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Elemental composition and bacterial occurrence in sediment samples on two sides of Brøggerhalvøya, Svalbard

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ABSTRACT. The present study was conducted to determine the elemental concentration and bacterial presence in the ocean on the two sides of Brøggerhalvøya, a peninsula in Svalbard. Sediments from 25 different locations were collected and subjected to elemental analysis using inductively coupled plasma mass spectrometry (ICPMS). In total, 21 elements were analysed. The elements in their decreasing order of concentrations on the Kongsfjorden side of Brøggerhalvøya were Fe> Mn> Ba > V > Zn > Sr > Rb > Cr > Li > Ni > As > Pb > Cu > Co > Cs >Ag > Be > U> Bi >Tl > Cd while that for Forlandsendet side of Brøggerhalvøya they were Fe > Ba >Mn > V> Sr > Zn > Rb > Cr > Li > Ni > Pb > Cu > As > Co > Cs > Be > U> Tl > Bi > Cd. On the other hand, at a coastal outcrop, elements in their decreasing order of concentration were Fe > Mn > Cr > Sr > Ba > Rb > Cr > Zn > V > Rb > Ni > Li > Co > Cu > As > Pb > Cs > Be > Cd > Tl > U > Bi. AMS dates confirmed the age of outcrop sediment to be 12,496 to 42,500 BP. The crustal enrichment factor calculated for all the elements with reference to Fe values, demonstrates that the elements have derived from a crustal source. Total bacterial counts ranged from 3.30×10^5 to 3.02×10^6 per gm soil sediment. Culturable bacterial counts in these sediments were between 2.00×10^2 to 2.09×10^5 CFU's per gm. Overall comparison showed high Fe and Mn concentrations around Brøggerhalvøya, due to the presence of specific bacteria which play key roles in metal cycling and carry out biogeochemical transformations.

Introduction

Brøggerhalvøya, a peninsula located on the west coast of Spitsbergen (Svalbard), has a length of approximately 20 km and is some 10 km wide. The peninsula is bordered on the north by Kongsfjorden and on the west by Forlandsendet (Miller and others 1989). The peninsula is covered by ranges of mountains and valleys with a large number of glaciers flowing into the adjacent waters.

Kongsfjorden is one of the largest glacial fjords of the Svalbard archipelago and is situated on a major tectonic boundary between the Tertiary fold-thrust belts of western Spitsbergen (Svendsen and others 2002). It is oriented from southeast to northeast. The total volume of this fjord is 29.4 km^3 (Ito and Kudoh 1997) and it has both Atlantic and Arctic water masses. The inner fjord facing tidal glaciers has a relatively shallow water level (less than 100 m) while the outer fjord is deeper and connected with the Greenland Sea (Hop and others 2002). It is to some extent divided into several deep basins (Cottier and others 2005). Kongsfjorden has recently received much research attention with focuses on seasonal hydrography (Cottier and others 2005), marine biology and ecosystem dynamics (Hop and others 2002).

The distribution and concentration levels of metals varied according to the natural processes and anthropogenic activities in different areas of Arctic. The transport of metals is a consequence of atmospheric, oceanic and biological cycling of elements. Recently, the distributions of metals have been assessed from many habitats of Arctic such as sea sediments (Cai and others 2011), seabird tissue (Blais and others 2005), Cryoconites and lichens (Singh and others 2012) and Glacier ice cores (Singh and others 2013). There are reports on elevated levels of trace metals [Zinc (Zn), Copper (Cu), Lead (Pb), Cadmium (Cd), Mercury (Hg), Cobalt (Co), Nickel (Ni), Manganese (Mn) and Chromium (Cr) due to anthropogenic processes (AMAP 1998, 2005; Macdonald and others 2000; Lu and others 2012). The distribution of trace metals in other areas of Arctic has also been assessed (Muir and others 2003; Trefry and others 2003; Braune and others 2005; Evenset and others 2007; Ma and others 2008 and Cai and others 2011). However, there have been no systematic studies on distribution and concentrations of different metal groups (alkali metal, alkaline earth metal, transition metal and other metal groups) in the sediments of fjords on the two sides of Brøggerhalvøya and along coastal outcrops. Therefore, the aim of the present study is to determine the composition and concentration of metals in the sediments of fjords and also to compare these with elemental analysis of other Arctic regions reported in earlier studies.

Experimental

Sampling site and collection of samples

Samples were taken from fjords on both sides of Brøggerhalvøya (Fig. 1) during the Indian Arctic Expedition in 2009. A 'grab sampler' was used to collect accurate representative samples of the sediment from the bottom of fjords. 25 samples were collected from different depths and locations (Table 1) following strict contamination-free procedures. Each sample was collected in sterile sampling bags, transported to the laboratory and stored at -20°C until processed.

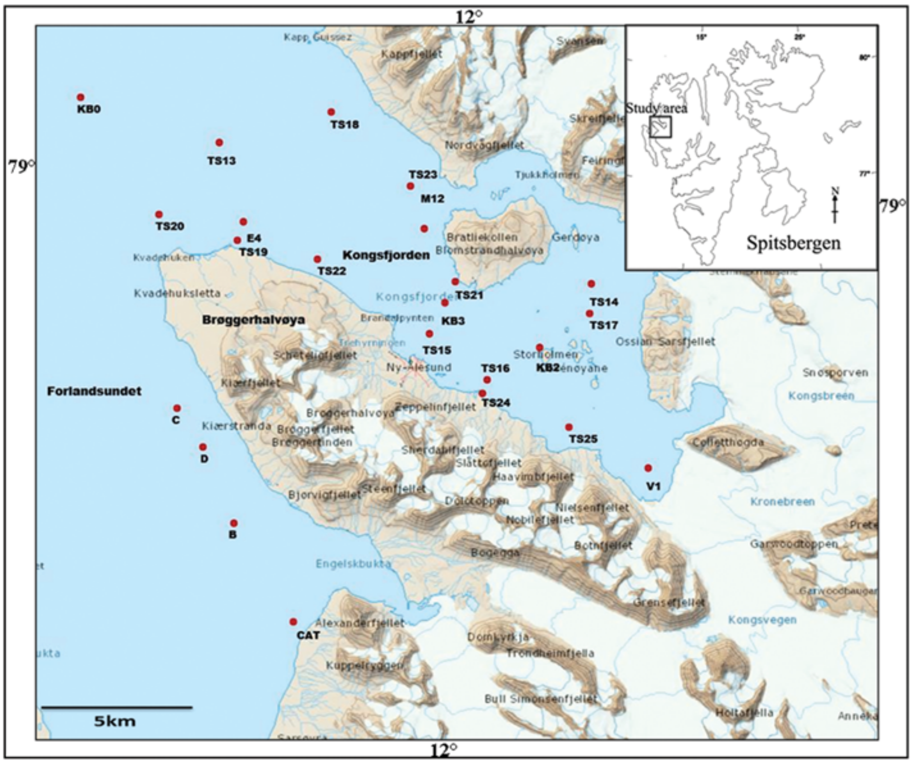

Fig. 1. Sampling locations on the two sides of Brøggerhalvøya peninsula, Svalbard. Map modified from the Norwegian Polar Institute's map resource. (www.toposvalbard.npolar.no)

