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Some Sediment Characteristics and Sedimentation Rates in an Arctic Fjord (Kongsfjorden, Svalbard)

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1. Introduction

Polar regions are thought to be susceptible to environmental perturbations resulting from global climate change [6]. Intensive reduction of the ice pack is expected to result in important changes to the structure and function of the Arctic marine environment. Recent climate changes cause glaciers to retreat, increases in meltwater outflow and intensive input of fine-grained mineral material to the coastal marine environment [39]. Significant increases of sediment flux to glacio-marine environments was also predicted by Syvitski and Andrews [41]. The understanding of recent sedimentary processes for glacier margins is therefore important to assess future changes in these systems.

Glaciomarine systems are characterised by a very complex and variable depositional setting [40]. Sedimentation in glaciated fjords is dominated by meltwater processes, effects of icebergs calving in proximal and distal basins, high sedimentation rates, seasonally stratified water masses, glacially-controlled water currents (in the vicinity of the glacier), the presence of katabatic winds (driving upwelling of water at the glacier front and changes in iceberg paths) [20, 34, 40]. Sedimentation of the material discharged by glaciers is considered to be an important factor influencing the fjord environment. It not only limits primary production, but changes physical and chemical properties of the water column and sea bottom [13, 14, 23]. The rates of sedimentation in glacial fjords (Svalbard fjords would be classified a s subpolar are usually high and can reach 10 cm$\cdot$year^{-1}

Sedimentation rates in tidewater glacial fjords is affected by the rate of sediment production from the glacier front, the rate of sediment production from fjord walls and side streams, the topographic influence on glacier retreat causing sediment trapping and hydrological conditions as tides, currents.

Spitsbergen is the largest of the Svalbard archipelago islands. Fjords of Svalbard provide good examples of meltwater-dominated glaciomarine processes and sediments [12]. Konsfjorden is a flagship site of European Arctic research (mainly ecological, Hop et al. 2002). Sediment accumulation there represents glaciomarine sedimentation conditions characterised by rapid deposition of terrigenous material [39]. Sediments characteristics in Kongsfjorden have previously been evaluated using acoustic records and sediment core analysis [13, 14, 37]. These studies found high input of fine-grained sediments transported in suspension from the glacier front. Calculations of suspended matter loads in fjord waters lead to a conclusion that it might take some 500 years for the inner part of the fjord to fill up [13]. This conclusion was based on the assumption that monosulphide layers in sediments are markers of annual sediment accumulation. The sedimentation rate was estimated to be in the range of 5÷10 $cm \cdot year^{-1}$. Since then the sedimentation regime has shifted to increased loads of suspended matter in the fjord. Therefore the rates reported by Elverhøi [13] may be underestimated.

Interesting features in the Kongsfjorden sedimentation regime were recently summed up by Svendsen et al. [39]. The environment of this fjord is very complex, characterised by large spatial, seasonal and inter-annual differences in sedimentation rate. Sediment accumulation rates close to the glacier margin were estimated to be 20 000g $m^{-2}year^{-1}$ and 1800÷3800 g $m^{-2}year^{-1}$ in the central part of the fjord. Sedimentation rates increase even order of magnitude in few kilometres, in transect from mouth of the fjord to the glacier. Recent climate changes, increase of meltwater input, causing shifts in loads of suspended matter entering the fjord, call for continuous investigation of sedimentation processes in Kongsfjorden. Of special interest is the inner part of the fjord where huge amounts of mineral material are deposited [39]. In this paper we report results of research on sedimentation in the entire fjord. Four sediment cores were collected along a transect from the glacier to the fjord mouth in 2000. Three additional cores were collected in 2001. The collected samples have been analysed in order to:

1. describe sediment properties and changes through the fjord,
2. estimate sedimentation rate in the vicinity of the glacier (inner Kongsfjorden),
3. assess major processes influencing sediment quality and the sedimentation regime.

2. Study area

Kongsfjorden is a 26.1 km long and 4 to 10 km wide fjord in the north-west part of Spitsbergen (Svalbard archipelago, Fig. 1). The fjord consists of two sub-basins. The inner part of the fjord, with maximum depth of 94 m, is strongly influenced by glacier outflow. The outer basin, with depth of some 350 m, communicates with the Greenland Sea through the Kongsfjordrenna. Between the sub-basins there is a shallow (20 m deep) sill [13]. Hydrological conditions are changing seasonally. During winter water masses are homogeneous. In summer fresh water outflow from the glaciers and warmer surface water layer causes a thermal-salinity stratification [39]. Circulation of water masses differs between the two layers. During summer, winds are unable to breakdown the stable pycnocline so surface water circulates independently of the deep-water masses. Moreover, Kelvin waves generated by tides and coastal winds enter the fjord along the southern coast forcing the outflow of water along the northern side [39]. Water mass characteristics influence the position of the glacier outflow within the water column, plume integrity and sediment settling characteristics and velocities [39].

