341	50
17	21	38	NA	283	1154	345	5
12	53	128	370	493	350	33	9
39	50	220	1070	587	140	179	6
9	9	15	177	98	94	78	69
5	4	6	5	119	151	282	72

We can see quite a wide range of results from 3 μg/m^3 in the corners of the quarry and up to 8900 μg/m^3 near the crusher.

TABLE 4. Grid map of dust concentrations in Pitkäkallio (each square is 50m x 50m; pink = crusher position; blue = ELPI and PM10 impactor; NA = not available)

Mass concentration (µg/m^3)

13	13	13	339	91	14	12	12
13	13	252	15	16	89	62	17
13	14	14	15	13	105	61	15
13	13	13	24	20	19	15	16
13	13	14	21	15	16	18	49
13	NA	NA	13	14	13	14	13

Situation in Pitkäkallio is different. The lowest value detected is 12 µg/m^3 and we can see a lot of sampling points with result of 13 µg/m^3 and the highest concentration is around 340 µg/m^3.

Color grid maps are very visualizing and on figures 2 and 3 below situation for both of the quarries is represented.

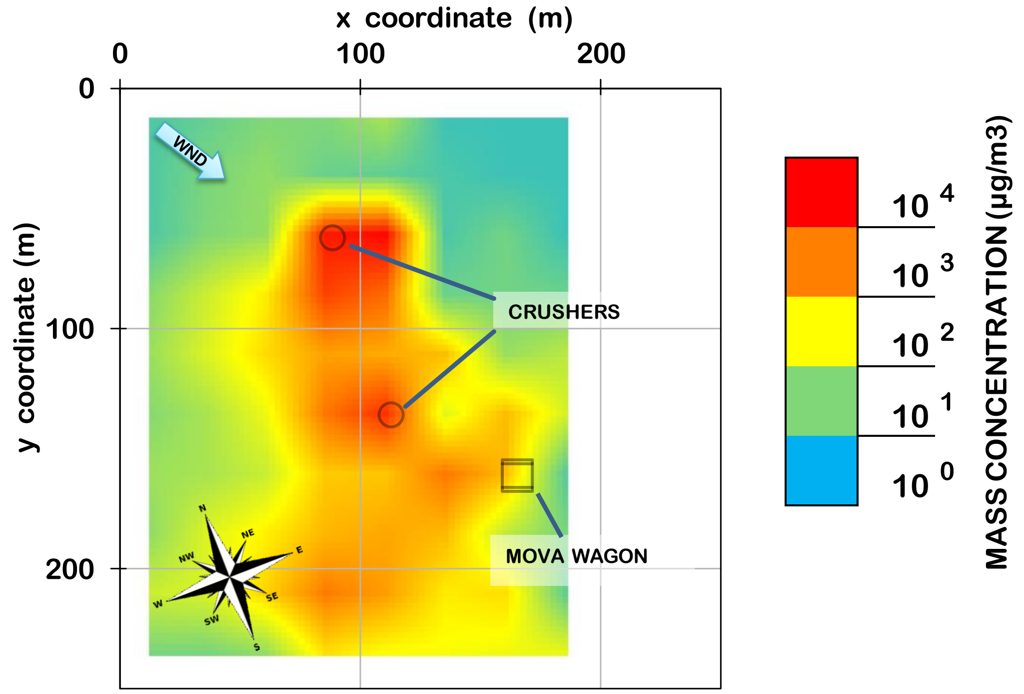


FIGURE 2. Colour grid map of quarry in Syrjänsalo (date 12.04.2018; t = 14 °C; RH = 17,5 %; v_{wind} = 0,6 m/s)

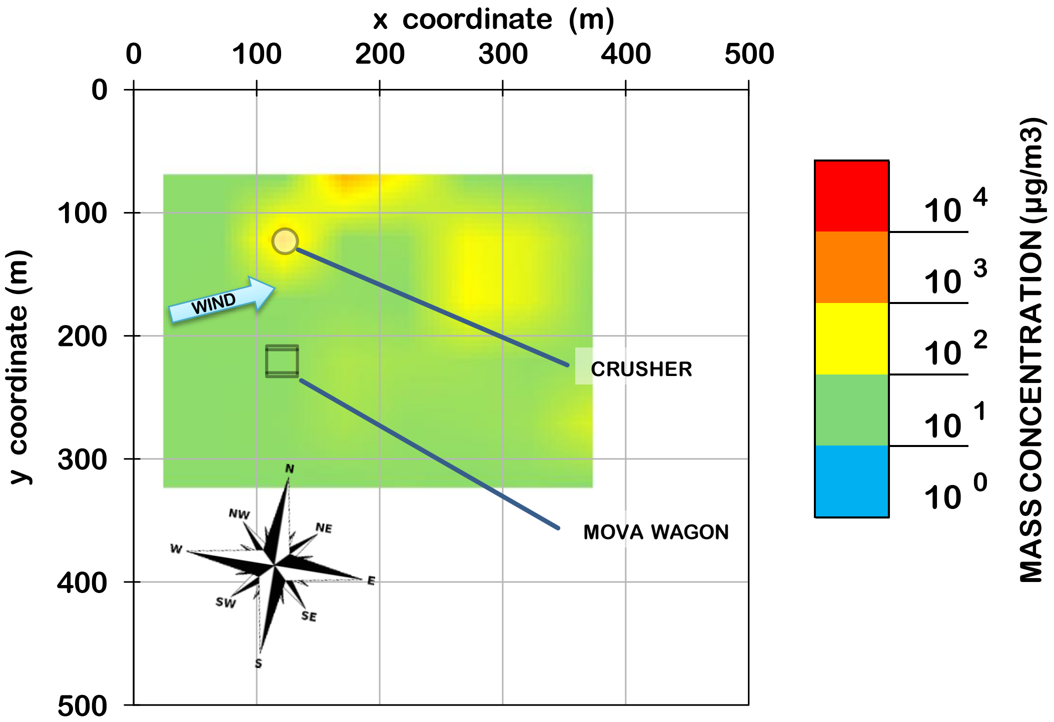


FIGURE 3. Colour grid map of quarry in Pitkäkallio (date 19.04.2018; t = 6 °C; RH = 90%; v_{wind} = 2,5 m/s)

Areas with high dust concentrations are clearly seen, bright red colour shows the most polluted areas. It is worth to notice that some points were unavailable to reach and average values from neighbouring points were used for colour map construction. To determine dust concentration at specific sector it is better to refer to tables 3 and 4 above. Colour maps show, as distance from the crusher increases, dust mass concentration in the air is getting lower. Talking about wind direction we see, that dust is moving the same route, but doesn't follow exactly the same direction. Also, it can be said that dust isn't spreading far beyond the borders of the quarries.

4.2 PM10 Impactor results

PM10 concentration calculations were done using official Excel template for PM10 Impactor developed by Dekati. Appendix 3 contains screenshots of Excel calculations. The file was provided by Jarmo Lilja, physics teacher and thesis supervisor. Reliable results from PM10 impactor could be gained in case of collecting necessary information about environmental conditions during sampling period.

4.2.1 Syrjänsalo

Table 5 contains information from the starting day of work and the last day of sampling in Syrjänsalo.

