EVALUATION OF LOCAL CONTAMINATION SOURCES FROM THE FORMER MINING OPERATION IN MAARMORILIK

NERI Technical Report no. 807 2010

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Data sheet

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Abstract: The company Angel Mining presently plans to re-open the Black Angel lead-zinc mine, which was operated by Greenex in Maarmorilik from 1973 to 1990. This report describes the closure activities, particularly how environmental issues were dealt with. In 2008 NERI conducted a study to document the present environmental background conditions in the Maarmorilik camp site area. Soil and sediment samples were collected in August 2008 and analyzed for heavy metals and oil components. The results clearly indicate high metal pollution in the “concentrate storage area” of the former mine site. This is not surprising, since this area was used to store mineralized waste rock, when the mine closed. Levels of Polycyclic Aromatic Hydrocarbons (PAHs) in soil and fiord sediment samples were low, indicating that the soil and the fiord are not significantly polluted by oil.

Keywords:	Black Angel, lead, zinc, oil, soil, sediments
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Summary

The company Angel Mining presently plans to re-open the Black Angel lead-zinc mine, which was operated by Greenex in Maarmorilik from 1973 to 1990. Angel Mining has started constructing facilities necessary to start production. In doing this, indications for on-site pollution were seen. Therefore NERI has conducted a study to document the present environmental background conditions particularly in the Maarmorilik camp site area, before the new mining operation will start. As part of this study, soil samples and sediment samples were collected in August 2008. The samples were analyzed for heavy metals and oil components. Few samples of drinking water and mussels were also collected and analyzed.

The results of the chemical analyses of the soil samples clearly indicate high metal pollution in the "concentrate storage area" of the former mine site. This is not surprising, since this area was used to store mineralized waste rock, when the mine closed. Levels of Polycyclic Aromatic Hydrocarbons (PAHs) in soil and fiord sediment samples were low, indicating that the soil and the fiord are not significantly polluted by oil. In drinking water from Maarmorilik the element concentration of elements are below EU standards.

This report also describes the environmental background conditions after closure of the former mining operation based on the closure plan of the Greenex operation and on information and observations gathered during closure operations. Finally, the report gives recommendations on how to deal with waste left from the previous operations on the site.

Eqqikkaaneq

Ingerlatseqatigiiffik Angel Mining Greenex ”Inngili Qernertumi” aqerlumik zinkimillu piiaavimmik Greenexip Maarmorilimmi 1973-imiit 1990-mut ingerlassimasaanik maanna ammaaqqilersaarpoq. Tunisassiornermut piareersarluni Angel Mining maanna sanaartugassanik suliaqarpoq. Piareersarnerup ingerlanerani tamaani mingutsitsisoqarsimanera paasineqarpoq. Taamaammat aatsitassarsiorneq aallarteqqitsinnagu Danmarkimi Avatangiisinik Misissuisoqarfik avatangiisit qanoq issusiat uppernarsaatissiorumallugu pingaartumik Maarmorillup eqqaani misissuisarpoq. Misissuinermut tassunga atatillugu 2008-imi augustimi nunaminernik marraminernillu tigooraasoqarpoq. Misissugassat oqimaatsunik saffiugassaqassusiinik uuliallu akuinik akoqassusiinik misissuiffigineqarput. Aammattaaq imeq uillullu misissuiffigineqarput.

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Resume

Selskabet Angel Mining planlægger for tiden at genåbne bly-zink minen "Den sorte Engel", som blev drevet af Greenex i Maarmorilik fra 1973 til 1990. Angel Mining har startet konstruktionsarbejde som forberedelse for at starte produktion. I forbindelse hermed blev der set tegn på, at et område var forurenet. Derfor har DMU udført en undersøgelse for at kunne dokumentere miljøtilstanden, særligt i selve Maarmorilik området, før starten af en ny mineoperation. Som led i denne undersøgelse blev der indsamlet jord- og sedimentprøver i august 2008. Prøverne blev analyseret for tungmetaller og oliekomponenter. Der blev også indsamlet og analyseret nogle få vand- og muslingeprøver.

Analyserne af jordprøverne viser, at der er en betydelig forurening med tungmetaller i området, hvor det tidligere koncentratlager lå. Dette er forventeligt, da området blev anvendt til opfyldning med mineraliseret gråbjerg, da minen lukkede. Niveauerne af "Polycyclic Aromatic Hydrocarbons" (PAHs) i jord og i fjordsedimenter var lave, hvilket indikerer, at disse ikke er forurenet med olie. Koncentrationen af en række grundstoffer i drikkevand fra Maarmorilik var under EUs grænseværdier for drikkevand.

Denne rapport beskriver tillige miljøtilstanden efter lukning af den tidligere mineoperation baseret på Greenex' nedlukningsplan og på oplysninger og observationer, som blev indsamlet under oprydningen. Endelig gives der i rapporten anbefalinger om, hvordan efterladt affald fra de tidligere mineaktiviteter bør håndteres.

1 Introduction

The Greenex mining operation from 1973 to 1990 caused significant pollution on land and in the surrounding fiords. This has been documented in the monitoring studies conducted by NERI during mining and after closure. The most recent monitoring was conducted in 2009 (Johansen et al. 2010).

The company Angel Mining (BAM) has an exploitation licence and presently plans to re-open the mine. BAM has started constructing facilities necessary to start production. In doing this, indications for on-site pollution were seen. It was agreed between BAM and Bureau of Minerals and Petroleum (BMP) to document the present environmental background conditions particularly in the Maarmorilik camp site area, before the new mining operation will start. As part of this agreement, soil samples were collected at Maarmorilik and sediment samples were collected in the Affarlikassaa and Qaamarujuk fiords between August 27 and September 1, 2008. The samples were analyzed for heavy metals and oil components. Few samples of drinking water and mussels were also collected and analyzed.

The objective of this document is to describe and assess the environmental background conditions after closure of the mining operation conducted by Greenex A/S from 1973 to 1990. The document is primarily based on the closure plan of the Greenex operation, on information and observations gathered when the mine closed and on the results of chemical analyses of samples taken in 2008.

The Bureau of Minerals and Petroleum funded the study.

List of some special names used:

Nunngarut tunnel: A tunnel starting at Maarmorilik and ending at the Nunngarut ore deposit app. 5 Km´s south of Maarmorilik at an elevation of app. 600 m.
White Angel: A test mine without ore, used to train new miners before they started real mining.
Concentrate storage building: The old marble query which in 1972 was covered by a roof and used for storage of concentrates.
Hotel Greenex: A wooden building used in old days for visitors, now refurbished and renamed Hotel Maarmorilik.
D23: A part in the Black Angel mine (drift 23) that was hampered by intruding water.
Dolphins: The peers where concentrate was loaded.
Råstofdirektoratet =Bureau of Minerals and Petroleum = BMP: The office in Nuuk that regulates all mater dealing with mining and oil.
Råstofforvaltningen = The Mineral Resources Administration. The office in Copenhagen that before 1998 had the tasks that now BMP has.

2 Closure activities – waste handling

When the mine was closed, a closure plan was implemented (Anon. 1990). This plan laid down the principles for removing buildings, processing plant and all installations in a manner that would – as far as possible – restrict contamination sources to certain, inaccessible areas. The closure plan held instructions on how to conduct demolition for each functional unit. Some of the buildings and the equipment were sold or handed over to other parties. Remains from demolished buildings, installations and material were stored as described below.

The work was conducted by Greenex A/S and their consultants. The authorities (at that time "The Mineral Resources Administration" -MRA) had a representative in Maarmorilik, while demolition work was conducted, to approve on a day by day basis the work conducted. In October 1990, it was concluded that all activities involving risk of contamination from the demolishment work had been finished. In early1991 some additional work was carried out involving demolishment of the second cableway and some buildings, and in the summer of 1991 the site was left by Greenex.

Based on the closure plan and the daily reports made by the MRA representatives, this report gives an overview of the status of the closed mine site. Annex 3 contains extracts from the daily reports and Annex 4 shows photos from the demolition in 1990.

Because of the way in which the mining operation was carried out, including inappropriate ways of disposal of mine tailings and waste rock, it was realized that there would be sources of contamination left at mine closure (as described below). Therefore it was expected that the mine would impact the surroundings for years after closure, as has later been documented in the monitoring studies. However, the impact today – 20 years after closure – is at a much lower level than during mining.

2.1 Mine

The work conducted at closure included:

- Removal of fuel, grease, explosives and other dangerous or toxic substances
- Casting of a concrete wall in D-23 (the place in the Deep Ice Zone, where freshwater entered the mine) and establishing a timber construction in the Nunngarut tunnel
- Cleaning of bins and plants used for storage of ore
- Closing ventilation shaft
- Closing entrance to Nunngarut tunnel and White Angel.

