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**Late Holocene Sedimentation and Environmental
Change Record in Billefjorden, Svalbard**

(Późnoolocenińska sedymentacja i zapis zmian środowiskowych
w osadach Billefjorden, Svalbard)

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1 INTRODUCTION

According to the last IPCC (Intergovernmental Panel on Climate Change) report (Houghton et al. 2001) the global average surface temperature has increased over the 20th century by $0.6 \pm 0.2^{\circ}\text{C}$, and the globally averaged surface temperature is projected to increase by 1.4 to 5.8°C over the period 1990 to 2100. The scale of the modern climate fluctuations is the biggest during last 10 ka, and they cause a range of direct and indirect consequences in the environment. In the last centuries a still growing influence on the environment has been done by human activity. After decades of intensive industrial development accompanied by the production of thousands of different chemicals, there is worldwide concern about the preservation of existing natural resources and possible harmful effects resulting from contamination of air, soil and water. One of the greatest tasks of contemporary science is to predict the likely scenarios of environment in the next centuries. It can be done by study of the present day, the past and attempts to model the future. This application of geology is so common over last years that some of the geologists have tempted to paraphrase the famous huttonian sentence "*The Present is the Key to the Past*" into a new one: "*The Past is the Key to the Future*" (Faure 1986; Hegerl 1998).

Growing interest in the response of natural systems to environmental changes on annual to millennial time scales has led to increasing use of marine deposits as natural recording systems. Especially valuable are fjords at high latitude where global change may be occurring earliest and will be the greatest (Gilbert 2000; Svendsen et al. 2002). Locations, which are – like Svalbard archipelago (Fig.1) - near boundaries of atmospheric and oceanic fronts, are especially sensitive to even small changes, and hence they are of particular interest (Overpeck et al. 1997; Snyder et al. 2000; Hald et al. 2001; Simoes & Zagorodnov 2001; Koç et al. 2002; Isaksson et al. 2003; Pälli et al. 2003). Reasonable understanding of modern conditions and reactions to known recent environmental changes can help in both interpretation of older records as well as making attempts to predict the future.

1.1 PROBLEM AND AIMS

The Late Holocene environmental changes are inferred from several records: lake and marine sediments, ice cores, tree rings, stalagmite records, historical notes and others (e.g. Smith & Schafer 1987; Bond et al. 1997; Kreutz et al. 1997; Dahl-Jensen et al. 1998; Mann et al. 1998; MacDonald et al. 2000; Moore et al. 2001; Jennings et al. 2001;

O'Sullivan et al. 2002; Hald et al. 2003; Smittenberg et al. 2004). For Svalbard archipelago region mainly fjord and lake sediments, and ice cores were used, however, only the latter were studied in high resolution (annual to centennial timescale). Recently retrieved ice cores from Lomonosovfonna (ice cap partly drained by Nordenskiöldbreen, which terminates in Billefjorden) cover the last 600 years, and are at the moment the best archives of past climate and pollution history (Gordiyenko et al. 1981; Isaksson et al. 2001; Pohjola et al. 2002; Isaksson et al. 2003). Ice core record, although very valuable, does not inform us about many aspects of possible important changes in the environment (for example: variations in denudation rates, fluctuations of sediment dispersal systems or modification of sea currents). The sedimentary records may widen our recognition of the earth system functioning and changes. Particularly great potential for assessment of environmental change at both low resolution (the scale of millennia) and high resolution (decadal to less than daily) has the sedimentary record of lakes (e.g. Birks et al. 2004a,b and references therein) and fjords (Smith & Schafer 1987; Paetzel & Schrader 1992; Dowdeswell et al. 1998; Gilbert 2000; Desloges et al. 2002; Pellatt et al. 2001; Hald et al. 2003). Hitherto existing works on sediment cores from fjords of Svalbard focused mainly on time scale of ka and reconstruction of postglacial changes (Sexton et al. 1992; Svendsen et al. 1992; Elverhøi et al. 1995; Snyder et al. 2000; Hald et al. 2001; Koç et al. 2002). The last 500 years were covered by some of them, however, no works were essentially dedicated to this period. Zajączkowski et al. (in press) have recently studied changes in sediment mass accumulation rates in Adventfjorden in the last 50 years. Modern fjord environment was intensively studied for selected fjords – (Elverhøi et al. 1980; Prior et al. 1981; Elverhøi et al. 1983; Görlich 1986; Görlich et al. 1987; Dowdeswell & Dowdeswell 1988; Dowdeswell & Cromack 1991; Węśławski et al. 1991; Beszczyńska – Möller et al. 1997; Węśławski et al. 1999; Zajączkowski & Legeżyńska 2001; Hop et al. 2002; Svendsen et al. 2002), however most of the studies were dedicated to oceanology and ecology, and only scarce information exist for Billefjorden. The main problem of presented dissertation is to find out the mechanisms and rates of modern fjord sedimentation, and their effect on contemporary sediment characteristics, then through study of the sedimentary record to uncover high resolution Late Holocene history (last 500 years) of changes in environmental conditions. As the study site Billefjorden in Svalbard archipelago was selected. It is medium sized silled fjord with sediment delivery directly from glaciers as well as from rivers, therefore wide range of environments can be studied. It was also directly influenced by local human activity so assessment of its significance is

also important. The solution is going to be presented through fulfilling the following research tasks:

- description of physiography and oceanography of research areas;
- qualitative and quantitative characteristics of modern sedimentary processes;
- categorization of modern marine sediments (sedimentological properties, mineralogical and chemical composition) and finding of their provenance;
- quantification of sedimentation rates and constructing a basis for geochronology of the studied cores;
- revealing early diagenesis influence on the sediment characteristics;
- study of multiproxy signal recorded in the deposits, and detection of natural and anthropogenic environmental changes;
- conceptual modeling of probable future changes in depositional system of the fjord.



Fig.1. Location of Svalbard (76 - 81° N and 7 - 30° E) in the Arctic. The major exchange route of water and heat between Arctic Ocean and surrounding seas takes place through Fram Strait, which is located between Greenland and Svalbard. The Arctic Circle is marked with blue line.

2 BACKGROUND

2.1 ENVIRONMENTAL CHANGES

Environmental changes are understood here as changes of parameters, values, dynamics etc., which describe state and functions of a given system, caused by external factors and forces. Most of them are primary powered and modified by solar forcing, tectonic and volcanic, or biogenic activity (Crowley 2000). In this study two recently the most intensively studied changes are underlined, namely: climate change and human impact, and their consequences.

Time span covered by the studied sedimentary record consists of the coldest and the warmest periods of the whole Holocene. The previous one is called 'Little Ice Age' (LIA) (nominally ~1400 to 1900 AD) - it was a period of cold, dry conditions and increased atmospheric circulation (Kreutz et al. 1997; Mann et al. 1998; Grove 2001; Nesje & Dahl 2003). The causes behind the LIA, whether global in extent or not, are not well understood. Three mechanisms of climate change that operate on century time scales have been considered: volcanic eruptions, variations in solar energy, and changes in ocean and atmospheric circulation. However, none of these on their own seem to reliably predict the observed climate changes throughout LIA. More probably, a combination of these and other climate forcing processes has influenced the climates of the last centuries. Bond et al. (1997) suggested that LIA has been the most recent cold phase in the series of millennial-scale cycles. The termination of LIA was followed by the warmest period in the last couple of millennia, though the record shows a great deal of variability. Most of the warming occurred in the 20th century, during two periods: 1910 to 1945 and 1976 to present (Dahl-Jensen et al. 1998; Mann et al. 1998; Mann 2000; Houghton et al. 2001).

On Svalbard the maximum of last major glacier advances was in the 1890s - termination of the Little Ice Age (Mangerud & Svendsen 1990; Sexton et al. 1992; Snyder et al. 2000; Hald et al. 2001; Ziaja 2001), and is marked on land by ice cored moraine ridges (Fig.3). The 20th century deglaciation continues today with retreat rate, for glaciers in Billefjorden region, in range of 2 to 50 m y⁻¹ on average (Rachlewicz & Szczuciński 2002). However, many glaciers in other parts of Svalbard belong to surge type, and fluctuate partly independently from climatic factors (Hagen et al. 1993; Hamilton & Dowdeswell 1996; Hagen et al. 2003).

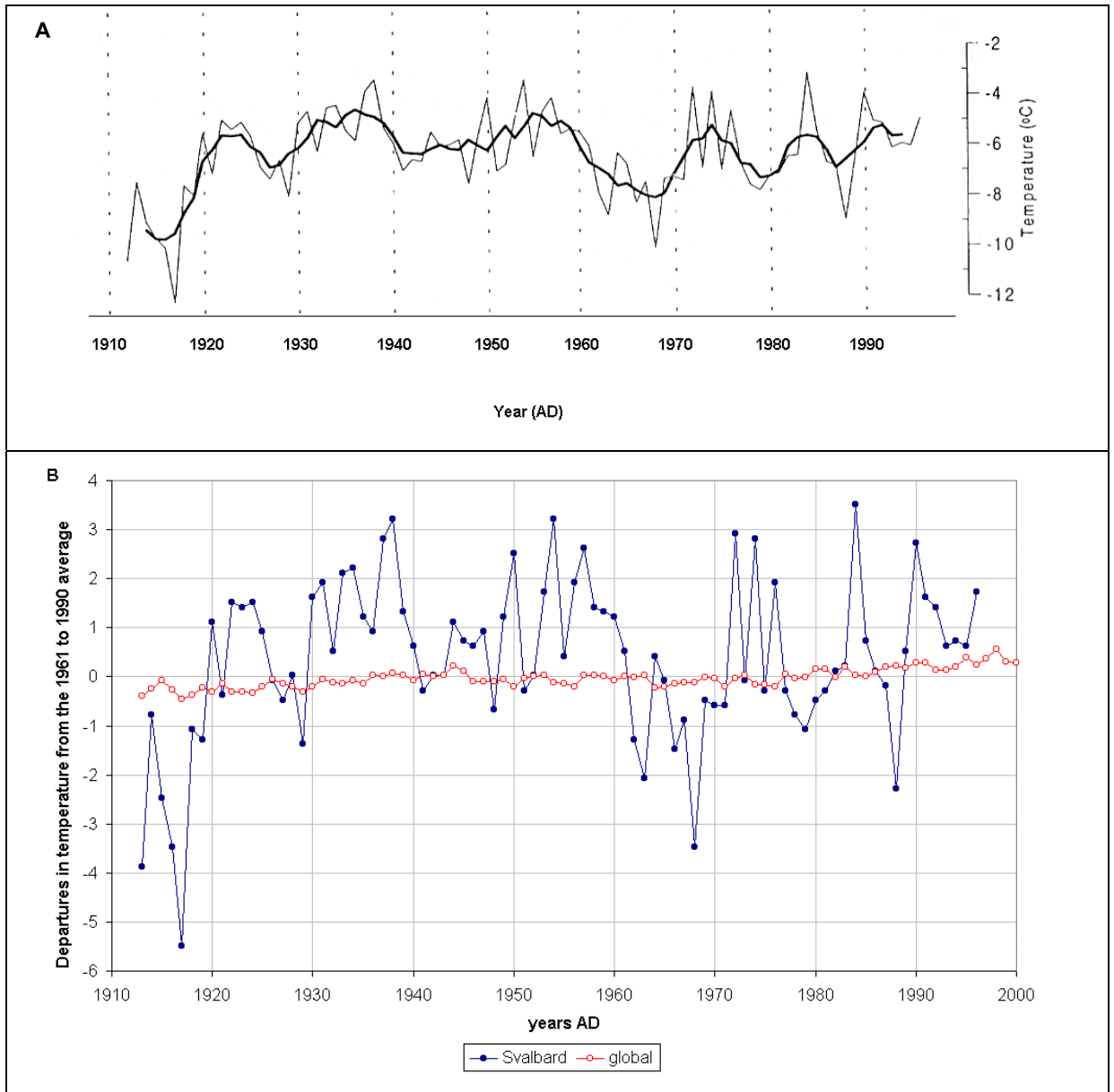


Fig.2. Changes in air temperature in the XX century. A): Mean annual temperature record from Longyearbyen (data from Norwegian Meteorological Institute after Nordli et al. 1996 and Isaksson et al. 2001). The data have been smoothed using running mean equivalent to about 4 years (after Isaksson et al. 2001). The abrupt warming occurred after temperature minimum in 1917 and lasted until the late 1930s. Following a cooler period that culminated in the late 1960s there has been a significant recent increase in temperature, but Svalbard is still somewhat colder than in the 1930s. B): Comparison of departures in average annual temperatures from the 1961 to 1990 average for Longyearbyen (data from A)) and the global one (data after IPCC report (Houghton et al. 2001)).

Continuous temperature record started on Svalbard in 1911 (Fig.2) in the vicinity of Longyearbyen (the main town on Spitsbergen, about 40 km to south west from

Billefjorden) and reveals temperature minimum in 1917, abrupt warming till 1930s, cooler period with minimum temperatures in 1960s and continuous warming till today (Nordli *et al.*, 1996). During the same period precipitation has increased by about 2.5 % per decade (Førland & Hanssen-Bauer, 2003). The changes are well correlated with NAO index (Nesje & Dahl, 2003), therefore reflect regional pattern of climate variations. Future scenarios predict further increase in temperature and precipitation for this region (Førland & Hanssen-Bauer, 2003).

In comparison with data on global air temperature changes (Fig.2) the most evident difference is in amplitude. In the studied period (1913 – 2000) the amplitude of the averaged annual temperatures was in Svalbard 9° in comparison to only 1°C globally. It may result in much more drastic environmental changes than elsewhere. The changes, although in general similar, are in delay or in advance to the global pattern. For example the LIA maximum was about 50 to 100 years later than in continental Europe (Nesje & Dahl 2003), but the warming of the 1940-s recorded in the global scale took place on Svalbard in the 30-s. The late XX century warming also is much less evident than the one recorded in global scale.

Svalbard is remote from major pollution sources, with the exception of coalmines at Barentsburg, Sveagruva, Longyearbyen (since 1911) and Pyramiden. The last one is located in Billefjorden catchment and was in operation between 1947 and 1998. Contaminants are however also delivered by long distance atmospheric transport from industrial areas of Europe and North America (Penkett 1984; Pacyna 1995; Simoes & Zagorodnov 2001). The maximum of their emissions took place between 1940s and early 1990s (Isaksson *et al.* 2001; Isaksson *et al.* 2003).

2.2 INTRODUCTION INTO THE STUDY AREA

Billefjorden (Figs. 3, 4) is located at the inner, northeastern end of Isfjorden in Spitsbergen, between 78°27' and 78°43' N, and 16°02' and 16°53'E. Its length is 32 km, and its smallest width 5 km. Four bays branch out from the fjord: Adolfbukta, Petuniabukta, Mimerbukta and Skansbukta. Shallow (10-50 m) sills at the fjord entrance separate the fjord from Isfjorden. The greatest depth in the main basin - 200 m, was found 3.8 km off the tidewater front (an ice cliff grounded in the sea) of Nordenskiöldbreen (breen = glacier), which is the only glacier in the Billefjorden area reaching sea level. Steep mountainsides rise to an average height of 600 m on both sides of the fjord; the highest mountain is Robertfjellet – 1116 m a.s.l.

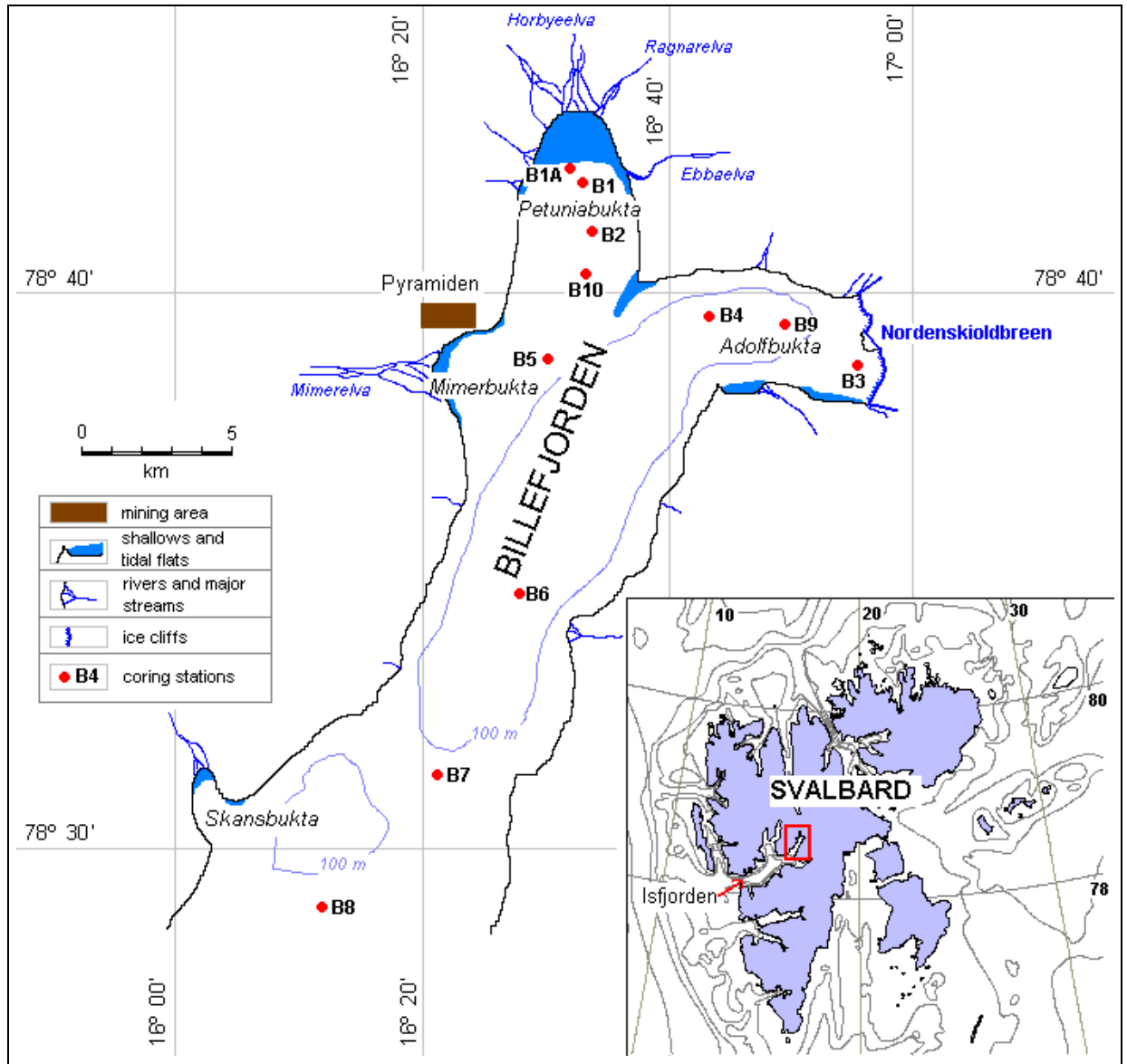


Fig.3. Locations of coring stations and place names in Billefjorden. Base map is combined from topographical and marine charts (Norsk Polarinstitutt 1978, 1984, 1988). The inset map shows locations of Isfjorden and its branch: Billefjorden (in red rectangular) on Spitsbergen – the largest island of Svalbard archipelago.

The geological setting (Fig.5) is dominated by N-S trending Billefjorden Fault Zone (Harland et al. 1974). In northern part of the catchment there are some isolated outcrops of Pre-Old Red rocks (Hecla Hoek Succession), which are mostly presented by crystalline rocks: amphibolites, granosyenite, gneisses, various schists and quartzites. These formations also underlie the largest glacier: Nordenskiöldbreen. The next structural unit is composed of Devonian clastic rocks with admixture of carbonates and coals. The third unit, the most common in Billefjorden, consists of carbonates, anhydrite, gypsum, clastic

rocks with coal measures – all of them are of Carboniferous and Permian age. There are also dolerite dykes and covers of Quaternary sediments - slope covers, taluses, outwash fans, moraines, raised marine terraces etc. (Feylinng – Hanssen 1955; Lauritzen et al. 1989; Karczewski et al. 1990; Dallmann et al. 1994; Dallmann et al. 1999). The main fjord basin was deglaciated at about 10 ka (Mangerud & Svendsen 1992) and with the whole region it was glacioisostatically uplifted, associated relative sea level fall was more than 90 m. There is, however, no evidence of sea level changes during the last 4 ka (Salvigsen 1984).

The climate of the region is strongly modified by warm West Spitsbergen Current (the northernmost extension of the Norwegian Atlantic Current), which makes it very mild, considering its northern position. The average annual temperature is about -6°C . The warmest month is July ($5-6^{\circ}\text{C}$), and the coldest January – March (about -15°C). Precipitation is relatively low, annually about 200 mm at sea level (Hansen-Bauer et al. 1990; Hagen et al. 1993). During a year there is strong climatic seasonality, which controls many hydrological, geomorphological, biological etc. processes (Węśławski et al. 1988). During short summer (end of June to beginning of September) temperatures are above 0°C , and there is continuous daylight. In fall temperatures are below freezing point, polar night starts but fast sea ice cover on fjords does not exist yet. Winter is characterised by very low temperatures, no sunshine and full ice cover on at least inner fjords, in spring the ice still exist but the daylight starts to operate and governs processes of melting, which are at maximum at the spring – summer onset.

The 44% of the Billefjorden drainage basin is covered with glacier ice (Hagen et al. 1993). Glaciers contribute the most sediment to the fjord either directly, or via systems of braided rivers. Only one (Skandsalsbreen - in southernmost part of Billefjorden) from 23 glaciers was reported to surge (Hagen et al. 1993). All the glaciers are polythermal (large and medium size glaciers) or cold (the ice temperature is below freezing point throughout the glaciers, thus frozen to their bed).

Svalbard fjord waters are influenced by relatively warm Atlantic Water transported from the south via the West Spitsbergen Current, and by Polar Water and Arctic Water from the north. Silled fjords in this part of the Arctic are usually dominated by three kinds of water masses: Surface Waters (of lower salinity), Intermediate or Transformed Atlantic Waters, and Local Waters, which are of higher salinity and temperature below -1°C (Swerpel 1985; Węśławski et al. 1991; Svendsen et al. 2002). The water masses are usually separated by strong pycnoclines. A continuous cover of fast ice forms in the major fjord systems about late November and usually remains until late May or June (Wadhams

1981). The Billefjorden is under influence of semidiurnal tides of maximum amplitude of 1.5 m.

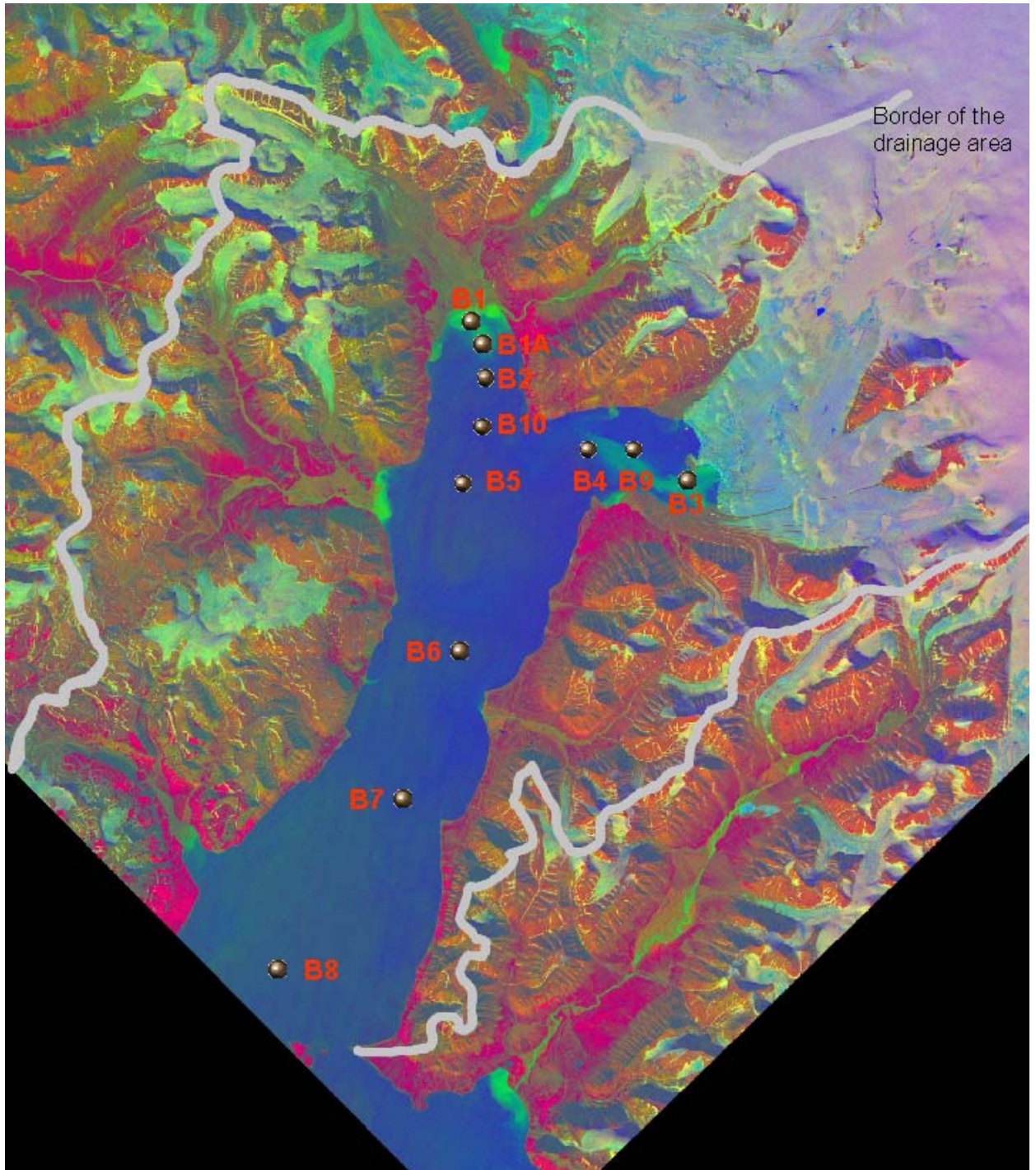


Fig.4. Satellite orthophotomap based on picture taken on 13.07.2002 from TERRA satellite in infrared and visible band, elaborated by Alfred Stach. Suspended matter plumes in surface fjord waters (especially in front of Nordenskiöldbreen) are visible. Pink areas represent plant-covered terrain. Note that almost all the glaciers are depleted from snow cover even in accumulation area. Coring stations and drainage area border are also marked.

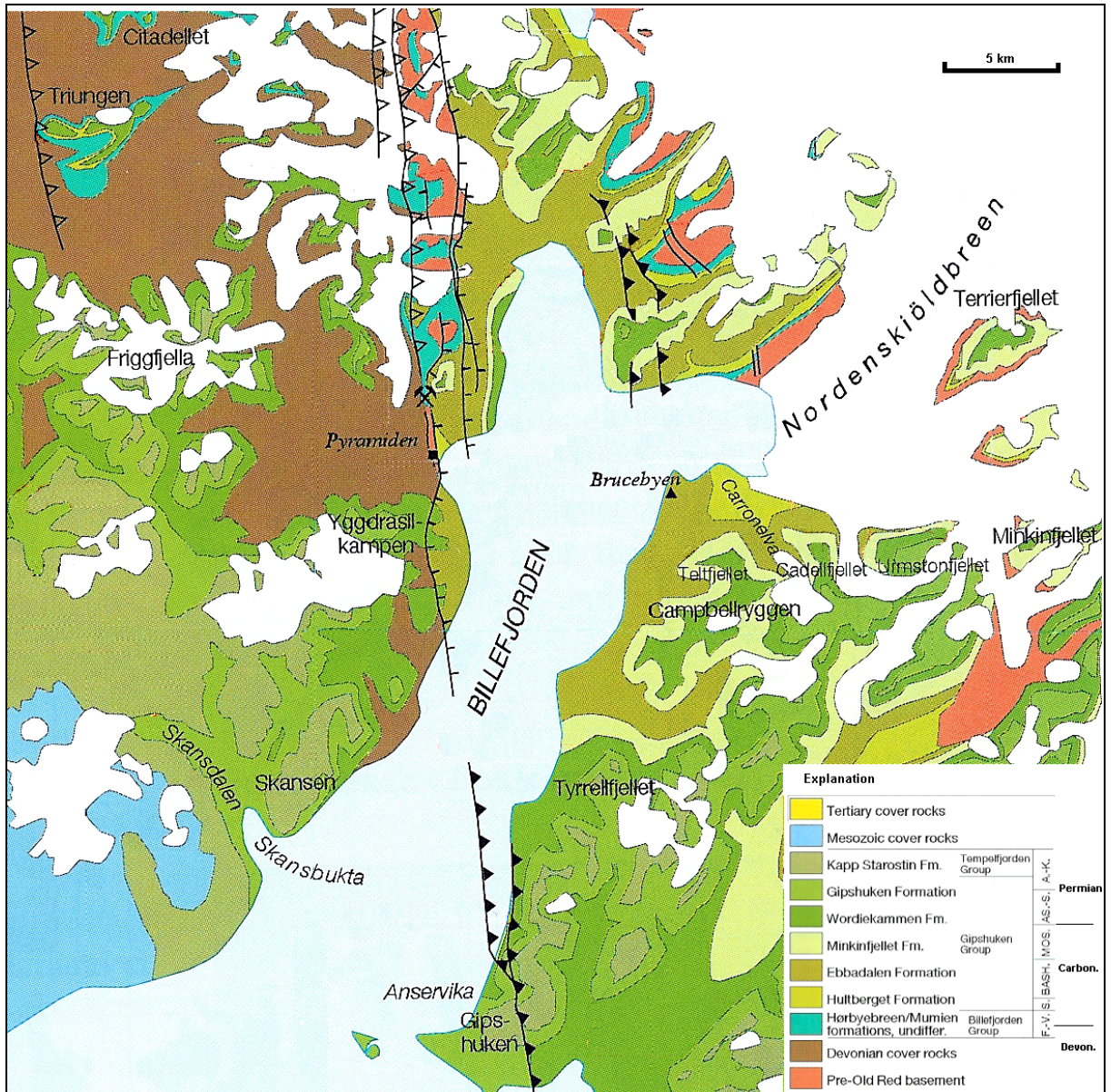


Fig.5. Geological sketch of the Billefjorden region, central Spitsbergen, Svalbard. Major part of the Billefjorden drainage area is composed of Carboniferous and Permian sedimentary rocks. The Nordenskiöldbreen is underlined by crystalline Pre-Old Red rocks. After Dallmann et al. (1999).

Among human activities mining has had the strongest impact on the natural environment in the region. Although first attempts were in the beginning of the 20th century (in Skansbukta and Adolfbukta – Fig.3) the continuous intensive exploitation started after the 2nd World War in Russian town Pyramiden (Mimerbukta), which was in operation between 1947 and 1998. Recent study on soil pollution in this region (Gulińska et al. 2003) has revealed that contaminants are only in short distance from sources (mines, settlements) and their concentrations are an order of magnitude lower than EU limits.

3 MATERIAL AND METHODS

3.1 MATERIAL

Materials were collected during 2000, 2001 and 2002 summer expeditions. Additional data were gained during 2003 spring and summer expeditions. STD measurements (water salinity, temperature, density) and sediment sampling in Billefjorden was done on the 4th and the 5th of August 2001 from R/V OCEANIA. On each of the stations an STD profile was done, surface sediments were taken by grab sampler, and two cores were sampled with Niemistö corer (Niemistö 1974): one for bulk chemical analysis and the other for sedimentological ones – see Fig.6. The cores were cut immediately into 1 cm thick slices. Furthermore, water samples were taken, and sediment traps were deployed during summer 2000 - 2002 expeditions from a rubber boat. The basic data on coring stations are given in Tab. 1 and in Figs. 3 and 4, and on water sampling and sediment trap stations in Tab. 2 and on Fig.7. Satellite and oblique air photos were also utilized.

Tab.1. Sediment sampling and STD stations; the coordinates are based on GPS satellite navigation. See also Fig.3 and 4. N1 and N2 stand for Niemistö core.

Station	Coordinates		Water depth [m]	Recovery [cm]	
	Latitude	Longitude		N1	N2 (A)
B1A/2001	78°42.251'N	16°31.874'E	26.7	3	-
B1/2001	78°41.917'N	16°32.220'E	38	25	27
B2/2001	78°41.055'N	16°33.038'E	33	33	32
B3/2001	78°38.879'N	16°53.436'E	40	30.7	28.5
B4/2001	78°39.515'N	16°42.483'E	200	11.5	8
B5/2001	78°38.983'N	16°31.590'E	67.5	12	25
B6/2001	78°35.564'N	16°27.928'E	151	23.5	14.5
B7/2001	78°32.032'N	16°20.888'E	84	18	13
B8/2001	78°29.542'N	16°09.873'E	48	3	-
B9/2001	78°39.537'N	16°47.953'E	153	19.25	19
B10/2001	78°40.363'N	16°32.440'E	32.5	28	23

3.2 OCEANOLOGICAL METHODS

To investigate modern oceanological conditions and sedimentation processes the fjord waters were studied through STD survey, water sampling and analysis, and sediment trap experiments.

Salinity, water temperature and density were measured with mini STD sonde (Mini CTD Sensor data SD202) from R/V OCEANIA in 11 depth profiles (at the same localities like sediment sampling stations in Billefjorden, see Tab.1 and Figs. 3 and 4). Additional data

on water masses circulation were collected during summer 2000, 2001 and 2002 expeditions and they include observations of tidal range, iceberg and suspended matter plumes movement, seawater temperature, and water sampling.

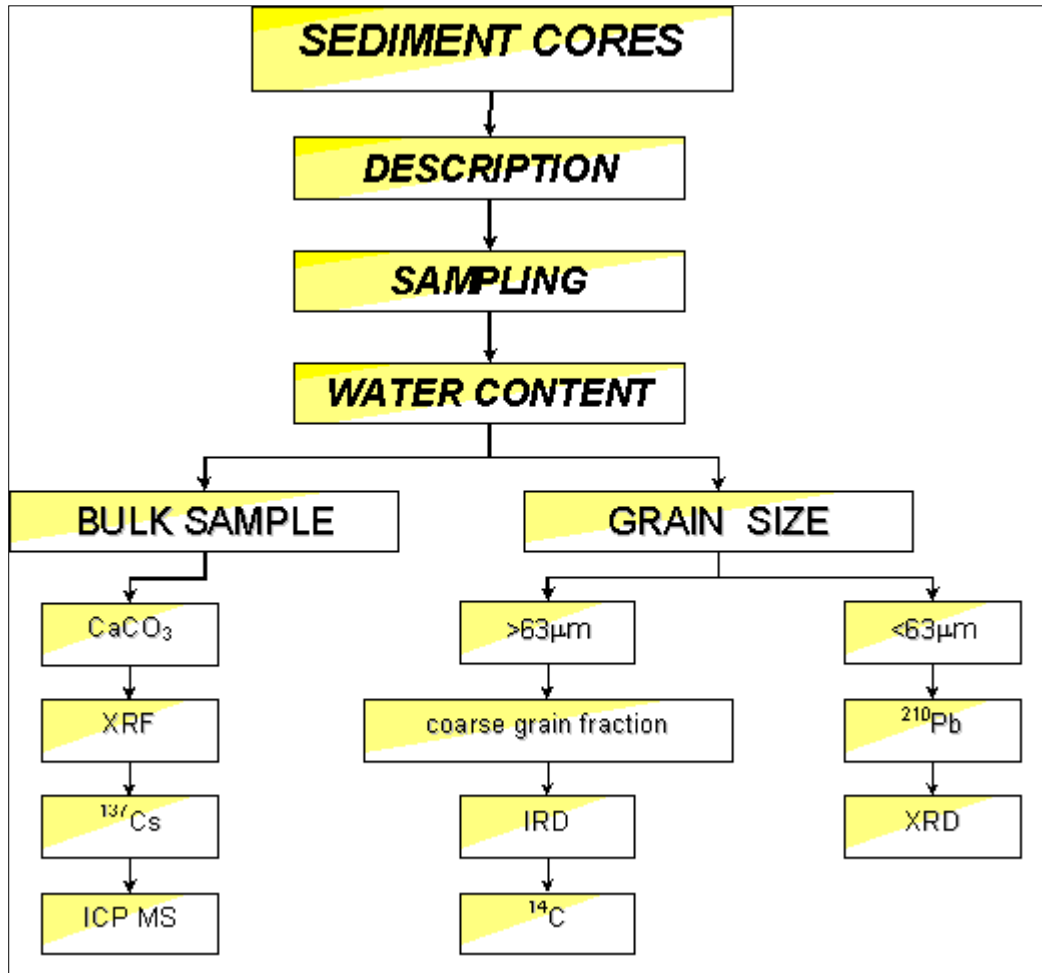


Fig.6. Flow chart, which shows the way of data production. XRF – X-ray fluorescence, ICP MS – inductively coupled plasma emission mass spectrometry, IRD – ice rafted debris, XRD – X-ray diffractometry.

Water samples were collected using plastic bottles for surface samples and 1.8 l Niskin sampler for subsurface samples. The recovered water was analysed for temperature, pH, conductivity, filtered and rinsed with distilled water on pre-weighed filters to obtain suspended particulate matter (SPM) concentrations.

Sediment traps were constructed from plastic cylinders 1m long and 10.56 cm inner diameter, closed on one end with plastic cap. The trap geometry and way of deployment (Fig.8) follows recommendation of Zajęzkowski (2002). They were used in summer – autumn season 2002 in Billefjorden, on eight stations (Tab. 2, Fig. 7), at two (in

Petuniabukta) or three (in Adolfbukta) water depths. Usually traps were doubled at the same depth to improve the statistics. The exposure time was 24 and 48 hours. Altogether a hundred sediment catches were collected.

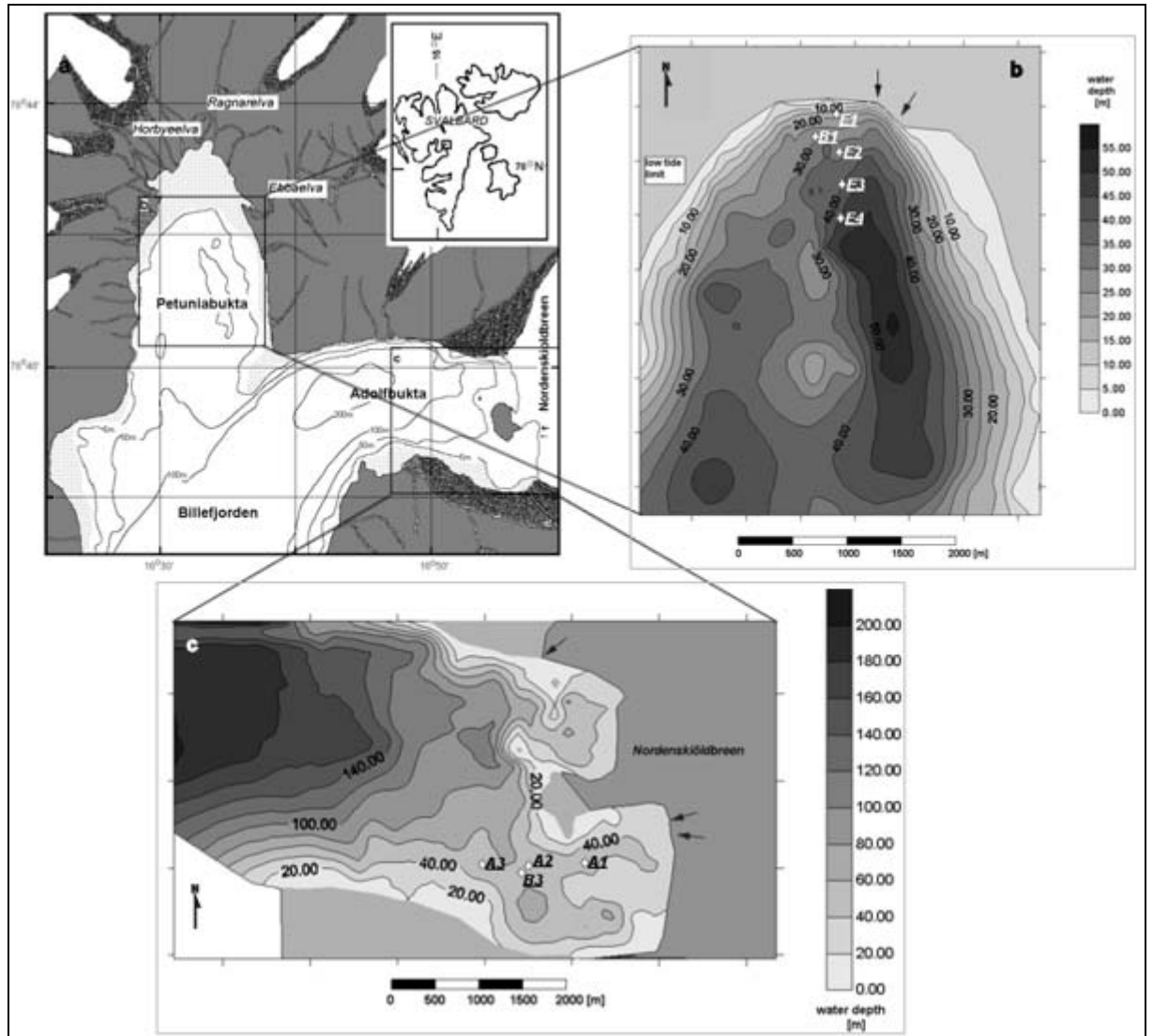


Fig.7. Sampling stations for water sampling and sediment trap experiments; a) northern part of Billefjorden and location of the study area in Svalbard archipelago; dotted areas mark tidal flats and shallows; b) Petuniabukta bathymetrical sketch; c) Adolfbukta bathymetrical sketch. Arrows indicate freshwater inflows and diamonds the sampling stations. The bathymetry in b) and c) is based on own survey with GPS Map Sounder, the tidewater ice cliff position based on 2002 summer situation.

3.4 SEDIMENTOLOGICAL METHODS

3.4.1 MACROSCOPIC DESCRIPTION

The macroscopic description consisted of standard description (color, grain size, structures, special features, organisms), supported by photographs, and was made twice: onboard and after delivery to laboratories. Since sampling with Niemisto corer requires the sediments to be extruded and cut into 1cm slices immediately after coring the description of sedimentary structures is limited.

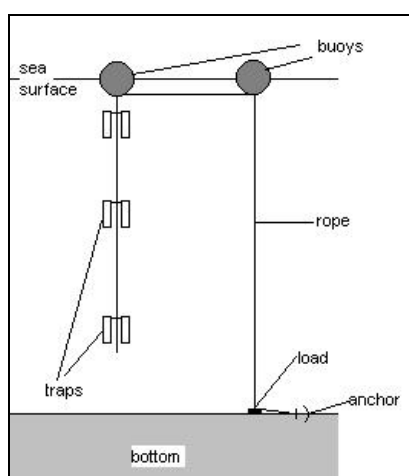


Fig.8. Way of deployment of sediment traps. Modified after Zajączkowski (2002) – not to scale.

Tab.2. Basic water sampling and sediment trap stations.

Station	Latitude	Longitude	Water depth [m]	Water sampling depths [m]	Sediment trap deployment depths [m]
B1	78°42.251'N	16°31.874'E	28	0;10;20	4;20
E1	78°42.386'N	16°32.430'E	11.7	0;5;10	3;9;10
E2	78°42.186'N	16°32.430'E	34	0;5;10;20;30;33	6;30
E3	78°41.986'N	16°32.430'E	36	0;5;10;30	6;30
E4	78°41.786'N	16°32.430'E	43	0;5;10;30	6;30
A1	78°38.938'N	16°55.307'E	46	0;5;20;40	5;20;40
A2	78°38.891'N	16°53.880'E	38	0;5;20;35	5;20;35
A3	78°38.913'N	16°52.375'E	49	0;5;20;40	5;20;40

3.4.2 WATER CONTENT

Water content was determined as a weight of water percentage. The samples were air-dried or oven dried (in no more than 50C° - because a part of samples was used for clay mineral analysis).

3.4.3 GRAIN SIZE

Grain size analysis was based on wet sieving (0.063 mm sieve) and subsequently sieving of coarser fraction and investigating the washed material with optical diffractometry method on laser diffraction based Mastersizer 2000 Particle Analyzer (with a possible detection range from 0.02 µm to 2000 µm). Samples were analysed in Institute of Quaternary Research and Geoecology, A. Mickiewicz University. Analysis of grain size statistics (using logarithmic method of moments) was performed by means of GRADISTAT program (Blott & Pye 2001).

3.4.4 COARSE GRAIN FRACTION

Coarse grain analysis was performed for >500 microns, and 250-500 microns fractions using binocular microscope. Every counted sample was split with microsplier to at least 300 grains. Six basic classes were distinguished: lithoclasts (with recognition of mineral type when possible), plant remnants, particulate coal, shell fragments, benthic and planktonic foraminifera tests. The amount of ice rafted debris (IRD) was determined through counting the number of mineral grains in the fraction >500 microns per gram of dry sediment (Hald et al. 2001). The concentration of benthic foraminifera (C_f) in sample was determined as all counts in >250 microns fraction per gram of dry sediment.

3.5 X-RAY DIFFRACTION (XRD) ANALYSIS OF CLAY MINERALS

The clay fraction (<2 µm) was analysed by X-ray diffraction (CuK α -radiation) in Institute of Geology, A. Mickiewicz University. A sample was investigated as oriented, glycolised and heated in 550 °C. Minerals identification followed instructions of Moore & Reynolds (1989). Semi quantitative analysis was done according to the method of Biscaye (1965) using MacDiff 4.2 software by Petchik (2000).

3.6 GEOCHEMICAL METHODS

3.6.1 CARBONATE BOMB

The carbonate content of a sample is determined by measuring the increase in gas pressure caused by acidifying a dried sediment sample in a closed vessel. The 0.79 g of a grounded sample was treated with 5 ml of 25 % HCl. The percent carbonate is then read from a graduated pressure-concentration curve. Every 10th sample was measured twice to estimate error, which is ± 1 %.

3.6.2 XRF

The major elements: Si, Al, Na, K, Fe, Ca, Mg, Mn, Ti and P (traditionally listed as oxides) and some trace elements (Ba, Nb, Rb, Sr, V, Y, Zn and Zr) were determined using X-ray fluorescence spectrometry (XRF). Glass beads from the powdered and heated in 1000 °C sample fused with lithium tetraborate were measured by a Bruker S4 Explorer (Institute of Geology, A. Mickiewicz University). LOI (loss on ignition) was also evaluated (it is a function of calcium carbonate, structural water (from clays), organic matter and other volatiles released during ignition) and for similar deposits was treated as relative proxy of organic matter content.

3.6.3 ICP-MS

ICP-MS (inductively coupled plasma emission mass spectrometry) was used for trace elements and heavy metals determination. Analyses were performed at ICP MS Lab in Institute of Geosciences, Christian Albrecht University in Kiel. Samples were decomposed by lithium borate fusion prior to analysis. Measurements were done on Agilent 7500 ICP mass spectrometer. For calibration blank samples, drift-control samples, rock standards (MESS-1 (for marine sediments) and G-2 (for granites)) and duplicates were used. The measuring error estimated from independent duplicate samples was for most elements better than 5-10% (Garbe-Schönberg 1993).

3.7 DATING METHODS

3.7.1 ^{210}Pb

^{210}Pb activities were determined by alpha spectroscopy of the granddaughter nuclide ^{210}Po . Samples were taken in 2 cm ranges, and after determination of water content and dry density were washed on 0.063 mm sieve. The washed fraction was dried to a constant weight and homogenized. For every ten samples one additional was taken twice, also one blank sample was prepared per ten, and one UREM (substance with known amount of ^{210}Po) per one set of samples (18). The samples (0.2 g each) were spiked with 0.2 ml ^{209}Po (^{209}Po does not exist in samples, and it behaves similar to ^{210}Po so it can be used for estimation of losses during digestion). ^{210}Po was leached from the sediments in a series of three concentrated acid digestions (in closed box for 10 hours in 120 °C with 3 ml of HCl, 1 ml of HNO_3 and 3 ml of HF; next 2 ml of HClO_4 was added and left in 190 °C to dry; finally 2 ml of 9 mol HCl was added). The final solution was then dissolved in distillate water to obtain concentration of approximately 1 mol HCl. Ascorbic acid was added to eliminate interference of Fe^{+3} during autodeposition. The polonium was autoplated onto a silver planchet (Flynn 1968), which was introduced and the solution was kept for 4 hours in sand bath in 80-90 °C. In that step ^{210}Po substitute Ag and after that planchets were alpha counted (together with ^{209}Po) on alpha spectrometer Octete by EG&G in Institute of Geosciences, Kiel University. Secular equilibrium was assumed to exist between ^{210}Pb and ^{210}Po .

3.7.2 ^{137}Cs

For ^{137}Cs detection samples were taken in 1 cm ranges, they were powdered and placed into 10 ml plastic vials, sealed and left for at least two weeks. ^{137}Cs activities were determined by gamma ray spectrometry at 661.91 keV, using high purity germanium detectors (in Medical Academy in Gdańsk and in Institute of Geosciences, Kiel University). Because of low activities of the radionuclide the measurements lasted up to a couple of days per sample.

3.7.3 AMS – ^{14}C -DATING

Age control and calibration of ^{210}Pb and ^{137}Cs datings were done by high precision ^{14}C measurements of calcareous shells using the technique of accelerator mass

spectrometry (AMS). Measurements were done in Poznań Radiocarbon Laboratory, which is equipped with the 1.5 SDH-Pelletron Model "Compact Carbon AMS". The surface layer of shells was scraped off to avoid contamination with younger carbonate encrustation. A reservoir age of 440 years is subtracted for all the samples that have obtained their carbon from seawater. This is standard value used for coasts of Svalbard (Mangerud & Gulliksen 1975).

3.8 MODELS AND COMPUTATION TECHNIQUES

3.8.1 RATES OF SEDIMENTATION BY ICEBERGS

Estimations of order of magnitude rates of sedimentation by icebergs were done according to simple two-dimensional model presented by Dowdeswell & Dowdewell (1989) and Dowdeswell & Murray (1990), and later applied to several studies (e.g. Schäfer-Neth & Stattegger 1999). The following parameters were computed: the flux of basal debris calved through a 1 m width of tidewater margin (f_s):

$$f_s = (h_d c 100^{-1}) v_c \quad (1)$$

where h_d and c are the thickness and percentage debris concentration of basal debris rich ice, and v_c is the rate of iceberg calving from a tidewater ice front:

$$v_c = u - m - M_c \quad (2)$$

where u is velocity at a tidewater glacier terminus, m is the rate of advance or retreat of the terminus, and M_c is the rate of direct melting of the tidewater ice cliff. The last factor and also iceberg basal melt rates (M_b) can be calculated according to empirical equation provided by Russell-Head (1980):

$$M_b \text{ or } M_c = 2.08 \cdot 10^{-7} (T_s + 1.8)^{1.5} \quad (3)$$

where T_s is sea water temperature ($^{\circ}\text{C}$), or using that presented by Weeks & Campbell (1973):

$$M_b \text{ or } M_c = 6.74 \cdot 10^{-6} v_w^{0.8} \Delta T X^{-0.2} \quad (4)$$

where v_w is free stream relative horizontal water velocity past a berg (or ice cliff), ΔT is temperature difference between an iceberg and surrounding water, and X is the length of iceberg side. The model assumes that time elapsed from calving is proportional to distance from the ice front. Debris release by basal melting (M_b) in any small horizontal element (dx) away from the ice front is calculated from:

$$dy = (M_b dx) v_b^{-1} \quad (5),$$

where v_b is iceberg horizontal velocity.

3.8.2 CALCULATION OF MASS ACCUMULATION RATES

Mass accumulation rates (MAR) were calculated according to Bruns & Hass (1999):

$$\text{MAR} = \text{DBD} \cdot \text{LAR} \quad (6),$$

where: MAR – mass accumulation rate [$\text{g cm}^{-2} \text{y}^{-1}$], DBD – dry bulk density [g cm^{-3}], LAR – linear accumulation rate [cm y^{-1}]. To compute dry bulk density (DBD) of measured water content, average grain density of 2.7 g cm^{-3} , and mean density of pore water considered as mean density of sea water 1.026 g cm^{-3} were used.

3.8.3 CALCULATION OF FRESHWATER INFLUX

Calculation of freshwater influx from tidewater glacier follows the methods described by Ketchum (1950), Nut & Coachman (1956) and Zajączkowski & Legeżyńska (2001) and used data on average velocity of outflow stream (from drifter experiments) and salinity profiles. The layer of brackish water was divided into nine sublayers: 0-0.5, 0.5-1, 1-1.5, 1.5-2, 2-2.5, 2.5-3, 3-3.5, 3.5-4, 4-5 m. The average salinity in each sublayer was taken into account in the calculation of freshwater fraction (FWF) according to the formula:

$$\text{FWF} = (S_0 - S) S_0^{-1} \cdot 100\% \quad (7),$$

where S_0 – background salinity of water beneath the outflow = 34.74 PSU (salinity of fjord waters at 30m water depth in central part of the fjord) and S – actual salinity of brackish water.

The freshwater influx from the rivers was measured in the near mouth cross sections, through measurements of river bed morphology and flow velocity, for details see Rachlewicz (2003a).

3.9 SOFTWARE

For analysis and presentation of data several computer programs were used. *Microsoft Excel* and *Statistica* were employed for statistical analysis, and *Pan Plot*, *Surfer* and *Corel Draw* for graphical data presentation.

4 RESULTS

4.1 FJORD BATHYMETRY

Billefjorden is a typical multiple basin fjord (Syvitski & Shaw 1995). It is composed of two main basins: the central and the outer one (Figs. 3 and 9), their bottoms are, however, uneven and are assembled of several sub basins. There are two major sills: between basins, and at the fjord mouth, both are elevated to water depth of about 40m. The first one can be classified as rock sill and the latter as rock-accumulative sill (Boulton 1979; Kowalewski et al. 1991). The bays branching off the main fjord are situated in submerged parts of hanging valleys (Petuniabukta, Mimerbukta, Skansbukta) and they also have basins, which are separated from the main fjord by sills (Fig. 9). As shown by echosounder profile on distal sides of sills acoustically opaque prolonged bottom echoes are observed, they could be interpreted as areas with increased thickness of not consolidated sediments (Elverhøi et al. 1983).

