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Threshold response of benthic macrofauna integrity to metal contamination in West Greenland

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ABSTRACT

Sediment metal chemistry and benthic infauna surveys have been conducted over 33 years following a BACI protocol in relation to submarine tailings deposition (STD) from a lead–zinc mine in a western Greenland fjord system. We found clear predictable changes of benthic fauna composition in response to STD both temporally and spatially. Faunal re-colonization 15 years after mine closure, was slow and the impacted areas were still dominated by opportunistic species, although the most opportunistic ones (e.g. *Capitella* species) had decreased in importance. Concentration-response relations between sediment lead and faunal indices of benthic community integrity (e.g. the AMBI and DKI indices) indicated a threshold of ca. 200 mg/kg, above which deterioration of faunal communities occurred. Above this threshold, diversity decreased dramatically and dominance of sensitive and indifferent species was substituted by tolerant or opportunistic species. Disposal of metal contaminated tailings may have long lasting effects on the biological system.

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1. Introduction

Structure of benthic invertebrate communities, measured as diversity and species composition in terms of sensitivity/tolerance, is often used as indicators of benthic ecological quality (Pearson and Rosenberg, 1978; Borja et al., 2000). The schemes of succession in relation to disturbance described by Pearson and Rosenberg (1978) were based largely on experience from organic impacts and primarily from temperate sea areas. Recent work, however, indicate that these successions also may occur in response to several different pressures (Borja et al., 2000; Muxika et al., 2005).

The response of benthic fauna community structure like species richness to environmental impact is often non-linear, that is the rate of community change increases above a threshold value of the impact factor. While threshold effects on community levels are fairly well documented with respect to oxygen deficiency (e.g. Diaz and Rosenberg, 1995; Levin and Gage, 1998) and organic sediment load (Hyland et al., 2005) from several environments at different latitudes, there are few examples of such impact from contaminants like heavy metals (but see Burd, 2002), and virtually none from arctic environments.

Submarine tailings deposition (STD) from mining, is a major source of impact on the marine coastal environment, and may damage benthic faunal communities either through smothering or by toxic influence by the contaminants in the tailings like heavy metals, or both (Ellis and Hoover, 1990; Burd et al., 2000; Burd, 2002). Effects on benthic fauna and the subsequent recovery from such impacts have been described from some temperate fjord systems (Burd et al., 2000; Burd, 2002). Unlike for instance urban runoff, where it may be difficult to separate effects of organic load from contaminants (Morrisey et al., 2003), tailings from mining typically have a very low organic content, being crushed rock material. Therefore, examination of the effects of STD may be a way to specify effects in nature of metal pollution.

Here we examine effects of submarine tailings deposition (STD) on benthic invertebrate community structure in an Arctic fjord system, where the tailings contained high concentrations of metals, mainly lead and zinc and to some extent copper. Environmental studies were conducted in the area since 1972 monitoring lead and zinc in seawater, sediments and several marine species, together with benthic invertebrate faunal structure (Asmund and Johansen, 1999; Johansen and Asmund, 1999; Johansen et al., 2006). A major impact on the environment was due to STD, although there were other metal pollution sources like rock dumping and spreading of dust from ore crushing.

Pre-mining conditions in this system may be considered pristine, since background levels of metals in the sediment before mining were comparable to other unpolluted areas, and since human impact through pollution or fishing in this sparsely populated region may be considered very low. The monitoring program in Maarmorilik, thus, gave the opportunity to assess impact of STD

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and metal contamination on benthic community structure, and to "test" the succession schemes of benthic macrofauna developed mainly from organic impacts, in a metal gradient without confounding effects of organics or oxygen deficiency.

2. Materials and methods

2.1. Study area

The area of study comprise two interconnected fjord arms, Affarlikassa and Quaamarujuk, hereafter called A-fjord and Q-fjord, respectively, located in the inner part of the Uummannaq fjord system in West Greenland (Fig. 1). The A-fjord, with a maximum water depth of some 70 m, is connected to the larger Q-fjord and delimited from it by a sill at 25 m depth. Salinity in the bottom water of benthic faunal stations varies typically between 31 and 34 psu, the O_2 content in the fjords is mostly above 10 mg/l, and temperatures vary between −2 and +5 °C. Sediment texture at most benthic stations were silty mud (i.e. <60 μm, Bondam, 1978). Background sediment levels of the trace elements Pb and Cu were similar between the A-fjord and the Q-fjord, ca 25 and 35 mg/kg, respectively. Zn background was slightly elevated in the A-fjord, ca 200 mg/kg, compared to the Q-fjord, ca 150 mg/kg (Bondam, 1978). The natural sedimentation rate, determined by Pb210 dating, in the deeper part of A-fjord was around 0.5 cm p.a. (Elberling et al., 2002).

