GEOLOGOS 6 (2003)

PL ISSN 1426-8981 · ISBN 83-89629-03-8

Sediment texture in contemporary glacial environment – examples from Hansbreen, southern Spitsbergen

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Abstract: The sediment texture data (grain size, quartz grain abrasion, and roundness) from a range of different glacial environments at Hansbreen in southern Spitsbergen are presented. The six main sediment groups were distinguished: subglacial till, supraglacial debris cover, debris flow deposits, supra- and englacial meltwater stream deposits, dirt cone and proglacial glaciofluvial deposits. The division is supported by grain size statistics (presented in form of 3D diagrams), and is also legible in quartz grain abrasion differences. The latter one reveals strong changeability depending on the grain size class. No correlation between clay ratio and standard deviation vs. quartz grain abrasion was found. Lithology has limited impact on clast roundness (analysed for > 2.8 mm fraction), although restricted by short distance and time of transportation. A comparison with similar data set from Werenskioldbreen shows the deposits of Hansbreen as more mature, which is probably caused by reworking of older deposits and longer transport.

Key words: glacial deposits, texture, Spitsbergen.

Introduction

The textural features (particle size and shape) of glacial deposits have been already intensively studied, and fundamental laws for their diagnostic importance are set (Boulton 1978), however they have recently emerged as a focus of attention for new research and reinterpretation. It is largely powered by new concepts of glacial sedimentation (e.g.: deformed subglacial till layer), and substantial increase in our knowledge on sedimentary processes, and diagenetic changes from glacial environments in wide range of settings. The grain size distribution is understood now, not only as an effect of acting processes but it is also considered as a cause for large scale subglacial deformed till layer variations (Boulton 1996). Sediment texture can be also used for an interpretation of former dynamic and thermal basal ice conditions and its changeability in space and time (Knight *et al*. 2000). Influences of early diagenesis and distance of transportation on sediment properties are found more important, as lately proved by Kjær (1999). Hence the classical concepts were developed on geographically limited areas, there is a need for testing them in other locations, in search for more universal modern model, which could be used in interpreting older deposits. Recently obtained results often do not support a common view. For example Bennett *et al*. (1997) did not find a correlation between lithology and degree of roundness in modern glacial deposits. Attention is also given to the methodological constrains and the ways of data visualization. It was discussed in many works (e.g.: Buller & McManus 1973; Olsen 1983), and recently introduced concepts underline the significance of angularity and elongation of pebbles in interpretation (Benn & Ballantyne 1994; Bennett *et al.* 1997).

The aims of this paper are threefold: (1) to present data on sediment texture from a range of different glacial environments of known origin in order to contribute to the growing body of reference material on textural properties; (2) to examine the role of grain size and lithology on the contrary to particle abrasion and roundness; and (3) to compare the new data set of data with similar one from Werenskioldbreen (Werenskiold Glacier – Fig.1) (Karczewski & Wiśniewski 1979) – land terminating glacier covering an area of comparable lithology, which is smaller than the Hansbreen (Hans Glacier), also to find reasons for similarities and dissimilarities between them.

Study area

Samples were collected from the western margin region of Hansbreen (Fig.1) – a tidewater glacier in the southern Spitsbergen (Hornsund fjord region). The geology of the studied part of Hansbreen, and of the Werenskioldbreen basin is dominated by rocks forming Hecla Hoek Succession: gneisses, schists, amphibolites, phyllites, marbles, quartzites and conglomerates (Birkenmajer 1990, 1992; Manecki *et al*. 1993). Glaciers in the study belong to a polythermal group (Jania 1988; Moore *et al*. 1999), and in the last few decades presented a strong negative mass balance (Jania 1988, Jania & Głowacki 1996).

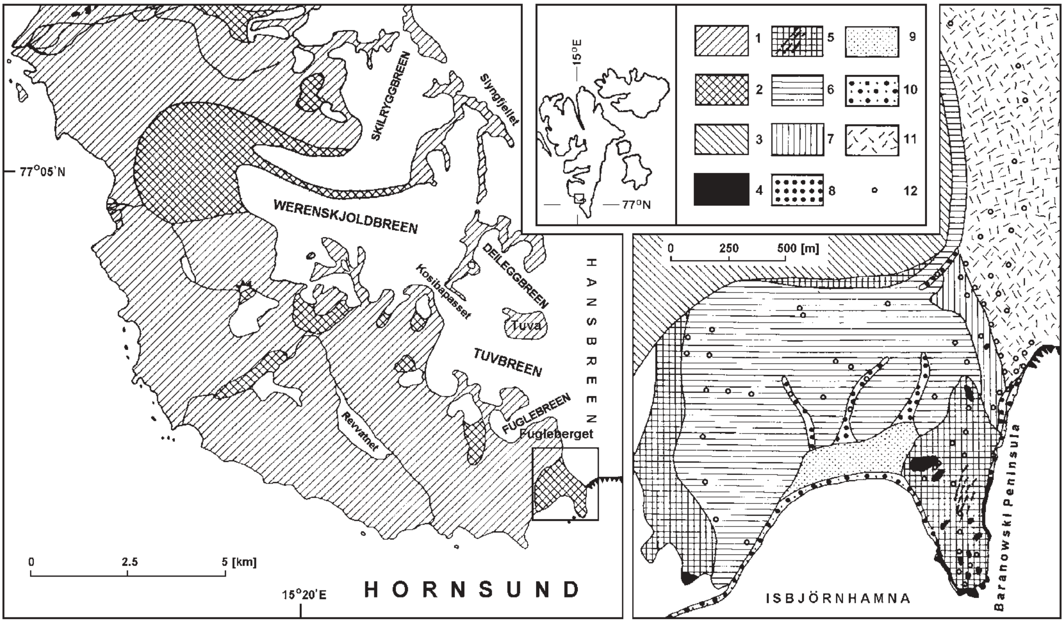


Fig. 1. Location of the study area. Distribution of sediments and sampling points on the western margin of Hansbreen: 1 – extraglacial features, 2 – glacigenic deposits, 3 – slope covers, 4 – bedrock outcrops, 5 – subglacial till with fluted ridges, 6 – debris covered dead ice area, 7 – unstable water-saturated supraglacial covers, 8 – glaciofluvial stream deposits, 9 – glaciofluvial still-water deposits, 10 – coastal deposits, 11 – glacier ice, 12 – sampling points.