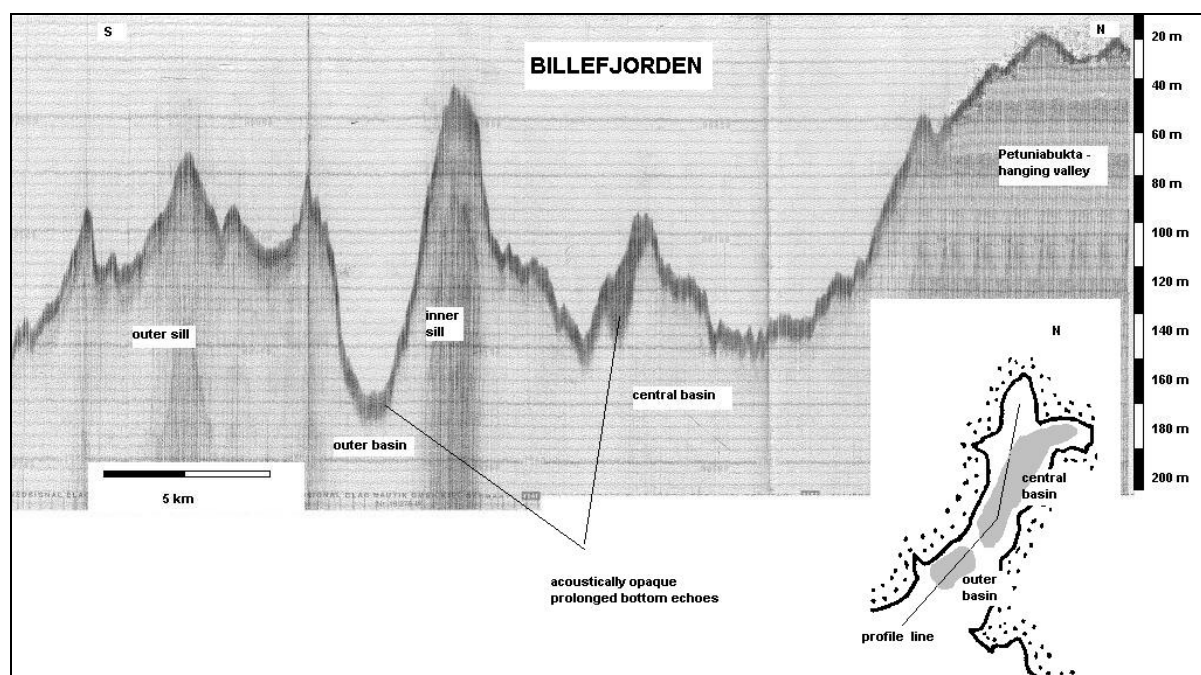


Fig.9. Echosounding profile from Billefjorden. Locations of the profile and main basins are included in insert sketch.

GPS Map-Sounder survey allows constructing detail bathymetrical sketches of Petuniabukta (Fig. 10) and Adolfbukta (Fig. 13) with a special attention paid to Ebbaelva

delta slope (Petuniabukta – Fig.11) and areas of recent retreat of Nordenskiöldbreen (Fig.12).

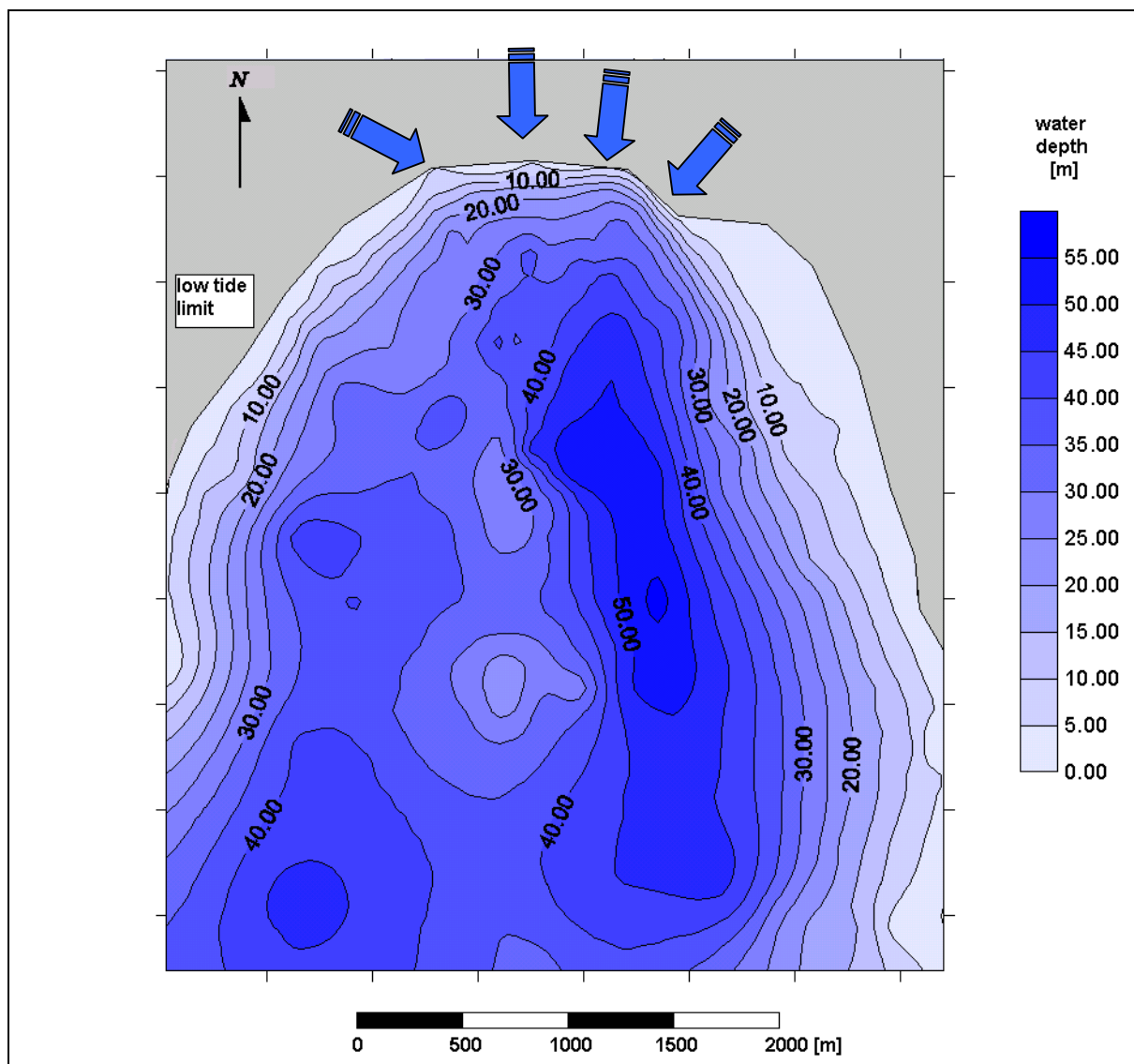


Fig.10. Bathymetrical sketch of Petuniabukta based on own GPS Map-Sounder survey. Arrows indicate main river outflows.

Petuniabukta (Fig.3, 10 and 11) is generally composed of two main basins: the eastern (with maximum measured water depth of 57 m), and western (maximum 46 m). They are separated by N-S extended shallower (25 - 40 m) ridge. The basins and the ridge have relatively gentle morphology. In the northern part there are main river outflows, they flow from upvalley glaciers via outwash fans and extensive tidal flat (Borówka 1989).

The intertidal zone is 2 km wide at maximum. All the main rivers discharge their waters to the bay via the tidal creeks on the tidal flat. The later ends with steep slope (7 – 15°), which descends to about 30 m water depth. In northeast and northwest nearshore areas are relatively flat and shallow, largely covered with kelp forests, as revealed by diving survey, whereas in other parts are relatively steep.



Fig.11. Inner part of Petuniabukata. The picture was taken during flood tide. Southwest wind had pushed turbid water plume to the east coast (closer to observer). Only the uppermost part of tidal flat is uncovered.

Adolfbukta (Figs. 3, 12 and 13) is the largest bay in Billefjorden, and also the deepest part of the fjord – a maximum measured water depth was 202 m. From the east it is bordered by tidewater glacier: Nordenskiöldbreen. The glacier has retreated since LIA (1895) position (Geer 1910; Slater 1925) up to 4 km. Recently retreat of calving bays is much faster than land based margins (Rachlewicz & Szczuciński 2002), however bedrock relief elevates toward east what is reflected in shallower water depths in front of ice cliff and in increase of ratio of land based to tidewater margin. Contemporary bays in front of ice cliff are characterized by uneven bottom relief in water depth range of 20 - 40 m. Westward from 1961 ice front (Norsk Polarinstitut 1988) the bottom is still undulated but

with increasing water depth up to 100m. Behind the LIA glacier limit the water depths significantly increase. Close to the shore, in prolongation of LIA moraines, bottom elevations are observed, they were also found by Plassen et al. (in press). Contemporary maximum ice thickness at its front (both, submarine and subaerial) one can estimate to be 50 m, but along the ice cliff it is usually not more than 30 m, and in many places bedrock outcrops above sea level.



Fig.12. Inner part of Adolfbukta with tidewater front of Nordenskiöldbreen.

4.2 FJORD WATER CIRCULATION

Surface water circulation pattern was observed by direct observations (including drifter experiments) and by studies of satellite images and air photos. In summer season the circulation is governed by freshwater inflow, wind stress, Coriolis force, icebergs and tides. The freshwater inflows with much suspended matter load are lighter than dense fjord ambient waters, and form overflow plumes (Figs. 11, 14). The phenomenon is observed in front of river mouths as well as in front of the tidewater glacier (Figs. 4, 15). This mode of circulation is called hypopycnal and is typical for fjord environment (Gilbert 1983; Syvitski et al. 1985; Syvitski 1989 and others). In Adolfbukta the surface plume velocities measured on several occasions were in the range of $0.2 - 0.5 \text{ m s}^{-1}$, however, there are places in front of the glacier with much higher velocities. The surface current velocities in Petuniabukta were in range of $0.1 - 0.25 \text{ m s}^{-1}$. In both cases the current

velocities were decreasing in seaward direction. The continuous observations of overflow plume development in tidal cycle have shown that in lack of strong winds and waves it is controlled by tides. Tidal currents dam up brackish water during flood tide, and plumes develop during ebb tide. In bays and especially in front of the calving glacier tidal currents are strong and complex – creating small circulation cells, eddies and vortexes. Waves and wave currents depend on strength, duration of winds and fetch length where they can develop. Winds strongly depend on topography and are highly differentiated along the fjord length (Rachlewicz 2003b). The only course which has sufficient fetch length to develop higher waves is from S, SW sector. Waves from these directions can largely intensify mixing of brackish water layer with fjord waters (for example Fig.15a) particularly in Petuniabukta. In Adolfbukta also shock – induced solitary waves are generated by iceberg calving. The most of observed icebergs have not exceeded 20 m.

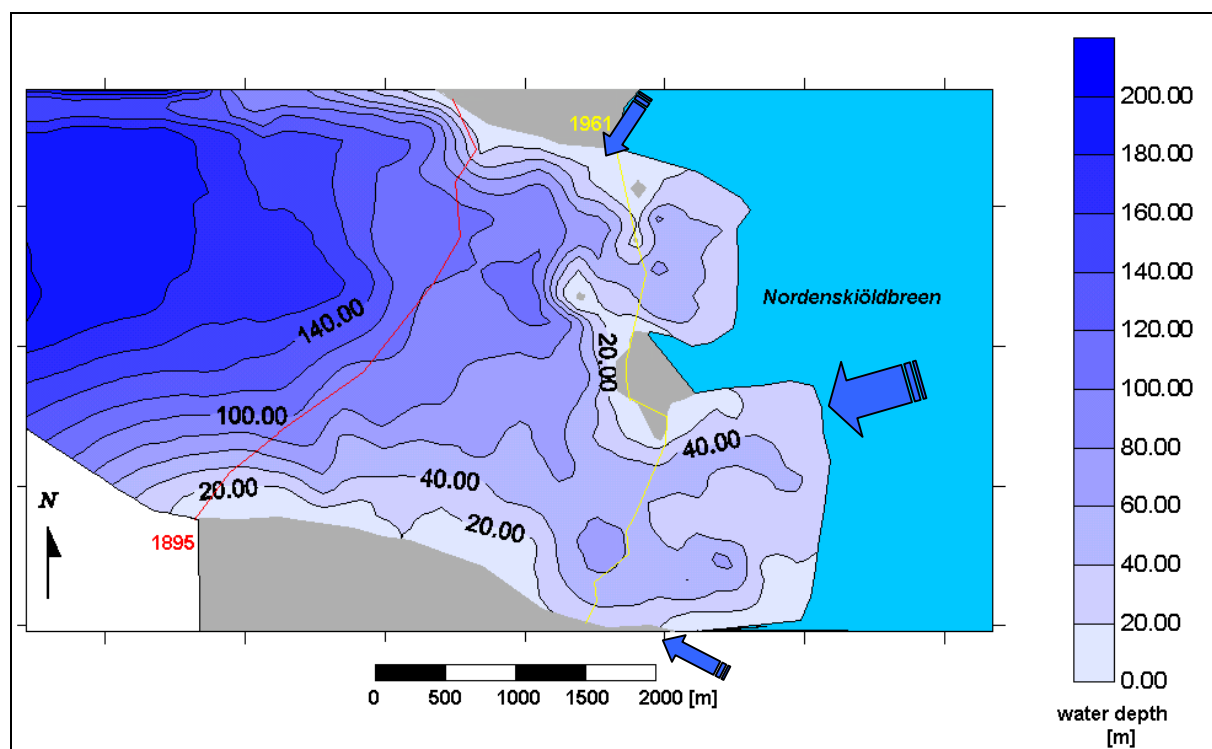


Fig.13. Bathymetrical sketch of Adolfbukta based on own GPS Map Sounder survey. Former glacier limits after Geer (1910), Slater (1925) and Norsk Polarinstitut (1988). Arrows indicate main freshwater inflows.

In the fjord and in Adolfbukta circulation is controlled by the Coriolis effect because the fjord width exceeds the internal Rossby radius of deformation, which depends on

latitude (Gilbert 1983). It results in anticlockwise alongshore current (Fig.16). This circulation is sustained throughout the year.

In fall the main difference in circulation is connected with strong reduction (in Adolfbukta) or even absence (in Petuniabukta) of freshwater inflow so hypopycnal circulation is limited. Also the iceberg production has diminished. In November a cover of sea ice forms, which remains usually till late June, however, the southern part of the fjord can be ice free even in winter.

4.3 WATER MASSES

The STD (salinity, temperature, density) survey performed in the early August 2001 revealed stable summer water stratification in Billefjorden (Figs. 15, 17, 18). Likewise in other fjords of the region (Swerpel 1985; Węśławski et al. 1991; Svendsen et al. 2002) three main water masses are recognized, which are named here: Surface Water (SW), Fjord Water (FW), which are also referred as Intermediate or Transformed Atlantic Waters, and Winter Cooled Water (WCW).



Fig.14. Buoyant plume of riverine freshwater with elevated concentration of suspended matter. The plume front velocity was up to 0.5 m s^{-1} during ebb tide. The picture taken during ebb tide in Petuniabukta.

The SW is generated by seasonal freshwater input, forms overflow plumes and is strongly influenced by local conditions (wind, tide, currents). In Adolfbukta its thickness reaches up to 12 m (fig.15b), however, in the remaining parts of the fjord it usually does

not exceed 2 m (Figs. 17, 18). Though additional mixing caused by wave action can increase its thickness (Fig. 15a). The thicker SW in Adolfbukta can be explained by delivery of freshwater not only at the sea level but also underneath (from subglacial outflows and from ice cliff and icebergs melting), and by more intense mixing facilitated by icebergs movement. The main feature of SW is smaller density if compared to FW. It is mostly an effect of lower salinity, which was 33.94 PSU at maximum but minimum values were as low as 5.26 PSU – typical for brackish waters. Its temperature is also highly variable. Temperature measured during STD survey was in the range of 2.77 to 4.46 °C, however, measurements of waters in Adolfbukta and Petuniabukta in different conditions showed wider range, between 1 and 12 °C. As shown by measurements during fall of 2002, when air temperatures were below 0 °C and surface freshwater input was largely diminished, the SW was still present only in front of Nordenskiöldbreen, which is a polythermal glacier (Glazovsky et al. 1998) and delivers freshwater directly to the fjord throughout the year (Hagen et al. 2003).

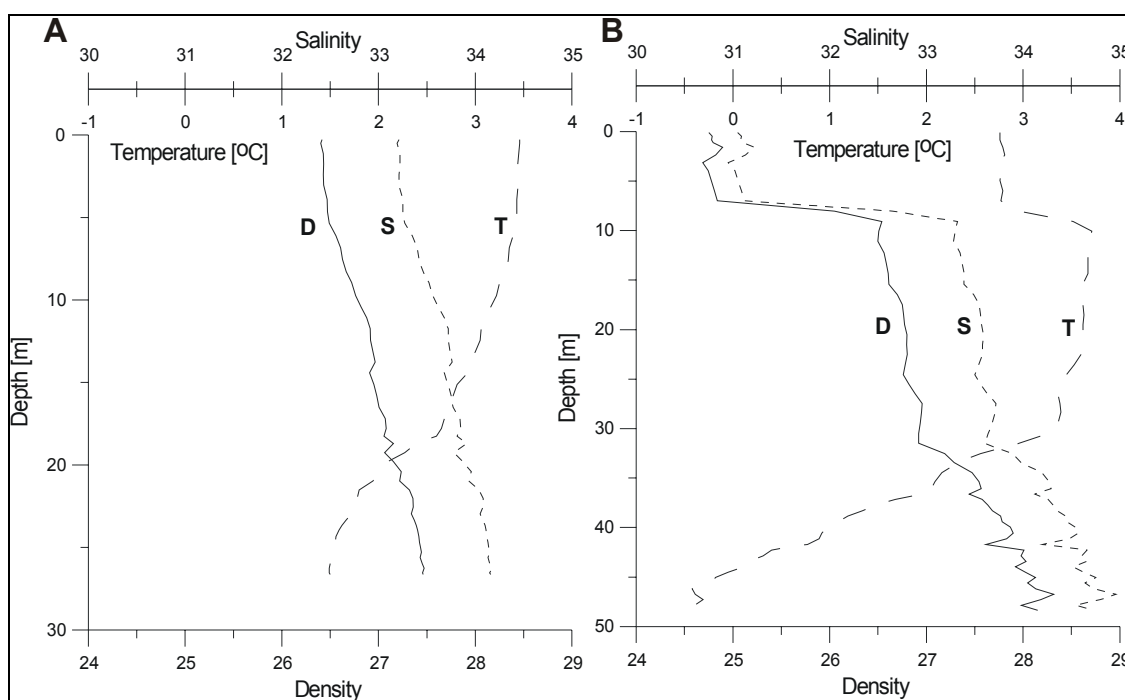


Fig.15. Salinity (S), temperature (T) and density (D) depth profiles at stations: a) B1 in Petuniabukta (330 m from the tidal flat edge) and b) at B3 in Adolfbukta (about 1.5 km from Nordenskiöldbreen ice cliff). During STD survey relatively strong wind and waves improved mixing at station B1; surface layer (7 m) of less saline and colder waters at B3 represents buoyant brackish water plume. Profiles were measured on 4th of August 2001.

The FW reaches 50 – 60 m water depth and is separated from underlying WCW by strong pycnocline and thermocline (Figs. 17, 18). Its thickness is limited by sill depth at the fjord entrance. Its temperature is in the range from -1.24 to 4.18 °C, and salinity varies between 33.56 and 34.98 PSU.

The deepest parts of the fjord are occupied by WCW. It is characterized by very low temperature (-1.76 to -1.44 °C), and high salinity (34.88 to 35.85 PSU). WCW is believed to be produced by salt rejection during sea-ice formation and sinking of dense very cold water in autumn and winter (Swerpel 1985; Gilbert 2000; Svendsen et al. 2002).

Water samples taken in proximal settings (Fig.7) in Petuniabukta (the first 3 km out from tidal channel outlets) and Adolfbukta (between 0.8 and 1.2 km from ice cliff) were analysed for conductivity, temperature, pH and suspended particulate matter concentrations (see chapter 4.5). The complete list of results is presented in Appendix I. The conductivity is correlated to salinity and along with temperature is summarized above. The pH is a relatively stable characteristic of analysed waters and varies between 7.3 to 8.1.

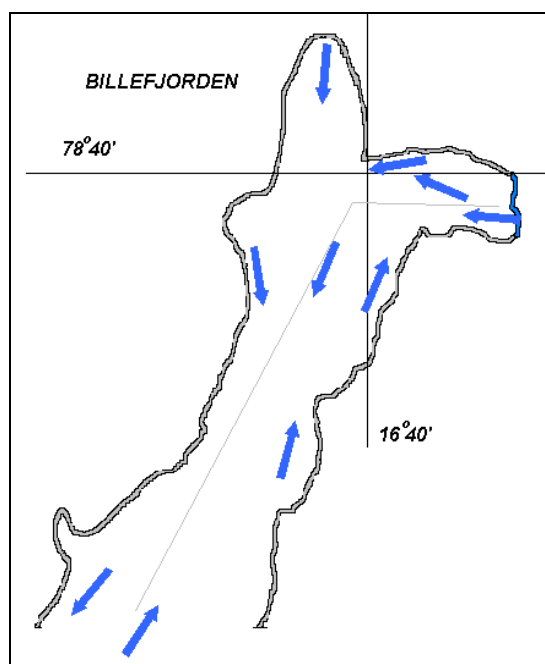


Fig.16. Simplified summer surface circulation pattern in Billefjorden. Coriolis force causes northward current along the eastern coast and reverse one along opposite shoreline. Offshore directed surface plumes in bays are driven by freshwater inflows. The gray line represents profile shown on Fig. 17 and 18.

4.4 FRESHWATER DISCHARGE

The freshwater influx to Billefjorden was estimated mainly for 2002 summer and fall seasons with emphasis paid to periods when sediment traps were employed.

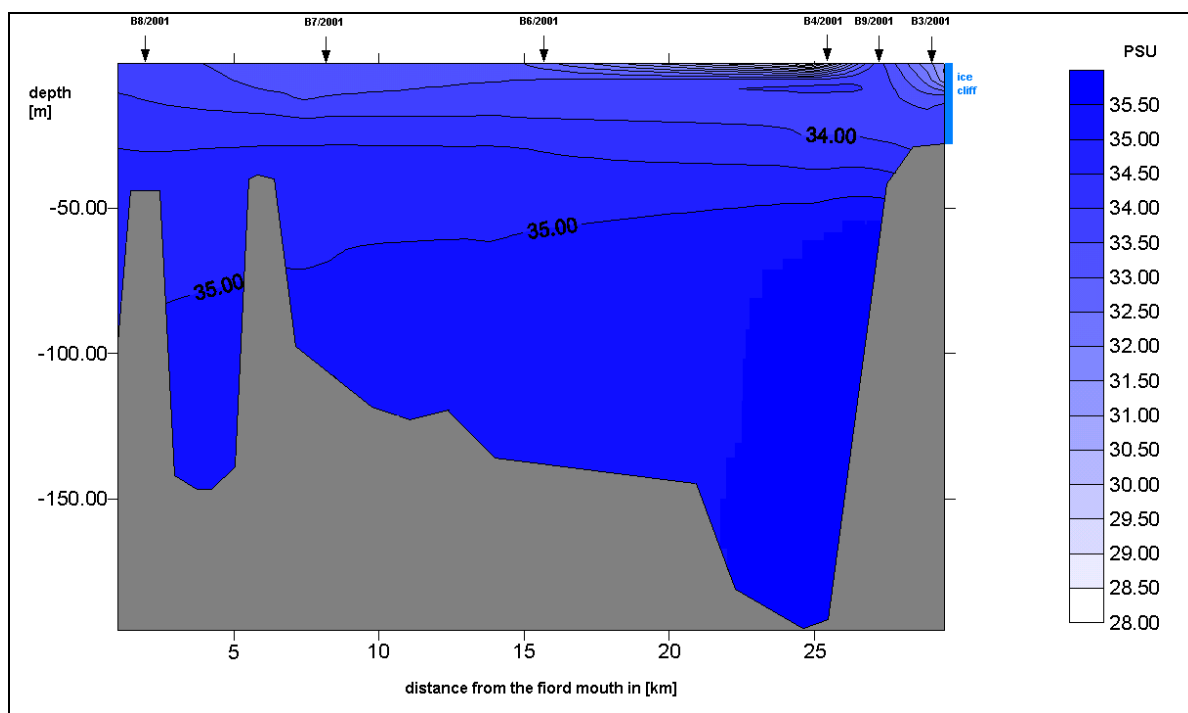


Fig.17. Water salinity [PSU – practical salinity unit] in the Billefjorden as measured on the 4th and 5th of August 2001. Interpolation, made by kriging, is based on data from stations B3, B9, B4, B6, B7 and B8. Profile location is shown on Fig.16.

River discharge to Petuniabukta was measured on three main rivers during the periods of sediment traps employment: 27-31.07.2002 (summer) and 17-20.09.2002 (fall). The averaged discharges for summer time were for the main rivers as follow: Hörbyeelva $14.07 \text{ m}^3 \text{ s}^{-1}$, for Ragnarelva $4.2 \text{ m}^3 \text{ s}^{-1}$ and for Ebbaelva $8.44 \text{ m}^3 \text{ s}^{-1}$. The total freshwater influx through tidal flat (including all the incoming rivers) was about $30 \text{ m}^3 \text{ s}^{-1}$. During the fall the discharge was drastically lower and most of the streams were frozen. The averaged discharges were $0.21 \text{ m}^3 \text{ s}^{-1}$, $0.2 \text{ m}^3 \text{ s}^{-1}$ and $0.19 \text{ m}^3 \text{ s}^{-1}$ for Hörbyeelva, Ragnarelva and Ebbaelva respectively. Total estimated influx during that period was about $0.6 \text{ m}^3 \text{ s}^{-1}$. (Data on river discharges to Petuniabukta after Rachlewicz 2003a and Rachlewicz et al. unpublished). With change in freshwater discharge also SPM concentration in river waters has fluctuated. For example the average concentrations in Hörbyeelva and Ragnarelva were 3.095 g dm^{-3} and 0.16 g dm^{-3} in summer and only 0.001

g dm^{-3} and 0.005 g dm^{-3} in fall (Rachlewicz et al. unpublished). The obtained average values agree with seasonal averages (Rachlewicz et al. unpublished) and are treated as representative.

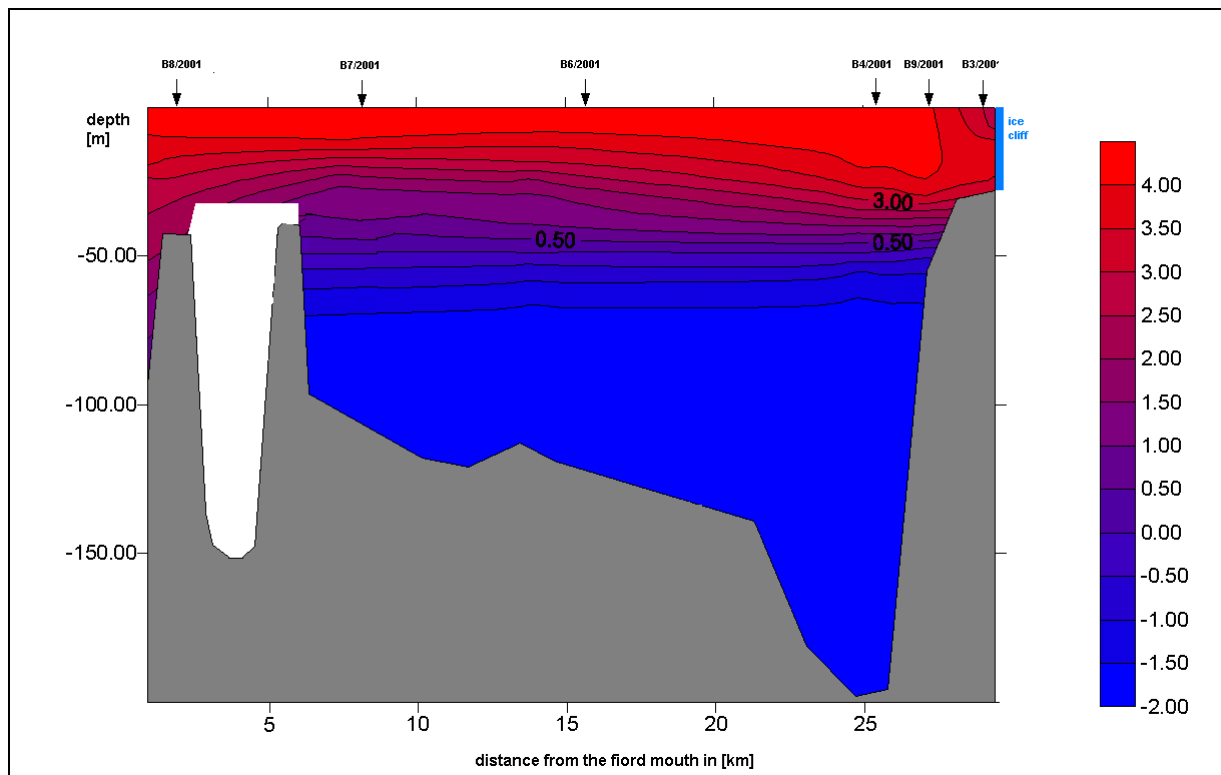


Fig.18. Water temperature [$^{\circ}\text{C}$] characteristic in the Billefjorden as measured on the 4th and 5th of August 2001. Interpolation was made by kriging and is based on data from stations B3, B9, B4, B6, B7 and B8. Water temperature in outer basin is not known. Profile location is shown on Fig.16.

Glacial meltwater discharge to Adolfbukta was estimated from spot measurements of water discharge made on inflowing rivers in summer and on calculation of freshwater influx from tidewater glacier (based on average velocity of outflow stream measurements and salinity profile). Nordenskiöldbreen supplies most of the water and SPM to the bay via two subglacial outflows in southern glacial bay, and lateral streams (Figs. 4, 7). The outflows merge a few hundred meters from the ice cliff and in calculation they are treated as a single one (the northern outflow is much stronger than southern one). The calculation is based on data from station B3 – about 1.5 km from the ice cliff. The average velocity of the outflow was 0.25 m s^{-1} . The thickness of the outflow stream was found to be 5 m (Fig.15) and its width was 350 m. The averaged freshwater fraction in brackish layer (averaged from calculations of nine sublayers) was 0.086. Estimated meltwater discharge

from the outflow is $37.6 \text{ m}^3 \text{ s}^{-1}$. The discharges from lateral streams were $1.21 \text{ m}^3 \text{ s}^{-1}$ and $8.27 \text{ m}^3 \text{ s}^{-1}$, respectively for northern and southern (which is composed of two bigger and a couple of smaller streams). The total freshwater flux to Adolfbukta in summer was estimated to be $48.9 \text{ m}^3 \text{ s}^{-1}$. The meltwater from ice cliff melting and icebergs melting is difficult to be estimated. However, attempts of calculations based on empirical equations provided by Weeks & Campbell (1973) and Russell-Head (1980) gave results of at least one order of magnitude lower. In fall the lateral streams were almost frozen and transported all together about $0.2 \text{ m}^3 \text{ s}^{-1}$, the discharge from the main outflow was not possible to be calculated, however, decrease in surface fjord water salinity was still observed suggesting that subglacial outflows were still active.

Freshwater discharge to Mimerbukta was studied by Gokhman & Khodakov (1986). They found maximum outflow of $30.6 \text{ m}^3 \text{ s}^{-1}$ and an average summer discharge of about $20 \text{ m}^3 \text{ s}^{-1}$.

Own observation on the other rivers flowing to Billefjorden shown that beside episodic floods with discharges of few $\text{m}^3 \text{ s}^{-1}$ they transport altogether up to $6 \text{ m}^3 \text{ s}^{-1}$. The total average freshwater discharge to Billefjorden is estimated to be in order of $110 \text{ m}^3 \text{ s}^{-1}$ during summer and $5 \text{ m}^3 \text{ s}^{-1}$ in early fall season.

4.5 SUSPENDED PARTICULATE MATTER CONCENTRATIONS

For over hundred water samples suspended particulate matter (SPM) concentration was determined (details in App. I). The majority of samples were collected in two profiles (Fig. 7) in proximal settings in Petuniabukta and Adolfbukta. The highest SPM concentrations were recorded in tidal channel outlets in Petuniabukta: 1660 mg dm^{-3} , the average values were in the range of $20 - 120 \text{ mg dm}^{-3}$ and the lowest $5 - 40 \text{ mg dm}^{-3}$. The latter were observed in deeper waters during early autumn. Usually the highest concentrations were noticed in surface water (in surface brackish water plume) and in near bottom waters.

The SPM concentration changes in tidal cycle are shown on Fig.19, where a 24 hours record is presented from station A1 (870 m from the outflow in ice cliff). The record documents two tidal cycles and shows that in general the highest concentrations are in surface water layer, especially during the ebb tide phase. At 20 m water depth the SPM concentrations are on average lower and the highest recorded values were found during high tide. Usually a complete range of particle sizes is released from the turbid overflow plume during each slack low tide when turbulence is at minimum (Cowan & Powell 1990). If the 20m SPM concentration maximum was the effect of settling of the suspended matter

from brackish plume during low tide then the SPM settling rate would be in order of 1 mm s^{-1} (approximately 15-20 m in 5-6 hours). Similar settling rates were reported from other fjord environments and are typical for flocculated particles (Hill et al. 1998; Curran et al. 2004). The near bottom waters have similar concentrations of suspended matter like at 20m depth except of one point with elevated value, which is ascribed to resuspension.

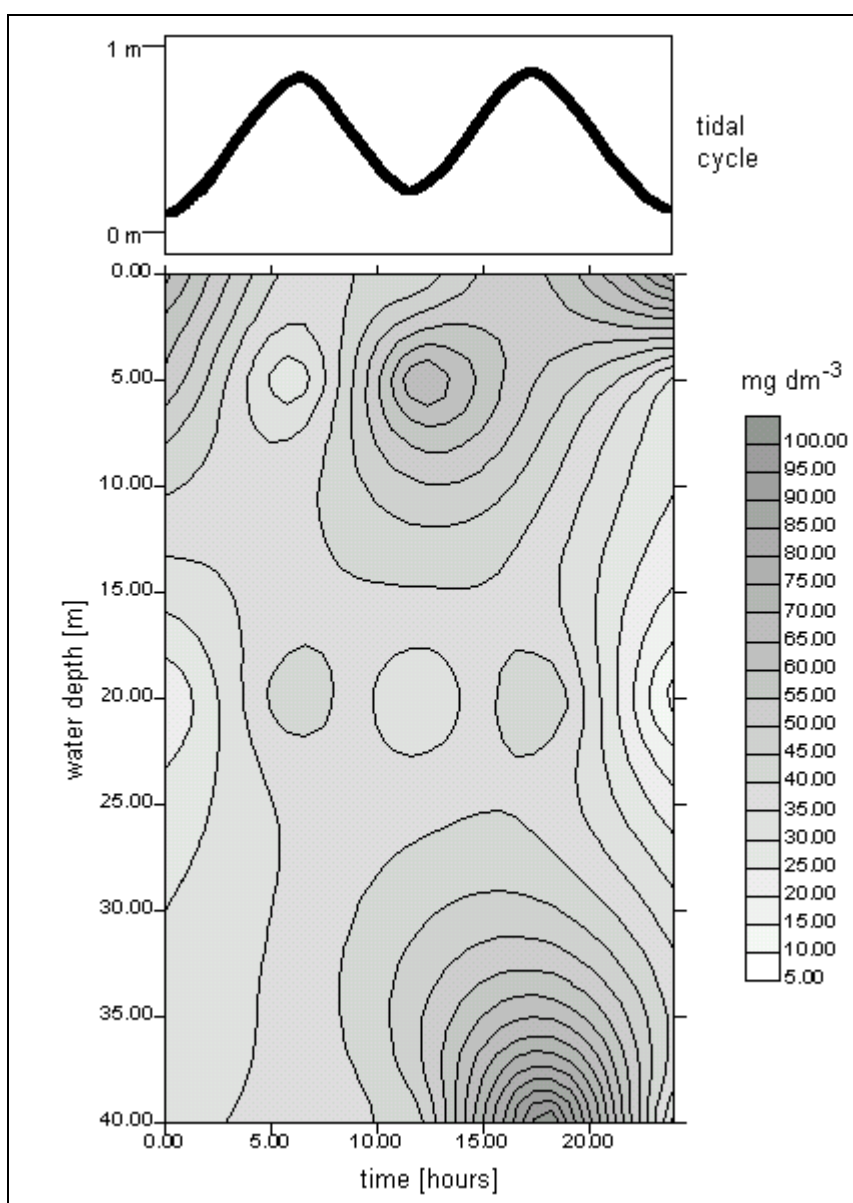


Fig.19. SPM concentration changes in tidal cycle (2-3.08.2002) at station A1 (870 m out from the ice cliff). Water samples were taken every 6 hours from the surface, 5 m, 20 m and 40 m water depth. Interpolation was made with kriging method. During the same period sediment traps were employed at 5, 20 and 40m and obtained particulate matter fluxes were 5.51 , 5.49 and $25.34 \text{ [g m}^{-2} \text{ day}^{-1}]$ respectively.

Seasonal and spatial changes in SPM concentration are shown in Fig.20. In Petuniabukta summer concentrations of SPM were the highest in surface and near bottom waters. Maximum in surface waters was probably associated with surface water plume, which was, however, not so well developed as in Adolfbukta (Fig.15). The near bottom increase in SPM was especially well visible at the prodelta slope and bottom. Although SPM measured in tidal channels was much below the $38,000 \text{ mg dm}^{-3}$ necessary to generate turbidity currents directly from inflow (Gilbert 1983), the elevated SPM at the sea floor may be caused by turbidity currents due to small slumps below the pycnocline on the rapidly oversteepening distributary's mouths and resuspension caused by turbidity currents and grain flows at the delta front. Such phenomena were reported and documented from similar settings by Prior et al. (1981), Phillips and Smith (1992) and Gilbert et al. (2002). During fall the average SPM concentration were two times lower than in summer. The maximum was in the vicinity of tidal flat and values decreased offshore. In the surface and near bottom waters, not alike in summer, the SPM concentrations were the lowest. The SPM concentration variation can be explained by lack of stratification (almost no freshwater discharge was observed at this time) and delivery of suspended matter from wave generated resuspension from tidal flat and upper prodelta slope. It is also advocated that the prodelta slope resedimentation processes (which are suggested to explain high near bottom summer SPM concentrations) may be at least partly driven by continuous delivery of sediment by rivers and thus are restricted mostly to summer period.

The SPM concentration in Adolfbukta in summer showed the highest value (70-80 mg dm^{-3}) in the surface water layer (upper 5 – 10 m), at the 20m water depth the values were at least three times lower. The near bottom waters had elevated SPM concentrations. The surface maximum is well correlated with surface brackish water plume. Much lower SPM concentrations below suggest that only a portion of particulate matter settles from above, the remaining SPM is advected further downfjord in surface plume. Near bottom elevated concentrations are tied to resuspension, which is privileged by undulated bottom relief. In fall season the SPM distribution was similar like in summer but the concentrations were about two times lower. The maximum was still in the surface water, which suggests that water stratification and meltwater discharge still existed.

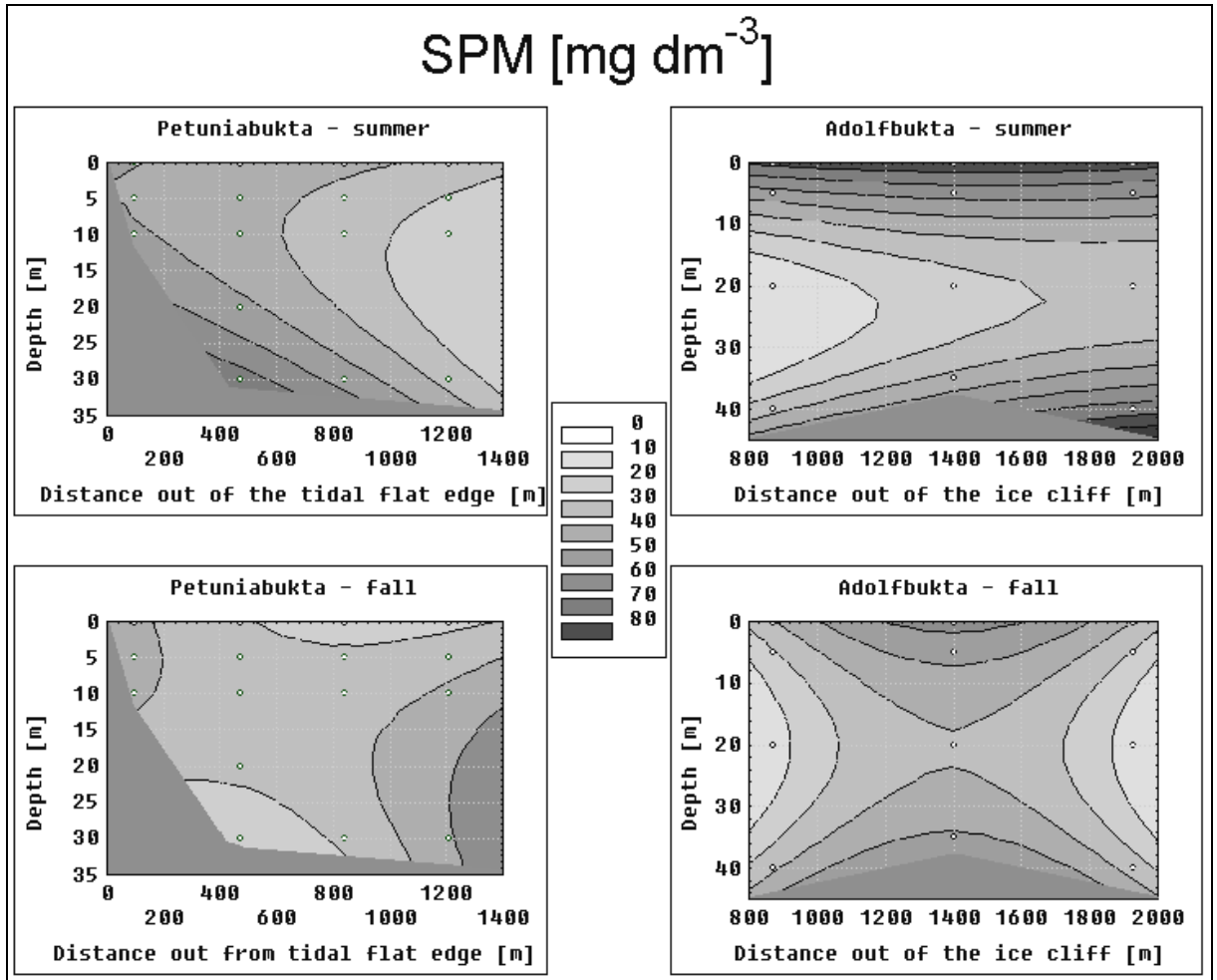


Fig.20. SPM concentration in Petuniabukta and Adolfbukta in summer and fall. Sampling points are marked with open circles. The data were collected in Petuniabukta on the 29th of July and 17th September 2002 and in Adolfbukta on 4th of August and 25th September 2002.

4.6 PARTICULATE MATTER FLUX

Particulate matter flux (PMF) was measured for summer and fall season in proximal settings of Petuniabukta and Adolfbukta (Fig. 7). The complete results are presented in App. IIa. In total 100 catches were collected.

During summer season in Petuniabukta the fluxes were usually in the range of 4 to 90 g m⁻² day⁻¹. The highest PMF was observed at the most proximal station (E1 – 100 m from tidal flat edge) and in offshore direction it dramatically decreased (Figs. 21, 22). The fluxes in upper and lower trap were usually very similar. Exceptional values of PMF were found for lower traps on stations located 100 and 400 m out from the source (on the delta slope), where once a trap was almost covered by sediment, it was probably caused by a grain flow or turbidity current. Similar values of the PMF in lower and upper traps suggest

that the matter is settling from surface plume. In early autumn (week after falling of air temperatures below 0 °C) the fluxes dropped significantly down to 0.25 -1 g m⁻² day⁻¹, so of an order of magnitude. The fluxes in upper and lower traps are similar and slight lateral increase in PMF in offshore direction was observed. The lowest values were found in most proximal upper trap – it suggests that the surface particulate matter laden plume did not exist anymore.

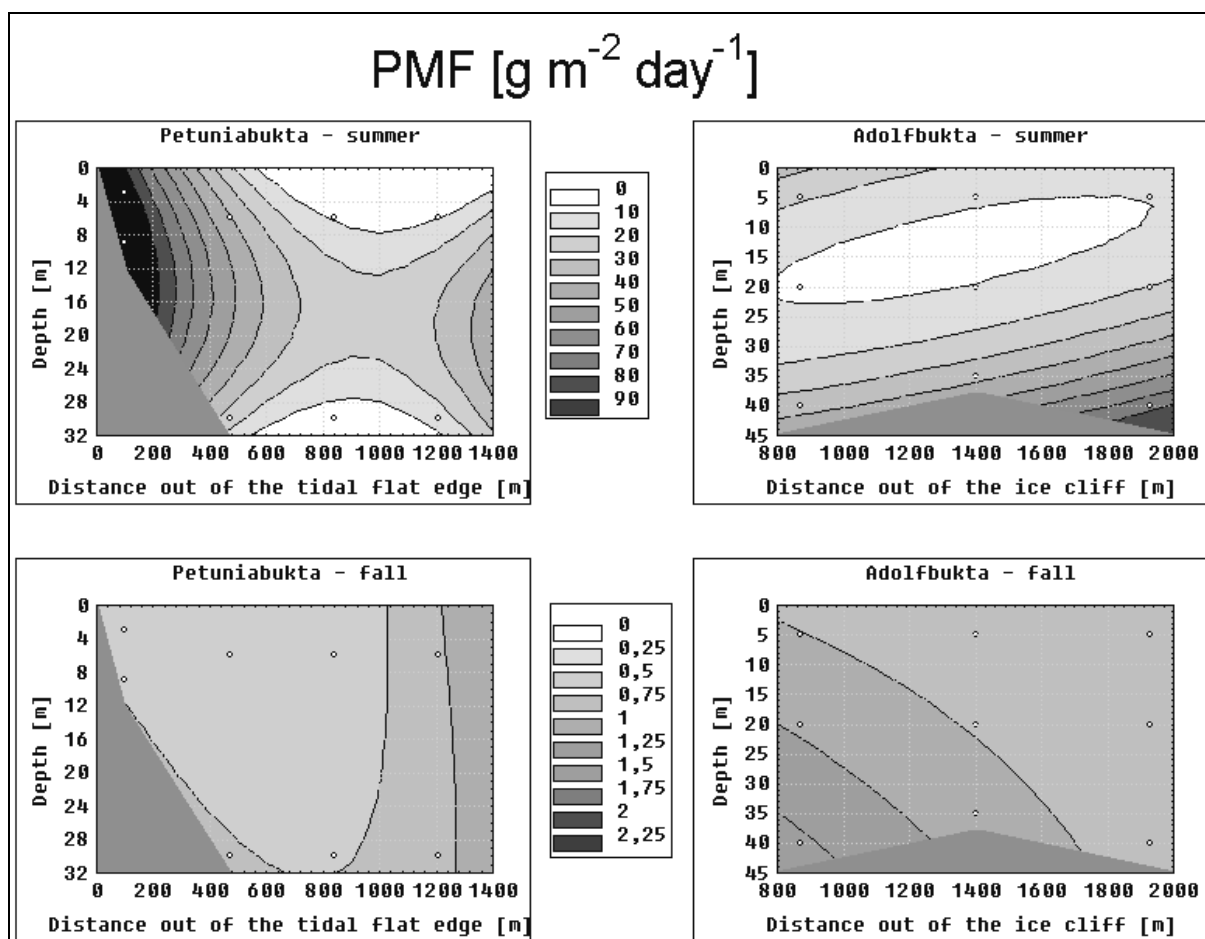


Fig.21. Particulate matter fluxes (PMF) in Petuniabukta and Adolfbukta in summer and fall. Sediment traps were employed in Petuniabukta on 27-31.07 and 17-20.09.2002, and in Adolfbukta on 2-5.08. and 23-26.09.2002. Note the independent scales for summer and fall seasons.

In Adolfbukta during summer the fluxes were the highest just below the surface brackish layer (20-30 g m⁻² day⁻¹) and in near-bottom traps (up to 70 g m⁻² day⁻¹). Mid water (20 m) fluxes were the smallest. At 5 m a slight offshore decreasing trends was observed (Fig.21, 22) and at 20 m increasing one. It could be associated with evolution and increasing thickness (due to mixing) of surface water plume. Higher sedimentation

rates close to the bottom are often ascribed to resuspension (Wassmann et al. 1996; Zajączkowski 2002). During fall the PMF had, as in Petuniabukta, radically dropped to 0.5 – 1.5 g m⁻² day⁻¹. Likewise slight decrease in offshore direction and with depth was observed.

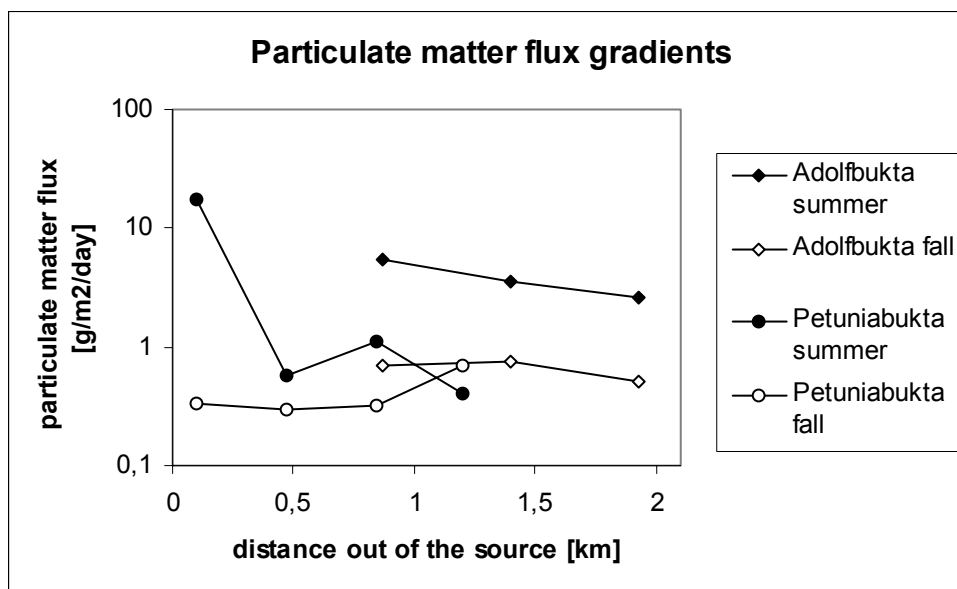


Fig.22. Comparison of particulate matter flux gradients during summer and fall. The fluxes are presented for upper sediment traps (to avoid influence of near bottom resuspension) – from 5 m and 6 m water depth for Adolfbukta and Petuniabukta, respectively. Note the logarithmic vertical scale.

4.6.1 GRAIN SIZE DISTRIBUTION OF TRAPPED SEDIMENTS

For samples collected in sediment traps during summer (samples from fall season were too small) disaggregated grain size distribution was obtained (complete results in App. IIb). The mean grain size ranges from very fine silt to coarse silt – but most of them belong to medium silt class (Fig. 23). Silt fraction constitutes usually of 70 to 90 % of the sediment. All analysed samples are unimodal, however, they are poorly to very poorly sorted.

In Petuniabukta (Fig. 23) in the most proximal station the sediment in upper and lower trap is nominally the same – they are also the coarsest among the analysed samples (sand content up to 15%), which can be easily explained by their proximal position. There was too little sediment in upper traps in more distal positions to analyse

them. Lower trap catches reveal fining in offshore direction except sample from E2, which is significantly finer. Although stations E1 - E4 were directly in line with discharge from the rivers, they may not have been continuously in axis of the plume body; consequently coarser sediments were found in stations E3 and E4 even though station E2 is closer to the source.