Analytical procedure and microbiological analyses

Soil sediment samples (0.25 g) were digested in a microwave digestion system using concentrated 3 ml HNO_3, 1 ml HCl, 1 ml H_2O_2 and 3 ml purified water. Elemental concentration in the processed samples was determined through ICPMS (Thermo Scientific ICPMS-X series II) equipped with nickel cones, a peristaltic sample delivery pump and cetac autosampler. Instrumental conditions for the ICP-MS were optimised, after completing the mass calibration and detector cross calibration, by following the manual tuning procedure using Thermo tuning Solution A containing the elements Li, Be, Co, Ni, In, Ba, Ce, Pb, Bi, and U at 10 μg/L. For data acquisition the ICPMS was operated in peak jump mode, with dwell time 20 ms, 100 sweeps, and a forward RF power of 1400 W. A CertiPUR ICP multi-element standard solution XXI for MS (Merck) was used. The elements analysed included Arsenic (As), Barium (Ba), Beryllium (Be), Bismuth (Bi), Cadmium (Cd), Cesium (Cs), Chromium (Cr), Cobalt (Co), Copper (Cu), Iron (Fe), Lead (Pb), Lithium (Li), Manganese (Mn), Nickel (Ni), Rubidium (Rb), Silver (Ag), Strontium (Sr), Thallium (Tl), Uranium (U), Vanadium (V) and Zinc (Zn). The concentrations of the elements in the sediment samples analysed in triplicate are expressed on an oven dry weight basis. ^{14}C radiocarbon dates of two depths middle (50–60cm) and bottom layer (120–30cm) of coastal samples were dated by the accelerator mass spectrometer, at National Ocean Science Accelerator Mass Spectrometry (NOSAMS) in Woods Hole Oceanographic Institute, USA by accelerator mass spectrometeric analysis.

Total bacterial counts (TC) and bacterial colony forming units (CFU's) were determined for per g sample. The procedure by Kuwae and Hosokawa (1999) was followed to measure total bacterial counts in the samples. One g soil sediments were aseptically added to 5 ml of filter-sterilised saline and vortexed thoroughly to dislodge the microbial cells from the sediment grains. One ml of this suspension was mixed with 20 μl DAPI (4′, 6-Diamidino-2-phenylindole) solution (0.25% w/v in sterile distilled water) and taken in a sterile vial. After keeping in the dark for ~30 minutes, the sample was filtered on to a 0.2 μm Nuclepore polycarbonate track etched membrane filter. The filter was rinsed with a few drops of saline to remove the unbound DAPI and observed under a epifluorescence microscope (BX-51, Olympus, Japan), using non-fluorescent immersion oil. Bacterial cells appearing as bright blue spots against a dark background were manually counted in epi-fluorescence research microscope and number of cells per g sediments calculated. Culturable bacteria were enumerated using the spread plate method on Nutrient Agar (NA), 1/10 Nutrient Agar (1/10 NA) media, Marine Agar and 1/10 Marine Agar (pH 7.0 and 9.0).

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Table 1. Elemental composition (in mg/kg) of the sediments in the study area.