TABLE 5. PM10 impactor sampling conditions in Syrjänsalo

	START			END		
	t (°C)	*p* (kPa)	RH (%)	*t* (°C)	*p* (kPa)	RH (%)
Impactor	6	100	25	14,6	100	18,5
Pump	10	100	22	19,2	100	26,7

In general, weather was rather warm, not rainy and average daily temperature was slowly raising through a sampling period. For Excel calculations average values from the first and last day of experiment were used. As a result, mass concentration of PM10 particles measured in Syrjänsalo is 170 $\mu g/m^3$.

4.2.2 Pitkäkallio

Situation in Pitkäkallio was different. Table 6 represents environmental conditions during measurement period.

TABLE 6. PM10 impactor sampling conditions in Pitkäkallio

	START			END		
	t (°C)	*p* (kPa)	RH (%)	*t* (°C)	*p* (kPa)	RH (%)
Impactor	5,5	100	85	17	100	46
Pump	9	100	73	20	100	50

Sampling days were rather rainy and cloudy. Sun appeared rarely and during daily visits PM10 impactor was noticed to be all in water drops. Air was very humid. PM10 concentration measured in Pitkäkallio is 25 $\mu g/m^3$.

4.2.3 Particles distribution

With the same Excel sheet developed by Dekati it is possible to evaluate for particles a mass size distribution and graphs are shown on figures 4 and 5.

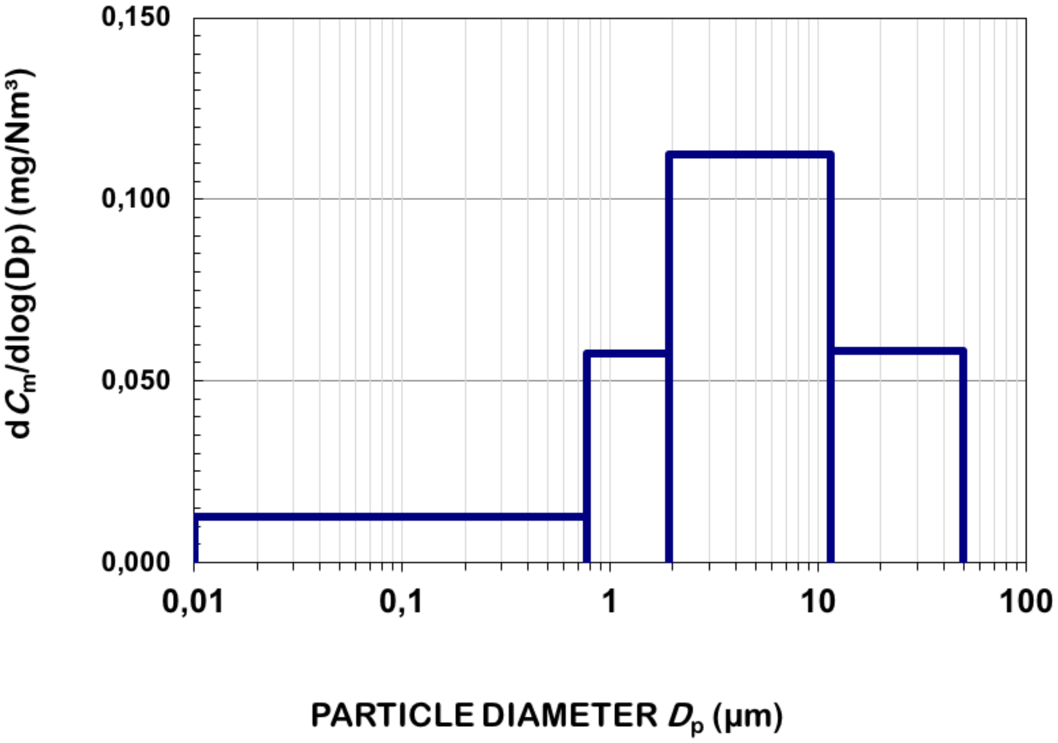


FIGURE 4. Mass distribution of particles with logarithmic size scale in Syrjänsalo (average for the whole sampling period; *x-axis* = particle diameter (µm); *y-axis* = normalised mass distribution)

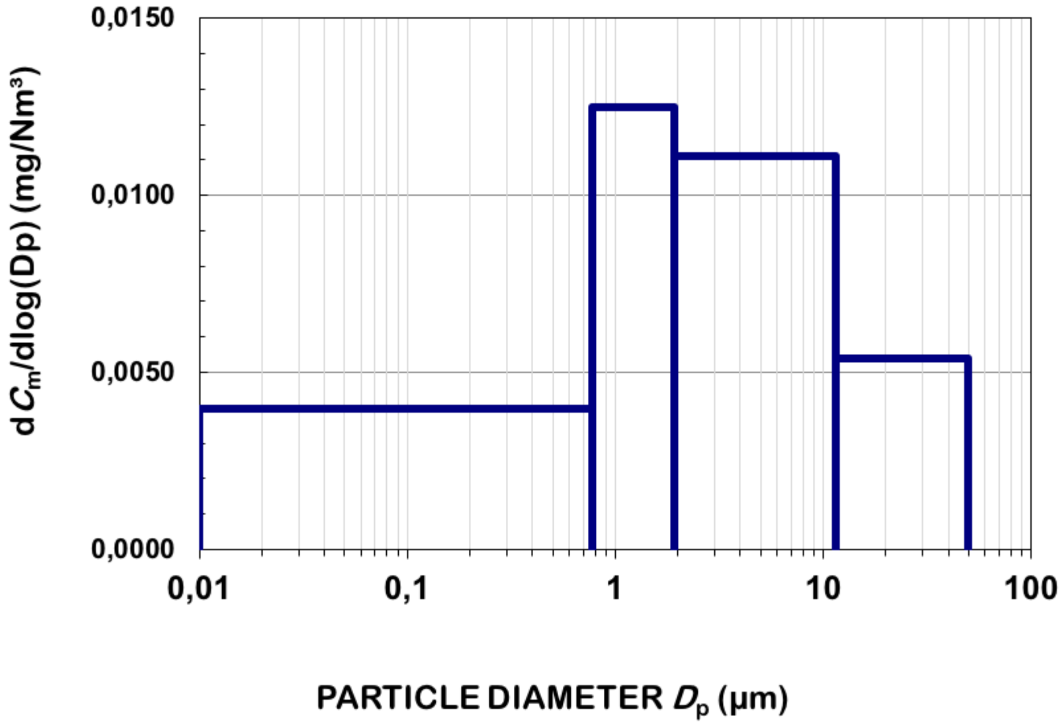
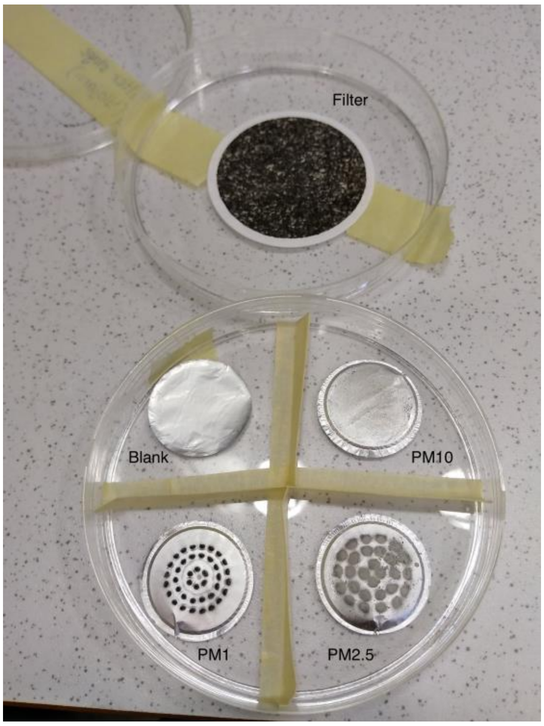