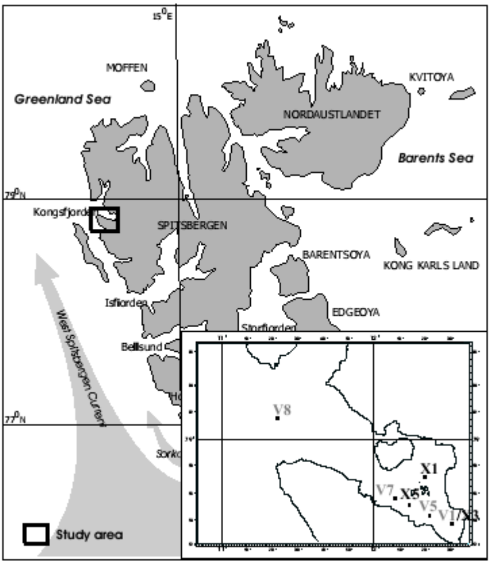

Fig. 1. Svalbard Archipelago and localization of sediment cores sampling stations. X – cores analised for sedimentation rate, V – cores analised for moisture, grain size and organic matter content

Rys. 1. Archipelag Svalbard oraz lokalizacja stacji poboru prób. X – rdzenie, w których badano prędkość sedymentacji, V – rdzenie, w których badano wilgoć, rozmiar ziaren i zawartość substancji organicznych

Kongsfjorden's main sources of freshwater are glacier ablation, snowmelt, summer rainfalls and melting of icebergs originating from ice calving. Kongsfjorden is influenced by three tidewater glaciers: Kongsbreen, Conwaybreen and Blomstrandbreen. Kongsbreen is one of the most active glaciers on Svalbard, retreating at a rate of 0.20÷0.25 km^3 $year^{-1}$ [33]. Glaciers supply the fjord with freshwater by both calving and melting. During melting, glacier outflow transports $2.6 \cdot 10^5 m^3$ $tons \cdot year^{-1}$ of mineral material into the fjord [13].

Most of the discharged solid material is deposited to the fjord bottom. Sedimentation rates depend on physical properties of suspension components and on gradients of temperature and salinity, they are segregated according to sinking rate. The coarser grains are deposited close to the glacier front. However, fine particles, due to aggregation, can undergo sedimentation in the neighbourhood of glacier outflow [23]; the rest is transported with surface waters away from the glacier front and deposited in the central and outer part of the fjord.

Table 1. Station information and core description
Table 1. Informacje o stacjach i opis rdzenia

Station	Longitude °N	Latitude °E	Depth (m)	Core length (cm)	Sediment colour	Other remarks
V5	78°90	12°34	26	36	Reddish brown, lower parts brown	High water content at first 4 cm
V7	78°91	12°10	143	22	Brown	Some polychets penetrating sediment till 10 cm
V8	79°01	11°32	320	18	Dark grey	Many polychets penetrating sediment till 10 cm
V1/X3	78°89	12°47	72	30	Reddish brown	Very high water content at first 4 cm
X1	78°57	12°21	68	40	Reddish brown	Bright grey layers in the upper part
X5	78°55	12°14	127	40	Reddish brown	Bright grey layers in the upper part

The highest concentrations of suspended matter (more than 300 $mg \cdot dm^{-3}$) were found in the surface water layer between 0 and 10 m depth, close to the glacier front. Similar suspended matter concentrations were measured at 10 m depth at a distance of, 5 km from the glacier [45].

3. Materials and methods

3.1. Sample collection

Sediment cores were collected in July 2000 and July 2001 from the r/v "Oceania" by Niemistö corer (Niemistö, 1974). Four stations were selected for examination of sediment properties, while three additional cores were used to quantify sediment accumulation rates (fig. 1). Cores were 80 mm diameter with lengths ranging from 18 to 36 cm. Cores were sliced onboard the ship into 10 mm thick layers, transferred to plastic bags, and deep-frozen until analysis on shore.