Lokalizacja obszaru badań. Rozkład osadów powierzchniowych oraz punkty opróbowań w obrębie zachodniej strefy marginalnej lodowca Hansa: 1 – obszar poza oddziaływaniem lodowca, 2 – osady glacjalne, 3 – pokrywy stokowe, 4 – wychodnie skał podłoża, 5 – subglacjalna morena żłobkowa, 6 – obszar martwego lodu pokryty stałą pokrywą osadów, 7 – niestabilne nasycone wodą pokrywy supraglacjalne, 8 – osady potoków fluwioglacjalych, 9 – fluwioglacjalne osady wód stagnujących, 10 – osady brzegowe, 11 – lód lodowcowy, 12 – punkty poboru prób.

Methods

Typical deposits were sampled from number of different sedimentological environments in the western margin region of Hansbreen. The set of 75 samples was analysed by combined methods of dry and wet sieving and size analysis by sedimentation to obtain the grain size distribution. The boulder size fraction was excluded from laboratory investigations of the particle size distribution. Several standard parameters were calculated: the mean diameter (Folk & Ward 1957), standard deviation, kurtosis, asymmetry index (Friedman 1962), and clay ratio (I = < 0.002 mm / > 0.002 mm 100%; Karczewski 1963).

The degree of abrasion of quartz grain (mechanical graniformametry, rollability) was investigated, with the help of a graniformameter (Krygowski 1964), in two grain size classes (0.8–1.0 and 1.0–1.25 mm). The analysis was based on 100 selected quartz grains which were laid down on a plain steel surface, which inclination was increased stepwise (15 angle classes: 1º,3º,5º,7º etc). The degree of abrasion was calculated by counting the amount of the grains, rolled down under the particular angle of inclination. Every sample was examined twice, and results are averaged. The statistical value Wo ($Wo = (2400 - \Sigma nk)/N \cdot 100$; where n – the number of grains in certain angle class, k – average angle in angle class, N – number of the grains in sample) – roundness index (Krygowski 1964) was used for analysis of the results (the higher Wo, the more abraded grains).

The roundness of grains in > 2.8mm fraction was investigated in 16 samples (200 pebbles per sample), and for certain lithologies therein, using the classification proposed by Pettijohn (1957) and modified by Olsen (1983). The middle roundness number (MR) (Olsen 1983), was obtained for the bulk sample, and for the particular lithologies. The MR number is calculated by assignment of following numbers 1,2,3 etc. to Pettijohn's group: angular – 1, subangular – 2, rounded – 3, and well-rounded – 4. The percentage of each class is multiplied by the fixed number (1–4). The subproducts are divided by 100 and added. The resulting index is a value between 1 and 4. Numbers 1 and 4 indicate that all particles in the sample are angular and well-rounded, respectively.

Results and discussion

Dominating sediment types

Supraglacial cover on active, passive and dead glacier ice (Fig.1) dominates the sedimentation style in the study area. It is derived mostly from subglacial deposits or debris contained in the basal ice layer. The process of its upward transportation is caused by compressive ice tectonics (Rachlewicz & Szczuciński 2000). Mass movement processes intensively rework the supraglacial cover, mostly in form of debris flows (Pl. 1, Fig. 1–2). Other subenvironments are in minority although in some cases are classically developed, for example as fluted moraines (Pl. 2, Fig. 3), short glaciofluvial cones and lakelets. Among supraglacial covers are also parts, which represent point-bar, and channel deposits left by meltwater supraglacial streams. A number of dirt cones mostly correspond to these sediments (Pl. 2, Fig. 4). For the further analysis sediments are divided into six main groups:

(1) – subglacial till
(2) – supra- and englacial stream deposits
(3) – dirt cones

(4) – debris cover on glacier ice
(5) – debris flow deposits
(6) – proglacial glaciofluvial deposits.

Grain size distribution

Deposits under study reveal a wide spectrum of grain size distribution (Tab. 1) with the highest diversity among the sediments of active debris flows. They are very poorly and extremely poorly sorted, except the supraglacial stream deposits (and dirt cones), which belongs to poorly sorted class. Kurtosis exhibits the highest values for the glaciofluvial deposits and other, influenced by flowing water, sediments. Fine skewed sediments are dominating, only a couple of samples are coarse skewed. The clay ratio has a significant value only in the subglacial, debris flow and supraglacial cover deposits.

Table 1. Grain size distribution statistical parameters calculated for genetic groups of sediment samples. N – number of samples.

Statystyczne parametry uziarnienia dla genetycznie pogrupowanych prób osadów. N – liczba próbek.

Environment	Mean grain diameter			Standard deviation			Skewness			Kurtosis			Clay ratio	N
	min	average	max	min	average	max	min	average	max	min	average	max	average	
Subglacial till	0.88	2.32	2.81	3.33	4.16	4.57	–0.24	0.03	0.34	0.70	0.77	0.97	0.08	15
Supra- and englacial stream	–1.2	–0.1	0.83	1.78	2.27	2.84	0.03	0.14	0.32	0.95	1.12	1.32	0.007	5
Dirt cones	–1.08	0.34	2.63	1.27	1.93	2.71	–0.21	0.16	0.4	0.75	1.04	1.43	0.003	8
Debris cover on ice	–0.84	1.43	2.79	1.96	3.84	4.44	0.01	0.2	0.44	0.69	0.78	1.17	0.04	24
Debris flows	–0.04	1.69	2.57	3.78	4.23	4.77	–0.41	0.13	0.29	0.73	0.81	1.32	0.06	14
Proglacial glacifluvial	–1.1	–0.2	1.09	2.04	2.46	2.93	0.02	0.19	0.52	0.94	1.54	2.93	0.01	5