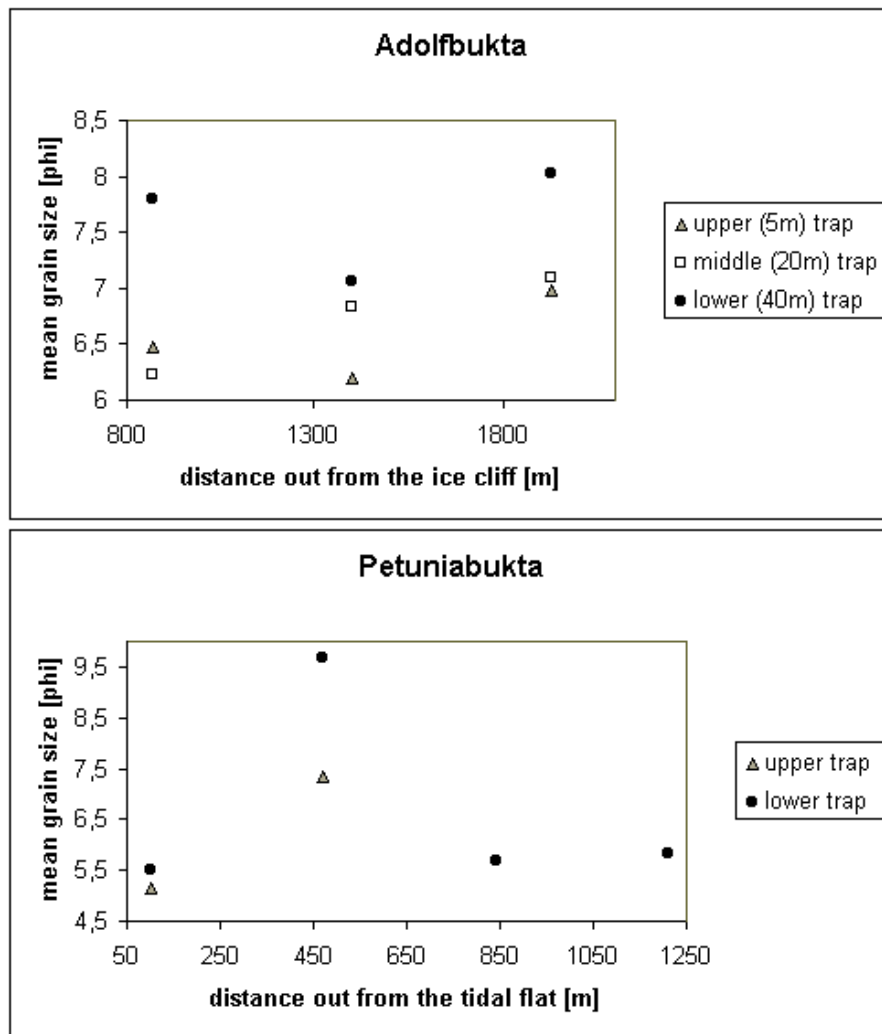


Fig.23. Relation of mean grain size values of particulate matter from sediment traps to distance from the material source as well as to the depth of trap deployment. In Petuniabukta the traps were on depths of 6 and 30 m except of the most proximal pair of traps, which were situated at 3 and 9m. The amount of material in upper traps on distal stations was not sufficient for analysis.

In Adolfbukta mean grain size decreased with depth and distance – especially the relation to water depth is well visible with coarser sediments in the upper traps and finer in the lower. It can be attributed to resuspension from the bottom – only finer particles were

resuspended, and they probably caused fining of the average grain size. The grain sizes from Adolfbukta are much more uniform than from Petunia possibly because their represent more distal environment.

4.7 BOTTOM SEDIMENTS

4.7.1 MACROSCOPIC SEDIMENT CHARACTERISTIC

The fjord sediments are brownish gray in color and belong mostly to mud and sandy mud facies, except of the delta front deposits in Petuniabukta, which are composed of silty sand (stations: B1A, B1). Pebbles, which are up to 4 cm in diameter, are common components. They are mostly amphibolites and schists (which compose parts of Nordenskiöldbreen bedrock). There are also some shells, mostly of *Hiatella sp.* and *Astarte sp.*, however, only in sediments from fjord entrance sill (station B8) calcareous components take a significant part. Besides mentioned bivalves there are also barnacles (*Balanus*), bryozoans, foraminifera and algal encrustation (*Lithothamnion sp.*). The uppermost sediment layer is composed of fluid mud (also referred as fluffy layer suspended matter). In Petuniabukta, the bottom is probably partly covered by *Ophiuroideas*, which can influence sediment properties (Gilbert 2000).

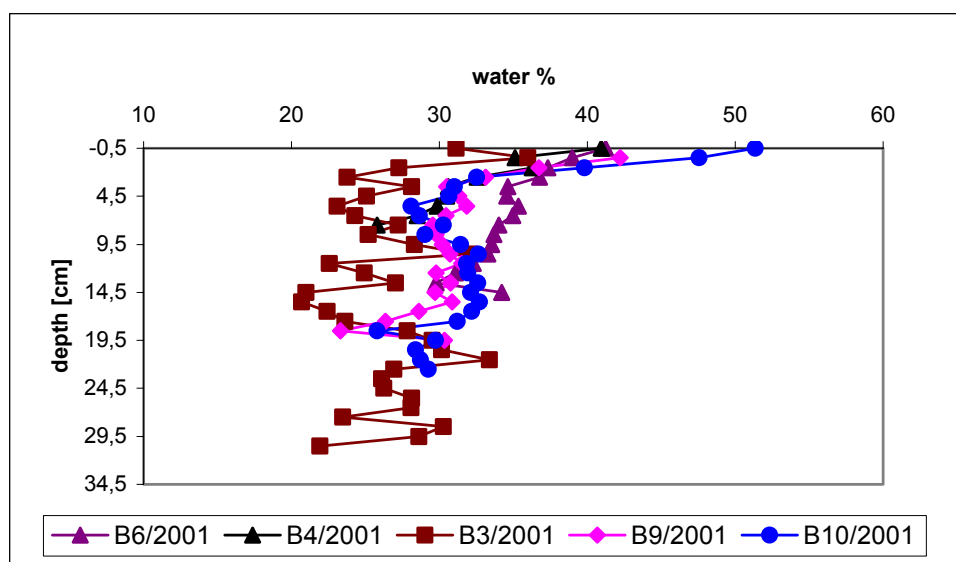


Fig.24. Minimum water content in selected cores from Billefjorden.

Because of sampling method (the cores were cut immediately after coring) it was hardly possible to observe any structures, however, the uppermost 2 – 3 cm of sediment

column was usually lighter – a common indication of oxidation conditions (Chester 2000). In some cores darker lenses and intercalations of possibly organic rich matter were visible.

4.7.2 WATER CONTENT

Water content was determined some time after sampling so although the sampling was done immediately on board and samples were kept closed in sealed bags and frozen, the per cents presented here can be only treated as minimum values. The complete list is presented in App.III. The water contents fall in the range of 20 to 40 %. Only in uppermost samples the water content reaches 40 to 53 %. At the depth of 1 – 5 cm it falls to a stable level, which is usually kept downcore (Fig. 24). It was the only physical property, which was measured in the same way on twin cores from every station and it shows relatively good correspondence between them (Fig. 25).

The sediment bulk densities were calculated using the water content values and representative bedrock density of 2.7 g m^{-3} . The obtained results vary from about 1.35 (for surface fluid mud) through 1.75 to 2.1 g m^{-3} .

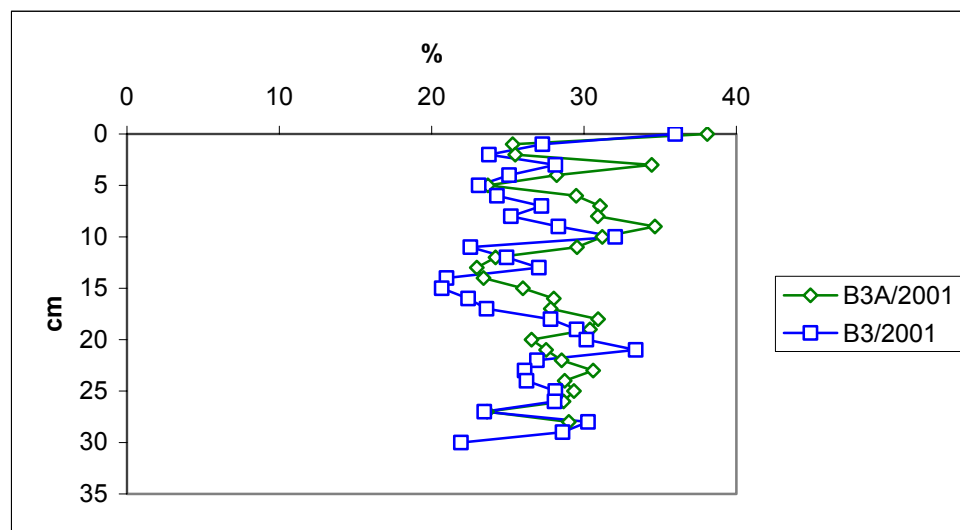


Fig.25. Minimum water content for two cores from the same locality – station B3.

4.7.3 GRAIN SIZE

The grain size distribution was determined through sieving on 63 μm sieve and succeeding analysis of finer and coarser fractions. The complete list of $> 63 \mu\text{m}$ fraction

content is presented in App. III, and in App. IV are shown results of all analyses of silt and clay fractions.

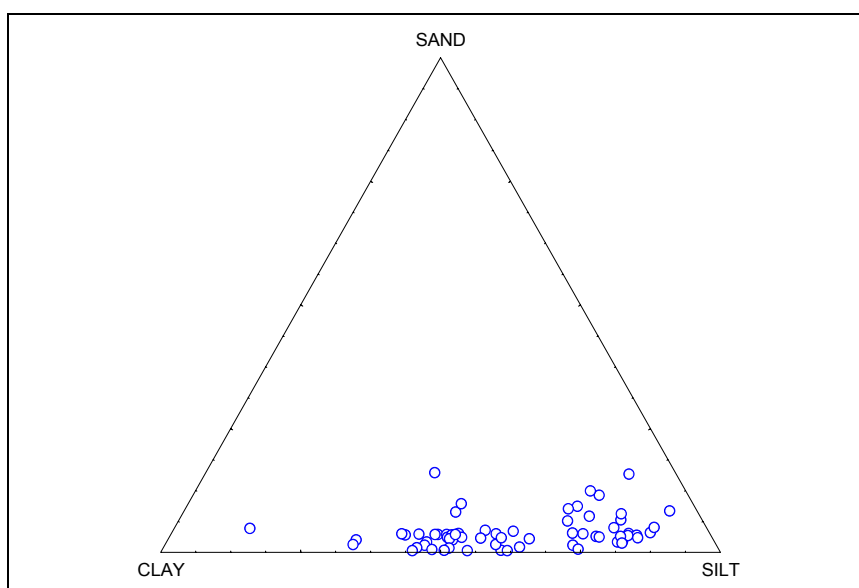


Fig.26. Relative content of clay, silt and sand fraction in samples from cores B3, B4 and B6.

Majority of samples belong to silt and mud fractions, a few are from sandy silt and sandy mud class (Fig. 26). The $>63 \mu\text{m}$ fraction content (Fig. 27) in sediments is relatively low, usually less than 10 %. Some exceptionally high values - up to 20 – 30 %, are caused by single pebbles, which perturb the results. The lowest values of the fraction are found in Adolfbukta (except the most proximal core – B3), where they do not reach 2%. In the rest of analysed cores both from Petuniabukta, proximal core in Adolfbukta (B3) and in central fjord cores the values are on average about 3 to 10 %. Downcore variations (Fig. 27) of sand fraction are relatively small, only in the core B3/2001 a kind of cyclicity, with maximum values at every 3 - 4 cm is observed.

Almost all analysed samples revealed bimodal grain size distribution (Fig. 28). The more prominent mode is in clay or fine silt fraction and the secondary one in sand fraction. It points to at least two modes of sedimentation (possibly from suspension settling and iceberg rafting). Only in the most proximal cores (B1 and B3) the sediments have unimodal distribution. Grain size statistics (using logarithmic method of moments) show that the sediments can be classified as poorly to very poorly sorted, very coarse skewed and very leptokurtic. However, the statistics are of low interpretation value for bimodal deposits.

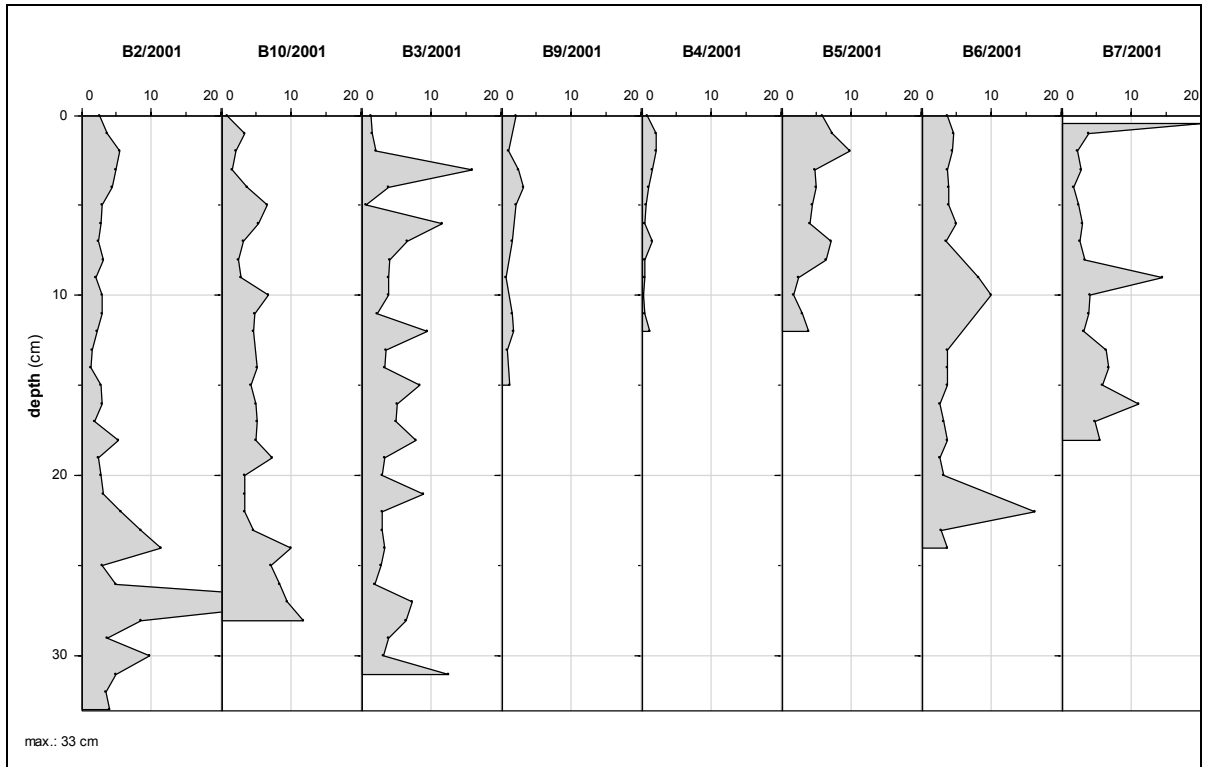


Fig.27. The >63 μm fraction content [weight %] in cores from Billefjorden. Two samples reached above scale values, in core B2 – 36% and in B7 – 33%. Cores B2 and B10 are from Petuniabukta, B3, B9 and B4 from Adolfbukta and remaining are from central part of the fjord.

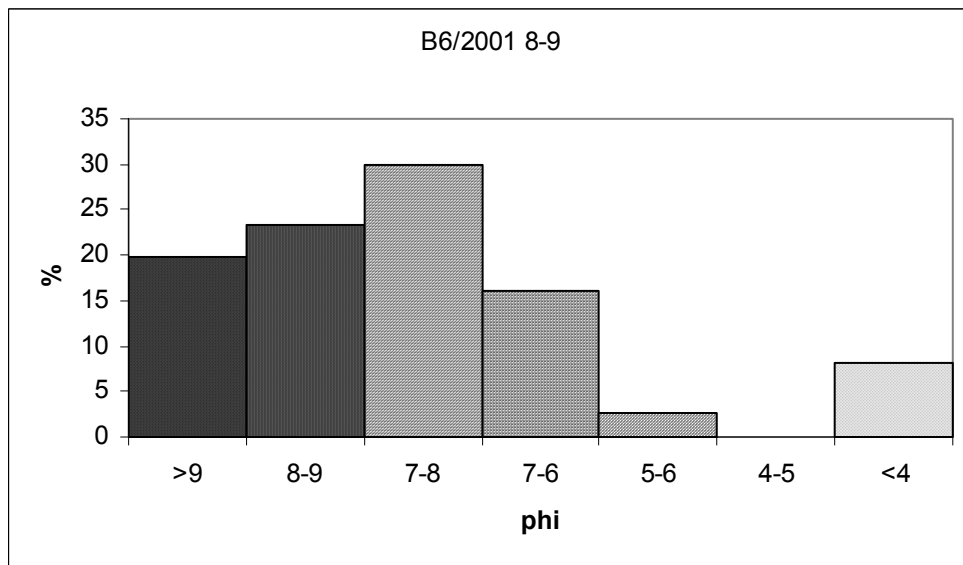


Fig.28. Typical example (sample B6/2001 8-9) of grain size distribution with underlined bimodality.

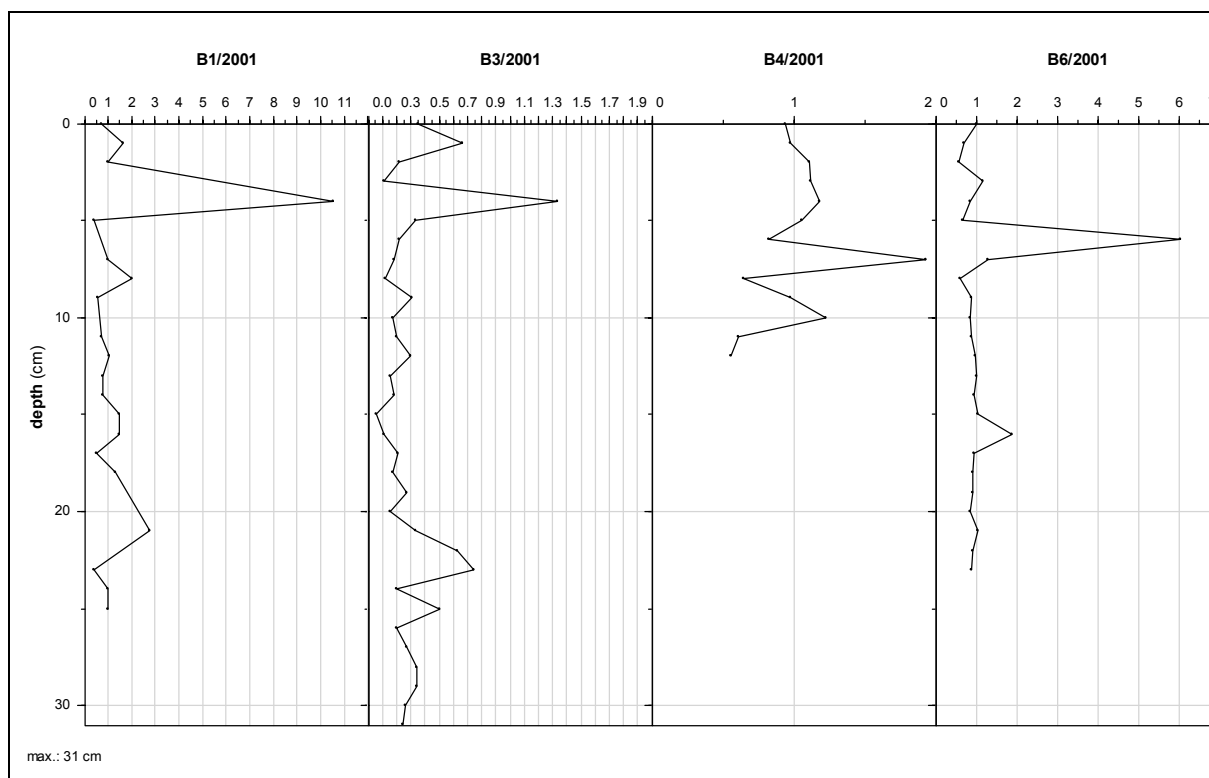


Fig.29. Clay to silt fraction ratio for selected cores (8 phi was used as a border value between clay and silt fraction). The lowest ratio (so the coarsest sediment) is in the B3/2001 core – proximal to Nordenskiöldbreen.

The clay to silt ratio varies (Fig. 29) independently from changes in $>63 \mu\text{m}$ fraction. Only in unimodal samples (core B3) the variation pattern is repeated. Most of the samples have the ratio close to one. The core B4/2001 shows a slight increase trend upward in the ratio value and B6/2001 the decreasing trend.

4.7.4 COARSE GRAIN FRACTION ANALYSIS

Qualitative and quantitative analysis of coarse grain fraction ($>250 \mu\text{m}$) is suitable for identification of short-lasting environmental changes. It allows to identify autochthonous (shells of organisms, foraminifera tests) and allochthonous (lithoclasts, plant-remnants as well as partly anthropogenically introduced coal sand) components. Complete list of results are presented in App. Va for $250 - 500 \mu\text{m}$ fraction and in App. Vb for $> 500 \mu\text{m}$ fraction. Figures 30 and 31 - 32 show examples of spatial and downcore variability, respectively, in the components.

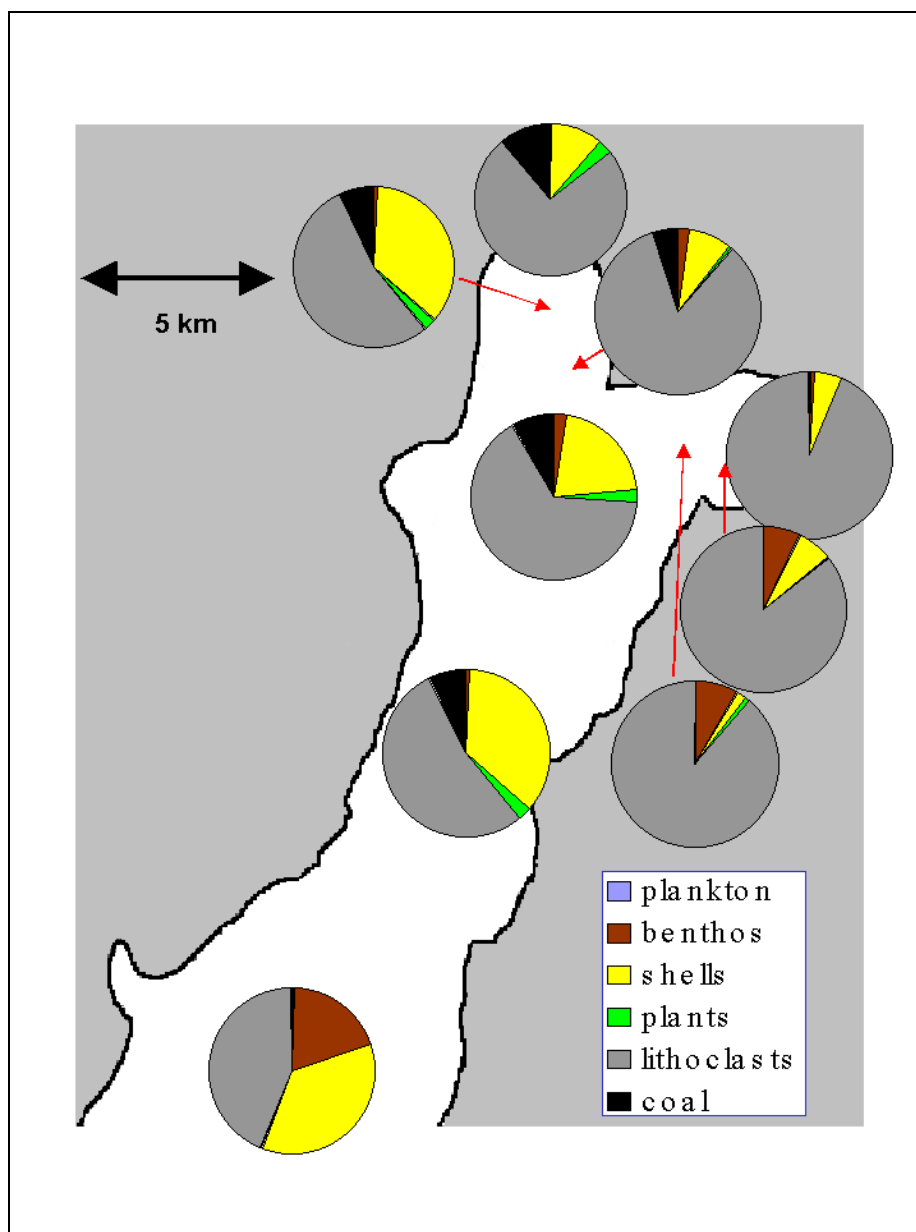


Fig.30 Coarse grain size analysis of >500 μm fraction in surface grab samples. Plankton and benthos stand for planktonic and benthic foraminifera respectively.

Lithoclasts constitute between 45 and 95 % of total number of grains in given fractions. They are the most frequent in Adolfbukta (Fig.30) where the studied size classes consist almost entirely of lithoclasts. The lowest participation is observed in the samples from the fjord entrance sill. Downcore variations in all the cores are driven mostly by fluctuations in the presence of other components – mostly foraminifera and coal. The finer fraction is composed mostly of quartz with significant portion of hematite-stained

grains (possibly from clastic source rocks of Devonian age, Bond et al. 1997). The grains in coarser class are mostly composed of parts of rocks: amphibolites and schists are the most common but also other types like limestone and anhydrite were found. The presence of the latter points to a very short transport path. This fraction was used for calculations of IRD index.

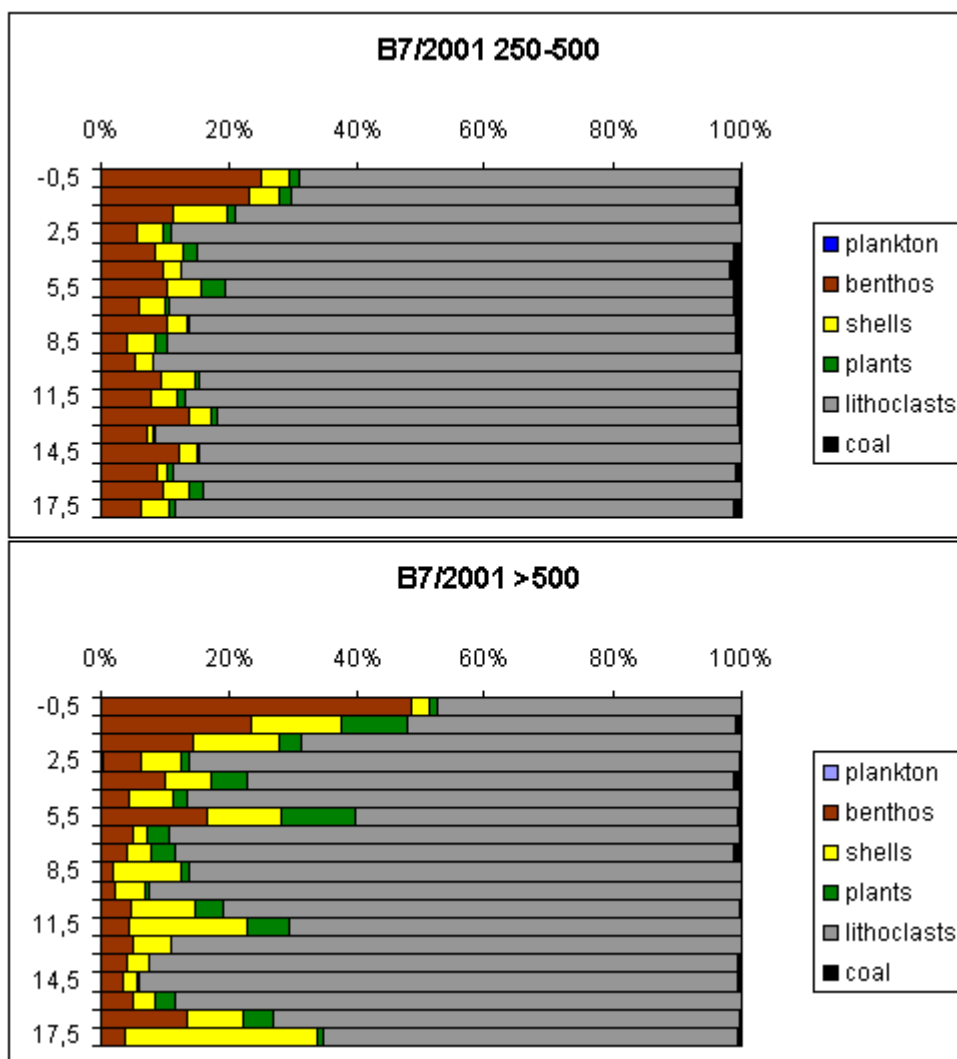


Fig. 31. Coarse grain fraction analysis for core B7/2001 in fractions 250-500 and > 500 μm . Plankton and benthos stand for planktonic and benthic foraminifera respectively.

Shell fragments are the second most common group of components. They constitute from a few percent to almost 50 % (in coarser fraction in central part of the fjord, in Petuniabukta, and at the entrance sill). In Adolfbukta they are almost absent. Among

the most common components of this class are: bivalve shell fragments, ostracoda tests and parts of bryozoan skeletons.

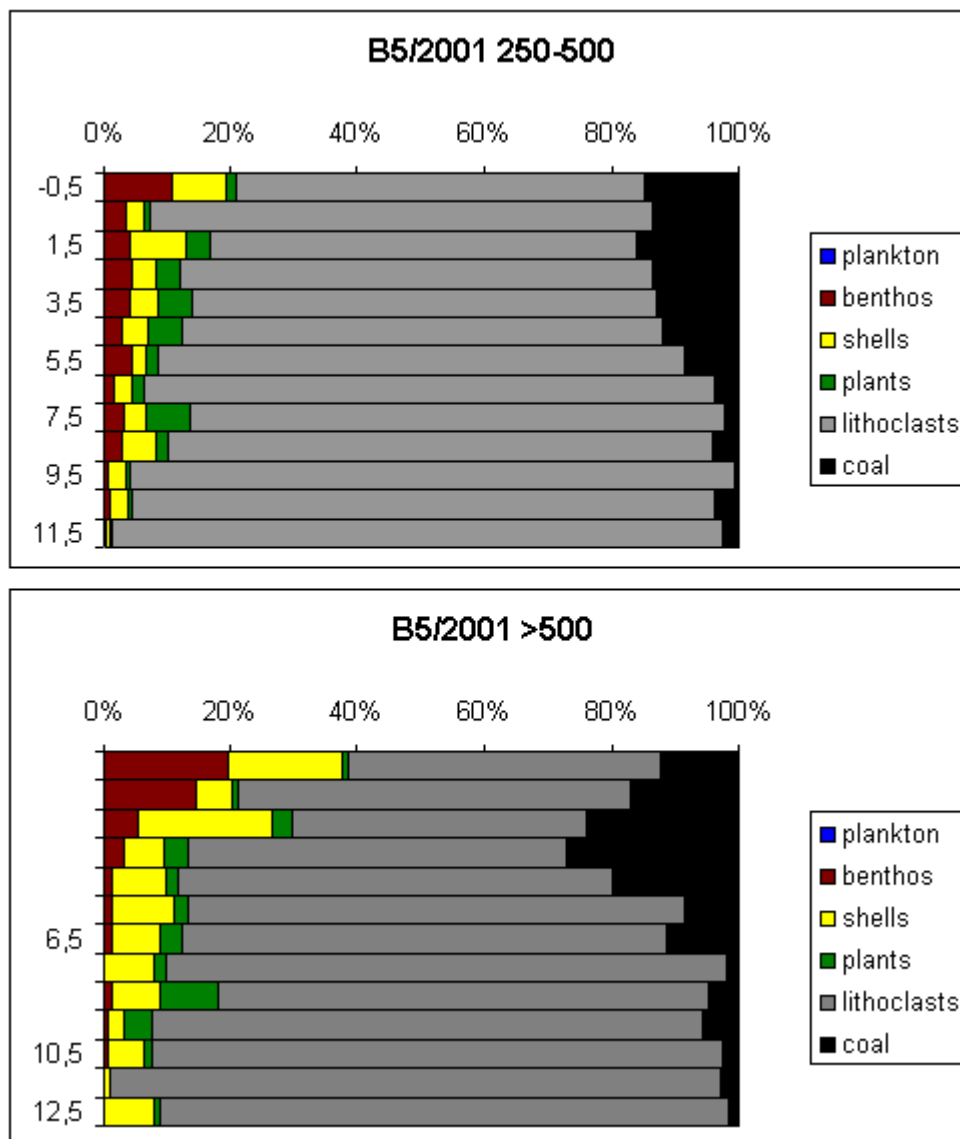


Fig.32. Coarse grain fraction analysis for core B5/2001 in fractions 250-500 and > 500 µm. Plankton and benthos stand for planktonic and benthic foraminifera, respectively.

Benthic foraminifera tests stand for up to 25 % (in one sample even 48 %), but only in surface samples – deeper they constitute 0 – 5 % of the studied fractions. They are more numerous in central fjord stations than in the bays (especially low contents of foraminifera are in Adolfbukta). Sharp downcore decline (Figs .31, 32) within several top cm is associated with abundance of agglutinated (aranaceous) foraminifera tests in surface layer and their total lack in the lower parts of the cores. The most plausible

explanation is a taphonomical decay of their cements below redox zone. *Cassidulina reniforme* and *Nonion labradoricum* were dominant species for middle and outer parts of the fjords, and the *Elphidium excavatum* for turbid water masses close to glacier termini, so similar to other fjords of Svalbard (Hald & Korsun 1997). Among the agglutinated foraminifera the *Alveolophragmium* (*Labrospira*) *crassimargo* species was the most common.

Planktonic foraminifera tests were found only occasionally in a few samples. Probably they were advected with water masses from outer part of Isfjorden.

Plant fragments were the most abundant (up to 40%) in B1/2001 core (in Petuniabukta) – close to outflows of the meltwater rivers, which cross several km of tundra covered areas. In most of the samples they constitute, however, only minor portion (a few percent), or are not found (in Adolfbukta). They are some downcore variations of their number, for example in B5/2001 (Fig. 32).

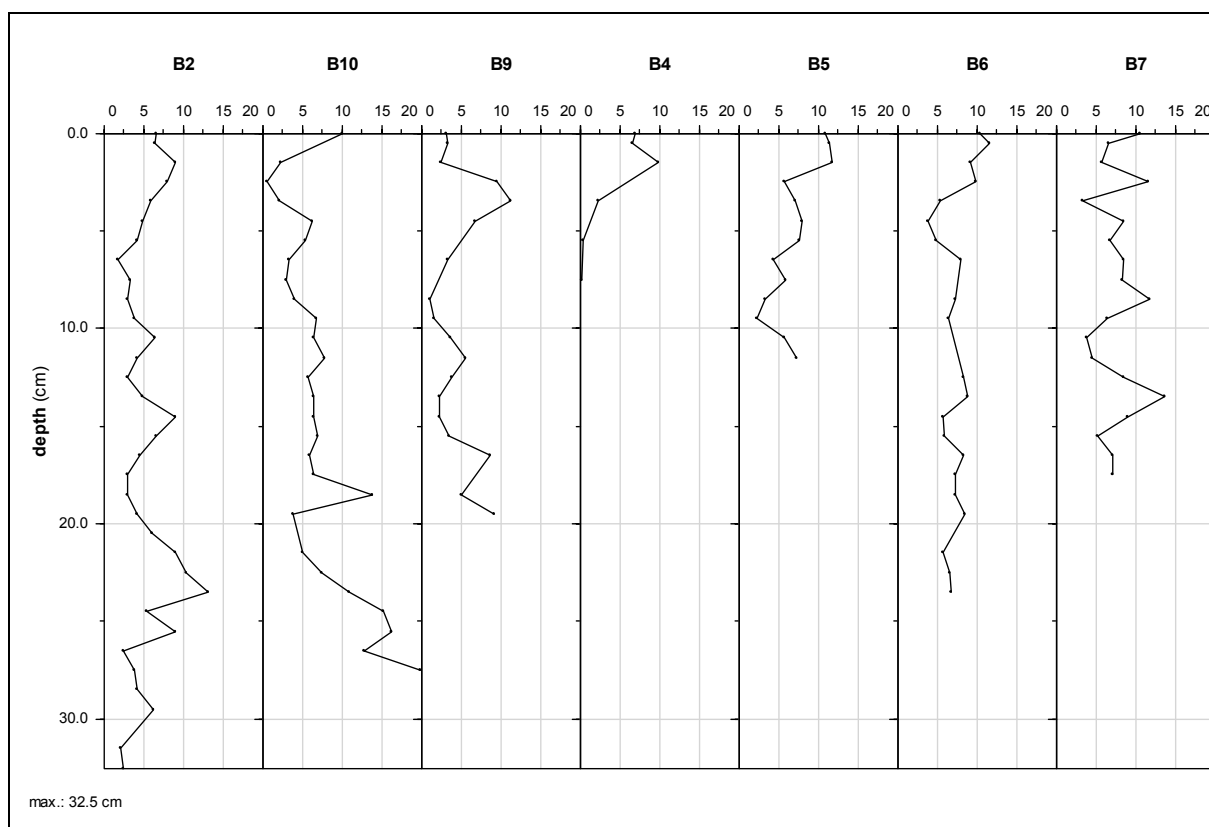


Fig.33: IRD variations in selected cores from the Billefjorden.

Coal sand and ash were observed only in limited part of the fjord: in its central part and in Petuniabukta. The maxima were in sediments from station B5 (the closest to

Mimerbukta, where Pyramiden settlement is situated), and from shallow portion of Petuniabukta (B1). The downcore changes in coal sand are evident especially in the B5/2001 (Fig. 32) and B6/2001 cores, where lower parts are depleted of coal and maxima are at the depths of 3 – 4 cm.

4.7.4.1 Ice rafted debris

Ice rafted debris (IRD) index is one of the most common proxies used for paleoenvironmental reconstructions (e.g. Bond et al. 1997; Smith & Andrews 2000; Hald et al. 2001; Winkler et al. 2002). Depending on the sedimentary environment (ocean, fjord) the grain size limits are different, and as shown in detail by Gilbert (1990), interpretation of this index requires a lot of caution. The grains in the studied class are not entirely transported by icebergs but also can be rafted by seashore ice or even by algae (Gilbert 1984).



Fig.34. Pebble with attached fucoid algae found on Petuniabukta tidal flat during low tide. The tidal flat is composed at that place of silty sand. Note the traces of rolling and dragging of the algae. The measure is 20 cm long.

Fig. 33 represents downcore variations of IRD in selected cores and in App. III is presented the complete list of results. The values of this index are in similar range for all

analysed cores, with lowest for the B4 and B9/2001 cores (both from Adolfbukta), and highest for stations from central fjord.

The grains in the studied fraction often represent crystalline rocks, which dominate the Nordenskiöldbreen basin. Some of them possessed also striae – evidently suggesting iceberg origin. However, observations in spring and early summer show that sea ice can also transport noteworthy portion of IRD fraction, especially in Petuniabukta. Furthermore, on the beaches and tidal flats, gravel clasts with attached fucoid algae (mainly *Fucus vesiculosus*, Fig. 34) were commonly found. As was determined by Gilbert (1984) such stones can be floated when the algae is at least three times heavier than the clast. Even if algae is not heavy enough it can strongly facilitate to drag and lift, and to transport much larger stones than would be possible otherwise. These mechanisms offer a means of transporting coarse sediments to deep water where they can be confused with ice rafted debris.

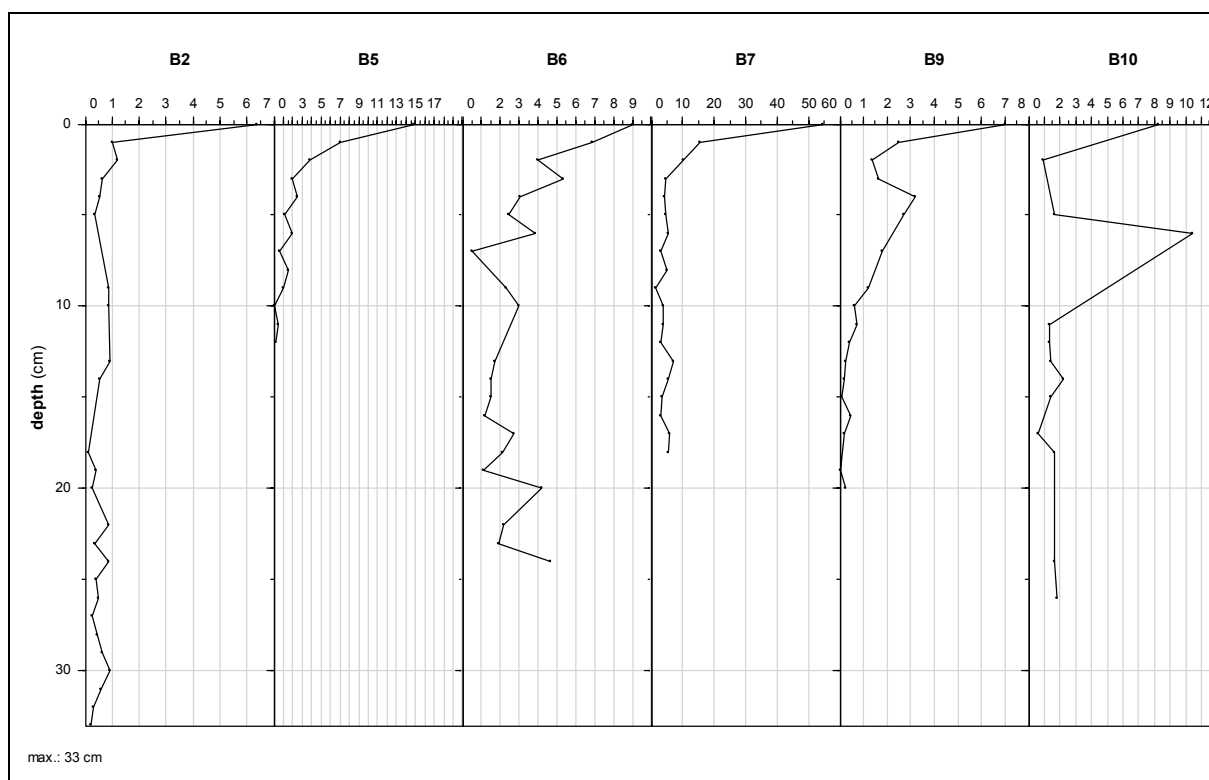


Fig.35. Concentration of benthic foraminifera (C_f) index for selected cores from the Billefjorden.

4.7.4.2 Concentration of benthic foraminifera

On the basis of coarse grain fraction analysis the concentration of benthic foraminifera (C_f) index was determined. The index was calculated as all counts in >250

μm fraction per gram of dry sediment. The C_f is own modification of commonly used indexes for planktonic foraminifera (e.g. Jennings et al. 2001). The complete list of results is presented in App. III, and most of them are shown on Fig. 35.

The C_f is the highest in the cores from central part of Billefjorden (Fig. 35). Its downcore distribution is marked by sharp decline from maximum values in uppermost parts of the cores, which is caused by dissolution of araneous foraminifera tests. In deeper portions of the cores only minor fluctuations are visible: minima in lower parts of the B5 and B9/2001 cores and in middle portion of the B6/2001 core.

4.7.5 CLAY MINERALS

Clay minerals were analysed in semi quantitative way in $< 2 \mu\text{m}$ fraction for selected surface samples (B1, B2, B4, B6, B8, B9, and B10) and in the cores B1 and B6/2001. Additionally seven samples from coastal and terrestrial deposits in Petuniabukta region were analysed.

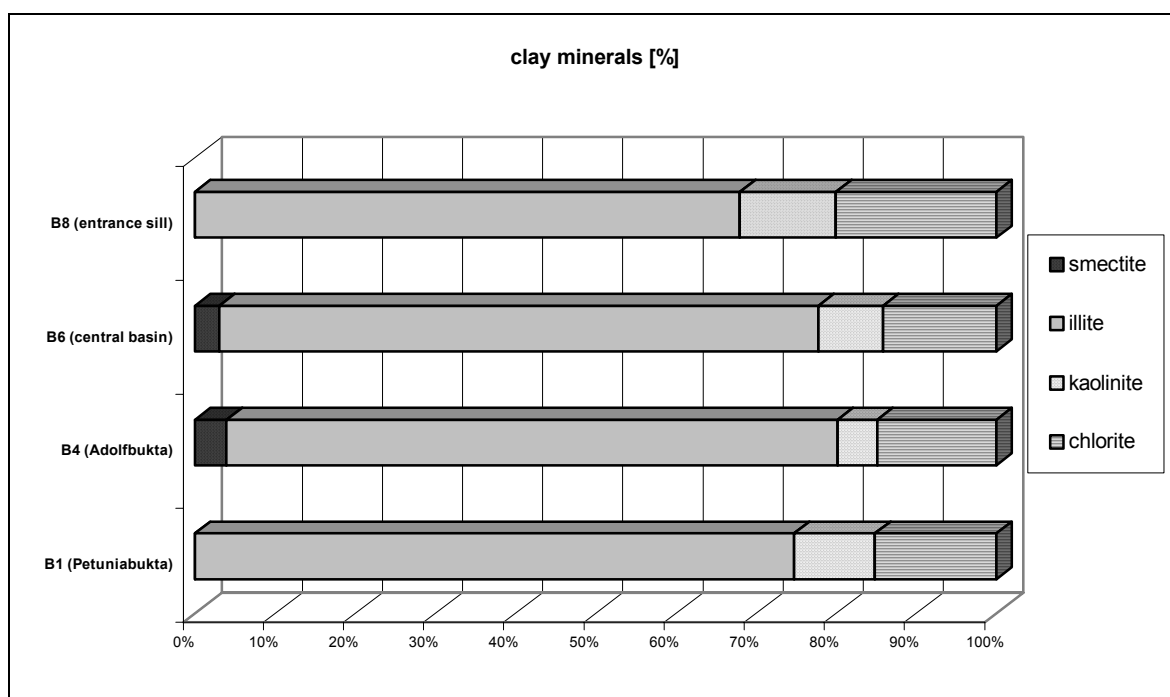


Fig.36. Participation of main clay minerals group in surface sediment samples. The shown examples are representative for the regions and also the downcore samples).

Four main groups of clay minerals were identified in the sediments: illite, chlorite, kaolinite and smectite. In the studied fraction ($< 2 \mu\text{m}$) also quartz and calcite was found. Their variations between samples were very small (Figs. 36, 37). Illite is the most frequent

mineral and it amounts to between 68 % (fjord entrance) to 77 % (Adolfbukta). The second most common clay mineral group is chlorite, which is between 14 – 15 % in all the samples, except the one from B8 station where it approaches 20 %. The kaolinite group is the least common in Adolfbukta (5 %) and central basin (8 %). In Petuniabukta and at the fjord entrance it had slightly higher concentrations, 10 and 12 %, respectively. The most rare group was smectite – it was found only in sediments of Adolfbukta and in central part of the fjord in small amount (3-4 %). There are no downcore variations in clay mineral composition in studied cores (Fig. 37).

Illite, kaolinite, chlorite group and in few samples also vermiculate were found in samples from weathering covers (on rocks dominated by Carboniferous carbonates) and from tidal flat in Petuniabukta. Smectite was not found – alike in Petuniabukta fjord sediments. Vermiculate is not a stable phase in marine environment (Chamley 1989), and was probably changed to illite. The obtained results are in agreement with previous studies on clay minerals in terrestrial and coastal deposits of Petuniabukta region (Stankowska 1989).

4.7.6 CARBONATE CONTENT

Carbonate content was investigated spatially and downcore. Complete list of results is in App. III. The carbonate content variations in surface sediment (Fig. 38) allow distinguishing of three regions: Adolfbukta (with 12-14 % of carbonates), Petuniabukta (15-21%) and the central part of Billefjorden (20-27 %). The carbonate content does not correlate to water depth and probably reflects source area geology and bioproduction. The latter is proved by good correlation between carbonate particles in sand fraction (shell fragments and foraminifera tests) with carbonate content (Figs. 30 and 38).

The downcore variations are in the range of 3% (for B6A/2001) to 9% (for B2A/2001). In some cores trends in this deviations are observed (Fig. 39). An evident downcore decrease in carbonate content is visible in cores: B5A/2001, B6A/2001 and B10A/2001. The B4A/2001 core revealed small downcore increase and in cores B3A/2001 and B9A/2001 a kind of semicyclic variation was observed.

4.7.7 MAJOR ELEMENTS

The major elements: Si, Al, Na, K, Fe, Ca, Mg, Mn, Ti, P (traditionally listed as oxides) and LOI (loss on ignition) were determined for all the surface samples and selected cores (B4, B5, B6, B7) using X-ray fluorescence spectrometry (XRF). The detailed results are listed in App. VIa, and are illustrated in Figs. 40 - 44. Bulk chemical

deviations in the major elements in surface samples are displayed on variation diagrams using Al_2O_3 along x-axis (Fig.40), and correlation factors between the elements are listed in Tab.3.

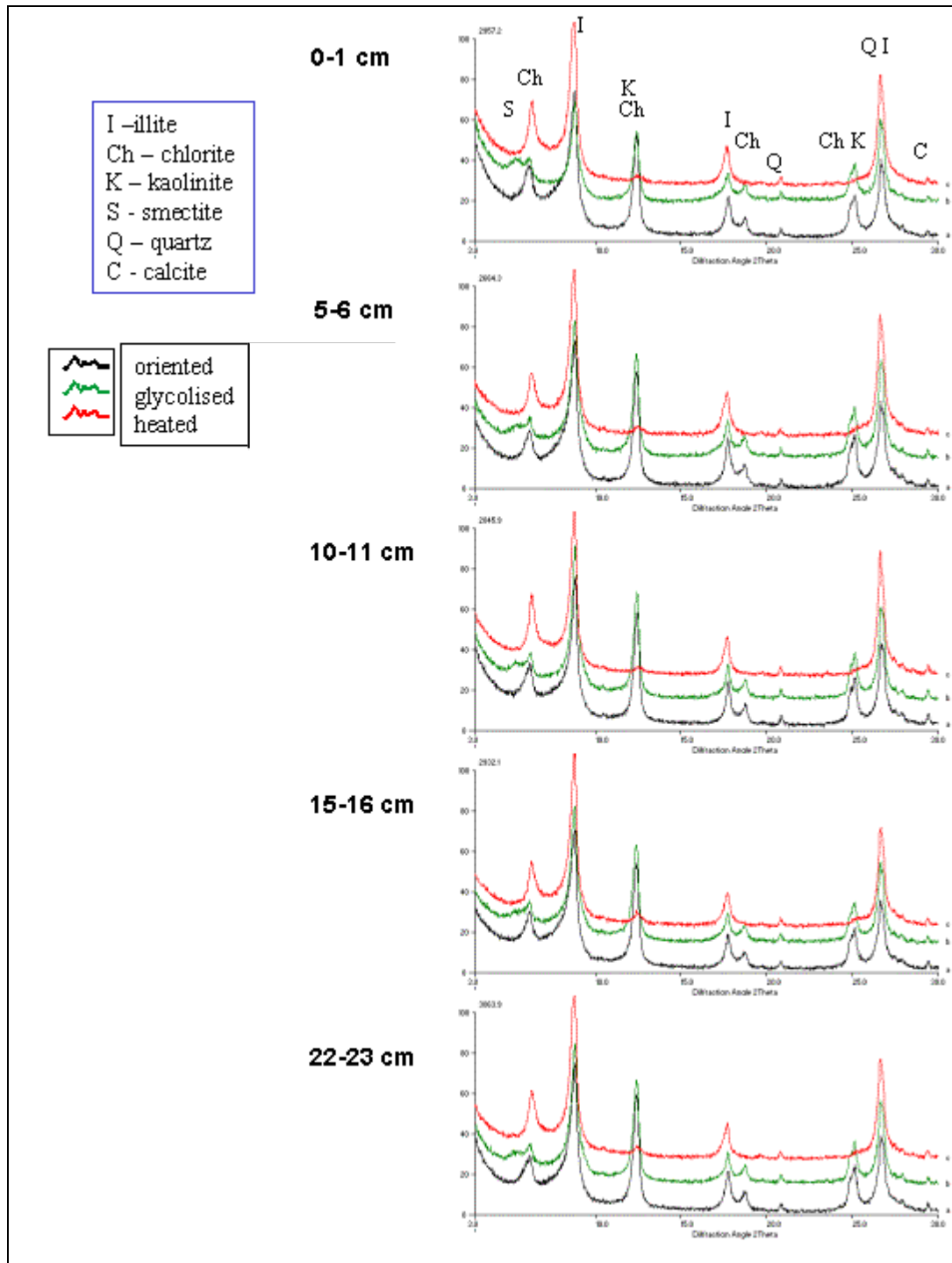


Fig.37. X-ray diffractograms of $< 2 \mu m$ fraction in the core B6/2001. All the samples along the core represent identical clay mineral composition, which is dominated by illite group with subordinate amount of minerals from chlorite, kaolinite and smectite groups.

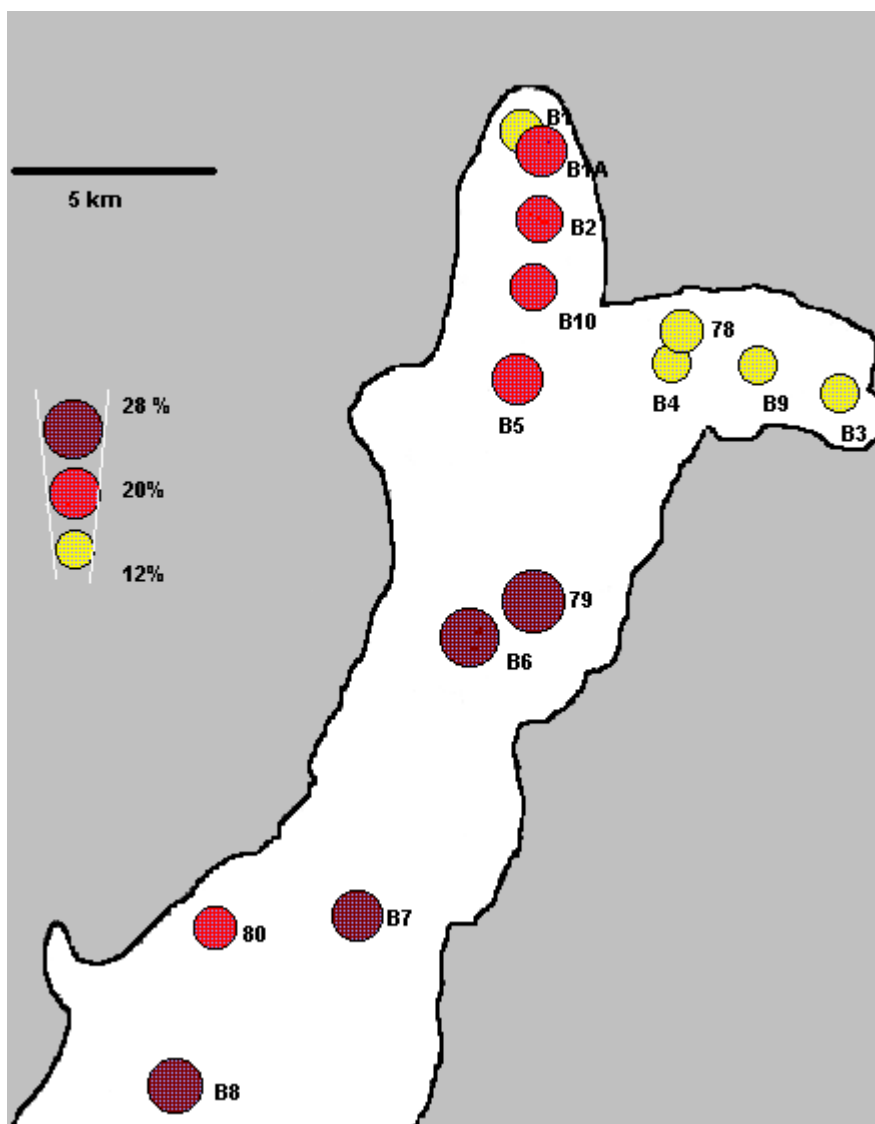


Fig.38. Carbonate content in the surface samples. Samples 78, 79, 80 from Hald & Korsun (1997) were included for comparison.

