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Data sheet

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Abstract: This report compiles information about and assesses the environmental impact of the former lead-zinc mine at Mestersvig to document the present state of the environment in areas affected by the mining operation. The report has been prepared on the request by International Molybdenum PLC (InterMoly), who is exploring the molybdenum deposit at Malmbjerget to the south of Mestersvig. The preparation of the report is funded by InterMoly as part of environmental studies initiated to prepare an environmental impact assessment report of the Malmbjerget project.
The report documents that the former mine that was in operation from 1956 to 1963 has caused a significant pollution with lead and zinc on-land, in a river and in Kong Oscars Fjord. Mine tailings and spill of concentrate are the main pollution sources. Areas at the mine site have been monitored since 1979.

Keywords: Mestersvig, lead, zinc, mining, pollution

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Contents

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Summary

At Mestersvig, East Greenland the Danish company Nordisk Mineselskab operated a lead-zinc mine from 1956 to 1963. The mine was underground, located c. 10 km inland from Kong Oscars Fjord. 554,000 tonnes of ore was mined, and 58,000 tonnes of lead concentrate and 75,000 tonnes of zinc concentrate produced. A road was constructed between the site and the fjord, where concentrate was shipped out. Tailings from the concentrator were discharged at the mine on a nearby mountain slope, from where most has slid into the river Tunnelelv flowing to Kong Oscars Fjord.

The first environmental studies at Mestersvig were conducted in 1979. They showed that there were high levels of lead and zinc in the sediments of Tunnelelv and in the river delta at Kong Oscars Fjord. Also high concentrations of dissolved and particulate lead and zinc were found in the water of Tunnelelv downstream the mine. In lichens elevated zinc and lead levels were found up to 10 km from the mine site, demonstrating that some airborne transport of metals had taken place. The most significant impact was found in brown seaweed from the intertidal zone. Elevated lead and zinc levels were found on a significant part of the south coast of Kong Oscars Fjord. The heavy metal pollution of the fjord originates from three main areas: The northern and the southern delta of Tunnelelv and the harbor area in-between reflecting the transport of tailings in Tunnelelv and the spill of concentrate at the quay in Nyhavn.

Further environmental studies of biota were conducted in 1985, 1991, 1996 and 2001, and they included seaweed in all cases. In 1985 also bivalves were included, and so were fish and seals in 1991. Fish were also sampled in 2001. These studies showed that cadmium and copper were not elevated in marine biota, and that zinc was only elevated in seaweed, whereas lead was elevated in several species, including three bivalve species and the liver and bone tissue of sculpin. In seals levels were not higher in Kong Oscars Fjord than elsewhere in Greenland.

In 1985, 1986, 1991 and 2001 studies of beach sand and marine sediments showed that spill of concentrate at Nyhavn and transport of tailings with Tunnelelv had heavily polluted beaches and marine sediments in the southern part of Kong Oscars Fjord.

Both lead and zinc concentrations have decreased since 1979 in the media monitored: sediments, seaweed and fish. However, Kong Oscars Fjord will be affected by heavy metal pollution for many years. Overall levels are expected to decline only at a slow rate, as the contaminated material becomes more and more dispersed and gets mixed up with or covered by non-polluted sediments. Lead and zinc concentrations in the marine environment may be expected to fluctuate with high levels following coastal erosion of major contaminated land areas, especially at the quay, followed by decreasing levels in periods with no erosion.

Sammenfatning

Det danske selskab Nordisk Mineselskab drev en bly-zink mine ved Mestersvig i Østgrønland fra 1956 til 1963. Minedriften fandt sted under overfladen ca. 10 km inde i landet syd for Kong Oscars Fjord. Der blev brudt 554.000 tons malm og produceret 58.000 tons blykoncentrat og 75.000 tons zinkkoncentrat. En vej blev anlagt mellem minen og fjorden, hvorfra koncentraterne blev udskibet. Affaldet (tailings) fra det anlæg, der koncentrerede malmens indhold af bly og zink, blev udledt ved minen på en bjergskråning, hvorfra det meste er skredet ned i elven Tunnelelv, som løber ud i Kong Oscars Fjord.

De første miljøundersøgelser ved Mestersvig blev udført i 1979. De viste, at der var høje koncentrationer af bly og zink i sedimenter fra Tunnelelv og i elvdeltaet ved Kong Oscars Fjord. Der blev også fundet høje koncentrationer af bly og zink (opløst og i form af partikler) i Tunnelelvs vand nedenfor minen. I lavplanter blev der fundet forhøjede værdier af bly og zink op til 10 km fra minen, hvilket viser, at der var sket spredning af bly og zink gennem luften. Den mest omfattende påvirkning fandtes i brunalger i tidevandszonen. Der fandtes forhøjede bly- og zinkværdier på en betydelig del af den sydlige kyststrækning af Kong Oscars Fjord. Tungmetalforureningen af fjorden stammer især fra tre områder: Fra den nordlige og sydlige del af Tunnelevls delta og fra havneområdet (Nyhavn), som ligger mellem elvdeltaerne. Forureningskilderne er tailings, som er transporteret af Tunnelelv, samt spild af bly- og zinkkoncentrat i kajområdet ved Nyhavn.

Der er udført yderligere undersøgelser af organismer fra området i 1985, 1991, 1996 og 2001, og de omfattede brunalger ved alle undersøgelser. I 1985 omfattede undersøgelserne også muslinger og i 1991 tillige fisk og sæler. Undersøgelserne har vist, at cadmium- og kobberværdierne ikke var forhøjet i marine organismer, og at zinkværdierne kun var forhøjet i brunalger. Derimod var blyværdierne forhøjet i adskillige arter, herunder 3 muslingearter og lever- og benvæv fra ulke. I sæler var der ikke højere tungmetalniveauer i Kong Oscars Fjord end i andre grønlandske områder.

Undersøgelser udført i 1985, 1986, 1991 og 2001 viste, at koncentratspild Nyhavn og transport af tailings med Tunnelelv havde medført en omfattende forurening af strandsand og marine sedimenter i den sydlige del af Kong Oscars Fjord.

Både bly- og zinkværdierne har været faldende siden 1979 i de undersøgte medier: sedimenter, brunalger og fisk. Men Kong Oscars Fjord må forventes at være påvirket af tungmetalforurening i mange år ud i fremtiden. Forureningsniveauerne må forventes kun at falde langsomt, efterhånden som de forurenede materialer (tailings og koncentrater) spredes mere og mere og blandes med eller dækkes af ikke-forurenet sediment. Derudover må bly- og zinkværdierne i det marine miljø forventes at variere med højere værdier efter perioder, hvor der sker erosion af forurenede områder, specielt ved kajen, efterfulgt af perioder uden erosion, hvor værdierne vil falde.

Eqikkaaneq

1956-imiit 1963-mut Danskit aatsitassarsioqatigiiffiata Nordisk Mineselskabip Tunumi Mestersvigimi aqerloq zinkilu qallorpaa. Kong Oscars Fjordip kujataata timaani nunap iluagut 10 kilometerinik sulluliornikkut aatsitassat qallorneqarput. Akuigassat 554.000 tonsiusut piiarneqarmata aqerloq akuiariigaq 58.000 tons kiisalu zinki akuiagaq 75.000 tons tunisassiarineqarput. Aatsitassarsiorfimmiit kangerlummi sissamut akuiakkat aallarussorneqartarfiannut aqquserniortoqarpoq. Akuiarnerlukut aqerlumik zinkimillu akuiaaffimmeersut aatsitassarsiorfiup eqqaani sivinganermut iliorarneqarput, tassanngalu amerlanersaat kuummut Tunnelelvimut taaneqartartumut Kong Oscars Fjordimut kuuttumut sarrisimallutik.

Mestersvigip avatangiisiinik misissuinerit siulleq 1979-imi ingerlanneqarput. Taamani paasinarsivoq Tunnelelvip marraa Kong Oscars Fjordimullu akua aqerlumik zinkimillu akulerujussuusut. Aammattaaq aatsitassarsiorfiup ataatungaani Tunnelelvip ernga (arrorsimasunik seqummakuaqqanillu) aqerlumik zinkimillu akulerujussuusut paasinarsivoq. Qillinerit (ujaqqat naaneri) aatsitassarsiorfimmiit 10 kilometerit tikillugit ungasissulik tikillugu aqerlumik zinkimillu akoqarnerulersimapput, tamatumuunalu aqerlup zinkillu silaannakkut siammarsimanerat takuneqarsinnaavoq. Annerpaamik sunnerneqartut tassaapput aappilattut ulittarneraniittut. Kong Oscars Fjordip kujataata tungaata ilarujussua aqerlumik zinkimillu annerusumik akoqarfiulersimavoq. Saffiugassamik oqimaatsumik mingutsitsineq pingaartumik piffinnit pingasunit pisuuvoq: Tunnelelvip akuata avannaata aamma kujataata tungaanit kiisalu umiarsualiveqarfimmit (Nyhavn), kuup akuisa akoranniittumit. Mingutsitsinerup aallaavigisai tassaapput akuiarnerlukut Tunnelelvikkut ingerlaarsimasut, kiisalu umiarsualiveqarfimmi Nyhavniumi aqerlup zinkillu akuiakkat aniasoorutigineqartarsimasut.

