QUAESTIONES GEOGRAPHICAE 43(4) • 2024

50 years of QUAESTIONES GEOGRAPHICAE

SOURCES OF THE AEOLIAN MATERIAL IN PERIGLACIAL CONDITIONS BASED ON QUARTZ GRAIN ANALYSIS, EBBA VALLEY, SVALBARD

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Manuscript received: August 21, 2024
Revised version: October 12, 2024

Rymer K.G., Wachecka-Kotkowska L., 2024. Sources of the aeolian material in periglacial conditions based on quartz grain analysis, Ebba Valley, Svalbard. *Quaestiones Geographicae* 43(4), Bogucki Wydawnictwo Naukowe, Poznań, pp. 179–191. 4 figs, 5 tables.

Abstract: The research conducted in this study is an attempt to quantitatively and qualitatively supplement the still insufficient knowledge on aeolian processes under polar conditions, where some of the most visible and dynamic climate changes are occurring. This study presents the results of rounding and matting analysis of quartz grains collected from aeolian deposition traps located in the Ebba Valley, Svalbard. The results are based on four summer field campaigns (2015–2018). Quartz grains with a diameter of 0.8–1.0 mm were selected and subjected to further analysis under a microscope, which allowed them to be divided into six individual classes. The nature of the grains can largely indicate the environmental conditions in which the material was transported. The collected material was dominated by grains with a low degree of roundness, which may indicate relatively short fluvial or aeolian transport. The small amounts of typically matted quartz grains may indicate low environmental dynamics and short transport, as well as the fact that large amounts of the material are blown from the valley interior to the nearby bay and fjord. This study highlights the importance of a fresh sediment supply from two main sources (i.e., moraines and rivers) and their subsequent aeolian redistribution, particularly in a wind-channelled valley environment. These findings underscore the complex interactions between aeolian processes and environmental conditions in cold regions. Climate change may significantly affect the magnitude of aeolian processes. Further research is needed to refine these correlations and enhance the understanding of sedimentary dynamics in polar settings.

Keywords: aeolian processes, polar desert, sedimentary environments, meteorological variables, statistical analysis, Arctic

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Introduction

Studying the characteristics of the environment via the rounding and matting analysis of quartz grains is a common research method, especially at moderate latitudes (Woronko, Bujak 2018). A method originally proposed by Cailleux (1942) has been applied, especially in the context of distinguishing sedimentary environments (Wachecka-Kotkowska 2004, 2015). With the advancement of analytical techniques, foundational knowledge on sedimentary rock origins and

https://doi.org/10.14746/quageo-2024-0034
ISSN 2082-2103, eISSN 2081-6383

processes, as well as discussions on the petrography and sedimentology of sand and sandstone, with an emphasis on quartz grains, has developed (e.g., Blatt et al. 1980, Pettijohn et al. 1987). Different quartz grain textures, their implications for sedimentary processes, and methods as well as various case studies for sedimentary rock and environmental analyses have also been presented (e.g., Blott, Pye 2001, Mahaney 2002, Boggs 2009, Lyu et al. 2019). Different environments (fluvial, glacial, and aeolian) contribute to variations in grain mineralogy and texture. Therefore, the possibility of separating grains formed in the aquatic environment from those shaped by the wind is particularly useful not only in the study of aeolian processes but it also allows for a broad analysis of the processes taking place in the geoecosystems (cf. Folk 1980, Pye, Tsoar 2009, Wachecka-Kotkowska et al. 2014, Woronko et al. 2015, Zieliński et al. 2015).

Despite the growing interest in sedimentary systems in cold regions (Zhang et al. 2022), information about aeolian processes in the Arctic and Antarctic regions is currently incomplete, which is due to the low availability of these areas and problems in obtaining reliable quantitative data under polar conditions and in various seasons (Müller et al. 2016). Studies have been sparsely distributed and have selectively covered different aspects of aeolian activity, including erosion and sediment transport, deposition and landform development, and seasonal and climatic influences, as well as ecological and environmental implications (e.g., Borysiak et al. 2020). However, data regarding aeolian processes are crucial for better understanding the functioning of polar geoecosystems, which are important markers of environmental changes occurring at global and local scales (Beylich et al. 2016).

The current knowledge on wind activity in periglacial environments was collected by Seppälä (2004) and Brookfield (2011). Recently, Rymer et al. (2022) summarised the work on aeolian processes occurring under polar conditions in recent decades. Notably, in recent years, interest in aeolian processes in polar environments has increased (see Kavan et al. 2020), as has interest in the nature of transported sediments (Kalińska-Nartiša et al. 2017, Kalińska 2019, Kalińska et al. 2019).

Owing to the lack of detailed research on the aeolian activity in this part of the Arctic, this work was intended to further develop and interpret the previously obtained research material (aeolian deposits collected in traps), with a particular emphasis on a detailed analysis of the nature and character of aeolian sediments (quartz grains 0.8–1.0 mm in size). Therefore, a quantitative and qualitative analysis of quartz grains collected from the aeolian material deposited in traps was performed. The obtained data were subjected to further statistical analysis. This study aimed to determine the main source of the deposited aeolian material as well as to determine the degree of aeolisation (acquisition of typically aeolian features by quartz grains) of the material transported by wind inside a relatively small postglacial valley under periglacial conditions. Additionally, the possible influences of meteorological variables on grain type distributions were investigated.

