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Provenance, processes and productivity through spatial distribution of the surface sediments from Kongsfjord to Krossfjord system, Svalbard

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Abstract: Krossfjord-Kongsfjord is a glacial fjord system in West Spitsbergen (Svalbard archipelago) situated adjacent to the Arctic and Atlantic water mass, a suitable site to study the effect of climate change on the environment. To understand the sedimentary characteristics, depositional processes, source and their implications on productivity in the fjord, spatial variations of grain size, organic carbon, nitrogen, phosphorus, biogenic silica and calcium carbonate in the surface sediments were studied. Grain size showed the dominance of fine-grained sediment (silt and clay) suggesting relatively quieter hydrodynamic conditions prevailing in the fjord. The nutrient (C, N, P and BSi) concentrations in surface sediments of both the fjords show a clear spatial gradient with lower values in the glacier-dominated inner fjord and higher values towards the outer fjord as high turbidity towards the fjord head diminishes the expanse of the photic zone leading to low primary productivity close to the glacier fronts. Along Krossfjord, the C: N ratio varied from 1.01 to 26.37 and along the Kongsfjord the C: N ratio varied from 6.67 to 17.00 indicating the derivation of the organic matter from both terrestrial as well as marine sources with increasing marine influence towards the fjord mouth. Carbonate production in this region is low and the calcium carbonate occurring here may be of detrital origin. Sediment grain size seems to be a dominant controlling factor in the distribution of organic and inorganic matter in Krossfjord-Kongsfjord system.

Keywords: Surface sediment, nutrients, Krossfjord-Kongsfjord, hydrodynamics

Introduction

Fjords are considered as a link between the ocean and the land through cross-shelf exchanges, which result in circulation and mixing in the fjords (Nilsen et al., 2008). The fjords on the west coast of Spitsbergen balance Atlantic, Arctic, brine and freshwater inputs, which are sensitive indicators of environmental changes (Nilsen et al., 2008). One of the fjord system affected by a warm current is Kongsfjord-Krossfjord system-a suitable site for studying glacial history and palaeoclimate. Changes in climate influence the currents flowing in the fjord and which will be reflected in the distribution pattern of environmental parameters inducing changes in composition and abundance of organic matter throughout the fjord.

It has been documented that apart from serving as a tool for studying depositional environment, transport pathways, remineralization and past climate conditions, source characterization of the sedimentary organic matter is required to estimate the deposition of marine and terrigenous organic matter (Stein and MacDonald, 2004). Various geochemical proxies such as C/N ratio of sedimentary organic matter (Meyers, 1997, 2003; Stein and MacDonald, 2004; Schubert and Calvert, 2001), specific biomarkers (Fahl and Stein, 1999) and Rock-Eval parameters (Peters, 1986) are used to identify relative composition of land and marine-derived components of organic matter. However, a multiproxy approach for identification of source and composition of organic matter is rare due to which factors controlling spatial variations of different biogeochemical parameters are rarely identified. Despite previous investigations (Stein et al., 1994; Shetye et al., 2011; Kumar et al., 2016; Koziorowska et al., 2017), the source of sediments, processes involved during and after sediment deposition and their implications on productivity in the recent past still remain unclear primarily on account of proxy specific limitations.

In the present study, we have investigated the spatial variability of sediment grain size, organic elements and calcium

carbonate within Krossfjord-Kongsfjord system with water depths ranging from 41 m to 332 m situated at the west coast of Svalbard to understand the source, depositional processes and productivity in the recent past.

Study Area

Kongsfjord-Krossfjord is a glacial fjord system in the Arctic that opens onto a submarine glacial trough in the western Svalbard shelf, called Kongsfjordrenna (Fig.1). This system is located between 78º50'-79º30'N and 11º-13ºE. The orientation of the southern arm of the fjord system, Kongsfjord, is south-east to north-west, whereas the northern arm Krossfjord is north to south (Kumar et al., 2014). The length of the Kongsfjord is 20 km and its width varies from 4–10 km (MacLachlan