Machines, installations and equipment were left in the mine after removal of fuel. Grease in the engines of vehicles could be left, if they were placed in an area, from where oil spills were not likely to spread. Transformers were treated separately, see section 2.8.

In D-23 a concrete wall was build to prevent water from The Deep Ice Zone to enter the Angel Zone. However, this wall was not tight enough to prevent water from still seeping. This water diverted to sumps and from there to an outlet at the Tributary Glacier. In the ventilation opening over the Nunngarut Mine a timber construction was set up to prevent water from entering the mine. A similar timber construction was made below the N1 area and above the N2 area in the Nunngarut Tunnel.

All constructions in the area between the mouth of the tunnel (with the conveyer belt transporting ore from Nunngarut) and the ore bin were removed after cleaning for ore and moved to waste storage areas.

The waste storage areas comprised the former concentrate building area, the ore bin and some areas in the former flotation building. Only cleaned equipment and scrap from the demolishment (as described below) were placed in these waste storage areas outside the mine areas. At the end of the operation, the storage areas were covered by a layer of crushed marble.

2.2 Cableways

The closure work included removal of the ore/person cableway and the service cableway including the terminals in Maarmorilik. The ore cableway was removed and stored in the concentrate storage pit in 1990. A transformer at the lower terminal contained the chemical Clophen and thus was treated as described in section 2.8. The service cable way was removed in 1991.

2.3 Production facilities

The work included cleaning the fine ore bin, removal of the ore conveyer belt, the flotation plant, the concentrate conveyer belts, the tailings pipe, the concentrate storage building and the concentrate loading facility.

The fine ore bin was cleaned of ore, which was deposited in the Nunngarut mine. However, about 400 tons of ore at the bottom could not be removed and were left behind. Three openings for emptying ore from the bin were welded. The bin was then filled with cleaned scrap and covered with crushed marble.

The tunnel for ore transport from the ore bin to the flotation plant was closed with a cast concrete wall. The transport belt in the tunnel was left where it was. The construction with belt west of building B2021 was cleaned for ore, which was deposited in the Nunngarut mine. This construction was cut down to the foundation level and was deposited in the waste storage areas.

In the flotation plant all equipment was removed, including mills, flotation cells, filters, drying ovens etc. Initially all equipment and supporting steel constructions were cleaned by high pressure flushing and the water from this was cleaned by sedimentation in a sump or by filtration in a thickener. The sludge was deposited in the lower part of the N2 area of

Nunngarut, i.e. in a dry area with permafrost so that leaching was prevented. Flotation tanks, thickener tanks and large machine parts which were difficult to clean were placed in The White Angel or in the Nunngarut Mine. Other cleaned parts were deposited in the waste storage areas. Steel constructions were cut down to foundation level and were deposited in the waste storage areas. The mill floor, basements and room below the thickeners were filled with cleaned waste from the demolishment and covered by crushed marble. The zinc thickener, foundations of buildings and machines were left as they were.

The concentrate conveyor belt and its construction (between the flotation plant and the concentrate storage building and between this building and the loading facility) and the loading facility were vacuum cleaned. The areas below the conveyor belts were cleaned. The material from the cleaned areas was deposited in the lower part of the N2 area of Nunngarut, i.e. in a dry area with permafrost so that leaching was prevented. The belt and supporting construction was cut down to level of foundation and was deposited in the waste storage areas. Some constructions that were difficult to compress may have been deposited in The White Angel or in Nunngarut. The harbour and the quay constructions were left as they were.

The tailings pipe and supporting constructions were removed and deposited in the waste storage areas. The tailings discharge arrangement at Dolphin 4 was cut below sea level and deposited in the waste storage areas. Foundations of buildings and machines were left as they were.

In the concentrate storage building the walls were first cleaned with machine operated shovels and brushes. After that the walls were either rinsed by vacuum cleaning, compressed air or by high pressure flushing. Before demolishment of the roof construction and the roof itself, everything was cleaned with manual brushes and with vacuum cleaning. This was repeated after the demolition of the roof construction and the walls. The floor was cleaned with machine operated shovels and brushes. Concentrate and material from cleaned areas not shipped out were deposited in the lower part of the N2 area of Nunngarut, i.e. in a dry area with permafrost so that leaching was prevented. All installations were left as they were. The edges of the pit (that used to host the concentrate building) were blasted in order to leave clean marble at the surface of the pit and prevent remains of concentrate to be exposed. The pit was used extensively as a waste storage area for cleaned equipment etc. Having finalized this the original plan was to cover all of the area with crushed marble, but as some waste rock had to be placed here too (see section 2.9 below), this was not done until the placement of the waste rock had been finished.

2.4 Buildings

All buildings except Hotel Greenex and the hangar were demolished. Constructions were cut down to level of foundation and were deposited in the waste storage areas. Fixed foundations were left as they were. Buried tubes, drains, cables etc. were cut below terrain surface and deposited in the waste storage areas. Holes were filled.

2.5 Supply plants

The work included removal of the power and water supply plants (diesel generators, transformers, desalination plant, boilers, tanks, pumps, water treatment plant), backup power plant, tank farm (steel tanks for diesel fuel and jet-fuel, pumping arrangement in steel shed, concrete reservoir, fuel tanks at power plant and at other sites, foam extinguishers), water tanks for salt and freshwater, supply boxes with tubes for water, drain and oil).

All tanks were emptied. Diesel was filled in drums or tank truck for re-use. Grease was removed from engines and treated as described in section 2.8. Transformers were removed as a whole and treated as described in section 2.8. Other electric equipment was deposited in the waste store areas. Engines or parts of these difficult to compress were stored in the White Angel or in the Nunngarut Mine. The pumping basement and well at the harbour was filled with crushed marble. The tank farms were cleaned before demolishment. Sludge and other cleaning products were put into drums for destruction outside Greenland. The tanks in the tank farm were cut up and the placed in the waste deposit areas, in the White Angel or in the Nunngarut Mine. Other fuel tanks were deposited in the White Angel or in the Nunngarut Mine. The foam extinguisher plant was emptied and deposited in the White Angel or in the Nunngarut Mine. Tubes used for fuel or foam extinguishing equipment were cleaned and deposited in the White Angel or in the Nunngarut Mine.

2.6 Other work

The work included the cleanup of the explosive storage, other storages, roads and heliport, the rubbish dump and ditches.

Remaining explosives were destroyed or exported. Storage areas were emptied. If storage areas were contaminated, e.g. by concentrate at the concentrate storage building, the contaminated layer was removed and placed in the lower part of the N2 area of Nunngarut, i.e. in a dry area with permafrost so that leaching was prevented. Cleaned areas were levelled or covered by clean crushed marble. Waste, signs and damaged crash fence at roads and the heliport were removed. The rubbish dump was covered with a layer of clean crushed marble. The waste incinerator was deposited in the waste disposal area. Watercourses draining the Nunngarut Mountain were diverted around particular contaminated areas like the concentrate storage, the mill and the rubbish dump.

2.7 Exploration areas

Chemicals, oil and explosives were transported to Maarmorilik and handled as other similar waste there. Large non-combustible waste like tank vehicles was transported to The White Angel or the Nunngarut Mine. Combustible material was burned and the ash and small non-combustible waste was buried below 0.5 metres of “soil” or transported to Maarmorilik. Burial of waste was done so that melt water was not running through or eroding the area.

2.8 Transformers, oil waste and chemicals

Transformers containing Clophen were not emptied but transported as a whole for destruction outside Greenland. Other transformers were emptied for oil and either left behind (in the mine) or stored in the waste storage areas. Oil waste was burned in generators and furnaces as long as the power plant was operating. After that the waste oil was put on drums for destruction outside Greenland. Chemical waste, including remaining flotation chemicals, was sent to destruction outside Greenland. Remaining ammonium nitrate was sold. All equipment containing halon, Freon and anzul was send to destruction in Denmark, except for some Freon that was send to Uummannaq for re-use.

2.9 The North Face waste rock dump

This waste rock dump was located on the northern slope of The Black Angel Mountain. It was in use since mine construction in 1972 and until 1978. In 1989 Greenex estimated that this dump contained 403000 tons of ore with 0.72% lead and 2.00% zinc. It contained about 80% dolomite. A picture of the dump as it looked in 1986 is shown below. This dump was considered particularly important as a source of lead and zinc pollution, as it was a direct source to the sea, forming part of the coastline along a 210 metres stretch.

The North Face dump in 1986 (Photo: Poul Johansen).