Tappavani suut uumassusillit 1985, 1991, 1996 aammalu 2001-mi misissuiffigeqqinneqarput, misissuinernilu tamani aappitaluttut ilanngunneqartarlutik. 1985-imi misissuinermi uillut ilanngunneqarput 1991-imilu aalisakkat puisillu aamma ilanngunneqarlutik. Misissuinikkut paasineqarpoq uumassusillit immarmiut cadmiummimik kanngussamillu akoqarnerulersimanngitsut, aappilattullu kisimik zinkimik akoqarnerulersimasut. Uumasulli allat aqerlumik akoqarnerulersimapput, soorlu uilukkut assigiinngitsut pingasut akoqarnerulersimapput kiisalu kanassut tingui saarngilu aqerloqarnerulersimallutik. Puisit 3 Kong Oscars Fjordimiittut Kalaallit Nunaanni sumiiffinnut allanut sanilliullutik saffiugassamik oqimaatsumik akoqarnerunngillat.

1985, 1986, 1991 aammalu 2001-imi misissuisoqarmat Nyhavnimi akuiakkanit aniasoorutigineqarsimasut akuiarnerlukullu Tunnelelvikkoorussat Kong Oscars Fjordip kujataata tungaani sissami sioqqanik marrarmillu assorsuaq mingutsitsimanerat paasineqarpoq.

Suut unerarfiit 1979-imili misissuiffigineqartartut aqerlumik zinkimillu akuerukkiartorsimapput: marraq, aappilattut aalisakkallu. Kisiannili Kong Oscars Fjord suli ukiorpassuarni saffiugassanit oqimaatsunit mingutsitaanissaa naatsorsuutigisariaqarpoq. Suut mingutsinneqarsimasut (akuiarnerlukut akuiakkallu) siammariartornerat aammalu marrarmik mingutsitaanngitsumik akoorneqarnerat qallernerneqarneralluunniit ilutigalugu mingutsitsinerup kigaatsuinnarmik annikilliartornissaa naatsorsuutigisariaqarpoq. Tamatumalu saniatigut immami avatangiisit aqerlumik zinkimillu akui allanngorartarnissaat naatsorsuutigisariaqarpoq, tassa sumiiffiit mingutsitaasimasut neriorneqarlutik qulaarneqaraangata qaffasittarlutik, pingaartumik umiarsualiviup eqqaani, kingornalu neriuisoqartinnagu akugisaat appartarlutik.

1 Introduction

This report compiles information about and assesses the environmental impact of the former lead-zinc mine at Mestersvig to document the present state of the environment in areas affected by the mining operation. The report has been prepared for International Molybdenum PLC (InterMoly), who is exploring the molybdenum deposit at Malmbjerget to the south of Mestersvig. The preparation of the report is funded by InterMoly as part of environmental studies initiated to prepare an environmental impact assessment report of the Malmbjerget project.

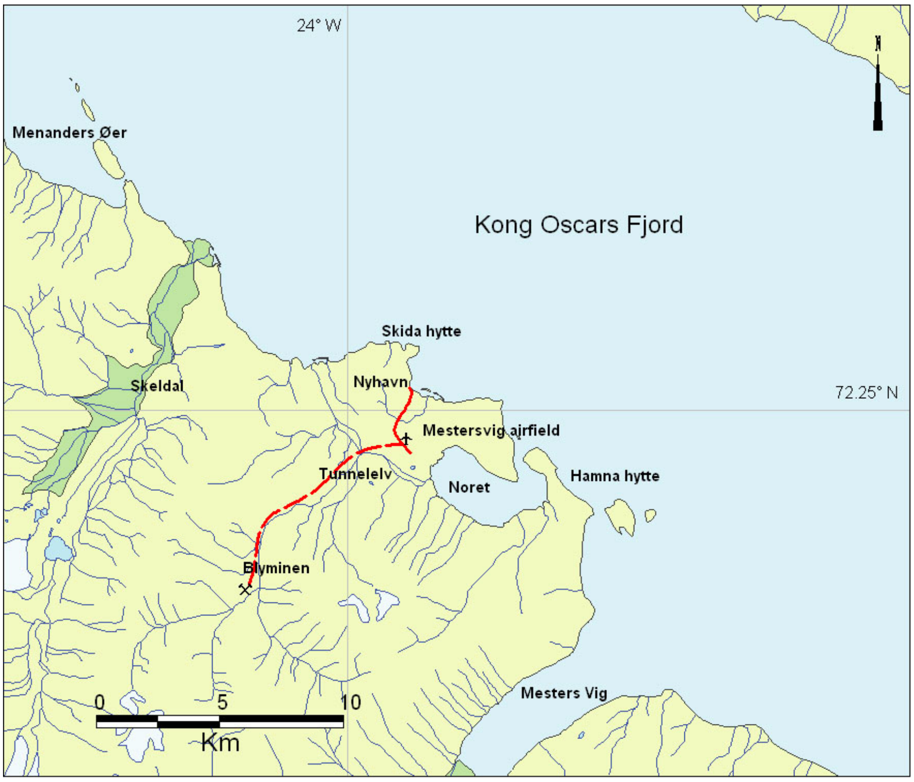
At Mestersvig, East Greenland, the Danish company Nordisk Mineselskab operated a lead-zinc mine from 1956 to 1963. The mine was underground, located c. 10-km inland from Kong Oscars Fjord. An outline of the operation is shown in Figure 1. 554.000 tonnes of ore was mined, and 58.000 tonnes of lead concentrate and 75.000 tonnes of zinc concentrate produced. A road was constructed between the site and the fjord, where concentrate was shipped out. Tailings from the concentrator were discharged at the mine on a nearby mountain slope, from where most has slid into the river Tunnelelv flowing to Kong Oscars Fjord.

During mining, environmental impacts and protection were not issues dealt with. This first happened in the 1980'es, after it became known that part of Kong Oscars Fjord was affected by lead and zinc pollution from the mine. Studies were initiated by the Danish government to assess if the pollution could be mitigated. One possibility was to partly seal the coastal area that had been severely polluted by loss of concentrate. The proposal was to cover the most contaminated area with stones and gravel and shield the covered area from the sea with a bentonite layer. But the costs of this operation would be very high and would only solve the problem to some degree. It would significantly reduce the lead pollution, which mainly seems to originate from concentrate spillage, but it would not affect the pollution from the other main source, the tailings that have been dispersed over so vast areas, that no realistic abatement measures were possible.

Environmental studies at the mine were initiated in 1979 and as they demonstrated that the mining operation had caused a widespread pollution with lead and zinc, environmental monitoring continued in 1985, 1986, 1991, 1996 and 2001. These studies have been reported, but mainly in Danish (Asmund 1983, Asmund 1986, Hansen & Asmund 1986, Agger et al. 1991, Asmund et al. 1997, Aastrup et al. 2003). The most comprehensive English reporting is found in Johansen & Asmund (1999).

Field work, chemical analyses and reporting of all previous studies at Mestersvig described in this report has been funded by the Danish government, except a terrestrial study conducted as part of the EU financed MINEO study (Aastrup et al. 2001, Tamstorf et al. 2003).

Figure 1. Outline of the lead zinc mine at Mestersvig. The approximate location of the existing road is shown with a red line.



2 Data

Table 1 gives a summary of the sample types used to prepare this report. All samples have been analyzed for lead, but many also for zinc, cadmium and copper.

Table 1. Samples collected and analyzed as part of the monitoring of the Mestersvig mine.

Sample type	1979	1983	1985	1986	1991	1996	2001
Mine tailings	x	x					x
River water	x						
River sediments	x						x
Soil			x				x
Lichens	x						x
Vascular plants							x
Beach sand			x	x		x	x
Marine sediments			x	x			
Seawater	x						
Seaweed	x		x		x	x	x
Bivalves			x				
Sculpin			x		x	x	x
Ringed seal			x		x		

We do not report analytical results from single samples. These may be found in the reports mentioned above. Nor do we discuss the quality of data, except that data from before 1991 cannot be validated, since QA programs were not in place at that time. However, many samples, also the old ones, are still kept in a freezer at NERI, so it is possible to reanalyze these, if needed.

3 Results and discussion

In the following sections we summarize the findings on each of the sample types shown in Table 1.

3.1 Tailings

About 400 000 tons of tailings were produced by the mine, but in 1979 it was estimated that only 66 000 tons remained in the original disposal area, and that most of the tailings had been washed into the river, the river deltas and the fjord. Figure 2 and 3 shows the tailings disposal area.

Figure 2. The mine site. Tailings, the existing road and the remaining buildings and fuel storage can be seen.

The metal content of tailings has been studied in 1979, 1983 and 2001. Table 2 shows that the mean lead concentration is about 0.6% and the mean zinc concentration about 2.5% at the most recent study conducted, but with a large variation among samples. The copper concentration in tailings is about 0.04%, cadmium is about 0.01% and silver about 2 ppm.