Sampling locations	Depth (m)	GPS point	**As** (mg/kg)	**Ba** (mg/kg)	**Be** (mg/kg)	**Bi** (mg/kg)	**Cd** (mg/kg)	**Cs** (mg/kg)	**Cr** (mg/kg)	**Co** (mg/kg)	**Cu** (mg/kg)	**Fe** (mg/kg)	**Pb** (mg/kg)
B	112	78°51′.397″N 11°32′.797″E	21.98 ± 0.36	209.06 ± 0.42	1.51 ± 0.04	0.22 ± 0.01	0.17 ± 0.05	3.09 ± 0.03	71.42 ± 0.3	10.69 ± 0.06	22.84 ± 0.3	24030 ± 185.51	22.95 ± 0.54
C	7	78°54′.141″N 11°23′.569″E	13.89 ± 0.44	374.6 ± 5.26	2.07 ± 0.06	0.21 ± 0.00	0.18 ± 0.01	3.81 ± 0.03	74.77 ± 0.5	10.32 ± 0.1	19.45 ± 0.34	22546 ± 199.73	21.18 ± 0.37
D	147	78°53′.010″N 11°27′.412″E	14.35 ± 0.25	267.32 ± 2.12	1.55 ± 0.03	0.19 ± 0.00	0.19 ± 0.01	3.01 ± 0.04	57.41 ± 0.43	8.33 ± 0.1	18.2 ± 0.3	19903 ± 143.99	19.29 ± 0.19
KB0	310	79°02′.554″N 11°07′.851″E	29.53 ± 0.13	127.66 ± 0.45	1.32 ± 0.05	0.24 ± 0.00	0.25 ± 0.02	3.21 ± 0.02	44.12 ± 0.28	9.06 ± 0.05	20.07 ± 0.25	34041 ± 40.07	19.4 ± 0.1
KB2	294	78°56′.848″N 11°73′.155″E	9.03 ± 0.09	130.62 ± 0.27	1.25 ± 0.01	0.25 ± 0.02	0.2 ± 0.03	3.65 ± 0.01	36.53 ± 0.23	9.92 ± 0.09	16.33 ± 0.19	29900 ± 153.18	16.83 ± 0.18
KB3	330	78°57′.179″N 11°59′.567″E	11.87 ± 0.63	208.88 ± 1.87	1.99 ± 0.05	0.31 ± 0.01	0.17 ± 0.04	5.63 ± 0.08	57.23 ± 0.51	12.72 ± 0.09	18.88 ± 0.21	24287 ± 133.22	18.5 ± 0.26
V-1	200	78°53′.537″N 12°28′.300″E	5.50 ± 0.1	157.29 ± 0.95	1.47 ± 0.05	0.21 ± 0.01	0.14 ± 0.01	4.53 ± 0.03	41.28 ± 0.21	11.77 ± 0.03	16.57 ± 0.03	19562 ± 76.09	12.26 ± 0.02
E-4	276	78°59′.091″N 11°31′.731″E	15.39 ± 0.01	249.35 ± 0.66	2 ± 0.08	0.32 ± 0.01	0.18 ± 0.03	4.93 ± 0.05	64.88 ± 0.32	11.5 ± 0.08	20.1 ± 0.32	24910 ± 122.09	26.82 ± 0.08
M12	200	78°59′.725″N 11°56′.100″E	12.39 ± 0.13	218.82 ± 1.93	1.96 ± 0.07	0.31 ± 0.00	0.21 ± 0.02	5.93 ± 0.02	59.95 ± 0.51	13.12 ± 0.06	19.25 ± 0.03	24838 ± 194.56	19.62 ± 0.07
TS 13	266	79°01′.936″N 11°27′.769″N	13.74 ± 0.3	227.74 ± 1	2.24 ± 0.01	0.29 ± 0.01	0.26 ± 0.01	5.05 ± 0.04	64.59 ± 0.09	12.07 ± 0.06	20.71 ± 0.04	26052 ± 108.67	20.22 ± 0.16
TS 14	84	78°58′.271″N 12°19′.257″E	8.94 ± 0.05	220.72 ± 1.62	2.56 ± 0.03	0.3 ± 0.02	0.12 ± 0.02	6.88 ± 0.03	63.22 ± 0.24	17.35 ± 0.04	24.86 ± 0.46	30266 ± 231.27	14.54 ± 0.14
TS 15	289	78°56′.768″N 11°57′.018″E	9.57 ± 0.28	200.24 ± 1.49	1.97 ± 0.07	0.25 ± 0.01	0.22 ± 0.01	5.12 ± 0.05	56.19 ± 0.47	12.15 ± 0.09	18.48 ± 0.26	24170 ± 159.03	15.46 ± 0.25
TS 16	152	78°55′.430″N 12°05′.804″E	9.29 ± 0.16	228.87 ± 2.31	2.24 ± 0.04	0.25 ± 0.01	0.15 ± 0.01	5.72 ± 0.02	58.63 ± 0.09	13.63 ± 0.08	20.07 ± 0.23	24880 ± 189.68	14.72 ± 0.24

Table 1. Continued.

Sampling locations	Depth (m)	GPS point	**As** (mg/kg)	**Ba** (mg/kg)	**Be** (mg/kg)	**Bi** (mg/kg)	**Cd** (mg/kg)	**Cs** (mg/kg)	**Cr** (mg/kg)	**Co** (mg/kg)	**Cu** (mg/kg)	**Fe** (mg/kg)	**Pb** (mg/kg)
TS 17	198	78°56′.769″N 12°12′.190″E	6.34 ± 0.28	120.41 ± 0.55	1.46 ± 0.06	0.18 ± 0.01	0.11 ± 0.02	4.01 ± 0.03	36.74 ± 0.1	11.18 ± 0.03	15.61 ± 0.32	19557 ± 41.71	9.94 ± 0.19
TS 18	108	79°02′.336″N 11°42′.611″E	12.22 ± 0.32	214.54 ± 0.39	2.06 ± 0.05	0.25 ± 0.01	0.21 ± 0.01	5.45 ± 0.03	54.85 ± 0.04	12.84 ± 0.08	20.26 ± 0.36	25194 ± 24.92	15.11 ± 0.11
TS 19	288	78°58′.876″N 11°30′.330″E	17.41 ± 0.21	292.91 ± 1.25	2.15 ± 0.02	0.24 ± 0.01	0.2 ± 0.02	4.5 ± 0.02	78.54 ± 0.58	10.55 ± 0.07	19.44 ± 0.2	24865 ± 95.87	21.34 ± 0.2
TS 20	219	78°59′.842″N 11°19′.450″E	12.74 ± 0.63	243.88 ± 1.02	1.82 ± 0.04	0.19 ± 0.01	0.22 ± 0.03	3.47 ± 0.03	67.34 ± 0.13	8.75 ± 0.06	17.82 ± 0.02	20292 ± 37.27	17.86 ± 0.15
TS 21	124	78°57′.389N 12°00′.860″E	9.65 ± 0.17	144.33 ± 0.72	1.88 ± 0.06	0.28 ± 0.02	0.18 ± 0.01	5.24 ± 0.02	53.76 ± 0.4	13.86 ± 0.07	20.27 ± 0.15	25170 ± 129.75	14.47 ± 0.05
TS 22	284	78°58′.302″N 11°41′.608″E	14.9 ± 0.17	355.96 ± 0.38	2.1 ± 0.07	0.18 ± 0.01	0.23 ± 0.03	4.24 ± 0.04	62 ± 0.33	9.43 ± 0.02	17.3 ± 0.2	21617 ± 62.42	17.47 ± 0.14
TS 23	146	79°00′.062″N 11°54′.923″E	10.14 ± 0.32	191.26 ± 0.78	2.02 ± 0.07	0.26 ± 0.02	0.2 ± 0.02	5.62 ± 0.04	54.24 ± 0.44	13.63 ± 0.07	19.57 ± 0.41	25813 ± 100.79	15.49 ± 0.22
TS 24	44	78°53′.791″N 12°02′.703″E	3.02 ± 0.12	108.43 ± 1.47	0.81 ± 0.04	0.16 ± 0.01	0.07 ± 0.01	1.66 ± 0.03	16.65 ± 0.09	8.57 ± 0.02	14.78 ± 0.23	13584 ± 147.28	8.82 ± 0.08
TS 25	34	78°54′.002″N 12°17′.287″E	6.85 ± 0.27	166.22 ± 2	1.89 ± 0.07	0.28 ± 0.01	0.17 ± 0.01	0.11 ± 0.01	49.23 ± 0.31	13.68 ± 0.16	20.02 ± 0.22	24092 ± 328.12	13.14 ± 0.22
CT	5–10cm	78°48′.613″N 11°43′.575″E	10.24 ± 0.06	137.52 ± 0.15	0.92 ± 0.01	0.12 ± 0.01	0.2 ± 0.02	0.01 ± 0.00	38.7 ± 0.05	12.68 ± 0.09	24.26 ± 0.23	18013 ± 14.1	21.06 ± 0.3
CM	50–60cm		23.46 ± 0.64	135.47 ± 0.27	1 ± 0.01	0.10 ± 0.01	0.35 ± 0.04	3.06 ± 0.01	207.53 ± 1.3	32.98 ± 0.32	28.7 ± 0.13	29425 ± 207	6.91 ± 0.17
CB	120–30cm		10.75 ± 0.43	131.4 ± 0.59	1.76 ± 0.02	0.15 ± 0.01	0.17 ± 0.03	3.11 ± 0.01	33.46 ± 0.14	11.76 ± 0.09	31.77 ± 0.37	22325 ± 13.7	14.29 ± 0.05

Table 1. Continued.