In June 1990 two excavators and four bulldozers started to bring the dump material to sea level from up to 260 metres a.s.l. The dump had a slope of about 30°. It was partly frozen and had to be blasted. Two dumpers and two frontend loaders were used to load the dump material into a split barge, which emptied about 800 tons at one time into the dumping area in Affarlikassaa. Some turbidity could be seen for about 10 minutes after the barge had emptied a load. It was estimated that 320000 tons of waste rock was dumped into Affarlikassaa. But then the dumping became a political issue, and the dumping had to be stopped on August 22. The MRA had to change plans and it was decided to place the remaining part of the waste dump in the waste storage in the area of the old concentrate building. This meant that the waste rock had to be unloaded at a quay that was constructed in Maarmorilik and transported on dumpers and it was not possible to avoid spillage of waste rock in Maarmorilik during that process, because the equipment used was not suited for the work (this was an un-planned operation). During unloading and transport, spill of waste was observed, maybe 1-2% of the amount transported. After the work was finished, the top layer of the quay area and the road between this and the former concentrate building was dug up and transported to the waste deposit in the former concentrate building. One quarter of the dump was deposited in this waste storage area on top of previous stored remains of buildings and equipment as described in other parts of this report. Afterwards the waste storage was covered with a layer of clean crushed marble. It was not possible to move the whole dump and a significant, but unknown amount is still present underwater below the dump foot. Without doubt, some remains of waste rock have also been left in Affarlikassaa at the quay area, which was constructed for unloading waste rock. Finally, some remains are also left on land at the quay and on the road used to transport the waste to the former concentrate building.

2.10 Other waste rock dumps

There are 6 other waste rock dumps located in the Maarmorilik area as shown in Figure 1. Until 1985 waste rock was dumped outside the mine unregulated, but since 1985 a control program was put in place implying that only waste containing less than 0.1% lead could be dumped outside the mine. The waste rock dumps (N1 and N2) associated with the development of the Nunngarut Mine were made after the introduction of the control program and have low content of lead and zinc. The Tributary Dump also has a low lead and zinc concentration. An overview of the estimated amounts of rock and the lead and zinc content in these three waste rock dumps is shown in Table 1.

Table 1. Waste rock dumps, see also Figure 1 (Greenex, 1989).

Name	Amount (tons)	% Pb	% Zn
D1, G-west	13000	0.8	2.3
17x-cut	670000	0.8	2.3
Tributary-dump	1500000	0.1	0.3

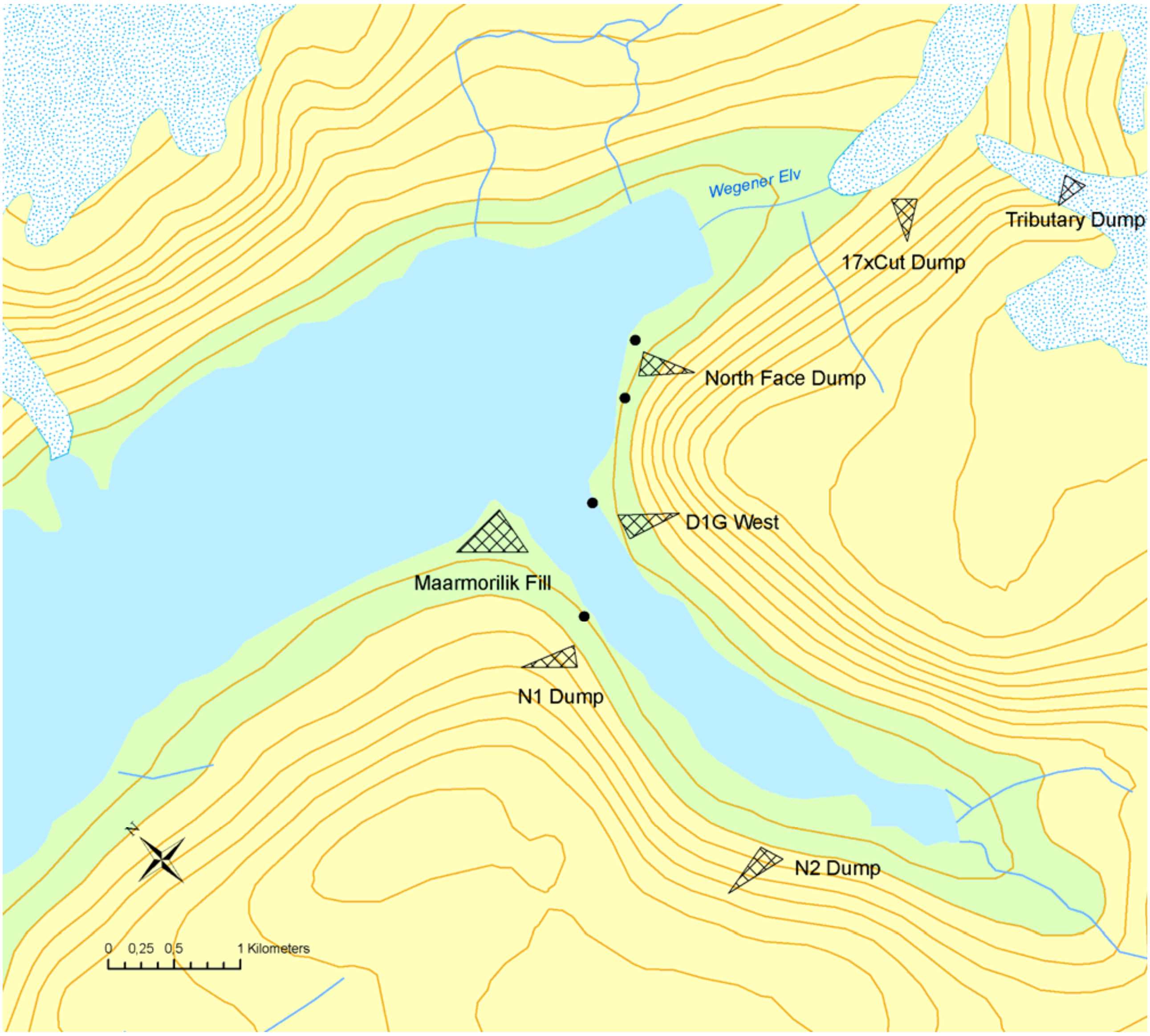


Figure 1. Sketch map of the most important waste rock dumps in the area surrounding Maarmorilik. "Maarmorilik Fill" refers to the area where clean marble was used as a coverage at several places adjacent to the mine site, including the area where waste rock was deposited in the former concentrate storage facility. N1 dump and N2 dump are waste rock dumps from the Nunngarut mine, D1G,west is an old waste rock dump from the first years of mining. Gl. North Face Dump is the waste rock dump that was removed at mine closure in 1990. The Tributary dump is the dump placed on the Tributary Glacier, and the 17x-cut dump is a waste rock dump placed in the Wegener valley.

These dumps, probably mainly the 17x-cut dump, are still a source of lead and zinc being transported with water to the fiords. In the late 1980s Greenex estimated that the Wegener River, draining the valley where the 17x-cut dump and the Tributary dump are located, annually carried 5.7 tons of lead and 18 tons of zinc primarily in particles to the river outlet in the inner Qaamarujuk.

2.11 Tailings

During mining from 1973-90, about 8 million tons of tailings were discharged into the Affarlikassaa fiord and almost all of it settled there. After mine closure, seawater measurements performed by NERI indicate that the tailings are no longer releasing lead to the water column, whereas zinc is still released, but less than during mining (Schiedek et al. 2009).

2.12 Dust sources

During mining, in particular during the first years, significant amounts of lead and zinc were transported as dust via the atmosphere and deposited on land and in the sea. The main sources were the ore crusher in the mine and the handling of concentrate. In 1980 a study of ground surface samples from Maarmorilik showed that there were highly elevated lead and zinc levels. In 49 surface samples the lead concentration was 2.46±2.18% (mean±SD) and the zinc concentration 4.41±3.70% (Greenex, 1989). Studies of lichens as part of the regular environmental monitoring programme have shown that dust is still a pollution source almost 20 years after mine closure. It appears likely that the dust source is redistributed dust created and dispersed in the area at the time when Greenex operated the mine (Johansen et al. 2010).

2.13 Oil pollution incident in 1979

On August 13, 1990 an oil film on the fiord at the harbour was observed, but it quickly evaporated, and there was no oil observed the day after. It is likely that the source of this pollution was a spill in 1979 below the lower terminal of the service cable car. According to Greenex personnel, the contaminated soil was removed in 1979 but not all oil could be removed, and oil leaching from the area has occasionally been observed since then.

3 Chemical analyses in 2008

3.1 Soil samples

The environment around the Maarmorilik mining site is well documented as part of the ongoing annual environmental monitoring studies performed by NERI during and after the mine operation. However, the area where the old mining facilities have been located has not been regularly investigated. In August 2008, soil samples were taken at different locations at the mine site (Figure 2 and pictures below). All samples were deep-frozen (-20°C) directly after collection and later analysed by an institute in Germany for metals following standard international protocols (e.g. OSPAR, HELCOM) and quality measures (QUASIMEME). PAH measurements on soil samples were conducted by NERI (Department of Environmental Chemistry and Microbiology).