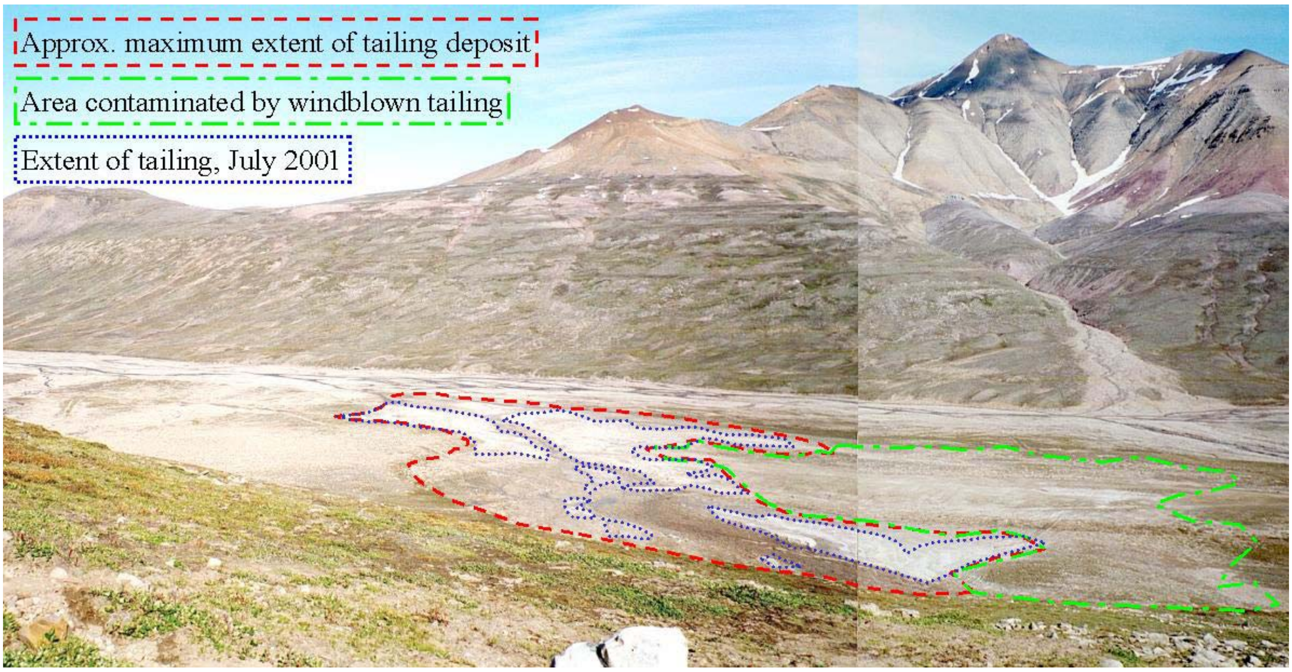


Figure 3. Tailings at the Mestersvig mine. The red stippled line shows the original extent of the tailings dump, the blue dotted line the extent in 2001 and the green stippled line the area directly affected by tailings from wind and water erosion.

Table 2. Lead and zinc concentrations (%) in tailings. n: number of samples, SD: standard deviation.

		1979	1983	2001
n		1	20	11
Pb	mean	0.89	0.74	0.58
	SD		0.39	0.34
	min		0.28	0.19
	max		1.70	1.26
Zn	mean	2.34	2.96	2.48
	SD		1.83	1.38
	min		0.96	1.11
	max		9.70	5.97

3.2 River water

There are only data from 1979. Samples in Tunnelelv were taken between August 28 and September 3 at different distances upstream and downstream the tailings deposit. Figure 4 and figure 5 show the concentrations of lead and zinc in the river. Seven kilometers downstream the tailings deposit Tunnelelv divides into an eastern and a western branch.

In the 1979 study Tunnelelv received heavily polluted water from a brook running through the tailings. This brook had 4200 µg/l dissolved zinc and 138 µg/l dissolved lead. Figure 4 and 5 shows that all water samples downstream the tailings dump had elevated lead and zinc concentrations, and that zinc are elevated to higher levels than lead. Cadmium levels in river water were also elevated, but not as much as lead and zinc.

Figure 4. The concentration of lead in Tunnelelv in 1979 up- and downstream the tailings deposit. Negative values are upstream locations.

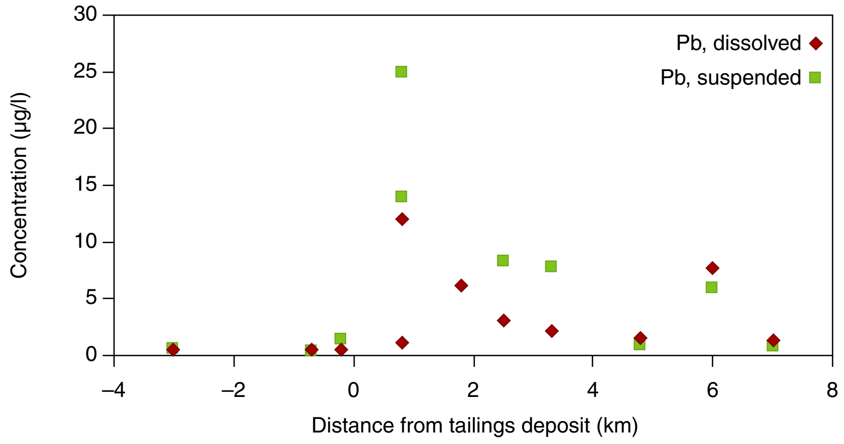
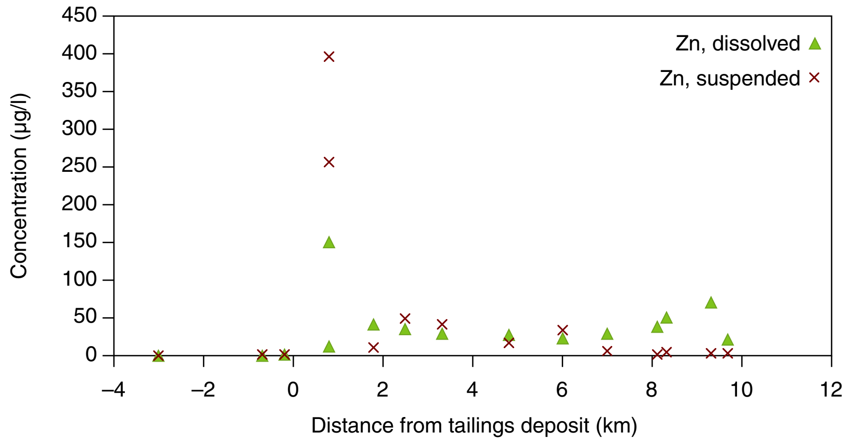


Figure 5. The concentration of zinc in Tunnelelv in 1979 up- and downstream the tailings deposit. Negative values are upstream locations.



In other rivers (Gylfe Elv, Gefion Elv, Tværelv, Lejrelv and Rungsted Elv) lead, zinc and cadmium levels were similar to what was found in Tunnelelv upstream the tailings dump.

3.3 River sediments

In 1979 three sediment cores from the delta of Tunnelelv were sampled and cut up in 10-cm slices that were analyzed for lead and zinc. Three particle size fractions (<50 µ, 50-100 µ and 100-200 µ) were analyzed separately, and in almost all cases the lead and zinc concentration increased towards the finest fraction (Table 3 and 4).

Table 3. Lead concentration (µg/g) in river sediments from Tunnelelv's delta.

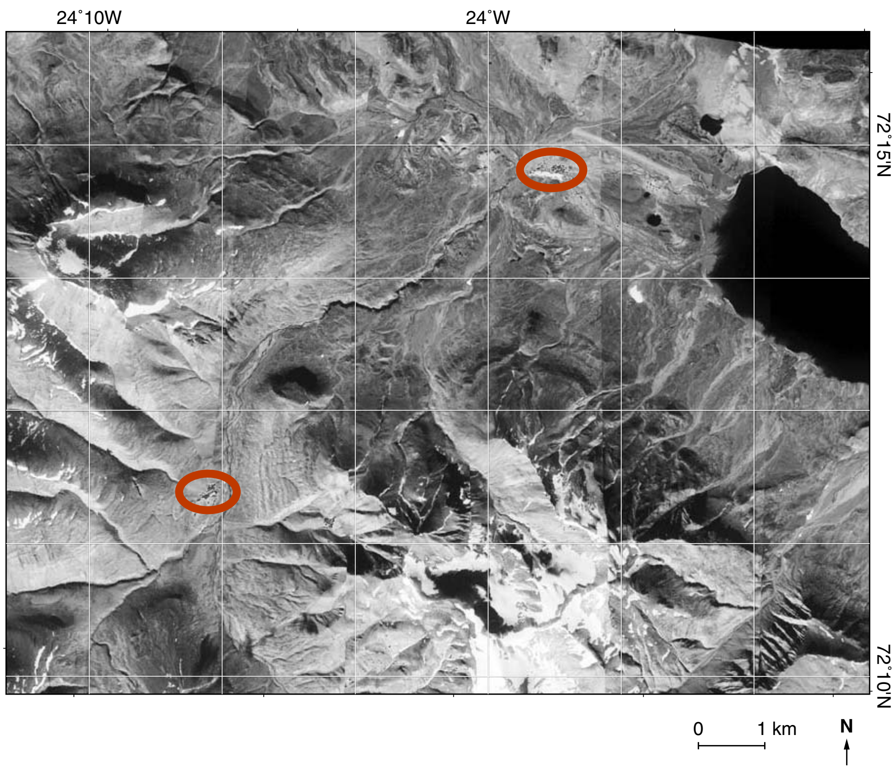
Depth cm	Eastern delta at Noret, core III			Eastern delta at Noret, core IV			Western delta at Kong Oscars Fjord		
	100-200µ	50-100µ	<50µ	100-200µ	50-100µ	<50µ	100-200µ	50-100µ	<50µ
0-10	282	353	392	87	123	144	97	184	389
10-20				87	93	109	57	93	227
20-30	7300	1570	5350	19	17	18	70	79	116
30-40	800	1900	6500	20	21	21	43	47	99
40-50	25	36	110				183	31	48
50-60	22	26	33				24	29	45
60-70	31	57	95						

Table 4. Zinc concentration (µg/g) in river sediments from Tunnelelv's delta.