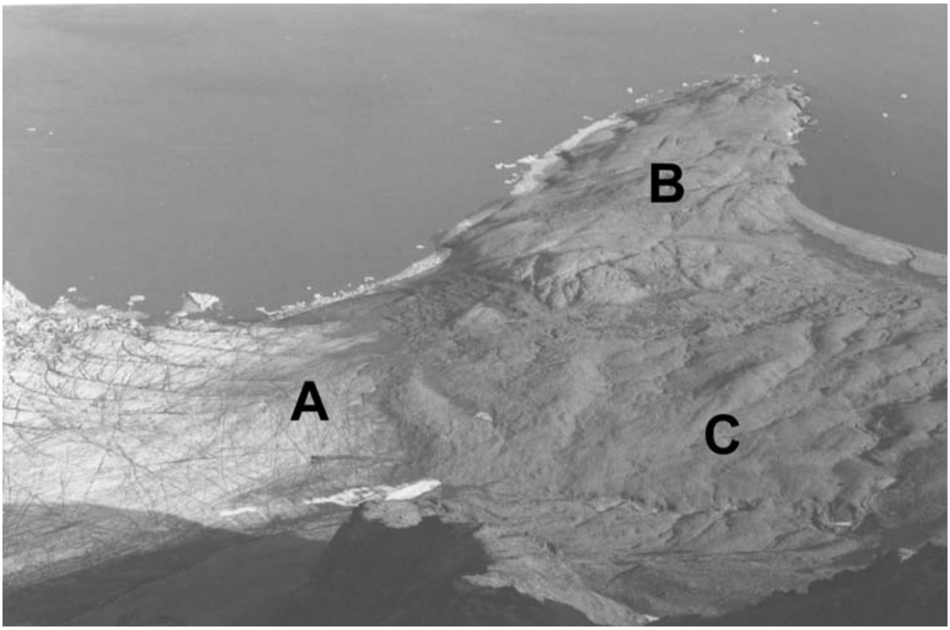
Plate 1

Fig. 1. Western marginal region of Hansbreen. A – glacier margin, B – Baranowski Peninsula, a zone of subglacial sedimentation indicated *e.g.* by lineation of flutings, C – continuous sediment cover on dead-ice.

Zachodnia strefa marginalna lodowca Hansa. A – krawędź lodowca, B – Półwysep Baranowskiego, ze strefą sedymentacji subglacjalnej podkreśloną moreną żłobkową, C – ciągła pokrywa osadowa na martwym lodzie.

Fig. 2. A dirt cone (point-bar deposits) and supraglacial channel filled with debris flow deposits

Stożek ablacyjny (osady odsypu korytowego) i kanał supraglacjalny wypełniony osadami spływu błotnego.



1

2

Plate 2

Fig. 3. Two generations of debris flow tongues delimited with about 0.8 m high edge of niches

Jęzory spływów błotnych dwóch generacji, oddzielone wysoką na około 0,8 m krawędź niszy.

Fig. 4. A profile of continuous mineral cover deposited on dead-ice (here exposed because of local debris slide).

Przekrój przez ciągłą pokrywę osadową na martwym lodzie (odsłonięty dzięki lokalnemu osuwisku).

3

4

For glacial sediments a discrimination diagram (standard deviation versus average grain size) is used for separation of debris transported in high level (supra- and englacial) from tractional debris (subglacial transport). It was found (Boulton 1978; Karczewski & Wiśniewski 1979; Rachlewicz 1996) that the high level transport debris is coarser and better sorted than subglacial deposits. Here this pattern is absent (Fig. 2) because majority of supraglacial cover is of subglacial origin (Rachlewicz & Szczuciński 2000). The diagram however shows two groups (Fig. 2): driven by flowing water agent (coarser mean grain size, better sorting, and smaller value of kurtosis, extremely low clay ratio) or by other processes (glacial and mass movement).

A 3D diagram showing a relationship between average grain size, standard deviation and skewness (Fig. 3) is proposed for more detailed characterization

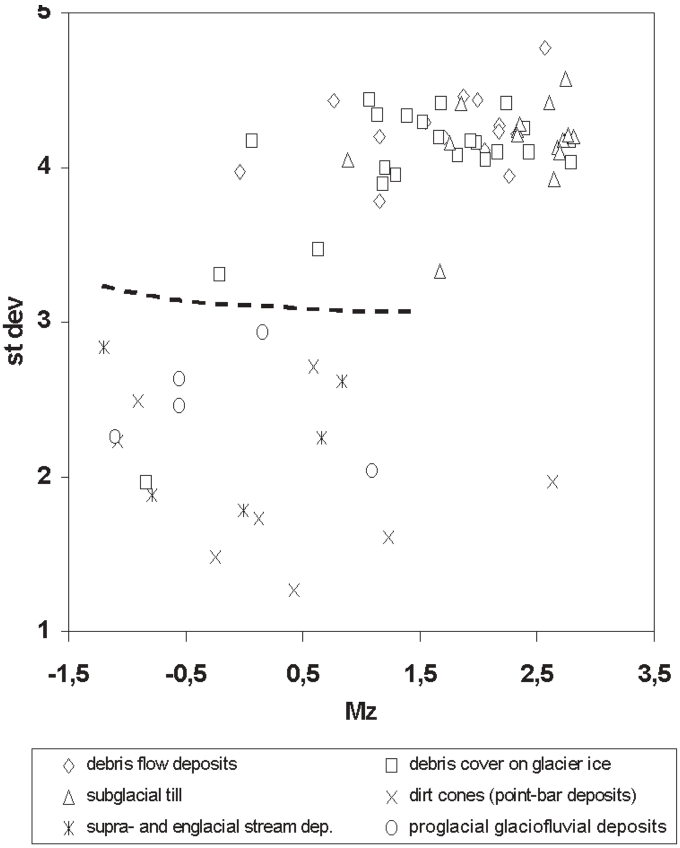


Fig. 2. A plot of mean grain diameter vs. standard deviation for certain genetic types of sediments. The dashed line separates sediments which were influenced by flowing water from others.

Wykres przedstawiający zależność średniej średnicy ziarn względem odchylenia standardowego dla określonych grup osadów. Przerywana linia oddziela grupę osadów, które były deponowane w warunkach wody płynącej.