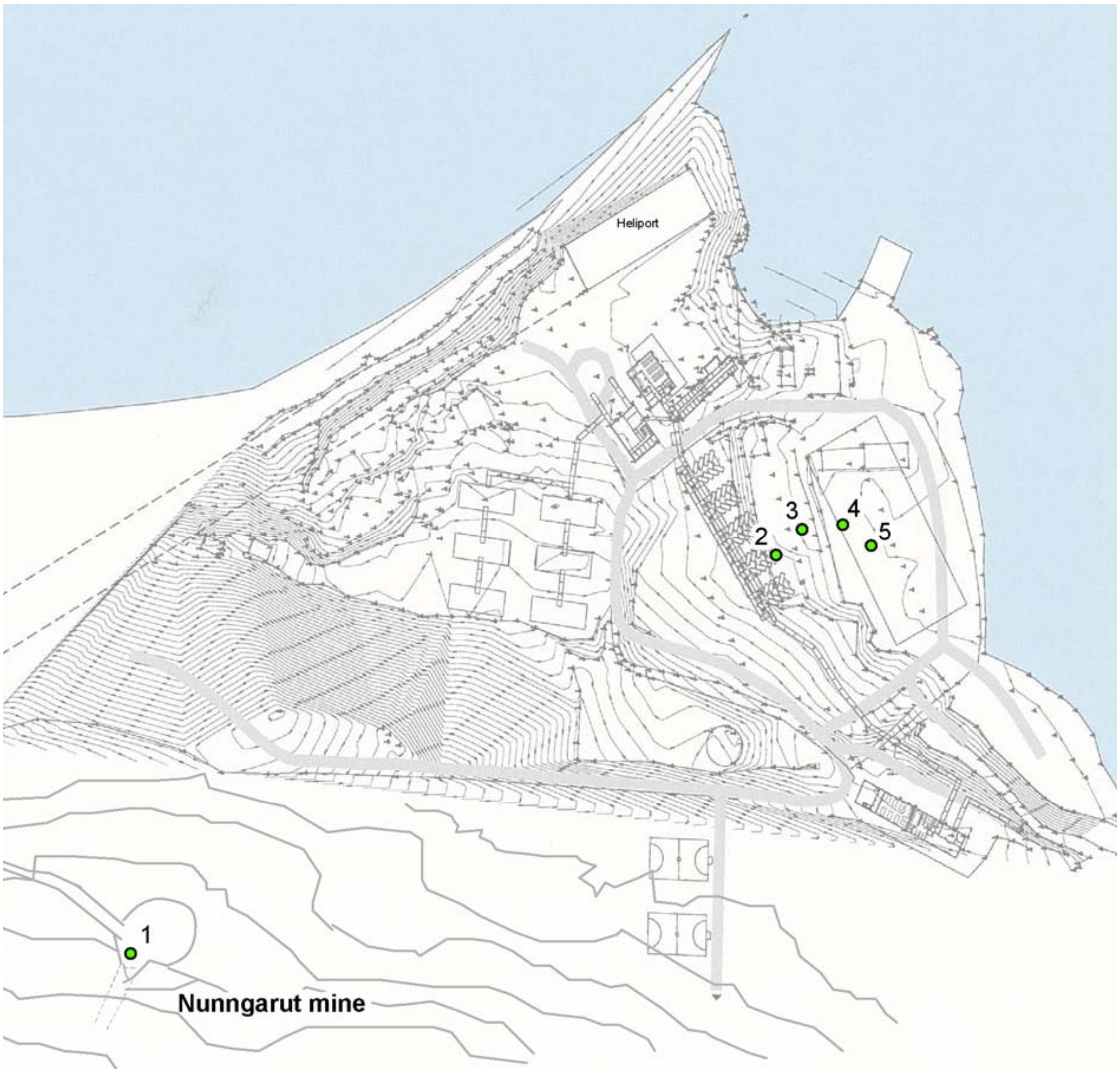


Figure 2. Map of Maarmorilik indicating the sites where soil samples (1-5) was taken in 2008 (see picture below).

Sample 1. Entrance to the Nunngarut tunnel. Photo: Doris Schiedek.

Sample 2 and 3. Composite soil sample from a trench (about 50 cm deep) made below the old concentrate storage building. Photo: Doris Schiedek.

Sample 4. Composite soil sample from the same trench with unknown green precipitate on the surface. Photo: Doris Schiedek.

Sample 5 was a composite soil sample from the trench area, prepared from 5 sub-samples.

The chemical analyses revealed high contents of different metals in all 5 soil samples (Annex 2, Table A2) among them were lead (Pb), copper (Cu), zinc (Zn), cadmium (Cd) and mercury (Hg). The highest copper concentrations were found in sample 4, which explains the green precipitate found in the soil. The concentration of other relevant metals was highest in sample 3 (Figure 3 and 4). The high metal concentrations in the samples taken in the trench are very likely the result of the waste rock disposal in the old concentrate storage building and the area around it during closure as described in Section 2.1.

Figure 3. Concentration of zinc, lead and copper in soil samples from Maarmorilik in August 2008.

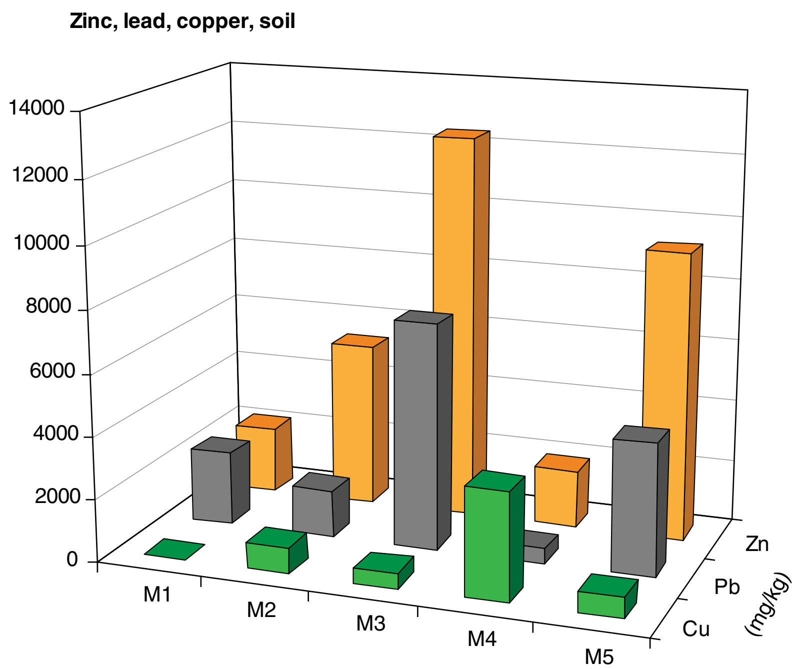
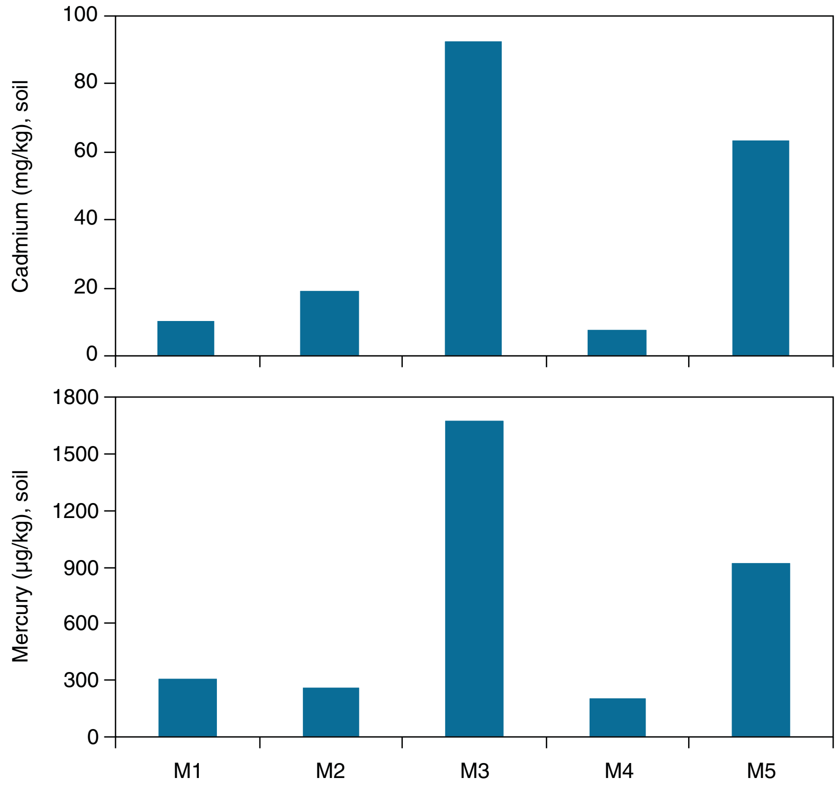


Figure 4. Concentration of mercury and cadmium in soil samples from Maarmorilik in August 2008



The results from the PAH analyses are shown in Table 2. In all three samples, the PAH-concentrations were very low, even lower than in the sediment samples taken in the fiords next to the mine (see below). Due to the low concentrations, it is not possible to establish weather the PAH's originate from petrogenic or pyrogenic sources.