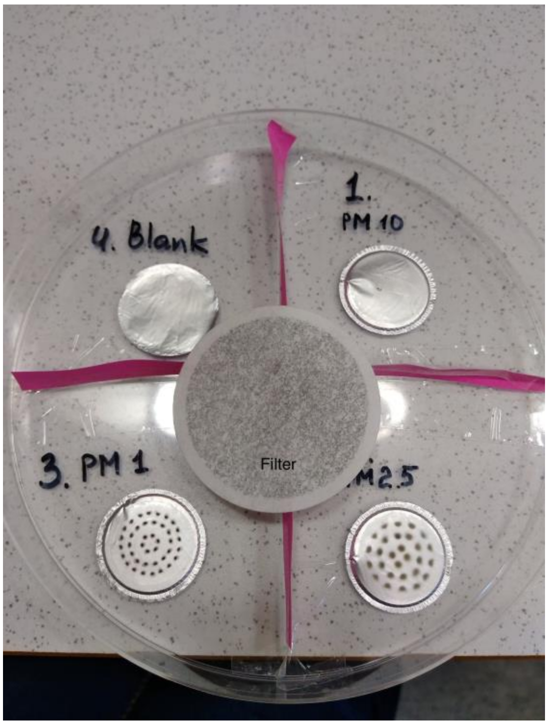
FIGURE 5. Mass distribution of particles with logarithmic size scale in Pitkäkallio (average for the whole sampling period; *x-axis* = particle diameter (µm); *y-axis* = normalised mass distribution)

Graphs show that the biggest share of dust particles captured by PM10 impactor lays within the range from 1 to 10 µm diameter. In Syrjänsalo more particles with diameter closer to 10 µm were detected, while in Pitkäkallio we see that there were a little bit more particles with diameter around 1µm.

4.3 X-ray diffraction

X-ray diffraction (XRD) was used for qualitative analysis of samples, not quantitative. Therefore, a specific amount of quartz in samples could not be determined. In general, samples collected by the Impactor had either too small grain size or amount of dust was not enough for more thorough analysis. Picture 10 and 11 are representing aluminium plates and filters with dust extracted from PM10 Impactor.





PICTURE 10. Syrjänsalo samples

PICTURE 11. Pitkäkallio samples

The only suitable fraction for analysis was PM2.5 and it is possible to compare results from both of the quarries. Figures 6 and 7 below represent graphs of XRD with several peaks.