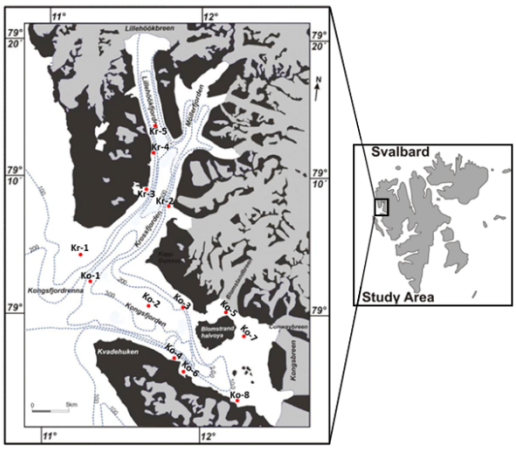

Fig.1 Map showing the study area (modified after Svendsen et al., 2002)

et al., 2010) with the deepest point of 394 m. The Krossfjord is narrower (3–6 km) and longer (~30 km) compare to Kongsfjord, with a maximum depth of 374 m (Svendsen et al., 2002). The total volumes of Kongsfjord and Krossfjord have been estimated to be equal to 29.4 and 25 km^3, respectively (Ito and Kudoh, 1997).

The climate of Svalbard is strongly influenced by the atmospheric circulation, Arctic sea ice extent and ocean currents. Western Spitsbergen is flanked by a northerly warm West Spitsbergen Current (WSC), with Atlantic water mass (AW). The presence of these currents towards the mouth of the fjord give rise to fronts and instabilities associated with them causes exchange of warm saline shelf transformed Atlantic water with the cold freshwater from the glacial discharge. The western Spitsbergen Current (WSC) causes ice-free conditions along the west coast throughout the year and partially ice-free waters north of Svalbard even during winter (Vinje, 1982). The prevailing winds are from NE to the SE sectors, except during summer (Forland et al., 1997).

The Kongsfjord-Krossfjord system lies close to a major tectonic boundary separating the Cenozoic fold and thrust belt of western Spitsbergen to the southwest and the Northwestern Basement province to the northeast (Svendsen et al., 2002). The northern side of the fault zone consists of pre-Devonian metasediments and igneous rocks, whereas towards south Late Palaeozoic sedimentary strata, such as carbonates, conglomerates and calcareous sand-stones are found (Streuff, 2013). Mostly, the coastal part of the fjord system is covered with unconsolidated deposits of Quaternary age which includes moraines, marine shore and fluvial deposits (Kumar et al., 2014). Glacial processes like active glacial, hydro-glacial, periglacial and coastal processes have modified the landforms of this area.

Both of these fjords are largely influenced by the presence of tidewater glaciers: Lilliehookbroon at the head of Krossfjord (Lilliehookfjord) and five other calving glaciers along its eastern coast. Glaciers like Kronebreen and Kongsvegen at the head of Kongsfjord and Conwaybreen and Blomstrandbreen on the northern coast influence the fjord. Mass balance studies from these fjords have shown that the major contribution of fresh water into the fjord comes from the glacial discharge (MacLachlan et al., 2007) since precipitation plays a limited role.

Materials and Methods

Sampling and collection

Thirteen surface sediment grab samples were collected at various water depths from Kongsfjord and Krossfjord during August 2016 (Table1). Surface sediment samples were collected using stainless steel Van Veen Grab sampler using the workboat "MS Teisten" to understand the source, depositional processes, productivity and trace the glaciomarine contrast along the fjords. Samples were labeled and brought back to the laboratory in a frozen condition for analysis. In the laboratory, samples were dried at 60ºC in the oven and used for further analysis.

Sample name	Water Depth (m)	Latitude (ºN)	Longitude (ºE)
Kr-1	285.00	79.0675	11.2193
Kr-2	130.00	79.1346	11.7843
Kr-3	180.00	79.1535	11.6501
Kr-4	189.00	79.1995	11.6928
Kr-5	265.00	79.2337	11.6894
Ko-1	332.00	79.0365	11.2955
Ko-2	180.00	79.0081	11.6083
Ko-3	283.00	79.0087	11.7887
Ko-4	235.00	78.9510	11.8278
Ko-5	41.70	79.0073	12.1797
Ko-6	302.00	78.9403	11.9622
Ko-7	90.00	78.9725	12.3309
Ko-8	70.10	78.9045	12.2300