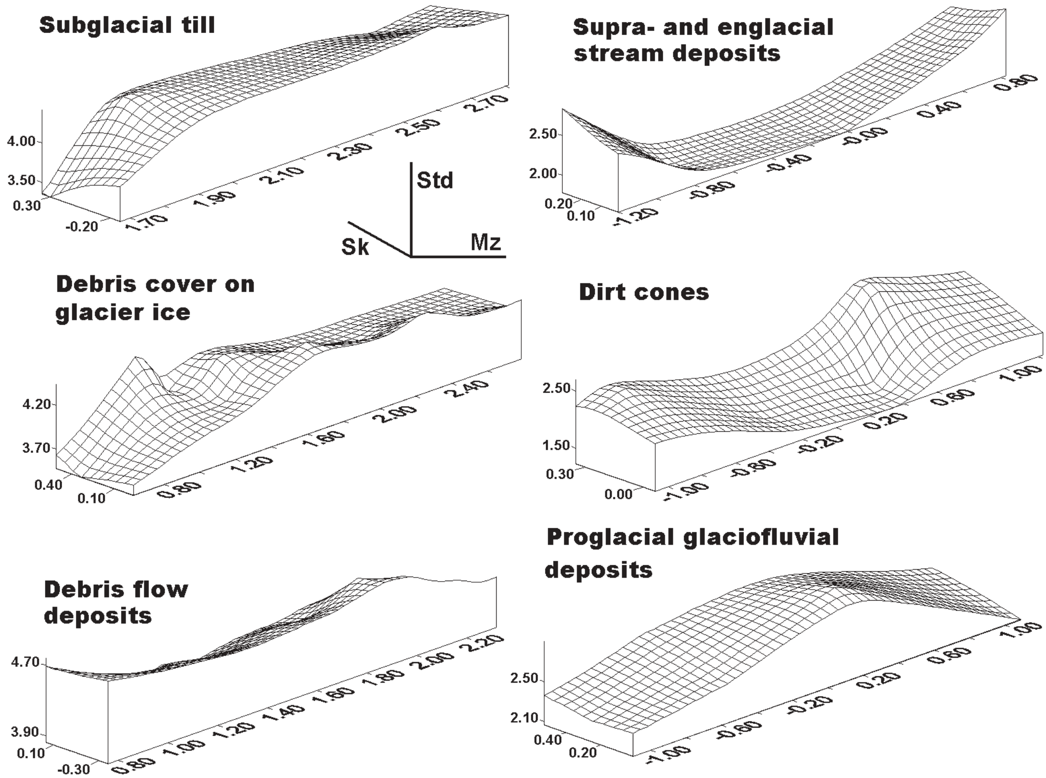


Fig. 3. Relationships between mean grain diameter, standard deviation and skewness for sediments of known origin.

Relacja pomiędzy średnią średnicą ziarn, odchyleniem standardowym i skośnością dla osadów o znanym pochodzeniu.

of the subenvironments. In subglacial tills the standard deviation (about 4.0) and the skewness (about 0.0) are relatively stable for the range of observed mean grain sizes, only for coarser samples a decrease of their values is noted. For debris cover on ice (which is mostly of subglacial origin) a similar pattern is obtained but there are several irregularities and the range of changes is wider. These sediments are also more fine skewed and represent coarser mean grain size. The debris flow deposits resemble the subglacial deposits but they are slightly coarser and a strong relationship between skewness and standard deviation is observed: for more fine skewed sediments their sorting is worse. In the group of sediments influenced by flowing water two opposite patterns were observed. The first one is typical for supra- and englacial stream deposits, and dirt cones sediments. They are characterised by the best sorting for average mean grain size classes, and the worst for extreme ones. Their skewness is also associated with standard deviation (better sorting for more fine skewed deposits). The second pattern is presented by proglacial glaciofluvial deposits. Although they have the same ranges of mean grain size, standard deviation and skewness values, the relationship between them shows opposite dependence. For the average mean grain size, the standard deviation is the highest. Skewness and standard deviation show weak dependence.

If the subglacial till is treated as an input material (and hence – the reference) for supraglacial cover and debris flow deposits (as in fact is observed), we can try to follow the changes between them. Debris covers on ice are subjected to changes caused by several redepositional processes (differential melting, mass movement, washing, mixing of sediments etc.) it is reflected in the much bigger variability of their pattern (Fig. 3). Debris flow deposits are more uniform (one dominating process). Their distinct relationship between skewness and standard deviation can be explained by participation of water in such a flow. If a certain sediment is saturated enough phenomena of washing can easily occur (Lawson 1981; Szczuciński 2000), and even if it is on a small scale it can improves sorting and makes sediment more coarse skewed. In the similar evolutional way can be treated also the next group of the sediments. The initial stage is presented by supra- and englacial stream deposits. Dirt cones represent a little bit less clear pattern, which is associated with addition of melted out sediments. The pattern of the glaciofluvial sediments reflects strong similarity to sieve deposits. These deposits form mostly short alluvial cones, which are supplied at least from three sources: meltwater streams, debris flows from glacier margin, and directly melted out debris from the glacier. If we also keep in mind a strong changebility of the amount of water in action (diurnal cycle) it can be easily imagined a situation when a filling of pore spaces occurs.

The degree of abrasion of quartz grains

In the 0.8–1.0 mm fraction (Tab. 2) the highest degree of quartz grain abrasion is revealed by dirt cone deposits, glaciofluvial, and supra- and englacial stream sediments. They are followed by the debris flow deposits, which contain more abraded grains than debris covers on ice and subglacial till, although all these groups are expected to have similar values, because they origin from the same source (subglacial till *sensu lato*). The higher Wo of debris flow deposits can be explained by incorporation of glaciofluvial sediments (including supraglacial stream deposits or dirt cones). Subglacial abrasion of quartz grains must be not the most important abrading factor, as would one presume (e.g. Haldorsen 1981), since subglacial till samples show the lowest values of Wo. Glaciofluvial environment and supraglacial streams deposits have similar level. It is doubtful if reworking of sediments is so intensive in these streams to be visible in such an analysis. It is more probable that grains from eroded sediments, (better rounded and easier transported) form and in a certain distance from the source a selection and concentration of more abraded grains. Samples taken from sediments, which were influenced mostly by flowing water, have also much lower standard deviation of Wo results than in other deposits.

The analysis of 1–1.25 mm class (Tab. 3) reveals smaller changeability. Sediments related to the flowing water transport show slightly higher Wo value than the deposits of debris flows or supraglacial debris cover, and subglacial tills. Only quartz grains from dirt cone sediments are definitely more abraded. The most probable reason is that sediments were in majority redeposited from the same source (and short transport path was insufficient for reworking in this class). A smaller number of samples (it was difficult to find a sufficient number of quartz grains for analysis) can be also a reason for observed pattern.

It can be easily observed that Wo values for fraction 0.8–1 mm are smaller than these for 1–1.25 mm (compare Tab. 2 and 3). It can be caused by preferential abrasion (depending on fraction – compare also with Fig.6 showing that

Table 2. The results of mechanical graniformametry analysis for 0.8–1.0 mm class (given as Wo, after Krygowski 1964). The Wo average values for Werenskioldbreen are given after Karczewski and Wiśniewski (1979).

Wyniki analiz graniformametrii mechanicznej dla frakcji 0,8–1,0 mm (podane jako Wo, za Krygowskim 1964). Dla porównania podano średnie wartości Wo dla odpowiednich środowisk lodowca Werenskiolda (Karczewski & Wiśniewski 1979).