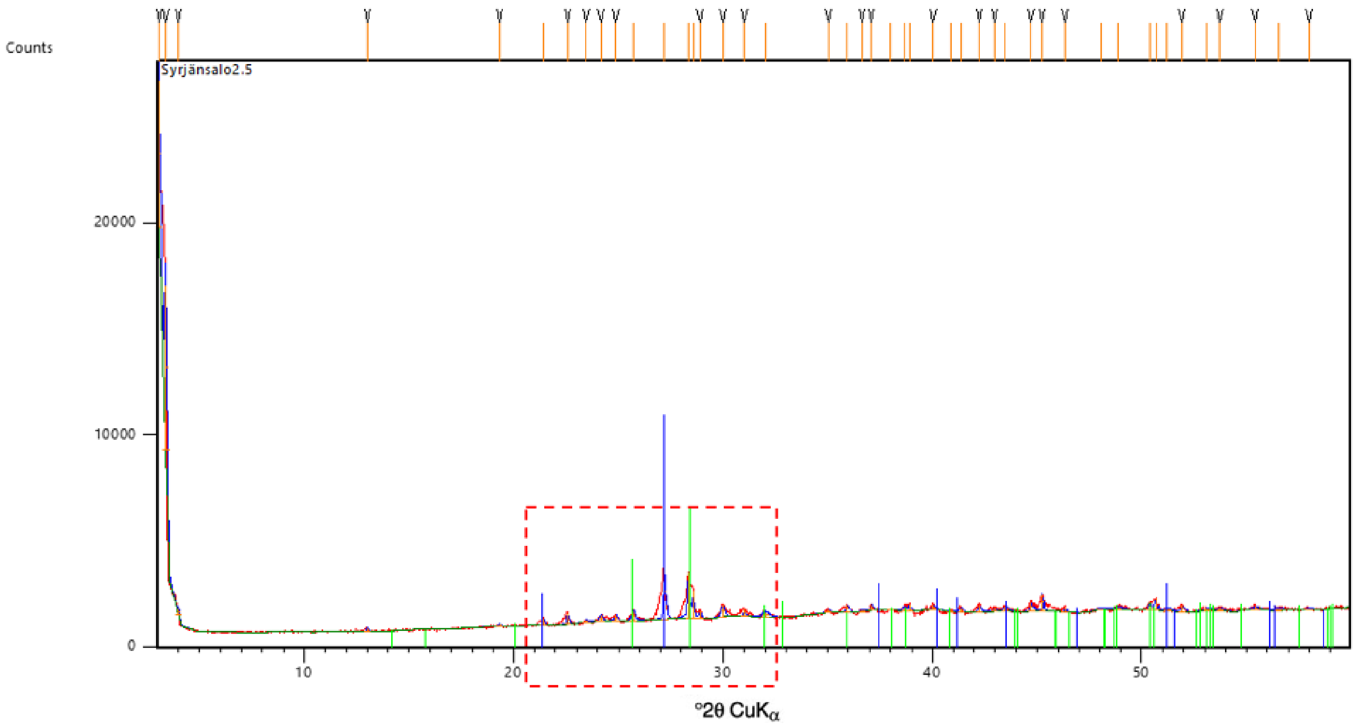


FIGURE 6. XRD graph of PM2.5 from Syrjänsalo

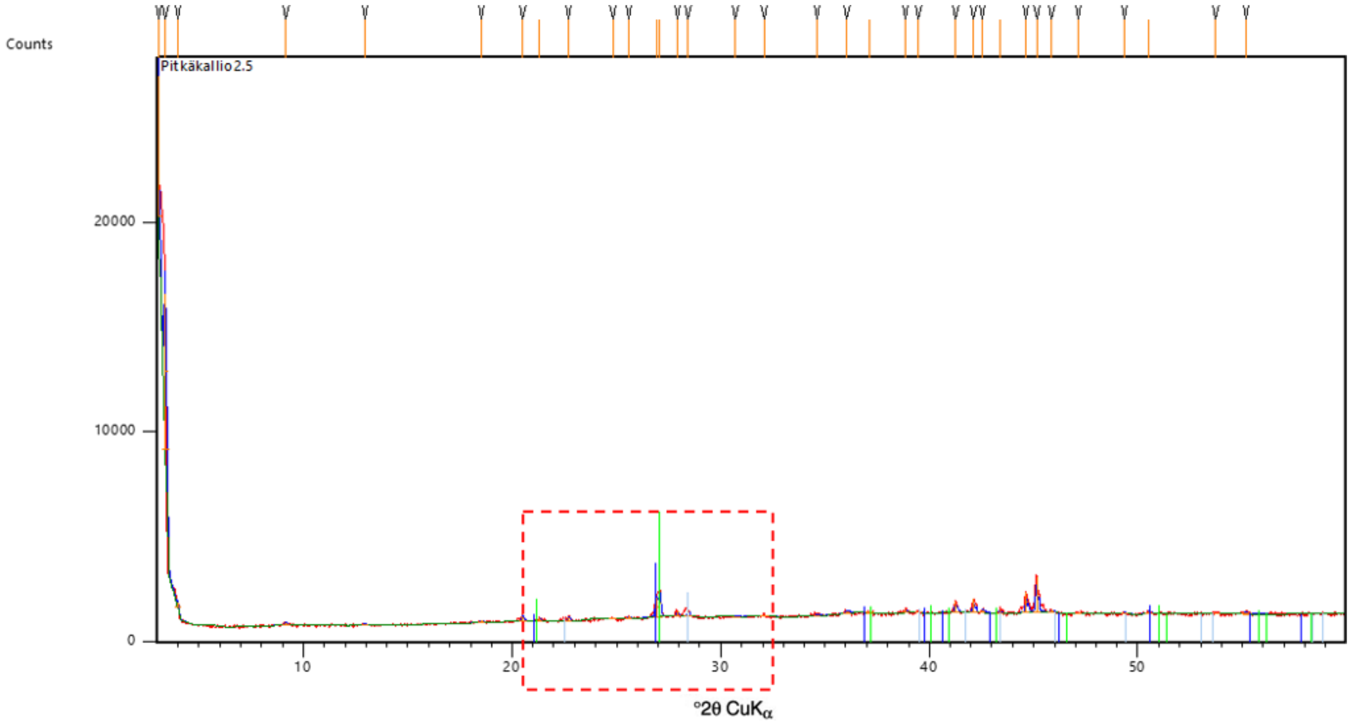


FIGURE 7. XRD graph of PM2.5 from Pitkäkallio

Graphs show that some amounts of quartz and silicon oxide were detected in samples. Very roughly saying, peaks on the graphs can represent various compounds and blue lines are pointing spots on the graph where quartz was found, green lines are for silicon oxide. The area marked with red rectangle is the most informative in a sense of quartz amount estimation. Figure 8 shows a zoomed picture of that area.

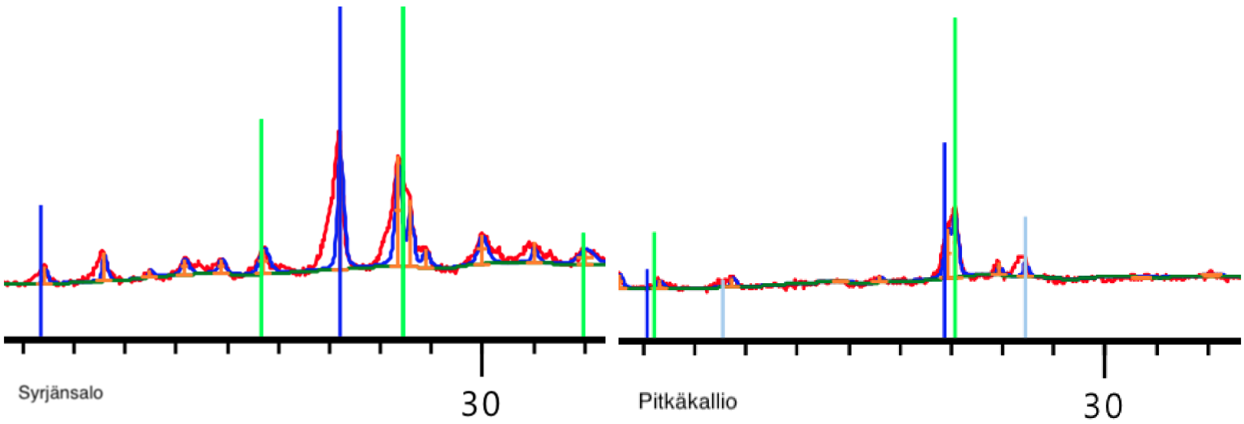


FIGURE 8. Zoomed part of XRD graphs

Comparing results for almost equal duration of sampling (± 30 min) the same grain size (PM2.5) it can be said that amount of quartz detected in dust samples in Syrjänsalo is higher, because area of the peaks, belonging to quartz, is bigger than in Pitkäkallio.

4.4 ELPI results

Attempts to make measurements with Electrical Low Pressure Impactor (ELPI) were done in both of the quarries, but unfortunately, in Syrjänsalo something went wrong and data saving was not possible. However, the problem was fixed and in Pitkäkallio the device was working properly. Data collection happened with interruption, because on 18th of April during sampling, blasting of rock happened and electricity generation stopped at some point. ELPI pump stopped working and it had to be started manually. The same day data collection continued. Graphs on figures 9 and 10 represent mass concentrations of particles measured in Pitkäkallio and also mass distribution of particles with logarithmic size scale for different periods of time.