Table 1. Sampling depth and Location

Laboratory analysis

The samples were analyzed for grain size using pipette method (Folk, 1968) which is based on Stoke's settling velocity principle. Total Carbon (TC) and Total Nitrogen (TN) was estimated using elemental analyzer (Elementar, Vario isotope cube). The analytical precision for TN and TOC are ±0.31% and ±0.30% (1σ standard deviation) obtained by repeatedly running Sulfanilamide as the standard. Total Inorganic carbon (TIC) was measured by using UIC carbon coulometer. Total organic carbon (TOC) was calculated by subtracting TIC from TC. Calcium Carbonate ($CaCO_3$) was computed as TIC *8.333. The sediment for total phosphorus
(TP) analysis was digested using HF-HNO_3-$HClO_4$ mixture and brought to liquid phase as adopted by Yu et al. (2013) and further determined following the procedure given by Murphy and Riley (1962), where the intensity of phosphomolybdenum blue complex was measured at 880 nm using UV-1800(Shimadzu) visible spectrophotometer. The accuracy of phosphorus analysis was determined using a digested sample of JLK-1 and obtained a recovery of 98%. Biogenic silica (BSi) from the freeze-dried sample was extracted using 25 ml of 1% Na_2CO_3 in an 85ºC water bath for 5 hours and measured by the wet alkaline extraction method, modified by Mortlock and Froelich (1989) and Muller and Schneider (1993) where intensity of blue silico-molybdenum complex was measured at 810 nm using UV-1800 (Shimadzu) visible spectrophotometer. Duplicate measurements were conducted on each sample and relative error was noted to be less than 3%.

Results

Distribution of Sediment components

Sand, silt and clay vary in the Krossfjord in the range from 5.70 to 21.24%, 43.15 to 61.04% and 20.00 to 48.27% respectively, with the average value of 10.46%, 52.95% and 36.59% respectively. Among sediment components silt is predominant. Sand is highest at station Kr-2 due to its close proximity to the D'Arodesbreen glacier, silt shows decreasing trend from station Kr-5 to Kr-1 while clay exhibits an increasing trend from station Kr-5 to Kr-1. Along the Kongsfjord, sand, silt and clay vary from 5.66 to 33.78%, 29.69 to 53.35% and 32.27 to 50.67% respectively, with the average value of 18.21%, 42.22% and 39.57% respectively. Silt is dominant amongst the sediment components. Station

Ko-8, Ko-6, Ko-5 and Ko-4, except station Ko-7, show a high concentration of sand as compared to the other stations due to their glacial fed and proximal location to the coast while station Ko-3, Ko-2 and Ko-1 show comparatively lower concentration as they are located away from the glacier and the coast. However, station Ko-1 shows higher sand as compared to the station Ko-7, Ko-3 and Ko-2 possibly due to the presence of Ice-rafted debris (IRD) which disturbs the current sorted grain size fraction (Hass, 2002). Silt and clay exhibit an increasing trend from station Ko-8 to Ko-1. Further, the data on sediment components of surface sediments from Krossfjord and Kongsfjord is presented in figure 2.

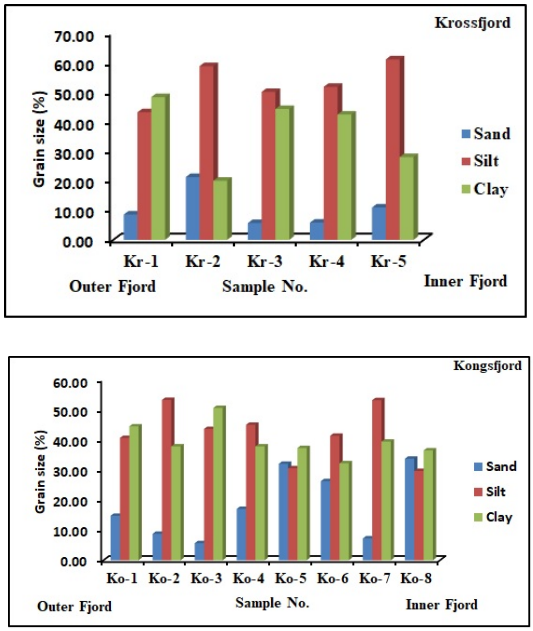

Fig.2. Variation in sediment components along Krossfjord (Kr) and Kongsfjord (Ko).

Distribution of organic elements (C, N, P and BSi)

TOC and TN concentration vary within a range from 0.04% to 1.70% and 0.04 % to 0.17% respectively (Table 2**)** along the Krossfjord**.** TOC (1.70%) and TN (0.17%) are highest at station Kr-1 while least concentration of TOC (0.04%) at station Kr-4 and TN (0.04%) at station Kr-4 and Kr-5 is noted (Fig.3a). TP varies from 0.019 to 0.023 % (Table 2). High concentration is at station Kr-1 while least concentration is at station Kr-2 and Kr-5. BSi varies from 2.74% to 4.19%. High concentration of BSi is at station Kr-1 and least concentration is at Kr-5 (Fig. 3a).