	Wo min	Wo average	Wo max	Number of samples	Werenskioldbreen
Subglacial till	580	647	723	14	380
Supra and englacial stream deposits	795	807	826	4	339
Dirt cones	821	870	936	4	–
Debris cover on glacier ice	512	660	840	21	373
Debris flow deposits	541	746	886	5	–
Proglacial glaciofluvial	782	830	873	14	495

Table 3. Mechanical graniformametry results for 1.0–1.25 mm class.

Rezultaty graniformametrii mechanicznej dla frakcji 1,0–1,25 mm.

	Wo average	Number of samples
Subglacial till	844	1
Supra and englacial stream deposits	846	3
Dirt cones	918	4
Debris cover on glacier ice	821	4
Debris flow deposits	852	1
Proglacial glaciofluvial	831	3

roundness of > 2.8 mm fraction is even worse), but the influence of the method can not be excluded.

The Wo was compared with the standard deviation of grain size distribution (Fig. 4) and with clay ratio (Fig. 5). The first one shows a slight dependence: the lower standard deviation – the higher Wo. It is easy to explain, hence both fea-

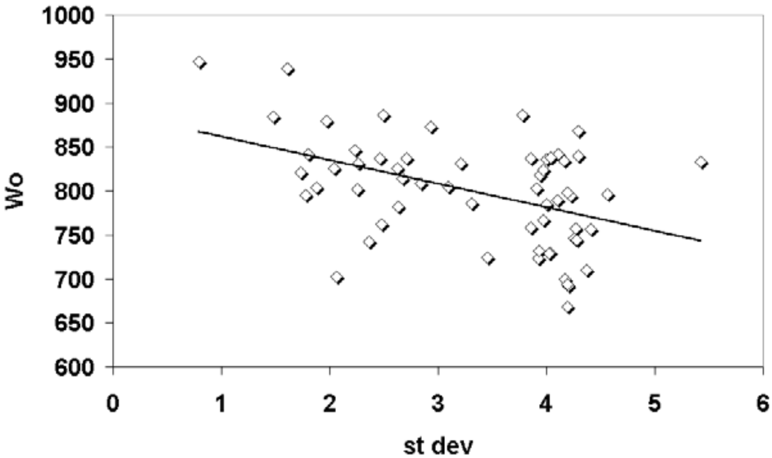


Fig. 4. A general dependence between index of grain abrasion (Wo) plotted vs. standard deviation of grain size distribution. Straight line shows correlation between these factors.

Wykres zależności wskaźnika obtoczenia (abrazja ziarna kwarcowego) a odchylenia standardowego rozkładu uziarnienia. Linia ciągła prezentuje korelację pomiędzy nimi.

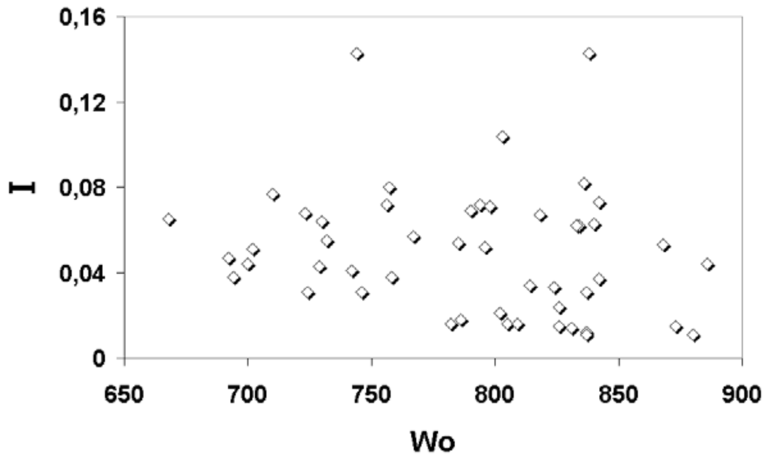


Fig. 5. Relationship between index of grain abrasion (Wo) and clay ratio (I).

Wykres zależności wskaźnika obtoczenia (abrazja ziarna kwarcowego) i wskaźnika ilastości (I).

tures were observed to have good sorting and well abraded quartz grains in case of flowing water deposits. Clay ratio has no relationship with the Wo value although it could be expected (*e.g.* high clay content could defend other grains against abrasion).

Karczewski & Wiśniewski (1979) made a detailed study on the Werenskioldbreen using the same method. Values, which were obtained by them, are significantly lower for all the groups of sediments (Tab. 2). Hence the geology of Werenskioldbreen basin is similar to that of the Hansbreen, the reason can be searched in the distance they are transported (Hansbreen is longer) or/and in the reworking of older deposits. The evidence of the latter was found in the form of organic and marine deposits incorporated into modern glacial sediments (Rachlewicz & Szczuciński 2000), but such evidence is also known from Werenskioldbreen (Baranowski & Karlen 1976; Karczewski & Wiśniewski 1979). The solution can be hidden in a type of redeposited sediments: in the case of Hansbreen they were mostly deposits of former marine terraces and outwash plains, which contain relatively well abraded grains (in contemporary beach deposits in Hornsund fjord Wo is more than 1000 (Szczuciński 2000)). In Werenskioldbreen basin even if they were of marine origin, they were formed in a sheltered environment of much lower energy (lagoonal etc.), on the other hand, potential older glaciofluvial deposits were transported on a shorter path.

Roundness

In the roundness analysis an overwhelming dominance of angular grains in both supraglacial covers and subglacial tills is evident (Fig. 6). The participation of roundness classes in all studied samples is very similar, except some samples from supraglacial cover sediments, where a rounded class is lacking. These results do not agree with facts presented above about the relatively well abraded quartz grains, and with the commonly reported data on a good roundness of subglacial deposits (e.g. Boulton 1978; Dowdeswell et al. 1985; Drewry 1986; Hambrey *et al*. 1999). There are at least two possible reasons for such a situation. The first one comes from the lithological analysis of the same samples (Fig.6) – different types of schists and phyllites are dominant – their structure supports the angularity of the grains. The second reason is connected with the subglacial and weathering processes, which cause crushing of the grains. Although they reveal *e.g.* well-rounded surface from one side, they are crushed – so they have sharp edges on the opposite side.