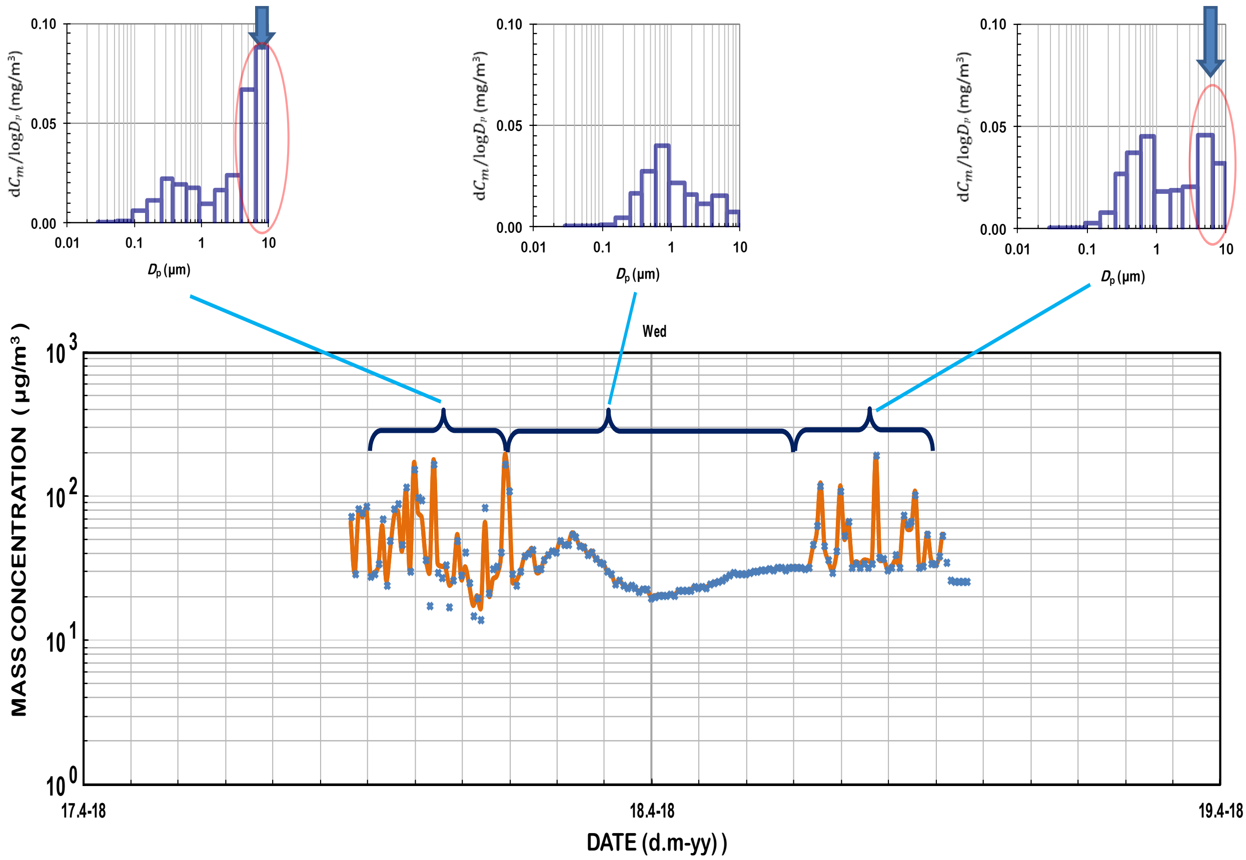


FIGURE 9. Particles mass concentration and mass size distribution in Pitkäkallio (first part)

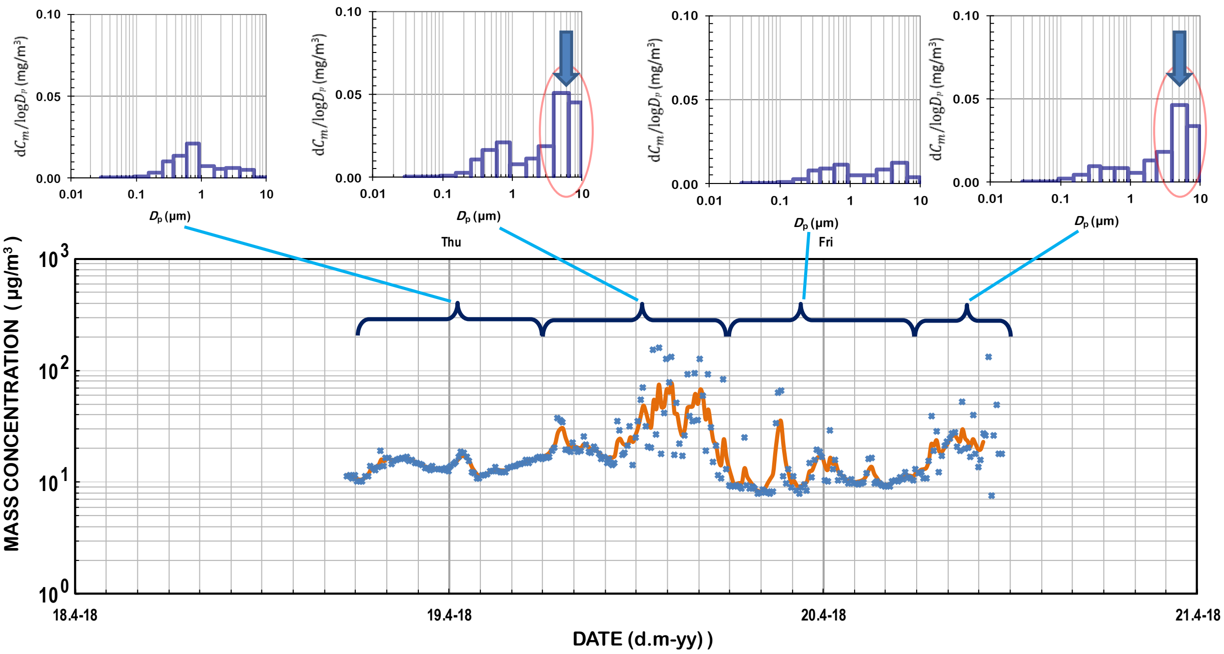


FIGURE 10. Particles mass concentration and mass size distribution in Pitkäkallio (second part)

Measurement has started on 17th April at 11:17 and as can be seen from the graph on figure 9 stopped at 17:07 on 18th April, however, pump was not working since 12:50 about and last few hours have zero results. We can see a "standstill" in between 17.04.2018 18:17 and 18.04.2018 06:27 which tells us, that no work was conducted during night time. Peaks and drops of particles concentration in the air happen because of the heavy cars passing by the ELPI wagon and because of loading and transportation of aggregates. New measurement was started on 18th April at 17:27 and represented on figure 10 above. The highest mass concentration detected equals 137 µg/m^3.

Night periods have significant drop of dust concentration in the air. From the graphs it can be noticed that amount of particles is higher during day time, when crushing and transportation is going on. It is important that during crushing activity hours particles with bigger diameter are produced, it is marked with red circle and arrow on the graphs. Overall mass concentration of particles in second part of measurements was smaller.

Also, ELPI data can help in estimation of workers' daily 8 hours TWA dust exposure. It was decided to take data for 19.04.2018 from 6:37 till 14:37 (values are represented in appendix 4) and as a result dust concentration calculated is 20 µg/m^3.

5 DISCUSSION

One of the goals of this work was to determine quartz dust concentration on rock crushing quarries. Since in a frame of this work it is impossible to determine the exact quartz amounts, it will be estimated based on received data and also based on petrographic description of rocks from the quarries provided by Destia. Copies of documents can be found in appendix 5. According to petrographic description, the quarry in Syrjänsalo has 26% of quartz in its rock, while Pitkäkallio's rock has much more – 40%. However, if we refer to the results of X-ray diffraction analysis, they show higher amount of quartz in samples from Syrjänsalo. Talking about such results, it should be taken into account that composition of rock on both of the quarries is different, they contain various minerals with different hardness. Moreover, petrographic description was made based on sample taken from one point and rock composition may vary in the area of the same quarry. Weather conditions and type of rock crushing (primary, secondary or tertiary) should influence results as well. As Pirjo Kuula said during discussion of XRD results: «quartz is the hardest mineral», which means that only in the worst-case scenario dust released into air will contain the same percent of quartz as a solid rock. In Pitkäkallio, 8 hours TWA exposure of workers to dust is around 20 $\mu g/m^3$. If we assume there is 40% of quartz in it as petrographic description states, then 8 hours TWA to quartz dust will be 8 $\mu g/m^3$, which is well below 50 $\mu g/m^3$, stated in regulations. Based on the same principle, we can estimate maximum quartz dust exposure during sampling period. For Pitkäkallio it is around 140 $\mu g/m^3$ and for Syrjänsalo 2300 $\mu g/m^3$. Values are rather high, especially in Syrjänsalo, but they are concluded from results measured with DustTrak near the crusher where nobody usually walks or works. And once again, this is the worst-case scenario. For more exact results, future studies with experiment should be made. As Pirjo Kuula advices, sampling period has to be at least 2 weeks in order to have enough material for analysis. The way to know quartz percent can be derived manually with the help of XRD analysis. First, pure quartz should be examined in order to create a reference graph. Then several samples should be prepared where quartz dust is mixed in known proportion with other substance (for example, 10%, 20% 30% of quartz and so on…). Thus, we can see the behaviour of graph with specific concentration of quartz in analysed sample. And after this stage, we can examine field samples and compare graphs. Another method is very difficult, but also can be an option. Electron microscope can reveal structure of small objects, it has high resolution and magnification factor up to 10,000,000x (John Innes

Centre, 2018). Usage of microscope might allow to see structure of dust particles and recognise quartz among them.