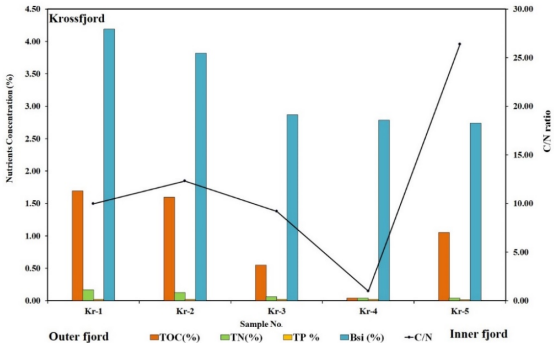

Fig.3a. Distribution of total organic carbon (TOC), total nitrogen(TN), total phosphorus(TP), biogenic silica (BSi) and C/N ratio in surface sediments of Krossfjord (Kr).

Along the Kongsfjord, TOC and TN vary from 0.20% to 1.74% and 0.03% to 0.17% (Table 2**).** TOC (1.74%) and TN (0.17%) are highest at station Ko-1 and least concentration of TOC (0.20%) and TN (0.03%) at station Ko-7. TP varies from 0.017% to 0.061%. Ko-5 shows high concentration while Ko-7 shows the lowest concentration. BSi varies from 1.42% to 4.03%. High concentration of BSi is noted at station Ko-1 and least concentration at station Ko-8 (Fig.3b**).**

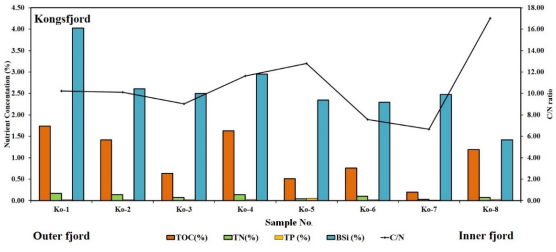

Fig.3b. Distribution of total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP), biogenic silica (BSi) and C/N ratio in surface sediments of Kongsfjord (Ko).

Sample	Sand (%)	Silt (%)	Clay (%)	TOC (%)	TN (%)	C/N	TP (%)	BSi (%)	$CaCO_3$ (%)
Kr-1	8.58	43.15	48.27	1.70	0.17	9.98	0.023	4.19	10.95
Kr-2	21.24	58.76	20.00	1.60	0.13	12.31	0.019	3.82	10.91
Kr-3	5.70	50.03	44.27	0.55	0.06	9.19	0.022	2.87	4.32
Kr-4	5.84	51.76	42.40	0.04	0.04	1.01	0.021	2.79	4.91
Kr-5	10.96	61.04	28.00	1.05	0.04	26.37	0.019	2.74	13.79
Ko-1	14.78	40.69	44.53	1.74	0.17	10.23	0.019	4.03	9.00
Ko-2	8.78	53.35	37.87	1.41	0.14	10.10	0.022	2.61	12.54
Ko-3	5.66	43.67	50.67	0.63	0.07	9.03	0.022	2.50	4.81
Ko-4	17.06	45.07	37.87	1.63	0.14	11.62	0.029	2.95	11.60
Ko-5	32.06	30.61	37.33	0.51	0.04	12.81	0.061	2.34	15.56
Ko-6	26.32	41.41	32.27	0.76	0.10	7.57	0.024	2.29	9.94
Ko-7	7.26	53.27	39.47	0.20	0.03	6.67	0.017	2.48	13.24
Ko-8	33.78	29.69	36.53	1.19	0.07	17.00	0.026	1.42	12.00

Table 2 Sediment components, TOC, TN, TP, BSi and $CaCO_3$ content along Krossfjord and Kongsfjord.

Distribution of Calcium carbonate

In general, the carbonate content of the surface sediments is relatively low, most of the values are lower than 15% (Table 2). Calcium Carbonate ($CaCO_3$) varies within a range from 4.32% to 13.79% along the Krossfjord. $CaCO_3$ (13.79%) is highest at station Kr-5 while least concentration (4.32%) at station Kr-3. Along the Kongsfjord, $CaCO_3$ varies from 4.81% to 15.56%. Ko-5 station exhibits a high concentration of $CaCO_3$ while least concentration is exhibited by station Ko-3.