In general the samples are composed primarily of Si, Al, Ca, Mg, Fe and K. Between 73 and 86% of bulk samples are composed of Si, Al and carbonates. Most of the remaining elements concentrations correlate to one of these three.

SiO₂ constitutes from 41.67 % in surface layer of the B6A/2001 cores (Fig. 43) to 57.86 % in sediments from the B3 station. In surface sediments the biggest concentrations it has in Adolfbukta (over 52 %) next in Petuniabukta (48 – 52 %) and the lowest in central fjord deposits (42 – 50 %) (Fig. 40). In all the analysed cores downcore decline in concentration was observed, especially in the B5 and B6 cores, where a step like change in its concentration is visible at few cm depth (Figs. 42, 43). The changes are

accompanied by reverse trends in Al_2O_3 (station B4, Fig. 41) or carbonates (stations B5-B7, Figs. 42 - 44) content. The first relation (Si versus Al) is usually attributed to grain size composition changes (and indeed they are observed in the B4 core, Fig. 29). Si is related to coarser fraction (silt and sand) and Al to finer (clay minerals). Also surface samples from Adolfbukta and partly from Petuniabukta show a very good negative correlation between SiO_2 and Al_2O_3 (Fig. 40) – supporting grain size control. However, in the remaining surface samples and cores they are positively correlated (Fig. 40). It is believed that in this group minerals containing Si and Al are delivered in the stable proportion and bulk content is controlled by the third factor – calcium and manganese carbonates (Fig. 40, for cores see Figs. 42 - 44). SiO_2 reveals also very high correlation to K_2O and TiO_2 contents. It can point to common presence of potassium feldspar and biotite (they were indeed observed in samples).

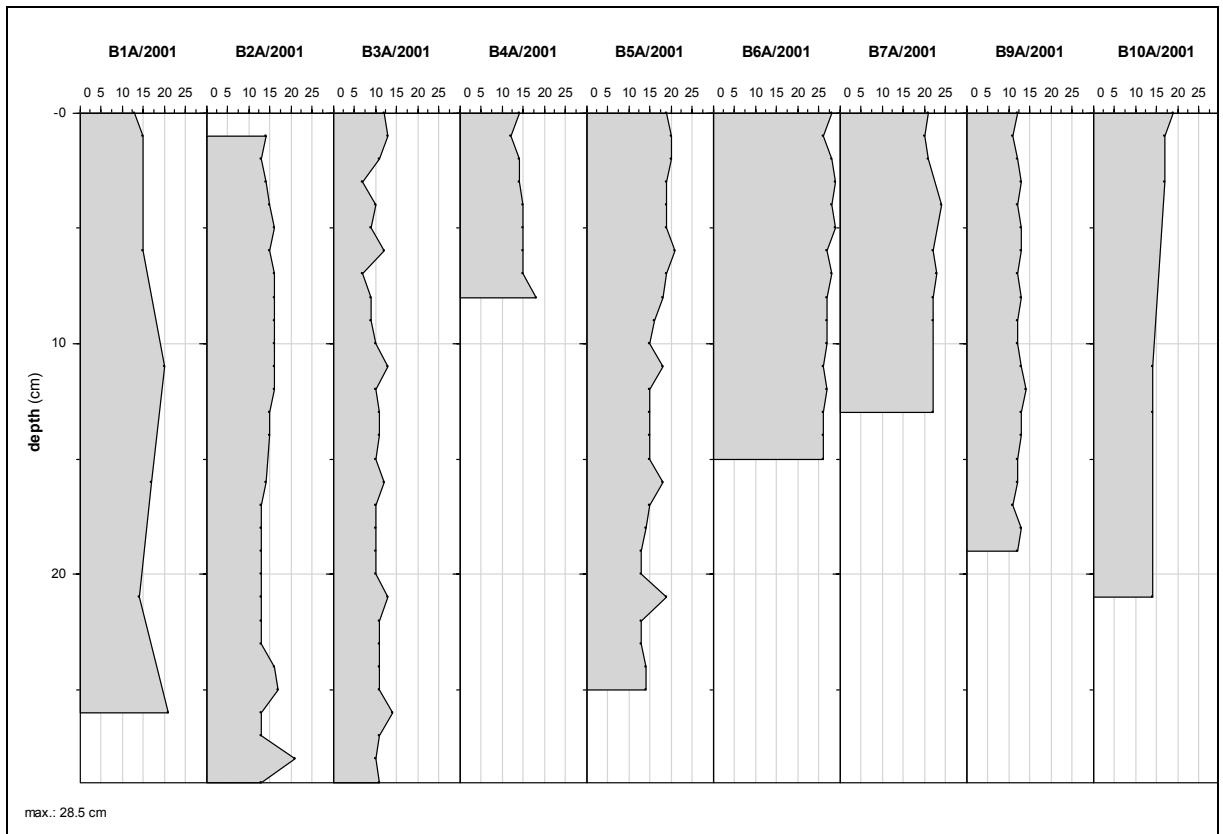


Fig.39. Downcore variations in carbonate content for the cores from the Billefjorden. Values are given in %.

Al₂O₃ contents in studied samples varied between 10.66 % and 15.01 % with maximum values in sediments of Petuniabukta. Good correlation between Al and Ti (Tab.3) points to possible presence of fine grained aluminosilicate minerals.

Na₂O concentration is between 1.01 % and 2.32 %. Its contents are however not correlated to any of the other components (Tab.3). It could be caused by sea salt contamination so significance of this element for further analysis is limited.

Tab.3. Correlation between major elements concentrations, LOI and carbonate content based on 58 samples. The most significant correlations are marked in red.

	SiO ₂ (%)	Al ₂ O ₃ (%)	Na ₂ O (%)	K ₂ O (%)	Fe ₂ O ₃ (%)	CaO (%)	MgO (%)	MnO (%)	TiO ₂ (%)	P ₂ O ₅ (%)	LOI (%)	Carbonate (%)
SiO ₂ (%)	1.00	0.40	0.34	0.81	0.18	-0.90	-0.91	-0.37	0.86	-0.57	-0.97	-0.89
Al ₂ O ₃ (%)	0.40	1.00	0.08	0.66	0.71	-0.62	-0.51	-0.45	0.77	-0.46	-0.53	-0.56
Na ₂ O (%)	0.34	0.08	1.00	0.33	0.42	-0.49	-0.36	0.13	0.34	0.29	-0.38	-0.58
K ₂ O (%)	0.81	0.66	0.33	1.00	0.48	-0.80	-0.74	-0.40	0.91	-0.55	-0.91	-0.82
Fe ₂ O ₃ (%)	0.18	0.71	0.42	0.48	1.00	-0.49	-0.24	-0.08	0.52	0.09	-0.33	-0.45
CaO (%)	-0.90	-0.62	-0.49	-0.80	-0.49	1.00	0.86	0.32	-0.91	0.44	0.91	0.96
MgO (%)	-0.91	-0.51	-0.36	-0.74	-0.24	0.86	1.00	0.44	-0.83	0.46	0.90	0.88
MnO (%)	-0.37	-0.45	0.13	-0.40	-0.08	0.32	0.44	1.00	-0.43	0.50	0.37	0.31
TiO ₂ (%)	0.86	0.77	0.34	0.91	0.52	-0.91	-0.83	-0.43	1.00	-0.57	-0.92	-0.90
P ₂ O ₅ (%)	-0.57	-0.46	0.29	-0.55	0.09	0.44	0.46	0.50	-0.57	1.00	0.56	0.39
LOI (%)	-0.97	-0.53	-0.38	-0.91	-0.33	0.91	0.90	0.37	-0.92	0.56	1.00	0.92
Carbonate (%)	-0.89	-0.56	-0.58	-0.82	-0.45	0.96	0.88	0.31	-0.90	0.39	0.92	1.00

Sediments from Adolfbukta contain the highest amount of K₂O (up to 3.92 %) and in the central basin deposits are its lowest contents (1.88 % - B7 station). Potassium content reveals high positive correlation to Si, Ti and also Al. It suggests that the main K-bearing mineral phases are potassium feldspars and illite. The spatial and downcore distribution (Figs.40 - 44) are similar as in the cases of Si and Al. The downcore distribution mimics the one of Al – with downcore increase in the case of the cores B5 – B7, and decrease in the B4 core.

Fe₂O₃ has concentration in range of 4.29 % to 5.83 %. It has relatively high correlation to Al (Fig. 40), but almost no correlation to the other elements (Tab.3). It would suggest different mineral phases containing Fe (biotite, hematite, clay minerals) and possible early diagenetic changes.

CaO content in sediments is between 6.12 % in Adolfbukta and 11.23 % (at fjord sill – station B8). It has a very strong positive correlation to carbonates, MgO and LOI, and negative one to SiO₂, K₂O and TiO₂ (Tab. 3). It implies that almost entire Ca is tied in carbonate fraction, and indeed its spatial and downcore distribution mimic the carbonates (Figs.38 - 44).

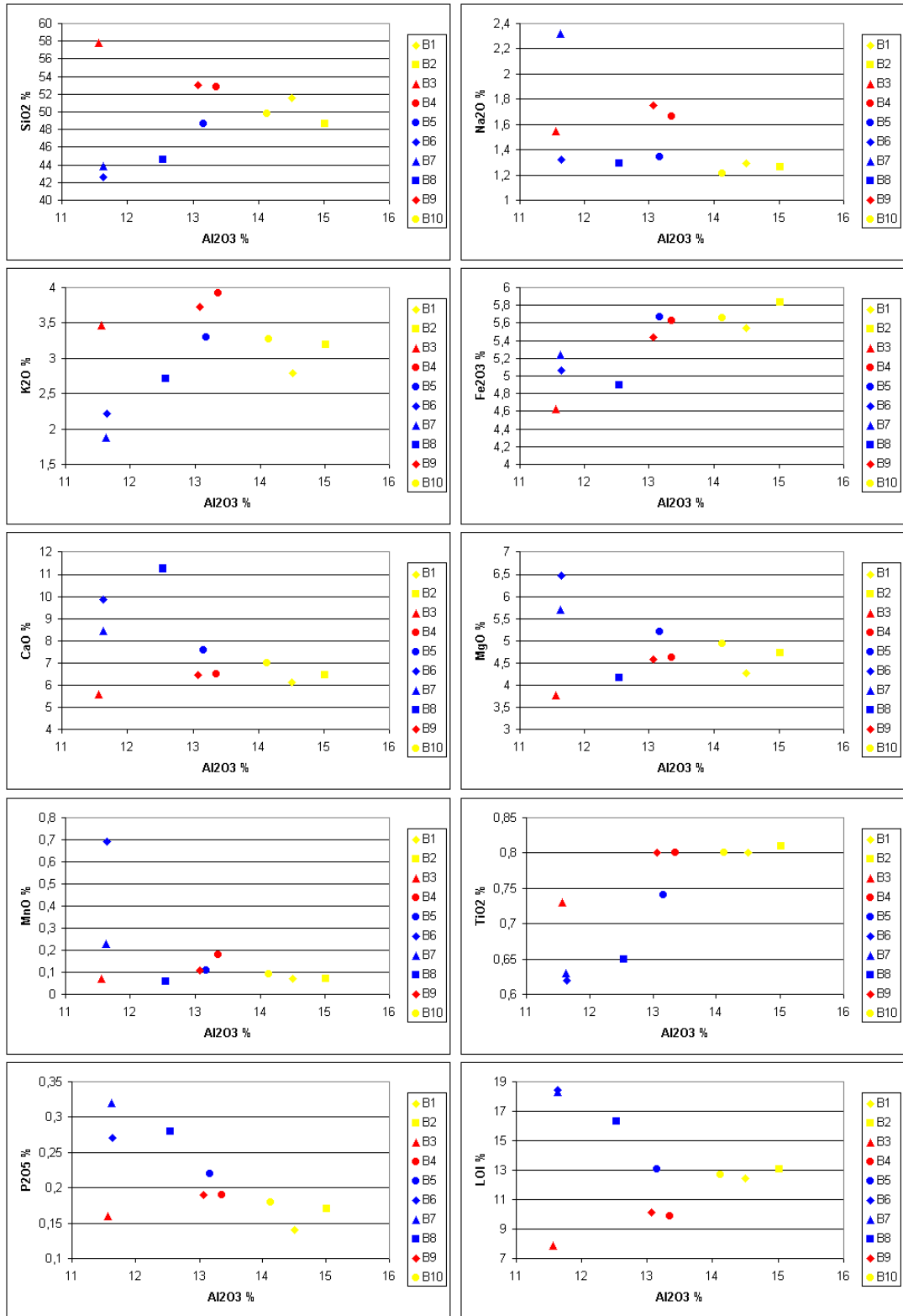


Fig.40 Variation diagrams of major elements of Billefjorden bottom sediments. Stations from Petuniabukta are in yellow, from Adolfbukta in red and from central basin area in blue.

Concentrations of MgO vary between 3.77 % (Adolfbukta - B3 station) and 6.78 % (central basin - B6 station). Its very high positive correlations to Ca, LOI and carbonates, and negative to Si, K and Ti show that almost entirely Mg is in carbonate fraction. Relatively high Mg concentrations and abundance of dolomite in catchment forming rocks (Dallmann et al. 1994) suggest that detrital dolomite may contain large part of the element.

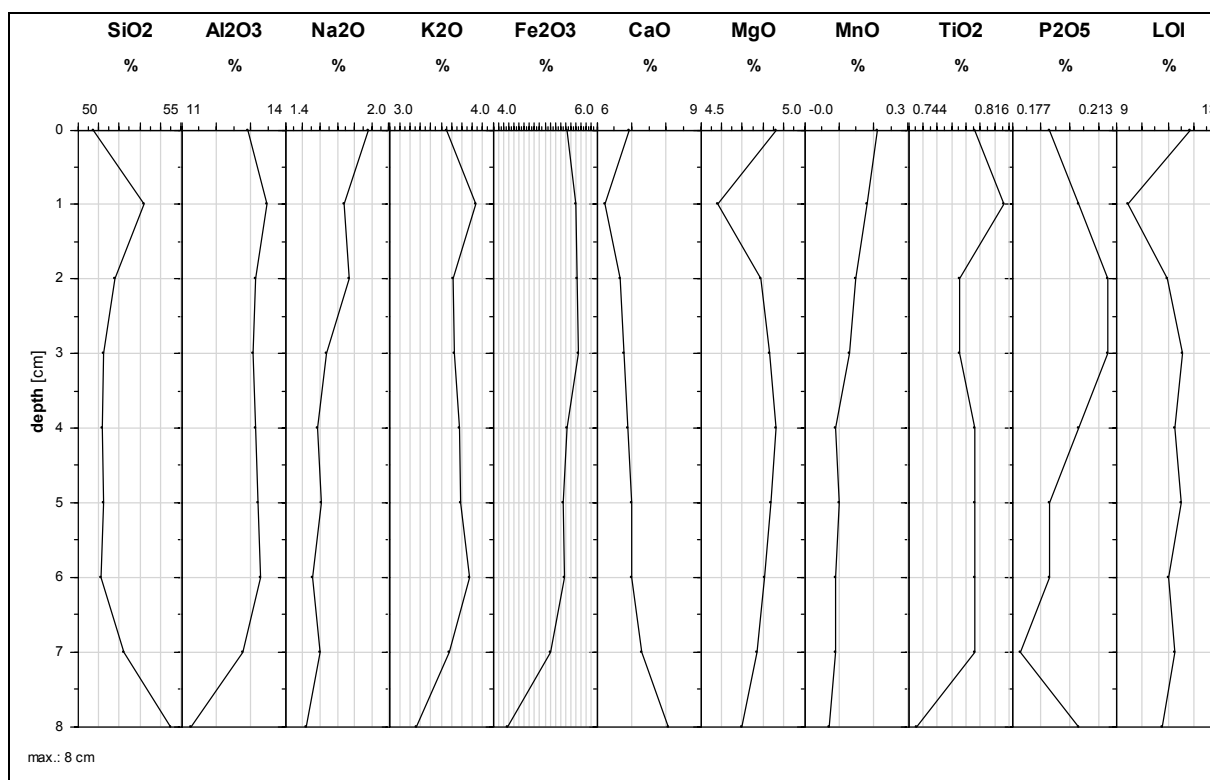


Fig. 41 Total major elements concentrations in the B4A/2001 core.

MnO has average concentrations in the range of 0.06 – 0.2 % with maximum of 0.94 % in surface sediment layer. It does not correlate with any of the measured elements (Tab. 3). In the cores a near surface Mn enrichment is observed (Figs. 41 - 44). It is very typical for marine sediments with oxidized surface layer, and shows that an oxide component is also present (Lynn & Bonatti 1965).

TiO₂ has concentrations between 0.61 % (central fjord surface sediments) and 0.81 % in surface sediments of Petuniabukta and Adolfbukta. In spatial (Fig. 40) and downcore (Figs. 41 – 44) distribution TiO₂ very well correlates with other elements typical for detrital non-calcareous fraction: Si, Al and K. Very high correlation between K and Ti and high to Fe suggest that one of important minerals is biotite. This element reveals

also strong negative correlation to Ca, Mg, LOI and carbonates (Tab. 3). If the LOI would be treated as organic matter content proxy, the strong negative correlation would point to separate supply controls for mineral and organic matter (Boyle et al. 2004).

P_2O_5 reveals concentration between 0.14 % (station B1) and 0.39 % (surface sediments of central basin). The elevated values of phosphorus are in central basin sediments. In downcore distribution it has usually maximum in surface or subsurface layer and almost uniform pattern downcore.

LOI fraction consists of 9.45 % to 19.74 %. LOI is a function of calcium carbonate, structural water (from clays), organic matter and other volatiles released during ignition) but for similar deposits can be treated as relative proxy of organic matter content. However, it has a very high correlation (Tab.3) to carbonates and they have probably dominant influence on its variation. In the cores it reveals downcore decline, which would be expected also for organic matter.

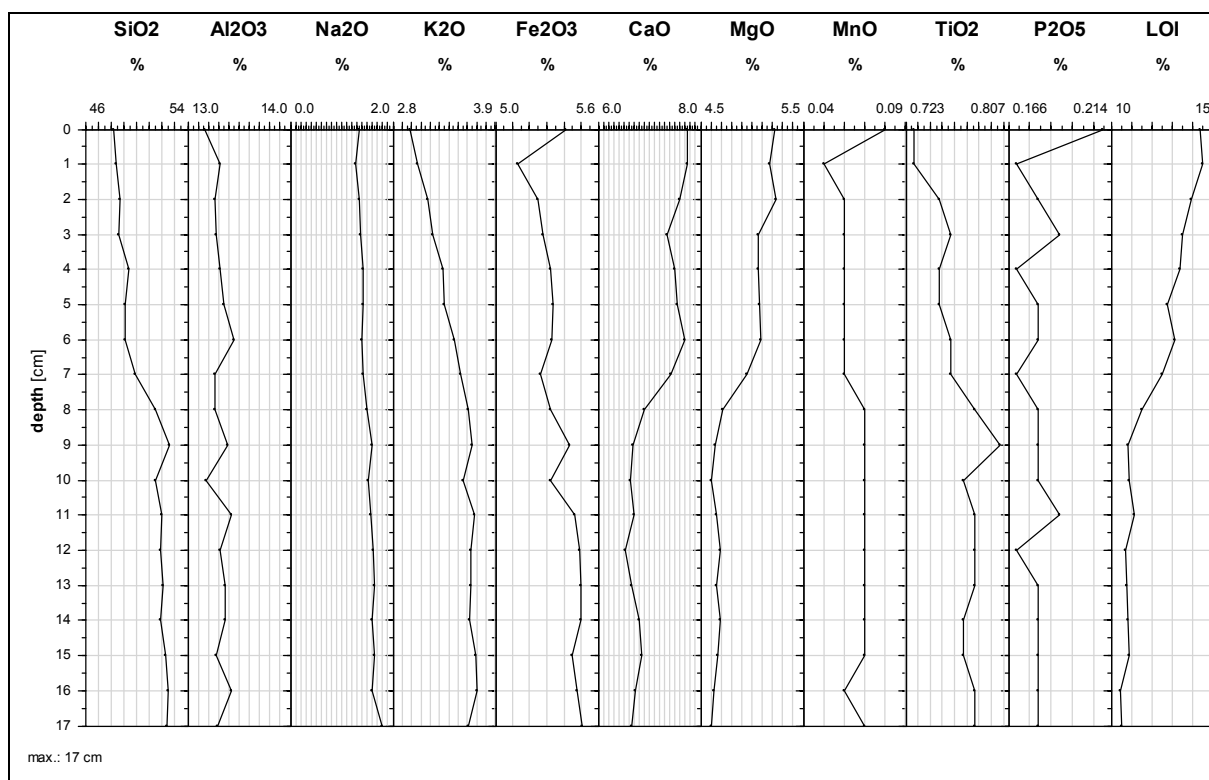


Fig.42. Major elements concentrations in the B5A/2001 core.

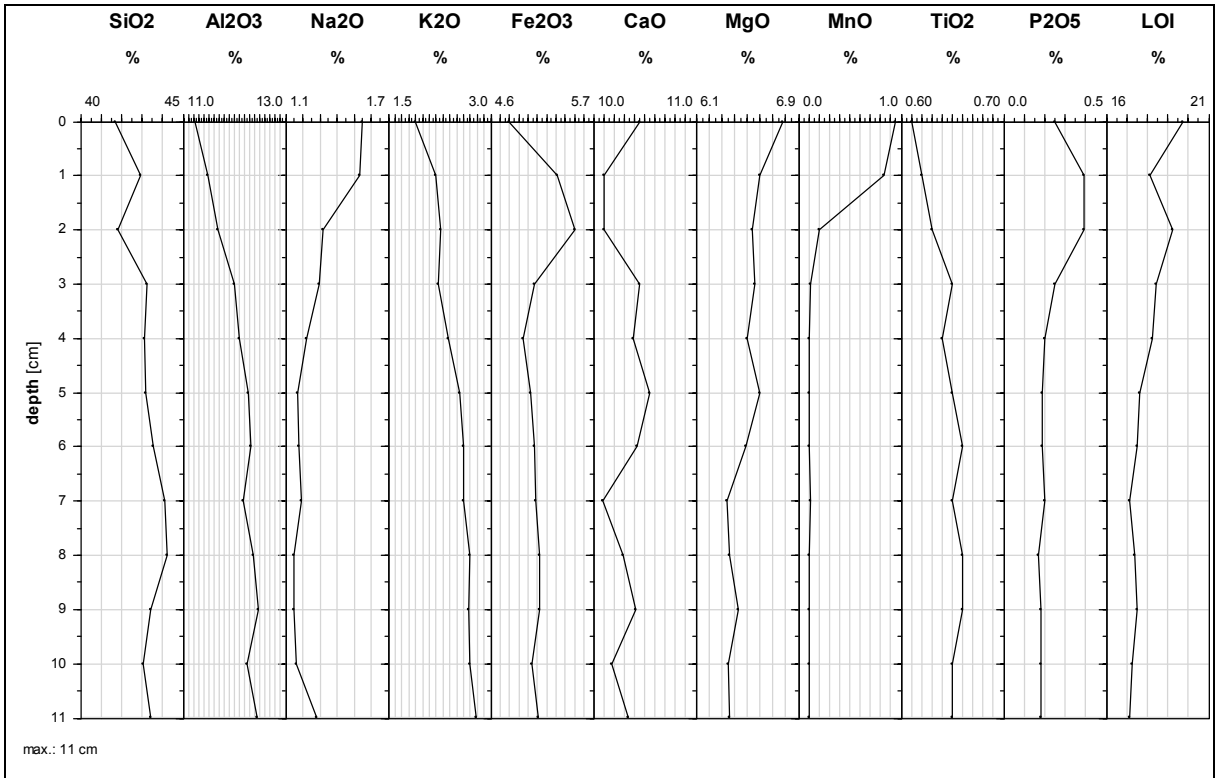


Fig.43. Major elements concentrations in the B6A/2001 core.

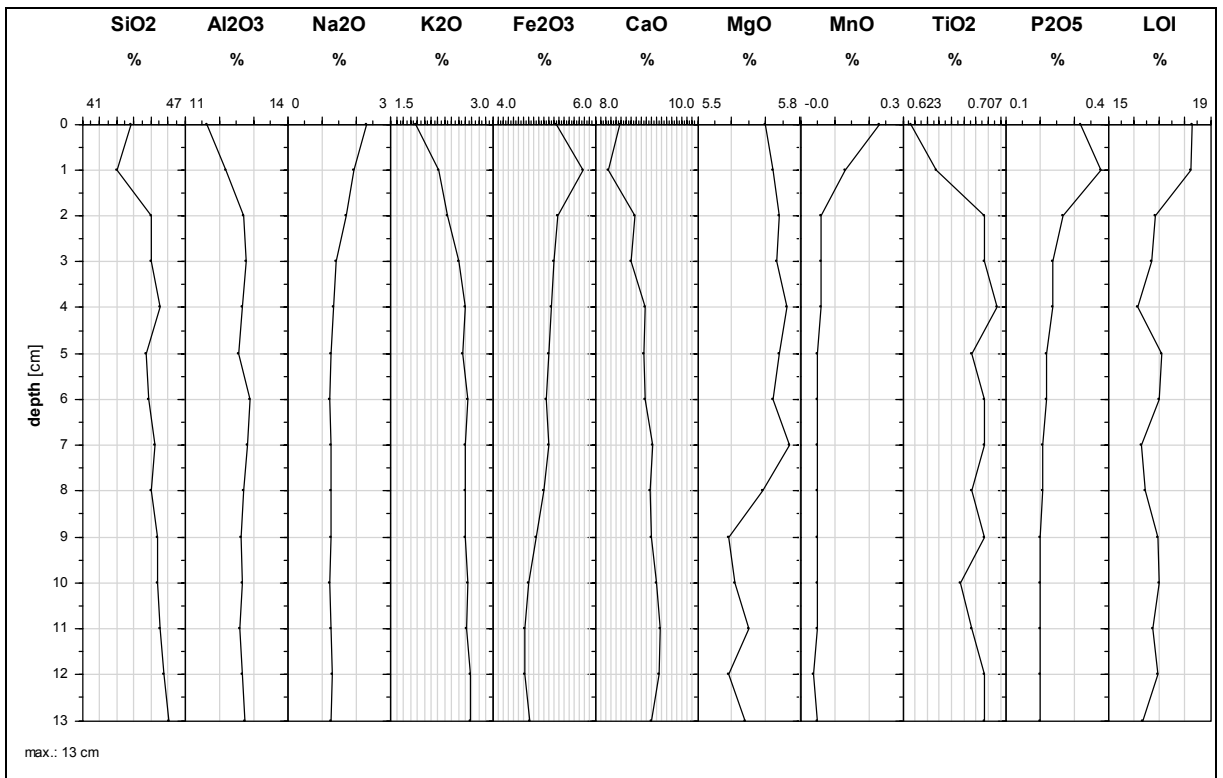


Fig.44. Major elements concentrations in the B7A/2001 core.

4.7.8 TRACE ELEMENTS

Trace elements were determined for all the surface samples with two methods: XRF (Ba, Nb, Rb, Sr, V, Y, Zn, Zr) and with ICP MS (V, Cr, Co, Ni, Cu, Zn, Ga, Rb, Sr, Y, Zr, Nb, Mo, Sn, Cs, Ba, Hf, Ta, W, Th, U, Pb). With the latter method also REE were analysed, which are presented separately in chapter 4.15. The downcore variations of 8 trace elements were analysed with XRF method for the B4, B5, B6, and B7 cores. All the results are listed in App. VIb (XRF method) and App. VII (ICP MS method). The surface elemental concentrations are shown on Fig. 45 and their downcore variations on Figs. 46 – 49.

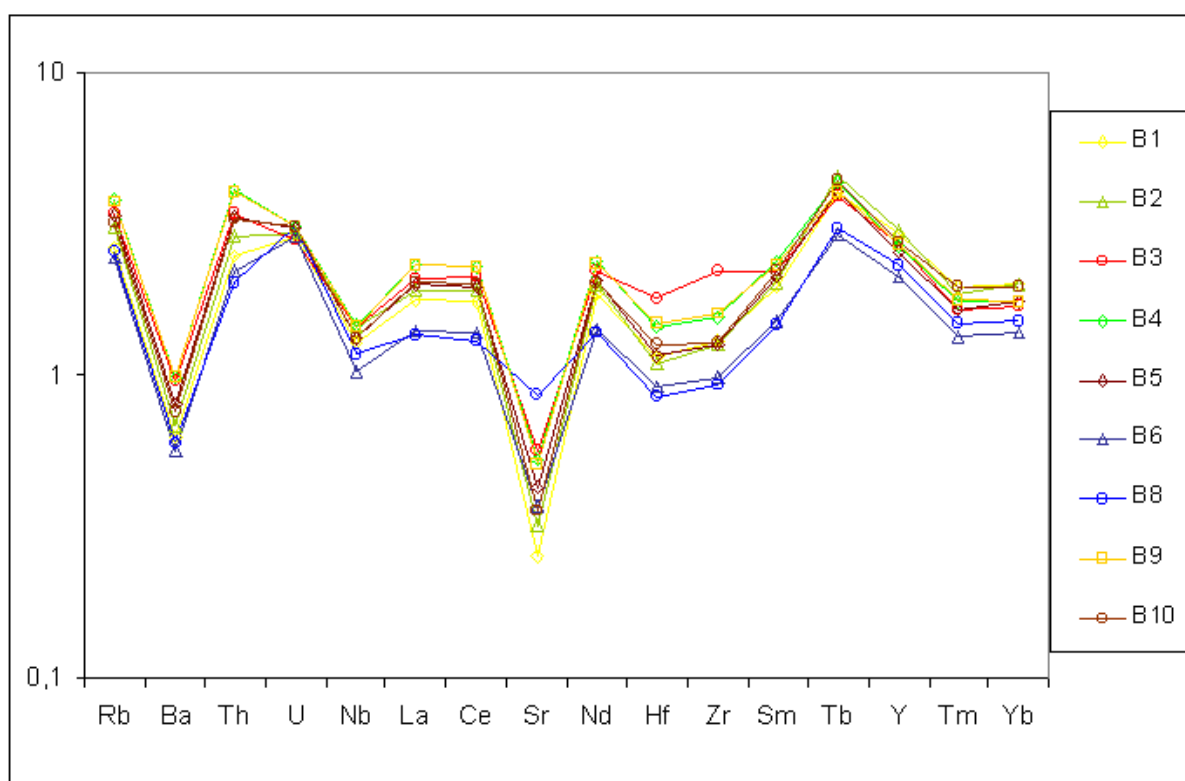


Fig.45. Trace element concentrations [ppm] of the fjord bottom sediments normalized to the composition of average continental crust (Weaver & Tarney 1984). Note the logarithmic scale.

Trace elements in fjord bottom sediments have generally higher concentrations than in average continental crust (Fig. 45). They represent similar trends for samples from Adolfbukta and Petuniabukta, and slightly different for central basin sediments, which are depleted of most of the trace elements except of Sr, which correlates with Ca carbonate. Some of the trace elements have very high correlation - especially to K (Rb and Y) and to Si (Zr, Ba). The Ba, Rb, Y and Zr are well correlated between them and Si, K and Ti.

These correlations are also well visible in downcore variations (Figs. 46-49). They possibly represent the same mineralogical change in sediment composition. Further interpretations of trace element composition are presented in chapters 6 and 9.

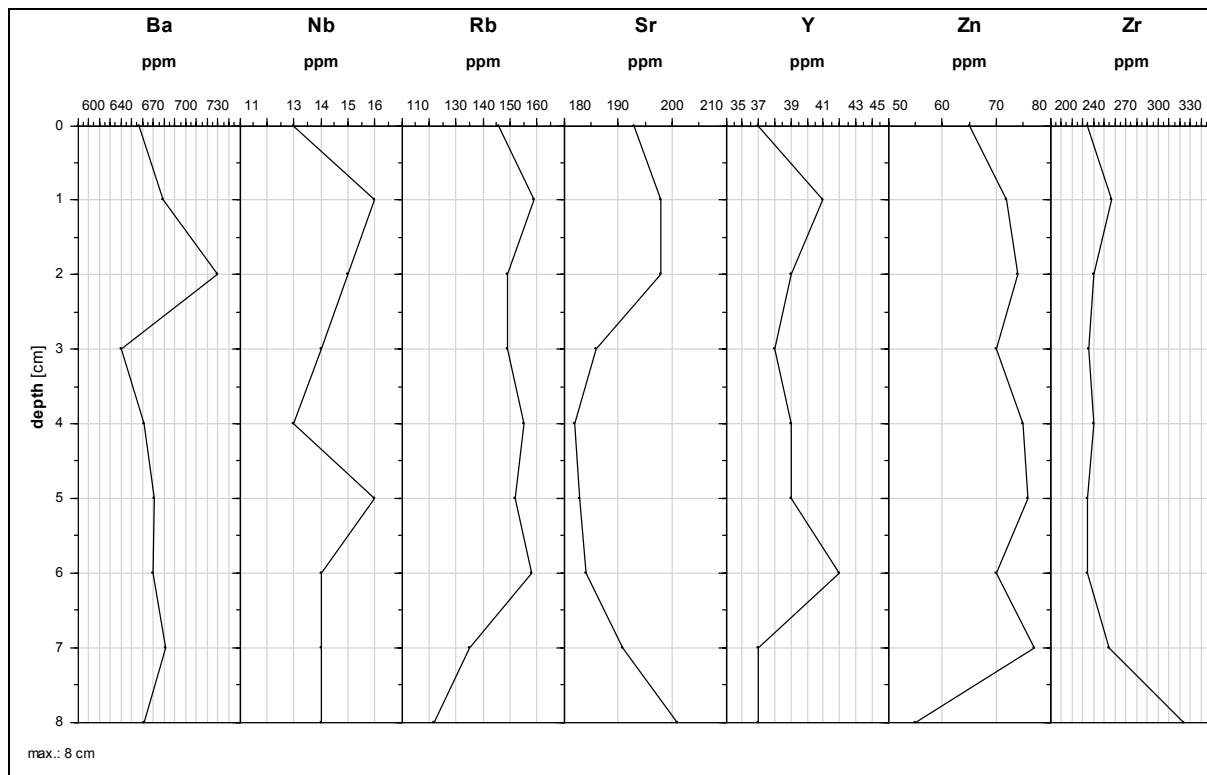


Fig.46. Trace elements concentrations in the B4A/2001 core.

4.7.9 RARE EARTH ELEMENTS

Rare earth elements (REE) constitute important for geological interpretations group of trace elements (Lipin & McKay 1989, Rollinson 1998). The concentrations of REE were analysed for surface samples and are listed in App. VII.

The total amount of REE is the biggest in Adolfbukta (273-300 ppm), and decreases through values of 236-263 ppm in Petuniabukta and in northern part of the central basin, to 176-182 ppm in central basin and at the entrance sill. It can point to source rocks since the most of REE are enclosed in typical for crystalline rocks minerals (Rollinson 1998).

The tendencies in variability of REE may be grasped both from a comparison of the concentrations between samples and from their normalisation with respect to a standard composition of chondrite, Post Archaean Average Australian Shale (PAAS) or others (for review see McLennan 1989 and Rollinson 1998).

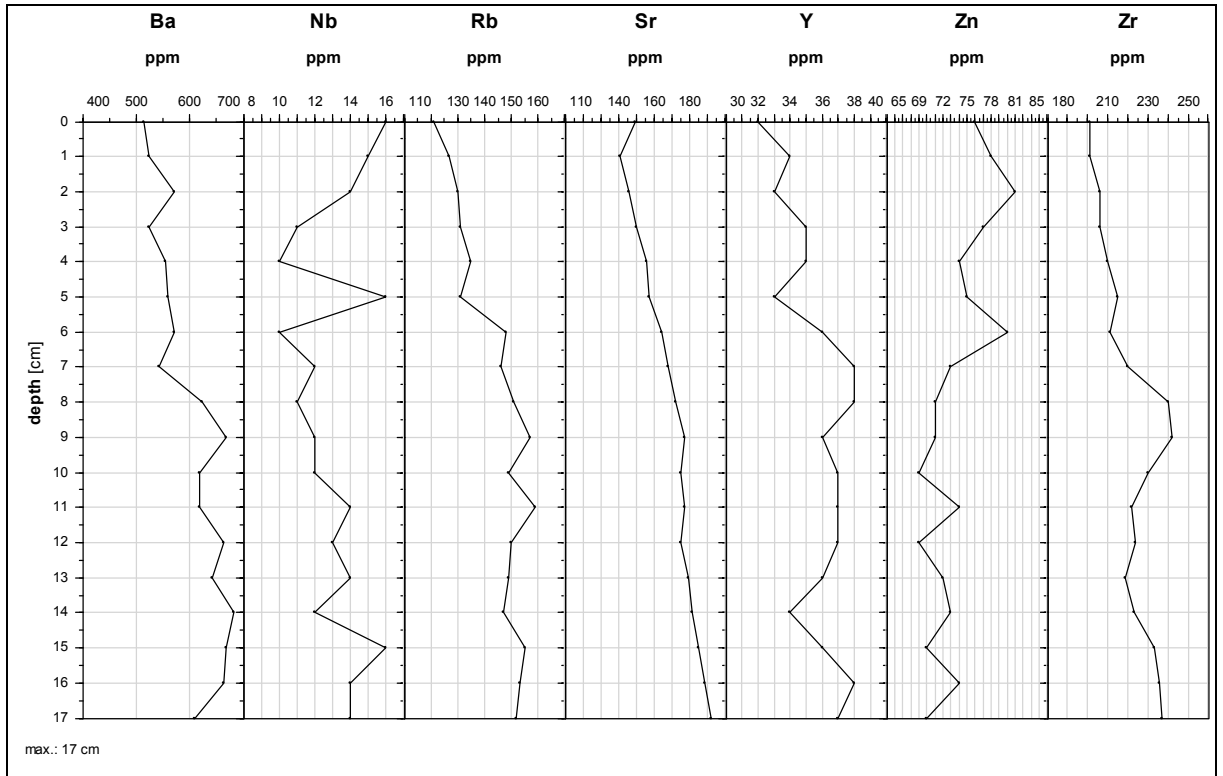


Fig.47. Trace elements concentrations in the B5A/2001 core.

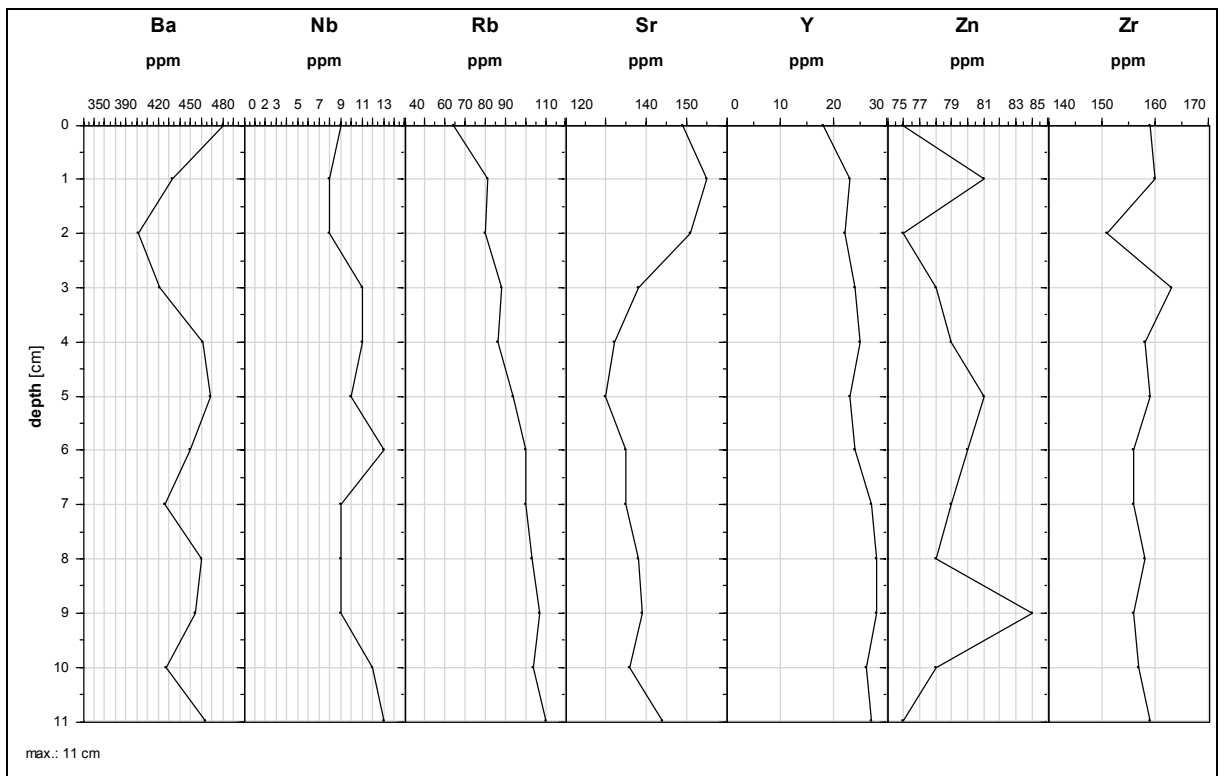


Fig.48. Trace elements concentrations in the B6A/2001 core.

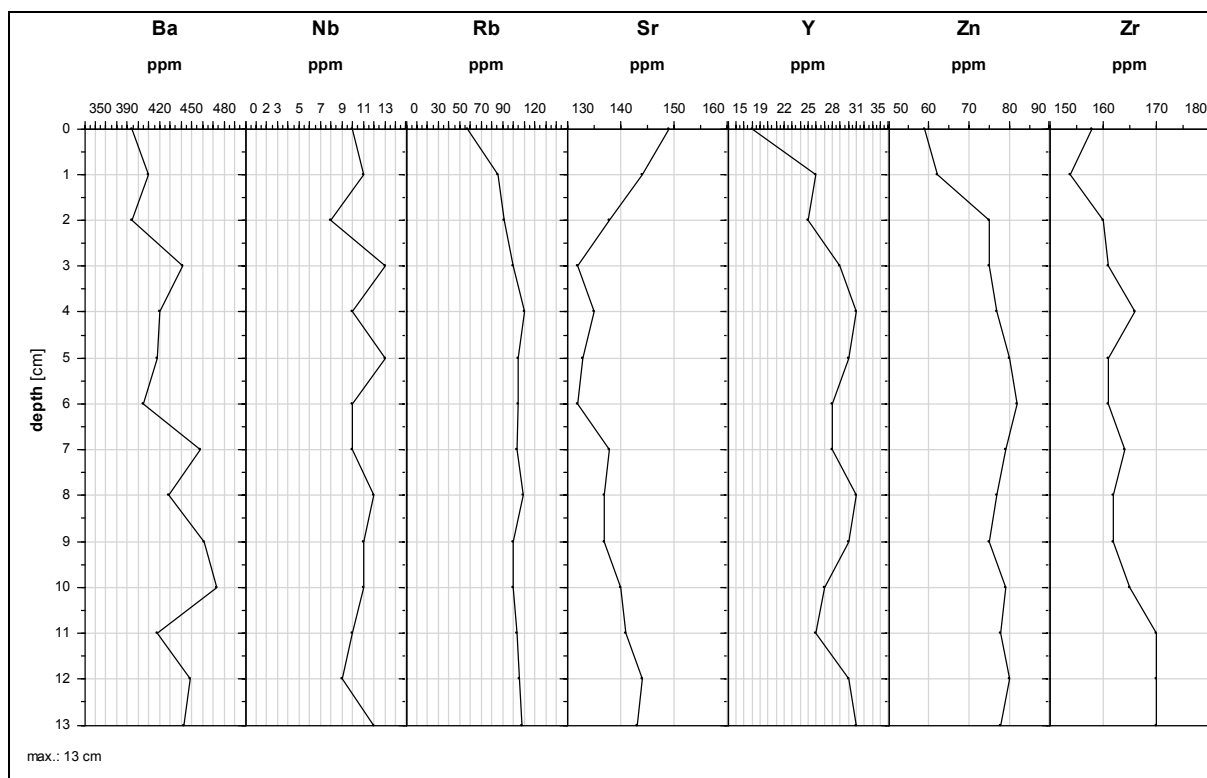


Fig.49. Trace elements concentrations in the B7A/2001 core.

Chondrite normalised REE patterns show light rare earth elements (LREE) enrichment and a negative Eu anomaly, which is characteristic of upper continental crust (McLennan 1989). Europium anomalies (Eu/Eu^*) calculated (according to McLennan 1989) for analysed samples are in the range of 0.6 – 0.66, typical for sedimentary rocks, and reveals increasing trend from station B3 (in front of Nordenskiöldbreen) to B8 (at the fjord mouth). The ratios of normalised La, Gd and Y show relative enrichment in fraction of light or heavy rare earth elements (LREE and HREE, respectively). La_N/Yb_N (11 to 16.2 for sediments from Adolfbukta) and Gd_N/Yb_N (1.76 to 2.25 – again with the highest values for samples from Adolfbukta). The $\text{La}_N/\text{Yb}_N > 15$ and $\text{Gd}_N/\text{Yb}_N > 2$ can be caused by enrichment in heavy minerals: monazite and allanite respectively (McLennan 1989).

In comparison with PAAS the samples are enriched in LREE (except of samples B6 and B8) and HREE (only samples B1 and B2). Compositions of sediments from Petuniabukta and Adolfbukata are clearly different from central basin samples but also are differentiated between each other.

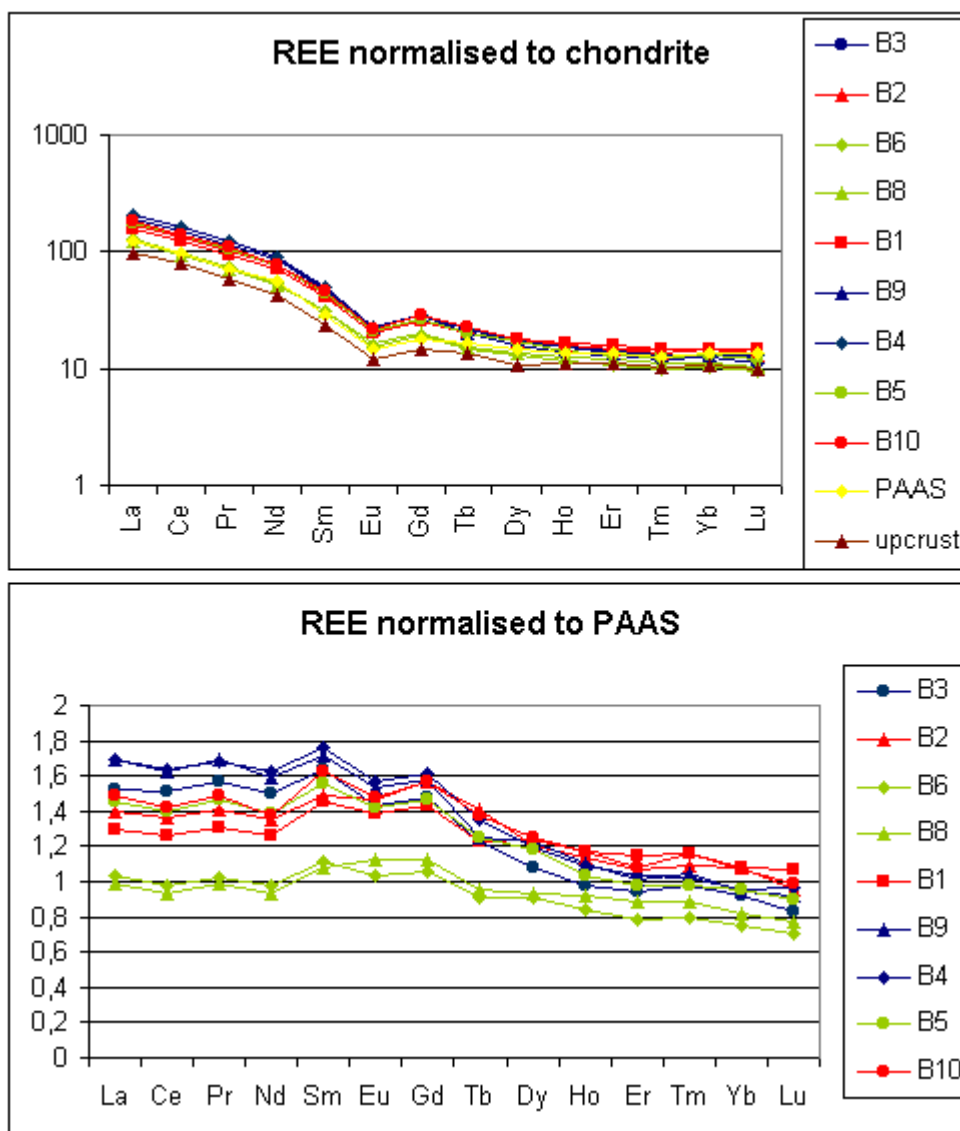


Fig.50. Results of REE analysis in surface samples in normalisation to chondrite (Rollinson 1998), and to PAAS (McLennan 1989). PAAS and the average upper continental crust (upcrust) composition (Rollinson 1998) are included for comparison in chondrite - normalised chart. Samples from Adolfbukta are in blue, from Petuniabukta in red and from central basin in green.

4.7.10 ^{210}Pb

^{210}Pb dating is the most widely used method for determining ages and sediment accumulation rates of lacustrine and nearshore marine sediments for last 100 - 150 years (Koide et al. 1972; Robbins & Edgington 1975; Appleby et al. 1978; Nittrouer et al. 1979; Carpenter et al. 1985; DeMaster et al. 1985; Jaeger et al. 1998). The isotope ^{210}Pb occurs naturally as a part of the radioactive decay chain of ^{238}U . It is formed from decay of ^{222}Rn

and its half-life is 22.26 years (Höhndorf 1969). ^{210}Pb is added to sediment column primarily from atmospheric fallout (Henderson & Maier-Reimer 2002). This atmospherically derived excess ^{210}Pb decays to a background level supported by the decay of ^{226}Ra in the sediment. Excess ^{210}Pb activities are determined by subtracting the average supported activity of a core from total activities. Supported activity is ascertained by averaging the near uniform, low-level ^{210}Pb activities below the region of radioactive decay (Figs. 51, 52).

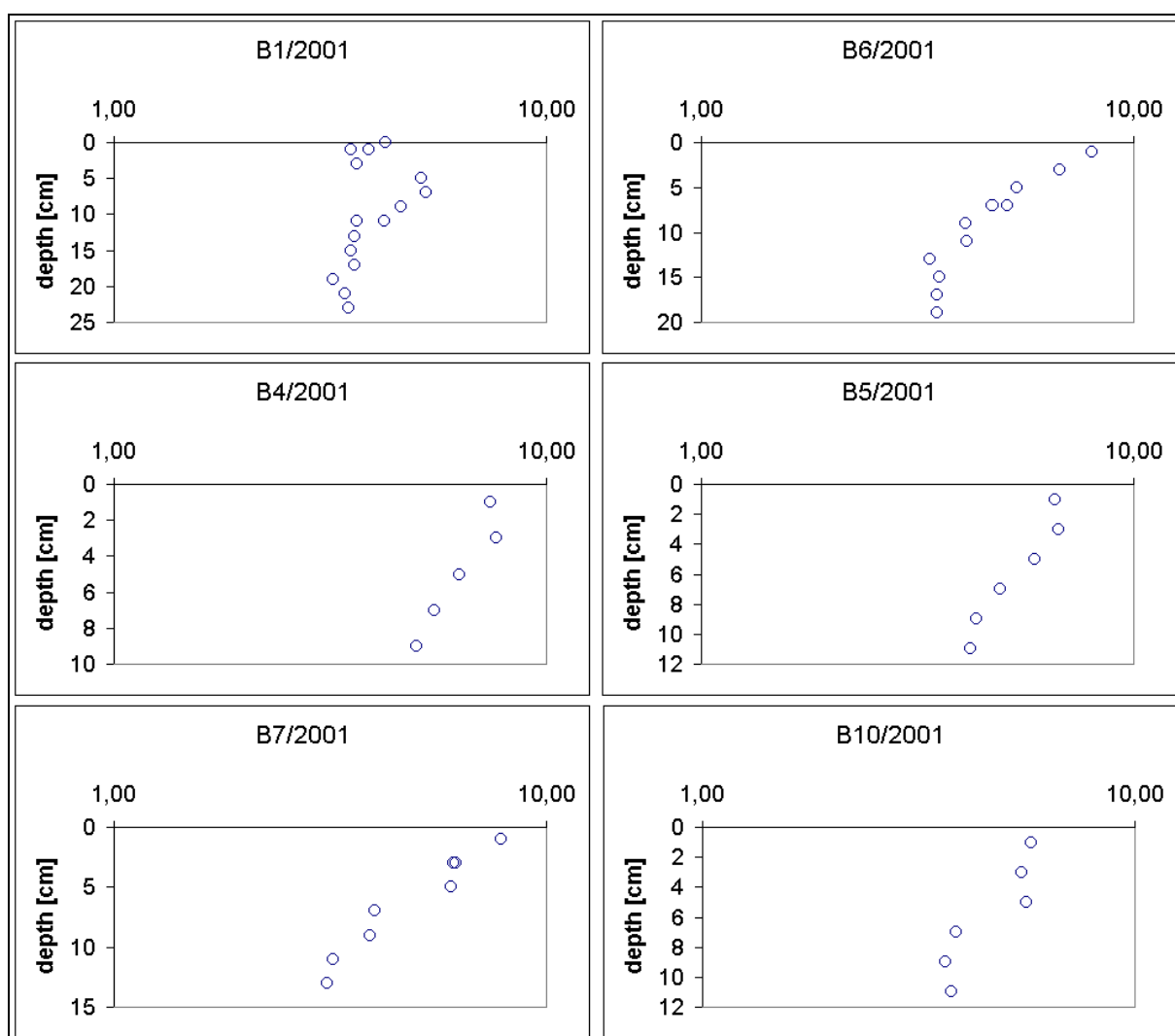


Fig.51. Total activities of ^{210}Pb in $[\text{dpm g}^{-1}]$. Note the semi logarithmic scale.