Table 2. PAH concentrations (mg/kg d.w.) in soils samples taken at Maarmorilik in August 2008.

AM ID	M2	M3	M4
MIMI ID	2009-7361	2009-7362	2009-7363
Naphthalene	0.030	0.008	0.032
2-Methylnaphthalene	0.025	0.007	0.029
1-Methylnaphthalene	0.091	0.017	0.084
Dimethylnaphthalenes	0.194	0.067	0.308
trimethylnaphthalenes	0.306	0.123	0.521
acenaphthylene	<0.003	<0.003	0.055
Acenaphthene	0.612	0.466	0.905
Fluorene	n.a.	n.a.	n.a.
Dibenzothiophene	n.a.	n.a.	n.a.
C1-Dibenzothiophenes	n.a.	n.a.	n.a.
C2-dibenzothiopenes	n.a.	n.a.	n.a.
Phenanthrene	0.086	0.246	0.301
2-methylphenanthrene	0.024	<0.005	0.045
C1-phenanthrenes	0.177	0.010	0.287
3.6-dimethyldimethylphenanthene	0.028	<0.005	0.022
C2-Phenanthrenes	0.322	0.013	0.303
C3-Phenanthrenes	0.087	0.030	0.037
Antracene	0.034	0.172	0.061
Benz(a)fluorene	<0.003	<0.003	<0.003
Fluoranthene	0.023	0.007	0.033
Pyrene	0.035	<0.003	0.051
1-methylpyrene	<0.003	<0.003	<0.003
Benz(a)antracene	0.021	0.005	0.024
Chrysene/Triphenylene	0.050	0.014	0.031
Benz(b+j+k)fluoranthene	0.156	0.060	0.010
Benz(e)pyrene	0.232	0.044	0.026
Benz(a)pyrene	0.049	0.007	0.023
Perylene	0.034	0.020	0.020
Indeno(1.2.3-cd)pyrene	0.020	<0.010	0.017
Benzo(ghi)perylene	<0.005	<0.005	0.009
Dibenzo(ah)antracene	<0.010	<0.010	0.033
Sum PAH	2.636	1.316	3.268

3.2 Marine sediments

In addition to soil samples, sediment samples were taken at different locations in the Affarlikassaa and Qaamarujuk fiords (Figure 5 and Annex 2 Table A1) and analysed for metals and PAHs. Results are shown in Annex 2, Table A3 and A4.

The zinc and lead concentrations were highest in the marine sediment samples taken in the A-fiord (T1 and T2, Figure 6). At station T2, the level in the surface layer was almost the same as in 10-15 cm depths, whereas at T1, the zinc concentration was more than twice as high in the deeper part of the sediment (Figure 6). This is probably a result of differences in sedimentation rates at the two sites. Beside zinc and lead, mercury and cadmium also show higher concentrations in the sediments at station T1 and T2 (Figure 7).

Figure 5. Map showing the locations, where the sediment cores were taken: S1 (T1-1 S1/B1); S3 (T2 S3/B3); S5 (T22 S5/B5) and S7 (T12 S7/B7). Blue mussels were sampled at station T1. Included are also the stations used in the annual environmental monitoring programme in Maarmorilik.

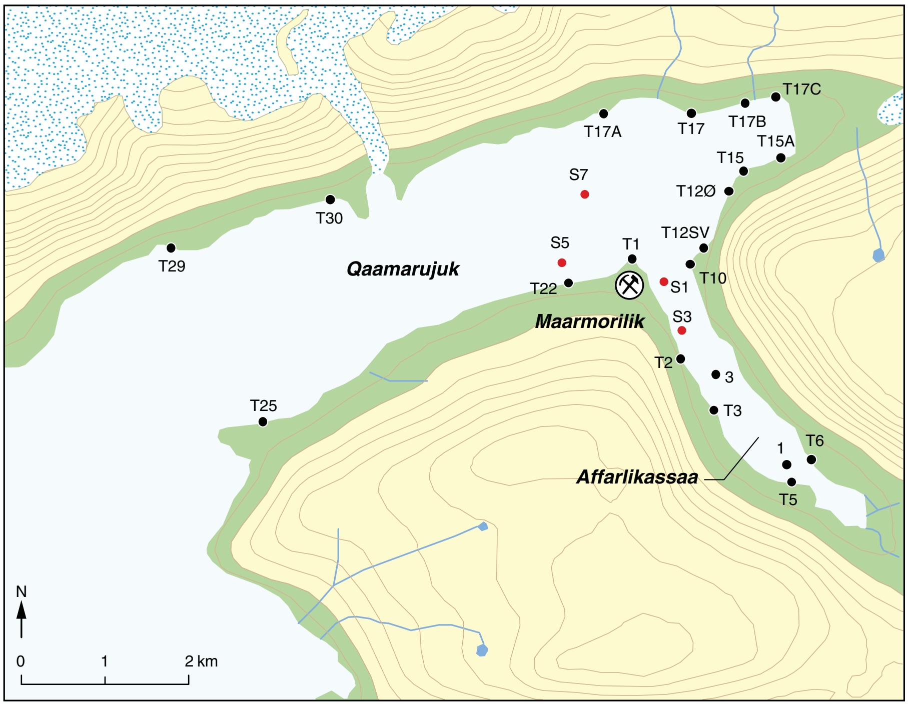


Figure 6. Concentration of zinc (Zn), lead (Pb) and copper (Cu) in marine sediments from the Affarlikassaa and Qaamarujuk fiords and in blue mussels from Station T1.

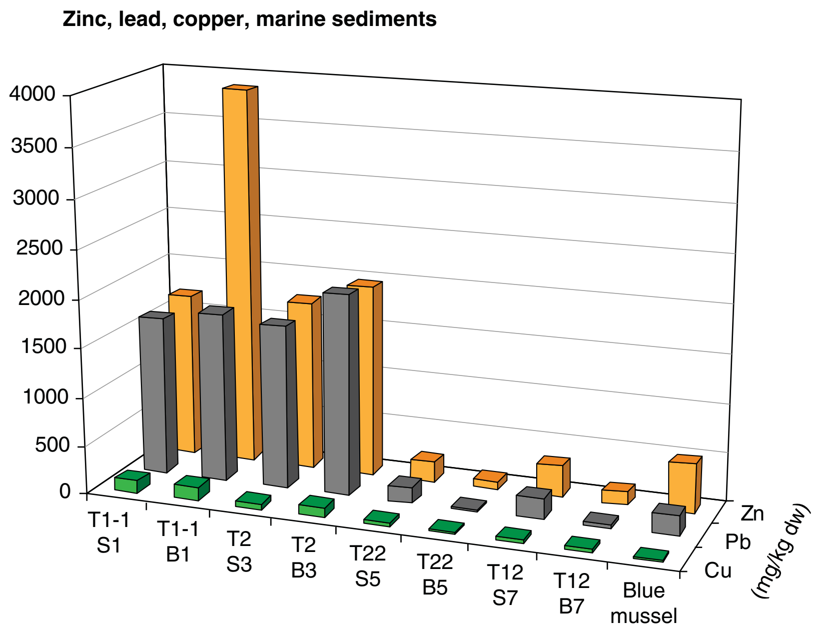
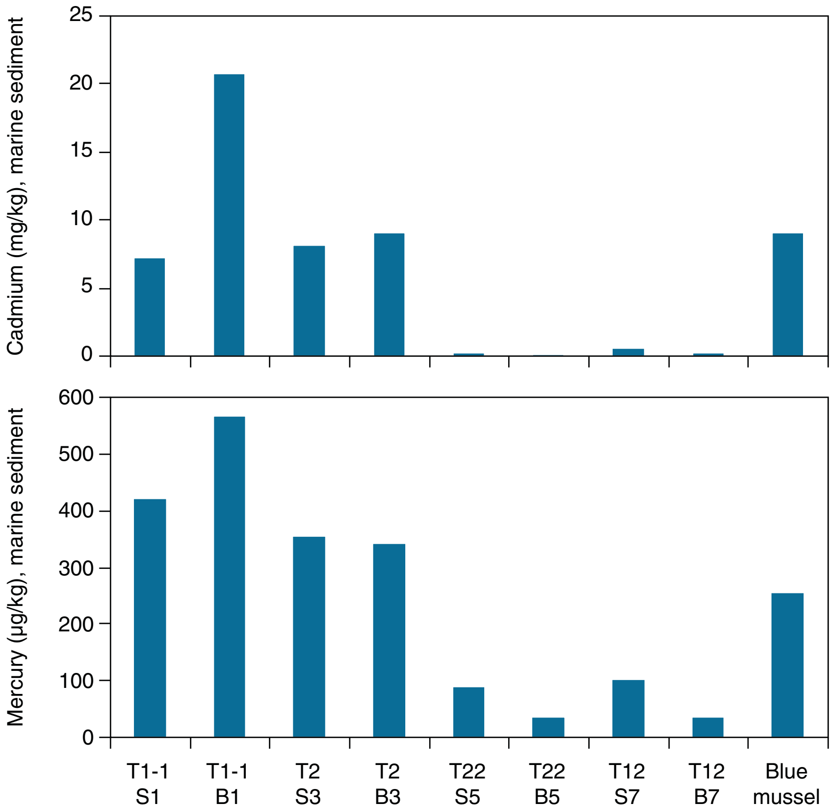
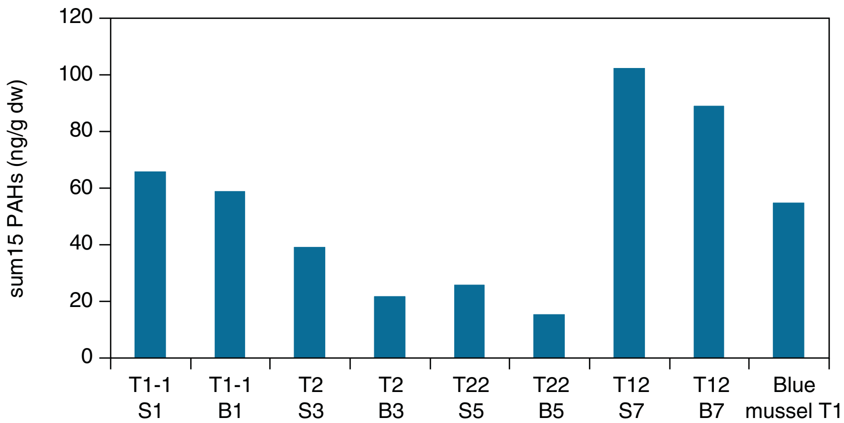