3.2. Laboratory analysis

3.2.1. Moisture, Grain size, organic matter, POC, PON

Moisture contents were calculated based on loss on drying at 60°C. Based on information of sediment grain size it's possible to study trends in surface processes related to the dynamic conditions of transportation and deposition [35]. Grain size measurements were determined using a combination of sieving and the hydrometer method. Sediment samples were first sieved using 2 mm and 0,63 mm mesh sieves. For finer fractions evaluation of the hydrometer method was used [4]. The arithmetic mean, sorting, modal frequencies were calculated using logarithmic method of moments [17, 31]. Organic matter content was measured as loss on ignition at temperature 450°C for 4h. Organic carbon (C_{org}) and organic nitrogen (N_{org}) concentrations were measured in a CHN elemental analyser Perkin Elmer 2400.

3.2.2. Radioisotope analysis

Samples were analysed for ^{210}Pb and ^{137}Cs in the ENEA, La Spezia laboratory. Before analyses samples were dried in temperature 45°C and homogenised. Activities of ^{210}Pb (46.5 KeV), and ^{137}Cs (661.7 KeV) were measured in HPGe detectors for 80000 seconds. The calibration was performed using a certified IAEA source with the same geometry.

The ^{210}Pb method was used to estimate sediment accumulation rates. The ^{210}Pb dating method can be applied to the measurement of sedimentation rate in lakes, estuaries and coastal marine sediments [22, 30]. ^{210}Pb (half-life=22.3 y) is ascribed to its precursor ^{222}Rn. Radon, a daughter product of ^{238}U, is a noble gas. Part of it is released from rocks. In the atmosphere ^{222}Rn undergoes radioactive decay. Through a few short-lived products this leads to ^{210}Pb. ^{210}Pb is removed from the atmosphere by dry and wet precipitation. It is assumed that the supply of this isotope is constant at given locality. ^{210}Pb is highly particle reactive and is sorbed from the dissolved phase onto sinking particles [29]. Experiments have shown that ^{210}Pb is sorbed mainly by finer particles [26]. An association with organic carbon [1] and absorption by biota [3] has also been observed. This natural removal from the water column results in an excess of ^{210}Pb in sediments. Apart from the amount of ^{210}Pb brought to sediments from the atmosphere (excess ^{210}Pb), a fraction of ^{210}Pb is produced in the course of the ^{222}Rn decay in the sediments. The activity of supported ^{210}Pb was estimated from activities of ^{214}Pb and ^{214}Bi assuming isotopic equilibrium between nuclides. Sediment depths in profiles were corrected for porosity (calculated from moisture and sediment density) of sediments. The constant rate of supply model [2] was used to calculate sedimentation rates from the excess ^{210}Pb vs depth profiles. ^{137}Cs activity profiles were utilised to validate the ^{210}Pb dating results. The history of ^{137}Cs inputs to the environment from atmospheric thermonuclear tests (1952, 1961÷62), major accidents (for instance Chernobyl 1986), and routine discharges are well-established [36].

4. Results and discussion

4.1. Moisture

Moisture content of fine-grained and coarse-grained sediments differs substantially. It is influenced by sediment compaction and composition. In the inner part of Kongsfjorden, in the vicinity of the glacier, water contents in sediments ranges between 56.5% – in upper layers, and 28.5% – in lower layers of the core. Since pressure from overlying sediment layers results in water displacement and leads to decreased moisture of subsurface sediments, high moisture and weak compaction of surface sediments indicates large and recent sedimentation of inorganic particles [20, 40].

There is also high (42.1% to 56.7%), relatively more constant, water contents in sediments collected from the outer part of the fjord. This is probably due to the large proportion of fine-grained material: clay minerals with organic matter admixtures capable of water retention.

4.2. Grain size

Kongsfjorden's sediment grain size distributions vary with distance from the glacier and local sedimentation conditions (Fig. 2). Generally, sediments are fine-grained indicating deposition from water column suspensions or turbidity currents. It is worth noting that the contribution of the clay fraction (1.0%÷8.4%) in the uppermost segment of the station V1, collected close to the glacier, is much smaller than in the subsurface segment (15.6%÷45%). This difference could have been caused by a change in a) the glacier outflow, b) temperature-salinity stratification (aggregation of fine particles), and/or c) the hydrodynamic conditions, which lead to the offshore transport of fine-grained material. The increase of fine fractions in both V7 and V8 cores would support the conclusions.

On the sill, close to Lovenoyane, small difference between granulometry of surface and subsurface layers was found (silt 52.1% to 60.5%, clay 36.1% to 43.3%). The uniform granulometric profile is attributed to surface mechanical mixing, confirmed by ^{210}Pb profiles. Most likely the phenomenon is caused by anchoring icebergs that scour the sea bottom in shallow areas of the fjord (Station V5 was situated at the depth of 26m). Larger icebergs (up to 10 m high) often anchor in the Lovenoyanne archipelago [11]. Simultaneously this sill acts as a trap for the finest material.