Total ^{210}Pb activities are plotted versus depth in sediment cores (Fig. 51). Complete list of all data is in App.VIII. Fig. 52 presents a typical ^{210}Pb profile for marine sediments (Nittrouer et al. 1979). It has three distinct regions: a surface layer with

homogenous activities called surface mixed layer – SML), a middle region where activities decrease logarithmically with depth in core, and a lower region of constant low activities. This profile is observed in the cores B4, B5 and B6 (although in the last the SML is confined only to the uppermost sample). However, many modifications of this model were observed in the nature. As examples can serve the cores B7 and B10, which ^{210}Pb profiles resemble a step like style – often interpreted as an effect of event sedimentation, where each “step” represents a certain event (Jaeger et al. 1998). The B1 profile represents non-steady sedimentation.

The measured activities are generally low (less than 10 dpm g^{-1}), which is partly an effect of lower input of ^{210}Pb to high latitudes (Henderson & Maier-Reimer 2002; Paatero et al. 2003). The background activities are determined to be about 3 dpm g^{-1} , so similar (Cromack 1991) or slightly higher than elsewhere in Svalbard (Zajaczkowski et al. 2004; Dahlgren unpublished). Further interpretations based on ^{210}Pb are presented in chapter 7.

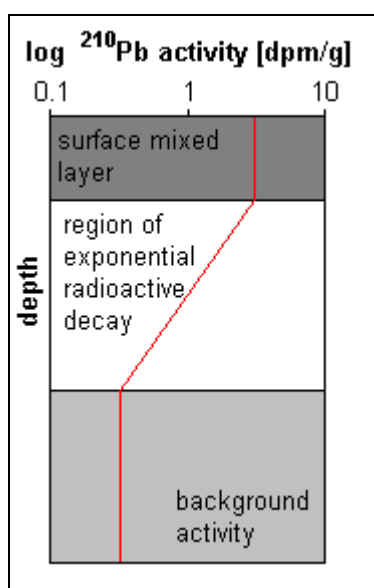


Fig.52. Idealized ^{210}Pb profile showing $\log ^{210}\text{Pb}$ activity vs. depth. A top layer of uniform ^{210}Pb activity marks the apparent sediment mixed layer (its thickness can vary usually from 1-2 up to 20 cm). Below is a region of steady state radioactive decay where ^{210}Pb activity decreases with depth to background level. The region of exponential radioactive decay serves for age and sedimentation rate calculations. After Nittrouer et al. (1979) and Lewis et al. (2002).

4.7.11 ^{137}Cs

Dating with ^{137}Cs data is based on assumptions of certain age for particular parts of its depth profile (Ritchie & McHenry, 1990; Ely et al., 1992; Pinglot et al., 1999): the deepest occurrence of ^{137}Cs activity corresponds to the first significant atmospheric releases in 1952 - 1953, the depth of maximum ^{137}Cs activity in the sediment relates to the maximum atmospheric production in 1963, the second maximum of radiocaesium (recorded only in part of the Northern hemisphere) is associated with 1986 Chernobyl accident.

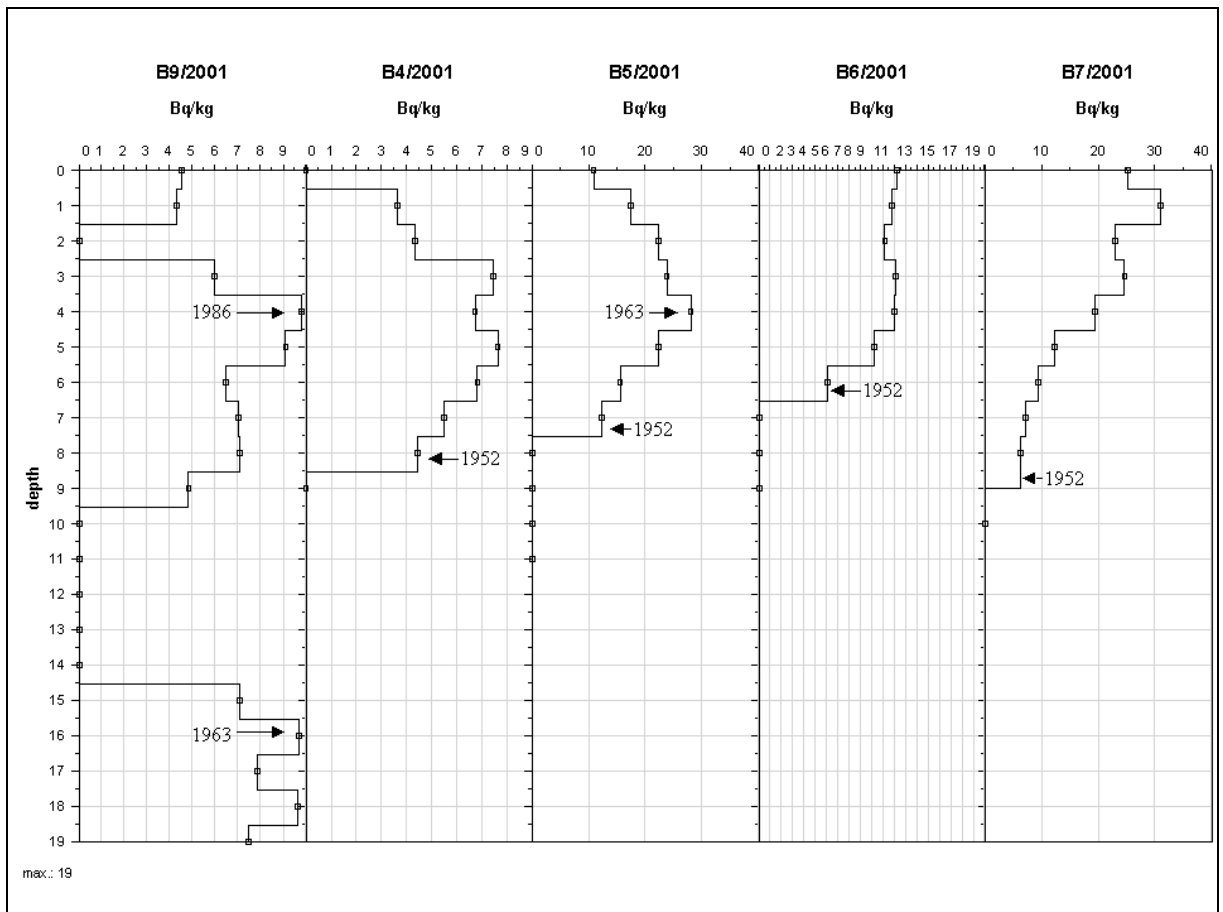


Fig.53. Downcore changes in ^{137}Cs activities [Bq kg^{-1}]. Marked dates correspond to the first significant atmospheric releases in 1952 - 1953, the maximum ^{137}Cs atmospheric production in 1963, the secondary maximum of radiocaesium (only in part of the Northern hemisphere) associated with 1986 Chernobyl accident. For further discussion see chapter 7.

All the measurements of ^{137}Cs are presented in App. IX, and on Fig. 53. In general the activities are very low a few to 30 Bq kg^{-1} at maximum. It is similar range as noted from

other studies in Svalbard area (Heldal et al. 2002, Zajączkowski et al. 2004). Low activities and also low sediment accumulation rate effect in not fully resolve potential activity peak. The 1963 peak was found in B9A/2001 and B5A/2001 cores and 1986 only in the previous one. Further interpretation of ^{137}Cs distribution is presented in chapter 7.

4.7.12 AMS - ^{14}C -DATING

The 3 samples from two localities were selected for AMS ^{14}C dating. Two of them were mussel shells from B8/2001 grab sample (located on outer sill). They were brownish and were dated to find if any sedimentation occurs at the site or not. Also the possibility of erosion associated with Spitsbergen glacioisostatic uplift was taken into account (Andruleit et al. 1996). The third sample was taken from the lower part of B6/2001 core, which is also dated with ^{210}Pb method to obtain linear deposition rate for longer time scale. The results are presented in Tab. 4. A reservoir age of 440 years is subtracted for the samples. This value was obtained by Mangerud and Gulliksen (1975) through analysis of modern (older than nuclear bomb tests) shells from coasts of the northern Norway and Svalbard. The age was used in many geochronological works on Svalbard (Salvigsen 1984; Landvik et al. 1987; Mangerud & Svendsen 1992; Elverhøi et al. 1995) and is kept here also for comparison purposes. It is worth noticing that in some cases the more reliable ages were obtained with correction of 350 or 400 years (e.g. Birkenmajer & Olsson 1998), however, they were obtained through dating of bones of migrating whales, so should not be applicable to local shells.

Tab.4. AMS ^{14}C ages for samples from Billefjorden

Sample	Description	Location	Lab Nr	Age*
B8A/2001	<i>Astarte borealis</i>	Station B8 surface	Poz-273	460 ± 35 BP
B8B/2001	<i>Hiatella arctica</i>	Station B8 surface	Poz-276	60 ± 40 BP
B6A/2001 21-22	Small paired shells	Station B6, core B6A/2001, depth 21-22 cm	Poz-261	490 ± 35 BP

*A reservoir age of 440 years is subtracted for the samples (Mangerud & Gulliksen 1975)

4.8 SEDIMENTATION FROM ICEBERGS

Observed icebergs were up to 25m in length, but most of bergs are less than 10m. In the calving bays the most are gravlers with maximum size of 4 - 5 m. Most of ice pieces created during calving events are relatively small (up to 3m in diameter), which is probably

partly caused by differentiated subglacial relief and hence a significant number of crevasses which prevent bigger icebergs to be created. Because of small sizes most of them melt in glacier bays, the remaining are transported across Adolfbukta to NWW, where part of them is anchored and successfully melted on Rudmosepynten shallow (located on the confluence of Petuniabukta and Adolfbukta). Only minor portion is transported further downfjord, however, on several occasions icebergs have been observed as far as 25 km from the tidewater ice cliff. Only in particular situations icebergs are transported to the north – to Petuniabukta.

In several icebergs - especially of bigger size, debris rich ice layer was noticed (Fig. 54). The land based observations of Nordenskiöldbreen supported reports from other Spitsbergen glaciers (e.g. Dowdeswell & Dowdeswell 1989; Rachlewicz & Szczuciński 2000) that the most of transported debris is concentrated in about 0.8 – 1.5 m thick basal debris rich layer. The measured debris volume concentration in the debris rich ice layer was 3.9 % on average.



Fig.54. Large iceberg in Adolfbukta with well visible debris rich basal ice layer. Approximate width on the water line is 25 m; the height above water is up to 3.5 m.

The total length of an active ice cliff was in 2002 about 3.5 km. Iceberg calving rate is one of the most difficult factors to be estimated. The only available ice velocity measurements at the center line close to the equilibrium line in years 1997-99 was about 150 m a^{-1} (Hedfors unpublished, after Isaksson et al. 2001). It is likely that close to the

termini the velocity is even higher (Jania 1988; Vieli et al. 2002). The modern retreat rate varies for different parts of the ice front. On average there are 9.4 m y^{-1} in the northern bay and 34 m y^{-1} in the southern glacial bay (Rachlewicz & Szczuciński 2002). The estimations of the ice cliff melting rate are based on empirical equations (3) and (4). It was not possible to measure the water temperature at the cliff front. The values used here are from the closest sampling stations and are probably too high ($2 - 2.5 \text{ }^{\circ}\text{C}$). The relative water velocity also varies in different parts of ice front. The values used for calculations are between 0.01 to 0.5 m s^{-1} . The obtained values of melting are two orders of magnitude lower than retreat rate, which is driven mostly by calving. To estimate order of magnitude of the flux of basal debris calved through a 1 m width of tidewater margin (f_s) the minimum and maximum values of particular components were used and gave 12 and $21.6 \text{ g m}^{-1} \text{ y}^{-1}$, respectively.

Subtracting values presented above to formulas (4) and (5) the obtained estimates of order of magnitude of sedimentation rate from icebergs within first 15 km from the source (averaged over the area) are about 0.1 mm y^{-1} , and the maximum distance to which icebergs can be transported before they melt out is about $28 - 33 \text{ km}$.

5 SEDIMENTATION PROCESSES AND THEIR SEASONAL CHANGES

Arctic glaciated fjords are characterised by strong linear environmental gradients (Gilbert 1983; Syvistki 1989; Svendsen et al. 2002): the tidewater glacier or meltwater river at the head of the fjord discharge large amount of freshwater with SPM, thus conditions change from stable marine at the fjord entrances to very unstable brackish in inner fjord basins. Sedimentation is usually influenced by three mechanisms: suspension sedimentation from turbid meltwater plumes, sediment-gravity flow, and iceberg rafting. Below are drawn interpretations and conclusions on qualitative and quantitative characteristics of modern sedimentary processes with respect to setting (glacier contact and non-glacier contact) and season (summer and fall) mostly based on two upper fjord proximal settings (Adolfbukta and Petuniabukta). Also summary on freshwater discharge is presented as background.

FRESHWATER DISCHARGE AND FJORD HYDROLOGY

The estimated summer water discharge to Petuniabukta (drainage area 158 km²) was 30 m³ s⁻¹. Rachlewicz (2003a) showed on an example of the year 2002 record for the main river in the catchment (Hörbyeelva) that the runoff is at maximum in the beginning of July and slowly decreases through summer. At the beginning of the fall (which coincides with falling of the air temperature below 0°C) it rapidly ceased to the level which is estimated for the whole Petuniabukta catchment to be as low as 0.6 m³ s⁻¹. He also documented SPM concentration in the river to fluctuate only slightly in summer and to be significantly lower in fall. The maximum observed suspended matter concentration was about 5 g dm⁻³ – so much below the 38 g dm⁻³ necessary to generate turbidity currents directly from an inflow (Gilbert 1983). The SPM fluctuations are well correlated with rainfall events, which are believed to mobilize otherwise not available surface material. Estimated summer freshwater influx to Adolfbukta (drainage area of 287 km²) is about 49 m³ s⁻¹. The ratios of discharge to drainage area are similar for both catchments. The freshwater enters Petuniabukta through tidal flat where it is effectively mixed with saline fjord water, what causes weaker stratification in the bay. Adolfbukta is mainly supplied by two subglacial outflows at the base of tidewater ice cliff. The freshwater forms a buoyant plume, which spreads out from the outflows over ambient fjord waters. If compared with other Svalbard fjords, the summer freshwater discharges are higher than for larger (694 km²) but less glaciated (21%) catchment of Adventfjorden where average summer

discharge was estimated as $26 \text{ m}^3 \text{ s}^{-1}$ (Węśławski et al. 1999) but much smaller than for Kongsfjorden (drainage area about 2250 km^2 , glaciated in 77%), where discharge from major outflow in largest tidewater glacier was reported to be as high as almost $140 \text{ m}^3 \text{ s}^{-1}$ (Zajączkowski & Legeżyńska 2001).

SEDIMENTATION PROCESSES

Particulate matter entering glacier-influenced fjords is dispersed and deposited by three primary sets of processes: SPM settling, iceberg rafting and sediment gravity flows. The suspension settling was intensively studied especially for Alaskan fjords (Lewis & Syvistki 1983; Syvitski et al. 1985; Cowan et al. 1988; Syvistki 1989; Cowan & Powell 1990; Hill et al. 1998; Cowan et al. 1999; Curran et al. 2004), where, however, SPM concentrations are an order of magnitude higher than in Svalbard (Elverhøi et al. 1980; Görlich et al. 1987; Boulton 1990; Svendsen et al. 2002). Iceberg rafting is relatively problematic – especially for quantitative studies, hence simple modeling was introduced for quantitative estimation of its significance (Dowdeswell & Dowdeswell 1988; Dowdeswell & Murray 1990; Gilbert 1990). Even more problematic are studies on different types of turbidity currents, debris flows etc, and most of existing data is from indirect evidence (Prior et al. 1981; Gilbert 1983; Boulton 1986; Phillips & Smith 1992)

SPM SETTLING AND FLOCCULATION

Unless inflowing meltwater has SPM concentration $>38 \text{ g dm}^{-3}$ (Gilbert 1983), it will become buoyant upon entering the marine water and rise to the surface (if the inflow is below sea surface) due to the density difference with the ambient sea water. Syvitski (1989) and Powell (1990) have detailed the processes operating at meltwater effluxes in the glacial marine environment. The less saline waters form buoyant overflow plume with elevated SPM content and spread out from the inflow.

The brackish water plume may transport material up to fine sand size in suspension (chapter 4.6.1), and is characterized by turbid appearance at the water surface (Fig. 14). Particle transport and release from the plume are controlled predominantly by semi-diurnal tidal fluctuations (Fig. 19) in addition to daily and seasonal variations in meltwater discharge. As presented by Cowan & Powell (1990), large amounts of fine grained material are maintained in suspension during flood tide on account of the relatively high current velocities. Reduction in current and vertical eddy velocities at high and ebb tides allows the particulate matter to settle vertically downwards in the overflow plume. Around low tide, fine and coarse material is released from the plume and deposited onto fjord floor. Similar situation was observed during the

experiment in Adolfbukta (Fig. 19), where low tide maximum was at about 5 m depth (so in the lower part of the plume) and six hours later some 15 m lower. From this the settling rate is estimated to be between 0.5 to 2 cm s⁻¹. Similar velocities were observed also in other fjords, and as shown by underwater cameras are typical for flocculated particles (Hill et al. 1998; Curran et al. 2004).

Flocculation due to physicochemical forces that cause molecular attraction between crystal surfaces has long been recognized as a factor in sediment transport and deposition (Kranck 1980; Syvitski & Murray 1981; Syvitski et al. 1985; Hunt 1986; Hill et al. 1998, 2000; Curran et al. 2004). Flocculation depends on interparticle collision, and interparticle adhesion after collision. Particle collision will increase with increase in concentration. Factors causing particle adhesion are related both to the nature of the suspended particles and to the fluid in which they are suspended. Laboratory studies show that at salinities less than 2 PSU flocculation, as measured by settling rate, increases consistently with the salinity of the suspensate. At higher salinities little increase in flocculation occurs (Kranck 1980). Physical repackaging of small particles into faster sinking flocs enhances removal of fine matter from turbid suspensions (e.g. Syvitski et al. 1985, Sternberg et al. 1999). Individual grains less than 1 µm, require more than 100 days to settle through 5 m of water according to Stokes Law, the same grain in form of flocs can settle with up to several hundred meters per day. All the samples from sediment traps were poorly sorted what is also likely an effect of flocculation of particles (Kranck 1980). Hence the aggregates are composed of particles of different sizes, which settle down together at the same - accelerated rate.

The particulate matter fluxes are comparable or slightly lower in Billefjorden than in other regions of similar setting (Węśławski et al. 1999; Zajączkowski 2000; Svendsen et al. 2002). The rapid removal of particulate matter in front of tidal flat is probably a consequence of flocculation process, which starts on the tidal flat so the SPM reaching the bay is in the form of flocs. In general the most (over 90%) of the sediments is probably trapped in the proximal few hundred meters (in case of rivers ending on tidal flats) to a couple of km in the case of tidewater glacier (flocculation takes place after reaching the fjord waters).

The concentration of suspended matter is not the main driving factor for flocculation process and is not proportional to particulate matter flux. In fall season when PMF has diminished at least by a factor of 10, the SPM concentrations were only twofold smaller. In the studied environments the freshwater influx is the first order driving factor which controls flocculation and subsequently sedimentation rates.

ICEBERG RAFTING

In summer high velocities of surface current out from the tidewater glacier cause the icebergs to be drifted away very fast and along with lower temperatures of surface brackish plume cause that very little sediment in this setting originates from iceberg rafting. However, some gravel size clasts were found in sediment traps, which prove some participation of this mode of sedimentation as well. Using model of Dowdeswell & Murray (1990) for estimation rates of iceberg sedimentation the value of approximately 1 mm a^{-1} was calculated for Adolfbukta. It is at least an order of magnitude less than sedimentation rates from suspension settling. Icebergs were also drifted further to the central basin of Billefjorden where their participation in the deposits is visible (for instance in bimodal grain size distribution) owing to low sediment accumulation rates.

During spring, when the fast sea ice starts to disintegrate, a portion of the ice rafted material can be transported by sea ice. It was observed in Petuniabukta where several layers of particulate matter rich sea ice were observed. However, it is insignificant if considered quantitatively.

As supported by own observations in Petuniabukta but also by earlier reports (Gilbert 1984; Gilbert 1990), a portion of material can be also moved under influence of marine algae within and from littoral environment. Many clasts attached to algae form *Fucus* kind where found at the shore, but this is quantitatively insignificant transporting mechanism.

SEDIMENT GRAVITY FLOW

One of the most dynamic zones are actively prograding glaciofluvial deltas and their prodelta slopes. As was shown by Prior et al. (1981) for examples from Adventfjorden (small branch of Isfjorden, Svalbard) the prodelta slopes are often cut by chutes or delta-front gullies (usually 10-30m wide and 2-5m deep), which are probably associated to mass movement processes (avalanching or debris flow). Hence bottom slopes are steeply inclined (even more than 7° in a case of Petuniabukta fjord-head deltas), and rapid progradation occurs in the summer, causes temporary oversteeping and increases in gravitational stress. Rapid deposition of sands, silts, and clays can cause local excess pore pressure. Furthermore waves can impart significant cyclic loading effects on the bar front sediments. Sediment gravity flows from the delta front possibly occur during low tides when tidal flat is completely exposed and fluvial bed load is transported directly to the tidal flat edge (Phillips et al. 1991). The direct evidence of such

phenomena was found on delta slope, when the sediment trap (originally 1 m above sea bottom during low tide) was partly infilled (more than 20 cm) by normally graded sandy to silty deposits. The indirect evidence of frequent sediment gravity flow is gained from grain size analysis of lower traps and SPM measurements. The finer fraction found in near bottom sediment traps (Fig. 23) could point to significant resuspension of once deposited (so probably deflocculated) matter. In the near bottom conditions of high salinity, lower turbulence and shorter time of residence in water the flocculation is not expected to be significant. So a finer portion of sediment previously deposited as flocculated will later be redeposited as deflocculated fine particles. The frequency of this phenomenon must be quite high since elevated SPM concentrations (Fig. 20) in near bottom waters were often observed.

MAIN MODES OF SEDIMENTATION GLACIER CONTACT / NON-GLACIER CONTACT SETTING

There are several significant differences in sedimentation processes between glacier contact and non-glacier contact settings (Tab.5). The first is in gradients of particulate matter flux (Fig. 22). Much higher gradient in Petuniabukta is interpreted as an effect of flocculation already on tidal flat so the aggregated particles reach the tidal flat edge, in glacier contact setting the flocculation takes place after discharging to the fjord so the effect is more gradual. The particulate matter fluxes are significantly larger in the same distance from the tidal flat edge or tidewater glacier front, in the second setting (more than 50 times in summer and more than two times in fall). In glacier contact setting gravity flows may lack sufficient slope inclinations for their generation – fluctuating ice front position dispersed ice contact sedimentation over wider area.

Obviously iceberg rafted debris is more common in glacier contact setting, however, as mentioned above this mode of sedimentation is marginal. Sea ice rafted deposition is probably more often in Petuniabukta where near shore ice (especially on tidal flat) may incorporate larger amount of sediment.

SEASONAL CHANGES IN SEDIMENTATION

With seasonal change from summer (July – August) to fall (subzero temperatures) the sedimentation has changed significantly both in terms of rate as well as of process. In fall both freshwater and SPM flux to the fjord has significantly diminished (Tab.5). It is associated with twofold decrease in average SPM concentration in fjord waters and dramatic reduction of PMF of an order of magnitude. The discrepancy in magnitude of reduction in SPM and PMF is interpreted by change in sedimentation processes. As presented above, flocculation is believed to be driving mechanism in sedimentation in

proximal settings. It is largely powered by mixing of fresh with saline waters. In absence of sufficient freshwater supply the flocculation is strongly limited. Reduced flocculation has diminished PMF and enlarged residence time of particles in water column. As in summer most of the supplied particles are expected to settle within one day, in fall this period can be elongated to tens of days.

Tab.5. Comparison of selected characteristics in glacier contact and non-glacier contact settings with respect to season. Averaged values are given in brackets.

Feature	Glacier contact setting* (Adolfbukta)		Non-glacier contact setting* (Petuniabukta)	
	summer	fall	summer	fall
Freshwater influx [m^3s^{-1}]	48.9	?	30	0.6
Average SPM concentration in rivers [g dm^{-3}]	0.2**	0.002**	0.16 – 3.095	0 – 0.005
Icebergs	common	rare	rare	very rare
Fjord surface water temperature [$^{\circ}\text{C}$]	2.2 – 4.7 (3.4)	2.0 – 3.9 (2.9)	4.3 – 8.7 (7.1)	5.3 – 5.5 (5.4)
SPM concentration [mg dm^{-3}]	7.1 – 108 (56.65)	5.8 – 78.7 (27.5)	11.4 – 150 (41.85)	9.6 – 50.1 (26)
Particulate matter flux [$\text{g m}^{-2}\text{day}^{-1}$]	1.7 – 263 (33.5)	0.39 – 1.27 (0.75)	0.36 – 254 (25.3)	0.28 – 0.93 (0.53)

*Data on SPM, particulate matter flux and water temperature are for zone between 0.8 and 2 km from tidewater glacier ice cliff (Adolfbukta), and 0.1 to 1.2 km off the tidal flat edge (Petuniabukta).

**For lateral streams only.

Comparison of particulate matter flux offshore gradients for analysed seasons reveals a clear difference. In summer the gradients are steeper and in fall they hardly exist. Such a pattern also points to flocculation as important mechanism for acceleration of suspended matter removal from water column. Sedimentation offshore of the tidal flat edge is rapid and immediate, which occurs in part due to packaging of fine sediments into flocs already over the tidal flat.

With seasons also influence of ice rafting fluctuates. Icebergs are produced mainly in summer season. In fall the calving events were less frequent and for winter and spring almost no calving is observed (Węśławski et al. 1988). Deposition from sea ice is expected to occur mainly in late spring and beginning of summer when the ice cover disintegrates.

POSSIBLE IMPLICATIONS

The SPM concentration and processes responsible for its changes are governing factors of light penetration into the marine environment, which is of great importance for the productivity and ecology of marine ecosystems. For instance, in Kongsfjorden summer concentrations of SPM of 15 to 50 mg dm⁻³ result in euphotic zone (zone of light penetration efficient to support photosynthesis) of 6 to 25 m (Svendsen et al. 2002). As was presented above the SPM residence time in water column depends largely on flocculation. Even larger discharges of SPM with freshwater are expected in future (Førland & Hanssen-Bauer 2003; Hagen et al. 2003). They may have important influence on living biota through decrease in euphotic zone and also through osmotic stress caused by freshwater (Węsławski et al. 1995; Zajączkowski & Legeżyńska 2001). On the other hand maybe even bigger importance could have delivery of SPM by coast erosion not associated with freshwater inflow. As presented above, in lack of freshwater the flocculation is largely diminished and particle residence time in water can be several times longer. It can be of primary importance in spring when phytoplankton blooms occur.

Expected increase in meltwater and particulate matter flux from retreating glaciers (Hagen et al. 2003) along with elongation of ablation season, would result in higher sedimentation rates. It may effect in progradation of deltas and through decrease of water depth in front of tidewater glaciers may improve ice front stability or even facilitate future glacier advance (Powell 1991).

6 SEDIMENT PROVENANCE

The provenance of modern fjord sediments is determined on the basis of chemical analysis of sediments (carbonates, major elements, trace elements, REE – concentrations of 47 elements were identified), coarse grain analysis, and semi-quantitative clay mineral analysis. One of the objectives is to give a baseline for further analysis of sediment cores. REE are the most useful elements for provenance characterization (e.g. McLennan et al. 1993; Vital et al. 1999), because they are among the least soluble trace elements and are relatively immobile. These elements are believed to be transported exclusively in the terrigenous component of sediments and therefore reflect the chemistry of their source (McLennan et al. 1980; Fleet 1984; McLennan 1989; Rollinson 1998). The remaining methods (mineralogical, geochemical) were also used by previous researches in provenance studies in fjords (e.g. Syvitski & Macdonald 1982; Görlich 1986; Görlich et al. 1987) and other marine environments (e.g. Calvert 1976; Manjunatha & Shankar 1997; Cho et al. 1999).

The coarse grain analysis (Fig. 30) shows that Adolfbukta sediments are different from the remaining stations (domination of lithoclasts). Interesting distribution is shown by coal sand content, which is the highest in stations in Petuniabukta and northern stations of the central basin. Its distribution is closely related to the region of coal mining around Pyramiden settlement.

From clay minerals analysis only smectites reveal larger difference (Fig. 36). They were found only in Adolfbukta and at the entrance sill. They are usually derived from weathering of basic igneous and metamorphic rocks (dolerite, amphibolites), which are common in Adolfbukta drainage area and form sills in the southernmost part of the fjord surrounding (Weigand & Testa 1982; Lauritzen et al. 1989; Dallmann et al. 1994). The lack of smectites in central basin may suggest restricted participation of transport from Adolfbukta.

The discrimination of 3 provinces (Adolfbukta, Petuniabukta, central basin) in carbonate content (Fig. 38) probably reflects the source area geology - Nordenskiöldbreen, which terminates in Adolfbukta drains mostly crystalline rocks of Hecla Hoek Succession in contrast to commonly exposed Carboniferous and Permian rocks with high participation of carbonates. Carbonate bioproduction and simultaneous low sedimentation rate probably cause the increase in carbonate content in deep fjord.

Use of chemical analysis for provenance studies require correction of grain size effect. It is commonly done by presenting the data as ratio to Al (Kemp et al. 1976;

Windom et al. 1989), to Rb (Ackermann 1980) and others. The analysis of major element contents (Al corrected) shows distinct trend in relation to the distance from Nordenskiöldbreen (Fig.55). Some elements, which are common in crystalline rocks like Si, Ti and K decrease with distance from their potential source. On the other hand the carbonate related elements have the reverse trends.

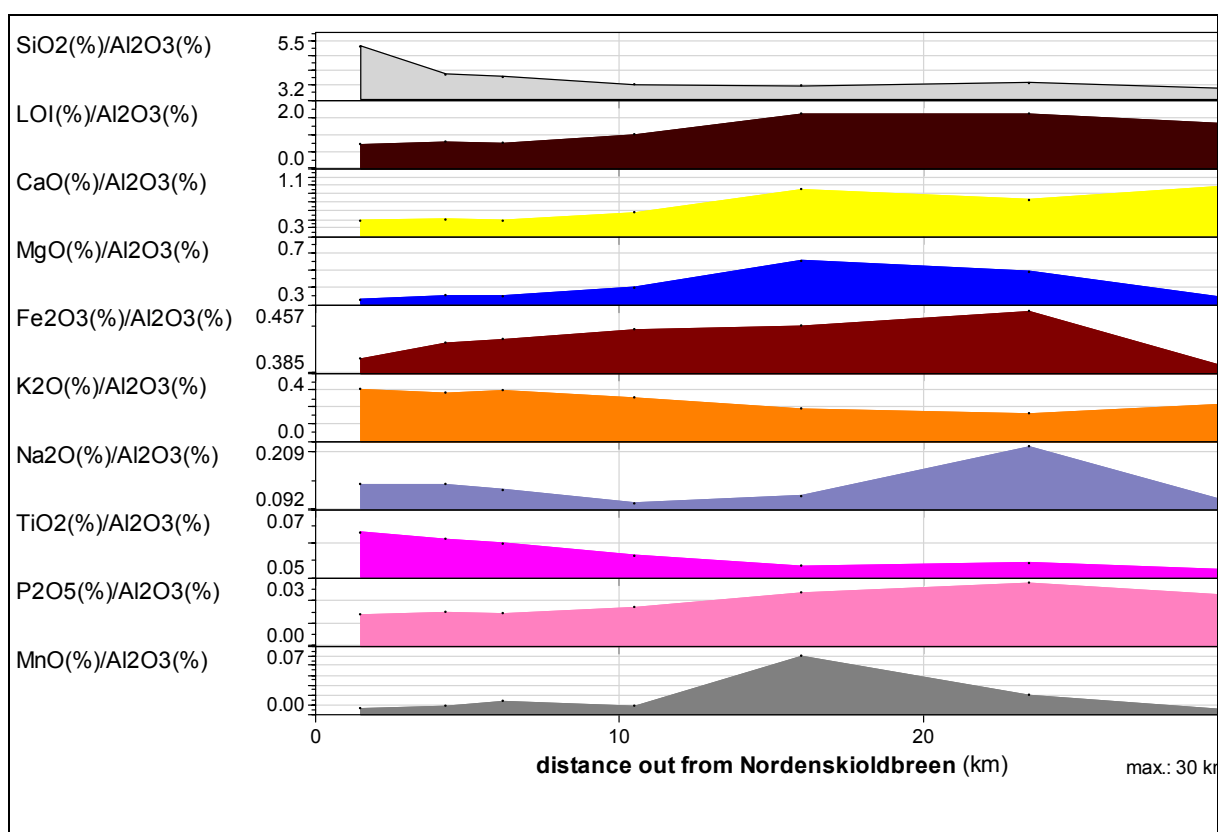


Fig.55. Changes of major elements content (corrected to Al) in surface samples in relation to distance from the ice front of Nordenskiöldbreen. Most of the elements show increasing or decreasing trends except for Mn and Fe, which are engaged in diagenetic reactions, and Na, which concentrations can be contaminated by sea salt.

For analysis of larger data sets cluster analysis is commonly used. Cluster analysis was done to reveal significant associations among variables and among studied locations. Cluster analysis in this study places sampling locations into more or less homogenous groups on the basis of geochemical and sedimentological similarity (altogether over 100 variables were considered). Hierarchical clustering joins the most similar observations then successively connects the next most similar observations to these (Davis 1986).

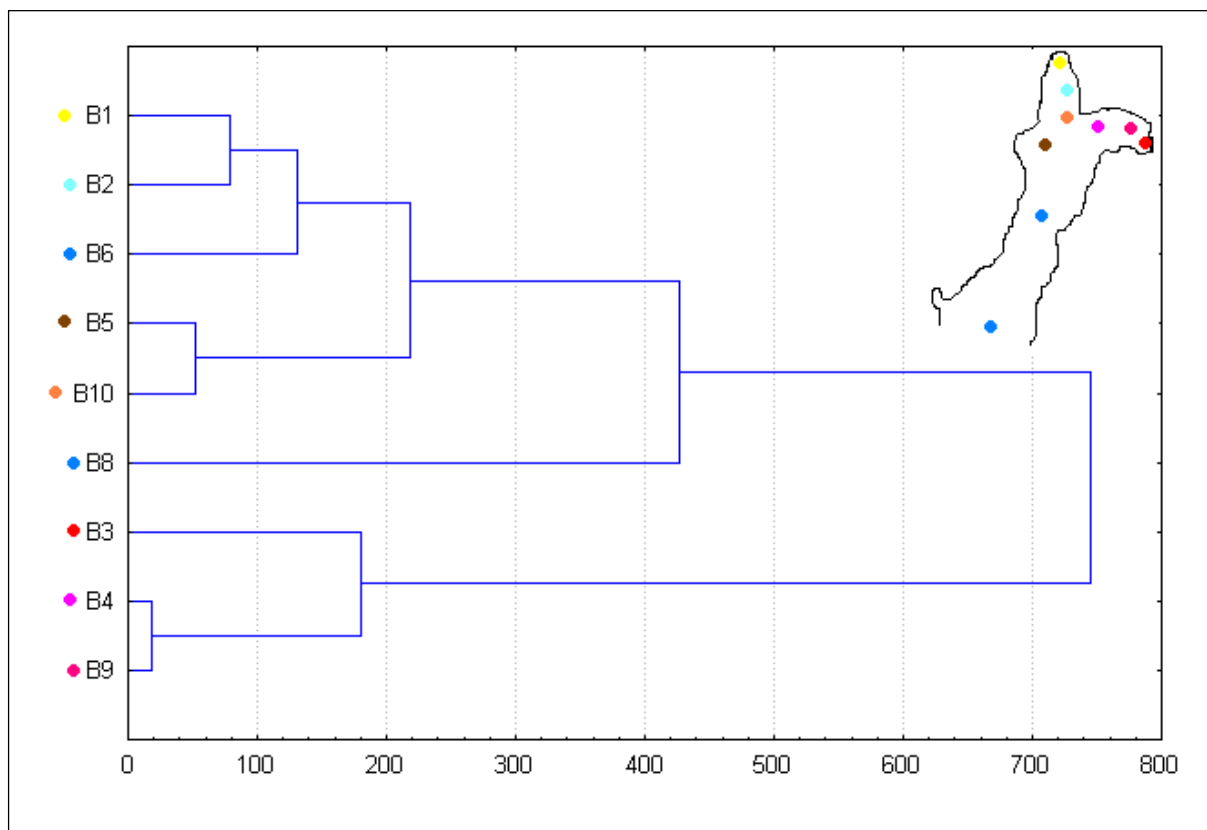


Fig.56. Cluster analysis for REE compositions of surface sediment samples from Billefjorden. The analysis was performed with the Ward method. The x-axis distance is a measure of dissimilarity (the further is the knot, the more different are the samples).

The analysis was performed for a number of sets: the bulk chemical composition, the trace elements, REE and the above listed corrected to Al and Rb. Fig. 56 shows cluster analysis presentation for REE, which are the most suitable for provenance analysis, and shows very similar results to the other mentioned analysis. Cluster analysis of all analysed elements in surface samples has revealed that samples from Adolfbukta and from the rest of the fjord are different. It suggests that the most of sediments delivered by Nordenskiöldbreen – potentially the main source of material to the fjord is trapped in the nearby basin (within the first 5 km). Samples of Mimerbukta, central basin and Petuniabukta form the second cluster to which also the sample of the entrance sill is added of a much higher dissimilarity level. The significant similarity of the last groups is an effect of almost identical geology of drainage areas. In the analysis of major and trace elements very similar pattern is observed with closely related samples from Adolfbukta in one group, from Petuniabukta and central basin in the second, and with sample from the fjord sill as the most dissimilar one. However, the results of all the cluster analysis must be

treated with caution since the correlation between data sets for the stations are very high. It is exemplified by Tab. 6, where correlation matrix for REE concentrations is presented. The high correlation between chemical composition of samples can be partly an effect of mixing of the eroded material in glacial environment – fjord sediments are in significant portion derived from erosion of previously deposited terrestrial glacial and glacial deposits as well as raised (due to glacioisostasy) marine deposits. Another source of similarity is related to geological history of the region. The younger sedimentary strata were created mostly from material, which was eroded from older crystalline rocks (Harland et al. 1974; Dallmann et al. 1999) so at least in part they are marked with similar geochemical signal.

Tab.6. Correlation matrix between surface sediment samples based on their REE compositions.

	B1	B2	B3	B4	B5	B6	B8	B9	B10
B1	X	1.00	0.98	0.98	0.99	0.98	0.85	0.98	0.99
B2	1.00	X	0.97	0.99	0.99	0.99	0.88	0.99	1.00
B3	0.98	0.97	X	0.99	0.98	0.97	0.87	0.99	0.98
B4	0.98	0.99	0.99	X	1.00	0.98	0.88	1.00	1.00
B5	0.99	0.99	0.98	1.00	X	0.99	0.89	1.00	1.00
B6	0.98	0.99	0.97	0.98	0.99	X	0.93	0.98	0.99
B8	0.85	0.88	0.87	0.88	0.89	0.93	X	0.88	0.88
B9	0.98	0.99	0.99	1.00	1.00	0.98	0.88	X	1.00
B10	0.99	1.00	0.98	1.00	1.00	0.99	0.88	1.00	X

The provenance study is limited by similarities in sediments throughout the fjord, however available evidence supports conclusion about trapping of sediments in the direct vicinity of their sources (within a few km). Only the iceberg rafting has limited longer distance impact on sediment properties.

7 SEDIMENT ACCUMULATION RATES

Sediment accumulation rates were computed on the basis of radioisotopes analysis (^{210}Pb , ^{137}Cs and AMS ^{14}C), and sediment trap experiments. One of the goals of the analysis was to establish age models for the studied cores.

^{210}Pb DERIVED SEDIMENT ACCUMULATION RATES

They are several models for calculation of sediment accumulation rates from ^{210}Pb depth profile: CIC (constant initial concentration), CRS (constant rate of supply, Appleby & Oldfield 1978), IMZ (incomplete mixing zone model, Abril et al. 1992) and others. For present study was employed an equation, which is based on CIC model (Goldberg & Koide 1962; Harden et al. 1992), and which is believed to be the most suitable for linear sedimentation rate [cm yr^{-1}] or mass accumulation rate [$\text{g cm}^{-2} \text{yr}^{-1}$] calculations in sediments with surface mixed layer:

$$S = \lambda z [\ln \{A_0 / A(z)\}]^{-1} \quad (8),$$

where

λ - ^{210}Pb decay constant (0.031 yr^{-1}),

z - depth in core [cm],

A_0 - specific activity of ^{210}Pb at a particular reference horizon [dpmg^{-1}],

$A(z)$ - specific activity of ^{210}Pb at depth z below the reference horizon [dpmg^{-1}].

In the equation deep mixing is assumed to be negligible and hence often it is not, the calculated sediment accumulation rate represents an upper limit to the true sediment accumulation rate (Benninger et al. 1979; Nittrouer et al. 1984). The effects of deep mixing can be evaluated by testing with another radionuclide covering comparable time scale – for instance ^{137}Cs (Nittrouer et al. 1984; DeMaster et al. 1985; Smith 2001).

Tab.7. Sediment accumulation rates calculated on the basis of ^{210}Pb profiles.

core	Linear accumulation rate [cm y^{-1}]	Mass accumulation rate [$\text{g cm}^{-2} \text{y}^{-1}$]
B1/2001	> 0.15 (?)	> 0.21
B4/2001	0.18	0.26
B5/2001	0.16	0.23
B6/2001	0.12	0.17
B7/2001	0.08	0.11
B10/2001	0.09	0.12

The results are listed in Tab. 7 and Fig. 57. In general sediment accumulation rates vary between $0.1 - 0.2 \text{ cm y}^{-1}$ ($0.1 - 0.25 \text{ g cm}^{-2} \text{y}^{-1}$) and are higher in distal parts of

bays (Adolfbukta, Petuniabukta, Mimerbukta) than in the central basin. The sediment accumulation rates from the B1/2001 core are estimated only as the lower limit. The profile represents non-steady sedimentation and the excess activities are very low, possibly due to dilution by rapid sedimentation. Some uncertainties are also related to the cores B7/2001 and particularly to B10/2001, whose profiles resemble ones of event layer deposition (Jaeger et al. 1998). In the core B5/2001 the middle part of the profile is steeper – probably an effect of increased sedimentation rate.

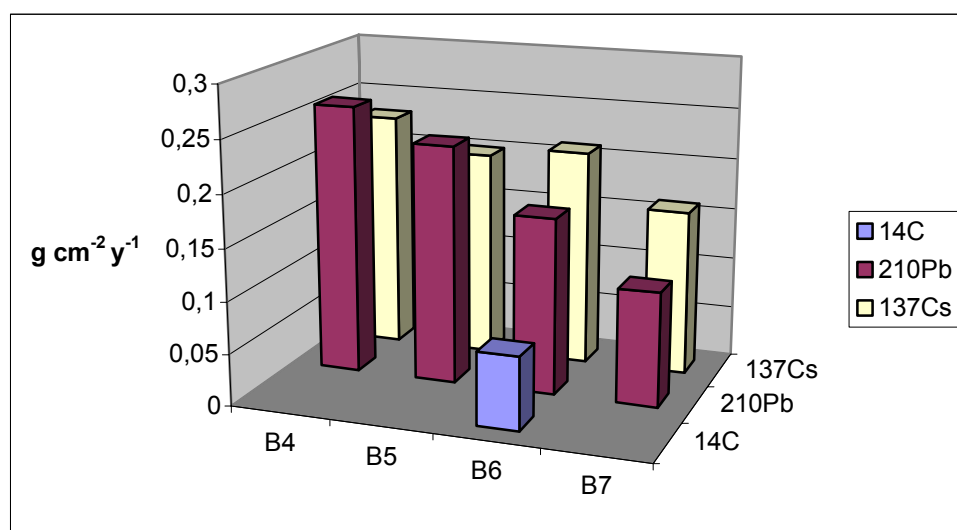


Fig. 57. Comparison of recent sediment accumulation rates obtained with different methods. The coring stations are ordered in distance from Nordenskiöldbreen.

¹³⁷Cs DERIVED SEDIMENT ACCUMULATION RATES

¹³⁷Cs is an artificial radionuclide with a half-life of 30.17 years. In the most of sedimentary environments, ¹³⁷Cs deposited as fallout is rapidly and strongly fixed by sediment (particularly clay) particles (Livens & Rimmer 1988). Further, ¹³⁷Cs redistribution occurs in association with sediment particles. Dating with ¹³⁷Cs data is based on assumptions of certain age for particular parts of its depth profile (Ritchie & McHenry 1990; Ely et al. 1992; Pinglot et al. 1999): the deepest occurrence of ¹³⁷Cs activity corresponds to the first significant atmospheric releases in 1952 - 1953, the depth of maximum ¹³⁷Cs activity in the sediment relates to the maximum atmospheric production in 1963, the second maximum of radiocaesium (only in part of the Northern hemisphere) is associated with 1986 Chernobyl accident. Tab.8. and Fig. 57 show the calculated sediment accumulation rates for available time spans. For calculations the first

appearance (1952) of the isotope was used, only in cores where higher sediment accumulation rates (B5, B9) the 1963 and 1986 peaks were resolved (Fig. 53). Very good correlation of ^{210}Pb and ^{137}Cs (only for B7 station is slightly worse, Fig. 57) results show that deep mixing can be assumed negligible in the considerations. It also supports the interpretations of ^{137}Cs activity peaks.

Tab.8. Sediment accumulation rates calculated from ^{137}Cs distribution.

Core	Distance from the fjord head (Nordenskiöldbreen)	Time span	Linear accumulation rate [cm y^{-1}]	Mass accumulation rate [$\text{g cm}^{-2} \text{y}^{-1}$]
B9/2001	4.3 km	1952-2001	≥ 0.39	≥ 0.59
		1963-2001	0.42	0.63
		1963-1986	0.52	0.81
		1986-2001	0.27	0.38
B4/2001	6.2 km	1952-2001	≥ 0.16	≥ 0.23
B5/2001	10.5 km	1952-2001	0.14	0.20
		1963-2001	0.11	0.16
		1952-1963	0.36	0.59
B6/2001	16 km	1952-2001	0.12	0.21
B7/2001	23.5 km	1952-2001	0.16	0.16

Tab.9. ^{14}C and ^{137}Cs based sediment accumulation rates for B6 core.

Time span	Linear accumulation rate [cm y^{-1}]	Mass accumulation rate [$\text{g cm}^{-2} \text{y}^{-1}$]
1952-2001	0.12	0.21
1460-2001	0.049	0.07
1460-1952	0.029	0.04

^{14}C DERIVED SEDIMENT ACCUMULATION RATES

The ^{14}C results show that there is almost no sedimentation in the sill region (station B8). Although the dated shells were brownish (likely a sign of alteration), they represent both modern (60 yr BP) and fossil (460 yr BP) ages. The dating of the bivalve shell from B6A/2001 core gave a linear accumulation rate of $0.049 \text{ [cm y}^{-1}\text{]}$ (mass accumulation rate – $0.07 \text{ [g cm}^{-2} \text{y}^{-1}\text{]}$). This result is in agreement with dating presented by Elverhøi et al. (1995) on sample from gravity core taken nearby. They obtained age of $525 \pm 55 \text{ BP}$ for foraminifera from 20 cm depth. In comparison with own ^{210}Pb and ^{137}Cs datings for the same core it is concluded that sediment accumulation rate has increased fourfold in the XXth century (Tab.9, Fig. 57).

Tab.10. Modern sediment accumulation rates in fjords of Svalbard. The data on accumulation rates averaged over the Holocene were not included (mainly based on acoustic survey), because of large differences between modern rates and Holocene ones (see below and also Elverhøi et al. 1995, Hald et al. 2001 and others). Billefjorden, Tempelfjorden and Adventfjorden are branches of the largest fjord in Svalbard – Isfjorden; Kongsfjorden- Krossfjorden is a fjord system in north western Svalbard, and Van Mijenfjorden and Hornsund are big fjords in southern Svalbard.

Fjord	setting	method	Linear accumulation rate [cm y⁻¹]	Mass accumulation rate [g cm⁻² y⁻¹]	Reference
Billefjorden	proximal	²¹⁰ Pb, sediment traps, cyclic sedimentary record	0.13 - 4	0.2 - 6	this work
Kongsfjorden	Inner fjord	monosuphide layers	5 – 10	-	Elverhøi et al. 1980
Kongsfjorden	Proximal	²¹⁰ Pb, ¹³⁷ Cs	-	> 1.8	Svendsen et al. 2002
Hornsund	Proximal	monosuphide layers, acoustic	< 35	-	Görlich 1986; Görlich et al. 1987
Adventfjorden	Central part	²¹⁰ Pb, ¹³⁷ Cs	0.87 – 1.87	1.14 – 2.5	Zajaczkowski et al. in press
Kongsfjorden	Secondary sill	²¹⁰ Pb, ¹³⁷ Cs	-	0.18 - 0.38	Svendsen et al. 2002
Billefjorden	central basin	²¹⁰ Pb, ¹³⁷ Cs	0.08 – 0.18	0.11 – 0.26	this work
Kongsfjorden	Outer fjord	¹⁴ C	0.04	-	Elverhøi et al. 1983
Kongsfjorden	Outer fjord	²¹⁰ Pb, ¹³⁷ Cs	-	0.02	Svendsen et al. 2002
Van Mijenfjorden	Central basin	²¹⁰ Pb, ¹⁴ C	0.18 – 0.35	-	Hald et al. 2001
Tempelfjorden	Central basin	varve counting	1.7	-	Plassen et al. In press
Isfjorden	Central basin	²¹⁰ Pb	0.11 - 0.17	-	Elverhøi et al. 1995
Krossfjorden	Central basin	²¹⁰ Pb	0.2	-	Sexton et al. 1992
Hornsund	Central basin	monosuphide layers, acoustic	1	-	Görlich 1986; Görlich et al. 1987
Hornsund	Outer fjord	monosuphide layers, acoustic	< 0.1	-	Görlich 1986; Görlich et al. 1987

PARTICULATE MATTER FLUXES

For more proximal locations it was not possible to obtain sediment accumulation rates with help of radioisotopes because of too short cores and non steady sedimentation (for example B1 – Fig. 51). To give at least an estimation of the rates the results from sediment traps were recalculated. The average summer values of PMF (Tab.5) from upper traps (to exclude influence of resuspension from calculations) were used as representative for two months (July and August). The obtained average fall PMF (Tab.5) was treated as representative for the remaining 10 months (Zajączkowski (2000) found that also in winter the sedimentation exist). The resulting accumulation rates are in order of $0.2 - 0.6 \text{ g cm}^{-2} \text{ y}^{-1}$. These values include only suspension settling and hence should be treated as minimum ones (sediment gravity flows may significantly contribute in proximal settings). One must also keep in mind that the calculations are based on several assumptions concerning duration of the seasons and that the average values do not include extreme events, which are known to deliver significant amount of sediments (e.g. Cowan et al. 1988). During field work several rainstorms were observed with extreme discharges as well as in the beginning of summer discharges are much higher.

In the B3 core (about 1 km from the tidewater glacier front) a kind of cyclicity in sediment properties is observed (sand content – Fig. 27, carbonates – Fig. 39). If one assume it to be annual the sediment accumulation rates would be in order of $2 - 4 \text{ cm y}^{-1}$ ($3 - 6 \text{ g cm}^{-2} \text{ y}^{-1}$). So few times more than the rate calculated from sediment traps, however, if in comparison with other results from Svalbard fjords (Elverhøi et al. 1980, 1983) this value does not seem to be unrealistic.

MODERN SEDIMENT ACCUMULATION RATES

Modern sediment accumulation rates in fjords of different climatic zones vary through a few orders of magnitude. Several comparisons existing in the literature (e.g. Powell & Domack 1995; Gilbert et al. 1998; Boulton 1990; Jaeger & Nittrouer 1999b) point out that the differences can be related to the position of a given fjord in continuum classification proposed by Dowdeswell et al. (1998) with division into polar, subpolar and temperate settings. The highest sediment accumulation rates are observed in temperate fjords of Alaska (in order of m y^{-1}) and the lowest in high polar setting (as low as 0.01 cm y^{-1}). The Svalbard fjords belongs to the subpolar type and the rates of 0.01 to 10 cm y^{-1} were reported (Tab. 10). The rates observed in Billefjorden are about $0.1 - 0.2 \text{ cm y}^{-1}$ for central part of the fjord and 0.5 up to probably even 4 cm y^{-1} for the more proximal settings. These values situate the fjord into typical range, however, closer to lower values

– it is probably caused partly by smaller drainage basin to fjord area ratio, and by localization in part of island with less precipitation (Hagen et al. 1993). There are also no active surging glaciers, which can supply substantial amount of sediments during surge events (Gilbert et al. 2002).