Study area

Ebba Valley (nor. Ebbadalen) is located in the central part of Spitsbergen, the largest island in the Svalbard Archipelago (Fig. 1). The central part of the valley with aeolian deposits is located at approximately 78°42' N latitude and 16°39' E longitude. This postglacial valley is flanked by steep mountain ranges, with prominent glacial features etched into the landscape (Rachlewicz 2009, Rymer et al. 2022). Geologically, Ebbadalen features an array of pre-Devonian metamorphic rock outcrops associated with overlapping sedimentary formations, primarily from the Carboniferous, including sequences of shale, sandstone, limestone, and anhydrite layers, which record a history of ancient tropical environments, marine transgressions, and orogenic cycles (Harland 1997, Dallmann et al. 2002). In many places, geological stratification is much more complicated because of the presence of tectonic faults in the area. The weathering of rock outcrops is one of the sources of the material supplied to the valley floor. However, there is no current data on the volume of this material supply and the impact of climate change on the intensification of these processes. The bottom of the valley is composed of morainic and glaciofluvial forms generated by the decaying Ebba and Bertram glaciers and their proglacial streams, eroding a series of six raised marine terraces in the mouth section of the valley

(Fig. 2). The terraces are elevated to 30 m a.s.l., and their thermoluminescence ages vary from 13.3 ka to 1.3 ka (Kłysz et al. 1989, Rachlewicz 2009, van der Meij et al. 2016). The terraces were also dated by AMS radiocarbon dating of *Astarte borealis* shells, and their ^{14}C ages varied from 9.9 to ca. 3 ka (Long et al. 2012).

The high Arctic environment of Ebbadalen is characterised by a cold climate, with a mean annual temperature slightly below −6.0°C, positive temperatures usually occur between May and October and are warmest in July and August, when they rise to 5–6°C on a daily average (Rachlewicz, Szczuciński 2008, Rymer, Rachlewicz 2014). The inner-fiord location results in the quasi-continental individuality of the area, which is slightly warmer during summer and much drier than the southern and western parts of Spitsbergen, with precipitation not exceeding 200 mm annually (Rachlewicz, Styszyńska 2007, Przybylak et al. 2014). Recent studies have shown significant warming trends, lengthening melt seasons, and increasing rainfall rather than snowfall from spring to autumn (Førland et al. 2011, Sobota et al. 2020). These changes and their consequences may be of key importance for the intensity of aeolian processes, but further work is necessary to determine the nature and direction of changes. Typically, thick snow cover does not occur there during the winter (Przybylak et al. 2006). The wind structure is dominated by southern and north-eastern directions; whereas, the strongest gusts are observed from the north and northwest and are affected by the morphology of the surrounding mountain chains (Rachlewicz 2003, Przybylak et al. 2006, Małecki 2015). A typical feature of areas in the immediate vicinity of glacier-covered areas is the occurrence of katabatic winds, which may ultimately lead to the wind blowing aeolian material out of valley.

Ebbadalen supports various Arctic flora adapted to extreme conditions. The sparse vegetation