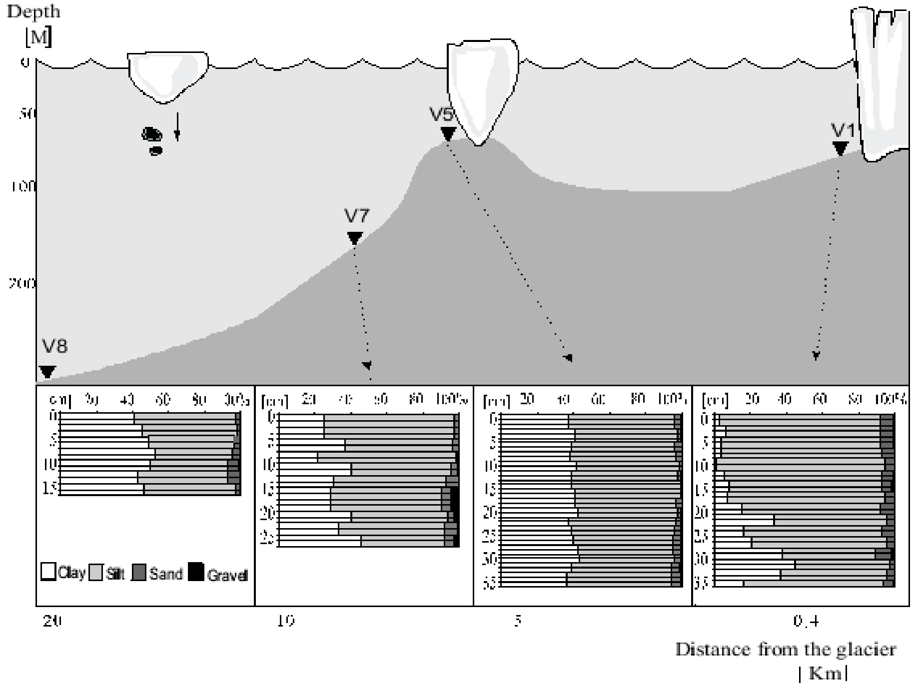

Fig. 2. Cross section along the fjord depicting: A – Water depth and iceberg friction against the bottom, B – Grain size distribution in sediments

Fig. 2. Przekrój przez fjord opisujący: A – głębokość wody i tarcie gór lodowej o dno, B – rozkład rozmiaru ziaren w osadzie

Variations in the grain size profile were found in core V7 collected from the steep slope (silt 71.6% in the upper layers to 46.5% in the deepest layer).

This might be attributed to redeposition and resuspension. Beds and laminae that exhibit a range of particle sizes can be produced by turbidity currents (sediment slumping on the slopes) [34]]. Sediments from the outer part of the fjord (station V8) were exhibited a homogenous distribution of silty clays. This suggests stable sedimentation conditions at the site.

The relatively high proportion of coarse material (sand+gravel, up to 10.4%) in Kongsfjorden sediments is, most likely, caused by material deposited to the bottom from icebergs, which melt in this area, releasing material [11]. Icebergs are the main mechanism by which coarse-grained material can be transported to the deep ocean [12]. The sedimentation rate of debris content from icebergs has been estimated to range from 0.1÷0.8 $cm \cdot year^{-1}$ based on two Spitsbergen fjords [10].

Sediment grain sizes in Kongsfjorden was previously measured on three stations by Fetzer et al. [16]. These authors noticed that silt and clay fractions dominate in the fjord, an increase in the sand fraction from the inner to outer part of Kongsfjorden and a significant proportion of pebbles (1.6%) in the inner part of the fjord. This situation was not observed in our study. Pebbles were found along the whole fjord in similar proportions (averages for cores: V1-1.5%, V5-0.9%, V7-1.7%, V8-1,0%). No variation in concentration of ice-rafted debris within several kilometres of a glacier front (Muir Inlet, Alaska) was also noticed by Mackiewicz et al. [34].

Grain size of glaciomarine sediments was described by Gilbert et al. [19] in two Greenland fjords (Akulliit and Kangerluk). Generally the silty fraction dominated in the Akulliit fjord, but close to the fjord head (mouth), and further from the glacier front, a higher proportion of the sandy–silt fraction was found, while the clay class component was stable at 5%. In the mouth of the fjord the clay content increased to an average of 13%. Fine-grained sediments were found in Kangerluk. Close to the fjord head the clay content was 40%, while it reached 78% at the distal part of the fjord. Fine-grained sediments occur also in three Greenland fjords studied by Smith and Andrews [38]. Also in other fjords of Svalbard fine-grained deposits originating from surface overflow were measured [13].