Figure 7. Concentration of cadmium (Cd) and mercury (Hg) in marine sediments from the Affarlikassaa and Qaamarujuk fiords and in blue mussels from Station T1.



The analyses of the content of Polycyclic Aromatic Hydrocarbon (PAH) in the sediment showed relatively low PAH levels in all samples. The total concentrations of 15 representative PAHs are presented in Figure 8. The highest levels (about 100 ng/g dry wt) were found in the core from the deeper part (190 m) of the Q-fiord (T 22), which indicates that this area acts as a sink for PAHs which have been transported and accumulated there over the years. In general, the concentrations found can be considered as background levels since they are in a similar range as those found in other parts of Greenland (Mosbech et al. 2007). Even the level found at station T22 is still 5 times lower than in surface sediments from Thule Airbase or from locations close to other dump sites near towns and settlements in Greenland (Mosbech et al. 2007).

Figure 8. Sum of 15 PAHs (ng/g dry wt) in marine sediments (T1, T2, T12, T22) in the upper 4 cm (S) and between 10-14 cm depths (B) and in blue mussel from St. 1 (T1)



The main PAH compounds in all samples were fluorene, which is an indicator for petrogenic sources and phenanthrene, fluoranthene and pyrene (Figure 9). They are all pyrolytic compounds originating either from combustion processes or long distance transport via the atmosphere.

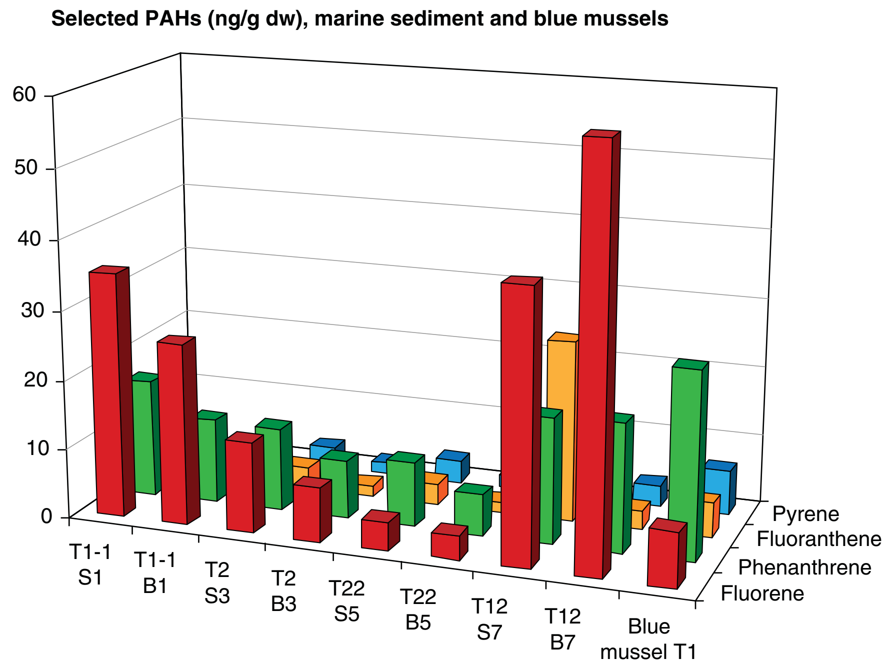


Figure 9. Concentration (ng/g dry wt) of selected PAHs in marine sediments (T1, T2, T12, T22) and blue mussels from St. T1.

3.3 Blue mussels

Blue mussels from a location closed to the camp site (Station T1) were collected and analysed for trace metals and PAHs. The results are shown in Table A3 and A4 and in Figure 6-9. In the previous years, no mussels were found at this location. Their re-settlement could be an indicator for the improvement of the environmental conditions in this area. The metal content found in the mussels (i.e. zinc, lead), however, is as high as in mussels from stations T12SV or T10, which are the stations monitored regularly and which show the highest lead and zinc levels in the area (Johansen et al. 2008).

Among the PAHs measured, phenanthrene showed the highest concentrations in the mussels, but the level was clearly lower than in blue mussels from more polluted locations in South Greenland (Mosbech et al. 2007).

3.4 Drinking water

In August 2008 the drinking water at Maarmorilik was produced by inverse osmosis from seawater taken close to Maarmorilik. Since it was known that seawater was polluted with lead and zinc there could be a risk that the drinking water produced from this seawater could also be contaminated. Water samples were collected in August 2008 and analyzed for a number of elements by NERI. The results are presented in Table 3.

Table 3. Analyses of drinking water from Maarmorilik and EU drinking water standards (µg/kg).

	Mean detection limit	EU drinking water standard	Kitchen 31/8-14:30	Kitchen 31/8-14:30	Bathroom 31/8	Kitchen spare sample
Li	0.20		1.31	1.19	1.10	1.67
Be	0.003		<dl	0.008	<dl	<dl
Na	68	200000	105053	90096	115783	105711
Mg	0		5374	5318	5906	5391
Al	1.2	200	45.3	168.3	<dl	<dl
P	7.61		<dl	9.44	<dl	<dl
S	510	83000	6788	4178	7945	7315
K	30		3228	3572	3268	3655
Ca	2		5029	4792	4568	5322
Sc	0.28		<dl	0.46	<dl	<dl
Ti	0.11		4.43	15.03	0.14	0.23
V	0.02		0.34	0.36	0.38	0.16
Cr	0.08	50	1.19	0.23	0.26	0.17
Mn	0.03	50	0.13	0.10	0.07	0.03
Fe	4.53	200	35.57	124.70	<dl	6.52
Ni	0.08	20	1.14	1.84	<dl	<dl
Co	0.02		<dl	<dl	<dl	<dl
Cu	0.03	2000	0.33	0.43	0.23	0.15
Zn	0.03		2.24	1.64	3.77	2.69
Ga	0.017		<dl	0.019	<dl	<dl
As	0.35	10	<dl	<dl	<dl	0.56
Se	0.71	10	<dl	<dl	<dl	<dl
Rb	0.01		0.53	0.54	0.53	0.64
Sr	0.01		38.11	50.55	36.87	44.34
Y	0.001		0.004	0.022	<dl	<dl
Zr	0.008		<dl	<dl	<dl	<dl
Mo	0.12		<dl	<dl	<dl	<dl
Rh	0.002		<dl	<dl	<dl	<dl
Pd	0.010		0.028	0.011	0.032	0.023
Ag	0.08		<dl	<dl	<dl	<dl
Cd	0.01	5	<dl	<dl	<dl	<dl
Sn	0.010		0.028	0.031	0.021	0.031
Sb	0.05	5	<dl	<dl	<dl	<dl
Te	0.03		<dl	<dl	0.04	<dl
Cs	0.003		0.005	0.009	<dl	0.008
Ba	0.019		0.207	0.449	0.068	0.126
La	0.001		0.002	0.007	<dl	0.001
Ce	0.001		0.003	0.017	<dl	<dl
Nd	0.010		<dl	0.016	<dl	<dl
Ta	0.002		0.004	0.009	<dl	0.004
W	0.14		<dl	<dl	<dl	<dl
Au	0.037		<dl	<dl	<dl	<dl
Pt	0.002		<dl	0.002	<dl	0.002
Hg	0.038	1	<dl	<dl	<dl	0.082
Tl	0.011		0.066	0.049	0.031	0.020
Pb	0.005	10	0.119	0.142	0.166	0.118
Bi	0.0010		<dl	<dl	<dl	<dl
Th	0.0003		0.0008	0.0016	<dl	<dl
U	0.0005		0.0012	0.0037	0.0026	0.0013