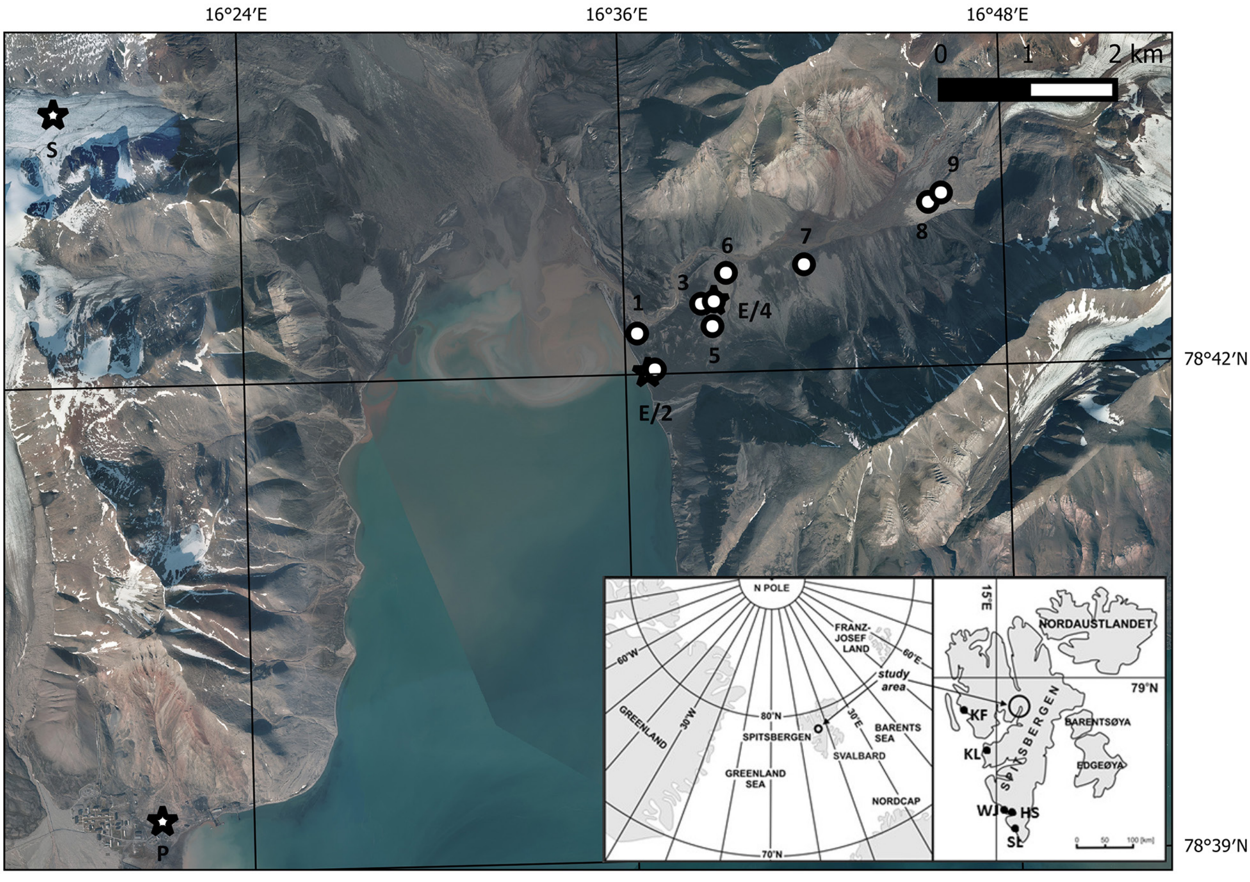

Fig. 1. Orthophotomap of the study area with nine aeolian deposition test sites (1–9) located within the Ebba Valley. Weather stations (E – Ebba Valley, S – Sven Glacier, and P – Pyramiden city) are marked with black stars. Orthophotomap source – Norwegian Polar Institute. Inner map shows the location of the study area (black arrows and circle) in the central Spitsbergen, High Arctic.

includes mosses, lichens, and shrubby species that form a fragile tundra ecosystem, colonising bare surfaces uncovered by glacial retreat and reaching climax on terraces in the valley mouths (Stawska 2017). Studies leading to the determination of individual types of vegetation have been carried out in this area, among others, by Prach et al. (2012) and Johansen et al. (2012). Plant communities provide a unique environment for trapping aeolian sediment (Borysiak et al. 2020). The area's biodiversity, although limited, is important for understanding ecological responses to a changing climate (Elvebakk 2005, Buchwal et al. 2013). The occurrence of vegetation is one of the important factors limiting the occurrence of aeolian processes (Seppälä 2004).

Within the Ebba Valley, there are no typical large forms resulting from the aeolian activity (such as dunes, ripple marks, or eologlyptoliths). In the field, only one larger cover composed of sandy sediments with a thickness not exceeding approximately 60 cm can be observed. In some places, mainly on slopes and local depressions, small niveo-aeolian covers can be found (see the locations of the sandy surface and windward slope test sites in the next section).

Materials and methods

Samples of summer aeolian deposition were collected using plastic trays (195 mm or 210 mm diameter) filled with glass marbles or pre-rinsed local beach gravel sediments from nine test sites located in the Ebba Valley. Test sites were chosen to reflect different geomorphological and vegetation settings along the Ebbadalen axis (Fig. 1): wet (1) and dry (2) tundra sites located closest to the fjord with dense tundra vegetation; leeward slope (3), top (4), and windward slope (5) sites located on the highest marine terrace with less or sparse tundra vegetation; a sandy surface (6) site covered only with individual tufts of grass; and three test sites with almost no vegetation located in the central part of the valley (7), as well as the upper part of the valley: sandur (8) and moraine (9). Test sites 3–5 were located around an old marine terrace with a height of approximately 40–45 m a.s.l., which is a minor terrain obstacle in the valley axis.

The measurement season for logistical and technical reasons usually starts in mid-July and ends at the beginning of September or mid-September. The length of the measuring season