Sampling point	**Li** (mg/kg)	**Mn** (mg/kg)	**Ni** (mg/kg)	**Rb** (mg/kg)	**Ag** (mg/kg)	**Sr** (mg/kg)	**Tl** (mg/kg)	**U** (mg/kg)	**V** (mg/kg)	**Zn** (mg/kg)
B	39.12 ± 0.26	263.26 ± 1	34.95 ± 0.09	63.3 ± 0.3	0.14 ± 0.01	97.75 ± 0.06	0.33 ± 0.01	0.93 ± 0.02	108.42 ± 0.25	117.72 ± 3.57
C	45.26 ± 0.29	246.13 ± 2.73	32.89 ± 0.38	98.26 ± 1.08		110.68 ± 0.8	0.53 ± 0.01	1.5 ± 0.01	130.3 ± 2.2	96.56 ± 0.88
D	38.39 ± 0.59	209.31 ± 2.16	28.83 ± 0.15	65.97 ± 0.61		120.06 ± 1.11	0.38 ± 0.00	1.29 ± 0.03	111.37 ± 0.7	88.31 ± 1.17
KB0	34.88 ± 0.36	360.61 ± 0.71	31.46 ± 0.43	47.88 ± 0.16	0.39 ± 0.01	80.05 ± 0.35	0.29 ± 0.01	1.48 ± 0.01	103.27 ± 0.81	100.93 ± 0.44
KB2	27.78 ± 0.17	330.71 ± 2.5	27.36 ± 0.16	51.32 ± 0.31		73.79 ± 0.31	0.29 ± 0.01	1.77 ± 0.01	78.73 ± 0.7	86.01 ± 0.46
KB3	39.55 ± 0.07	466.84 ± 3.27	32.98 ± 0.22	89.78 ± 0.54		81.1 ± 0.32	0.52 ± 0.01	1.71 ± 0.01	101.79 ± 0.71	108.01 ± 0.59
V-1	28.21 ± 0.29	332.87 ± 0.9	27.29 ± 0.47	67.45 ± 0.44		85.87 ± 0.14	0.4 ± 0.01	1.52 ± 0.02	52.9 ± 0.15	86.27 ± 0.85
E-4	48 ± 0.31	264.01 ± 0.8	33.86 ± 0.5	87.95 ± 0.36		86.79 ± 0.29	0.47 ± 0.01	1.70 ± 0.02	132.06 ± 0.6	111.8 ± 0.87
M-12	41.01 ± 0.55	308.51 ± 2.38	32.82 ± 0.25	96.72 ± 0.56	0.13 ± 0.00	87.48 ± 0.63	0.53 ± 0.01	1.90 ± 0.01	94.75 ± 0.69	110.45 ± 1.14
TS 13	53.08 ± 1.0	280.71 ± 1.23	33.95 ± 0.33	90.84 ± 0.35		80.47 ± 0.14	0.43 ± 0.01	1.70 ± 0.01	130.16 ± 0.34	115.73 ± 0.27
TS 14	48.66 ± 0.36	457.23 ± 2.64	36.19 ± 0.42	114.84 ± 0.84		69.77 ± 0.42	0.55 ± 0.01	1.31 ± 0.03	90.13 ± 0.55	132.32 ± 0.44
TS 15	42.53 ± 0.26	288.44 ± 2.32	31.36 ± 0.14	86.31 ± 0.79		78.88 ± 0.73	0.43 ± 0.02	1.83 ± 0.05	100.42 ± 0.9	96.23 ± 1.00
TS 16	42.27 ± 0.91	347.16 ± 3.01	32.6 ± 0.43	98.09 ± 0.86	2.79 ± 0.06	88.14 ± 0.72	0.50 ± 0.01	1.51 ± 0.02	83.15 ± 0.21	106.27 ± 0.21
TS 17	28.57 ± 0.31	318.1 ± 0.66	24.07 ± 0.25	60.56 ± 0.14	2.81 ± 0.08	71.49 ± 0.32	0.31 ± 0.01	1.18 ± 0.01	52.34 ± 0.5	88.63 ± 0.40
TS 18	40.17 ± 0.38	326.2 ± 0.14	29.06 ± 0.16	97.26 ± 0.24	2.86 ± 0.02	81.79 ± 0.25	0.48 ± 0.00	1.51 ± 0.03	91.13 ± 0.32	103.79 ± 0.43
TS 19	52.1 ± 0.4	265.97 ± 0.86	32.46 ± 0.17	90.52 ± 0.5	3.26 ± 0.02	102.32 ± 0.47	0.43 ± 0.01	1.24 ± 0.02	133.03 ± 0.51	104.19 ± 0.77
TS 20	45.58 ± 0.3	250.35 ± 64.03	28.63 ± 0.17	73.16 ± 0.23	3.06 ± 0.08	129.02 ± 0.22	0.37 ± 0.00	1.32 ± 0.01	116.46 ± 0.21	84.71 ± 0.67
TS 21	37.48 ± 0.28	351.08 ± 1.13	32.56 ± 0.33	75.16 ± 0.46	3.09 ± 0.05	79.65 ± 0.12	0.39 ± 0.00	1.38 ± 0.01	71.44 ± 0.29	113.44 ± 0.68
TS 22	42.15 ± 0.16	240.28 ± 0.21	28.32 ± 0.36	87.06 ± 0.38	2.89 ± 0.08	88.33 ± 0.42	0.42 ± 0.01	1.22 ± 0.02	108.78 ± 0.99	86.79 ± 0.85
TS 23	40.68 ± 0.34	337.44 ± 2.6	32.65 ± 0.23	91.28 ± 0.87		78.96 ± 0.53	0.47 ± 0.01	1.59 ± 0.01	86.89 ± 1.16	112.7 ± 1.89
TS 24	12.87 ± 0.09	230.56 ± 2.74	13.92 ± 0.02	33.39 ± 0.31		10.84 ± 0.15	0.19 ± 0.01	0.82 ± 0.03	25.94 ± 0.08	61.73 ± 0.35
TS 25	35.88 ± 1.02	371.76 ± 4.04	31.81 ±	80.19 ± 1.36		82.73 ± 1.19	0.42 ± 0.01	1.25 ± 0.01	63.54 ± 0.41	105.51 ± 1.87
CT	17.18 ± 0.2	445.59 ± 0.92	43.28 ±	34.91 ± 0.25		14.47 ± 0.09	0.21 ± 0.01	0.22 ± 0.01	39.25 ± 0.14	91.04 ± 0.48
CM	39.46 ± 0.07	547.45 ± 3.27	31.30 ± 0.19	35.51 ± 0.05		64.19 ± 0.18	0.17 ± 0.01	0.23 ± 0.02	69.96 ± 1.01	67.91 ± 0.37
CB	32.34 ± 0.43	461.03 ± 1.12	30.95 ± 0.05	64.89 ± 0.27		152.91 ± 0.53	0.33 ± 0.01	0.7 ± 0.02	55.23 ± 0.17	114.52 ± 0.59