4.3. Statistical description

The arithmetic mean (in phi scale) of all sediment samples was higher than 2 phi (what could suggest that the sediments were transported as suspension). Arithmetic mean calculated for the core V1 was a bit lower than for the other cores (tab. 2)

All sediments of Kongsfjorden were very poorly sorted (table 2). Such sorting (σ_{φ}) values are characteristic for sediments originated from glacier material.

From mode frequencies calculation we can conclude that as for all cores, sediments had two modes, there is a stabile process (with two “active periods”) influencing sedimentation. We would suggest tides to be this factor.

Table 2. Statistical description of sediment samples
Table 2. Statystyczny opis próbek osadów

Station	Arithmetic mean (phi)	Sorting (σ_{φ})
V1	5.8÷7.1.	2.0÷2.9
V5	7.1÷8.4	2.0÷3.4
V7	7.0÷8.3	2.3÷3.4
V8	7.7÷8,7	2.6÷3.6

4.4. ^{210}Pb dating

Profiles of ^{210}Pb and ^{137}Cs activities are presented in Fig. 3. Supported ^{210}Pb values ranged from 32.3 Bq·kg^{-1} for sediments taken from the sill (core X5) to 32.9 Bq·kg^{-1} for sediments taken close to the glacier outflow. The cores were not long enough to reach the “ ^{210}Pb supported” layers.

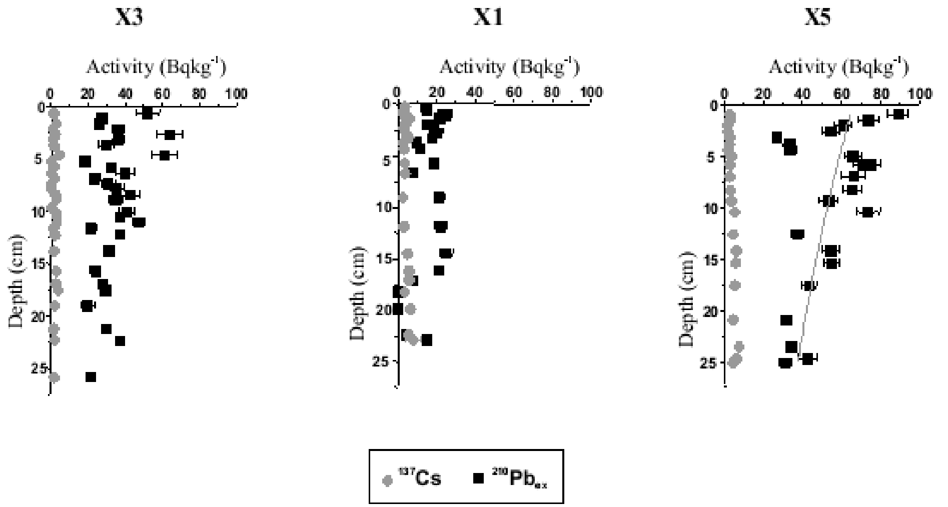

Fig. 3. Activity of ^{137}Cs and $^{210}Pb_{ex}$ in sediment cores collected in transect from Kongsbreen to the mouth of Kongsfjorden

Fig. 3. Aktywność ^{137}Cs i $^{210}Pb_{ex}$ w rdzeniach osadów pobranych w przekroju od Kongsbreen do ujścia Kongsfjorden

In the core X3, collected close to the glacier, $^{210}Pb_{ex}$ was present in whole core and ranged from 63.5 Bq·kg^{-1} to 18.0 Bq·kg^{-1}. The $^{210}Pb_{ex}$ profile in this core was disturbed and the secular equilibrium between ^{210}Pb and ^{226}Ra was not reached, therefore sedimentation rate can't be derived from the profile [2, 36]. A very high sedimentation rate in the vicinity of the glacier is assumed, with sediment flux up to 20000 g m^{-2} y^{-1} [39].

$^{210}Pb_{ex}$ activity varies from 24.9 Bq·kg^{-1} to 4.3 Bq·kg^{-1} in core X1. The profile (to approximately 35 cm) is typical of sediment with surface mixing [36]. That mixing can be caused by bioturbation processes but benthic organisms found in this region reached just 12 cm depth . Therefore mixing of sediments is more likely the result of scouring by icebergs. Station X1 was situated close to the Lovenoyane Archipelago where icebergs are frequently observed anchored [11]. Because of discontinuity of $^{210}Pb_{ex}$ profile and the absence of exponential degrease, sedimentation rate can not be evaluated at this station.