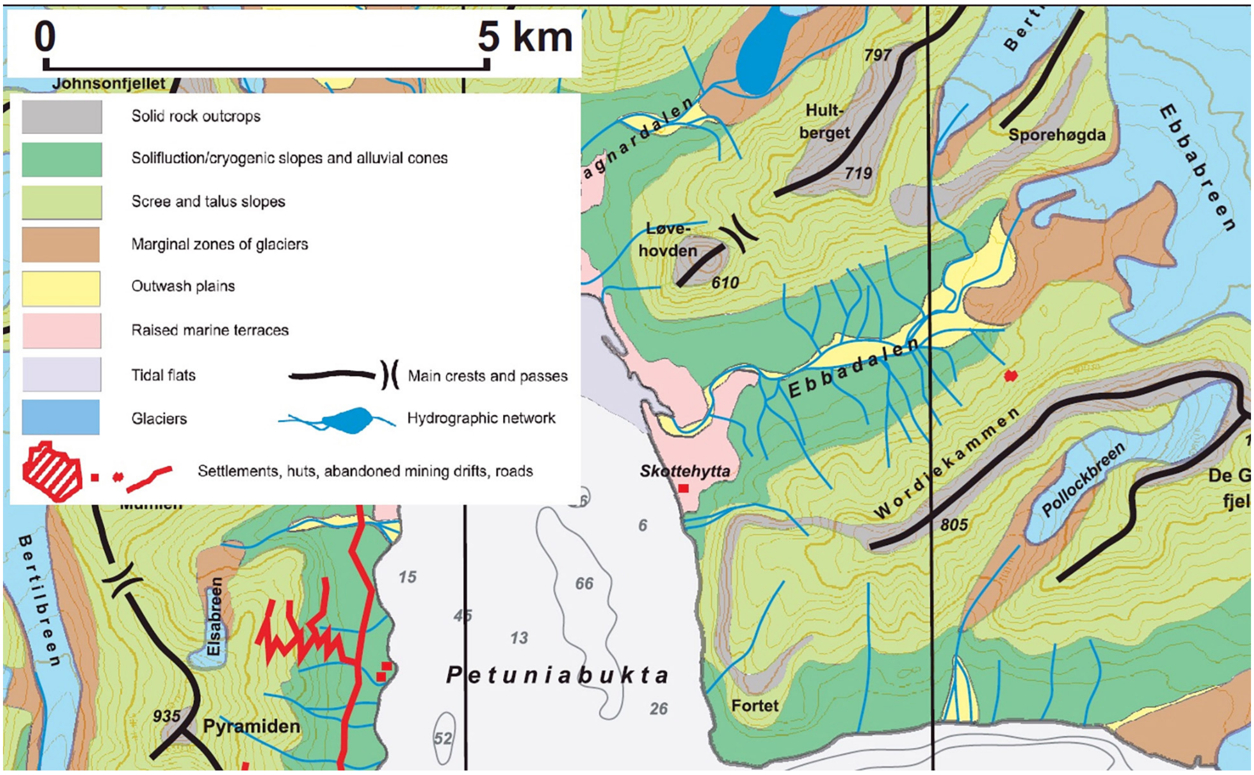

Fig. 2. Geomorphological sketch of the study area (Ebba Valley, Svalbard). Modified after the original figure by Rachlewicz (2009).

varied across the years (from 44 days to 64 days). Certainly, shorter measurement seasons resulted in less representative data, but further work is necessary to assess the resulting errors (especially when comparable measurement periods are used, which is, however, extremely difficult under polar conditions).

Although the measurements of aeolian deposition started in 2012, only samples from 2015 to 2018 were selected for this analysis to ensure greater representativeness, which involved placing three traps at each test site (for technical reasons, there were only two traps at a sandy surface test site in 2015 and at the central part test site in 2016).

The traps, together with gravel or glass marbles, were then washed with water to separate the collected material, dried, and subjected to further analyses. Previous studies have not shown significant differences between the uses of different materials in traps (despite the greater roughness of the gravel material). However, the use of glass marbles facilitated the subsequent recovery of the deposited material (Rymer et al. 2022). An additional source of errors could be the accumulation of rainwater in the traps. In future studies, it would be advisable to use a system that allows for the drainage of rainwater from traps.

The aeolian material obtained during the measurements was sieved to isolate grains with a diameter of 0.8–1.0 mm, which is typical for this type of analysis (Goździk 1980, 1995, Mycielska-Dowgiałło, Woronko 1998). Only quartz grains were then selected for further analyses. HCl was not used because of the lack of grain contamination with carbonates.

The quartz grains were then classified, using binocular microscope, into six groups based on the method of rounding and matting according to Krumbein (1941) and the classification of the degree of rounding and a modified method of matting of the surface of the quartz grains according to Cailleux (1942), together with modifications proposed by Goździk (1980, 1995) and Mycielska-Dowgiałło and Woronko (1998): angular (NU), matte rounded (RM), shiny rounded (EL), transitional matte (EM–RM), transitional shiny (EM–EL), and broken grains (C). The collected aeolian deposition samples allowed for the analysis of 1974 quartz grains from 106 samples in terms of rounding and matting.

Spearman's rank correlation coefficient between the characteristics of the quartz grains and the meteorological variables (average wind speed at three weather stations, average air temperature, total precipitation, and average air humidity during the sampling period) was estimated in the stats library using R software (Version. 4.2; R Development Core Team). The assumptions were checked visually (histogram plots) and tested with formal methods (Shapiro–Wilk test). Before analysis, all the data were log-transformed (ln) to approximate the data to a normal distribution.

Meteorological data (average air temperature and average air humidity) for the Ebba Valley were collected via ONSET HOBO devices, located close to the highest marine terrace test site (E/4, Fig. 1). The wind speed and direction (at a height of 2 m) were recorded at the same location at 15 min intervals (in 2016, 2017, and 2018). Unfortunately, some of the recording devices left in the area were occasionally damaged. Therefore, wind speed and direction data from the automatic weather station (recorded at one-hour intervals) located near the dry tundra test site (E/2, Fig. 1) were used to fill the data gaps for 2015. Owing to sensor failure in 2015, the recording of wind direction only started on August 17. Additionally, wind speed data from stations installed on Sven Glacier (S, Fig. 1; see Małecki 2019) and Pyramiden (P, Fig. 1) were also used. Both of these weather stations were located approximately 10 km from the centre of the Ebba Valley. Moreover, the total precipitation data were collected from the Longyearbyen meteorological station, which is located approximately 60 km southwest of the study area. The Norwegian Meteorological Institute collected data from the Pyramiden and Longyearbyen stations. The meteorological data were previously presented by Rymer et al. (2022).

Results

A full summary of the data is attached to the publication (Appendix 1). The greatest amounts of grains were recorded in 2015 and 2018 (Table 1), mainly because of relatively greater deposition in the indicated measurement seasons (according to Rymer et al. (2022), the mean seasonal aeolian

Table 1. Total number of quartz grains collected in the Ebba Valley in 2015–2018 divided into grain rounding and matting classes according to Cailleux (1942) with modification by Goździk (1995) and Mycielska-Dowgiałło and Woronko (1998).