Depth cm	Eastern delta at Noret, core III			Eastern delta at Noret, core IV			Western delta at Kong Oscars Fjord		
	100-200µ	50-100µ	<50µ	100-200µ	50-100µ	<50µ	100-200µ	50-100µ	<50µ
0-10	2300	2400	2150	174	267	346	1043	749	1234
10-20				127	140	198	306	745	931
20-30	7400	35500	130400	48	57	82	436	668	906
30-40	1900	4600	21100	56	66	126	155	193	280
40-50	73	126	313				297	50	111
50-60	51	86	116				56	86	137
60-70	118	307	368						

Although there are large variations from one core to another taken in the same part of the delta, the high lead and zinc concentrations in the upper (and most recent) sediment indicate, that significant amounts of lead and zinc has accumulated in the river deltas. This was confirmed in the MINEO project, which by means of hyperspectral data showed that tailings have been transported from the tailings dump and deposited in the river delta especially in the area towards Noret, see Figure 6.

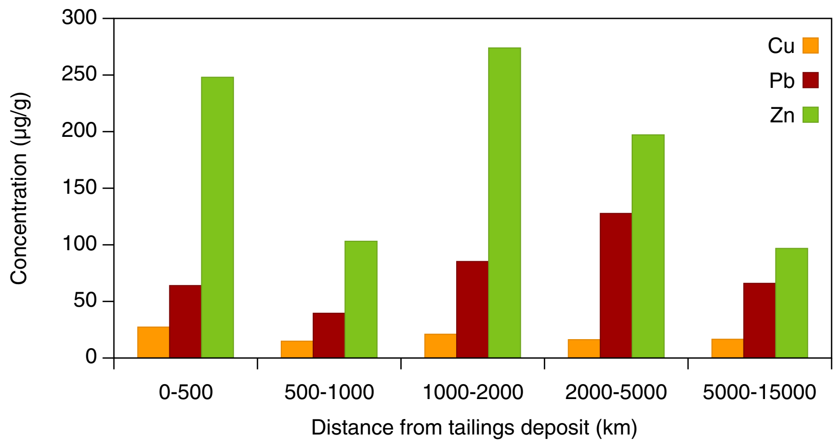
Figure 6. Mapping of tailings by means of hyperspectral data. The circled area to the left shows the tailings dump at the mine and the circled area to the right shows re-deposited tailings in the river delta towards Noret. The landing strip in Mestersvig can be seen just above this circle.



In 2001 sediment samples from Tunnelelv were collected at different distances from the tailings dump. Lead, zinc and copper were analyzed, and the results are shown in Figure 7.

All along the river concentrations of lead and zinc are elevated. There is not a clear pattern with the highest levels close to the tailings dump and the lowest at the longest distance from the dump. This appears to be the result of tailings being transported with the river and thus affecting all of it. However single samples of river sediment at the tailings dump have very high concentrations, more than 3500 µg/g lead and 25000 µg/g zinc.

Figure 7. Copper, lead and zinc concentration (µg/g) in river sediments of Tunnelelv within different distances (meters) from the mine.

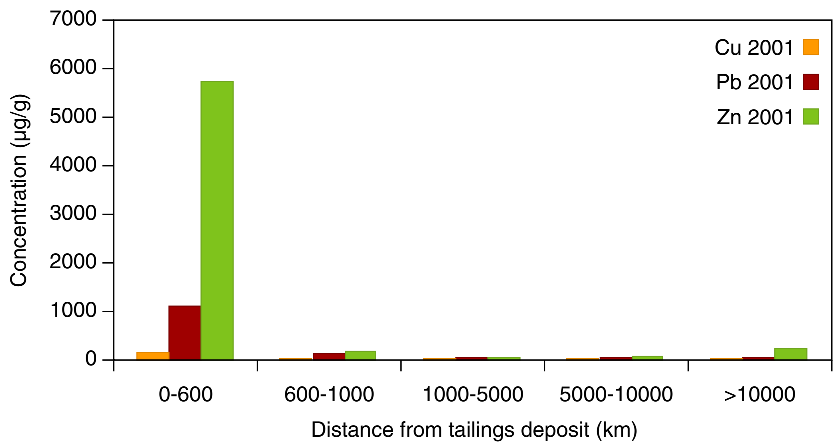


3.4 Soil and ground

Two types of samples have been collected. Soil samples contain organic material and were collected in vegetated areas. Ground samples were collected in non-vegetated bare ground areas without visible organic material.

Soil samples were collected in 2001 and analyzed for lead, zinc and copper. The result of this study is summarized in Figure 8.

Figure 8. Copper, lead and zinc concentration (µg/g) in soil within different distances (meters) from the mine sampled in 2001.



The figure indicates that the impact on soil is confined to an area within about one kilometer from the mine site, where single very high concentrations were seen, e.g. between 8000 and 15000 µg/g zinc. At the mine and at Nyhavn also very high lead concentrations were found, up to about 3000 µg/g. The source probably is dust, which has been wind spread locally at the mine and at Nyhavn.

In 1985 bare ground samples were collected in the Nyhavn area in the quay and around it. Samples were collected in an area with visible signs of physical impact on the ground. The results are summarized in Table 5.

Table 5. Lead and zinc concentrations (%) in bare ground samples at Nyhavn in 1985.

Area	Sample # (no. of samples)	% Pb	% Zn
Beach south of quay	1-6 (6)	2.0-10	1.1-7.3
Beach north of quay	7-10 (4)	0.07-0.13	0.03-0.08
On land 1-10 m from coastline	11-22 (12)	0.03-2.2	0.03-10
Surface on quay	23-28 (6)	0.4-44	0.5-12

Very high lead and zinc concentrations were found in many samples from all areas, except on the beach north of the quay. This is likely caused by loss of concentrate, when this was loaded on barges at Nyhavn. At one site (sample #28) the lead concentration decreased from 44% in the surface to 0.1% at 52 cm depth.

Lichens

Lichens are widely used to assess airborne pollution with heavy metals, which they accumulate from atmospheric deposition. In Greenland we have mainly used the species *Cetraria nivalis* and it has also been sampled at Mestersvig in 1979 and in 2001. The results are shown in Figure 9 (1979) and in Figure 10 (2001).

Figure 9. Mean lead and zinc concentrations (µg/g d.w.) in 1979 in lichens.

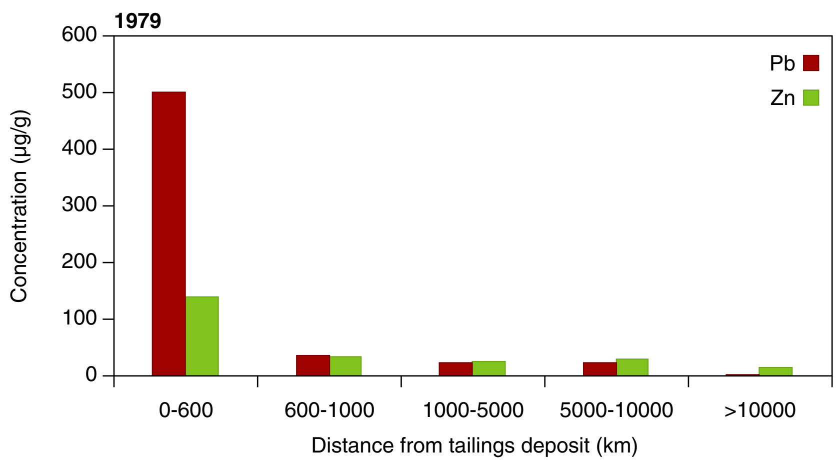
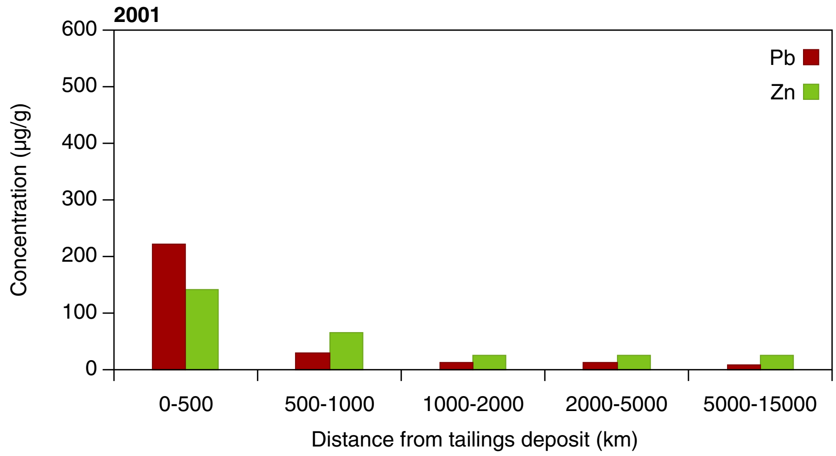


Figure 10. Mean lead and zinc concentrations (µg/g d.w.) in 2001 in lichens.