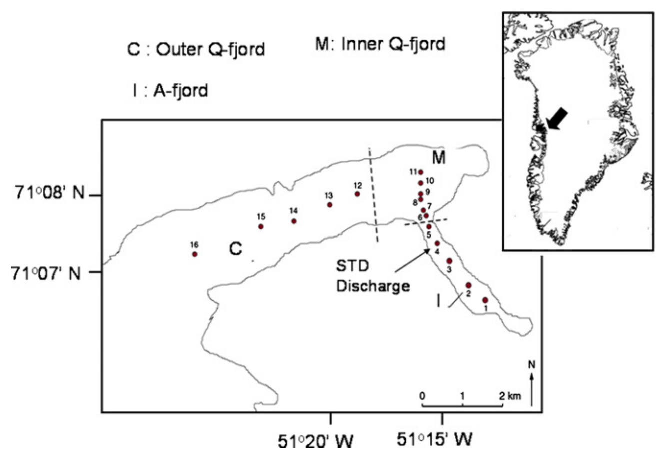

Fig. 1. Map over the investigation area at Maarmorilik with positions of 16 benthic faunal stations. Borders between the three areas with different impact are indicated by dashed lines. The border between the highest impacted area, Affarlikassaa (I) and the middle field area, Indre Quaamarujuk (M) is on the top of the sill at 25 m water depth. The disposal point for tailings was at 30 m depth close to station 4.

Lead and zinc ore was mined from 1973 to 1990 at the Black Angel Mine, (Fig. 1). In a processing plant located at Maarmorilik at the mouth of Affarlikassaa, metal concentrates were produced leaving fine-grained tailings mainly composed of marble and pyrite (iron disulfide, FeS_2) and with concentrations of the metals: lead, zinc, cadmium, copper, arsenic and mercury (Poling and Ellis, 1995; Asmund and Johansen, 1999; Elberling et al., 2002). Of these metals, lead and zinc occurred with by far the highest concentrations. The grain size of the tailings was similar to fine sand, i.e. 60 μm and coarser. The tailings were pumped through a pipe from the plant out into the smaller of two fjord arms, A-fjord, and discharged subsurface at 30 m depth south of the sill between this arm and the Q-fjord (Fig. 1). From this point, tailings subsequently spread to deeper parts primarily in the A-fjord, and formed a several cm thick layer on the sea floor. The mining activities and STD in particular, created steep metal gradients, both temporally and spatially, with sediment concentrations from background level to several thousands of mg/kg of lead and zink.

Measurements of tailings thickness and oxygen concentrations in the bottom water at 11 sites in the A-fjord in 1975 two years after start of the discharge showed no effect of tailings thickness on oxygen levels (minimum concentration at station 4 of 8.1 mg/l), although this was suspected due to the high sulphide content (FeS_2 pyrite) of the tailings. Tailings layers thicker than 5 cm were restricted to the deeper parts of the A-fjord within 2 km from the point of discharge. STD thickness at the most distant stations in A-fjord, No. 1 and 2 was 0–2 cm, while thickness close to the discharge at station 4 was more than 80 cm at this stage.

2.2. Sampling scheme

Tailings deposition (STD) started in September 1973 and ended in 1990. The monitoring of benthic macrofauna following a BACI design, started before the STD disposal activities (1972 and July 1973), comprised three samplings during the disposal (1975, 1981 and 1984), and one sampling 15 years after the closure of the mine in 1990 (2005). Sampling was made at some 16 stations

Table 1
Benthic fauna stations with positions, water depth and sampling information

Station	Lat N	Lon W	Water depth (m)	Zone	1972*	1973*	1975	1981	1984	2005
1	7106.4	5114.0	55	I	1	1	3	2		3
2	7106.7	5114.8	54	I		1	3	3	2½	3
3	7107.0	5115.0	72	I	1	1	3**	3**		3
4	7107.4	5116.0	70	I	1	1	3**	3**		3
5	7107.6	5116.5	25	I			3	6		3
6	7107.7	5116.4	29	M			2	6		3
7	7107.8	5116.5	50	M	3		3	5	8	3
8	7107.9	5116.5	90	M			3	6	8	3
9	7108.0	5116.5	110	M			3	5	8	3
10	7108.1	5116.8	116	M			3			3
11	7108.4	5117.4	202	M		1	3	8	7	3
12	7107.9	5119.3	180	C	1					3
13	7107.8	5120.4	202	C		1	3	9	8	3
14	7107.5	5121.6	204	C	1	1	3	9	8	3
15	7107.5	5123.4	222	C		1	3	4	8	3
16	7107.2	5125.3	205	C	5	1	3		8	3

* Nr of pooled Van Veen samples ($3 \times 0.1\ m^2$).
** Samples devoid of macrofauna.
Stations were partitioned into three impact zones: The main impact zone, Affarlikassa (I), an intermediate zone, Inner Quaamarujuk (M) and a control zone, Outer Quaamarujuk (C). Apart from 1972 and 1973 when only pooled samples were available, figures denote number of Van Veen grabs taken.

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