Year	Class						
	C	EL	EM–EL	RM	EM–RM	NU	Total
2015	83	45	213	55	215	126	737
2016	55	29	125	37	73	67	386
2017	40	8	64	27	59	14	212
2018	47	88	197	110	177	20	639

deposition was almost 7 times greater in 2015 and more than 5 times greater in 2018 than the mean aeolian deposition rates measured in 2017). The differences in the number of quartz grains caught in traps between the individual seasons were relatively significant. The total number of grains in 2015 was almost 3.5 times greater than that in 2017. In total, the number of EL grains in 2017 was the lowest (only eight grains). The largest number of one type of grain was recorded in 2015 (the number of EM–RM grains reached 215).

In 2016–2018, transitional shiny (EM–EL) grains dominated, reaching 30.2–32.4% of the values (Table 2 and Fig. 3). Transitional matte (EM–RM) grains constitute 29.2% of the total grains only in 2015. In total, both transitional classes (EM–EL and EM–RM) exceeded more than half of the analysed grains in all years. Moreover, the share of angular (NU) grains in 2018 and shiny rounded (EL) grains in 2017 was the smallest, at 3.1% and 3.8%, respectively. The lowest percentage differences within the class were observed for the EM–EL class (3.5% between 2015 and 2016). On the contrary, the highest seasonal variability in the percentage share was observed for the NU class (14.3% between 2016 and 2018). This means that the percentage of grains belonging to the NU class was more than 5.6 times greater in 2016 than in 2018. In the case of the remaining classes, the seasonal differences oscillated approximately 10%.

Table 2. Percentage of quartz grains collected in the Ebba Valley in 2015–2018 divided into grain rounding and matting classes according to Cailleux (1942) with modification by Goździk (1995) and Mycielska-Dowgiałło and Woronko (1998).

Year	Class					
	C	EL	EM–EL	RM	EM–RM	NU
2015	11.3	6.1	28.9	7.5	29.2	17.1
2016	14.2	7.5	32.4	9.6	18.9	17.4
2017	18.9	3.8	30.2	12.7	27.8	6.6
2018	7.4	13.8	30.8	17.2	27.7	3.1

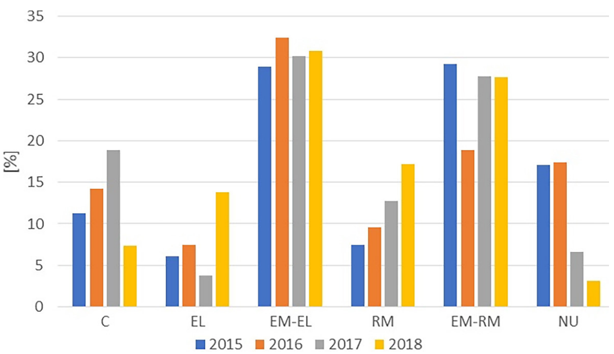

Fig. 3. Percentage of quartz grains in the Ebba Valley in 2015–2018 divided into grain rounding and matting classes according to Cailleux (1942) with modification by Goździk (1995) and Mycielska-Dowgiałło and Woronko (1998).

The greatest number of quartz grains over the four research seasons was recorded on the sandy surface (645) and windward slope (530) test sites (Table 3). The total number of quartz grains at these two sites alone was almost 60% of the total grains analysed. In the case of the windward slope test site, the amount of deposition was approximately 2 times greater than the average. At both of the abovementioned test sites, transitional grains were dominant. Almost 1/3 of the grains collected at the sandy surface test site were the EM–EL class. On the contrary, three test sites with relatively high plant coverage (wet tundra, dry tundra, and leeward slope) together accounted for only 3% of all the analysed grains. The remaining test sites with a significantly lower share of vegetation were characterized by an average

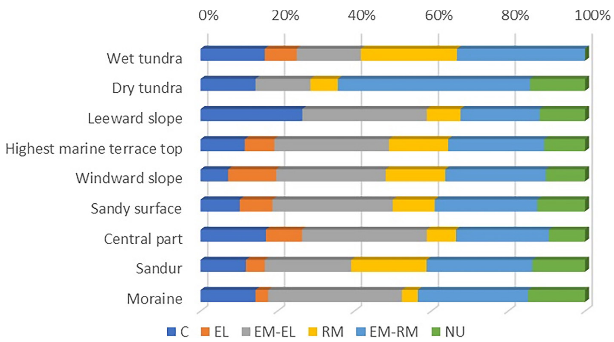

Fig. 4. Percentage of quartz grains in the years 2015–2018 collected in Ebba Valley divided into grain rounding and matting classes according to Cailleux (1942) with modification by Goździk (1995) and Mycielska-Dowgiałło and Woronko (1998) at nine test sites.

number of collected quartz grains ranging from 102 to 277 grains for the entire 4-year period.

The mentioned tundra sites were also characterised by greater dominance of certain grain types: 50% of the grains at the dry tundra test site were assigned to the EM–RM class, no grains belonging to the EL class were found at the dry tundra and leeward slope test sites, and no grains were assigned to the NU class at the wet tundra test site (Table 4 and Fig. 4.). This could have been influenced by the greater randomness of grains reaching the aeolian traps, which resulted from the significantly lower aeolian deposition at these test sites (according to Rymer et al. (2022), the mean values of aeolian deposition at the dry and wet tundra test sites were more than 50 times lower than the average for the entire valley). Considering the remaining test sites (where the sample size was larger and amounted to at least 100 grains), there was a significant proportion of grains in the EM–EL class (28.5–34.8%), except for the sandur test site, where the share of grains belonging to the EM–RM class was greater (27.5%) than that of the other classes. At most test sites, the share of grains in the EM–RM class was slightly lower but still higher (24.2–28.7%) than the share of EM–EL grains. Most often, the smallest proportion of grains belonged to classes that fully defined the depositional environment (i.e., EL and RM). The percentage of quartz grains belonging to the NU and C classes, apart from a few exemptions, was usually approximately a dozen at most test sites throughout the 4-year period. The relatively small (10.9%) percentage of typically aeolian RM quartz grains collected at the sandy surface test site is surprising, as the

Table 3. Total number of quartz grains collected in the Ebba Valley in 2015–2018 divided into grain rounding and matting classes according to Cailleux (1942) with modification by Goździk (1995) and Mycielska-Dowgiałło and Woronko (1998) at nine test sites.