Having a closer look at DustTrak results and colour maps we will notice uneven dust distribution. It is worth to notice that some points were unavailable to reach and average values from neighbouring points were used for colour map construction. General trend is rather obvious – dust is moving in a similar direction with wind, but not exactly the same. It can be explained by the fact that on both of the quarries there were huge piles of rocks and ready aggregates, which blocked movement of wind and dust or created turbulence. Also, those piles prevented dust from spreading far beyond quarry borders. As we can see from colour maps and tables with results, there are no high dust concentrations found far from crushers.

Creation of a simple tool, which could be used for assessing the risks of quartz dust spreading into environment is difficult with current results and would be inaccurate. Data from only two sampling areas doesn’t show much dependence between different factors, however, we can firmly say that weather conditions such as wind and humidity influence results significantly. As experiment with Dust Trak showed, in Pitkäkallio wind speed was higher than in Syrjänsalo and dust was spreading on a further distance, at the same time overall particles mass concentration in the air was lower in Pitkäkallio and one of the reasons is very humid air.

We can also notice that quartz is not so easily realized into environment in a form of dust, or its particles are so small that can be hardly detected. It doesn’t mean that if there is a specific proportion of quartz in a rock, then dust released during crushing will have the same proportion of quartz.

6 CONCLUSIONS

Table 7 summarises all the important numbers in one place. Talking about dust in general, we see that results gained in Syrjänsalo do not allow us to call it a place with high air quality. But we should take into account that averaging period of 1 year is used by European Commission for PM10 to make a final conclusion about air quality. And rock crushing works are done only for several weeks (or month) during a year.

Estimating quartz dust exposure we see that even in the worst-case scenario occupational exposure limits of workers for 8 hours time weighted average are not exceeded. However, if Binding Occupational Exposure Limit value 100 $\mu g/m^3$ will be established within next few years, there is probability to exceed this limit especially if a person will be working in close proximity to dust source. In this case personal protective gear and water spreading should help. Water spreading was not applied during sampling, but weather conditions in Pitkäkallio prove that water in the air (artificially spread, natural rain or fog) decrease dust concentration and do not let dust spread far.

Results show that during day time amount of PM10 particles in the air is higher than during nights, which leads to conclusion, that rock crushing works release a lot of respirable dust. Especially, crushing activity produces particles with grain size around 10 μm.

Unfortunately, all aims of this work were not achieved and attempts to make a tool for estimation of quartz dust spreading into environment during rock crushing work lead to the conclusion that more experiments should be done. It is better to have more sampling areas and longer sampling period in order to have enough material for analysis and see dependences between wind speed, humidity, temperature, intensity and type of rock crushing work and quartz amount in solid material.

It can be concluded that only in the worst-case scenario percent of quartz dust will be same as in the rock producing this dust. In all other cases this value will be less and it is explained by properties of quartz mineral.

TABLE 7. Summarized results and limit values

<table>
<tr><td rowspan="2">Environmental air quality standards</td><td colspan="2">PM 10 limits (European Commission, 2005)</td></tr>
<tr><td colspan="2">Averaging period 24 hours 50 µg/m^3 *1
Averaging period 1 year 40 µg/m^3</td></tr>
<tr><td rowspan="2">Occupational exposure limits</td><td colspan="2">Silica (quartz)</td></tr>
<tr><td colspan="2">50 µg/m^3 8 hour TWA</td></tr>
<tr><td rowspan="2">Binding Occupational Exposure Limit Value</td><td colspan="2">Silica (quartz)</td></tr>
<tr><td colspan="2">Might get into force in the coming years 100 µg/m^3
No environmental limitations for quartz dust</td></tr>
<tr><td rowspan="2">Results from the quarries (average for the sampling period)</td><td>Syrjänsalo</td><td>Pitkäkallio</td></tr>
<tr><td>C_m = 170 µg/m^3 *2
$C_{m\ \mathrm{Quartz}}$ ≈ 44 µg/m^3 *3
$C_{m\ \mathrm{Max.Quartz}}$ ≈2300 µg/m^3 *4
$C_{m\ \mathrm{TWA\ Quartz}}$ – NA *5</td><td>C_m = 25 µg/m^3 *2
$C_{m\ \mathrm{Quartz}}$ ≈ 10 µg/m^3 *3
$C_{m\ \mathrm{Max.Quartz}}$ ≈ 140 µg/m^3 *4
$C_{m\ \mathrm{TWA\ Quartz}}$ ≈ 8 µg/m^3 *5</td></tr>
</table>

*1) can be exceeded 35 times per year

*2) dust mass concentration measured by PM10 Impactor

*3) average quartz mass concentration calculated based on petrographic description

*4) measured extremely close to the crusher

*5) Time Weighted Average for 8 hours (NA = not available)

To conclude, the work was very interesting for the author, because it required written materials review, work with equipment, field sampling and cooperation with many people. During quarry visits, it has been a chance to talk with few workers about their thoughts and health. Nobody was complaining about any lung problems or other issues related to health, which in their opinion could be caused by heavy dust exposure. Some aims of the work were achieved, some – not on a full scale, but they reveal necessity of future researches about airborne quartz dust behaviour.

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APPENDICES

Appendix 1. Measurement Plan

1) Wagon with ELPI is installed at sampling point and connected to the source of electricity. ELPI is set for working and collects real time data. It is required for the purpose to see maximum dust concentrations detected in the area and particle number concentration.

2) Also, inside of the wagon pump for PM10 impactor is located. It needs electricity and should be covered from outside precipitations.

3) PM10 impactor is placed outside, but near the wagon and collects dust for several days for future chemical analysis.

4) **During night rock crushing work is not conducted and electricity generation is stopped → pump and ELPI are not working. However, it doesn't cause a trouble for measurements since pump starts working when electricity is turned on again and therefore PM10 impactor continues to collect dust when work starts next day. But, ELPI will not start working again unless turned on manually. It means that data about maximum dust concentration will be collected not during the whole sampling period.**

5) One full working day after wagon installation I am coming to the site for data collection with DustTrak. It will be used later to see distance attenuation in dust spreading.

6) After 3 days of sampling all equipment can be removed from the place and data analysis can start.