Highly elevated lead and zinc levels are found within 500 m from the tailings dump, and outside this area levels are considerably lower, although still elevated somewhere between 5 and 10 km from the mine. In regions of Greenland not affected by local sources, baseline mean concentrations vary between 1.1 to 6.4 µg/g for lead and 11-22 µg/g for zinc. Cadmium concentrations also appear elevated, but not copper.

3.5 Vascular plants

In 2001 two species, *Cassiope tetragona* (White arctic bell-heather) and *Salix arctica* (Arctic willow), were sampled at the tailings dump, about 1 km away and at "Sorte Hjørne" below a lead-zinc deposit, which could be expected to have naturally elevated lead and zinc concentrations. These samples were analyzed for lead, zinc, copper and cadmium. Lead results are shown in Table 6.

Table 6. Lead concentrations (µg/g d.w.) in *Cassiope tetragona* and *Salix arctica* from Mestersvig 2001.

Area	*Cassiope tetragona*	*Salix arctica*
At tailings dump	1075-9155	755
1 km from tailings dump	12-29	8.9
Sorte Hjørne	2.6-3.5	5.8-13

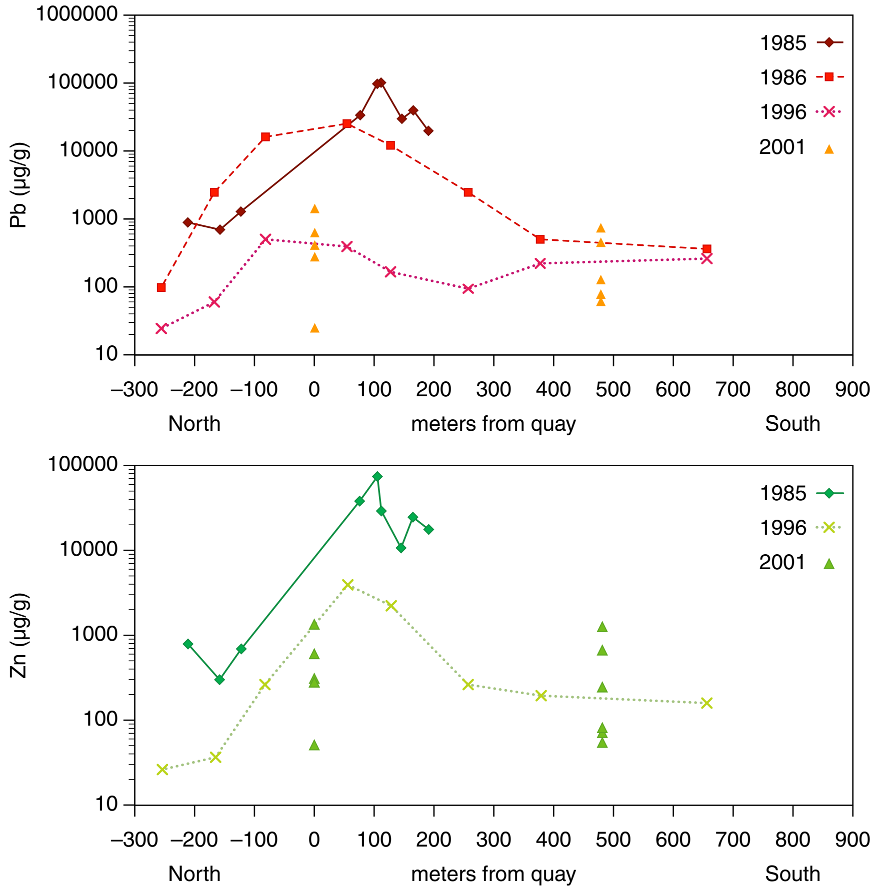
Very high metal concentrations were found at the tailings dump and decreased to much lower levels at the two other sites, but appeared elevated also 1 km from the mine in *Cassiope*. The lowest levels are found at "Sorte Hjørne" (app. 10 km south of the mine), and baseline concentrations may not be documented.

3.6 Beach sand

As described in section 3.4, very high metal concentrations were found in bare ground samples and on the beach at Nyhavn in 1985. Further studies were conducted in 1996 and 2001.

For the area at Nyhavn the result of these studies are summarized in Figure 11.

Figure 11. Lead and zinc concentrations (µg/g d.w.) in beach sand at Nyhavn. Y-axis is logarithmic.

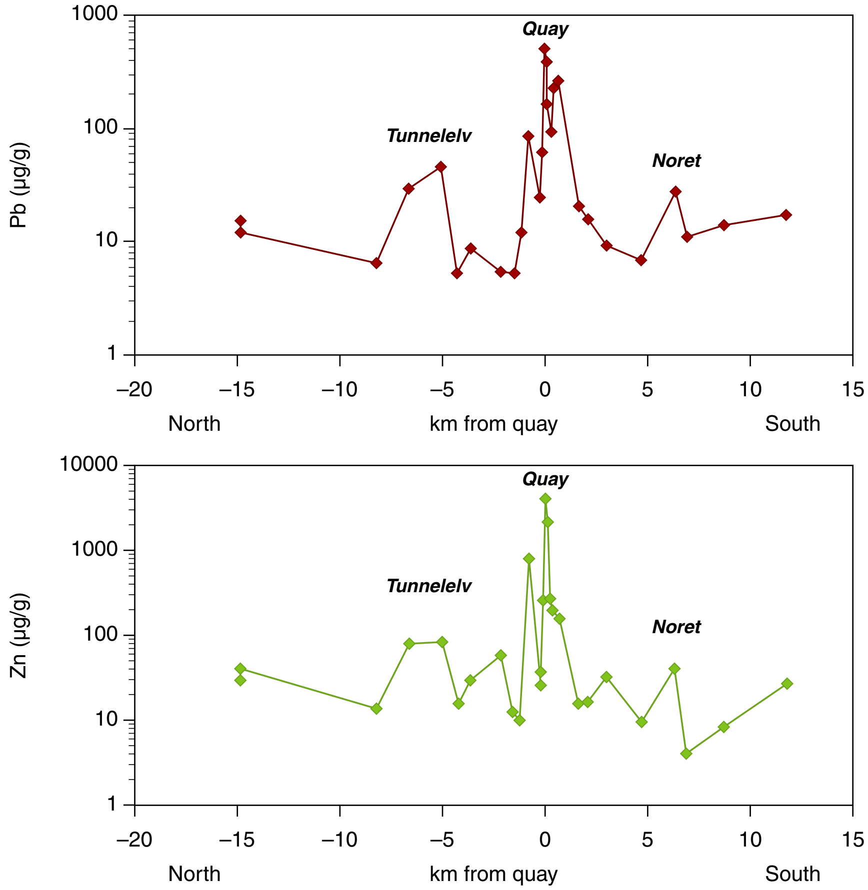


The figure shows that the lead concentration has decreased considerably since 1985, particularly between 1986 and 1996, with a factor between 50 and 200. Also zinc concentrations have decreased, about a factor of 10. This indicates that highly polluted beach sand has been eroded and transported to deeper water from 1985 to 1996, without being replaced by "new" highly polluted material from land.

In 1996 and 2001 beach sand was collected in a wider area along the coast, both towards north and south in Kong Oscars Fjord. The results from 1996 are shown in Figure 12. Distance is kilometers measured along the coastline from the southwestern corner of the Quay.