Test site name	Class						
	C	EL	EM–EL	RM	EM–RM	NU	Total
The mouth of the valley with dense vegetation							
1. Wet tundra	4	2	4	6	8	0	24
2. Dry tundra	2	0	2	1	7	2	14
The middle part of the valley floor with little or no vegetation							
3. Leeward slope	9	0	11	3	7	4	34
4. Highest marine terrace top	12	8	31	16	26	11	104
5. Windward slope	38	66	151	82	139	54	530
6. Sandy surface	66	55	202	70	172	80	645
7. Central part of the valley	47	26	90	21	67	26	277
The upper part of the valley without vegetation cover							
8. Sandur	12	5	23	20	28	14	102
9. Moraine	35	8	85	10	70	36	244

Table 4. Percentage of quartz grains collected in the Ebba Valley in 2015–2018 divided into grain rounding and matting classes according to Cailleux (1942) with modification by Goździk (1995) and Mycielska-Dowgiałło and Woronko (1998) at nine test sites.

Test site name	Class					
	C	EL	EM–EL	RM	EM–RM	NU
The mouth of the valley with dense vegetation						
1. Wet tundra	16.7	8.3	16.7	25.0	33.3	0.0
2. Dry tundra	14.3	0.0	14.3	7.1	50.0	14.3
The middle part of the valley floor with little or no vegetation						
3. Leeward slope	26.5	0.0	32.4	8.8	20.6	11.8
4. Highest marine terrace top	11.5	7.7	29.8	15.4	25.0	10.6
5. Windward slope	7.2	12.5	28.5	15.5	26.2	10.2
6. Sandy surface	10.2	8.5	31.3	10.9	26.7	12.4
7. Central part of the valley	17.0	9.4	32.5	7.6	24.2	9.4
The upper part of the valley without vegetation cover						
8. Sandur	11.8	4.9	22.5	19.6	27.5	13.7
9. Moraine	14.3	3.3	34.8	4.1	28.7	14.8

expected values were higher for this type of surface and local landform, assuming a mainly local nature of aeolian transport in this area.

Discussion

Owing to the unique nature of the obtained data, it is extremely difficult to find comparative studies, especially in polar areas. In most cases, the analysis of quartz grains is carried out based on the samples collected from sediments and concerns to ancient aeolian and fluvioglacial palaeoenvironments. The samples collected from these sediments cover a longer period of time than just a few months of the year. There have been many studies on the 'European Sand Belt', that is, the area of Europe where periglacial conditions were present in the past (see Kalińska 2019, Kalińska et al. 2019, Łopuch, Jary 2023, Łopuch et al. 2023). Kalińska and Nartišs (2014) observed similar percentages of RM and EM–RM quartz grains in many profiles located in central Poland, Latvia, Estonia, and Finland compared with those collected in traps at test sites located in the Ebba Valley. However, the share of EL and EM–EL grains was significantly lower in those palaeoenvironments than in the current periglacial conditions observed on Spitsbergen.

For the weathered sediments of north-western Spitsbergen, Kowalkowski and Kocoń (1991) observed a small number of quartz grains, exhibiting features acquired through transport in an aeolian environment. In the modern glacial and proglacial environments of southwestern Greenland, Kalińska-Nartiša et al. (2017) estimated the share of non-abraded fresh grains with sharp edges and shiny surfaces to be 78% of the sample collected from aeolian cover on a hillslope. Interestingly, samples collected close to the glacial margin presented greater numbers of moderately rounded grains with both shiny and matte surfaces (up to 27%). The proportions of moderately rounded grains were even greater in the part of the area farther from the glacier. The percentage of moderately rounded grains with shiny surfaces reached 34–37% at some locations, and the percentage of moderately rounded grains with matte surfaces was even greater (up to 46%). A comparison of the results obtained in this study with the modern example from Greenland may therefore indicate that the occurrence of incompletely rounded grains is typical for contemporary periglacial environments (such as small postglacial valleys). The decrease in the degree of grain rounding in contemporary environments compared with the Last Glacial Maximum period was also noted by Warrier et al. (2016) for East Antarctica. Owing to the formation process (mutual impact while suspended in the air), RM grains require high transport dynamics over a longer time to fully form.

The statistically significant Spearman's rank correlation coefficient (r_s) results between the number of quartz grains in different classes and the meteorological variables were relatively low (r_s up to 0.49). This was possibly due to the small amount of data associated with only four measurement seasons. However, on this basis, certain conclusions can be drawn regarding the regularities concerning the sources of the material and the influence of meteorological conditions on

Table 5. Spearman's rank correlation coefficient between different quartz grain types collected in the Ebba Valley and different meteorological variables. The red colour indicates a positive correlation. The blue colour indicates a negative correlation.