$^{210}Pb_{ex}$ activity varies from 89,1 Bq·kg^{-1} to 31,6 Bq·kg^{-1} in core X5. This profile is very disturbed too, and the exact sediment accumulation rate cannot be calculated. Estimation of accumulation rate can be mathematically forced considering an exponential decrease of $^{210}Pb_{ex}$ activity observed in subsurface part of the profile. Discontinuity in the surface layers may be caused by sediment mixing due to physical and biological phenomena or change in mineral composition of sediments. The sediment accumulation rate estimation was performed without surface mixed layer and using ^{210}Pb supported (known from ^{214}Bi and ^{214}Pb data). It was estimated (as lower limit) to be 2 cm·y^{-1}.

^{137}Cs activity was detected in all sediment samples. This indicates that sediments were deposited after the massive ^{137}Cs introduction to the environment (late 50`s) and supports the conclusions derived based on the $^{210}Pb_{ex}$ profiles.

The sediment in glaciomarine environments can be derived from glacier meltwater and/or drifting icebergs [12, 20, 38]. Alaskan fjords are typical examples of areas with high sedimentation from glacier meltwater [8]. In most Alaskan and Canadian fjords sedimentation rates are very high near the glacier front, decreasing exponentially away from the source [18, 42]. Layers with just $^{210}Pb_{ex}$ were observed in several cores from the Glacier Bay fjord, Alaska [9] too. The author attributed the feature to very high sedimentation rate in the ice-proximal basins. Activities of supported $^{210}Pb_{ex}$ were measured to a depth of 60 cm in a core collected 50 km from the glacier. The estimated sediment accumulation rate ranged from 82 cm·year^{-1} (near the Muir Glacier) to 16 cm·year^{-1} (in the distal part of Glacier Bay). In another study, Cowan [7] reported sedimentation rates in the Alaskan fjords ranging from 200 to 2000 cm·year^{-1}. By contrast sediments in Greenland fjords are derived from melting icebergs and sedimentation rates are thus much lower [43]. A sedimentation rate of 5.3 cm·year^{-1} was measured in the glacier head in Kangerdlugssuaq Fjord (East Greenland) by Syvitski et al. [43].

Fjords containing glaciers (Alaskan, Greenland fjords and Kongsfjorden) were chosen for comparison (Table 3). Although these fjords have similar physical settings (length, width, depth), we should remember that glacier erosion rates in Alaskan fjords are two orders of magnitude higher then reported for Svalbard glaciers [25]. Sedimentation rates measured for station X5, several kilometres from the glacier in this study (2 cm·year^{-1}), seems to be low compared to sedimentation rates found in Alaskan fjords.

Table 3. The comparison of sedimentation rates between similar arctic fjords with temperate glaciers
Table 3. Porównanie prędkości sedymentacji w podobnych fiordach arktycznych z umiarkowanymi lodowcami

Arctic fjords with temperate glaciers	Distance from the glacier	Accumulation rate [cm/year]
Alascan glaciers (Powell, 1991)	Glacier head	Up to 500
Alascan fjords [7]	1km	200÷2000
Tarr Inlet, Glacier Bay, Alaska [5]	1.5km 7km 9km 12km 15km	82 40 19 6 3.2
Muir Glacier, Alaska [9]	2km 5km 6km 7km	82 33 20 16
Kangerdlugssuaq Fjord, Greenland [43]	Gracier head 50km	5.3 1.4
Kongsbreen Glacier, Kongsfjorden, Svalbard (this study)	4km	2.5

4.5. Organic matter

Organic matter concentrations in sediments vary along the investigated transect (Fig. 4). Low concentrations of organic matter (average 2.7%) close to the glacier are related to limited primary production and is most likely due to limited transparency of water caused by suspended matter. Corf for sediments collected at station V1 (close to the glacier) ranged from 0.10% to 0.21%. Results for station V8 (situated in the outer part of the fjord) were much higher and ranged from 2.59% to 3.42%.

This is accompanied by low benthic biomass due to sediment dynamics and low food supply [44]. Moreover high sediment accumulation rates cause ”dilution” of organic matter by mineral particles [24]. Low organic production in fjords was also reported by Smith and Andrews [38] and is attributed to high terrigenous sediment accumulation associated with large drainage areas.

In the outer part of the fjord, sediments are highly bioturbated indicating a dense benthic community. The high content of organic matter (up to 9.4%) in sediments supports this conclusion. It may be attributed to suitable environmental conditions including a thicker euphotic zone due to decreased turbidity.