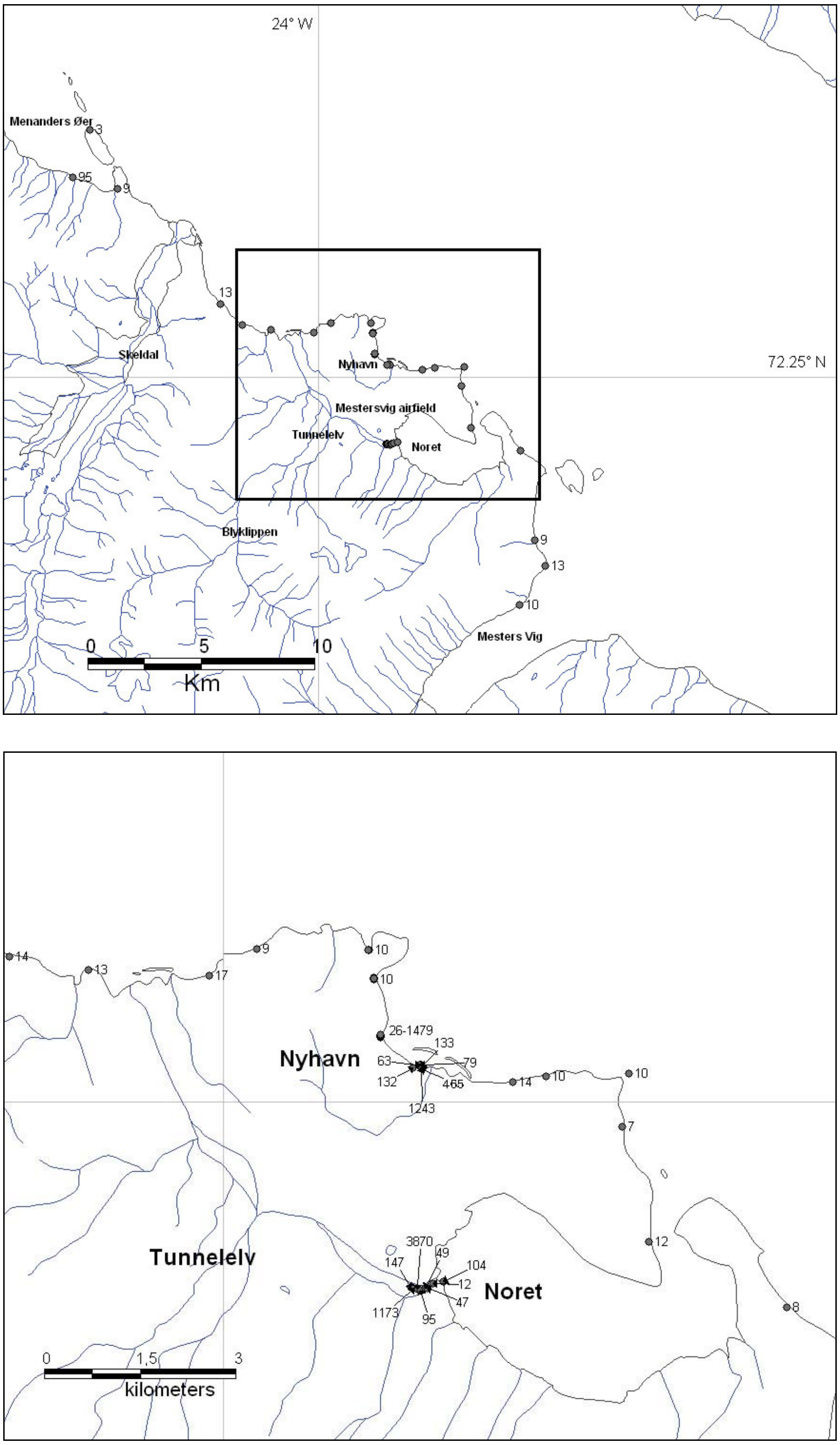
The highest lead and zinc concentrations in beach sand were found at Nyhavn and decreased towards north and south. Further towards north they increased again at Tunnelelv's outlet towards Kong Oscars Fjord, but decreased further north. The same pattern is seen towards south with an increase in concentrations at Tunnelelv's outlet in Noret. It may be concluded that Tunnelelv has transported lead and zinc to Kong Oscars Fjord, but that Nyhavn also has been a significant source.

Figure 12. Lead concentration (above) (µg/g d.w.) and zinc concentration (below) in beach sand from Mestersvig 1996.



The 2001 study of beach sand shows similar results as the 1996 study as illustrated in Figure 13 and 14. Concentrations were highest at Nyhavn and at Tunnelv's outlet in Noret. However lead and zinc concentrations were also high 20 km north of Nyhavn, whereas they were low at Tunnelelv's outlet in Kong Oscars Fjord, about 6 km north of Nyhavn. This seems unlikely and we suspect that samples from these two areas have been interchanged and wrongly labeled.

Figure 13. Lead concentration (µg/g d.w.) in beach sand from 2001.



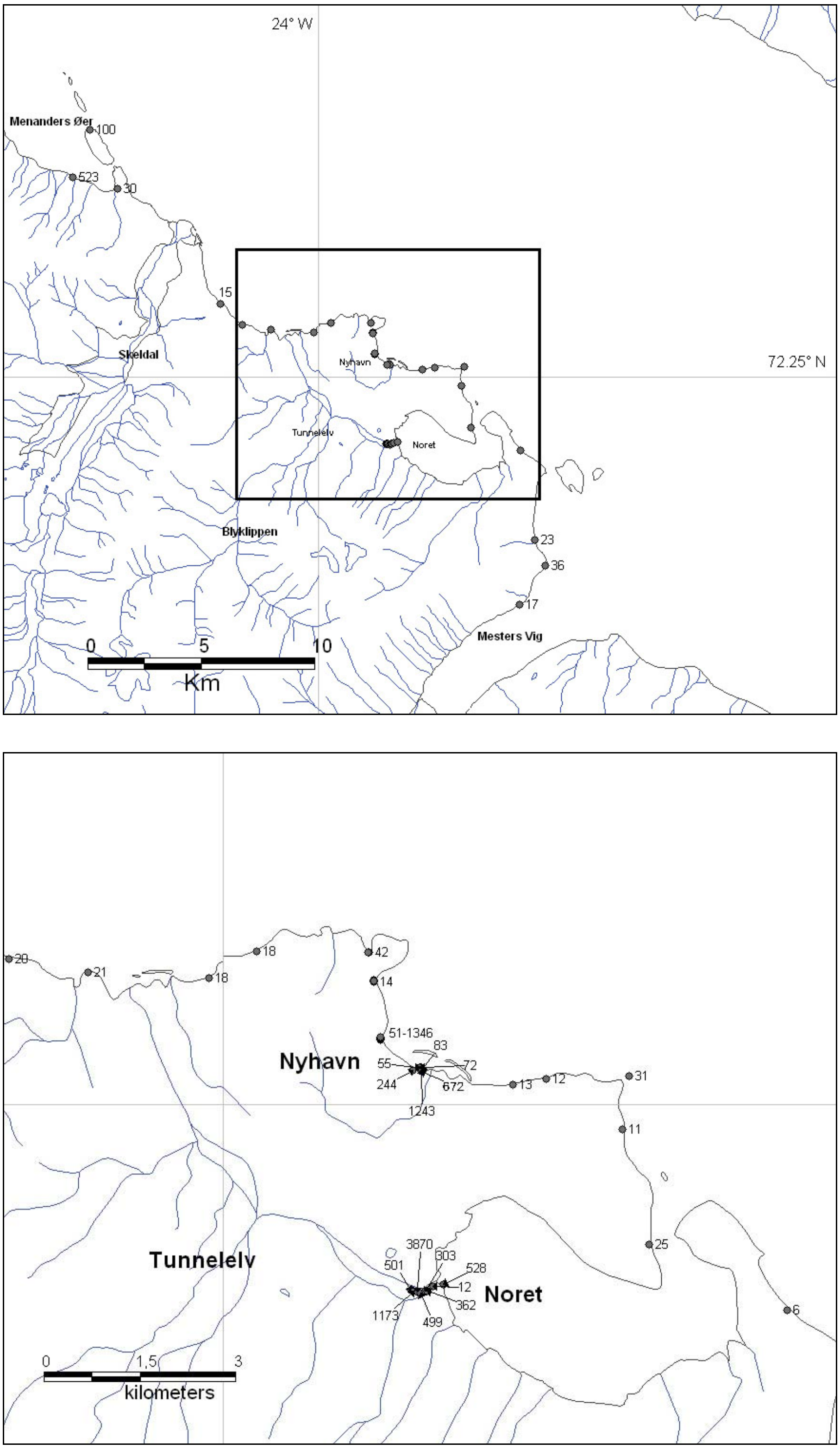


Figure 14. Zinc concentration (µg/g d.w.) in beach sand from 2001.

3.7 Marine sediments

Marine sediments were collected in 1985 and 1986. The 1985 study included two sediment cores, which were cut up in 1 cm slices that were analyzed for lead, zinc and copper, a few also for cadmium. One core, called Nyhavn 1, was collected on 4.5 m water depth ca. 200 m northeast of the quay, and the other, Nyhavn 2, at 50 m water depth ca. 1000 m northeast of the quay. The results are summarized in Table 7. All lead and zinc values of the sediments appear elevated and levels are highest closest to the coast as could be expected. Copper levels at Mestersvig are at the same level as the reference site. Cadmium may be elevated, but data are too scarce to conclude.

Table 7. Metal concentrations (µg/g d.w.) in marine sediments at Mestersvig 1985. Reference values are from a coastal region in Baffin Bay.

	Nyhavn 1	Nyhavn 2		Reference
Distance from coast	200 m	1000 m		
Part of core	Upper 3 cm	Upper 3 cm	Deeper than 7 cm	
Pb	387	64	26	15
Zn	245	130	95	61
Cu	32	23	26	29
Cd	0.45			0.17

In 1986 a larger area at Nyhavn was studied. Surface marine sediments were collected at 161 positions on water depths down to 36 m and analyzed for lead. Samples on the coast were also included in the study. A map of concentrations was produced using an interpolation procedure of data. This map is shown in Figure 15.