Results and discussion

The sediments around Brøggerhalvøya were analysed for elements belonging to the alkali metal group such as Cs, Li and Rb; alkaline earth metal group such as Be, Ba and Sr; transition metal group such as Ag, Cd, Co, Cr, Cu, Fe, Mn, Ni, V, and Zn; other metal group such as Bi, Pb and Tl; non-metal group such as As; and Actinide element such as U. Their concentrations in each of the locations are given in Table 1 together with standard deviations based on triplicate readings. In the sediment samples studied, the elements were present in variable concentrations (Figs 2, 3) on both sides of the peninsula. Although no comparative studies have been published for the region, a study by Larsen and others (2001) in the Maarmorilik region of west Greenland observed that the levels of zinc and lead in the surrounding fjord systems were high affecting the marine biota of the area. In another study on local pollution and glacier induced sedimentation in two fjords of Svalbard (Adventfjord and Grønfjord) it was observed that the concentration of polycyclic aromatic hydrocarbons and chlorinated hydrocarbons was several times higher than the background values as a result of terrestrial water drainage and industrial activities (Holte and others 1996).

Elemental concentration at different locations on Kongsfjorden and Forlandsendet side of Brøggerhalvøya

The average values of elements in decreasing order of concentration in the Kongsfjorden side of Brøggerhalvøya were Fe> Mn> Ba > V > Zn > Sr > Rb > Cr > Li > Ni > As > Pb > Cu > Co > Cs >Ag > Be > U> Bi >Tl > Cd (Table 1). Nineteen sampling sites (KB-0, KB-2, KB-3, V-1, E-4, M-12 and TS13 to TS25) at Kongsfjorden side of Brøggerhalvøya showed variability in concentration of different elements (Table 1).

Three sampling sites (B, C and D) are located in water at the opposite side of Brøggerhalvøya facing towards Forlandsendet. The elements in decreasing order of their concentration on the Forlandsendet side of Brøggerhalvøya were Fe > Ba >Mn > V> Sr > Zn > Rb > Cr > Li > Ni > Pb > Cu > As > Co > Cs > Be > U> Tl > Bi > Cd (Table 1).

The coastal outcrop on the Forlandsendet side of Brøggerhalvøya has elements in decreasing order of concentration: Fe > Mn > Cr > Sr > Ba > Rb > Cr > Zn > V > Rb > Ni > Li > Co > Cu > As > Pb > Cs > Be > Cd > Tl > U > Bi (Table 1). The levels of the metals varied in the top layer (recent), the middle (12,496BP), and the bottom layer (42,500BP) in this coastal outcrop (Table 1).

The distribution of metals on both side of Brøggerhalvøya is influenced by many factors such as microbial activity, different water masses, glacier activity, ice cover in the area and mountain terrain. The melt water and inorganic particles are mainly accumulated in Kongsfjorden due to glacier activities (Svendsen and others 2002). The sampling site V-1 is close to the Kronebreen and Kongsvegen glaciers, where the sedimentation rate is very high. Though the sampling sites KB-3, TS-14 and TS-19 are located away from direct runoffs from the glaciers, the higher metal concentrations at these sites may be due to factors such as different scientific-logistics activities at Ny-Alesund harbor, bacterial activity, deposition of eroded materials from Blomstrandhalvøya and mountainous areas. The site KB0, located out of Kongsfjorden area, showed comparatively lower concentrations of metals than the other sites in the inner part of Kongsfjorden.

Distribution of trace metals and its comparison with previous studies

In the current study, the concentration of trace metals in Kongsfjorden range from 0.07 to 0.35 mg/kg for Cd, 16.65 to 78.54mg/kg for Cr, 8.57 to 17.35 mg/kg for Co, 14.78 to 24.86 mg/kg for Cu, 8.82 to 26.82 mg/kg for Pb, 230.56 to 457.23 mg/kg for Mn, 13.92 to 36.19 mg/kg for Ni and 61.73 to 132.32 mg/kg for Zn (Table 1). The concentrations of the elements varied at different locations in Kongsfjorden.

The concentrations of trace metals in the Forlandsendet side of Brøggerhalvøya are 0.17 to 0.19 mg/kg for Cd, 57.41 to 74.77 mg/kg for Cr, 8.33 to 10.69 mg/kg for Co, 18.2 to 22.84 mg/kg for Cu, 19.29 to 22.95 mg/kg Pb, 209.31 to 263.26 mg/kg for Mn, 28.83 to 34.95 mg/kg for Ni, and 88.31 to 117.72 mg/kg for Zn, respectively (Table 1). The trace metal concentrations at the coastal outcrop ranged from 0.17 to 0.35 mg/kg for Cd, 33.46 to 207.53 mg/kg for Cr, 11.76 to 32.98 mg/kg for Co, 24.26 to 31.77 mg/kg for Cu, 6.91 to 21.06 mg/kg for Pb, 445.59 to 461.03 mg/kg for Mn, 30.95 to 43.28 mg/kg for Ni and 67.91 to 114.52 mg/kg for Zn, respectively (Table 1).