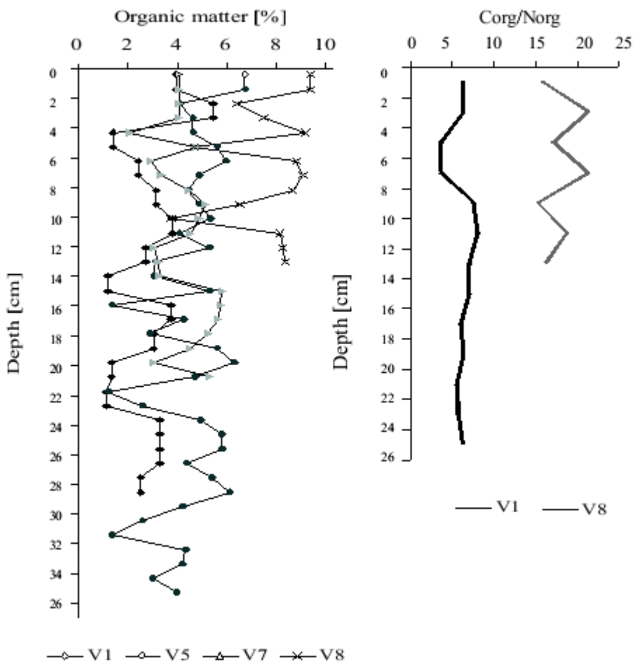

Fig. 4. Profiles of organic matter (loss on ignition) and C_{org}/N_{org} ratio in two selected sediment cores

Fig. 4. Profile zawartości substancji organicznych (strata po prażeniu) oraz stosunku C_{org}/N_{org} w dwóch wybranych rdzeniach osadów

Similar values of organic matter concentration were found in other Arctic fjords. Fine-grained and strongly bioturbated sediments were found in the mouth of the Kangerdluk fjord, Greenland. The organic mater content there ranged from 6 to 8% [21]. In other fjords organic matter content ranged from 5.5% in the inner Akulliit fjord to 7% near the mouth of the fjord, reaching up to 9% in the distal part of Kuanersuit fjord [19].

4.6. C_{org}/N_{org}

Small C_{org}/N_{org} ratios (3.7÷7.4) in sediments of the inner part of the fjord (Fig. 4) indicate sedimentation of fresh organic matter. Similar C_{org}/N_{org} ratios in inner Kongsfjorden sediments (3.8) were reported by Fetzer et al. [16]. This feature may be attributed to zooplankton removal in the contact zone of saline and freshwater, from glacier outflow, reported for Kongsfjorden by Zajaczkowski and Legezynska [46].

In sediments collected at the fjord mouth the C_{org}/N_{org} ratio ranged from to 15.3÷21.4. The C_{org}/N_{org} profile in the core collected from the outer fjord shows variability exceeding the precision of the determinations. High degradation of organic matter was tentatively attributed to longer sedimentation time caused by the increased water depth (more than 300 m). Other explanations of the phenomena may be also a change in the organic matter source (e.g. a terrestial source) and quality. C_{org}/N_{org} ratios of 9.9 were found out of Kongsfjorden by Hulh et al. [27]. Based on high C_{org}/N_{org} ratios and high concentrations of organic carbon they also suggested the possibility of a terrestrial source of organic matter.

5. Summary and conclusions

Here we present a summary of some sedimentation features in Kongfsfjorden (table 4). All investigated sediments of the Kongsfjorden were classified as mud, but the proportion of clay increased with distance from the glacier. Sediment granulometry was affected by local conditions of sedimentation. High moisture content of sediment surface layers close to the glacier is due to intensive, recent sedimentation of material brought with the glacier. This study of glacial marine sediment in Kongsfjorden indicates high and varying sedimentation rates in the inner fjord. Accurate determination of the sediment accumulation rates was difficult since the ^{210}Pb dating method proved to be unsuitable for measuring exceptionally high sedimentation rates in the glacier proximal zone. The organic matter concentration in sediments increases with distance from the glacier.