Parameter	C	EL	EM–EL	RM	EM–RM	NU
Average wind speed Ebba Valley	−0.01 p = 0.92	−0.02 p = 0.87	−0.03 p = 0.75	−0,14 p = 0.19	−0.05 p = 0.63	0.49 p < 0.01
Average wind speed Pyramiden	0.08 p = 0.43	−0.31 p < 0.01	−0.22 p = 0.04	−0.08 p = 0.47	0 p = 0.99	−0.01 p = 0.92
Average wind speed Sven Glacier	−0.04 p = 0.71	−0.1 p = 0.34	0.04 p = 0.73	−0.18 p = 0.08	−0.13 p = 0.23	0.45 p < 0.01
Average temperature Ebba Valley	−0.07 p = 0.52	0.31 p < 0.01	0.21 p = 0.05	0.03 p = 0.76	0.01 p = 0.91	0.23 p = 0.03
Total precipitation Longyearbyen	−0.08 p = 0.43	0.31 p < 0.01	0.22 p = 0.04	0.08 p = 0.47	0 p = 0.99	0.01 p = 0.92
Average air humidity Ebba Valley	−0.08 p = 0.46	0.08 p = 0.47	0.11 p = 0.3	0.05 p = 0.66	−0.07 p = 0.5	−0.26 p = 0.01

the functioning of aeolian processes in the Ebba Valley (Table 5). The strongest positive relationships (r_s = 0.49–0.45) were observed between the occurrence of NU grains and average wind speed in the Ebba Valley and on the Sven Glacier. These grains are commonly associated with frost weathering and are most often found in moraine deposits (Mycielska-Dowgiałło, Woronko 1998). Considering the dominant directions of the strongest winds (especially in the Ebba Valley), this may mean that stronger winds from the north and east (i.e., along the valley axis) influence the appearance of a greater amount of the fresh material of the glacial origin (NU grains). Therefore, the moraine areas (and possibly weathered material on the slopes) were the first significant source of the material transported by wind within the valley. On the contrary, stronger winds from the south and west (typical for the Pyramiden station) were negatively related to the supply of EL and EM–EL grains, which are usually related to aquatic transport. Most likely, the occurrence of these winds limited the delivery and transport of the material brought to the valley by the river. The importance of the river as one of the main sources of the material available for wind transport was also evidenced by the occurrence of positive relationships between the presence of EL and EM–EL grains and the average air temperature and total precipitation. Both of these variables significantly influence river discharge (Rachlewicz 2009) and, consequently, the amount of the material carried by it and delivered to the valley. Interestingly, a positive correlation was also detected between the average air temperature and the appearance of NU grains. Perhaps in the warmest periods, the water flow in the river was so intense that there was greater erosion of moraine zones, and fresh NU grains were thus transported short distances across the river (so that they had no opportunity to acquire the characteristics of the aquatic environment). However, sediments carried by rivers usually become available for aeolian transport only at the end of the summer season when the water level decreases and the sediments dry out (Rasmussen et al. 2023). Moreover, there was a noticeable negative relationship between the occurrence of fresh angular NU grains and the average air humidity. Higher air humidity may result in greater wind transport capabilities and, consequently, greater intensity of processing of the material carried by the wind (Csavina et al. 2014). This issue, however, certainly requires further analysis and broader research.

Conclusions

On the basis of new data, it was possible to establish certain relationships between the occurrence of grains belonging to certain classes and other environmental variables (meteorological and geomorphological). It is therefore important to carry out further analyses, especially in years when the aeolian deposition values are the highest, as well as to conduct measurements in similar time periods.

Two main sources of origin for the aeolian material deposited in the traps were identified. One was the fresh angular material (NU grains) derived from moraines, where there is strong crumbling of the material. This non-abraded material is distributed over short distances within the valley by the wind (in line with the valley axis) and possibly processed into other types of transitional grains, the percentage of which was usually the highest. The second was the fluvioglacial material (EL and EM–EL grains) originating from river alluvia. The amount of this material supply is most often dependent on the river level and therefore on the amount of carried sediment. This level, in turn, depends on the temperature and amount of precipitation in a given year. This material supply can be limited by stronger winds that are off-axis with the valley axis. Both aeolian and fluvial transports are usually not long, which translates into the largest share of grains belonging to the EM–EL and EM–RM classes. These grains may also have their features acquired in the original sedimentary environments – glacial and fluvioglacial.

The relatively small number of grains belonging to the RM class, that is, those with typical aeolian characteristics, may indicate very short transport or low environmental dynamics in this type of periglacial valley. Most of the material (grains) before reaching its final form is possibly blown away and deposited in nearby bay and fjord. This may be confirmed by the relatively high share of RM grains near the bay at the dry tundra site. The second reason for such a small aeolisation is the short period of study for the abrasion of the material in the valley. The summer season is too short for the surface of a single grain to be sufficiently rounded and matted and for its classification as an RM grain. In this case, there is no question of accidental addition of grains that are already matted. To prove greater aeolisation, studies should be performed over longer periods, especially concerning autumn.

Owing to its orientation and morphology (the valley floor is surrounded by high formations in close proximity to a glacier), Ebba Valley acts as a wind tunnel where newly deposited sediments under periglacial conditions undergo the initial phase of aeolisation.