Highly polluted sediment was found just off the quay and to the south of it, but elevated lead levels were found in a larger region as seen on the map. Lead concentrations between 0.1 and 1.2% were found within 300 m from the quay, primarily near the coast towards southeast. Concentrations above 0.1% were mainly found to water depths less than 1.5 m but also down to 3.1 m. We estimated that 57500 m² of marine sediments had lead concentrations above 0.1%.

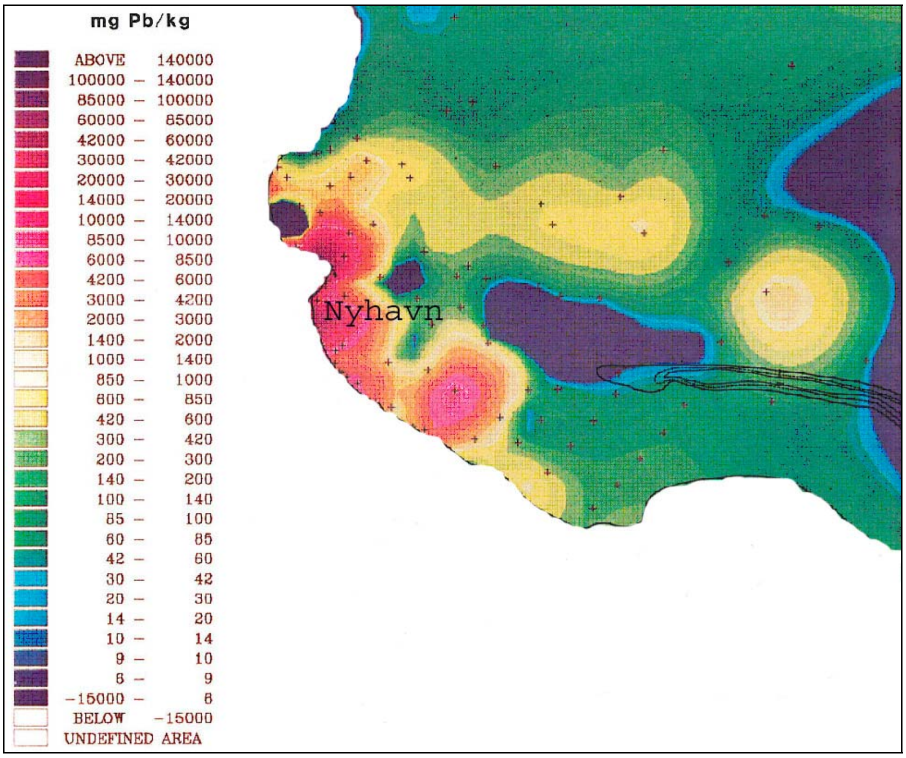


Figure 15. Distribution of lead (µg/g d.w.) in surface marine sediments and on the coast at Nyhavn 1986. (Contour lines continue on land but they are only valid in the sea).

3.8 Seawater

Metal concentrations in seawater have only been studied in 1979. Six stations were sampled and water from 5-40 meters water depth analyzed for lead, zinc and cadmium. Results are summarized in Table 8.

Table 8. Metal concentrations (µg/l) in seawater at Mestersvig 1979.

Area	Depth, m	Pb	Zn	Cd
Off the northern branch of Tunnelelv	5	0.14	0.64	0.056
	10	0.23	0.48	0.034
	20	0.32	0.61	0.084
	30	0.49	0.79	0.030
Nyhavn Bugt	5	0.51	0.58	0.028
	10	0.21	0.50	0.044
	20	0.21	0.44	0.025
	30	0.24	0.46	0.028
Noret	5	0.62	1.21	0.181
	10	0.79	4.67	0.118
	20	0.61	3.96	0.152
	30	0.50	2.92	0.106
	40	0.45	4.21	0.204
Bay at Hamna Hytte	5	0.25	0.66	0.045
	10	0.21	0.44	0.029
	20	0.29	0.44	0.025
	30	0.38	0.38	0.025
Mesters Vig	5	0.19	0.90	0.059
	10	0.28	0.81	0.073
	20	0.16	0.60	0.051
	30	0.17	0.98	0.055
	40	0.39	0.38	0.059

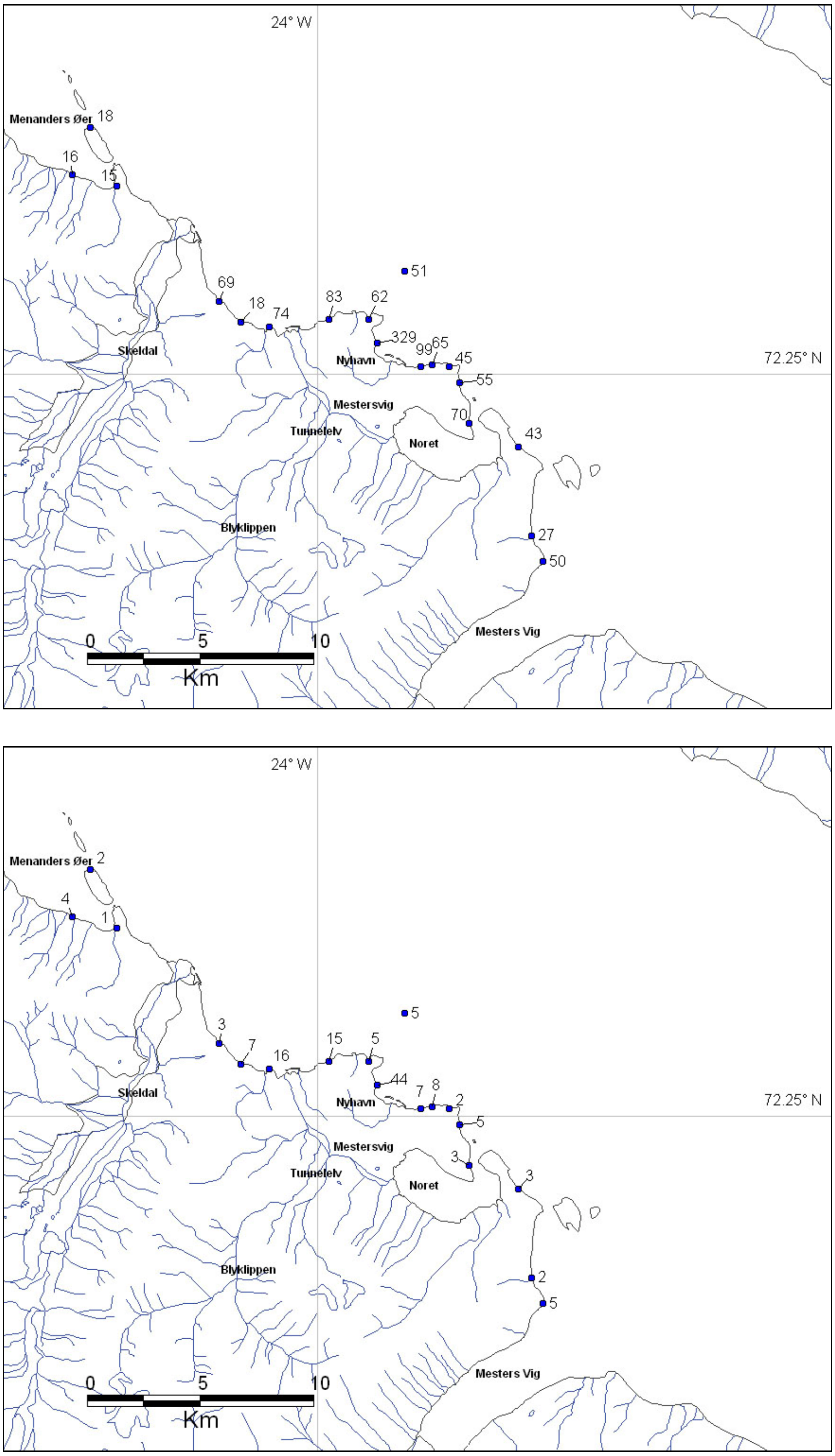
Lead, zinc and cadmium concentrations were clearly higher in Noret than at the sample stations in Kong Oscars Fjord around Mestersvig. The likely reason for that is a sill at the mouth of Noret, reducing the water exchange from Kong Oscars Fjord and resulting in relatively stagnant water below sill depth in Noret. This could allow for a build-up of higher metal concentrations released from the tailings which has been transported to Noret by Tunnelelv.

3.9 Seaweed

Seaweed is widely used to monitor pollution with heavy metals, since seaweed accumulate metals from seawater and therefore reflects the integrated exposure to pollution where it grows. In Mestersvig we have sampled a brown seaweed species (*Fucus distichus*) along the coast in 1979, 1985, 1991, 1996 and 2001. All samples have been analyzed for lead and zinc, but some also for cadmium and copper. In this section we summarize the results.

One purpose of monitoring seaweed along the coast is to evaluate the significance of different sources by looking at the geographical distribution of lead and zinc. The highest metal concentrations are expected in areas with the highest metal input. The geographical distribution of lead and zinc is shown in Figure 16.