Discussion

Sources and transport mechanism of sediment components

In the Krossfjord-Kongsfjord system, in general, coarse-grained sediments depicts increasing trend from the mouth (outer fjord) towards the head (inner part of the fjord) indicating that the coarser grains are deposited close to the glacier front which corresponds to glacial deposition due to the retreat of glaciers in the study area. This suggests warm conditions in the region due to which coarse-grained particles have been transported to the fjord through physical (glacial) weathering of rocks present in the catchment area. While the finer fractions are transported by the surface waters to the central and outer part of the fjord (Fig.2). Overall, sediment grain size shows the dominance of fine-grained sediment (silt and clay) in both the fjords suggesting deposition from water column suspensions. The freshwater runoff from calving and ablation of the glacier, melting of sea ice and precipitation increases the turbidity in the inner fjord, and thus diminishes the vertical extent of the euphotic zone (Keck et al., 1999).

Further, an attempt has been made to infer the hydrodynamic conditions of the depositional environment using textural analysis. For this purpose, a ternary diagram (Fig.4) proposed by Pejrup (1988) has been used. The hydrodynamics are distinguished in the diagram into four sections labeled as I to IV. Section I indicates the very calm hydrodynamic condition and section II to IV indicate increasingly violent hydrodynamic conditions. Further, sections A to D

provides an environment with respect to the size of the sediments. When the data was plotted, surface sediments collected from Krossfjord mostly falls between section III(C) and III(D) with a single point being part of II(D) indicating less calm to less violent conditions prevailed facilitating deposition of finer sediments. In the Kongsfjord, all the data points lie between section II(C), II(D), III(C) and III(D) indicating not much variation in sediment size and deposition environment. Therefore, quieter hydrodynamic conditions prevailing in the fjord system from the glacier front to the mouth of the fjord which is responsible for the deposition of finer grained sediments towards the outer fjord. In addition,

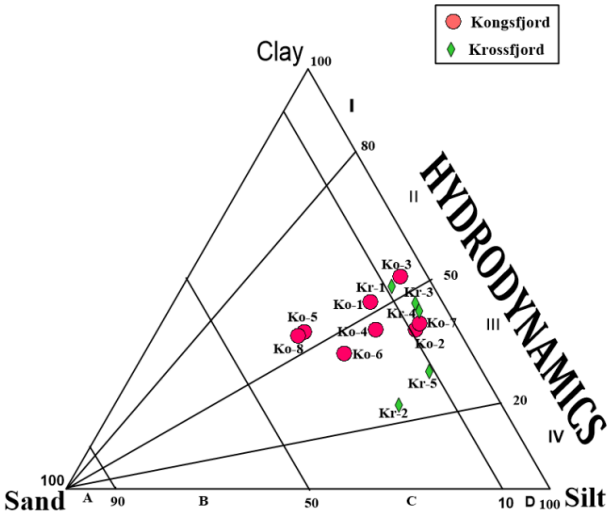

Fig.4. Triangular diagram for classification of hydrodynamic conditions of a) Kongsfjord and b) Krossfjord (after Pejrup, 1988).

factors like glacier outflow and temperature-salinity stratification (aggregation of fine particles) lead to the offshore transportation of fine-grained material (Zaborska et al., 2006).

Biogeochemical proxies in fjord sediments

Organic carbon content in the surface sediment shows an increasing trend towards the mouth of the Krossfjord and Kongsfjord (Table 2). The total nitrogen concentration in surface sediments follows a similar increasing trend. TOC and TN in surface sediments of both the fjords shows a clear spatial gradient with lower values in the glacier-dominated inner fjord and higher values towards the outer fjord due to the high turbidity towards the fjord head, which gives rise to a shallow photic zone close to the glacier fronts (Shetye et al., 2011). Consequently, algae become light limited and Eilertsen et al. (1989) suggested that during the summer, algal biomass decreased due to increased grazing in the inner part of the fjord. High input of sediment-loaded glacial meltwater deteriorates growth of phytoplanktons during summer (Svendsen et al., 2002), therefore, low organic matter in the inner part of the fjord resulted in lower primary productivity. A steep gradient in the deposition of sediment and grain size sorting from inner fjord to the outer fjord may also have played a role in their distribution. It is well established that the finer particles of the sediments provide, large surface area, thus having high adsorption capacity (Siraswar and Nayak, 2012; Fernandes and Nayak, 2017) which is supported by increase in organic carbon and finer sediments in the outer fjord and coarser sediments and low organic carbon in the inner fjord.