Table 3 shows that the concentration of all elements are below EU drinking water standards (anon. 1998), where standards exist. The zinc concentration (for which there is no EU standard is low and lower than the standard for cadmium and is therefore considered acceptable. The sodium concentration is high (about half of the EU standard) because the drinking water is prepared from seawater.

4 Conclusion and recommendations

The results of the chemical analyses of the soil samples taken in August 2008 clearly indicate high metal pollution in the "storage area" of the former mine site. This is not surprising, since this area was used to store waste rock, when the mine was closed. PAH levels in soil samples were low, indicating that the soil is not significantly polluted by oil. . In drinking water from Maarmorilik the element concentration of elements are below EU standards.

4.1 New constructions

Waste rock has been spilled over most of the areas between the old concentrate storage building and the harbour. These areas have been covered by clean marble, but below the marble potential pollution sources still exists. Dust from concentrate handling has also been dispersed during the mining operations, which contributes to the contamination of soil in the area.

It is recommended to take these facts into account when planning new constructions. If this implies digging in the soil, one has to assume that the soil below the top marble layer is contaminated with lead, zinc and copper. It is easy to see the difference between the marble and the underlying soil. The soil below the marble layer should be treated as being polluted and deposited in a safe way. One safe way could be to transport it into side-tunnels of the Nunngarut tunnel in areas without water flow and which are not foreseen to be used for future mining.

4.2 Use of old tunnels

Since the Nunngarut tunnel and the White Angel have been used to deposit contaminated waste, it is recommended not to re-open the White Angel as well as to leave the waste that has been deposited in the Nunngarut tunnel. In case the waste deposited in the Nunngarut tunnel has to be removed, it is recommended to treat it as contaminated waste and redeposit it in other places in the Nunngarut tunnel system that are not in use.

4.3 Oil pollution

Both the sediments of Affarlikassa fiord and the soil have quite low concentrations of oil components e.g. PAH, indicating that oil pollution is not a significant problem in Maarmorilik. Other oil contaminated areas however may exist, e.g. below the lower terminal of the former service cable car. If oil contaminated soil is found, it has to be treated as contaminated waste and deposited in a controlled manner (as described above).

5 References

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Annex 1. Oil analyses

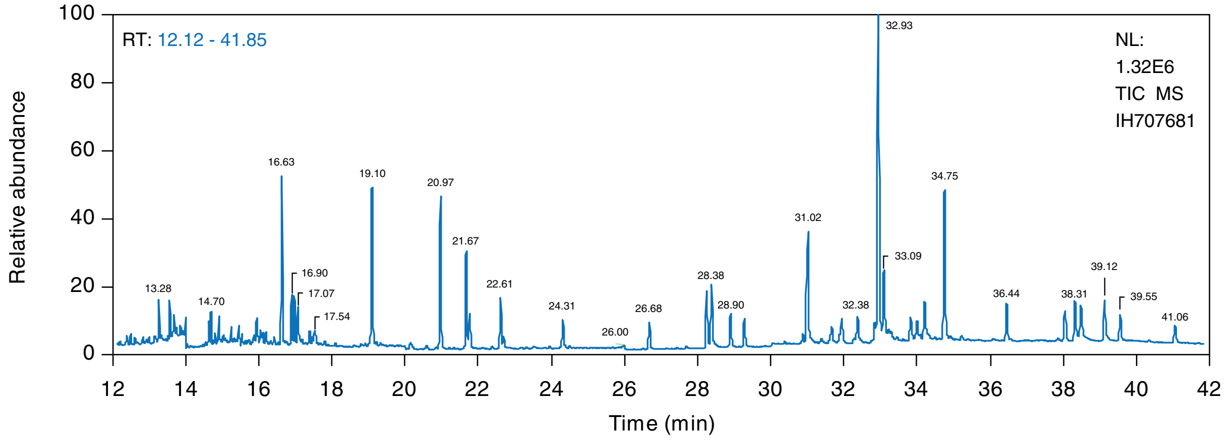
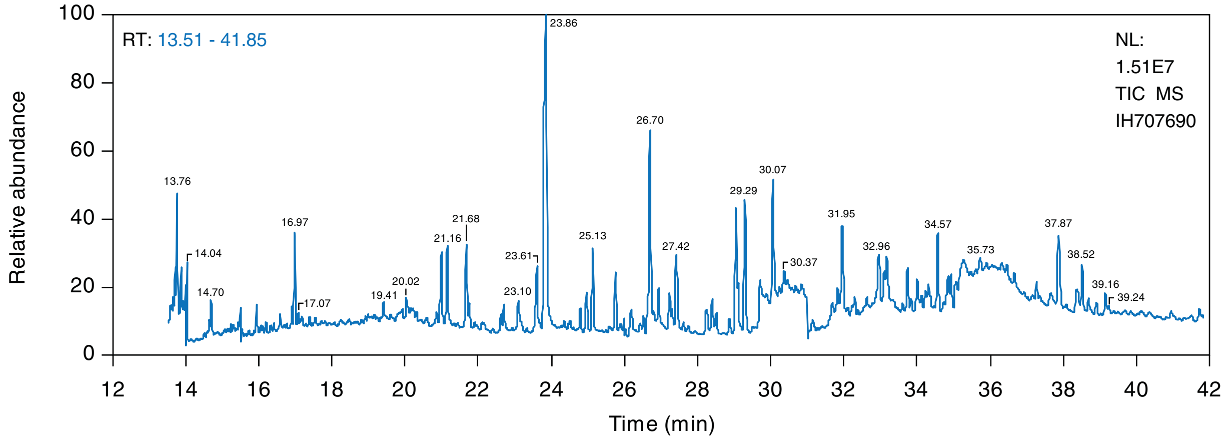
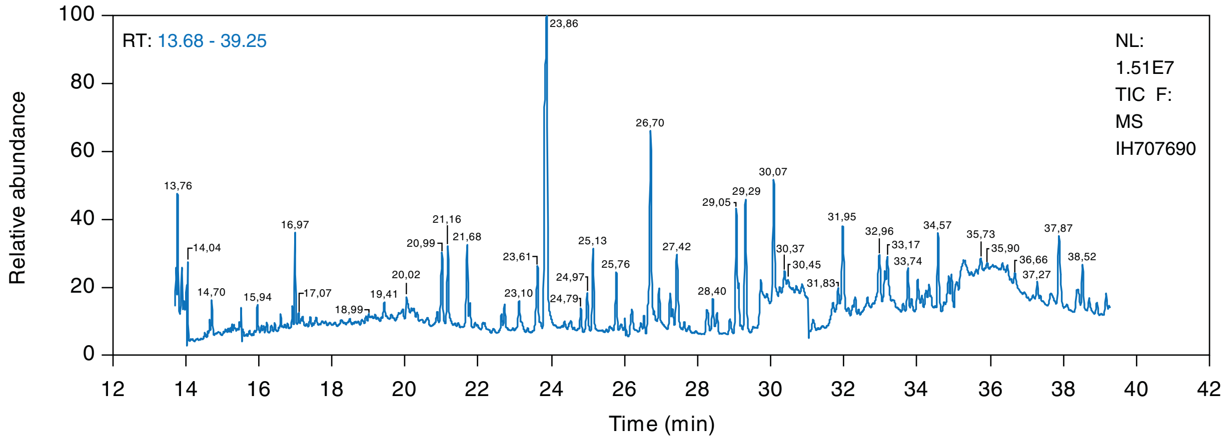


Figure A0.