In Tab. 4. the MR (middle roundness number) for the selected lithological classes is presented. It must be kept in mind that certain lithological types participate in different degree in the bulk sample (Fig. 6). The vein quartz grains and all kinds of schist and phyllites are extremely angular. The slightly better roundness of non-mica schists can originate in longer transport paths from their sour-

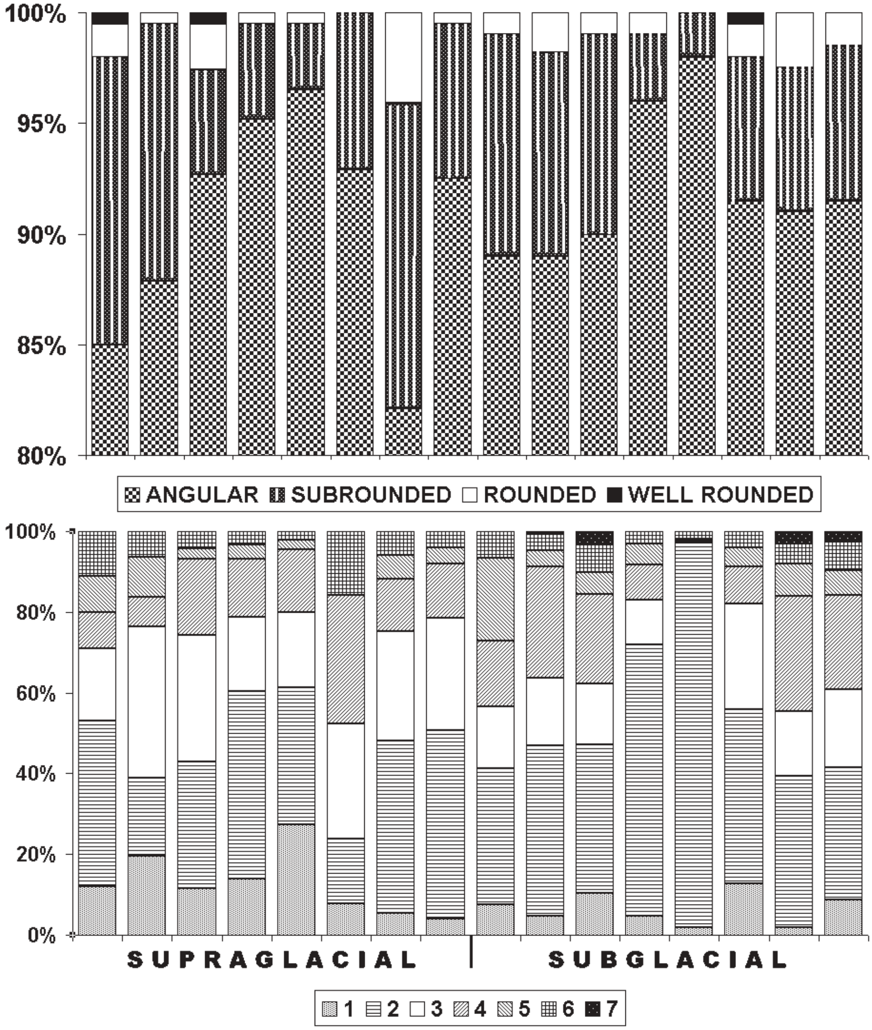


Fig. 6. Roundness value and lithological composition of selected samples (fraction > 2.8 mm) from subglacial and supraglacial environments. 1 – mica schists; 2 – schists without carbonates and mica; 3 – carbonates and carbonate rich rocks; 4 – quartzite; 5 – amphibolites; 6 – vein quartz; 7 – shell fragments.

Wartości obtoczenia i skład litologiczny (dla frakcji > 2,8 mm) prób reprezentujących środowisko subglacjalne i supraglacjalne. 1 – łupki łyszczykowe; 2 – łupki bezłyszczykowe; 3 – skały węglanowe; 4 – kwarcyty; 5 – amfibolity; 6 – kwarc żyłowy; 7 – fragmenty muszli.

ces (northern part of Tuvbreen basin and further to the north). Carbonate rocks, quartzites and amphibolites, reveal better roundness. The last one outcrops close to the glacier margin (Baranowski Peninsula, eastern slopes of Fugleberget) and in the vicinity of Kosibapasset. They come from a short distance source, and

Table 4. The roundness of different lithological grain types. The 16 samples, 200 clasts in each one, were analysed, divided into 6 basic lithological classes, and recalculated into MR index (see text for explanation).

Obtoczenie w zależności od litologii; oparte na podstawie analizy 16 prób zawierających 200 klastów, które zostały sklasyfikowane w 6 podstawowych klasach litologicznych. Wyniki są przedstawione w postaci wskaźnika MR (dalsze wyjaśnienia w tekście).

	MR min	MR average	MR max
Mica schists	1	1.03	1.22
Other schists and phyllites	1	1.06	1.22
Carbonate rocks	1	1.2	1.45
Quartzite	1	1.19	1.53
Amphibolite	1	1.19	1.47
Vein quartz	1	1.04	1.3

their relatively better roundness degree can be explained in terms of weaker resistance to weathering and abrasion. The carbonate rocks can be of varied provenance (basin of Fuglebreen, Tuvbreen or even Deileggbreen) so it is difficult to analyse their roundness in term of the distance of transportation. However carbonates belong to the softest rocks, and the most predisposed to chemical weathering in the Hansbreen basin, so it is possible that they do not need to be moved a long distance to gain such a degree of roundness. Quartzites and quartzitic conglomerates are known from Slyngfjellet and Deilegga, so they are probably transported the longest way. Some of them can be also redeposited from Quaternary coastal and fluvial sediments. The presented data supports a weak dependence of roundness on clast lithology.

Conclusions

The analysis of the textural properties in modern glacial sediments from the Hansbreen margin region allow the following conclusions:

(1) On the basis of the grain size distribution statistics the division into 6 main, process driven groups is supported. Namely they are: subglacial till, supra- and englacial stream deposits, dirt cones, debris cover on glacier ice, debris flow sediments, and proglacial glaciofluvial deposits. The 3D diagram (standard deviation, mean grain size and skewness) turned out to be a useful tool for such an analysis. Discrimination of the debris transported in high level (supra- and englacial) from tractional debris (subglacial transport) was not possible hence most of supraglacial sediments are of subglacial origin.

(2) The analysis of the degree of quartz grain abrasion and the roundness proved that the different grain size classes of the same samples differ significantly. For 0.8–1.0 mm class the abrasion of quartz grains was good for group of sediments influenced by water flow and poor for glacial and mass movement deposits. For the same samples but in fraction 1.0 – 1.25 mm the degree of abrasion was fairly good for all the sediment types. On contrary, the roundness analysis for > 2.8 mm fraction has revealed all the samples to be angular and very angular. The abrasion of quartz grains when compared with the standard deviation of grain size distribution shows a slight dependence, and no relationship when compared with the clay ratio.