Under climate change conditions, the dynamics of the environment may change significantly. The proportions of the supply of the aeolian material from moraines and weathering to those supplied by the river may also change. The second material source may gain importance because of the increasing rainfall and temperatures in the Arctic. These changes may significantly affect the functioning of periglacial geoecosystems at both local and regional scales.

Acknowledgments

The study was conducted at Adam Mickiewicz Polar Station 'Petuniabukta' (AMUPS) and was funded by the National Science Centre (Grant No. 2014/15/N/ST10/00825). We would like to thank Alfred Stach, Michał Rybak, and Agata Buchwał for their help with statistical analysis, as well as Grzegorz Rachlewicz for his valuable comments on the manuscript, and Tomasz Kurczaba for the help in fieldwork. We are particularly grateful to Jakub Małecki for sharing his meteorological data from Sven glacier (Project funded by the National Science Centre, Grant No. N N306 062940). We also gratefully thank four anonymous reviewers for their valuable comments.

Author's contribution

KGR: conceptualization, formal analysis, funding acquisition, investigation, methodology, writing – original draft, writing – review & editing, visualization. LW-K: formal analysis, investigation, writing – review & editing, visualization.

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Appendix 1. Full summary of quartz grains numbers collected in the Ebba Valley in 2015-2018 divided into grain rounding and matting classes according to Cailleux (1942) with modification by Goździk (1995) and Mycielska-Dowgiałło and Woronko (1998) at nine test.

2015	Trap 1						Trap 2						Trap 3					
	C	EL	EM-EL	RM	EM-RM	NU	C	EL	EM-EL	RM	EM-RM	NU	C	EL	EM-EL	RM	EM-RM	NU
Wet tundra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dry tundra	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leeward slope	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Highest marine terrace top	1	1	6	4	4	3	2	0	2	3	5	1	3	1	5	1	3	0
Windward slope	3	10	13	21	30	7	2	9	8	5	15	5	5	0	7	0	6	5
Sandy surface	26	0	68	5	65	57	9	2	13	0	10	4						
Central part	10	3	30	3	27	3	2	8	10	3	6	5	3	4	7	3	5	4
Sandur	3	2	4	2	4	2	1	2	5	1	4	4	0	0	3	2	0	1
Moraine	10	1	18	1	21	13	3	2	6	0	8	9	0	0	8	0	2	3
2016	Trap 1						Trap 2						Trap 3					
	C	EL	EM-EL	RM	EM-RM	NU	C	EL	EM-EL	RM	EM-RM	NU	C	EL	EM-EL	RM	EM-RM	NU
Wet tundra	2	0	3	2	2	0	0	0	0	0	1	0	0	0	0	0	0	0
Dry tundra	0	0	1	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0
Leeward slope	4	0	4	0	2	3	0	0	0	0	1	1	1	0	0	0	0	0
Highest marine terrace top	0	1	0	1	0	0	0	0	1	1	2	0	0	0	4	3	1	0
Windward slope	7	6	21	9	13	6	7	3	11	0	6	11	4	1	22	0	5	15
Sandy surface	1	3	3	2	3	1	6	4	10	7	8	6	4	9	19	10	12	3
Central part	6	0	7	2	5	8	5	2	5	0	3	0						
Sandur	1	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1
Moraine	0	0	0	0	1	3	5	0	7	0	3	5	2	0	4	0	4	2
2017	Trap 1						Trap 2						Trap 3					
	C	EL	EM-EL	RM	EM-RM	NU	C	EL	EM-EL	RM	EM-RM	NU	C	EL	EM-EL	RM	EM-RM	NU
Wet tundra	1	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	1	0
Dry tundra	0	0	0	0	2	1	2	0	0	1	2	0	0	0	0	0	1	0
Leeward slope	2	0	1	1	1	0	0	0	0	1	0	0	2	0	1	0	0	0
Highest marine terrace top	0	0	1	0	2	3	1	1	3	0	1	0	1	0	0	0	3	0
Windward slope	1	1	3	2	2	0	1	2	7	3	6	2	1	0	11	4	4	0
Sandy surface	2	0	1	1	1	0	0	1	0	1	0	0	5	0	4	2	2	2
Central part	4	1	7	0	2	1	5	0	3	1	3	0	3	0	5	2	4	0
Sandur	1	0	1	0	2	2	1	1	2	3	2	1	0	0	1	1	4	1
Moraine	3	0	5	0	5	0	0	1	6	1	5	1	4	0	2	2	2	0
2018	Trap 1						Trap 2						Trap 3					
	C	EL	EM-EL	RM	EM-RM	NU	C	EL	EM-EL	RM	EM-RM	NU	C	EL	EM-EL	RM	EM-RM	NU
Wet tundra	1	0	1	0	0	0	0	0	0	0	0	0	0	2	0	3	2	0
Dry tundra	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Leeward slope	0	0	0	0	0	0	0	0	1	0	0	0	0	0	4	0	3	0
Highest marine terrace top	2	3	5	2	4	4	1	0	1	0	0	0	1	1	3	1	1	0
Windward slope	2	14	14	4	10	0	1	11	16	10	8	1	4	9	18	24	34	2
Sandy surface	3	12	32	5	22	1	5	18	41	10	16	4	5	6	11	27	33	2
Central part	2	3	3	2	4	1	3	3	4	3	4	4	4	2	9	2	4	0
Sandur	3	0	1	2	3	0	1	0	2	4	4	1	1	0	2	5	5	0
Moraine	2	0	8	1	6	0	3	4	6	2	7	0	3	0	15	3	6	0