A strong correlation between TOC and TN exist in the surface sediments of Krossfjord (r^2=0.69) and Kongsfjord (r^2=0.84) suggesting that the contribution of inorganic nitrogen to the total nitrogen pool is negligible in Krossfjord-Kongsfjord system (Kim et al., 2011). TP fluctuates without any particular trend in both the fjords. TOC and TN show poor association with TP indicating a differential pathway for phosphorus. BSi shows an increasing trend from inner fjord towards the outer fjord indicating high productivity towards the outer fjord. The nutrient (C, N, P and Si) concentrations in the inner fjord are low may be due to less concentration of organic matter, possibly because of the proximity of glacier as glacial meltwater is low in nutrient

concentrations and also diluted possibly by the presence of coarse-grained sediments. All geochemical proxies TN, TOC and BSi show similar variations from outer fjord to inner fjord indicating their common source. The close relationship between BSi and other nutrient parameters could confirm that sedimentary organic matter is predominantly derived from the natural source and anthropogenic organic input did not significantly influence the organic matter.

Source of organic matter in fjord sediments

The C: N ratio has been widely used to trace sources of organic matter (marine vs. terrestrial) in Arctic environments (Stein and Macdonald, 2004). Organic matter derived from higher plants is typically characterized by a higher C: N ratio (>20; Meyers and Ishiwatari,1993) as compared to the organic matter derived from marine organisms (6-9; Muller, 1977) as terrestrial organic matter contains a high percentage of non-proteinaceous material (cellulose and lignin). According to Bordowskiy (1965) and Hedges et al. (1986), C: N ratios of marine organic matter are around 6 whereas terrigenous organic matter has C: N ratios of >15. Along Krossfjord, the C: N ratio in sediments varies from 1.01 to 26.37 and along the Krossfjord the C: N ratio varies from 6.67 to 17.00 (Table 2) suggesting the mixed source of organic matter derived from terrestrial as well as marine source increasing marine influence towards the fjord mouth. High terrestrial organic matter (TOM) supply to the fjord corresponds to the meltwater discharge and glacial erosion processes. The contribution of organic matter from the vegetation cover seems to play a minor role since the area is glaciated and small areas provide favorable ground for plant growth. A higher proportion of marine organic matter (MOM) towards the mouth of the fjord reflects the dominant influence of nutrient-rich Atlantic water inflow is indicated by a high temporal variability in annual primary productivity (4—180 gC m^{-2} yr^{-1}) (Hop et al., 2002). Both the fjords show higher C: N values in shallower regions because of the presence of high amount of terrestrial material and their association with coarse-grained sediment suggesting grain size to be a dominant factor regulating the distribution of organic matter. Winkelmann and Kneis (2005) suggested that C: N values of marine surface sediments off Spitsbergen, were substantially affected by a contribution of inorganic nitrogen, which accounted for up to 70% of the total nitrogen content. This indicated that relatively low C: N values are possibly due to the high amount of inorganic nitrogen present in fine-grained sediments. However, in the present study, TOC shows a strong correlation with TN indicating that most of the nitrogen was associated with organic carbon and it can be considered as a measure of organic nitrogen suggesting a negligible contribution of inorganic nitrogen to the total nitrogen pool as reported by Kim et al., 2011.

Factors controlling Carbonate content

Variations in carbonate content are mainly controlled by dissolution during its journey through the water column, dilution by the non-carbonate fraction and terrigenous matter and/or productivity changes (Stein et al., 1994). In general, in polar regions, CO_2 dissolution is high which leads to increase in carbonic acid concentration which in turn explains the low $CaCO_3$ content. The $CaCO_3$ concentration is associated with coarse grain size where with increasing sand fraction towards the head of the fjord calcium carbonate increased. While the $CaCO_3$ content is low towards the mouth of the fjord due to increased clay loads which caused dilution of carbonates. Association of carbonate with coarse-grained sediment in the surface sediments of the fjord indicates that it is of detrital origin derived from the weathering of rocks present in the catchment area of the fjord

(Midproterozoic and Proterozoic metamorphic rocks, mainly marble towards north and south of Kongsfjord respectively).

Conclusions

The sediment size decreases with increasing distance from the glacier fronts and shows the dominance of fine-grained sediment (silt and clay) in both the fjords suggesting deposition from water column suspension indicating the relatively quieter hydrodynamic condition. The sediment seems to have been released from physical and mechanical (glacial) weathering. Organic matter concentration increases with increasing distance from the glaciers. C/N ratio suggests that the inner fjord region is dominated by terrestrial source while marine source becomes dominant away from the glaciers. Grain size seems to be a controlling factor regulating the distribution of organic matter. High concentration of nutrients C, N, P and BSi towards the mouth of the fjord away from the glacier suggests the influence of Atlantic water mass in western Spitsbergen. Carbonate concentration in this region is low (< 15%) due to increased clay loads which caused dilution of carbonates. The carbonate is mainly of detrital origin derived from the weathering of rocks present in the catchment area.