Table 4. Summary of sedimentation characteristic features in the Kongsfjorden
Table 4. Podsumowanie charakterystycznych cech sedymentacji w Kongsfjorden

Property	Inner fjord	Central fjord	Outer fjord
Concentration of suspended matter in surface water Inorganic matter Organic matter	 up to 340 gm^{-3} [45] 20 000 gm^{-3} [45]	 25-30 gm^{-3} [45] 1800÷3800 gm^{-3} [45]	 <20 gm^{-3} [45] 200 gm^{-3} [45]
Sedimentation rate	800 gm^{-2}day	200 gm^{-2}day	25 gm^{-2}day
Accumulation rate	Very high 5÷10 cm/year (lamination [13]) 6÷8 cm/year (acoustic records [14]) 20,000 $gm^{-2}year^{-1}$ (sediment traps [39])	High 5÷10 cm/year (lamination [13]) 0.1÷0.2 cm/year (acoustic records [14]) 1,800÷3,800 $gm^{-2}year^{-1}$ (sediment traps [39]) 2.5 cm $year^{-1}$ or 56,000 gm^{2} $year^{-1}$ (by ^{210}Pb method, this study)	Lower 0.04 cm/year (acoustic records [14]) 200 $gm^{-2}year^{-1}$ (sediment traps [39])
Sediment type	Sandy silts [13] Sandy silts (this study)	Silts [13, 14] Silts (this study)	Silts [14] Silty clays (this study)
Dropstone fraction	Present [13] Present (this study)	Present [13, 14] Present (this study)	Present [14] Present (this study)
Bentic biomass	Low [44]		High [44]
Posibility of icebergs scraching	Absent	Present [14]	Absent
Bioturbation tracks	Absent (this study)	Present ([14], this study)	Present ([14], this study)

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Wybrane własności osadów oraz prędkości sedymentacji w arktycznym fiordzie (Kongsfjorden, Svalbard)

Streszczenie

Uważa się, że regiony podbiegunowe są wrażliwe na zaburzenia środowiskowe wynikające ze zmian klimatu. Ostanie zmiany klimatu powodują wycofanie się lodowce, wzrost odpływu wód roztopowych i intensywne wprowadzanie materiału drobnoziarnistego nadbrzeżnego środowiska morskiego. Zrozumienie niedawnych procesów sedymentacyjnych w pobliżu lodowców jest więc ważne, aby ocenić przyszłe zmiany w tych systemach.

W artykule przedstawiono wyniki badań osadów oraz prędkości sedymentacji w Kongsfjorden (Svalbard). Rdzenie osadu zostały pobrane wzdłuż przekroju od lodowca Kongsbreen do ujścia Kongsfjorden. Rdzenie datowano za pomocą ^{210}Pb i analizowano w nich zmienność, wzdłuż całego rdzenia, wielkości ziaren, zawartości wilgoci, zawartości substancji organicznych (strata po prażeniu) oraz C_{org} i N_{org}.

Prędkość gromadzenia się osadów wynosząca 2 $cm \cdot rok^{-1}$ (oznaczona za pomocą ^{210}Pb) była oszacowana w jednym rdzeniu (pobranym 4 km od wylotu lodowca). Wysoka prędkość gromadzenie się osadu zgadzała się z profilem ^{137}Cs. W sąsiedztwie lodowca metoda ^{210}Pb okazała się nieodpowiednia do datowania osadów.

Analizy wielkości ziaren pokazały zróżnicowanie osadów w Kongsfjorden. Jest to spowodowane przez różne warunki sedymentacji w regionach graniczących z fiordem. W rdzeniu pobranym obok lodowca wzdłuż jego długości stwierdzono zmiany w wielkości ziaren (zawartość gliny: górna część 1,0%÷6,5%, głębsza część 15,6%÷45,0%). Osady w rdzeniu pobranym w płytkiej wodzie były homogeniczne. Najdrobniejsze osady osadziły się w zewnętrznej części Kongsfjorden. Pomimo faktu, że góry lodowe zazwyczaj nie dopływają po zewnętrznej części fiordu, to w osadach stwierdzono duży procentowy udział rumoszu pochodzenia lodowcowego (piasek + kamyki do 8%).

W obrębie regionu frontu lodowca stwierdzono niskie stężenia substancji organicznych, jako wynik małej produkcji pierwotnej, małej biomasy i rozcieńczania materii organicznej w ogromnych ładunkach materiału nieorganicznego. Natomiast w zewnętrznej części fiordu stężenie substancji organicznych sięgało 9,4%. Wysoka zawartość wody w powierzchniowych warstwach osadów w pobliżu lodowca wynika z intensywnej niedawnej sedymentacji materiału naniesionego przez lodowiec.

Badania pokazały, że system wewnątrz Kongsfjorden jest systemem o szybkiej sedymentacji i zmiennym rozkładem własności osadu, co wynika z procesów lodowcowych, które wpływają na cząstki zawiesiny i prędkości opadania, pierwotną i wtórną produkcję. Ekstensywne przetwarzanie osadów powierzchniowych w zewnętrznej części fiordu spowodowane bioturbacją i procesami fizycznymi, ma wpływ na własności osadu dna morskiego.