The Kongsfjorden side of Brøggerhalvøya has higher levels of trace metals (Cd, Cr, Co, Cu, Pb, Mn, Ni, Zn) than the three sites (B, C and D) on the Forlandsendet side of Brøggerhalvøya. However, other trace metals (Cd, Cr, Co, Cu, Mn, Ni, and Zn) except lead (Pb) are highest in the coastal out crop.

AMAP Assessment 2002 (AMAP 2005) focused on Hg, Pb and Cd which are hazardous to living organisms in the Arctic. In the current study, higher concentrations of Pb and Cd were recorded at site E-4 and TS-13, respectively. The concentrations of Cd and Pb determined in the present study are lower than the data from Chukchi Sea (Ma and others 2008). Cu, Pb and Zn concentrations were lower than the data previously reported in other Arctic areas such as Alaska (AMAP Assessment 2002), Laptev Sea (Holemann and others 1999), Kongsfjorden (Lu and others 2012) and Cryoconites, Svalbard (Singh and others 2012). The concentration of Cr was also found to be lower than previous studies at Kongsfjorden (Lu and others 2012), Beaufort Sea (Sweeney and Sathy-Naidu 1989), Chukchi Sea (Shang 2008; Ma and others 2008), East Siberia Sea (Presley 1997), East Greenland (Naidu

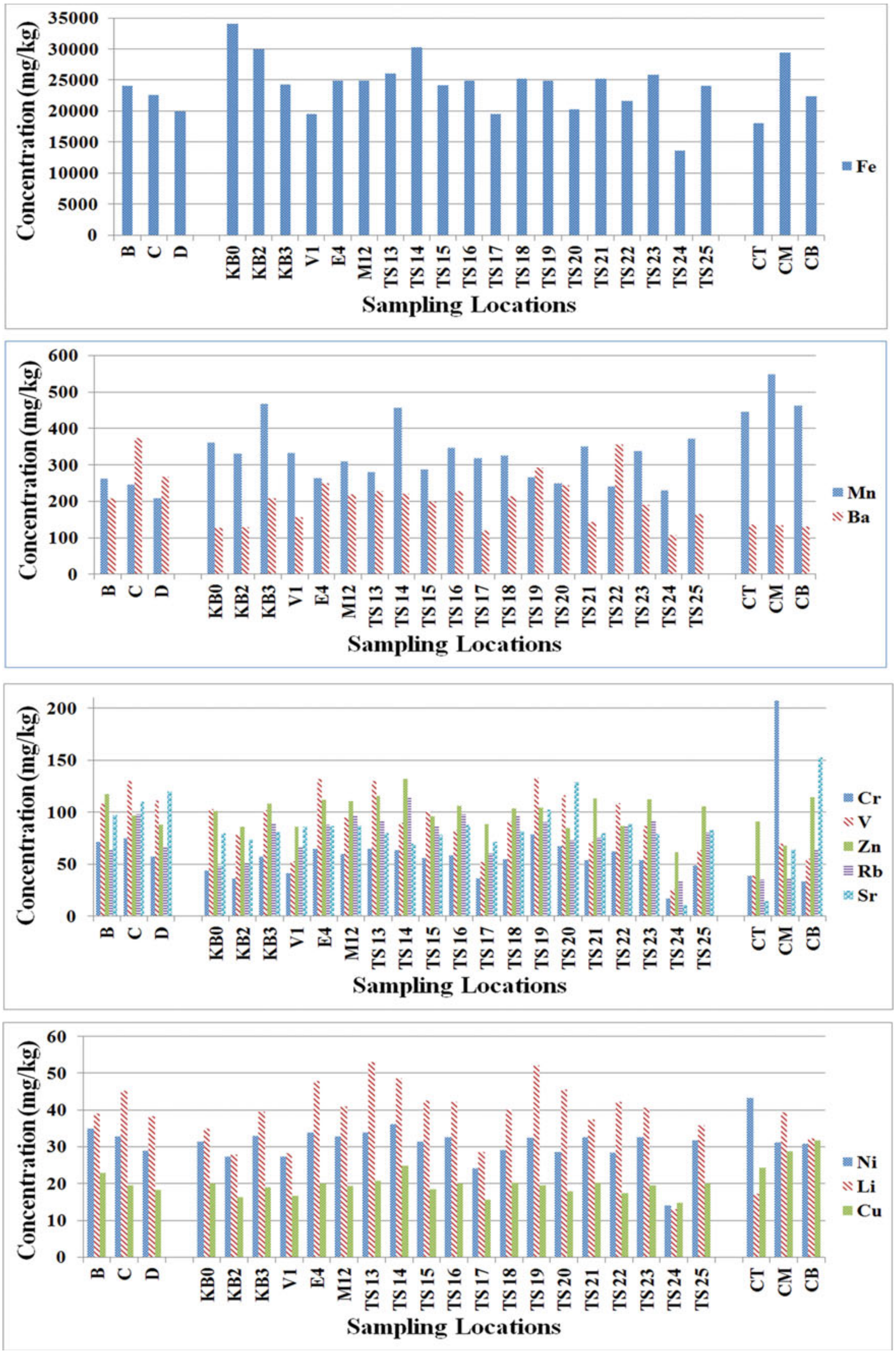

Fig. 2. Elemental concentrations of Fe, Mn, Ba, Cr, V, Zn, Rb, Sr, Ni, Li and Cu.