In Adolfbukta the sediment accumulation rate decays in exponential way as in other glacimarine settings (e.g. Görlich 1986; Görlich et al. 1987; Syvitski 1989; Cowan & Powell 1991). However, along the central basin the rates are very similar – probably as effect of overlapping of sedimentation from several sources.

FLUCTUATIONS OF SEDIMENT ACCUMULATION RATES IN TIME; AGE MODELS

In the studied cores also changes in sediment accumulation rates in time are recorded. The changes are documented in three cores: B6, B9 and B5 (Fig. 58).

In the core B6, which covers last 500 years a fourfold increase in sediment accumulation rate in the last century is observed. It is probably correlated with changes in climatic conditions and glaciers mass balance during maximum and termination of LIA. The problem is further discussed in the chapter 9.

In core B5 (located in the vicinity of Pyramiden) a prominent increase in sediment accumulation rate in the 50s is detected. It well correlates with the period of the Pyramiden settlements and mining area development, which was associated with increased erosion. This explanation is supported by local scale of the accumulation fluctuation (only found in this core). After that period sediment accumulation rate is even lower than before, which might be caused by building of dam across the Mimerelva outwash plain.

The third type of change in sediment accumulation rate is observed in the core from station B9, where decrease in last decades is observed. It is possibly associated with change in distance to the main sediment source (retreating tidewater glacier).

In glacimarine setting variations in sediment accumulation rates can be caused also by other factors, for example glacier surges (Jaeger & Nittrouer 1999a; Gilbert et al. 2002) or rainstorms (Cowan et al. 1988), however, in the light of remaining sediment proxies (see chapter 9) the presented explanations seem to be the most probable.

The obtained data on sediment accumulation rates and their fluctuations served as basis for constructing age models for investigating cores (Fig. 59). The periods covered by certain cores varied from several centuries to several decades. The models are used for interpretation of sedimentary and geochemical record (chapter 9), however, one must keep in mind the model limitations. The sediment accumulation rates are based on

analysis of 1 (^{137}Cs) or 2 cm (^{210}Pb) thick sediment samples, which limits the resolution of the record. Also samples for further analysis were taken in 1 cm increment so the presented values of proxies are averaged over period which was necessary to accumulate 1 cm of sediment. This period varies from 100 years as in case of lower part of B6 core to only 2 years in case of a part of B9 core. In most of the samples it is approximately 10 years and it is not possible to obtain more exact date from the record.

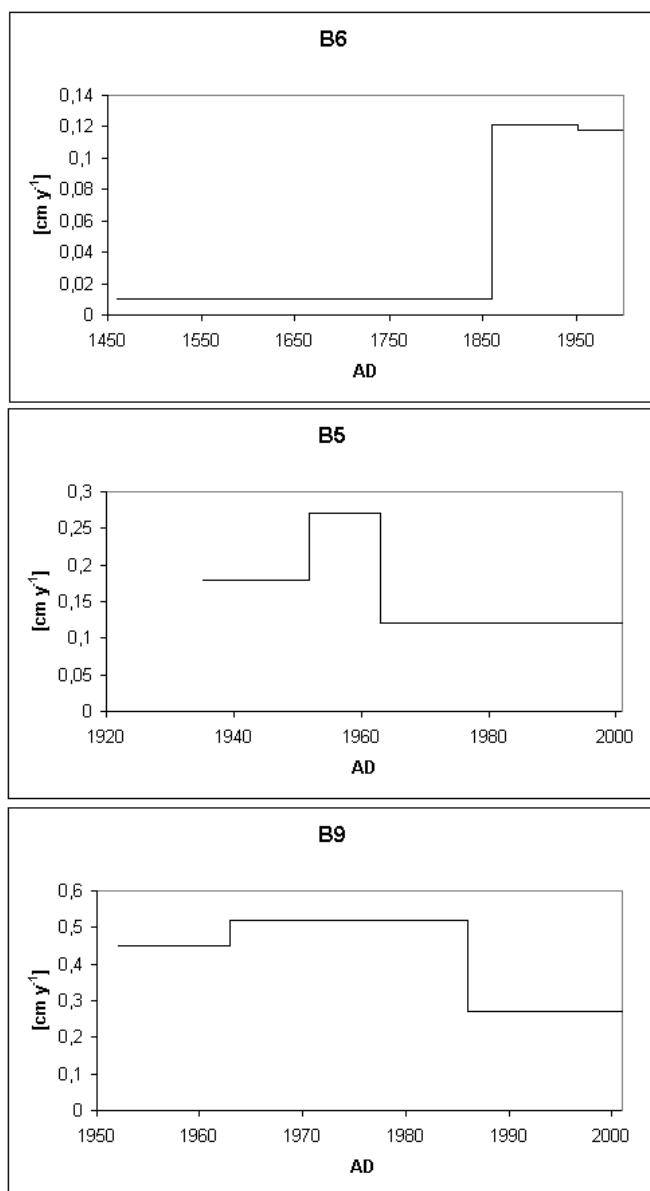


Fig. 58 Changes in sediment accumulation rates for stations B6, B5, and B9.

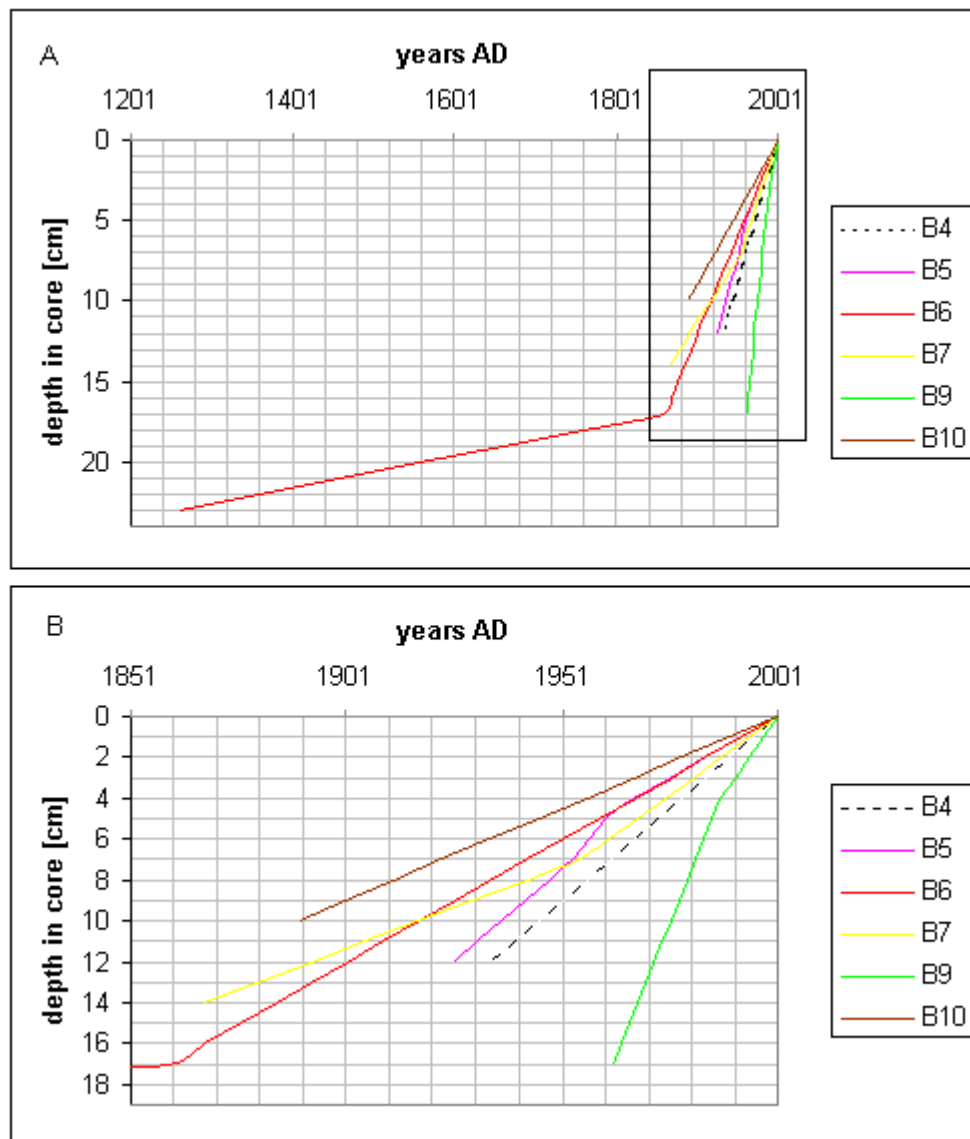


Fig.59. Age models for constructed for cores: B6 (based on ^{210}Pb , ^{137}Cs and ^{14}C datings), B4, B5, B7 (based on ^{210}Pb and ^{137}Cs), B9 (based on ^{137}Cs) and B10 (based on ^{210}Pb). Figure B) shows magnified picture of a part of figure A) (in rectangular).

8 EARLY DIAGENESIS

Diagenesis is an important factor, which has to be considered in deciphering any environmental signals from sedimentary record. The diagenesis is understood here as “the sum total of processes that bring about changes in a sediment or sedimentary rock subsequent to its deposition in water” (Berner 1980). Because the studied sediments are buried to only 30 - 40 cm and the oldest were deposited approximately 500 years ago only its very early effects are well thought-out. The early diagenesis processes are both physical and chemical. To the first group belong sediment compaction and physical mixing. To the second group belong many chemical changes – mainly redox mediated, i.e. they depend on the redox environment in the sediment – interstitial water – seawater system. Redox environment is largely controlled by bottom water exchange rate, and by the degree to which organic carbon is preserved, or undergoes decomposition, in sediment complex. Fjord waters in Billefjorden are well stratified in summer but they are mixed throughout during fall and winter (see chapter 4.3). The mixing is caused primary by brine rejection under sea ice, and by storms and associated inflows of shelf water over the sill. Both mechanisms result in oxygen restoration in bottom waters at least once a year. This, along with restricted bioproduction (Görlich et al. 1987; Svendsen 2002), results in bottom oxic conditions, facilitating benthic fauna existence and in consequence bioturbation of sediments, as well as specific diagenetic reactions (Chester 2000).

Compaction of sediment is visible in all studied cores. However, below the surface (1-4 cm) layer it is very limited in the studied cores (till 20 – 30 cm).

Bioturbation and physical mixing are present in the sediments. Their impact is relatively low. Bioturbation is more common in shallow and more energetic water environments (most of the studied cores were selected in deep and low energy waters). The mixing from dropstone fall can be equal to that from bioturbation.

In all the studied cores a sharp downcore decline within several top cm araneous (agglutinated) foraminifera tests (especially *Alveolophragmium* (Labrospira) *crassimargo*) was noticed (Figs. 31, 32, 35, 60). Many authors have noticed similar situation in other marine environments (Elverhøi et al. 1980; Murray & Alve 1999a, 1999b; Murray et al. 2003). The most plausible explanation is a taphonomical decay of the cement. The downcore decline in arenaceous foraminifera is indeed often associated with the redox cline, but not always so. The araneous foraminifera assemblage in the fjord consists exclusively of non-calcareous, organo- and ferro-agglutinated foraminifera. Therefore the disintegration of the cement is due to either the Fe^{3+} to Fe^{2+} reduction or the

bacterial decay of organic compounds. Parallel observation was made in Kongsfjorden (one of the fjords in western Spitsbergen), where Elverhøi et al. (1980) found similar downcore decline in another agglutinated species – *Spiroplectammia biformis*.

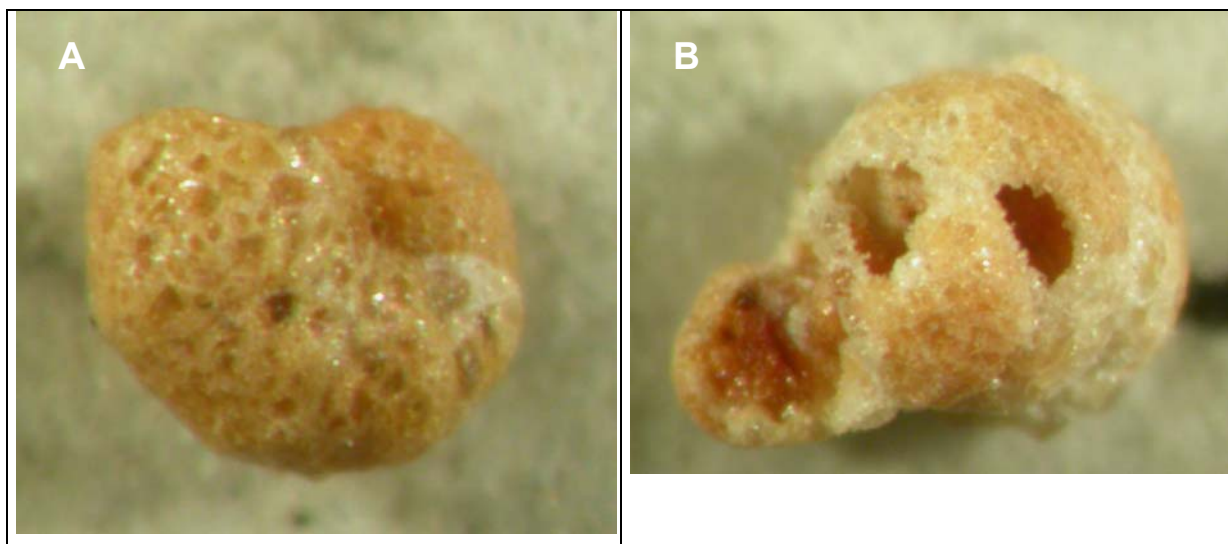


Fig.60. Agglutinated foraminifera in fresh state (A) and partly disintegrated (B). Both examples from B6 core from surface (A) and 2-3 cm deep sample (B). The size of both tests is about 0.6 mm.

Organic matter decomposition is one of the fundamental processes of marine sediments early diagenesis (Chester 2000). The values of LOI (which are believed to be also a function of organic matter content) is characterised by an up-core increase. This can be explained by at least three processes (Boyle et al. 2004): eutrophication (leading to enhanced within-fjord production of organic matter), progressive diagenetic consumption of a constant natural supply of organic matter, and enhanced top-soil erosion on land, delivering oxidation resistant solid organic matter. The last two seem to be the most probable.

Near surface Mn enrichment of marine sediments is very typical for sediments with oxidized surface layer and was also found in the all studied cores from Billefjorden (Fig.41 - 44). On burial manganese oxides are reduced and solubilized and as consequence of diffusion soluble Mn^{2+} migrates upwards in the pore water and is reprecipitated as oxide near the sediment surface (Lynn & Bonatti 1965; Skei & Paus 1979; Deflandre et al. 2002). Due to the effect of scavenging of metals onto freshly precipitated manganese oxides enrichment in their concentrations can also occur (Murray 1975). However, in available dataset (chapters: 4.13 and 4.14) such a relationship was not found. Recently Sunda &

Kieber (1994) have shown that bacteria can coat themselves in Mn oxides possibly to assist oxidation of organic material, which they could not otherwise use, and in this way can stimulate the presence of Mn near surface maximum.

9 LATE HOLOCENE ENVIRONMENTAL CHANGE RECORDED IN FJORD SEDIMENTS

MULTIPROXY ANALYSIS

To reveal the Late Holocene environmental change record several cores were studied with help of multi proxy analysis. The cores (on each station two cores were collected – see chapter 3.1) from four stations with well established age models (Fig. 59) are presented below. They are: B4 from Adolfbukta, B5 from the neighborhood of Pyramiden settlement and B6, B7 from the central basin.

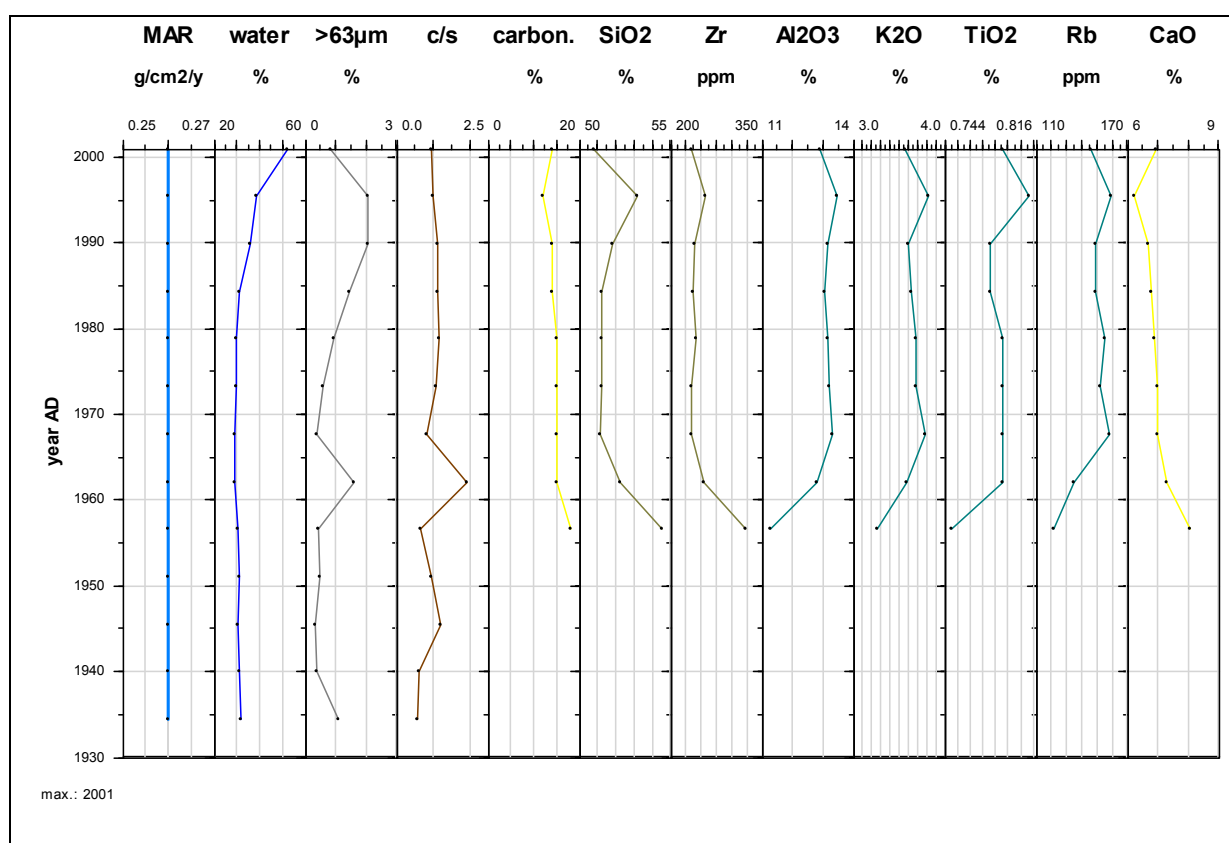


Fig. 60. Multiproxy record from B4 stations. MAR – mass accumulation rate; c/s – clay to silt ratio; carbon. – carbonate content.

In the cores from station B4, which is located in the deepest basin of the fjord, in Adolfbukta, the sedimentary record covers at maximum the last 70 years, but only last 50 years were recorded in both cores. The sediment accumulation rate was not changing during this period and was about $0.26 \text{ g cm}^{-2} \text{ y}^{-1}$. The most evident changes in the studied

sediment characteristics are shown in Fig.60 and, although their variations are very small, they present a similar pattern. The most important change occurred in the period from late 50-s to the early 70-s, when slight increase in sand content, clay/silt ratio, Al and related elements (K, Ti, Rb) content was noted. At the same time the participation of Si and Zr in bulk sediment composition decreased. The carbonate content, Ca and Mg did not change except of the middle 90-s when they were in decrease in comparison to Si and Al. The period of the main change (the 60-s) coincided with retreat of the Nordenskiöldbreen (the major source of sediments for this location – see chapter 6) from its position in deeper water (50 –70 m) to shallower (30-40 m – similar as at present, Fig. 61), and with division of its ice cliff into two parts (northern and southern) by rocky peninsula (Fig. 13). Shallower ice front position was accompanied with smaller ice thickness, and likely resulted in calving of much smaller icebergs, thus they could melt faster and leave more of the sediment load in Adolfbukta than previously, it would also result in less IRD in the main basin of Billefjorden. The slight increase in sand content (sand is probably entirely transported by icebergs to this location) could be explained by the mechanism described above. On the other hand the retreat caused an increase of distance between the coring location and the sediment source (meltwater outflow). The effect of this is probably recorded in slight upcore sediment fining (increase in clay / silt ratio). It is also visible in bulk chemical sediment composition: Si and Zr contents, which are usually typical for coarser fraction, decline in upcore direction, and Al, K, Ti and Rb – usually associated with finer (clay) fraction reveal a slight increase. The relatively remote position of the station (6.2 km from modern tidewater ice front) causes, however, that the observed fluctuations are very small.

The station B5 represents more distal position with respect to the Nordenskiöldbreen (approximately 10.5 km) than the B4. It is the closest of the studied locations to Pyramiden settlement and mouth of the Mimerelva. The reliable dated record (Fig.62) starts in the 1920s, so it covers the whole period of mining activities, which started in 1947, was at maximum in 70s and 80s and finally declined in 1998. In the core a prominent increase in sediment accumulation rate in the 50s is detected (Figs. 58, 62). It correlates well with the period of the Pyramiden settlements and mining area development, which was possibly associated with increased erosion due to earth works. This explanation is also supported by local scale of the sediment accumulation rate fluctuation (only found in this location). After that period sediment accumulation rate is even lower than before, which might be caused by a dam built across the Mimerelva outwash plain. One of the signs of intensified erosion on previously stable areas is

increase in plant fragments content in sand fraction, which maybe a sign of tundra destruction in the catchment. This proxy also well correlates with the period of mining activity. The most evident signal of anthropogenic influence among the studied proxies is coal sand content (Fig. 62). Its background concentrations were up to 3 % of sand fraction, however, since the 1950s this value increased, up to 30 % in the late 70s and early 80s, and declined later to about 12% in the surface sediments. The pattern corresponds very well to the changes in the mining intensity. Interestingly, the pattern of coal sand fraction changes is imitated by Zn concentration. So also the increased content of this heavy metal is postulated to be an effect of anthropogenic activity. Elevated values (in comparison to background values) of Zn and also of other heavy metals were recently found (Gulińska et al. 2003) in soils of Pyramiden settlements supporting the interpretation presented above. Another prominent change is observed in fluctuations of carbonate, CaO and MgO concentrations. All of them present almost identical pattern with the lowest values in the oldest part of the core, which increase significantly from the 40s to the 60s. Later the concentration levels are kept stable. Interestingly the change is not correlated to another potentially carbonate related proxies like shell fragment and foraminifera contents (Fig. 62). The last one shows sharp decline in the uppermost few cm associated with agglutinated foraminifera tests dissolution (see chapter 8). The change in carbonates, Ca and Mg is reflected by significant declines in concentrations (Fig. 62) of such elements as Si, K, Ti (since the 40s), and Rb, Y (since late the 50s). Although the timing of the presented changes is similar to the beginning of mining activity it is probably caused by different reason. The mining started in 1947 and observed changes were initiated even as early as in the late 30s. Possible explanation is change in iceberg derived sediment flux to the studied position. As shown in Figs. 13 and 61, as well as by record from the station B4, the only source of icebergs in the fjord – Nordenskiöldbreen, retreated significantly in the period of interest. So the icebergs had to be transported for longer distance to the studied location and they could lose more load due to melting before reaching it. Even more important, however, may be change in the ice front position water depths (Fig. 61). In shallower situation tidewater glacier calving rate is believed to decrease (Brown et al 1982). As the ice front is thinner (in shallower waters) also the produced icebergs are much smaller, so they can be melted much faster and a lot of potentially transported load might be left in more proximal locations. The elements, which are in decline in the studied cores have their maximum concentrations (in the scale of the fjord) in sediments of Adolfbukta (Figs. 40, 45 and 55) suggesting that the observed change is caused by diminished influence of material transported from that part of the fjord. To test this

hypothesis a cluster analysis of major and trace elements for representative samples of sediments from Adolfbukta (region dominated by sedimentation from Nordenskiöldbreen) and from upper (deposited after 1952) and lower portion of the B5 cores was conducted. Although all the samples are very similar in composition the older sediments from B5 core reveal much bigger similarity to modern sediments from Adolfbukta than to modern sediments from the same location. It suggests that in the first half of the XXth century the influence of sedimentation from Nordenskiöldbreen (in form of icebergs) was much more significant. One must keep in mind, however, that sedimentation from icebergs is only a secondary mode of deposition (see chapters 4.8 and 5) so its fluctuations only modified the sediment composition but did not change significantly the sediment accumulation rate, which is primarily controlled by suspension settling from more local sources (probably Mimerelva). They are also another possible explanations of the observed changes in the sediment composition: change in circulation pattern in the fjord or alterations in the nearby river drainage area but there are no prerequisites to support them.

The station B6 represents the longest record among the studied cores. The constructed age model (Fig. 59) reaches back till the end of XIIIth century (Fig. 63). Unfortunately the second from collected cores was shorter, so only the XXth century has the full coverage (Fig. 64). The most striking are changes in sediment accumulation rates. In the period 1300 AD to about 1895 (maximum extent of LIA glaciers) the rates were one order of magnitude lower than after LIA. The latter, when compared with record on nearby well dated gravity core (Elverhøi et al. 1995), are also the highest in the whole Holocene period (Fig. 65). This dramatic change is possibly related to climate changes. The older period is known as probably the largest glaciation on Svalbard during the Holocene (Mangerud & Svendsen 1990; Svendsen & Mangerud 1992; Snyder et al. 2000). The period was characterised by lower temperatures, probably lower precipitation and positive ice mass balance (Dowdeswell et al. 1997; Lefauconnier & Hagen 1990) so a portion of precipitation was kept in glaciers. It resulted in diminished surface runoff in terms of period (shorter ablation season) as well as magnitude (discharge based on precipitation reduced by a portion stored in growing glaciers). With the change at the end of XIXth and beginning of XXth century, which was in terms of temperature (Fig. 2) one of the most dramatic changes during the whole Holocene, the sediment supply to the fjord significantly increased. They are several processes, which probably contributed to this effect. Retreating glaciers are known to erode and release much more sediments than in stage of equilibrium or advance (Koppes & Hallet 2002). In front of their land based margins they left covers of unconsolidated sediments, which are very susceptible to erosion. Significant

warming resulted in a huge amount of meltwater released during summers, which together with increased precipitation (Førland et al. 1997) effected in much higher discharges to the fjord. Contemporary freshwater discharge in Svalbard is in at least 50% attributed to negative glacier mass balance (Killingtveit et al. 2003). Comparing proxies from the two periods (during and after LIA) one must keep in mind that in the older period one sample (1 cm) represents approximately 100 year and in modern only 10 years. The grain size of sediments is similar throughout the whole studied period. Two maxima in > 63 microns fraction are related to drop stones, which disturbed the results. Clay to silt ratio has approximately the value of one in the whole core except one sediment sample, which was deposited around the 1950s and, which may be result of turbidity flow. IRD is at similar level in the whole core although upper part reveals bigger variability. The same amount of IRD in the older part of the core together with lower sediment accumulation rates may indicate that delivery of debris by icebergs was probably up to 10 times lower. Shell fragment and foraminifera test contents reveal some variation, however, without any clear trend. Only in uppermost portion of the core an increase in foraminifera tests number is observed (because of agglutinated forams). Again similar values for periods of higher and low sediment accumulation rates suggest that the flux of shell fragments and forams tests to the bottom was several times lower during LIA, or that they were partly dissolved, however, no indication of such phenomena was found. The carbonate content during the last century increased independently from the discussed proxies. Slightly increased frequency of plant fragments in sediments, particularly at the beginning of the XXth century may be correlated to enhanced erosion rate. The coal sand content although very low shows steady increase since the middle of XIXth century. Probably it represents natural erosion of coal measures, which is supported in the second half of the last century by anthropogenic impact. During the last century (Fig. 64) the most spectacular change in sediment composition occurred in the 40s and 50s when contents of Ca and Mg started to increase and Si, Al., K, Ti, Rb and Y began to decline. This change in timing and in its character is identical to one observed in B5 station and is also explained as decrease in material delivery by icebergs, caused by retreat of the tidewater glacier into shallower position.

The cores from station B7, which is located in southern part of central basin and is the most distally located from the studied cores with respect of Nordenskiöldbreen, cover approximately the last 130 years (Fig. 66). It must be, however, underlined that in the case of this station the age model is the least reliable from the presented in this chapter. For station B4, B5 and B6 no reasonable indication of resedimentation or sediment gravity

flows was found (except when mentioned – for instance in the core B6). The core B7 in its ^{210}Pb profile shows pattern typical for event sedimentation (Jeager et al. 1998), which could be interpreted here is a series of small turbidities which, however, can also preserve environmental signal. Most of the analysed proxies reveal very similar variations to that observed in the B6 or even in B5 station. In particular the decline in concentrations Si, Al., K, Ti, Rb, Y and increase in Mg. The changes are much smaller, however, the timing (since the 40s and the 50s) suggest that the reason is the same as in the cores discussed above. The exception is upward decreasing content of Ca, which is difficult to be explained in the light of available data (no correlation to shell or foraminifera test contents). Also similarly as in B6 coal sand content increase in the second half of XX century, the concentrations are, however, very small.

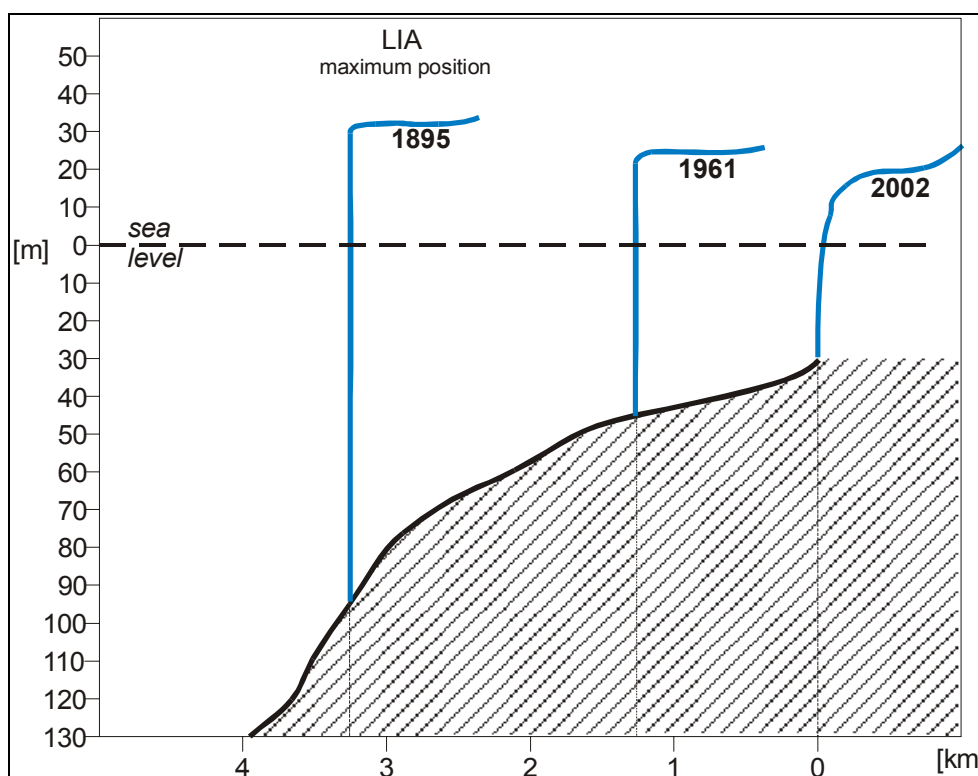


Fig.61. Changes of the tidewater front of the Nordenskiöldbreen in the last century. The maximum LIA position based on de Geer (1910) and Slater (1925), the 1961 after Norsk Polarinstittut map (1984, 1988), 2002 position and bathymetry – own survey. The average retreat rate along the iceflow centerline is about 30 m y^{-1} . Since the late 1950-s the tidewater front divided into two parts, which are separated now by rocky peninsula “Retretoya odden”.

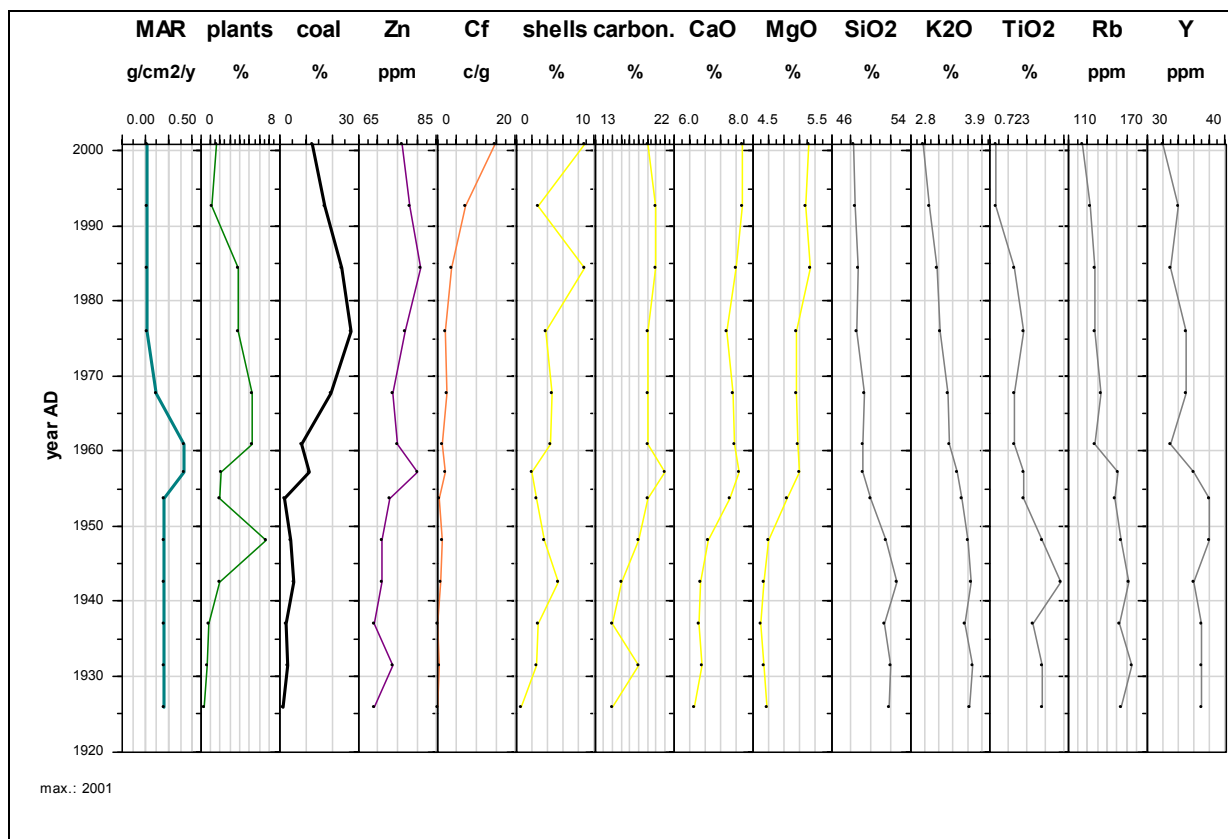


Fig.62. Multiproxy record from B5 station. MAR – mass accumulation rate; coal, plants and shells are presented in percent of their participation in >250 fraction c/g – counts per gram of dry sediment in >250 microns fraction; C_f – concentration of benthic foraminifera; carbon. – carbonate content.

MAIN EFFECTS OF CLIMATE CHANGE IN SEDIMENTARY RECORD

The Little Ice Age (LIA) appears in most Northern Hemisphere paleoclimate reconstructions as multiple, century-scale periods of anomalously cold, dry conditions between 15th and late 19th centuries (e.g. Grove 1988; Briffa et al. 1990; Fischer et al. 1998). Glacial advances in both hemispheres (Grove 1988) and enhanced polar atmospheric circulation (Kreutz et al. 1997) and sea surface temperatures suggest that LIA was a global-scale event, although some records suggest that it was restricted to higher latitudes. In Svalbard LIA effected in lowering of ELA (equilibrium line altitude) on glaciers of about 100 m (Liestøl 1988; Mangerud & Svendsen 1990), what caused their advance to the maximum Holocene positions. Following warming (exceptional in the global scale – Fig.2) caused several changes, which in particular influenced water cycle in glacial system and through freshwater and SPM discharges altered sediment

accumulation rates in fjords (Figs. 58, 65). All these changes in physical parameters influence also the biotic part of the environment (e.g. Hop et al. 2002). For example zooplankton can suffer direct mortality from the freshwater glacial outflows and primary production may be reduced because of limited light levels in the rich in SPM waters.

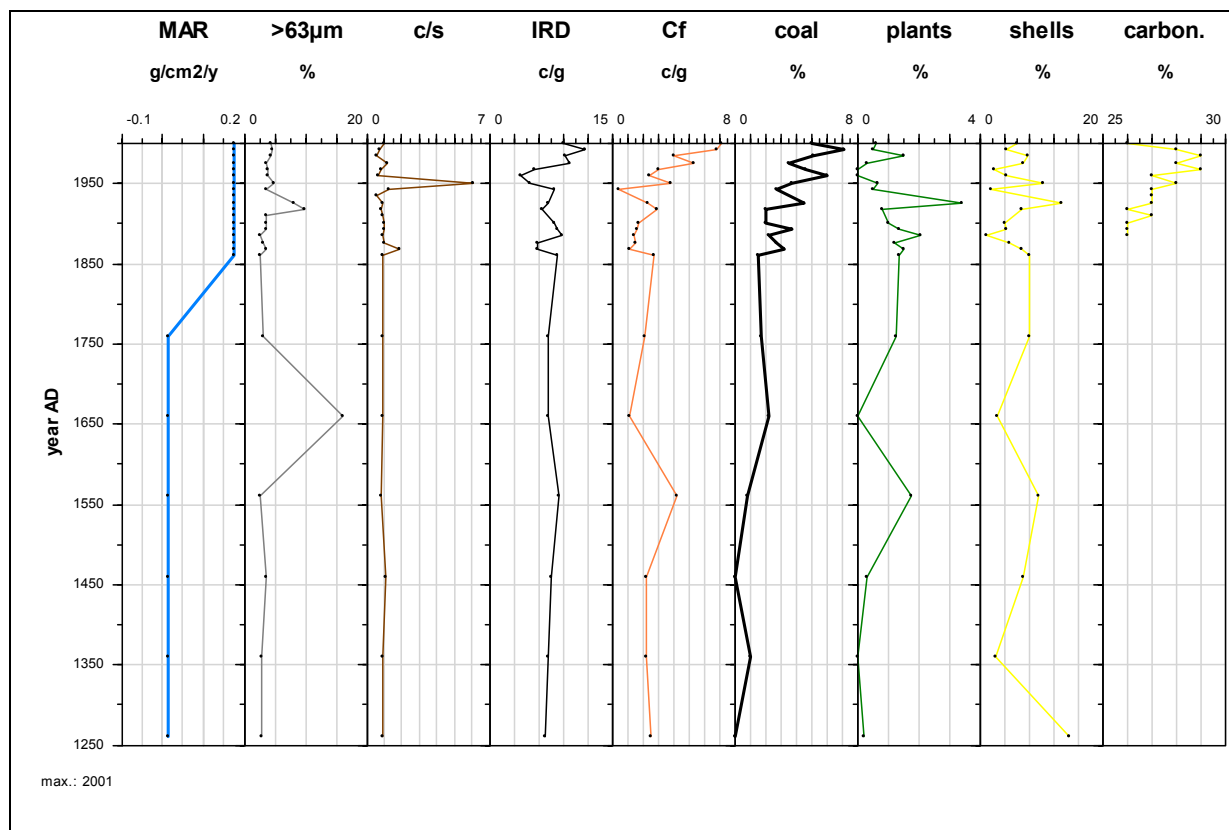


Fig.63. Multiproxy record from B6 station – the last seven centuries. MAR – mass accumulation rate; c/s – clay to silt ratio; c/g – counts per gram of dry sediment in > 500 microns (for IRD) and >250 microns (for C_f) fraction; IRD – ice rafted debris; C_f – concentration of benthic foraminifera; coal, plants and shells are presented in percent of their participation in >250 fraction; carbon. – carbonate content.

In the fjord sedimentary record the LIA transition is the most marked by dramatic change in sediment accumulation rate (Fig. 65). The recent increase in sediment accumulation rate was demonstrated by Elverhøi et al. (1995) for cores from central Isfjorden (based on ^{210}Pb and ^{14}C datings). The average rate for the last 80 years was between 0.11 and 0.17 cm y^{-1} , significantly higher than the general Holocene rates of 0.015 and 0.075 cm y^{-1} . The rapid increase in sedimentation rate over this period was attributed by Elverhøi et al. (1995) to high rates of sediment supply associated with surges of several glaciers in the Isfjorden drainage area during the last 100 years. Similar

explanation is not likely for Billefjorden since they are no certain surges recorded in this period (Hagen et al. 1993). Higher recent sediment accumulation rates were also noticed for other fjords of Svalbard by Hald et al. (2001) for van Mijenfjorden and by Zajączkowski et al. (in press) for Adventfjorden. Van Mijenfjorden is however supplied mostly by surging glaciers (so governed by nonclimatic fluctuations). Adventfjorden has no tidewater glacier and cited study shows a prominent increase in an average rate of accumulation in recent decade in comparison to the last 50 years.

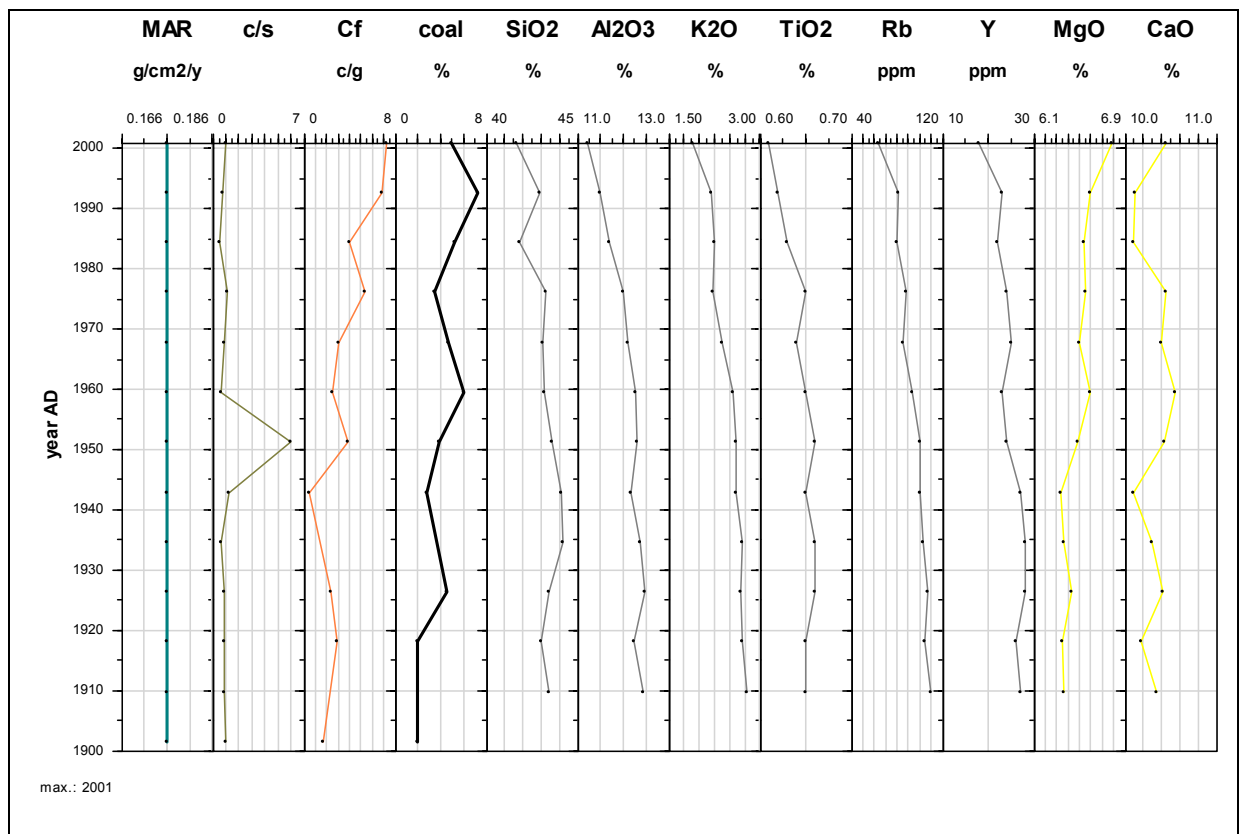


Fig.64. Multiproxy record from B6 station – the XXth century. MAR – mass accumulation rate; c/s – clay to silt ratio; c/g – counts per gram of dry sediment in >250 microns fraction; C_f – concentration of benthic foraminifera; coal is presented in per cent of its participation in >250 fraction.

It is, however, not possible to extrapolate climatic change into sediment accumulation rate directly. The link between climate change and the response of glacier mass balance and geometry to that change is not instantaneous. A time lag is present because mass balance is perturbed throughout glacier length, and is transferred down-glacier at finite velocities over a range of distances. For many Arctic glaciers the timescales for adjustment to changing mass balance are in the order of 10² yr for and

provide an approximation of the lag time between climatic variations and glacier response (Dowdeswell et al. 1997). There are also several non climatic factors, as for instance glacier surging and observed in Billefjorden influence of basal topography (water depth at ice front) on tidewater glacier dynamics (Brown et al. 1982; Jania 1988; Powell 1991; Vieli et al. 2002).

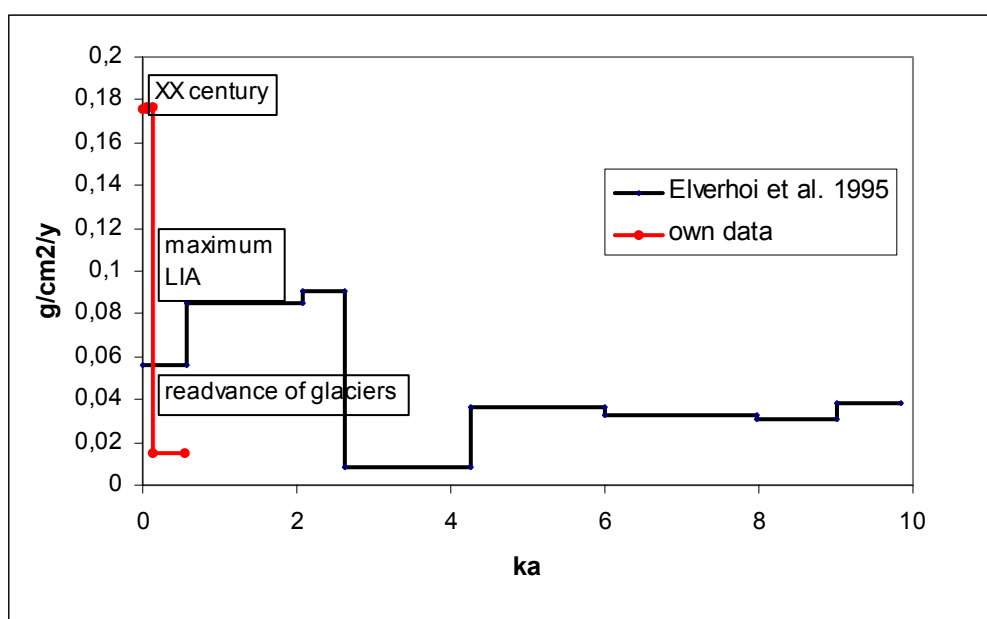


Fig.65. Mass accumulation rates [$\text{g cm}^{-2} \text{y}^{-1}$] in central basin of Billefjorden during the Holocene. The data from Elverhøi et al. (1995) are based on 10 AMS ^{14}C ages from gravity core no. 90-01 taken nearby to the B6 core location. The youngest obtained age (525 ± 55 BP for foraminifera from 20 cm depth) is in good agreement with one presented for B6 (490 ± 35 BP for sample from 21 cm depth) and allows correlation of the cores. Application of ^{137}Cs and ^{210}Pb dating methods has improved the resolution and resolved that mass accumulation rates in recent century were likely the highest in the whole Holocene period.

The presented here data on changes in sediment accumulation rates and recently published data on increased rates in other fjords of Svalbard (Hald et al. 2001; Zajączkowski et al. in press) are in agreement with observed and modeled sediment discharge in the Arctic (Syvitski & Andrews 1994; Syvitski 2002). If the anticipated future warming (Houghton et al. 2001; Førland & Hanssen-Bauer 2003) would proceed the continuous increase in sediment accumulation rates is also expected (Syvitski 2002).

Smith & Andrews (2000) in comparative sedimentological analysis of temperate and subpolar and polar fjords found that there is no distinct difference between them except of sediment accumulation rates (with the highest in temperate setting and the

lowest in polar). The presented results clearly show that using the criterion, in the course of modern climatic changes, fjords of Svalbard (exemplified by Billefjorden) are changing their character from typical subpolar into more temperate.

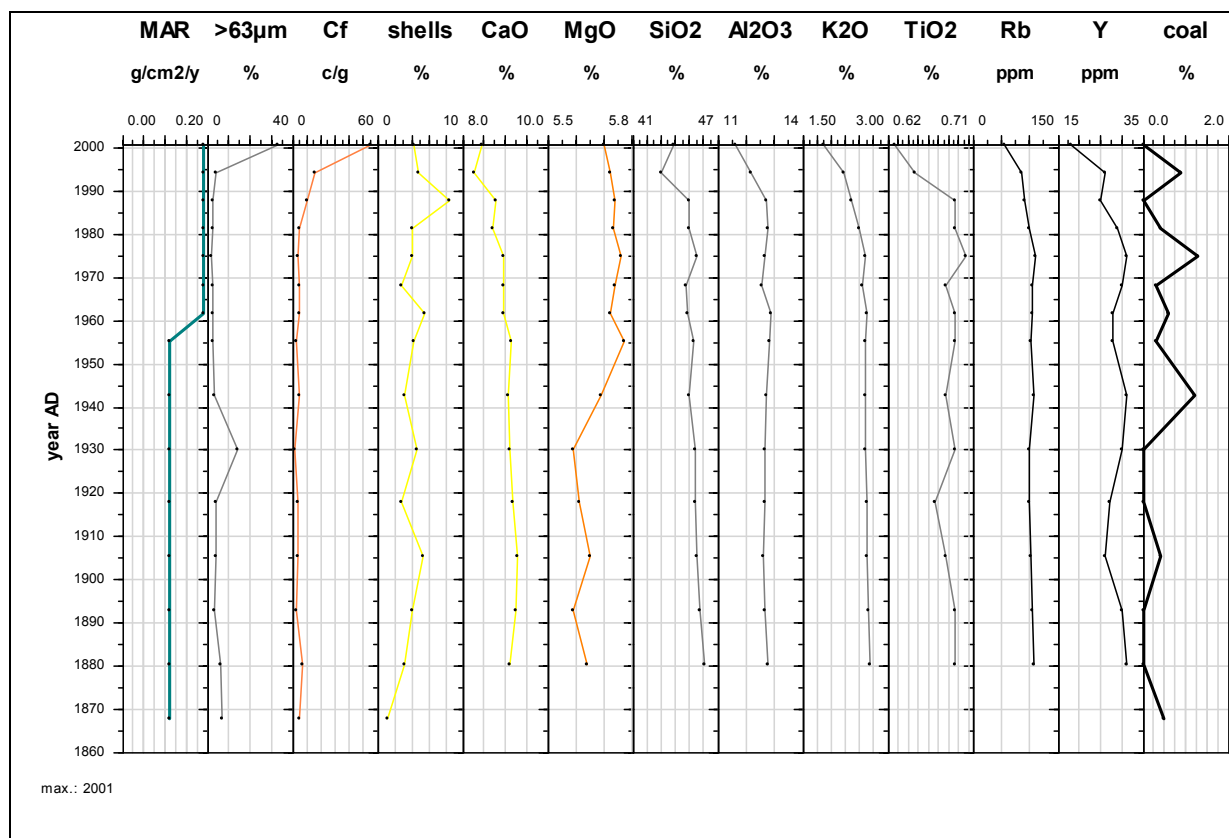


Fig. 66 Multiproxy record from B7 station. MAR – mass accumulation rate; c/g – counts per gram of dry sediment in >250 microns fraction; C_f – concentration of benthic foraminifera; coal and shells are presented in per cent of their participation in >250 fraction.

ANTHROPOGENIC IMPACT

Although Svalbard belongs to the most remote locations there is also concern due to anthropogenic impact. As presented by previous researches (e.g. Aakrog 1994; Headley 1996; Holte et al. 1996; Sikora et al. 1996; Gulińska et al. 2003) there are two main sources of contaminants: local associated mainly with mining settlements, and remote, caused by long distance transport from industrialised regions (mainly Europe). Both of them were also identified in the Billefjorden.

Local source of contaminants to marine environment is currently abandoned mining settlement Pyramiden. The detected changes are related to elevated amount of

coal sand and dust in the sediments and of Zn (and probably also other heavy metals). The changes caused by increased coal content are not known to have any impact on living biota. In contrast, heavy metals can be toxic if they are bioavailable. Sikora et al. (1996) showed, however, that most of them are contained in minerals in Svalbard fjord sediments, so they are of very low bioavailability. It is important also to notice that the documented elevated values (Fig. 62) in comparison to the background are still much below the European legal limits.