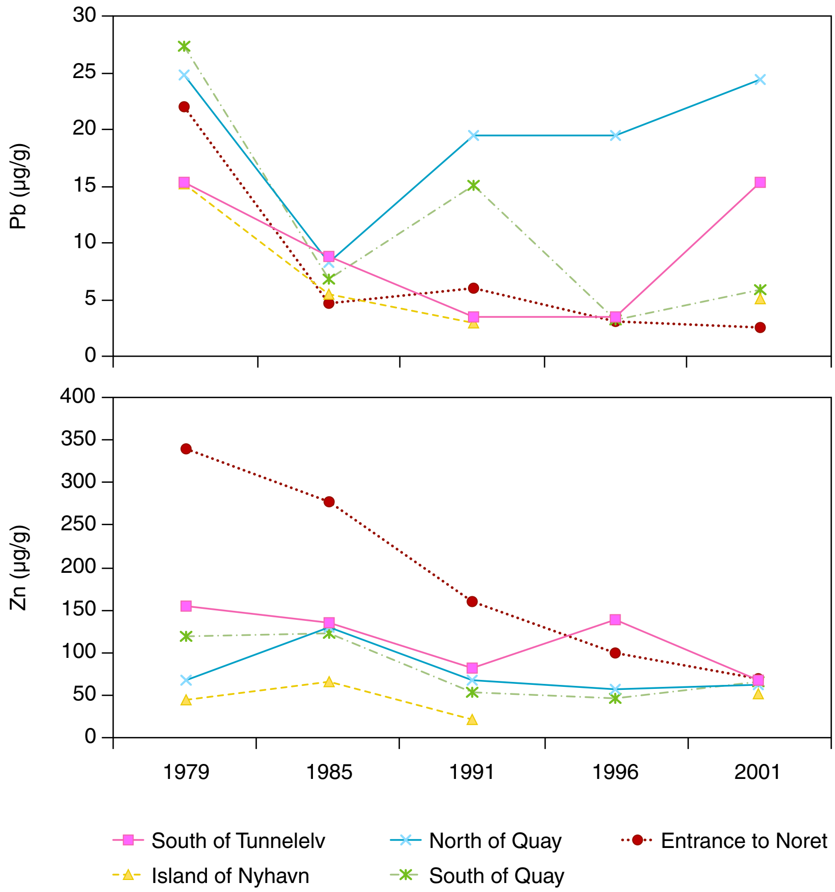
Figure 16. Zinc concentration (µg/g) (above) and lead concentration (µg/g) (below) in seaweed from Mestersvig 2001.



In Figure 17 we have shown time trend results for lead and zinc. In doing this we have computed mean concentrations in 5 different coastal areas at Mestersvig:

- South of Tunnelelv (stations 4, 4-5 and 5)
- Island off Nyhavn (station 6)
- North of quay in Nyhavn (station 1-2, 2 and 3)
- South of quay in Nyhavn (station 7, 9 and 10)
- Entrance to Noret (station 7-8 and 8).

Figure 17. Lead and zinc concentrations (µg/g) in seaweed at Mestersvig 1979-2001.



In most areas lead and zinc concentrations decrease over the monitoring period. But the only consistent trend appears to be at the entrance to Noret, whereas in the other areas there are also periods with increasing concentrations, particularly for lead in the area around the quay in Nyhavn. We think the likely cause of this is variation in the transport of lead to the sea caused by the gradually demolishing of the heavily polluted quay area.

3.10 Bivalves

In 1985 three bivalve species were collected at Nyhavn and at reference sites and analyzed for lead, zinc, cadmium and copper. These were a cockle (*Cardium ciliatum*), a clam (*Chlamys islandica*) and a mussel (*Musculus discors*). All species lives from filtering plankton. Very significant elevations were observed for lead (see Table 9), whereas there were no systematic differences for the other metals. A clear gradient in lead concentrations was also seen with much higher lead levels closer to Nyhavn than further offshore (Table 9).

Table 9. Lead concentration (µg/g d.w.) in bivalves at Nyhavn and at reference sites in Greenland. Number of samples analyzed is from 1 to 3.

Species	Water depth (m)	Lead conc. off Nyhavn	Lead conc. at Greenland reference site (Hall Bredning or Thule)
Cardium ciliatum	15	30.7	0.9
	30	3.3	
Chlamys islandica	15	138	0.9
Musculus discors	15	148	1.3

3.11 Sculpin

Two species (*Myoxocephalus scorpius* and *Myoxocephalus quadricornis*) have been sampled at Mestersvig and at reference sites and analyzed for lead. We have not distinguished between species in this presentation. In contrast to most fish species sculpins are considered to be very stationary and are therefore often used to monitor pollution from local sources.

Data are available from 1985, 1991, 1996 and 2001 as summarized in Table 10. Most data are from Nyhavn and from Mesters Vig, which has been used as a reference site.

Table 10. Median lead concentration (µg/g d.w.) in sculpins from Nyhavn, Skidal Bugt and reference sites.

Site	Year	Muscle	Liver	Bone
Nyhavn Bugt	1985	<0.15	0.32	1.55
	1991	0.39	4.13	6.82
	1996	0.06	0.36	0.28
	2001	0.02	0.10	0.57
Skidal Bugt, c. 1.5 km north of Nyhavn	1985	0.18	0.49	1.61
Mesters Vig, c. 13 km southeast of Nyhavn	1991	<0.15	<0.4	<0.35
	1996	0.05	0.07	0.24
	2001	0.03	0.04	0.06
Vega Sund, 125 km northeast of Nyhavn	1985	<0.15	<0.15	0.17

In the 2001 study there are clearly elevated lead levels in fish bone from Nyhavn, but levels were much lower than 10 years earlier. At this time levels were also elevated in liver and muscle, but in 2001 they have declined to about the same level as at Mesters Vig in these tissues.

3.12 Ringed seal

Samples from ringed seal (*Phoca hispida*) were collected in 1985 and 1991 from Kong Oscars Fjord and analyzed for lead. In 1985 elevated lead concentrations in the seals were found, but it was later documented that some of the 1985 samples had been contaminated with lead from the quay area where these seals were flensed. Therefore only the 1991 results are presented (Table 11).

Table 11. Lead concentration (µg/g w.w.) in ringed seals from Kong Oscars Fjord 1991.

Tissue	geo mean	minimum	maximum
Muscle	<0.05	<0.04	0.19
Liver	0.06	<0.04	0.30
Kidney	<0.05	<0.04	0.06

These are very low concentrations and they are not elevated compared to reference sites in other regions of Greenland.

4 References

Aastrup, P.J., Tamstorf, M.P. & Asmund, G. 2003: Miljøundersøgelser ved Mestersvig 2001. Danmarks Miljøundersøgelser 49 s.. - Faglig rapport fra DMU nr. 474.

Agger, C.T., Asmund, G., Dietz, R. & Johansen, P. 1991. Miljøundersøgelser ved Mestersvig 1991. Grønlands Miljøundersøgelser 23 pp.

Asmund, G. 1983. Oversigt over miljøundersøgelser ved Mestesvig 1979. Grønlands Geologiske Undersøgelse 21 s.

Asmund, G. 1986. Fordeling af bly i sedimenterne nær Nyhavn ved Mestersvig. Grønlands Geologiske Undersøgelse 9 s.

Asmund, G., Riget, F. & Johansen, P. 1997. Miljøundersøgelser ved Mestersvig 1996. Danmarks Miljøundersøgelser. 31 s. – Faglig rapport fra DMU, nr. 202.

Johansen, P. & Asmund, G. 1999: Pollution from Mining in Greenland. Monitoring and Mitigation of Environmental Impacts. In: Azcue, J.M. (ed.): Environmental Impacts of Mining Activities. Emphasis on Mitigation and Remedial Measures. Springer. pp. 245-262.

Hansen, M.M. & Asmund, G. 1986. Miljøundersøgelser i Kong Oscars Fjord 1985. Grønlands Fiskeri- og Miljøundersøgelser 41 pp.

Loring, D.H. 1984. Trace geochemistry of sediments from Baffin Bay. Can.J.Earth Sci. 21: 1368-1378.

Tamstorf, M.P., Aastrup, P.J. & Tukiainen, T. 2003: Assessing and monitoring the environmental impact of mining activities in Europe using advanced Earth Observation techniques. Project funded by the European Community under the Information Society Technology Programme (1998-2002). European Community. - MINEO Arctic environment test site Contamination/impact mapping and modelling – Final report. MINEO IST–1999-10337: 97 pp. http://www.brgm.fr/mineo/final.htm.

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This report compiles information about and assesses the environmental impact of the former lead-zinc mine at Mestersvig to document the present state of the environment in areas affected by the mining operation. The report has been prepared on the request by International Molybdenum PLC (InterMoly), who is exploring the molybdenum deposit at Malmbjerget to the south of Mestersvig. The preparation of the report is funded by InterMoly as part of environmental studies initiated to prepare an environmental impact assessment report of the Malmbjerget project.
The report documents that the former mine that was in operation from 1956 to 1963 has caused a significant pollution with lead and zinc on-land, in a river and in Kong Oscars Fjord. Mine tailings and spill of concentrate are the main pollution sources. Areas at the mine site have been monitored since 1979.

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241 Environmental Impact of the Lead-Zinc Mine at Mestersvig, East Greenland