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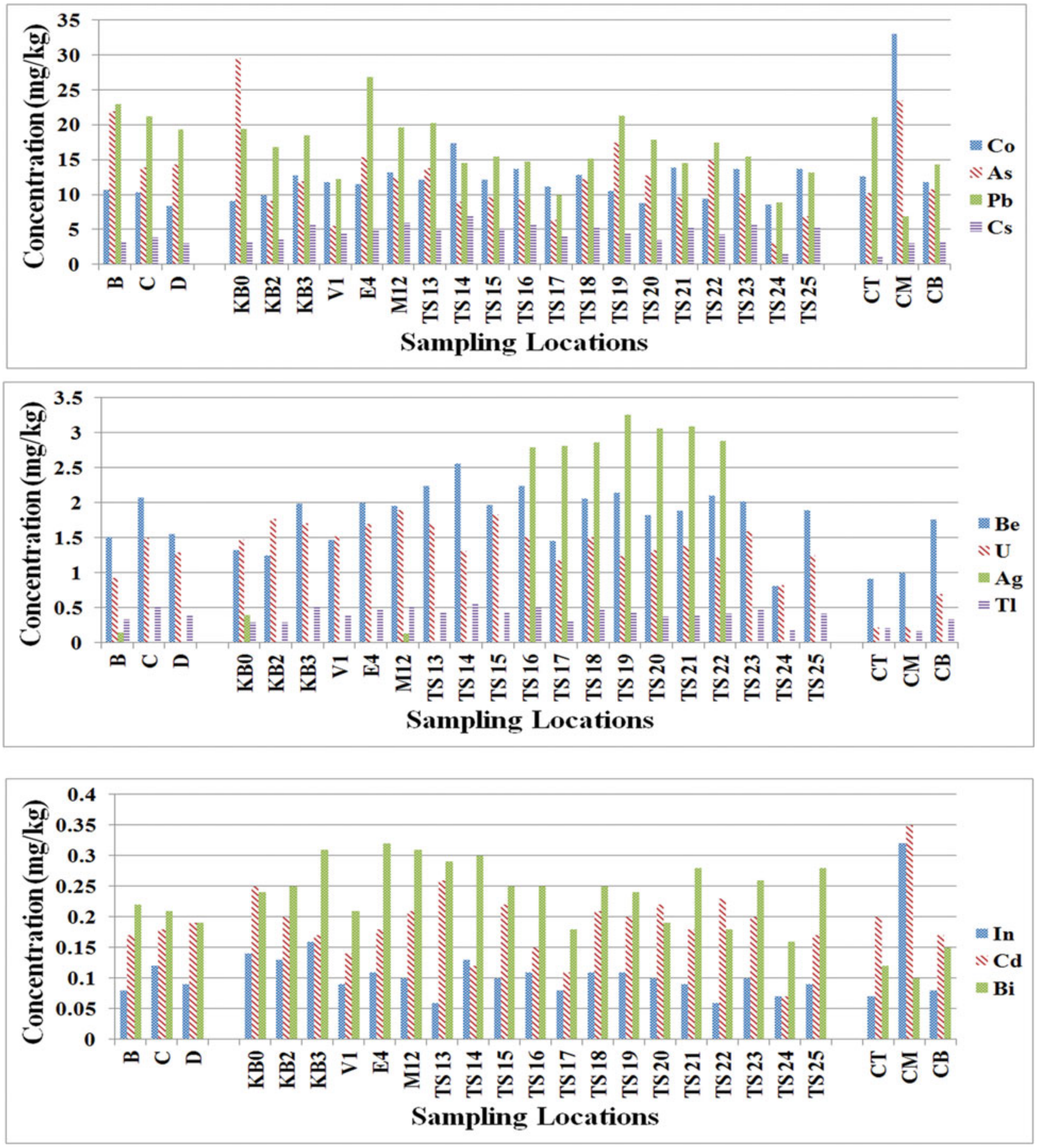

Fig. 3. Elemental concentrations of Co, As, Pb, Cs, Be, U, Ag, Tl, In, Cd and Bi.

and others 1997), Kara Sea (Esnough 1996), Laptev Sea (Holemann and others 1999) and Pechora Sea (Loring and others 1995).

In the present study Cr, and Cu are lower than reported from the northeastern Chukchi Sea (Naidu and others 1997), Beaufort Sea inner shelf (Sweeney and Sathy-Naidu 1989), Laptev Sea (Holemann and others 1999) and Kongsfjorden (Lu and others 2012) (Table 2). Compared to the current study the base line data of terrestrial habitats (glacier ice core and lichens) of Svalbard (Singh and others 2012, 2013) showed lower concentrations of metals. Lu and others (2012) reported higher concentration of three trace metals (Cr, Cu and Pb) in the sediments of Kongsfjord and concluded that probably the west Spitsbergen current (WSC) brings Pb from low and middle latitudes to the Arctic.

Crustal enrichment factors

To evaluate the contribution of the elements from natural sources the crustal input values were calculated using Fe as a reference element. The mean metal to Fe ratio was used to determine the percent contribution by individual

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Table 2. Comparison of the present study with published data at different habitats of Arctic.

Study area	**Cd** (mg/kg)	**Cr** (mg/kg)	**Cu** (mg/kg)	**Pb** (mg/kg)	**Zn** (mg/kg)	References
Kongsfjorden and Forlandsendet side of Brøggerhalvøya	0.19	60.13	20.22	16.71	99.66	Present study
Kongsfjorden, Svalbard	0.19	64.70	26.40	22.60	85.50	Lu and others (2012)
Svalbard Lichens	0.030	4.76	7.54	16.29	46.26	Singh and others (2012)
Svalbard Cryoconites	0.08	57.85	41.47	66.50	141.50	Singh and others (2012)
Svalbard Icecore*	0.0085	0.0343	3.46	0.0046	11.35	Singh and others (2013)
Alaska, Port Valdez, Mineral Creek Flats	0.11	–	70	18	170	AMAP Assessment (2002)
Alaska, Unakwit Inlet, Siwash Bay	0.08	–	49	18	120	
Beauford Sea	–	89	33	–	98	Sweeney and Sathy-Naidu (1989)
Chukchi Sea	0.22	81	81.10	14	89	Shang (2008)
Chukchi Sea	0.21	87.50	19.40	19.80	111	Ma and others (2008)
Chukchi Sea	0.24	27.20	13.60	4.40	84.90	Wang (2009)
East Siberia Sea	0.10	61.50	15.90	20.30	85	Presley (1997)
Greenland (east)	–	117	50	–	92	Naidu and others (1997)
Greenland (east)	0.11	–	46	19	89	Loring and Asmund (1996)
Greenland (west)	0.15	–	49	18	77	
Kara Sea	0.09	97.10	27	14	80	Esnough (1996)
Laptev Sea	0.11	–	19	20	92	Holemann and others (1999)
Laptev Sea (Siberia)	0.08	92	26	21	111	
Northeast of Chukchi Sea		82	22	–	79	Naidu and others (1997)
Pechora Sea	0.11	110	21	18	84	Loring and others (1995)

*Ice core values are in (μg/kg)

metals using standard continental crustal values as described by Shaw and others (1967, 1976) based on studies on the Canadian Precambrian shield. For elements Ag, As and Cs, as no estimate was available in Shaw and others (1967, 1976), baseline data of upper continental crust as recommended by Rudnick and Gao (2003) were considered. Providing appropriate space for variation in the crustal composition, the enrichment factors within the range 0.1 to 10 were considered as a contribution from crustal source while those above 10 were considered as enriched from other natural and/or anthropogenic sources in addition to the crustal material (Dasch and Wolff 1989; Veysseyre and others 2001). The mean crustal enrichment factor (EF) values of all metals at each sampling location have been graphically represented (Fig 4). Results indicate that most of the elements were sourced from crustal inputs with no enrichment by anthropogenic sources.