The remote contamination was detected in form of radionuclides. From several anthropogenic radionuclides (e.g. ^{238}Pu , $^{239,240}\text{Pu}$, ^{241}Am) only ^{137}Cs was studied. However, as it was presented in previous reports there is a strong relationship between them. There are several sources for radioactive contamination around Spitsbergen. The most substantial include global fallout from nuclear weapons testing near Novaya Zemlya and from the Chernobyl nuclear reactor accident, and from discharges from the nuclear reprocessing plants Sellafield (UK) and La Hague in France (Aakrog 1994; Heldal et al. 2002). In comparison to ^{137}Cs activities (Heldal et al. 2002) in Barents Sea sediments (around 2 – 5 Bq kg⁻¹) and on south and south west off Spitsbergen (up to 9.3 Bq kg⁻¹) the activities are higher but are similar to those observed in other fjord sediments (Svendsen et al. 2002; Zajączkowski et al. in press, Dahlgren unpublished). The higher ^{137}Cs contents could be a result of delivery from Svalbard where previously the isotope was also accumulated in the global fallout.

10 CONCLUSIONS

The Late Holocene sedimentation in Billefjorden was studied through investigations of modern sedimentation conditions and their effects in sediments. Sedimentation in the fjord is dominated by settling from surface turbid water plumes originated from rivers and subglacial outflows of tidewater glacier. Sedimentation is confined to summer season (July - August) and is largely influenced by flocculation. It results in high particulate matter fluxes (up to $100 \text{ g m}^{-2} \text{ day}^{-1}$), poorly sorted sediments and trapping of the most of the sediments in the proximal few hundred meters (in case of rivers ending on tidal flats – flocculation occurs on tidal flat) to a couple of km in the case of tidewater glacier (flocculation happens after reaching the fjord waters). In the fall season sedimentation rates are much smaller – mainly due to smaller sediment supply but also in effect of largely diminished flocculation process. The latter one was found to be controlled primary by mixing of fresh and saline waters (so by freshwater inflow) and not by SPM concentrations. Sediment accumulation rates decrease exponentially from the source with more than 4 cm per year in the proximal settings to about 0.1 cm y^{-1} in the central basin. Sedimentation from icebergs has at least one order of magnitude lower rates.

Fjord bottom sediments are mostly muds with bimodal grain size distribution (due to at least two sedimentation processes: suspension settling and iceberg rafting). Differences in their chemical (major, trace elements and REE) mineralogical and coarse grain fraction composition are small but distinct. The deposits can be divided into regions supplied by local sources (e.g. Adolfbukta, Petuniabukta, Mimerbukta, central basin, entrance sill), supporting the conclusion of sediment trapping in proximal settings. The influence of rafted sediments is visible – especially in central basin sediments, because bulk of them is supplied from catchments of different geology.

In the studied cores early diagenesis is exemplified by compaction, small sediment mixing (through bioturbation and physical processes), and chemical processes associated with redox zone. The most spectacular one is shown by dissolution of benthic agglutinated foraminifera cements and their sharp decline in the upper few cm of sediment cores.

Study of multiproxy signal revealed several changes associated with environmental as well as anthropogenic changes. The most striking are changes in sediment accumulation rates in fjord central basin. In the period 1300 AD to about 1895 (maximum extent of LIA glaciers) the rates were at least one order of magnitude lower than after LIA. The latter are also the highest in the whole Holocene period. Smaller

fluctuations were also associated in tidewater proximal cores where they decrease with increasing distance from sediment source (glacier retreat). Unusual situation was observed in the core located in the vicinity of Pyramiden (coal mine and settlement active between 1945 and 1998) where in the 50s sediment accumulation rates were elevated possibly in association with earth works in the settlement and in mining area. The sediment chemical composition also changed through time – the most distinct change happened around 1950s where in central basin cores increased the relative ratio between carbonate related elements (local catchments) and silica and aluminosilicate related elements (partly controlled by input from icebergs). It well correlates with tidewater glacier retreat into the shallower water area and consequently decreasing iceberg production. One of the main most striking changes in the sediments associated with anthropogenic activity is significantly elevated coal sand and dust content in the sediments, which concentrations well correlates with the intensity of coal mining in the Pyramiden.

In the light of projected future climatic changes in this part of the Arctic the main changes are expected in sediment budget. With increasing freshwater (due to increasing precipitation and ablation) and consequently in sediment delivery, the averaged sediment accumulation rate will increase. However, it will be even more concentrated in proximal settings (prolonged and intensified conditions for flocculation process). The input of deposition from icebergs will be likely smaller since the only tidewater glacier is retreating into more and more shallow setting.

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APPENDIX

I. WATER SAMPLES DATA.

The details on sampling stations are given in Tab.2.

Sample	Date of sampling	Time	Station	Water depth [m]	Temperature [°C]	Conductivity [mS]	pH	SPM [mg dm ⁻³]
NS1	21.07.2001	17:30	NS1	river mouth	1.3	0.0846	7.3	
NS2	21.07.2001	18:45	NS2	0	3.3	46.2	7.86	
NS3	21.07.2001	19:00	NS3	0	3.3	43.1	7.81	
NS4	21.07.2001	19:20	NS4	0	4.8	45.7	7.88	
NN1	21.07.2001	22:35	NN1	river mouth	2.3	0.0714	7.71	
NN2	21.07.2001	22:50	NN2	0	5.7	46	8.1	
NN3	21.07.2001	22:55	NN3	0	5.9	32.3	7.88	
NN4	21.07.2001	23:00	NN4	0	5.8	33.2	7.82	
RE1	26.07.2001	11:59	RE	0	5.1	0.12	7.52	285.92
RE2	26.07.2001	13:00	RE	0	5.3	0.346	7.4	631.70
RE3	26.07.2001	14:00	RE	0	5.3	0.313	7.43	1047.38
RE4	26.07.2001	15:00	RE	0	5	0.236	7.53	419.26
RE5	26.07.2001	16:00	RE	0	4.6	0.1742	7.52	596.77
RE6	26.07.2001	17:00	RE	0	8.4	0.334	7.51	999.61
RE7	26.07.2001	20:03	RE	0	6.9	0.815	7.52	327.26
RE8	26.07.2001	21:03	RE	0	3.2	0.322	7.57	651.81
RE9	26.07.2001	22:00	RE	0	2.3	0.206	7.74	758.38
RE10	26.07.2001	23:06	RE	0	1.7	0.206	7.61	873.55
RE11	26.07.2001	24:00	RE	0	1.4	0.223	7.73	1175.84
RE12	27.07.2001	00:59	RE	0	1.2	0.1998	7.48	622.86
RK1	26.07.2001	12:13	RK	0	8.5	0.428	7.5	1318.27
RK2	26.07.2001	13:21	RK	0	9.2	0.416	7.37	1551.65
RK3	26.07.2001	14:12	RK	0	9.3	0.417	7.49	1655.26
RK4	26.07.2001	15:17	RK	0	9.1	0.337	7.55	1572.88
RK5	26.07.2001	16:22	RK	0	9.4	2.02	7.58	1323.69
RK6	26.07.2001	17:17	RK	0	12	0.273	7.24	675.38
RK7	26.07.2001	20:25	RK	0	8.8			261.74
RK8	26.07.2001	21:25	RK	0	5.8	0.756	7.58	500.77
RK9	26.07.2001	22:21	RK	0	5.2	1.067	7.55	505.98
RK10	26.07.2001	23:20	RK	0	4.8	0.289	7.62	979.22
RK11	27.07.2001	00:14	RK	0	4.2	0.288	7.66	1091.55
RK12	27.07.2001	01:15	RK	0	3.9	0.27	7.44	735.69
M1	11.08.2001	11:00	M1	river mouth		0.1597		373.18
M2	11.08.2001	14:00	M2	0		7.85		131.64
M3	11.08.2001	14:10	M3	0		21.7		36.86
M4	11.08.2001	14:15	M4	0		41.1	7.86	88.15
P1	12.08.2001	13:20	P1	0		1005		15.61
P2	12.08.2001	13:25	P2	0		1121		42.03
P3	12.08.2001	13:30	P3	0		717		46.67
P4	12.08.2001	13:35	P4	0		320		296.27
P5	12.08.2001	13:40	P5	0		265		411.59
P6	12.08.2001	13:45	P6	0		311		1142.75
W 1	18.07.2002	10:15	B1	0	5.3	0.354	7.49	127.64
W 2	18.07.2002	10:20	B1	20	5.4	48.4	7.96	39.79
W 3	19.07.2002	10:30	B1	0	5.2	1.79	7.66	36.06
W 4	19.07.2002	10:45	B1	20	2.8	50.1	7.94	37.52
W 5	19.07.2002	11:15	E1	0	4.3	0.762	7.66	67.30
W 6	19.07.2002	11:30	E1	10	5.9	47.2	7.93	43.60
W 7	21.07.2002	11:00	B1	0	7.6	37.8	7.87	22.91
W 8	21.07.2002	11:00	B1	20	1.2	50.6	7.95	11.46
W 9	21.07.2002	12:00	E1	0	5.5	14.65	7.69	79.14

W 10	21.07.2002	12:00	E1	10	4.8	48.6	7.95	28.50
W 11	22.07.2002	12:00	E1	0	8.2	44.1	7.89	40.66
W 12	22.07.2002	12:10	E1	10	5.2	48.1	7.82	58.45
W 13	27.07.2002	15:00	E1	0	7.7	40.3	7.8	136.88
W 14	27.07.2002	15:10	E1	9	7.1	45.6	7.85	150.00
W 15	27.07.2002	15:20	E3	0	8.1	38.8	7.8	113.58
W 16	27.07.2002	16:00	E2	0	8.6	30.1	7.75	119.72
W 17	28.07.2002	15:30	E1	0	7.7	2.11	7.73	62.71
W 18	28.07.2002	15:30	E1	9	7.7	44.5	7.84	50.77
W 19	28.07.2002	16:10	E2	0	8.3	25.2	7.8	32.32
W 20	28.07.2002	16:10	E2	30	2.3	50.3	7.87	26.80
W 21	28.07.2002	16:25	E3	0	8.7	23.8	7.74	37.88
W 22	28.07.2002	16:25	E3	30	1.5	50.6	7.84	58.13
W 23	29.07.2002	15:20	E1	0	7.5	40.5	7.77	35.52
W 24	29.07.2002	15:30	E1	5	7.3	44.4	7.84	59.16
W 25	29.07.2002	15:40	E1	10	5.9	46.6	7.91	18.21
W 26	29.07.2002	16:00	E2	0	7.3	38.6	7.93	38.94
W 27	29.07.2002	16:20	E2	5	7.2	43.7	7.71	31.98
W 28	29.07.2002	16:30	E2	10	5	47.8	7.88	53.24
W 29	29.07.2002	16:40	E2	20	1.8	50.3	7.74	26.76
W 30	29.07.2002	17:00	E2	33	0.9	50.2	7.82	84.13
W 31	29.07.2002	18:00	E3	0		34.3	7.83	26.42
W 32	02.08.2002	12:15	A1	0		42.3	7.84	66.67
W 33	02.08.2002	12:25	A1	5		48.9	7.81	54.37
W 34	02.08.2002	12:45	A1	20		50.2	8	19.06
W 35	02.08.2002	13:05	A1	40		50.3	7.96	33.37
W 36	02.08.2002	13:40	A2	0		36.5	8.06	64.11
W 37	02.08.2002	14:00	A3	0		40.4	8.01	70.00
W 38	02.08.2002	18:30	A1	0		43	8.02	37.70
W 39	02.08.2002	18:40	A1	5		49	7.98	24.67
W 40	02.08.2002	18:55	A1	20		50.7	7.79	44.81
W 41	03.08.2002	00:10	A1	0		41.5	8.02	40.57
W 42	03.08.2002	00:15	A1	5		49.4	7.97	72.06
W 43	03.08.2002	00:20	A1	20		50.3	7.94	28.63
W 44	03.08.2002	00:30	A1	40		50.4	7.9	41.75
W 45	03.08.2002	07:30	A1	0	3.3	42.1	8.09	54.74
W 46	03.08.2002	07:35	A1	5	3.4	49.7	7.83	48.48
W 47	03.08.2002	07:45	A1	20	2.1	50.8	7.83	46.15
W 48	03.08.2002	07:55	A1	40	1.2	50.9	7.75	107.66
W 49	03.08.2002	13:10	A1	0	3.18	41.7	7.77	84.14
W 50	03.08.2002	13:15	A1	5	3.3	50.1	7.98	28.14
W 51	03.08.2002	13:25	A1	20	2.5	49.9	7.96	7.05
W 52	03.08.2002	13:40	A1	40	1.1	50.5	7.86	28.37
W 53	03.08.2002	15:00	A2	0	3.5	41.4	8.01	47.00
W 54	03.08.2002	15:05	A2	5	4.9	49.8	7.96	37.05
W 55	03.08.2002	15:20	A2	20	3.7	50.1	7.98	
W 56	03.08.2002	15:40	A2	35	1.2	50.6	7.91	45.84
W 57	04.08.2002	15:05	A2	0	4.1	35.5	7.95	81.09
W 58	04.08.2002	15:15	A2	5	6	46.5	7.78	49.62
W 59	04.08.2002	15:25	A2	20	3.7	49.6	7.94	25.69
W 60	04.08.2002	15:40	A2	35	1.7	50.8	7.93	24.85
W 61	04.08.2002	17:00	A3	0	4.7	39.7	7.83	87.86
W 62	04.08.2002	17:05	A3	5	6.8	46.4	7.82	30.67
W 63	04.08.2002	17:15	A3	20	4.9	49.5	7.78	30.43
W 64	04.08.2002	17:30	A3	40	1.4	50.3	7.71	65.43
W 65	27.08.2002	20:30	A1	0	2.2	29.5	8.03	7.88
W 66	27.08.2002	20:35	A1	5	6.9	44.6	8.03	52.34
W 67	27.08.2002	20:45	A1	20	6.1	48.5	8.02	7.60
W 68	27.08.2002	20:40	A1	40	4.5	50.8	7.98	26.09
W 69	27.08.2002	22:05	A3	0	2.8	34.9	8.07	7.30
W 70	27.08.2002	22:10	A3	5	7.1	45.4	7.99	36.54
W 71	27.08.2002	22:15	A3	20	7.2	47.7	8.01	14.35
W 72	27.08.2002	22:20	A3	40	5.9	50.2	8.02	9.05
W 73	17.09.2002	18:35	E1	0	5.3	50.9	8	19.81
W 74	17.09.2002	18:40	E1	5	4.8	50.3	7.96	30.95
W 75	17.09.2002	18:47	E1	10	5.1	50.3	7.92	50.15
W 76	17.09.2002	19:45	E2	0	5.4	50.3	7.92	19.71
W 77	17.09.2002	19:50	E2	5	5.2	50.2	7.98	22.50
W 78	17.09.2002	19:55	E2	10	5.1	50.6	8.05	30.20

W 79	17.09.2002	20:00	E2	30	2.8	51.4	7.76	9.66
W 80	17.09.2002	20:25	E3	0	5.5	50.2	7.97	30.48
W 81	17.09.2002	20:27	E3	5	5	50.1	7.97	17.22
W 82	17.09.2002	20:33	E3	10	4.6	50.4	8.07	28.24
W 83	17.09.2002	20:40	E3	30	3.1	51.3	7.92	21.90
W 84	17.09.2002	20:55	E4	0	5.5	50.2	8.08	14.01
W 85	17.09.2002	20:59	E4	5	4.8	50.3	8.07	31.30
W 86	17.09.2002	21:05	E4	10	5	51	7.83	19.31
W 87	17.09.2002	21:12	E4	30	3.3	52	7.86	45.10
W 88	25.09.2002	16:00	A1	0	2	50.1	8.01	24.95
W 89	25.09.2002	16:05	A1	5	3.8	51.7	8.09	9.50
W 90	25.09.2002	16:25	A1	20	4.3	52.2	8.01	19.90
W 91	25.09.2002	16:45	A1	40	4.2	53.1	7.98	28.02
W 92	25.09.2002	17:00	A2	0	3	51.2	7.92	78.74
W 93	25.09.2002	17:05	A2	5	4.1	51.7	7.99	30.71
W 94	25.09.2002	17:20	A2	20	4	51.8	8	26.93
W 95	25.09.2002	17:35	A2	35	4.3	52.1	8	31.80
W 96	25.09.2002	18:30	A3	0	3.9	51.5	8	21.60
W 97	25.09.2002	18:35	A3	5	4.1	51.6	8.01	21.11
W 98	25.09.2002	18:45	A3	20	4.3	53.1	7.96	5.80
W 99	25.09.2002	18:55	A3	40	3.9	52.2	7.96	30.36

II. SEDIMENT TRAPS

II.A SEDIMENT TRAPS DATA.

The details on sampling stations are given in Tab.2.

Trap No.	Date	Station	Water depth [m]	Exposure period [hours]	Particulate matter flux [g m ⁻² day ⁻¹]
1	19.07.2002	B1	4	24	0.86
2	19.07.2002	B1	20	24	1.10
3	21.07.2002	B1	4	48.33	1.06
4	21.07.2002	B1	20	48.33	1.46
5	22.07.2002	E1	3	23.66	5.26
6	22.07.2002	E1	10	23.66	6.98
7	24.07.2002	E1	3	48.42	4.49
8	24.07.2002	E1	10	48.42	>>1000
9	28.07.2002	E1	3	24.42	17.27
10	28.07.2002	E1	9	24.42	13.73
11	29.07.2002	E2	6	23.83	0.58
12	29.07.2002	E2	30	23.83	>>1000
13	30.07.2002	E3	6	22.67	1.13
14	30.07.2002	E3	30	22.67	0.36
15	31.07.2002	E4	6	24.75	0.40
16	03.08.2002	A1	5	24.33	5.21
17	03.08.2002	A1	5	24.33	5.52
18	03.08.2002	A1	20	24.33	5.16
19	03.08.2002	A1	20	24.33	5.50
20	03.08.2002	A1	40	24.33	25.34
21	03.08.2002	A1	40	24.33	52.07
22	04.08.2002	A2	5	24	2.98
23	04.08.2002	A2	5	24	3.61
24	04.08.2002	A2	20	24	5.78
25	04.08.2002	A2	20	24	6.20
26	04.08.2002	A2	35	24	19.06
27	04.08.2002	A2	35	24	185.41
28	05.08.2002	A3	5	24.08	2.57
29	05.08.2002	A3	5	24.08	2.61
30	05.08.2002	A3	20	24.08	2.10
31	05.08.2002	A3	20	24.08	1.74
32	05.08.2002	A3	40	24.08	72.11
33	05.08.2002	A3	40	24.08	637.32
34	13.08.2002	E1	3	24.75	90.74
35	13.08.2002	E1	3	24.75	87.86
36	13.08.2002	E1	9	24.75	93.05
37	13.08.2002	E1	9	24.75	102.95
38	14.08.2002	E2	6	26.66	24.93
39	14.08.2002	E2	6	26.66	25.19
40	14.08.2002	E2	30	26.66	9.04
41	14.08.2002	E2	30	26.66	10.64
42	15.08.2002	E3	6	23.83	0.74
43	15.08.2002	E3	6	23.83	0.62
44	15.08.2002	E3	30	23.83	1.18
45	15.08.2002	E3	30	23.83	1.07
46	16.08.2002	E4	6	24.83	0.69
47	16.08.2002	E4	6	24.83	0.55
48	16.08.2002	E4	30	24.83	1.00
49	16.08.2002	E4	30	24.83	1.12
50	26.08.2002	A1	5	24.33	13.00
51	26.08.2002	A1	5	24.33	12.88
52	26.08.2002	A1	20	24.33	5.35
53	26.08.2002	A1	20	24.33	5.74
54	26.08.2002	A1	40	24.33	163.72
55	27.08.2002	A2	5	23.83	41.06
56	27.08.2002	A2	5	23.83	37.78
57	27.08.2002	A2	20	23.83	39.29
58	27.08.2002	A2	20	23.83	41.50

59	27.08.2002	A2	35	23.83	27.28
60	27.08.2002	A2	35	23.83	38.87
61	28.08.2002	A3	5	23	10.69
62	28.08.2002	A3	5	23	11.83
63	28.08.2002	A3	20	23	12.56
64	28.08.2002	A3	20	23	12.42
65	28.08.2002	A3	40	23	15.80
66	28.08.2002	A3	40	23	17.31
67	17.09.2002	E1	3	23.5	0.28
68	17.09.2002	E1	3	23.5	0.33
69	17.09.2002	E1	9	23.5	0.43
70	17.09.2002	E1	9	23.5	0.37
71	18.09.2002	E2	6	24.5	0.30
72	18.09.2002	E2	6	24.5	0.68
73	18.09.2002	E2	30	24.5	0.59
74	18.09.2002	E2	30	24.5	0.69
75	19.09.2002	E3	6	24	0.32
76	19.09.2002	E3	6	24	0.48
77	19.09.2002	E3	30	24	0.48
78	19.09.2002	E3	30	24	0.39
79	20.09.2002	E4	6	24.33	0.71
80	20.09.2002	E4	6	24.33	0.76
81	20.09.2002	E4	30	24.33	0.94
82	20.09.2002	E4	30	24.33	0.73
83	24.09.2002	A1	5	24	0.69
84	24.09.2002	A1	5	24	0.40
85	24.09.2002	A1	20	24	1.05
86	24.09.2002	A1	20	24	0.97
87	24.09.2002	A1	40	24	1.10
88	24.09.2002	A1	40	24	1.28
89	25.09.2002	A2	5	24	0.57
90	25.09.2002	A2	5	24	0.75
91	25.09.2002	A2	20	24	0.58
92	25.09.2002	A2	20	24	0.57
93	25.09.2002	A2	35	24	0.89
94	25.09.2002	A2	35	24	0.84
95	26.09.2002	A3	5	24.66	0.52
96	26.09.2002	A3	5	24.66	0.81
97	26.09.2002	A3	20	24.66	0.64
98	26.09.2002	A3	20	24.66	0.68
99	26.09.2002	A3	40	24.66	0.64
100	26.09.2002	A3	40	24.66	0.61

II.B SEDIMENT TRAP DATA – GRAIN SIZE DISTRIBUTION OF TRAPPED SEDIMENTS

Classes in μm .

station	water depth	date	0 - 2	2 - 4	4 - 8	8 - 16	16 - 32	32 - 63	> 63
A1	20	03.08.02	8.15	7.77	13.78	20.39	26.97	20.02	2.91
A2	35	27.08.02	13.90	13.59	21.00	22.46	17.05	8.59	2.59
A2	20	27.08.02	16.00	15.65	23.97	23.84	14.22	5.13	1.19
A2	5	27.08.02	13.14	10.13	13.48	15.19	21.72	20.93	5.41
A1	40	26.08.02	34.70	20.32	15.96	10.35	8.00	7.40	3.27
A1	40	26.08.02	20.52	19.85	24.57	21.43	13.61	0.02	0.00
A3	20	05.08.02	14.74	14.36	21.86	22.71	16.71	7.10	2.51
A3	5	05.08.02	14.50	13.61	21.09	22.43	16.38	8.55	3.44
A1	5	03.08.02	12.28	9.43	13.31	18.78	25.40	17.41	3.40
A2	5	04.08.02	12.38	10.39	14.70	16.06	18.47	19.38	8.62
A2	35	04.08.02	15.64	12.46	19.40	22.23	18.63	9.89	1.75
A3	40	05.08.02	26.38	19.71	23.55	19.16	8.64	2.38	0.18
A2	20	04.08.02	13.72	13.02	20.02	21.16	17.16	10.92	4.00
E2	6	14.08.02	15.14	14.90	22.86	26.57	16.29	4.09	0.15
E4	30	16.08.02	10.95	9.68	14.25	15.97	16.81	19.20	13.13
E3	30	15.08.02	9.45	8.41	12.41	15.75	19.64	21.69	12.64
E2	30	14.08.02	63.99	10.25	8.52	8.26	6.29	2.68	0.00
E1	3	13.08.02	8.07	5.38	6.55	9.47	24.63	30.97	14.90
E1	9	13.08.02	10.42	6.95	8.54	12.08	22.60	26.12	13.27

III. BASIC DATA ON INVESTIGATED SEDIMENT SAMPLES:

minimum water content (in weight %), sand content (in weight %), carbonate content [%], IRD – ice rafted debris [number of mineral grains in >500µm fraction per g of dry sediment], C_f – concentration of benthic foraminifera [number of benthic foraminifera in >250µm fraction per g of dry sediment]; FLSM – Fluffy Layer Suspended Matter (surface fluidised sediment layer).

core	sample	water content	carbonate	sand content	IRD	C_f
		[%]	[%]	[%]		
B1A-grab sample	surface	36.87	15			
B1A-grab sample	subsurface	22.04				
B1-grab sample	surface	26.04	21		1.93	
B1-grab sample	subsurface	21.57				
B2-grab sample	surface	35.39	17		2.15	
B2-grab sample	subsurface	29.35				
B3-grab sample	surface	26.39	12		5.78	
B3-grab sample	subsurface	19.52				
B4-grab sample	surface	31.87	12		4.85	
B4-grab sample	subsurface	28.52				
B5-grab sample	surface	32.11	20		5.97	
B5-grab sample	subsurface	28.89				
B6-grab sample	surface	37.08	27		7.87	
B6-grab sample	subsurface	34.76				
B8-grab sample	surface	29.76	26		14.85	
B9-grab sample	surface	35.22	14		1.59	
B9-grab sample	subsurface	28.11				
B10-grab sample	surface	31.68	18		2.73	
B10-grab sample	subsurface	32.48				
B1A/2001	FLSM	39.55	13			
B1A/2001	0-1	35.44	15			
B1A/2001	1-2	31.85				
B1A/2001	2-3	33.13				
B1A/2001	3-4	33.28				
B1A/2001	4-5	32.27				
B1A/2001	5-6	30.44	15			
B1A/2001	6-7	33.67				
B1A/2001	7-8	31.83				
B1A/2001	8-9	29.03				
B1A/2001	9-10	28.10				
B1A/2001	10-11	26.66	20			
B1A/2001	11-12	26.75				
B1A/2001	12-13	28.37				
B1A/2001	13-14	30.71				
B1A/2001	14-15	26.95				
B1A/2001	15-16	27.03	17			
B1A/2001	16-17	26.68				
B1A/2001	17-18	28.41				
B1A/2001	18-19	30.56				
B1A/2001	19-20	32.54				
B1A/2001	20-21	30.56	14			
B1A/2001	21-22	26.87				
B1A/2001	22-23	30.61				
B1A/2001	23-24	30.26				
B1A/2001	24-25	30.60				
B1A/2001	25-26	27.95	21			
B1A/2001	26-27	25.71				
B2/2001	FLSM	56.50		2.54	6.62	6.37
B2/2001	0-1	47.10		3.64	6.45	1.02
B2/2001	1-2	43.70		5.43	9.12	1.21
B2/2001	2-3	39.17		4.97	7.98	0.63
B2/2001	3-4	36		4.31	5.92	0.52
B2/2001	4-5	36.33		3.01	4.91	0.35
B2/2001	5-6	39.66		2.73	4.30	
B2/2001	6-7	39.90		2.38	1.74	
B2/2001	7-8	36.62		3.07	3.44	
B2/2001	8-9	37.22		2.11	3.05	0.85
B2/2001	9-10	39.17		2.87	3.82	0.86

B2/2001	10-11	35.58		2.99	6.42	
B2/2001	11-12	36.37		2.24	4.19	
B2/2001	12-13	43.08		1.42	3	0.91
B2/2001	13-14	40.03		1.29	4.83	0.55
B2/2001	14-15	36.05		2.68	8.99	
B2/2001	15-16	33.60		3.02	6.67	
B2/2001	16-17	35.48		1.89	4.60	
B2/2001	17-18	35.32		5.22	3.03	0.10
B2/2001	18-19	35.64		2.32	3	0.38
B2/2001	19-20	35.72		2.78	4.27	0.28
B2/2001	20-21	36.55		3.04	6.06	0.89
B2/2001	21-22	34.04		5.67	9.08	0.37
B2/2001	22-23	33.07		8.50	10.43	0.89
B2/2001	23-24	31.86		11.34	13.10	0.39
B2/2001	24-25	32.45		2.94	5.49	0.49
B2/2001	25-26	33.19		4.90	9.12	0.25
B2/2001	26-27	32.47		36.07	2.46	0.43
B2/2001	27-28	30.95		8.54	3.95	0.63
B2/2001	28-29	26.03		3.72	4.19	0.90
B2/2001	29-30	31.28		9.67	6.30	0.57
B2/2001	30-31	32.23		4.99	7.25	0.32
B2/2001	31-32	31.99		3.49	2.12	0.23
B2/2001	32-33	31.70		4.08	2.42	6.37
B2A/2001	FLSM	37.16				
B2A/2001	0-1	44.15	14			
B2A/2001	1-2	36.63	13			
B2A/2001	2-3	38.03	14			
B2A/2001	3-4	34.49	15			
B2A/2001	4-5	35.99	16			
B2A/2001	5-6	36.38	15			
B2A/2001	6-7	35.25	16			
B2A/2001	7-8	35.22	16			
B2A/2001	8-9	37	16			
B2A/2001	9-10	36.97	16			
B2A/2001	10-11	33.69	16			
B2A/2001	11-12	33.37	16			
B2A/2001	12-13	34.25	15			
B2A/2001	13-14	37.52	15			
B2A/2001	14-15	37.20				
B2A/2001	15-16	37.77	14			
B2A/2001	16-17	34.53	13			
B2A/2001	17-18	35.57	13			
B2A/2001	18-19	37.26	13			
B2A/2001	19-20	37.41	13			
B2A/2001	20-21	37.65	13			
B2A/2001	21-22	36.80	13			
B2A/2001	22-23	35.57	13			
B2A/2001	23-24	37.24	16			
B2A/2001	24-25	36.60	17			
B2A/2001	25-26	36.15	13			
B2A/2001	26-27	32.07	13			
B2A/2001	27-28	35.65	21			
B2A/2001	28-29	35.20	13			
B2A/2001	29-30	34.50	12			
B2A/2001	30-31	33.66	14			
B2A/2001	31-32	34.21	13			
B3/2001	FLSM	31.11		1.42		
B3/2001	0-1	35.99		1.60		
B3/2001	1-2	27.27		2.12		
B3/2001	2-3	23.75		15.81		
B3/2001	3-4	28.11		3.75		
B3/2001	4-5	25.07		0.63		
B3/2001	5-6	23.08		11.57		
B3/2001	6-7	24.28		6.57		
B3/2001	7-8	27.21		3.97		
B3/2001	8-9	25.19		3.78		
B3/2001	9-10	28.32		3.79		
B3/2001	10-11	32.04		2.31		
B3/2001	11-12	22.54		9.32		

B3/2001	12-13	24.91		3.48		
B3/2001	13-14	27.04		3.37		
B3/2001	14-15	20.98		8.38		
B3/2001	15-16	20.66		5.06		
B3/2001	16-17	22.39		4.97		
B3/2001	17-18	23.60		7.83		
B3/2001	18-19	27.80		3.25		
B3/2001	19-20	29.51		2.95		
B3/2001	20-21	30.15		8.83		
B3/2001	21-22	33.39		2.97		
B3/2001	22-23	26.90		2.86		
B3/2001	23-24	26.09		3.27		
B3/2001	24-25	26.22		2.72		
B3/2001	25-26	28.11		1.85		
B3/2001	26-27	28.06		7.28		
B3/2001	27-28	23.45		6.38		
B3/2001	28-29	30.26		3.89		
B3/2001	29-30	28.59		3.08		
B3/2001	30-30.7	21.91		12.45		
B3A/2001	FLSM	48.29	12			
B3A/2001	0-1	32.22	13			
B3A/2001	1-2	38.09	11			
B3A/2001	2-3	25.31	7			
B3A/2001	3-4	25.48	10			
B3A/2001	4-5	34.44	9			
B3A/2001	5-6	28.2	12			
B3A/2001	6-7	23.68	7			
B3A/2001	7-8	29.48	9			
B3A/2001	8-9	31.04	9			
B3A/2001	9-10	30.9	10			
B3A/2001	10-11	34.65	13			
B3A/2001	11-12	31.19	10			
B3A/2001	12-13	29.54	11			
B3A/2001	13-14	24.19	11			
B3A/2001	14-15	22.95	10			
B3A/2001	15-16	23.4	12			
B3A/2001	16-17	25.98	10			
B3A/2001	17-18	28.01	10			
B3A/2001	18-19	27.81	10			
B3A/2001	19-20	30.92	10			
B3A/2001	20-21	30.39	13			
B3A/2001	21-22	26.55	11			
B3A/2001	22-23	27.51	11			
B3A/2001	23-24	28.53	11			
B3A/2001	24-25	30.6	11			
B3A/2001	25-26	28.72	14			
B3A/2001	26-27	29.33	11			
B3A/2001	27-28	28.65	10			
B3A/2001	28-28.5	23.63	11			
B4A/2001	FLSM	40.93	14			
B4A/2001	0-1	35.11	12			
B4A/2001	1-2	36.28	14			
B4A/2001	2-3	32.55	14			
B4A/2001	3-4	30.59	15			
B4A/2001	4-5	30.48	15			
B4A/2001	5-6	29.85	15			
B4A/2001	6-7	28.51	15			
B4A/2001	7-8	25.77	18			
B4/2001	FLSM	52.08		0.84		
B4/2001	0-1	38.72		2.08	6.66	
B4/2001	1-2	36.26		2.06	9.83	
B4/2001	2-3	31.15		1.46		
B4/2001	3-4	30.01		0.92	2.39	
B4/2001	4-5	29.99		0.61		
B4/2001	5-6	29.03		0.37	0.37	
B4/2001	6-7	28.9		1.58		
B4/2001	7-8	30.24		0.45	0.27	
B4/2001	8-9	30.98		0.46		
B4/2001	9-10	30.77		0.35		

B4/2001	10-11	31.12		0.36		
B4/2001	11-11.5	31.67		1.08		
B5/2001	FLSM	50.95		5.81	10.93	14.88
B5/2001	0-1	38.87		7.17	11.48	7.08
B5/2001	1-2	34.45		9.66	11.75	3.84
B5/2001	2-3	32.21		4.64	5.76	1.99
B5/2001	3-4	30.52		4.91	7.23	2.53
B5/2001	4-5	32.98		4.36	8.08	1.19
B5/2001	5-6	33.37		4.03	7.68	1.99
B5/2001	6-7	31.57		7.14	4.39	0.55
B5/2001	7-8	30.57		6.31	5.92	1.55
B5/2001	8-9	30.93		2.4	3.36	0.98
B5/2001	9-10	30.41		1.77	2.25	0.11
B5/2001	10-11	29.96		2.86	5.83	0.46
B5/2001	11-12	29.88		3.79	7.25	0.25
B5A/2001	FLSM	46.85	19			
B5A/2001	0-1	34.93	20			
B5A/2001	1-2	31.07	20			
B5A/2001	2-3	32.67	19			
B5A/2001	3-4	32.12	19			
B5A/2001	4-5	31.65	19			
B5A/2001	5-6	31.29	21			
B5A/2001	6-7	30.3	19			
B5A/2001	7-8	29.6	18			
B5A/2001	8-9	30	16			
B5A/2001	9-10	31.34	15			
B5A/2001	10-11	31.68	18			
B5A/2001	11-12	31.86	15			
B5A/2001	12-13	33.03	15			
B5A/2001	13-14	32.68	15			
B5A/2001	14-15	32.23	15			
B5A/2001	15-16	31.74	18			
B5A/2001	16-17	31.41	15			
B5A/2001	17-18	31.16	14			
B5A/2001	18-19	30.42	13			
B5A/2001	19-20	30.61	13			
B5A/2001	20-21	31.17	19			
B5A/2001	21-22	30.67	13			
B5A/2001	22-23	35.92	13			
B5A/2001	23-24	31.96	14			
B5A/2001	24-25	33.46	14			
B6A/2001	FLSM	41.24	28			
B6A/2001	0-1	38.99	26			
B6A/2001	1-2	37.34	28			
B6A/2001	2-3	36.75	29			
B6A/2001	3-4	34.64	28			
B6A/2001	4-5	34.55	29			
B6A/2001	5-6	35.32	27			
B6A/2001	6-7	34.97	28			
B6A/2001	7-8	34.01	27			
B6A/2001	8-9	33.67	27			
B6A/2001	9-10	33.55	27			
B6A/2001	10-11	33.28	26			
B6A/2001	11-12	32.29	27			
B6A/2001	12-13	31.08	26			
B6A/2001	13-14	29.76	26			
B6A/2001	14-14.5	34.2	26			
B6/2001	FLSM	44.86				
B6/2001	0-1	39.36		4.5	11.66	6.86
B6/2001	1-2	38.76		4.29	9.28	4.00
B6/2001	2-3	35.4		3.69	9.93	5.33
B6/2001	3-4	36.44		3.79	5.44	3.08
B6/2001	4-5	30.75		3.76	3.90	2.46
B6/2001	5-6	31.75		4.85	4.92	3.84
B6/2001	6-7	32.91		3.53	7.94	0.49
B6/2001	7-8	31.6				
B6/2001	8-9	31.51		8.2	7.30	2.35
B6/2001	9-10	30.92		9.82	6.47	2.97
B6/2001	12-13	32.8		3.57		

B6/2001	13-14	30.51		3.6		
B6/2001	14-15	31.51		3.63	8.29	1.69
B6/2001	15-16	33.22		2.52	8.85	1.49
B6/2001	16-17	32.52		3.06	5.85	1.51
B6/2001	17-18	30.73		3.57	5.95	1.15
B6/2001	18-19	30.19		2.56	8.39	2.72
B6/2001	19-20	33.11		3.05	7.26	2.11
B6/2001	21-22	26.98		16.13	7.31	1.12
B6/2001	22-23	34.32		2.74	8.60	4.22
B6/2001	23-23.5	33.29		3.63		2.21
B7A/2001	FLSM	53.99	21			
B7A/2001	0-1	51.9	20			
B7A/2001	1-2	48.21	21			
B7A/2001	2-3	40.39				
B7A/2001	3-4	38.32	24			
B7A/2001	4-5	36.5				
B7A/2001	5-6	36.69	22			
B7A/2001	6-7	36.88	23			
B7A/2001	7-8	35.68	22			
B7A/2001	8-9	35.6	22			
B7A/2001	9-10	32.9				
B7A/2001	10-11	34				
B7A/2001	11-12	33.42				
B7A/2001	12-13	34.79	22			
B7/2001	FLSM	63.73		33.33	10.60	54.55
B7/2001	0-1	48.85		3.92	6.69	15.69
B7/2001	1-2	35.64		2.3	5.84	10.46
B7/2001	2-3	37.85		2.79	11.65	4.47
B7/2001	3-4	34.95		1.77	3.35	4.03
B7/2001	4-5	34.82		2.41	8.57	4.61
B7/2001	5-6	35.89		2.88	6.77	5.30
B7/2001	6-7	35.03		2.57	8.50	3.11
B7/2001	7-8	31.36		3.22	8.44	5.10
B7/2001	8-9	30.43		14.46	11.72	1.47
B7/2001	9-10	33.84		3.96	6.44	3.94
B7/2001	10-11	35		3.76	3.91	3.69
B7/2001	11-12	34.47		3.17	4.48	3.08
B7/2001	12-13	34.36		6.41	8.54	7.01
B7/2001	13-14	32.49		6.69	13.64	5.33
B7/2001	14-15	31.86		5.81	9.01	3.24
B7/2001	15-16	32.47		10.92	5.21	3.03
B7/2001	16-17	33.7		4.71	7.23	5.79
B7/2001	17-18	33.8		5.39	7.12	5.61
B9/2001	FLSM	41.65		2.02		
B9/2001	0-1	42.21			3.41	2.51
B9/2001	1-2	36.73		0.94	2.41	1.37
B9/2001	2-3	33.11		2.35	9.56	1.65
B9/2001	3-4	30.48		3.21	11.34	3.18
B9/2001	4-5	31.32		1.971	6.88	2.72
B9/2001	5-6	31.83				
B9/2001	6-7	30.46		1.43	3.33	1.80
B9/2001	7-8	29.56				
B9/2001	8-9	29.77		0.7	1.11	1.22
B9/2001	9-10	30.2			1.65	0.60
B9/2001	10-11	30.7		1.59	3.79	0.74
B9/2001	11-12	31.48		1.7	5.68	0.38
B9/2001	12-13	29.77		0.81	3.87	0.24
B9/2001	13-14	30.76			2.27	0.21
B9/2001	14-15	29.69		1.19	2.26	0.07
B9/2001	15-16	30.85			3.5	0.48
B9/2001	16-17	28.61			8.77	0.18
B9/2001	17-18	26.34				
B9/2001	18-19	23.31			5	0.04
B9/2001	19-19.25	30.32			9.17	0.24
B9A/2001	FLSM	43.27	12			
B9A/2001	0-1	37.59	11			
B9A/2001	1-2	30.57	12			
B9A/2001	2-3	30.74	13			
B9A/2001	3-4	29.24	12			

B9A/2001	4-5	29.31	13			
B9A/2001	5-6	28.54	13			
B9A/2001	6-7	29.38	12			
B9A/2001	7-8	28.51	13			
B9A/2001	8-9	27.49	12			
B9A/2001	9-10	24.92	12			
B9A/2001	10-11	24.62	13			
B9A/2001	11-12	26.37	14			
B9A/2001	12-13	25.06	13			
B9A/2001	13-14	27.22	13			
B9A/2001	14-15	29.6	12			
B9A/2001	15-16	29.13	12			
B9A/2001	16-17	27.41	11			
B9A/2001	17-18	26.27	13			
B9A/2001	18-19	27.25	12			
B10A/2001	FLSM	51.35	19			
B10A/2001	0-1	47.54	17			
B10A/2001	1-2	39.79				
B10A/2001	2-3	32.51	17			
B10A/2001	3-4	31.02				
B10A/2001	4-5	30.64				
B10A/2001	5-6	28.07				
B10A/2001	6-7	28.64				
B10A/2001	7-8	30.26				
B10A/2001	8-9	29.04				
B10A/2001	9-10	31.41				
B10A/2001	10-11	32.63	14			
B10A/2001	11-12	31.83				
B10A/2001	12-13	31.9	14			
B10A/2001	13-14	32.59				
B10A/2001	14-15	32.11				
B10A/2001	15-16	32.72				
B10A/2001	16-17	32.16				
B10A/2001	17-18	31.18				
B10A/2001	18-19	25.79				
B10A/2001	19-20	29.73				
B10A/2001	20-21	28.38	14			
B10A/2001	21-22	28.71				
B10A/2001	22-23	29.23				
B10/2001	FLSM	49.15		0.83	10.16	8.25
B10/2001	0-1	46.91		3.25		
B10/2001	1-2	39.06		1.99	2.25	0.94
B10/2001	2-3	31.87		1.6	0.58	
B10/2001	3-4	32.52		3.59	2.09	
B10/2001	4-5	33.91		6.47	6.30	1.65
B10/2001	5-6	35.15		5.26	5.5	10.39
B10/2001	6-7	34.32		3.18	3.40	
B10/2001	7-8	32.49		2.4	2.94	
B10/2001	8-9	36.36		2.77	4.13	
B10/2001	9-10	33.28		6.72	6.82	
B10/2001	10-11	35.92		4.76	6.49	1.34
B10/2001	11-12	36.75		4.6	7.77	1.36
B10/2001	12-13	37.82			5.78	1.45
B10/2001	13-14	35.59		5.12	6.46	2.21
B10/2001	14-15	33.95		4.23	6.47	1.37
B10/2001	15-16	29.04		4.94	6.98	
B10/2001	16-17	33.59		5.03	6.01	0.58
B10/2001	17-18	36.33		4.88	6.42	1.65
B10/2001	18-19	33.09		7.15	13.93	
B10/2001	19-20	32.91		3.37	3.82	
B10/2001	20-21	32.86		3.31		
B10/2001	21-22	30.99		3.38	5.14	
B10/2001	22-23	32.07		4.53	7.44	1.67
B10/2001	23-24	29.77		10	10.96	
B10/2001	24-25	29.77		6.97	15.24	1.81
B10/2001	25-26	29.32		8.24	16.25	
B10/2001	26-27	29.91		9.34	12.91	
B10/2001	27-28	29.66		11.61	19.88	

IV. GRAIN SIZE COMPOSITION OF <63MM FRACTION

Classes in μm .

core	sample	0-2	2-4	4-8	8-16	16-32	32-63
B8/2001	GS	17.59	24.12	33.96	20.24	3.98	0.12
B1/2001	0-1	27.84	34.18	30.14	7.63	0.21	0.00
B1/2001	1-2	22.50	26.66	31.84	16.13	2.61	0.26
B1/2001	3-4	52.01	39.33	8.52	0.14	0.00	0.00
B1/2001	4-5	13.35	15.26	26.28	25.98	13.57	4.29
B1/2001	6-7	23.82	26.31	31.16	16.25	2.45	0.00
B1/2001	7-8	31.67	35.00	27.62	5.64	0.07	0.00
B1/2001	8-9	18.19	18.41	26.15	23.19	10.99	2.77
B1/2001	10-11	20.28	20.63	27.67	21.57	7.79	0.90
B1/2001	11-12	24.00	27.07	30.90	15.40	2.39	0.18
B1/2001	12-13	20.82	22.06	28.67	20.37	6.55	1.42
B1/2001	13-14	21.85	21.46	28.46	19.93	6.27	1.16
B1/2001	14-15	28.64	30.73	29.34	10.42	0.86	0.00
B1/2001	15-16	29.91	29.85	28.19	10.83	1.04	0.16
B1/2001	16-17	18.13	15.09	22.13	24.21	14.99	4.94
B1/2001	17-18	32.71	24.13	21.74	13.74	6.52	1.16
B1/2001	20-21	36.82	36.24	23.14	3.09	0.09	0.11
B1/2001	22-23	15.27	14.16	22.26	24.76	15.83	6.90
B1/2001	23-24	24.34	25.81	31.54	16.22	2.10	0.00
B1/2001	24-25	23.56	25.97	31.96	16.11	2.39	0.02
B2/2001	1-2	75.77	17.35	6.50	0.39	0.00	0.00
B2/2001	24-25	90.44	8.61	0.95	0.00	0.00	0.00
B3/2001	FLSM	82.94	14.29	2.77	0.00	0.00	0.00
B3/2001	0-1	86.55	11.97	1.48	0.00	0.00	0.00
B3/2001	1-2	76.25	19.31	4.29	0.16	0.00	0.00
B3/2001	3-4	87.72	11.54	0.74	0.00	0.00	0.00
B3/2001	4-5	80.35	16.77	2.88	0.00	0.00	0.00
B3/2001	5-6	77.69	17.93	4.38	0.00	0.00	0.00
B3/2001	6-7	75.76	19.06	3.96	1.20	0.02	0.00
B3/2001	7-8	72.71	19.76	7.44	0.09	0.00	0.00
B3/2001	8-9	81.38	15.47	3.15	0.00	0.00	0.00
B3/2001	9-10	73.93	20.74	5.33	0.00	0.00	0.00
B3/2001	10-11	78.33	16.91	4.76	0.00	0.00	0.00
B3/2001	11-12	83.01	13.75	3.24	0.00	0.00	0.00
B3/2001	12-13	72.87	21.21	5.93	0.00	0.00	0.00
B3/2001	13-14	73.44	21.32	5.24	0.00	0.00	0.00
B3/2001	14-15	58.71	26.24	13.58	1.48	0.00	0.00
B3/2001	15-16	68.89	22.65	8.37	0.09	0.00	0.00
B3/2001	16-17	72.46	23.01	4.53	0.00	0.00	0.00
B3/2001	17-18	74.29	20.32	5.39	0.00	0.00	0.00
B3/2001	18-19	79.78	16.65	3.02	0.55	0.00	0.00
B3/2001	19-20	68.37	25.69	5.77	0.18	0.00	0.00
B3/2001	20-21	82.31	14.76	2.48	0.44	0.00	0.00
B3/2001	21-22	82.20	16.25	1.27	0.28	0.00	0.00
B3/2001	22-23	81.49	17.18	1.32	0.01	0.00	0.00
B3/2001	23-24	77.89	17.37	4.66	0.08	0.00	0.00
B3/2001	24-25	86.02	12.05	1.53	0.40	0.00	0.00
B3/2001	25-26	75.26	20.08	4.54	0.12	0.00	0.00
B3/2001	26-27	76.91	19.53	3.50	0.05	0.00	0.00
B3/2001	27-28	82.11	15.09	2.73	0.07	0.00	0.00
B3/2001	28-29	82.53	14.62	2.79	0.06	0.00	0.00
B3/2001	29-30	78.69	17.63	3.13	0.55	0.00	0.00
B3/2001	30-30.7	78.50	17.51	3.98	0.00	0.00	0.00
B4/2001	FLSM	21.81	26.64	37.36	12.45	1.63	0.11
B4/2001	1-2	20.87	31.68	39.51	7.84	0.10	0.00
B4/2001	2-3	20.92	31.96	38.12	8.45	0.54	0.00
B4/2001	3-4	22.47	31.79	36.84	8.29	0.60	0.00
B4/2001	4-5	21.43	30.09	37.85	9.88	0.76	0.00
B4/2001	5-6	20.43	24.73	32.92	18.53	3.32	0.06
B4/2001	6-7	29.43	36.44	31.54	2.59	0.00	0.00
B4/2001	7-8	18.56	20.58	33.73	19.72	6.07	1.35
B4/2001	8-9	23.71	25.62	33.34	13.76	3.00	0.57

B4/2001	9-10	26.17	28.86	30.95	12.24	1.73	0.05
B4/2001	10-11	16.04	21.99	40.75	18.84	2.35	0.03
B4/2001	11-11.5	16.44	19.29	34.19	21.54	6.94	1.60
B6/2001	0-1	18.55	23.11	33.57	20.98	3.77	0.02
B6/2001	1-2	15.04	21.36	34.59	23.74	4.90	0.27
B6/2001	2-3	22.10	31.89	34.92	10.60	0.50	0.00
B6/2001	3-4	18.52	28.10	37.12	15.25	1.01	0.00
B6/2001	4-5	17.13	22.55	33.22	21.52	5.02	0.56
B6/2001	5-6	39.84	45.97	14.01	0.17	0.00	0.00
B6/2001	6-7	24.92	31.59	32.36	10.51	0.62	0.00
B6/2001	7-8	18.58	19.01	26.83	22.65	10.49	2.39
B6/2001	8-9	21.69	25.32	32.66	17.54	2.77	0.03
B6/2001	9-10	20.51	25.38	33.40	17.78	2.75	0.19
B6/2001	10-11	20.57	26.89	33.54	16.45	2.45	0.11
B6/2001	11-12	22.86	26.78	32.16	15.73	2.39	0.08
B6/2001	12-13	23.69	26.80	32.86	15.14	1.51	0.00
B6/2001	13-14	22.81	26.03	32.99	16.00	2.14	0.04
B6/2001	14-15	21.27	29.71	34.59	13.11	1.27	0.04
B6/2001	15-16	26.36	39.09	30.72	3.83	0.00	0.00
B6/2001	16-17	20.10	28.60	34.50	14.81	1.95	0.04
B6/2001	17-18	19.92	27.95	35.42	15.18	1.53	0.00
B6/2001	18-19	19.65	28.12	34.15	15.32	2.56	0.19
B6/2001	19-20	19.08	26.97	33.94	16.73	3.16	0.12
B6/2001	21-22	21.78	29.47	34.63	13.03	1.09	0.00
B6/2001	22-23	22.19	26.12	31.10	15.96	3.81	0.72
B6/2001	23-23.5	19.76	27.44	34.26	15.85	2.57	0.12
B9/2001	FLSM	88.90	9.93	1.17	0.00	0.00	0.00
B9/2001	1-2	91.34	8.07	0.59	0.00	0.00	0.00
B9/2001	2-3	93.85	5.65	0.50	0.00	0.00	0.00
B9/2001	3-4	88.07	10.19	1.74	0.00	0.00	0.00
B9/2001	6-7	86.46	11.87	1.67	0.00	0.00	0.00
B9/2001	12-13	81.92	15.53	2.44	0.11	0.00	0.00
B10/2001	7-8	25.57	30.51	31.50	11.43	0.98	0.00
B10/2001	11-12	27.65	31.33	30.98	9.59	0.44	0.00
B10/2001	12-13	20.86	26.11	31.23	16.94	4.42	0.45
B10/2001	21-22	88.91	10.09	1.00	0.00	0.00	0.00
B10/2001	22-23	91.81	7.78	0.41	0.00	0.00	0.00
B10/2001	23-24	85.90	12.66	1.44	0.00	0.00	0.00
B10/2001	24-25	85.82	12.39	1.79	0.00	0.00	0.00
B10/2001	25-26	87.49	11.21	1.31	0.00	0.00	0.00
B10/2001	26-27	90.46	8.78	0.76	0.00	0.00	0.00
B10/2001	27-28	87.84	10.87	1.29	0.00	0.00	0.00

V. COARSE GRAIN ANALYSIS

V.A COARSE GRAIN ANALYSIS FOR FRACTION 250 - 500 MM.