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References

Bordowskiy, O.K. (1965). Sources of organic matter in marine basins. *Marine Geology*, 3-5 31.

Eilertsen, H.C., Taasen, J.P. and WesIawski, J.M. (1989). Phytoplankton studies in the fjords of West Spitsbergen: physical environment and production in spring and summer. *Journal of Plankton Research*, *11* (6), 1245-1260.

Fahl, K. and Stein, R. (1999). Biomarkers as organic-carbon-source and environmental indicators in the Late Quaternary Arctic Ocean: problems and perspectives. *Marine Chemistry*, *63* (3), 293-309.

Fernandes, M.C. and Nayak, G.N. (2017). Geochemistry of mudflat and mangrove sedimentary environments, within tropical (Sharavati) estuary, Karnataka coast, India. *Journal of Indian Association of Sedimentologists,* 34(1-2), 103-119.

Folk, R.L. (1968). Petrology of Sedimentary rocks. Austin, Texas, Hemphills, 177.

Forland, E.J., Hanssen-Bauer, I. and Nordli, P.O. (1997). *Orographic precipitation at the glacier Austre Broggerbreen*, *DNMI Rep. 02/97 Klima.*

Hass, H.C. (2002). A method to reduce the influence of ice-rafted debris on a grain size record from northern Fram Strait, Arctic Ocean. *Polar research*, *21* (2), 299-306.

Hedges, J.I., Clark, W.A., Quay, P.D., Richey, J.E., Devol, A.H. and Santos, M. (1986). Compositions and fluxes of particulate organic material in the Amazon River. *Limnology and Oceanography*, *31* (4), 717-738.

Hop, H., Pearson, T., Hegseth, E.N., Kovacs, K.M., Wiencke, C., Kwasniewski, S., Eiane, K., Mehlum, F., Gulliksen, B., Wlodarska-Kowalczuk, M. and Lydersen, C. (2002). The marine ecosystem of Kongsfjorden, Svalbard. *Polar Research*, *21* (1), 167-208.

Ito, H. and Kudoh, S. (1997). Characteristics of water in Kongsfjorden, Svalbard. *Proceedings of 509 the NIPR Symposium on Polar meteorology and Glaciology. 11, 211-232*.

Keck, A., Wiktor, J., Hapter, R. and Nilsen R. (1999). Phytoplankton assemblages related to physical gradients in an Arctic glacier fed fjord in summer. ICES *Journal of Marine Science*,56, 203-214.

Kim, J.H., Peterse, F., Willmott, V., Kristensen, D.K., Baas, M., Schouten, S. and Sinninghe Damste, J.S. (2011). Large ancient organic

matter contributions to Arctic marine sediments (Svalbard). *Limnology and Oceanography*, *56* (4), 1463-1474.

Koziorowska, K., Kulinski, K. and Pempkowiak, J. (2017). Distribution and origin of inorganic and organic carbon in the sediments of Kongsfjorden, Northwest Spitsbergen, European Arctic. *Continental Shelf Research*, 1-150, 27-35.

Kumar, P., Pattanaik, J.K., Khare, N., Chopra, S., Yadav, S., Balakrishnan, S. and Kanjilal, D. (2014). Study of ^{10}Be in the sediments from the Krossfjorden and Kongsfjorden Fjord System, Svalbard. *Journal of Radioanalytical and Nuclear Chemistry*, *302* (2), 903-909.

Kumar, V., Tiwari, M., Nagoji, S. and Tripathi, S. (2016). Evidence of Anomalously Low δ^{13}C of marine organic matter in an Arctic Fjord. *Scientific reports*, *6*, 36192.

MacLachlan, S.E., Cottier, F.R., Austin, W.E. and Howe, J.A. (2007). The salinity: δ^{18}O water relationship in Kongsfjorden, western Spitsbergen. *Polar Research*, *26* (2), 160-167.

MacLachlan, S.E., Howe, J.A., Vardy, M.E. (2010). Morphodynamic evolution of Kongsfjorden-Krossfjorden, Svalbard, during the Late Weichselian and Holocene. *Geological Society, London, Special Publications*, *344* (1), .195-205.

Meyers, P.A. (1997). Organic geochemical proxies of paleoceanographic, paleolimnologic, and paleoclimatic processes. *Organic geochemistry*, *27* (5-6), 213-250.