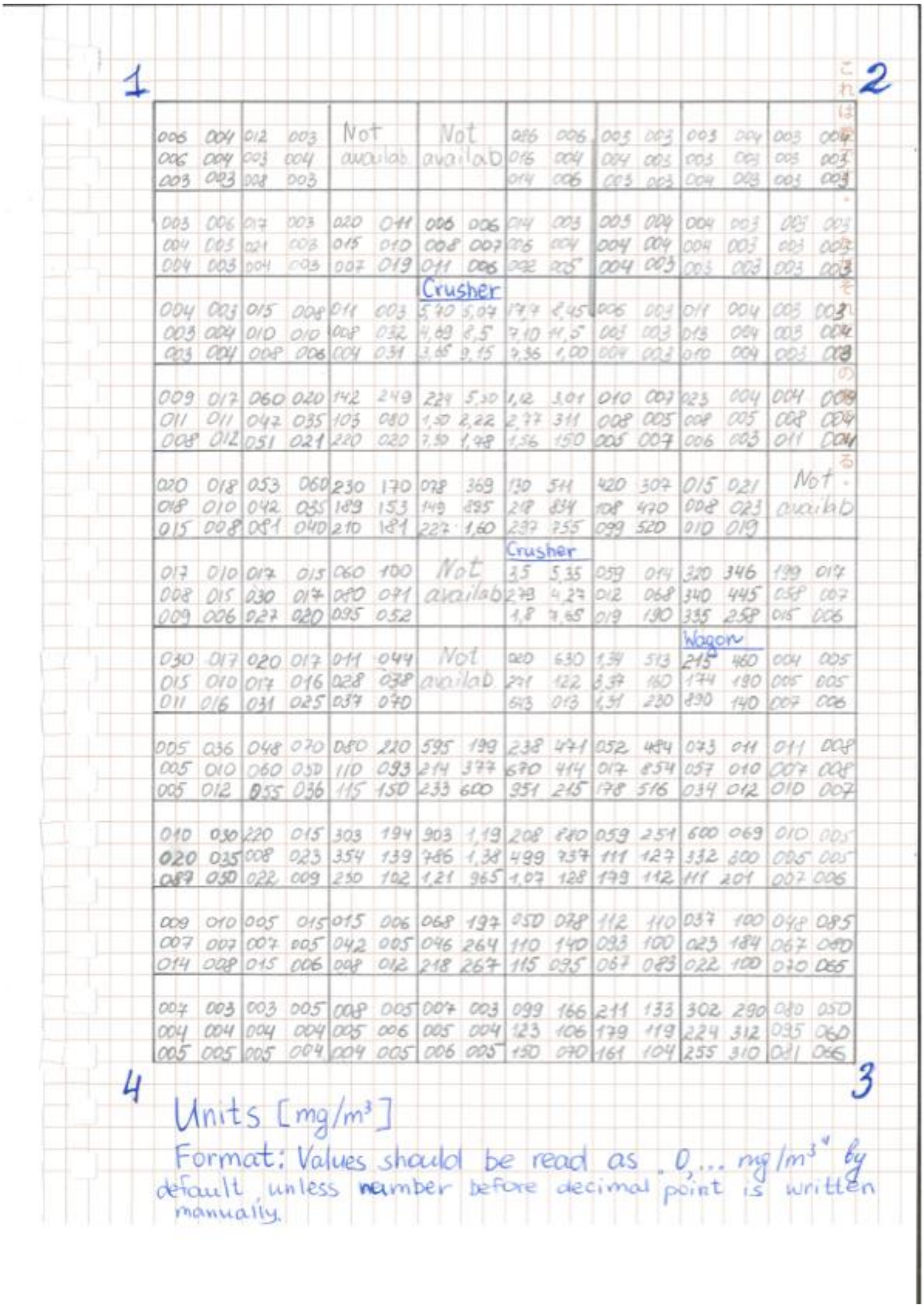
Data collection will be conducted at 2 rock crushing sites:

One of them is Syrjänsalo in Ylöjärvi (measurement during week 15)
Tuesday 10th April – installation of equipment.
Thursday 12th April – DustTrak measurements.
Friday 13th April – removal of equipment.

The other sampling place is Pitkäkallio in Lempäälä (measurements during week 16)
Tuesday 17th April – installation of equipment
Thursday 19th April – DustTrak measurements.
Friday 20th April – removal of equipment.

7) After drying samples from PM10 impactor they will be brought for X-ray diffraction analysis to see chemical composition of dust.

Appendix 2. Original data sheets from DustTrak sampling in Syrjänsalo (1) and Pitkäkallio (2).



1 2

006	004	012	003	Not		Not		026	006	003	003	003	004	003	004
006	004	003	004	availab		availab		016	004	004	003	003	003	003	003
003	003	008	003					014	006	003	003	004	003	003	003
003	006	017	003	020	011	006	006	014	003	003	004	004	003	003	003
004	003	021	003	015	010	008	007	005	004	004	004	004	003	003	003
004	003	004	003	007	019	011	006	002	005	004	003	003	003	003	003
						Crusher									
004	003	015	008	011	003	5,70	5,07	17,7	8,45	006	003	011	004	003	003
003	004	010	010	008	032	4,69	8,5	7,10	11,5	003	003	013	004	003	004
003	004	008	006	004	031	3,65	9,15	7,36	1,00	004	003	010	004	003	003
009	017	060	020	142	249	224	5,30	1,12	3,01	010	007	023	004	004	009
011	011	047	035	103	080	1,50	2,22	2,77	311	008	005	008	005	008	004
008	012	051	021	220	020	7,30	1,98	1,56	150	005	007	006	003	011	004
020	018	053	060	230	170	078	369	130	511	420	307	015	021	Not	
018	010	042	035	189	153	149	895	218	834	108	470	008	023	availab	
015	008	081	040	210	181	227	1,60	237	755	099	520	010	019		
								Crusher							
017	010	017	015	060	100	Not		3,5	5,35	059	014	320	346	199	017
008	015	030	017	080	071	availab		2,79	4,27	012	068	340	445	058	007
009	006	027	020	095	052			1,8	7,65	019	190	335	258	015	006
												Wagon			
030	017	020	017	011	044	Not		020	630	1,34	513	215	460	004	005
015	010	017	016	028	038	availab		271	122	3,37	160	174	190	005	005
011	016	031	025	037	070			613	013	1,31	230	890	140	007	006
005	036	048	070	080	220	595	199	238	471	052	484	073	011	011	008
005	010	060	030	110	093	214	377	670	414	017	854	057	010	007	008
005	012	055	036	115	150	233	600	951	215	178	516	034	012	010	007
010	030	220	015	303	194	903	1,19	208	880	059	251	600	069	010	005
020	035	008	023	354	139	786	1,38	499	737	111	127	332	800	095	005
087	050	022	009	230	102	1,21	965	1,07	128	179	112	111	201	007	006
009	010	005	015	015	006	068	197	050	078	112	110	037	100	048	085
007	007	007	005	042	005	046	264	110	140	093	100	023	184	067	080
014	008	015	006	008	012	218	267	115	035	067	083	022	100	070	065
007	003	003	005	008	005	007	003	099	166	211	133	302	290	080	050
004	004	004	004	005	006	005	004	123	106	179	119	224	312	095	060
005	005	005	004	004	005	006	005	150	070	161	104	255	310	081	066

4 3

Units [mg/m³]

Format: Values should be read as "0,... mg/m³" by default unless number before decimal point is written manually.