(3) The influence of lithology on the clast roundness is not very pronounced. Carbonates, amphibolites and quartzites are better rounded than schists, phyllites, and vein quartz.

(4) The comparison with data presented from Werenskioldbreen (Karczewski & Wiśniewski 1979) shows huge difference in the supraglacial deposits: on Hansbreen, owing to the glacial tectonics, they resemble the subglacial till very much. The comparison of the degree of quartz grain abrasion reveals that sediments from the Hansbreen are much more abraded in all the environments. Hence the geology of the western part of the Hansbreen basin and of Werenskioldbreen basin is similar, the reason probably lies in the length of trasnportation or/and in reworking of older deposits. The former sedimentological environments are expected to differ (shaltered lagoon or bay, versus relatively open coast in case of Hansbreen).

(5) Use of 3D diagrams, Olson's MR index, and application of mechanical graniformametry are recognised as helpful way of data visualization and analysis.

Acknowledgements: The research was funded by the Polish National Committee on Scientific Research grant No. 6 PO4E 016 10. Support was also provided by a *Europa Fellows* fellowship to W.Szczuciński. The authors wish to thank the staff of the Glacial Geology Division, A.Mickiewicz University, for assistance in the laboratory analysis. Prof. Wojciech Stankowski and an anonymous reviewer are acknowledged for constructive reviews.

References

Baranowski, S. & Karlen, W., 1976: Remnants of Viking age tundra in Spitsbergen and northern Scandinavia. *Geografiska Annaler*, **58A**: 35–40.

Benn, D.I. & Ballantyne, C.K., 1992: Pebble shape (and size!) – Discussion. *Journal of Sedimentary Petrology*, **62**: 1147–1150.

Bennett, M.R., Hambrey, M.J. & Huddart, D., 1997: Modification of clast shape in high-arctic glacial environments. *Journal of Sedimentary Research*, **67**: 550–559.

Birkenmajer, K., 1990: *Geology of the Hornsund area, Spitsbergen*. Map 1:75 000 and explanations. Katowice, Uniwersytet Śląski.

– 1992: Precambrian succession at Hornsund, south Spitsbergen: a lithostratigraphic guide. *Studia Geologica Polonica*, **98**: 7–66.

Boulton, G.S., 1978: Boulder shapes and grain-size distributions of debris as indicators of transport paths through a glacier and till genesis. *Sedimentology,* **25**: 773–799.

– 1996: Theory of glacial erosion, transport and deposition as a consequence of subglacial sediment deformation. *Journal of Glaciology*, **42**: 43–62.

BULLER, A.T. & MCMANUS, J., 1973: The quartile-deviation/median-diameter relationships of glacial deposits. *Sedimentary Geology* **10**: 135–146.

DOWDESWELL, J.A., HAMBREY, M.J. & WU, R., 1985: A comparison of clast fabric and shape in late Precambrian and modern glacigenic sediments. *Journal of Sedimentary Petrology* **55**: 691–704.

DREWRY, D.J., 1986: *Glacial geologic processes*. Edward Arnold, London; 276 pp.

FOLK, R.L. & WARD, W.C., 1957: Brazos river bar: a study in the significance of grain size parameters. *Journal of Sedimentary Petrology,* **27**: 3–26.

FRIEDMAN, G.M., 1962: On sorting, sorting coefficient and the lognormality of the grain-size distribution of sandstones. *Journal of Geology,* **70**: 737–753.

HALDORSEN, S., 1981: Grain-size distribution of subglacial till and its relation to glacial crushing and abrasion. *Boreas,* **10**: 91–105.

HAMBREY, M.J., BENNETT, M.R., DOWDESWELL, J.A., GLASSER, N.F. & HUDDART, D., 1999: Debris entrainment and transfer in polythermal valley glaciers. *Journal of Glaciology* **45**: 69–86.

JANIA, J., 1988: *Dynamiczne procesy glacjalne na południowym Spitsbergenie*. Uniwersytet Śląski, Katowice: 258 pp.

JANIA, J. & GŁOWACKI, P., 1996: Is the Hansbreen in South Spitsbergen (Svalbard) a surge-type glacier? In: W.E. Krawczyk (Ed.) *23rd Polar Symposium*, Sosnowiec: 27– 43.

KARCZEWSKI, A., 1963: Morphology, structure and texture of the moraine area of West Poland. *Prace Komisji Geograficzno-Geologicznej Poznańskiego Towarzystwa Przyjaciół Nauk,* **4**: 111 pp.

KARCZEWSKI, A. & WIŚNIEWSKI, E., 1979: Granulometric analysis of sediments from the marginal zone of the Werenskiold glacier (SW Spitsbergen). *Quaestiones Geographicae*, **5**: 35–53.

KJÆR, K.H., 1999: Mode of subglacial transport deduced from till properties, Myrdalsjökull, Iceland. *Sedimentary Geology*, **128**: 271–292.

KNIGHT, P.G., PATTERSON, C.J., WALLER, R.I., JONES, A.P. & ROBINSON, Z.P., 2000: Preservation of basal-ice sediment texture in ice-sheet moraines. *Quaternary Science Reviews*, **19**: 1255–1258.

KRYGOWSKI, B., 1964: Graniformametria mechaniczna – zastosowanie, teoria. *Prace Komisji Geograficzno-Geologicznej Poznańskiego Towarzystwa Przyjaciół Nauk*, **2**: 1–110.

LAWSON, D.E., 1981: Distinguishing characteristics of diamictons at the margin of the Matanuska Glacier, Alaska. *Annals of Glaciology*, **2**: 78–84.

MANECKI, A., CZERNY, J., KIERES, A., MANECKI, M. & RAJCHEL, J., 1993: *Geological map of SW part of Wedel Jarlsberg Land, Spitsbergen 1:25000*. Kraków, University of Mining and Metallurgy.

MOORE, J.C., PÄLLI, A., LUDWIG, F., BLATTER, H., JANIA, J., GĄDEK, B., GŁOWACKI, P., MOCHNACKI, D. & ISAKSSON, E., 1999: High Resolution Hydrothermal Structure of Hansbreen, Spitsbergen Mapped by Ground Penetrating Radar. *Journal of Glaciology*, **45**(151): 524–532.