In the present study, it is observed that the major crustal input of elements in the sediment samples probably comes from the glacial discharge along both the sides of the peninsula. Large numbers of glaciers, present on the peninsula, are highly sensitive to climate change (Fleming and others 1997; Nowak and Hodson 2013). Recent global warming events have caused considerable melting of the glaciers leading to draining down of huge amounts of glacial ice into the adjacent waters along with terrestrial sediments. Fjords being an important sink of these wash down materials from the glaciers and river erosion result in accumulation of the sediments in basins. The inputs from the large tidal glaciers create steep environmental gradients in sedimentation along the length of the water body.

Bacterial deposition

In the present study, bacterial count in the sediment samples was investigated through enumeration by both direct and culturable methods. The total cell counts varied from 3.30×10^5 to 3.02×10^6 per g soil sediment. These values were comparable to that reported by Junge and others (2002) in the Arctic sea ice (5.4×10^4 to 2.4×10^6 cells/ml) and that reported by Amato and others (2007) from nearby Kongsvegen glacier (2×10^5 cells/ml).

The culturability of the bacterial cells varied on the two sides of the peninsula. It was between 5 to 54% on the Forlandsendet side of Brøggerhalvøya and between 0.01 to 0.69% on the Kongsfjorden side of

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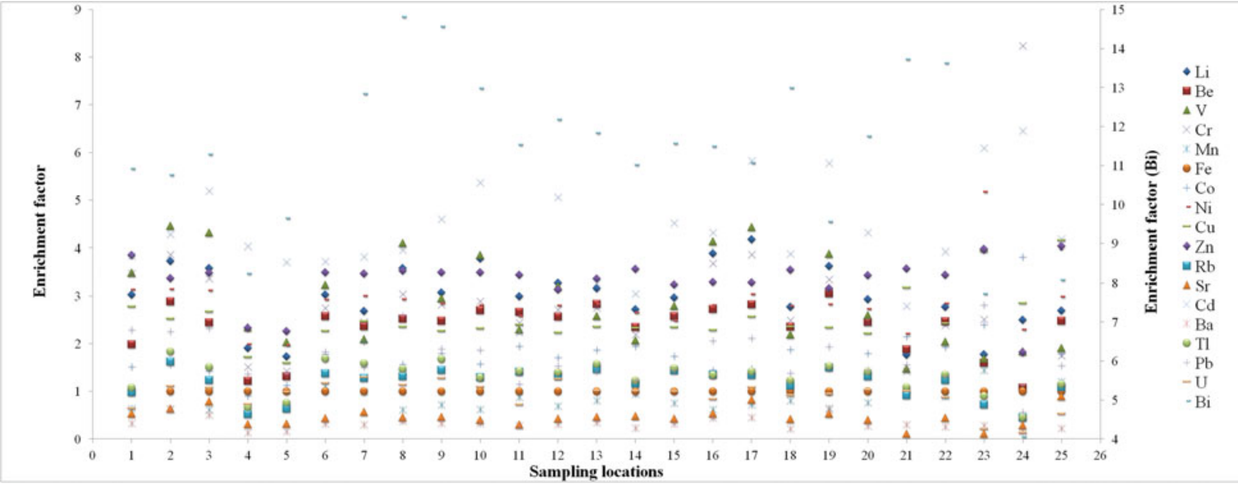

Fig. 4. Mean crustal enrichment factors for the different metals at different sampling locations 1–25 (B = 1, C = 2, D = 3, KB0 = 4, KB2 = 5, KB3 = 6, V1 = 7, E4 = 8, M12 = 9. TS 13 to TS 25 correspond to locations 10 to 22 respectively. CT = 23, CM = 24,CB = 25)

Brøggerhalvøya. It is noteworthy that the Forlandsendet side is the less disturbed coast of the Brøggerhalvøya, compared to the Kongsfjorden side of the peninsula which has more tourism, sampling and research activities. Srinivas and others (2009) have also observed that bacterial viable counts varied only marginally ($0.5 \times 10^3 - 1.3 \times 10^4$ cfu/g sediment) in the sediments from the innermost point Kongsfjorden to the outermost point. Bacterial activity and sediment composition has mutual effects. The role of bacteria in degradation of massive sulphides has been studied at Citronen fjord, north Greenland (Langdahl and Elberling 1997). Bacteria play a major role in ecosystem functioning (Fenchel 2011) through biogeochemical cycles of N and C. Therefore the study on sediment properties and bacteria together has an ecological significance. Pathways of carbon oxidation in fjord sediment of Svalbard are mainly by Fe (III)-reducing bacteria (Vandieken and other 2006). The concentration of Fe is highest on Kongsfjorden, Forlandsendet and at the coastal outcrop than other elements, this indicate that possibly Fe (III)-reducing bacteria are mainly responsible for such contribution.

Conclusion

The present work, based on calculation of the enrichment factors for various elements, provides evidence that the sediments in the waters adjacent to the Brøggerhalvøya peninsula contain elements solely of crustal origin. These sediments have probably been deposited there from adjoining landmasses by the process of glacier weathering and microbial activities. Iron was the most abundant element in all the sites followed by Mn, Ba, Cr and others. Probably Fe and Mn reducing bacteria are mainly responsible for mineralisation in Svalbard. The bacterial concentration in these sediments is high with percent culturability values lower on the Kongsfjorden side than the other side of the peninsula. The study also confirms that the environment indeed contains these elements that have accumulated over a period of time. Future studies needs to be carried out to secure a better insight of microbial diversity and biogeochemical cycle of the region. This is NCAOR contribution no. 02/2015.

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