1 2

	013	014	013	012	451	159	064	138	015	013	012	012	011	012
	013	013	012	012	319	155	073	052	015	015	012	012	012	012
	013	012	014	012	334	614	120	097	013	012	012	012	013	012
			Crusher											
	013	012	113	100	017	013	014	018	084	050	065	072	015	017
	012	013	226	077	016	014	015	016	160	105	044	077	017	020
	013	012	390	607	015	015	017	014	045	090	066	050	016	015
013 - 012 - 011			Wagon											
	013	014	014	013	014	015	013	014	102	110	060	079	016	014
	013	014	015	013	013	013	013	013	090	106	070	053	016	014
	014	013	013	013	016	017	014	013	116	099	048	055	015	014
	016	012	014	012	033	025	025	023	020	020	016	015	015	015
	014	012	013	012	026	019	014	015	017	018	017	013	015	017
	013	012	013	012	021	021	015	029	020	018	016	013	016	017
	012	014	014	013	033	017	016	016	014	016	016	017	080	038
	013	014	015	014	028	015	014	014	015	020	016	021	062	031
	012	013	015	013	017	016	015	013	015	014	015	020	058	026
	Not availab		Not availab		013	012	013	014	014	011	018	015	013	013
					014	013	013	013	013	011	013	013	012	013
					013	013	015	013	013	013	013	012	013	013

4 3

Start 10:00 End 11:45

$t^\circ = 6{,}1\,^\circ C$

$\varphi = 90\,\%$

Units [mg/m³]

Format: Values should be read as „0,… mg/m³" by default, unless number before decimal point is written manually

Appendix 3. Excel screenshots of PM10 Impactor calculations

Syrjänsalo

10 Collected mass

Stage	D_{50} (µm)	D_i (µm)	m_1 (mg)	m_2 (mg)	dm (mg)	$dlog(Dp)$	$dC_m/d\ log(Dp)$ (mg/Nm³)	cumulative (mg/Nm³)	cumulative % (%)
Pre-separator	50,00	-	0,00	0,00	0,000	-	-	0,00764	100,0
PM 10	11,41	23,89	14,66	17,15	2,490	0,641	0,05817	0,00764	100,0
PM 2.5	1,93	4,69	15,06	20,86	5,800	0,773	0,11251	0,00644	84,3
PM 1.0	0,77	1,22	15,10	16,62	1,520	0,397	0,05741	0,00569	74,5
Filter	0,01	0,09	270,34	271,90	1,560	1,888	0,01238	0,00480	62,7

11 Results

PM10 collected mass = 11,370000 mg

PM10 mass concentration = 0,170388 mg/Nm³ **= 170,4** µg/Nm³

Pitkäkallio

10 Collected mass

Stage	D_{50} (µm)	D_i (µm)	m_1 (mg)	m_2 (mg)	dm (mg)	$dlog(Dp)$	$dC_m/d\ log(Dp)$ (mg/Nm³)	cumulative (mg/Nm³)	cumulative % (%)
Pre-separator	50,00	-	0,00	0,00	0,000	-	-	0,00767	100,0
PM 10	11,46	23,93	14,89	15,12	0,230	0,640	0,00540	0,00767	100,0
PM 2.5	1,93	4,71	14,90	15,47	0,570	0,773	0,01109	0,00646	84,3
PM 1.0	0,78	1,22	15,13	15,46	0,330	0,397	0,01250	0,00571	74,5
Filter	0,01	0,09	280,62	281,12	0,500	1,890	0,00398	0,00481	62,7

11 Results

PM10 collected mass = 1,630000 mg

PM10 mass concentration = 0,024500 mg/Nm³ **= 24,5** µg/Nm³

Appendix 4. Data for 8 hours TWA calculations

Time	Mass concentration (mg/m3)
6:37	0,0165
6:47	0,0176
6:57	0,0229
7:07	0,0266
7:17	0,03
7:27	0,0171
7:37	0,0172
7:47	0,0169
7:57	0,019
8:07	0,0173
8:17	0,017
8:27	0,0173
8:37	0,0225
8:47	0,0188
8:57	0,0173
9:07	0,0169
9:17	0,0173
9:27	0,0174
9:37	0,016
9:47	0,0149
9:57	0,015
10:07	0,0138
10:17	0,0141
10:27	0,0129
10:37	0,0127
10:47	0,0171
10:57	0,0154
11:07	0,0129
11:17	0,0143
11:27	0,0138
11:37	0,0152
11:47	0,0127
11:57	0,0156
12:07	0,0176
12:17	0,0229
12:27	0,022
12:37	0,0172
12:47	0,0154
12:57	0,0153
13:07	0,0362
13:17	0,0163
13:27	0,0403
13:37	0,014
13:47	0,0174
13:57	0,0333
14:07	0,0226
14:17	0,0292
14:27	0,0139
14:37	0,0204
AVERAGE	**0,018694**

Appendix 5. Petrographic description of rock in Syrjänsalo (1) and Pitkäkallio (2)

DESTIA

3.1.2017

**YLÖJÄRVEN SYRJÄNSALON KALLION (VARASTON:O 25553)
KIVIAINEKSEN PETROGRAFINEN KUVAUS**

Destia Oy:n Ylöjärven Syrjänsalon kallioalueen kiviaineksen petrografinen kuvaus (SFS-EN 932-3+A1).

Kivilaji:

- hienorakeinen intermediäärinen vulkaniitti

Mineraalikoostumus:

- plagioklaasi	27 %
- kvartsi	26 %
- biotiitti	16 %
- epidootti	16 %
- serisiitti	7 %
- kloriitti	3 %
- saussuriitti	1 %
- karbonaatti	1 %
- malmimineraalit	3 %

Petrografisen tutkimuksen mukaan kiviaines ei ole rapautumisherkkää eikä vettä pidättävää. Kiviainesnäyte ei sisällä haitallisessa määrin kiille-, malmi- eikä sähköä johtavia mineraaleja. Kiviaines soveltuu petrografisen koostumuksensa puolesta sitomattomien rakennekerroksien, raidesepelin, betonin ja asfaltin raaka-aineeksi.

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DESTIA

11.1.2017

LEMPÄÄLÄN PITKÄKALLION (VARASTON:O 25503) KIVIAINEKSEN PETROGRAFINEN KUVAUS

Destia Oy:n Lempäälän Pitkäkallion kiviaineksen petrografinen kuvaus (SFS-EN 932-3+A1).

Kivilaji:

- hienorakeinen kvartsi-maasälpägneissi

Mineraalikoostumus:

- kvartsi	40 %
- plagioklaasi	28 %
- kalimaasälpä	19 %
- biotiitti	9 %
- saussuriitti	3 %
- muut	1 %

Petrografisen tutkimuksen mukaan kiviaines ei ole rapautumisherkkää eikä vettä pidättävää. Kiviaines ei sisällä haitallisessa määrin kiille-, malmi- eikä sähköä johtavia mineraaleja. Kiviaines soveltuu petrografisen koostumuksensa puolesta sitomattomien rakennekerroksien, raidesepelin, betonin ja asfaltin raaka-aineeksi.

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