core	sample	number of splits	counted grains	planktonic foraminifera		benthic foraminifera		other shells and skeleton parts		plant remnants		lithoclasts		coal	
				counts	%	counts	%	counts	%	counts	%	counts	%	counts	%
B1/2001	0-1	4	275	0	0	5	1.8	2	0.7	105	38.2	102	37.1	61	22.2
B1/2001	1-2	2	411	0	0	2	0.5	4	1	30	7.3	350	85.2	25	6.1
B1/2001	2-3	2	464	0	0	5	1.1	15	3.2	102	22	314	67.7	28	6
B1/2001	3-4	1	359	0	0	11	3.1	9	2.5	40	11.1	287	79.9	12	3.3
B1/2001	5-6	4	314	1	0.3	0	0	2	0.6	8	2.5	293	93.3	10	3.2
B1/2001	9-10	4	257	0	0	1	0.4	6	2.3	9	3.5	222	86.4	19	7.4
B1/2001	10-11	2	286	0	0	0	0	8	2.8	0	0	277	96.9	1	0.3
B1/2001	12-13	3	208	0	0	1	0.5	2	1	16	7.7	172	82.7	17	8.2
B1/2001	13-14	4	754	0	0	1	0.1	6	0.8	18	2.4	702	93.1	27	3.6
B1/2001	14-15	3	433	0	0	2	0.5	2	0.5	88	20.3	326	75.3	15	3.5
B1/2001	16-17	2	485	0	0	1	0.2	2	0.4	91	18.8	363	74.8	28	5.8
B1/2001	18-19	4	406	0	0	3	0.7	16	3.9	64	15.8	273	67.2	50	12.3
B1/2001	19-20	5	408	0	0	2	0.5	21	5.1	11	2.7	343	84.1	31	7.6
B1/2001	21-22	4	396	0	0	1	0.3	3	0.8	6	1.5	367	92.7	19	4.8
B1/2001	22-23	3	374	0	0	0	0	3	0.8	7	1.9	358	95.7	6	1.6
B1/2001	23-23	1	450	0	0	3	0.7	14	3.1	18	4	389	86.4	26	5.8
B1/2001	23-25	2	255	0	0	0	0	8	3.1	37	14.5	181	71	29	11.4
B2/2001	FLSM	3	329	0	0	14	4.3	26	7.9	7	2.1	273	83	9	2.7
B2/2001	0-1	4	272	0	0	2	0.7	10	3.7	1	0.4	256	94.1	3	1.1
B2/2001	1-2	5	290	0	0	2	0.7	3	1	5	1.7	278	95.9	2	0.7
B2/2001	2-3	5	307	0	0	2	0.7	3	1	3	1	295	96.1	4	1.3
B2/2001	3-4	5	304	0	0	4	1.3	14	4.6	3	1	279	91.8	4	1.3
B2/2001	4-5	4	368	0	0	3	0.8	8	2.2	2	0.5	351	95.4	4	1.1
B2/2001	8-9	3	327	0	0	9	2.8	7	2.1	9	2.8	298	91.1	4	1.2
B2/2001	9-10	2	499	0	0	11	2.2	45	9	13	2.6	426	85.4	4	0.8
B2/2001	12-13	2	445	0	0	10	2.2	8	1.8	10	2.2	407	91.5	10	2.2
B2/2001	13-14	3	212	0	0	5	2.4	0	0	0	0	204	96.2	3	1.4
B2/2001	17-18	3	242	0	0	1	0.4	2	0.8	1	0.4	238	98.3	0	0
B2/2001	18-19	2	356	0	0	5	1.4	5	1.4	2	0.6	340	95.5	4	1.1
B2/2001	19-20	3	313	0	0	3	1	5	1.6	2	0.6	303	96.8	0	0
B2/2001	20-21	3	263	0	0	0	0	6	2.3	4	1.5	248	94.3	5	1.9
B2/2001	21-22	3	393	0	0	8	2	15	3.8	10	2.5	352	89.6	8	2
B2/2001	22-23	4	322	0	0	3	0.9	7	2.2	0	0	311	96.6	1	0.3
B2/2001	23-24	5	304	0	0	8	2.6	24	7.9	3	1	268	88.2	1	0.3
B2/2001	24-25	3	328	0	0	4	1.2	3	0.9	1	0.3	318	97	2	0.6
B2/2001	25-26	4	262	0	0	4	1.5	4	1.5	0	0	249	95	5	1.9
B2/2001	26-27	3	311	0	0	3	1	11	3.5	1	0.3	293	94.2	3	1
B2/2001	27-28	3	491	0	0	5	1	14	2.9	2	0.4	462	94.1	8	1.6
B2/2001	28-29	3	480	0	0	9	1.9	7	1.5	5	1	448	93.3	11	2.3
B2/2001	29-30	4	308	0	0	5	1.6	5	1.6	0	0	291	94.5	7	2.3
B2/2001	30-31	5	293	0	0	6	2	12	4.1	1	0.3	270	92.2	4	1.4
B2/2001	31-32	3	306	0	0	3	1	14	4.6	1	0.3	282	92.2	6	2
B2/2001	32-33	2	426	0	0	3	0.7	7	1.6	1	0.2	408	95.8	7	1.6
B4/2001	0-1	2	384	0	0	25	6.5	26	6.8	1	0.3	331	86.2	1	0.3
B4/2001	1-2	4	238	0	0	32	13.4	12	5	2	0.8	189	79.4	3	1.3
B4/2001	3-4	3	300	0	0	7	2.3	2	0.7	11	3.7	268	89.3	12	4
B4/2001	7-8	0	172	0	0	7	4.1	12	7	3	1.7	146	84.9	4	2.3
B4/2001	10-11	0	58	0	0	3	5.2	3	5.2	3	5.2	49	84.5	0	0
B5/2001	FLSM	4	253	0	0	27	10.7	22	8.7	4	1.6	162	64	38	15

B5/2001	0-1	4	502	0	0	17	3.4	14	2.8	6	1.2	396	78.9	69	13.7
B5/2001	1-2	7	284	0	0	12	4.2	25	8.8	11	3.9	190	66.9	46	16.2
B5/2001	2-3	5	293	0	0	13	4.4	11	3.8	11	3.8	218	74.4	40	13.7
B5/2001	3-4	5	478	0	0	19	4	22	4.6	25	5.2	350	73.2	62	13
B5/2001	4-5	5	365	0	0	10	2.7	16	4.4	19	5.2	276	75.6	44	12.1
B5/2001	5-6	5	335	0	0	15	4.5	7	2.1	7	2.1	277	82.7	29	8.7
B5/2001	6-7	4	297	0	0	5	1.7	8	2.7	6	2	267	89.9	11	3.7
B5/2001	7-8	4	519	0	0	16	3.1	19	3.7	35	6.7	438	84.4	11	2.1
B5/2001	8-9	3	430	0	0	12	2.8	23	5.3	8	1.9	369	85.8	18	4.2
B5/2001	9-10	2	357	0	0	2	0.6	10	2.8	3	0.8	340	95.2	2	0.6
B5/2001	10-11	3	447	0	0	5	1.1	12	2.7	3	0.7	410	91.7	17	3.8
B5/2001	11-12	2	462	0	0	2	0.4	3	0.6	2	0.4	444	96.1	11	2.4
B6/2001	0-1	3	619	0	0	34	5.5	27	4.4	3	0.5	513	82.9	42	6.8
B6/2001	1-2	3	330	0	0	15	4.5	26	7.9	5	1.5	266	80.6	18	5.5
B6/2001	2-3	3	394	1	0.3	29	7.4	28	7.1	1	0.3	309	78.4	26	6.6
B6/2001	3-4	3	368	0	0	19	5.1	9	2.4	0	0	319	86.4	22	6
B6/2001	4-5	2	486	0	0	28	5.7	21	4.3	0	0	431	88.5	6	1.2
B6/2001	5-6	3	415	0	0	30	7.2	43	10.4	3	0.7	313	75.4	26	6.3
B6/2001	6-7	3	383	0	0	3	0.8	7	1.8	2	0.5	363	94.8	8	2.1
B6/2001	8-9	3	354	0	0	18	5.1	47	13.3	12	3.4	276	78	1	0.3
B6/2001	9-10	3	480	0	0	25	5.2	33	6.9	4	0.8	415	86.5	3	0.6
B6/2001	12-13	3	419	0	0	12	2.9	18	4.3	6	1.4	380	90.7	3	0.7
B6/2001	13-14	3	379	0	0	9	2.4	4	1.1	8	2.1	355	93.7	3	0.8
B6/2001	14-15	3	330	0	0	8	2.4	16	4.8	4	1.2	300	90.9	2	0.6
B6/2001	15-16	3	391	0	0	9	2.3	27	6.9	6	1.5	329	84.1	20	5.1
B6/2001	16-17	3	363	0	0	19	5.2	29	8	5	1.4	303	83.5	7	1.9
B6/2001	17-18	3	378	0	0	17	4.5	31	8.2	5	1.3	325	86	0	0
B6/2001	18-19	2	315	0	0	6	1.9	9	2.9	0	0	292	92.7	8	2.5
B6/2001	19-20	3	391	0	0	24	6.1	37	9.5	7	1.8	313	80.1	10	2.6
B6/2001	21-22	1	857	0	0	36	4.2	21	2.5	0	0	792	92.4	8	0.9
B6/2001	22-23	2	475	0	0	16	3.4	69	14.5	1	0.2	380	80	9	1.9
B6/2001	23-24	2	455	0	0	24	5.3	37	8.1	5	1.1	385	84.6	4	0.9
B7/2001	FLSM	1	286	0	0	72	25.2	12	4.2	5	1.7	196	68.5	1	0.3
B7/2001	0-1	4	389	0	0	90	23.1	19	4.9	7	1.8	269	69.2	4	1
B7/2001	1-2	3	657	0	0	75	11.4	55	8.4	8	1.2	517	78.7	2	0.3
B7/2001	2-3	4	521	0	0	30	5.8	21	4	6	1.2	464	89.1	0	0
B7/2001	3-4	3	560	0	0	48	8.6	23	4.1	13	2.3	470	83.9	6	1.1
B7/2001	4-5	3	425	0	0	41	9.6	12	2.8	1	0.2	363	85.4	8	1.9
B7/2001	5-6	3	362	0	0	37	10.2	20	5.5	13	3.6	288	79.6	4	1.1
B7/2001	6-7	3	463	0	0	27	5.8	20	4.3	2	0.4	409	88.3	5	1.1
B7/2001	7-8	3	476	0	0	49	10.3	15	3.2	1	0.2	407	85.5	4	0.8
B7/2001	8-9	5	351	0	0	14	4	16	4.6	6	1.7	312	88.9	3	0.9
B7/2001	9-10	3	712	0	0	37	5.2	20	2.8	2	0.3	652	91.6	1	0.1
B7/2001	10-11	3	490	0	0	46	9.4	26	5.3	4	0.8	412	84.1	2	0.4
B7/2001	11-12	3	398	0	0	31	7.8	16	4	5	1.3	344	86.4	2	0.5
B7/2001	12-13	4	438	0	0	61	13.9	14	3.2	5	1.1	356	81.3	2	0.5
B7/2001	13-14	4	533	0	0	38	7.1	6	1.1	1	0.2	487	91.4	1	0.2
B7/2001	14-15	5	279	0	0	34	12.2	8	2.9	1	0.4	236	84.6	0	0
B7/2001	15-16	3	288	0	0	25	8.7	5	1.7	3	1	252	87.5	3	1
B7/2001	16-17	5	452	0	0	44	9.7	18	4	11	2.4	379	83.8	0	0
B7/2001	17-18	2	374	0	0	24	6.4	16	4.3	3	0.8	327	87.4	4	1.1
B9/2001	0-1	2	204	0	0	12	5.9	12	5.9	4	2	175	85.8	1	0.5
B9/2001	1-2	1	421	0	0	23	5.5	7	1.7	2	0.5	388	92.2	1	0.2
B9/2001	2-3	3	321	0	0	17	5.3	17	5.3	5	1.6	278	86.6	4	1.2
B9/2001	3-4	3	472	0	0	36	7.6	5	1.1	1	0.2	427	90.5	3	0.6
B9/2001	4-5	3	406	0	0	26	6.4	2	0.5	1	0.2	377	92.9	0	0
B9/2001	6-7	2	417	0	0	31	7.4	4	1	5	1.2	375	89.9	2	0.5
B9/2001	8-9	1	457	0	0	33	7.2	10	2.2	2	0.4	411	89.9	1	0.2
B9/2001	9-10	2	367	0	0	9	2.5	13	3.5	5	1.4	339	92.4	1	0.3
B9/2001	10-11	3	301	0	0	8	2.7	5	1.7	0	0	286	95	2	0.7
B9/2001	11-12	2	446	0	0	6	1.3	8	1.8	1	0.2	423	94.8	8	1.8
B9/2001	12-13	3	258	0	0	3	1.2	5	1.9	2	0.8	247	95.7	1	0.4
B9/2001	13-14	2	518	0	0	3	0.6	5	1	8	1.5	501	96.7	1	0.2
B9/2001	14-15	2	269	0	0	1	0.4	1	0.4	1	0.4	262	97.4	4	1.5
B9/2001	15-16	3	340	0	0	6	1.8	3	0.9	4	1.2	326	95.9	1	0.3
B9/2001	16-17	3	484	0	0	3	0.6	5	1	2	0.4	473	97.7	1	0.2
B9/2001	18-19	0	543	0	0	0	0	3	0.6	5	0.9	532	98	3	0.6
B9/2001	19-20	0	823	0	0	2	0.2	15	1.8	3	0.4	798	97	5	0.6
B10/2001	FLSM	2	358	0	0	21	5.9	14	3.9	6	1.7	306	85.5	11	3.1

B10/2001	0-1	2	542	0	0	7	1.3	2	0.4	14	2.6	510	94.1	9	1.7
B10/2001	1-2	3	265	0	0	4	1.5	4	1.5	0	0	255	96.2	2	0.8
B10/2001	4-5	4	364	0	0	4	1.1	3	0.8	2	0.5	352	96.7	3	0.8
B10/2001	5-6	4	224	0	0	24	10.7	9	4	1	0.4	187	83.5	3	1.3
B10/2001	10-11	3	481	0	0	7	1.5	14	2.9	5	1	449	93.3	6	1.2
B10/2001	11-12	3	386	0	0	7	1.8	4	1	0	0	373	96.6	2	0.5
B10/2001	12-13	3	397	0	0	6	1.5	13	3.3	7	1.8	363	91.4	8	2
B10/2001	13-14	4	316	0	0	5	1.6	7	2.2	0	0	299	94.6	5	1.6
B10/2001	14-15	4	296	0	0	4	1.4	7	2.4	2	0.7	279	94.3	4	1.4
B10/2001	16-17	3	413	0	0	3	0.7	8	1.9	5	1.2	388	93.9	9	2.2
B10/2001	17-18	5	235	1	0.4	2	0.9	4	1.7	2	0.9	216	91.9	10	4.3
B10/2001	22-23	3	525	0	0	9	1.7	11	2.1	2	0.4	499	95	4	0.8
B10/2001	24-25	5	330	0	0	3	0.9	10	3	1	0.3	310	93.9	6	1.8
B1/2001	GS	3	309	0	0	3	1	4	1.3	56	18.1	207	67	39	12.6
B3/2001	GS	5	323	0	0	1	0.3	25	7.7	2	0.6	295	91.3	0	0
B8/2001	GS	4	327	0	0	71	21.7	86	26.3	8	2.4	160	48.9	2	0.6

V.B COARSE GRAIN ANALYSIS FOR FRACTION > 500 MM.

core	sample	number of splits	counted grains	planktonic foraminifera		benthic foraminifera		other shells and skeleton parts		plant remnants		lithoclasts		coal	
				counts	%	counts	%	counts	%	counts	%	counts	%	counts	%
B1/2001	1-2	0	158	0	0	0	0	4	2.5	89	56.3	62	39.2	3	1.9
B1/2001	2-3	0	119	0	0	1	0.8	6	5	37	31.1	74	62.2	1	0.8
B1/2001	3-4	0	45	0	0	0	0	10	22.2	6	13.3	29	64.4	0	0
B1/2001	4-5	0	413	0	0	4	1	10	2.4	44	10.7	338	81.8	17	4.1
B1/2001	5-6	0	208	1	0.5	5	2.4	20	9.6	52	25	124	59.6	6	2.9
B1/2001	7-8	0	81	0	0	0	0	3	3.7	4	4.9	72	88.9	2	2.5
B1/2001	8-9	0	130	0	0	0	0	4	3.1	7	5.4	115	88.5	4	3.1
B1/2001	9-10	0	222	0	0	2	0.9	12	5.4	40	18	166	74.8	2	0.9
B1/2001	11-12	0	207	0	0	1	0.5	6	2.9	34	16.4	149	72	17	8.2
B1/2001	12-13	0	88	1	1.1	0	0	1	1.1	23	26.1	60	68.2	3	3.4
B1/2001	13-14	0	272	0	0	0	0	8	2.9	34	12.5	217	79.8	13	4.8
B1/2001	14-15	0	327	0	0	0	0	3	0.9	153	46.8	170	52	1	0.3
B1/2001	15-16	0	190	0	0	1	0.5	4	2.1	12	6.3	170	89.5	3	1.6
B1/2001	16-17	0	146	0	0	0	0	3	2.1	6	4.1	133	91.1	4	2.7
B1/2001	17-18	0	321	0	0	2	0.6	34	10.6	59	18.4	181	56.4	45	14
B1/2001	18-19	0	118	0	0	0	0	1	0.8	62	52.5	42	35.6	13	11
B1/2001	19-20	0	175	0	0	0	0	2	1.1	7	4	158	90.3	8	4.6
B1/2001	21-22	0	182	0	0	0	0	6	3.3	6	3.3	166	91.2	4	2.2
B1/2001	22-23	0	72	0	0	0	0	1	1.4	9	12.5	53	73.6	9	12.5
B1/2001	24-25	0	63	0	0	1	1.6	3	4.8	17	27	37	58.7	5	7.9
B2/2001	FLSM	0	177	0	0	44	24.9	16	9	4	2.3	104	58.8	9	5.1
B2/2001	0-1	0	245	0	0	18	7.3	32	13.1	12	4.9	177	72.2	6	2.4
B2/2001	1-2	0	410	0	0	28	6.8	38	9.3	27	6.6	302	73.7	15	3.7
B2/2001	2-3	0	393	0	0	12	3.1	41	10.4	20	5.1	305	77.6	15	3.8
B2/2001	3-4	0	323	0	0	0	0	17	5.3	1	0.3	275	85.1	30	9.3
B2/2001	4-5	0	253	0	0	0	0	29	11.5	2	0.8	212	83.8	10	4
B2/2001	5-6	0	175	0	0	1	0.6	6	3.4	3	1.7	157	89.7	8	4.6
B2/2001	6-7	0	80	0	0	1	1.3	8	10	0	0	66	82.5	5	6.3
B2/2001	7-8	0	208	0	0	2	1	22	10.6	5	2.4	168	80.8	11	5.3
B2/2001	8-9	0	138	0	0	0	0	2	1.4	2	1.4	130	94.2	4	2.9
B2/2001	9-10	0	175	0	0	0	0	25	14.3	3	1.7	146	83.4	1	0.6
B2/2001	10-11	0	313	0	0	1	0.3	8	2.6	0	0	300	95.8	4	1.3
B2/2001	11-12	0	197	0	0	0	0	3	1.5	1	1.5	187	94.9	4	2
B2/2001	12-13	0	118	0	0	2	1.7	8	6.8	1	0.8	105	89	2	1.7
B2/2001	13-14	0	198	0	0	1	0.5	5	2.5	1	0.5	186	93.9	5	2.5
B2/2001	14-15	0	424	0	0	2	0.5	3	0.7	4	0.9	402	94.8	13	3.1
B2/2001	15-16	0	349	0	0	0	0	12	3.4	2	0.6	331	94.8	4	1.1
B2/2001	16-17	0	178	0	0	1	0.6	1	0.6	1	0.6	170	95.5	5	2.8
B2/2001	17-18	0	167	0	0	1	0.6	8	4.8	5	3	151	90.4	2	1.2
B2/2001	18-19	0	150	0	0	3	2	3	2	0	0	142	94.7	2	1.3
B2/2001	19-20	0	210	0	0	1	0.5	9	4.3	1	0.5	199	94.8	0	0
B2/2001	20-21	0	245	0	0	0	0	0	0	2	0.8	239	97.6	4	1.6
B2/2001	21-22	0	348	0	0	1	0.3	7	2	1	0.3	336	96.6	3	0.9
B2/2001	22-23	0	474	0	0	1	0.2	12	2.5	3	0.6	454	95.8	4	0.8
B2/2001	23-24	0	887	0	0	3	0.3	115	13	11	1.2	751	84.7	7	0.8
B2/2001	24-25	0	239	0	0	0	0	13	5.4	1	0.4	224	93.7	1	0.4
B2/2001	25-26	0	441	0	0	3	0.7	9	2	0	0	428	97.1	1	0.2
B2/2001	26-27	0	126	0	0	0	0	2	1.6	6	4.8	117	92.9	1	0.8
B2/2001	27-28	0	259	0	0	4	1.5	15	5.8	12	4.6	222	85.7	6	2.3
B2/2001	28-29	0	262	0	0	1	0.4	5	1.9	3	1.1	248	94.7	5	1.9
B2/2001	29-30	0	186	0	0	0	0	6	3.2	1	0.5	176	94.6	3	1.6
B2/2001	30-31	0	531	0	0	3	0.6	8	1.5	2	0.4	494	93	24	4.5

B2/2001	31-32	0	83	0	0	0	0	3	3.6	0	0	79	95.2	1	1.2
B2/2001	32-33	0	133	0	0	0	0	35	26.3	0	0	95	71.4	3	2.3
B4/2001	0-1	0	178	0	0	30	16.9	7	3.9	13	7.3	126	70.8	2	1.1
B4/2001	1-2	0	385	0	0	29	7.5	19	4.9	3	0.8	332	86.2	2	0.5
B4/2001	3-4	0	140	0	0	5	3.6	4	2.9	2	1.4	125	89.3	4	2.9
B4/2001	5-6	0	23	0	0	0	0	3	13	0	0	20	87	0	0
B4/2001	7-8	0	14	0	0	1	7.1	0	0	1	7.1	12	85.7	0	0
B5/2001	FLSM	0	289	0	0	57	19.7	52	18	3	1	141	48.8	36	12.5
B5/2001	0-1	0	363	0	0	53	14.6	21	5.8	3	0.8	224	61.7	62	17.1
B5/2001	1-2	0	985	0	0	53	5.4	210	21.3	29	2.9	456	46.3	237	24.1
B5/2001	2-3	0	447	0	0	14	3.1	29	6.5	16	3.6	267	59.7	121	27.1
B5/2001	3-4	0	505	0	0	7	1.4	42	8.3	10	2	346	68.5	100	19.8
B5/2001	4-5	0	592	0	0	8	1.4	57	9.6	13	2.2	463	78.2	51	8.6
B5/2001	5-6	0	488	0	0	6	1.2	37	7.6	18	3.7	371	76	56	11.5
B5/2001	6-7	0	226	0	0	0	0	18	8	4	1.8	200	88.5	4	1.8
B5/2001	7-8	0	424	0	0	6	1.4	32	7.5	38	9	328	77.4	20	4.7
B5/2001	8-9	0	194	0	0	1	0.5	5	2.6	9	4.6	168	86.6	11	5.7
B5/2001	9-10	0	156	0	0	1	0.6	9	5.8	2	1.3	140	89.7	4	2.6
B5/2001	10-11	0	266	0	0	0	0	3	1.1	0	0	255	95.9	8	3
B5/2001	11-12	0	192	0	0	0	0	15	7.8	2	1	172	89.6	3	1.6
B6/2001	0-1	0	403	3	0.7	24	6	75	18.6	0	0	272	67.5	29	7.2
B6/2001	1-2	0	210	0	0	8	3.8	31	14.8	2	1	158	75.2	11	5.2
B6/2001	2-3	0	289	0	0	8	2.8	38	13.1	2	0.7	231	79.9	10	3.5
B6/2001	3-4	0	192	0	0	10	5.2	20	10.4	1	0.5	152	79.2	9	4.7
B6/2001	4-5	0	181	0	0	1	0.6	34	18.8	0	0	135	74.6	11	6.1
B6/2001	5-6	0	185	0	0	1	0.5	13	7	9	4.9	155	83.8	7	3.8
B6/2001	6-7	0	287	0	0	4	1.4	15	5.2	2	0.7	258	89.9	8	2.8
B6/2001	8-9	0	263	0	0	1	0.4	20	7.6	3	1.1	227	86.3	12	4.6
B6/2001	9-10	0	255	0	0	0	0	17	6.7	15	5.9	218	85.5	5	2
B6/2001	12-13	0	326	0	0	1	0.3	59	18.1	13	4	241	73.9	12	3.7
B6/2001	13-14	0	231	0	0	0	0	6	2.6	6	2.6	214	92.6	5	2.2
B6/2001	14-15	0	145	0	0	2	1.4	5	3.4	2	1.4	132	91	4	2.8
B6/2001	15-16	0	219	0	0	0	0	16	7.3	9	4.1	186	85.4	7	3.2
B6/2001	16-17	0	271	0	0	3	1.1	13	4.8	7	2.6	244	90	4	1.5
B6/2001	17-18	0	280	0	0	3	1.1	26	9.3	2	0.7	244	87.1	5	1.8
B6/2001	18-19	0	182	0	0	6	3.3	5	2.7	10	5.5	157	86.3	4	2.2
B6/2001	19-20	0	226	0	0	2	0.9	13	5.8	9	4	200	88.5	2	0.9
B6/2001	21-22	0	208	0	0	4	1.9	6	2.9	0	0	196	94.2	2	1
B6/2001	22-23	0	178	0	0	2	1.1	6	3.4	0	0	170	95.5	0	0
B6/2001	23-24	0	115	0	0	0	0	8	7	1	0.9	105	91.3	1	0.9
B7/2001	FLSM	0	74	0	0	36	48.6	2	2.7	1	1.4	35	47.3	0	0
B7/2001	0-1	0	468	0	0	110	23.5	66	14.1	49	10.5	239	51.1	4	0.9
B7/2001	1-2	0	276	0	0	40	14.5	37	13.4	9	3.3	190	68.8	0	0
B7/2001	2-3	0	559	1	0.2	34	6.1	36	6.4	6	1.1	480	85.9	2	0.4
B7/2001	3-4	0	237	0	0	24	10.1	17	7.2	13	5.5	180	75.9	3	1.3
B7/2001	4-5	0	390	0	0	17	4.4	27	6.9	8	2.1	337	86.4	1	0.3
B7/2001	5-6	0	492	0	0	82	16.7	57	11.6	56	11.4	294	59.8	3	0.6
B7/2001	6-7	0	390	0	0	19	4.9	9	2.3	14	3.6	347	89	1	0.3
B7/2001	7-8	0	405	0	0	17	4.2	14	3.5	16	4	353	87.2	5	1.2
B7/2001	8-9	0	945	0	0	18	1.9	100	10.6	12	1.3	815	86.2	0	0
B7/2001	9-10	0	272	0	0	6	2.2	13	4.8	1	0.4	252	92.6	0	0
B7/2001	10-11	0	258	0	0	12	4.7	26	10.1	11	4.3	208	80.6	1	0.4
B7/2001	11-12	0	281	0	0	12	4.3	52	18.5	19	6.8	198	70.5	0	0
B7/2001	12-13	0	450	0	0	23	5.1	26	5.8	1	0.2	400	88.9	0	0
B7/2001	13-14	0	597	0	0	25	4.2	19	3.2	0	0	550	92.1	3	0.5
B7/2001	14-15	0	672	0	0	22	3.3	15	2.2	3	0.4	628	93.5	4	0.6
B7/2001	15-16	0	216	0	0	11	5.1	7	3.2	7	3.2	191	88.4	0	0
B7/2001	16-17	0	591	0	0	80	13.5	52	8.8	28	4.7	430	72.8	1	0.2
B7/2001	17-18	0	153	0	0	6	3.9	46	30.1	1	0.7	99	64.7	1	0.7
B9/2001	0-1	0	69	0	0	6	8.7	4	5.8	2	2.9	57	82.6	0	0
B9/2001	1-2	0	116	0	0	12	10.3	1	0.9	0	0	102	87.9	1	0.9
B9/2001	2-3	0	514	0	0	16	3.1	5	1	2	0.4	487	94.7	4	0.8
B9/2001	3-4	0	633	0	0	24	3.8	0	0	6	0.9	600	94.8	3	0.5
B9/2001	4-5	0	335	0	0	20	6	0	0	0	0	314	93.7	1	0.3
B9/2001	6-7	0	196	0	0	7	3.6	2	1	1	0.5	186	94.9	0	0
B9/2001	8-9	0	67	0	0	3	4.5	1	1.5	0	0	63	94	0	0
B9/2001	9-10	0	95	0	0	4	4.2	1	1.1	2	2.1	86	90.5	2	2.1
B9/2001	10-11	0	201	0	0	5	2.5	4	2	0	0	190	94.5	2	1
B9/2001	11-12	0	273	0	0	0	0	4	1.5	0	0	267	97.8	2	0.7

B9/2001	12-13	0	197	0	0	0	0	4	2	2	1	191	97	0	0
B9/2001	13-14	0	138	0	0	3	2.2	2	1.4	1	0.7	131	94.9	1	0.7
B9/2001	14-15	0	100	0	0	0	0	5	5	0	0	95	95	0	0
B9/2001	15-16	0	184	0	0	1	0.5	0	0	0	0	182	99.1	1	0.5
B9/2001	16-17	0	585	0	0	0	0	1	0.2	2	0.3	580	99.1	2	0.3
B9/2001	18-19	0	277	0	0	2	0.7	4	1.4	0	0	268	96.1	3	1.1
B9/2001	19-20	0	80	0	0	0	0	0	0	0	0	78	97.5	2	2.5
B10/2001	FLSM	0	198	0	0	15	7.6	56	28.3	4	2	122	61.6	1	0.5
B10/2001	1-2	0	97	0	0	1	1	10	10.3	2	2.1	79	81.4	5	5.2
B10/2001	2-3	0	43	0	0	0	0	12	27.9	2	4.7	29	67.4	0	0
B10/2001	3-4	0	121	0	0	0	0	5	4.1	5	4.1	111	91.7	0	0
B10/2001	4-5	0	290	0	0	5	1.7	12	4.1	5	1.7	263	90.7	5	1.7
B10/2001	5-6	0	226	0	0	11	4.9	0	0	5	2.2	209	92.5	1	0.4
B10/2001	6-7	0	156	0	0	3	1.9	2	1.3	0	0	150	96.2	1	0.6
B10/2001	7-8	0	118	0	0	3	2.5	2	1.7	1	0.8	110	93.2	2	1.7
B10/2001	8-9	0	207	0	0	6	2.9	4	1.9	1	0.5	194	93.7	2	1
B10/2001	9-10	0	311	0	0	10	3.2	2	0.6	3	1	294	94.5	2	0.6
B10/2001	10-11	0	334	0	0	6	1.8	28	8.4	0	0	300	89.8	0	0
B10/2001	11-12	0	340	0	0	0	0	16	4.7	3	0.9	321	94.4	0	0
B10/2001	12-13	0	200	0	0	0	0	3	1.5	1	0.5	192	96	4	2
B10/2001	13-14	0	275	0	0	2	0.7	28	10.2	2	0.7	240	87.3	3	1.1
B10/2001	14-15	0	374	0	0	4	1.1	42	11.2	6	1.6	321	85.8	1	0.3
B10/2001	15-16	0	308	0	0	0	0	0	0	6	1.9	297	96.4	5	1.6
B10/2001	16-17	0	262	0	0	0	0	7	2.7	1	0.4	251	95.8	3	1.1
B10/2001	17-18	0	253	0	0	0	0	1	0.4	1	0.4	250	98.8	1	0.4
B10/2001	18-19	0	683	0	0	2	0.3	7	1	3	0.4	662	96.9	9	1.3
B10/2001	19-20	0	219	0	0	0	0	9	4.1	1	0.5	204	93.2	5	2.3
B10/2001	21-22	0	245	0	0	0	0	1	0.4	0	0	243	99.2	1	0.4
B10/2001	22-23	0	389	0	0	9	2.3	17	4.4	0	0	361	92.8	2	0.5
B10/2001	23-24	0	578	0	0	2	0.3	24	4.2	1	0.2	548	94.8	3	0.5
B10/2001	24-25	0	877	0	0	5	0.6	13	1.5	5	0.6	852	97.1	2	0.2
B10/2001	25-26	0	625	0	0	4	0.6	9	1.4	1	0.2	611	97.6	1	0.2
B10/2001	26-27	0	748	0	0	2	0.3	8	1.1	0	0	732	97.9	6	0.8
B10/2001	27-28	0	872	0	0	3	0.3	29	3.3	0	0	839	96.2	1	0.1
B1/2001	GS	0	63	0	0	0	0	7	11.1	2	3.2	47	74.6	7	11.1
B2/2001	GS	0	182	0	0	1	0.5	65	35.7	5	2.7	98	53.8	13	7.1
B3/2001	GS	0	242	0	0	2	0.8	13	5.4	0	0	226	93.4	1	0.4
B4/2001	GS	0	134	0	0	11	8.2	3	2.2	1	0.7	119	88.8	0	0
B5/2001	GS	0	280	0	0	7	2.5	59	21.1	6	2.1	185	66.1	23	8.2
B6/2001	GS	0	358	0	0	5	1.4	45	12.6	14	3.9	270	75.4	24	6.7
B8/2001	GS	0	936	3	0.3	181	19.3	342	36.5	1	0.1	406	43.4	3	0.3
B9/2001	GS	0	56	0	0	4	7.1	4	7.1	0	0	48	85.7	0	0
B10/2001	GS	0	143	0	0	3	2.1	12	8.4	1	0.7	120	83.9	7	4.9

VI. XRF ANALYSIS

VI.A MAJOR ELEMENT CONCENTRATIONS [%] MEASURED ON XRF

core	sample	SiO ₂	Al ₂ O ₃	Na ₂ O	K ₂ O	Fe ₂ O ₃	CaO	MgO	MnO	TiO ₂	P ₂ O ₅	LOI
B2	GS	48.6	15.01	1.26	3.19	5.83	6.46	4.72	0.07	0.81	0.17	13.09
B4	GS	52.86	13.35	1.66	3.92	5.62	6.48	4.62	0.18	0.8	0.19	9.887
B9	GS	53.01	13.07	1.75	3.73	5.44	6.46	4.58	0.11	0.8	0.19	10.12
B1	GS	51.56	14.5	1.29	2.79	5.54	6.12	4.27	0.07	0.8	0.14	12.43
B5	GS	48.65	13.16	1.34	3.3	5.67	7.57	5.21	0.11	0.74	0.22	13.07
B1A	GS	54.7	10.66	1.01	1.99	4.34	7.92	4.38	0.08	0.68	0.14	13.22
B8	GS	44.59	12.54	1.29	2.71	4.9	11.23	4.17	0.06	0.65	0.28	16.33
B10	GS	49.75	14.13	1.21	3.27	5.66	6.98	4.94	0.09	0.8	0.18	12.71
B6	GS	42.57	11.64	1.32	2.21	5.06	9.89	6.48	0.69	0.62	0.27	18.46
B3	GS	57.86	11.56	1.55	3.47	4.62	5.58	3.77	0.07	0.73	0.16	7.896
B4A	FLSM	50.78	12.93	1.88	3.56	5.42	6.92	4.86	0.21	0.79	0.19	11.86
B4A	0-1	53.19	13.46	1.74	3.83	5.6	6.24	4.58	0.18	0.81	0.2	9.452
B4A	1-2	51.8	13.15	1.77	3.61	5.63	6.67	4.79	0.15	0.78	0.21	10.97
B4A	2-3	51.26	13.07	1.64	3.63	5.64	6.78	4.83	0.13	0.78	0.21	11.54
B4A	3-4	51.21	13.14	1.59	3.68	5.43	6.9	4.86	0.09	0.79	0.2	11.25
B4A	4-5	51.24	13.23	1.61	3.69	5.36	6.99	4.84	0.1	0.79	0.19	11.49
B4A	5-6	51.13	13.29	1.56	3.78	5.39	6.99	4.81	0.09	0.79	0.19	11.04
B4A	6-7	52.25	12.78	1.6	3.58	5.1	7.29	4.77	0.09	0.79	0.18	11.28
B4A	7-8	54.51	11.29	1.52	3.26	4.29	8.05	4.7	0.07	0.75	0.2	10.77
B5A	0-1	48.26	13.17	1.35	2.99	5.41	7.74	5.22	0.08	0.73	0.21	14.36
B5A	1-2	48.42	13.31	1.28	3.06	5.13	7.75	5.17	0.05	0.73	0.17	14.46
B5A	2-3	48.68	13.26	1.34	3.18	5.25	7.59	5.23	0.06	0.75	0.18	13.94
B5A	3-4	48.62	13.28	1.37	3.23	5.28	7.34	5.06	0.06	0.76	0.19	13.49
B5A	4-5	49.39	13.32	1.41	3.33	5.32	7.5	5.06	0.06	0.75	0.17	13.38
B5A	5-6	49.16	13.35	1.41	3.35	5.34	7.54	5.08	0.06	0.75	0.18	12.75
B5A	6-7	49.14	13.45	1.4	3.46	5.33	7.68	5.09	0.06	0.76	0.18	13.11
B5A	7-8	49.93	13.27	1.41	3.53	5.26	7.43	4.95	0.06	0.76	0.17	12.49
B5A	8-9	51.51	13.27	1.49	3.61	5.32	6.9	4.71	0.07	0.78	0.18	11.54
B5A	9-10	52.61	13.39	1.59	3.65	5.43	6.67	4.64	0.07	0.8	0.18	10.84
B5A	10-11	51.45	13.18	1.52	3.56	5.32	6.64	4.6	0.07	0.77	0.18	10.9
B5A	11-12	51.98	13.43	1.57	3.67	5.46	6.71	4.65	0.07	0.78	0.19	11.15
B5A	12-13	51.84	13.32	1.61	3.64	5.49	6.54	4.69	0.07	0.78	0.17	10.68
B5A	13-14	52.03	13.36	1.63	3.63	5.5	6.66	4.66	0.07	0.78	0.18	10.76
B5A	14-15	51.89	13.37	1.6	3.62	5.5	6.8	4.69	0.07	0.77	0.18	10.83
B5A	15-16	52.24	13.28	1.63	3.69	5.45	6.85	4.67	0.07	0.77	0.18	10.91
B5A	16-17	52.49	13.43	1.59	3.7	5.48	6.72	4.63	0.06	0.78	0.18	10.47
B5A	17-18	52.35	13.29	1.78	3.61	5.51	6.65	4.6	0.07	0.78	0.18	10.52
B6A	FLSM	41.67	11.23	1.55	1.9	4.8	10.45	6.78	0.94	0.61	0.25	19.74
B6A	0-1	42.95	11.49	1.53	2.2	5.31	10.11	6.6	0.83	0.62	0.39	18.1
B6A	1-2	41.85	11.68	1.32	2.26	5.5	10.1	6.54	0.2	0.63	0.39	19.26
B6A	2-3	43.24	11.99	1.3	2.23	5.07	10.45	6.56	0.12	0.65	0.25	18.44
B6A	3-4	43.09	12.1	1.22	2.38	4.94	10.39	6.5	0.11	0.64	0.2	18.28
B6A	4-5	43.19	12.27	1.17	2.55	5.03	10.55	6.6	0.1	0.65	0.19	17.65
B6A	5-6	43.58	12.32	1.18	2.61	5.07	10.43	6.49	0.11	0.66	0.19	17.51
B6A	6-7	44.08	12.17	1.19	2.61	5.08	10.09	6.34	0.12	0.65	0.2	17.17
B6A	7-8	44.23	12.36	1.15	2.7	5.12	10.29	6.36	0.11	0.66	0.17	17.38
B6A	8-9	43.45	12.47	1.15	2.67	5.12	10.41	6.43	0.1	0.66	0.18	17.52
B6A	9-10	43.05	12.24	1.16	2.7	5.04	10.18	6.35	0.1	0.65	0.18	17.25
B6A	10-11	43.45	12.44	1.28	2.79	5.11	10.34	6.36	0.1	0.65	0.18	17.13
B7A	FLSM	43.88	11.63	2.32	1.88	5.24	8.47	5.7	0.23	0.63	0.32	18.3
B7A	0-1	43.03	12.19	1.96	2.21	5.77	8.27	5.72	0.13	0.65	0.38	18.21
B7A	1-2	45.02	12.72	1.71	2.35	5.26	8.78	5.74	0.06	0.69	0.27	16.84
B7A	2-3	45.01	12.79	1.43	2.5	5.19	8.71	5.73	0.06	0.69	0.24	16.7
B7A	3-4	45.57	12.67	1.35	2.6	5.14	8.98	5.76	0.06	0.7	0.24	16.17
B7A	4-5	44.75	12.57	1.29	2.56	5.1	8.95	5.74	0.05	0.68	0.22	17.11
B7A	5-6	44.9	12.9	1.23	2.63	5.06	8.98	5.72	0.05	0.69	0.22	16.98
B7A	6-7	45.26	12.85	1.29	2.6	5.1	9.13	5.77	0.05	0.69	0.21	16.33
B7A	7-8	45.03	12.73	1.28	2.61	4.99	9.07	5.69	0.05	0.68	0.21	16.46
B7A	8-9	45.42	12.64	1.27	2.61	4.86	9.11	5.59	0.05	0.69	0.2	16.96
B7A	9-10	45.4	12.68	1.25	2.63	4.7	9.2	5.61	0.05	0.67	0.2	17.02
B7A	10-11	45.56	12.62	1.27	2.62	4.64	9.28	5.65	0.05	0.68	0.2	16.75
B7A	11-12	45.8	12.67	1.3	2.67	4.62	9.24	5.59	0.04	0.69	0.2	16.95
B7A	12-13	46.09	12.75	1.26	2.68	4.73	9.1	5.64	0.05	0.69	0.2	16.35

VI.B TRACE ELEMENT CONCENTRATIONS [PPM] MEASURED ON XRF

core	sample	Ba	Nb	Rb	Sr	Y	Zn	Zr
B2	GS	506	16	129	124	36	87	190
B4	GS	676	12	164	201	41	74	253
B9	GS	677	12	151	196	37	62	260
B1	GS	486	13	112	96	31	78	214
B5	GS	539	12	134	162	34	81	208
B1A	GS	417	11	78	100	25	72	267
B8	GS	422	10	116	302	29	89	141
B10	GS	521	13	139	140	37	84	211
B6	GS	433	8	83	146	21	78	162
B3	GS	641	14	144	204	36	55	335
B4A	FLSM	657	13	146	193	37	65	234
B4A	0-1	679	16	159	198	41	72	257
B4A	1-2	730	15	149	198	39	74	240
B4A	2-3	641	14	149	186	38	70	236
B4A	3-4	662	13	155	182	39	75	241
B4A	4-5	671	16	152	183	39	76	235
B4A	5-6	670	14	158	184	42	70	234
B4A	6-7	681	14	135	191	37	77	255
B4A	7-8	662	14	122	201	37	55	324
B5A	0-1	515	16	121	149	32	76	201
B5A	1-2	523	15	127	141	34	78	201
B5A	2-3	571	14	130	146	33	81	206
B5A	3-4	523	11	131	150	35	77	206
B5A	4-5	555	10	135	156	35	74	210
B5A	5-6	560	16	131	157	33	75	215
B5A	6-7	571	10	148	164	36	80	211
B5A	7-8	544	12	146	168	38	73	220
B5A	8-9	624	11	151	172	38	71	240
B5A	9-10	669	12	157	177	36	71	242
B5A	10-11	618	12	149	175	37	69	230
B5A	11-12	619	14	159	177	37	74	222
B5A	12-13	664	13	150	175	37	69	224
B5A	13-14	641	14	149	179	36	72	219
B5A	14-15	683	12	147	181	34	73	223
B5A	15-16	668	16	155	185	36	70	233
B5A	16-17	664	14	153	188	38	74	236
B5A	17-18	610	14	152	192	37	70	237
B6A	FLSM	480	9	64	149	18	76	159
B6A	0-1	433	8	81	155	23	81	160
B6A	1-2	401	8	80	151	22	76	151
B6A	2-3	422	11	88	138	24	78	163
B6A	3-4	462	11	86	132	25	79	158
B6A	4-5	469	10	94	130	23	81	159
B6A	5-6	450	13	100	135	24	80	156
B6A	6-7	426	9	100	135	27	79	156
B6A	7-8	461	9	103	138	28	78	158
B6A	8-9	455	9	107	139	28	84	156
B6A	9-10	427	12	104	136	26	78	157
B6A	10-11	464	13	110	144	27	76	159
B7A	FLSM	394	10	57	149	18	59	158
B7A	0-1	410	11	86	144	26	62	154
B7A	1-2	394	8	92	138	25	75	160
B7A	2-3	441	13	100	132	29	75	161
B7A	3-4	420	10	111	135	31	77	166
B7A	4-5	418	13	104	133	30	80	161
B7A	5-6	405	10	104	132	28	82	161
B7A	6-7	458	10	103	138	28	79	164
B7A	7-8	429	12	109	137	31	77	162
B7A	8-9	462	11	100	137	30	75	162
B7A	9-10	473	11	100	140	27	79	165
B7A	10-11	418	10	103	141	26	78	170
B7A	11-12	449	9	106	144	30	80	170
B7A	12-13	443	12	108	143	31	78	170

VII. REE AND TRACE ELEMENTS DATA MEASURED WITH ICP MS

Data for grab samples . The concentrations are given in [ppm].

Sample	MESS1 (standard)	G2 (standard)	G2-duplicate (standard)	B1/2001	B1A/2001	B2/2001	B3/2001	B3/2001 duplicate	B4/2001	B5/2001	B6/2001	B8/2001	B9/2001	B10/2001
V	115.07	54.39	52.10	126.40	103.63	156.13	112.33	111.43	122.42	132.21	144.11	235.05	118.69	134.62
Cr	97.37	19.86	9.06	103.49	87.76	134.63	143.48	140.63	153.25	133.72	114.59	117.25	148.21	127.54
Co	15.41	6.51	5.73	20.09	18.36	22.86	19.94	19.12	22.49	21.59	20.58	17.26	21.36	20.69
Ni	33.86	31.03	8.97	52.58	95.99	62.15	72.91	83.25	67.92	77.33	47.40	54.55	71.22	66.59
Cu	29.92	29.73	12.18	23.13	40.93	23.88	23.06	26.99	31.91	37.07	16.95	23.70	22.94	23.74
Zn	192.22	91.68	90.46	91.25	79.00	108.00	67.75	65.57	77.73	86.85	79.01	90.40	75.02	93.42
Ga	20.27	35.84	34.73	27.53	20.99	31.11	26.09	25.82	28.27	27.43	22.39	24.72	27.97	28.46
Rb	127.00	227.06	225.08	161.69	117.42	189.62	209.76	215.45	233.32	206.45	149.27	155.35	227.88	195.54
Sr	126.13	652.06	646.78	126.16	131.03	161.02	283.12	285.52	262.22	215.64	185.52	433.87	256.44	180.40
Y	45.61	12.18	12.06	41.40	39.31	42.05	38.13	37.90	37.67	35.98	29.59	32.40	37.77	38.52
Zr	777.30	394.92	426.10	275.10	367.28	266.67	464.64	449.66	326.69	264.58	207.24	195.87	337.31	270.70
Nb	19.25	11.69	14.34	16.71	15.11	18.70	18.64	18.91	19.00	17.20	13.41	15.18	18.73	17.23
Mo	2.81	1.69	0.19	1.90	1.90	3.16	1.39	1.70	2.48	2.55	10.35	3.75	1.46	2.51
Sn	1.80	1.55	1.21	1.69	1.83	1.31	1.78	2.10	1.83	2.00	1.29	1.69	2.14	1.86
Cs	4.12	1.38	1.32	7.87	5.18	8.85	5.57	5.93	7.64	7.89	6.40	7.94	7.24	8.43
Ba	309.09	1985.71	1973.97	440.08	396.76	482.24	676.26	687.07	695.36	566.50	397.23	421.03	697.90	537.21
La	37.14	91.05	91.00	49.43	37.56	53.49	58.34	60.25	64.51	55.60	39.51	37.88	64.48	56.88
Ce	77.13	164.94	165.38	100.06	77.14	108.88	120.05	123.05	130.34	111.37	78.20	74.38	129.75	113.28
Pr	9.32	16.66	16.82	11.57	8.99	12.46	13.87	14.18	14.87	12.97	9.06	8.72	14.91	13.14
Nd	35.51	53.02	53.20	42.75	33.58	45.97	50.92	52.86	55.03	46.94	32.94	31.59	54.01	46.76
Sm	7.51	7.07	7.28	8.07	6.48	8.28	9.08	9.43	9.77	8.66	6.16	5.96	9.49	8.99
Eu	1.26	1.38	1.37	1.49	1.29	1.59	1.55	1.65	1.69	1.54	1.11	1.21	1.66	1.60
Gd	6.22	4.28	4.22	6.65	6.08	7.28	6.89	7.23	7.50	6.82	4.94	5.22	7.38	7.33
Tb	0.96	0.47	0.44	0.95	0.85	1.08	0.94	0.93	1.04	0.96	0.70	0.73	0.96	1.06
Dy	5.64	2.02	2.05	5.79	5.17	5.63	5.04	5.20	5.58	5.55	4.27	4.38	5.75	5.85
Ho	1.11	0.30	0.32	1.16	1.00	1.12	0.97	1.00	1.08	1.03	0.83	0.91	1.09	1.16
Er	3.25	0.80	0.81	3.27	2.80	3.03	2.70	2.64	2.94	2.77	2.23	2.52	2.87	3.06
Tm	0.49	0.10	0.10	0.47	0.41	0.44	0.40	0.39	0.42	0.40	0.32	0.36	0.42	0.47
Yb	3.28	0.64	0.63	3.05	2.74	3.03	2.61	2.57	2.69	2.68	2.11	2.30	2.67	3.02
Lu	0.49	0.09	0.10	0.46	0.40	0.41	0.36	0.37	0.42	0.39	0.31	0.34	0.40	0.43
Hf	12.70	6.49	7.07	5.33	6.93	5.10	8.48	8.26	6.83	5.43	4.31	4.03	7.01	5.94
Ta	1.14	0.62	0.64	0.93	0.77	0.93	0.81	0.88	0.94	0.88	0.69	0.80	0.91	0.95
W	2.72	0.14	0.21	2.04	1.70	2.26	1.66	1.67	2.09	1.88	1.73	1.85	2.01	1.87
Th	11.96	24.93	25.48	14.16	11.43	16.34	19.60	20.51	23.43	18.96	12.61	11.52	22.97	18.67
U	3.74	1.72	2.47	3.73	3.41	3.87	3.62	3.80	4.02	3.98	3.76	4.05	4.01	4.02
Pb	21.32	26.20	25.88	18.47	15.03	20.25	15.63	16.35	18.14	18.51	13.46	15.98	18.26	19.91

VIII. TOTAL ²¹⁰PB ACTIVITIES.

core	depth [cm]	lab nr	total ²¹⁰ Pb [dpm g ⁻¹]	error +/-
B1/2001	FLSM	4863	4.23	0.19
	0-2	4867	3.52	0.19
	0-2	4868	3.86	0.16
	2-4	4870	3.63	0.15
	4-6	4866	5.12	0.21
	6-8	4865	5.25	0.17
	8-10	4871	4.59	0.24
	10-12	4872	3.64	0.16
	10-12	4873	4.20	0.27
	12-14	4874	3.59	0.20
	14-16	4875	3.53	0.19
	16-18	4869	3.59	0.17
	18-20	4876	3.21	0.17
	20-22	4864	3.40	0.14
	22-24	4877	3.49	0.21
B4/2001	0-2	5483	7.44	0.33
	2-4	5484	7.64	0.35
	4-6	5488	6.27	0.35
	6-8	5487	5.49	0.27
	8-10	5485	5.00	0.19
B5/2001	0-2	5469	6.57	0.40
	2-4	5470	6.71	0.29
	4-6	5471	5.90	0.28
	6-8	5542	4.91	0.26
	8-10	5472	4.33	0.20
	10-12	5473	4.22	0.22
B6/2001	0-2	5010	7.99	0.49
	2-4	5011	6.73	0.41
	4-6	5012	5.36	0.25
	6-8	5013	5.08	0.22
	6-8	5014	4.72	0.29
	8-10	5015	4.10	0.19
	10-12	5016	4.13	0.26
	12-14	5017	3.39	0.23
	14-16	5018	3.58	0.17
	16-18	5019	3.52	0.14
	18-20	5020	3.52	0.14
B7/2001	0-2	5562	7.83	0.43
	2-4	5563	6.17	0.36
	2-4	5564	6.10	0.36
	4-6	5565	6.03	0.38
	6-8	5566	4.00	0.24
	8-10	5567	3.91	0.25
	10-12	5568	3.21	0.18
	12-14	5569	3.10	0.20
B10/2001	0-2	5474	5.74	0.27
	2-4	5475	5.47	0.25
	4-6	5493	5.60	0.25
	6-8	5491	3.87	0.23
	8-10	5492	3.65	0.23
	10-12	5476	3.77	0.17

IX. TOTAL ¹³⁷Cs ACTIVITIES.

core	sample	Total ¹³⁷ Cs activity [Bq kg ⁻¹]	error +/-
B4A/2001	0-1	0	
	1-2	3.64	6.23
	2-3	4.33	5.595
	3-4	7.46	4.63
	4-5	6.73	4.855
	5-6	7.63	4.72
	6-7	6.83	4.905
	7-8	5.51	5.31
	8-9	4.46	5.22
B5A/2001	1-2	17.52	1.16
	2-3	22.32	1.28
	3-4	23.72	1.36
	4-5	28.13	1.54
	5-6	22.39	1.36
	6-7	15.45	0.99
	7-8	12.31	0.9
	8-9	0	
B6A/2001	9-10	0	
	10-11	0	
	11-12	0	
	0-1	12.22	3.79
	1-2	11.82	3.32
	2-3	11.12	3.24
	3-4	12.08	3.09
	4-5	12.05	3.11
B7A/2001	5-6	10.16	3.23
	6-7	6.1	3.66
	7-8	0	
	8-9	0	
	0-1	25.25	10.98
	1-2	30.90	8.48
	2-3	23.03	7.99
	3-4	24.68	7.83
B9A/2001	4-5	19.42	8.21
	5-6	12.47	9.41
	6-7	9.39	10.5
	7-8	7.08	11.29
	8-9	6.31	11.81
	9-10	0	
	10-11	0	
	0-1	4.50	5.49
B9A/2001	1-2	4.33	5.61
	2-3	0	
	3-4	6.02	5.3
	4-5	9.78	4.46
	5-6	9.10	4.55
	6-7	6.49	5.015
	7-8	7.06	4.905
	8-9	7.13	4.89
	9-10	4.85	5.385
	10-11	0	
	11-12	0	
	12-13	0	
	13-14	0	
	14-15	0	
	15-16	7.09	5.215
16-17	9.69	4.45	
17-18	7.84	4.605	
18-19	9.64	5.325	
19-20	7.46	5.02	