Meyers, P.A. (2003). Applications of organic geochemistry to paleolimnological reconstructions: a summary of examples from the Laurentian Great Lakes. *Organic geochemistry*, *34* (2), 261-289.

Meyers, P.A. and Ishiwatari, R. (1993). Lacustrine organic geochemistry—an overview of indicators of organic matter sources and diagenesis in lake sediments. *Organic geochemistry*, *20* (7), 867-900.

Mortlock, R.A. and Froelich, P.N. (1989). A simple method for the rapid determination of biogenic opal in pelagic marine sediments. *Deep Sea Research. Oceanography Research Papers,* 36 (9), 1415–1426.

Muller, P.J. (1977). C/N ratios in Pacific deep-sea sediments: Effect of inorganic ammonium and organic nitrogen compounds sorbed by clays. *Geochimica et Cosmochimica Acta*, *41* (6), 765-776.

Muller, P.J. and Schneider, R. (1993). An automated leaching method for the determination of opal in sediments and particulate matter. *Deep Sea Research Part I: Oceanography Research Papers*, 40 (3), 425–444.

Murphy, J.A.M.E.S. and Riley, J.P. (1962). A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta*, 27, 31–36.

Nilsen, F., Cottier, F., Skogseth, R. and Mattsson, S. (2008). Fjord–shelf exchanges controlled by ice and brine production: the interannual variation of Atlantic Water in Isfjorden, Svalbard. *Continental Shelf Research*, *28* (14), 1838-1853.

Pejrup, M. (1988). The triangular diagram used for classification of estuarine sediments: a new approach. In de Boer, P.L., van Gelder, A., Nios, S.D., (Eds) *Tide-influenced sedimentary environments and facies. (*Reidel, Dordrecht), 289-300.

Peters, K.E. (1986). Guidelines for evaluating petroleum source rock using programmed pyrolysis. *AAPG bulletin*, *70* (3), 318-329.

Siraswar, R.R. and Nayak, G.N. (2012). Distribution of Sediment Components and Metals in Recent Sediments within Tidal Flats along Mandovi Estuary. *Journal of Indian Association of Sedimentologists*, *31* (1&2), 33-44.

Schubert, C.J. and Calvert, S.E. (2001). Nitrogen and carbon isotopic composition of marine and terrestrial organic matter in Arctic Ocean sediments: implications for nutrient utilization and organic matter composition. *Deep Sea Research Part I: Oceanographic Research Papers*, *48* (3), 789-810.

Shetye, S., Mohan, R., Shukla, S.K., Maruthadu, S. and Ravindra, R. (2011). Variability of Nonionellina labradorica Dawson in surface sediments from Kongsfjorden, West Spitsbergen. *Acta Geologica Sinica (English Edition)*, *85* (3), 549-558.

Stein, R. and MacDonald, R.W. (2004). In: Stein, R. and MacDonald, R.W. (Eds.) The organic carbon cycle in the Arctic Ocean, 8, 315-322.

Stein, R., Grobe, H. and Wahsner, M. (1994). Organic carbon, carbonate, and clay mineral distributions in eastern central Arctic Ocean surface sediments. *Marine Geology*, *119* (3-4), 269-285.

Streuff, K. (2013). Master's thesis in Geology, Department of geology, University of Tromso, Norway.

Svendsen, H., Beszczynska-Moller, A., Hagen, J.O., Lefauconnier, B., Tverberg, V., Gerland, S., Borre Orbaek, J., Bischof, K., Papucci, C., Zajaczkowski, M. and Azzolini, R. (2002). The physical environment of Kongsfjorden–Krossfjorden, an Arctic fjord

system in Svalbard. *Polar research*, *21* (1), 133-166.

Vinje, T. (1982). Frequency distribution of sea ice in the Greenland and Barents Seas, 1971-80. *Norsk Polarinstitutt Arbok,* 57-61.

Winkelmann, D. and Knies., J. (2005). Recent distribution and accumulation of organic carbon on the continental margin west off Spitsbergen. *Geochemistry Geophysics Geosystems.* 6: Q09012.

Yu, Y., Song, J., Li, X., Yuan, H., Li, N. and Duan, L. (2013). Environmental significance of biogenic elements in surface sediments of the Changjiang estuary and its adjacent areas. *Journal of Environmental Science, 25 (11)*, 2185–2195.

Zaborska, A., Pempkowiak, J. and Papucci, C. (2006). Some sediment characteristics and sedimentation rates in an Arctic Fjord (Kongsfjorden, Svalbard). *Annual Environmental Protection*, *8*, 79-96.