OLSEN, L., 1983: A method for determining total clast roundness in sediments. *Boreas*, **12**: 17–21.

PETTIJOHN, F.J., 1957: *Sedimentary rocks.* New York, Harper and Bros; 718 pp.

Rachlewicz, G., 1996: Zmienność facjalna osadów przedpola lodowca Ekologii – Wyspa Króla Jerzego – Szetlandy Południowe. [In:] Andrzej Kostrzewski (Ed.) Geneza, Litologia i Stratygrafia Osadów Czwartorzędowych, Tom II. Wyd. Nauk. UAM Poznań, Seria Geogr., **57**: 249–262.

Rachlewicz, G. & Szczuciński, W., 2000: Ice tectonics and bedrock relief control on glacial sedimentation – an example from Hansbreen, Spitsbergen. *Polish Polar Studies. 27th International Polar Symposium*: 259–275.

Slatt, R.M., 1971: Texture of ice-cored deposits from ten alaskan valley glaciers. *Journal of Sedimentary Petrology*, **41**: 828–834.

Szczuciński, W., 2000: *Evolution of supraglacial covers on Hansbreen, Svalbard*. MSc. thesis, Uniwersytet im.A. Mickiewicza, Poznań: 92 pp.

Winkelmolen, A.M., 1971: Rollability, a functional shape property of sand grains. *Journal of Sedimentary Petrology*, **41**: 703–714.

Tekstury osadów współczesnych środowisk glacjalnych na przykładzie lodowca Hansa, południowy Spitsbergen

Streszczenie: Wybrane cechy teksturalne osadów (rozkład uziarnienia, abrazja ziarna kwarcowego – grainformametria mechaniczna i obtoczenie) zostały określone dla prób z różnych środowisk glacjalnych lodowca Hansa (Hansbreen), południowy Spitsbergen. Wyróżniono 6 podstawowych grup osadów: osady subglacjalane, pokryw supraglacjalnych, osady spływów błotnych, stożków ablacyjnych, supra- i inglacjalnych potoków wód roztopowych oraz proglacjalnych osadów fluwioglacjalnych. Podział ten znalazł swoje odzwierciedlenie w analizie statystycznych wskaźników uziarnienia (prezentowanych w postaci diagramów 3D) i jest również czytelny w zróżnicowaniu abrazji ziarna kwarcowego. Ta ostatnia wykazuje zróżnicowanie w zależności od wielkości frakcji. Nie wykryto wyraźnej relacji pomiędzy wskaźnikiem ilastości oraz odchyleniem standardowym a wskaźnikami obtoczenia. Litologia ma ograniczony wpływ na obtoczenie (analizowana frakcja > 2,8 mm). Porównanie z podobnym zestawem danych dla lodowca Werenskiolda (Werenskioldbreen) wskazuje na większą dojrzałość osadów lodowca Hansa, prawdopodobnie można to wiązać z redepozycją starszych osadów i dłuższym transportem.

Słowa kluczowe: osady glacjalne, cechy teksturalne Spitsbergenu.

Streszczenie

Wybrane cechy teksturalne współczesnych osadów z glacjalnych środowisk sedymentacyjnych zostały zbadane dla prób pobranych w rejonie zachodniej strefy marginalnej lodowca Hansa – Wedel Jarlsberg Land, Spitsbergen południowy (Fig. 1, Pl. 1 – Fig. 1). Celem pracy jest zaprezentowanie zestawu danych teksturalnych dla osadów o znanym pochodzeniu z różnych środowisk glacjalnych; analiza wpływu wielkości frakcji ziarnowej na abrazję ziarna kwarcowego i litologii osadu na obtoczenie; porównanie z podobnym zestawem danych uzyskanym przez Karczewskiego i Wiśniewskiego (1979) dla sąsiadującego lodowca Werenskiolda.

Szczególny nacisk został położony na analizę statystycznych wskaźników uziarnienia (Mz, Std, Sk, Kg, I – Fig. 2, 3, Tab. 1), abrazję ziarna kwarcowego metodą graniformametrii mechanicznej (Fig. 4, 5, Tab. 2, 3) i obtoczenie frakcji żwirowej (Fig. 6, Tab. 4). W oparciu o wskaźniki uziarnienia wyróżniono, powstałe w wyniku odrębnych procesów, dwie grupy osadów. Pierwsza jest wynikiem oddziaływania wody płynącej (większe wartości średniej średnicy ziaren, lepsze wysortowanie, niższe wartości kurtozy graficznej i wskaźnika ilastości) i zaliczają się do niej supra- i inglacjalne osady korytowe, odsypy przykorytowe typu *dirt-cone* (Pl.1 – Fig. 2) oraz osady cieków proglacjalnych. Na drugą grupę składają się osady, do których depozycji doprowadziły głównie glacjalne procesy transportu masowego. Są to: glina subglacjalna, pokrywy supraglacjalne i osady spływów błotnych (Pl. 2 – Fig. 1, 2). Obróbka ziarna kwarcowego poszczególnych środowisk wykazuje zróżnicowanie i niejednorodność w zależności od analizowanej frakcji, w przeciwieństwie do obtoczenia frakcji żwirowej, zaliczającego się głównie do klas ostrokrawędzistej i bardzo ostrokrawędzistej. W nieznacznym stopniu obróbka ziarn kwarcu jest dodatnio skorelowana z wysortowaniem osadu, brak natomiast spodziewanego związku z zawartością frakcji ilastej, mogącej wpływać ochronnie na pozostałe okruchy. Istnieje także zależność obtoczenia od typu litologicznego żwirów: do lepiej obtoczonych należą skały węglanowe, amfibolity i kwarcyty, a do słabiej – łupki, fylity i kwarce żyłowe. Stopień obróbki i obtoczenia jest prawdopodobnie efektem wielokrotnej redepozycji i wcześniejszego przerabiania w różnych, często wysokoenergetycznych środowiskach. W porównaniu z podobnym zestawem prób analizowanych dla przedpola lodowca Werenskiolda, osady przedpola Hansbreen odznaczają się istotnym wpływem tektoniki lodowcowej, powodującej dostarczanie materiału z pozycji subglacjalnej do supraglacjalnej bez istotnego ich przekształcania. Na tle zbliżonej geologii obu basenów lodowcowych osady przedpola lodowca Hansa są bardziej „dojrzałe”, co może być związane z dłuższym transportem, oraz z włączaniem starszych osadów (głównie morskich) w osady glacjalne.