FigureA1. Chromatograms of two sediments samples (39518 T2 B3 (upper) and 39519 T22 S5 (lower)).



FigureA2. Chromatograms of blue mussel Station 1.

Annex 2. Sediments

Table A1. Sediment sampling, Maarmorilik August 29, 2008. Samples were taken with a Haps corer in the proximity of the existing monitoring stations. For the PAH analyses, subsamples were taken with a plastic tube (ø 55mm) of the upper 4 cm (surface sediment –S) and at 10-14 cm depth (“bottom” –B). In addition, the fraction 4-10 cm was kept for most cores and deep frozen.

ID No.	Station	Sample	Co-ordinates	Depth (m)	Remarks
	T1	S	71°07' 720N	6	
			51°16' 389W		Very rocky, hard bottom community, only sample from surface which was taken directly from the Haps core
39517	T1-1	S1, B1	71°07' 581N	31	Surface and first 4-5 cm, fine sediment partly fluffy
		S2, B2	51°15' 910W		Lower part of the core > 6-8 cm, sandy sediment with silver shinning particles in it
39518	T2	S3, B3	71°07' 638N	47	Bioturbation in upper 4 cm, small polychaetes were visible, Surface consisted of fine sediment
		S4,B4	51°18' 259W		
39519	T22	S5, B5	71°07' 702N	51	Polychaete tubes were visible on the sediment surface; sandy-muddy sediment
		S6, B6	51°15' 555W		
39520	T12	S7, B7	71°08' 144N	170	very muddy sediment in the whole core
		S8, B8	51°17' 490W		

Table A2. Metal content in the soil samples.

Sample	Al [%]	As [mg/kg]	Ba [mg/kg]	Ca [%]	Cd [mg/kg]	Co [mg/kg]	Cr [mg/kg]	Cu [mg/kg]	Fe [%]	K [%]	Li [mg/kg]	Mg [%]	Mn [mg/kg]
M 1	034	725	75	3320	105	10	7	25	063	0,14	10	486	366
M 2	088	470	235	2987	193	11	8	855	058	0,32	9	421	376
M 3	040	1065	79	2427	926	15	6	505	110	0,14	8	799	580
M 4	050	195	97	3157	76	04	4	3470	028	0,18	8	435	394
M 5	096	1098	171	2697	634	19	23	681	119	0,26	10	746	628

Sample	Mo [mg/kg]	Na [%]	Ni [mg/kg]	P [%]	Pb [mg/kg]	S [%]	Sr [mg/kg]	Ti [%]	V [mg/kg]	Y [mg/kg]	Zn [mg/kg]	Hg (µg/kg)
M 1	9	010	9	0014	2390	030	157	0017	21	2	2130	313
M 2	2	031	8	0029	1500	029	121	0065	19	5	5310	266
M 3	2	014	10	0013	7290	133	92	0018	15	2	12400	1677
M 4	1	017	4	0012	482	013	105	0015	14	2	1860	209
M 5	1	029	12	0023	4270	131	118	0036	19	4	9270	921

Table A3. Metal content in marine sediments from Affarlikassaa and Qaamarujuk fiords and in blue mussels (pooled sample of 20 individuals, length group 5-6 cm) from Station T1.

	Al [%]	As [mg/kg]	Ba [mg/kg]	Ca [%]	Cd [mg/kg]	Co [mg/kg]	Cr [mg/kg]	Cu [mg/kg]	Fe [%]	K [%]	Li [mg/kg]	Mg [%]	Mn [mg/kg]
T1-1 B1	580	3441	689	794	208	162	72	140	698	226	66	461	673
T1-1 S1	459	5551	660	1437	72	111	72	125	837	158	45	488	738
T2 B3	091	8231	360	1847	90	64	14	102	2129	032	12	504	597
T2 S3	352	5273	502	1193	82	118	43	51	1101	139	40	500	658
T22 B5	566	582	681	715	01	85	49	15	228	177	30	402	431
T22 S5	600	996	599	660	02	103	54	24	301	197	40	418	503
T12 B7	676	691	513	538	02	147	73	29	351	207	47	350	551
T12 S7	633	1972	550	650	05	147	72	41	396	220	52	446	631
T1 S1	638	1655	703	549	05	152	73	54	410	241	59	405	595
Blue mussel	016	1380	24	056	90	09	4	12	014	135	2	079	23

	Mo [mg/kg]	Na [%]	Ni [mg/kg]	P [%]	Pb [mg/kg]	S [%]	Sr [mg/kg]	Ti [%]	V [mg/kg]	Y [mg/kg]	Zn [mg/kg]
T1-1 B1	2	2,11	50	0,069	1730	3,49	143	0,300	101	14	3870
T1-1 S1	2	1,68	32	0,071	1620	4,44	155	0,218	81	11	1690
T2 B3	2	0,60	6	0,037	2050	14,72	120	0,048	21	3	1970
T2 S3	3	1,40	28	0,063	1670	8,32	125	0,179	63	9	1740
T22 B5	2	2,18	28	0,064	19	0,09	178	0,253	67	14	78
T22 S5	1	2,37	35	0,076	166	0,11	172	0,271	87	14	205
T12 B7	2	2,50	48	0,069	35	0,08	211	0,324	100	14	138
T12 S7	2	2,63	50	0,097	207	0,14	176	0,307	114	15	326
T1 S1	2	2,62	49	0,106	206	0,26	171	0,299	99	14	301
Blue mussel	1	4,38	3	0,957	203	1,94	54	0,009	6	1	500

Table A4. PAH content in marine sediments from Affarlikassaa and Qaamarujuk fiords and in blue mussels (pooled sample of 20 individuals) from Station T1

Bor Nr	Station	Sample	Acenaphthylene	Acenaphthene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Benz(a)anthracene	Chrysene	Benz(b)fluoranthene	Benz(k)fluoranthene	Benz(a)pyrene	Indeno(1,2,3-c,d)pyren	Dibenzo(a,h)anthracene	Benz(g,h,i)perylene
			ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g	ng/g
	T1	S1	*	5,86	30,35	17,74	2,66	2,49	2,38	0,53	0,87	1,24		0,84	0,88	0,13	0,89
39517	T1-1	B1	*	3,71	26,10	12,23	1,88	3,38	2,73	0,85	1,31	2,23	0,86	0,82	1,39	0,27	1,34
	T1-1	S1	*	5,47	35,16	16,90	2,14	1,44	1,79	0,27	0,52	0,76	*	0,51	0,59	nn	0,50
39518	T2	S3	*	<d.l.	13,18	11,93	1,43	3,16	2,93	0,86	1,38	1,16	*	1,15	1,08	0,21	1,03
	T2	B3	*	0,82	7,76	8,39	0,47	1,56	1,69	0,23	0,25	nn	*	nn	0,26	nn	0,35
39519	T22	S5	*	0,78	4,03	9,39	0,43	3,04	3,21	0,38	0,97	1,32	*	0,48	0,83	nn	1,05
	T22	B5	*	1,37	3,48	5,98	0,27	1,43	1,91	0,21	0,42	nn	*	nn	0,26	nn	0,43
39520	T12	S7	*	<d.l.	38,98	18,14	2,54	25,97	5,90	1,76	1,90	2,70	*	1,76	1,32	nn	1,58
	T12	B7	*	<d.l.	58,91	18,40	2,52	2,69	3,07	0,35	0,79	1,01	*	nn	0,54	nn	0,84
	1	blue mussel	*	<d.l.	7,86	26,86	2,25	5,04	6,46	nn	2,53	1,61	*	nn	0,93	nn	1,49

* = no quantification possible, <d.l. = below detection limit

Annex 3. Extracts from the daily reports from Maarmorilik during close down and demolition

This report has covered all major items regarding the placement of polluted items at Maarmorilik. The list below might contain some detailed information needed during reopening of the mine.

Date 1990	Note
August 10	**Sludge** from the cleaning of the mill is deposited in a side tunnel in the Nunngerut tunnel
August 18	**Oil** is seeping at the turn of the conveyor belt
August 20	**Diesel** is seeping out of 2 drums east of the mill. This was stopped and the polluted soil deposited in the Nunngarut tunnel
August 29	**Cables** from the cableway are deposited in the concentrate storage.
August 30	Places for deposition of **lead containing waste**: appr.2.4 Km up in the Nunngarut tunnel to the right in the sump. Further 30 m up there is another sump with room for more waste
September 4	There is **steel scra**p in the basement below the two thickeners.
September 10	**Concentrate** lost under the conveyer belt is deposited in the Nunngarut mine and in fine ore bin.
September 23	The mill: All **scrap** is collected in basements and up to the solid rocks towards south. Then covered with marble
September 27	The wood constructions at the **dolphins** are described as in bad condition. They will be a danger after some years.
October 4	**Final ore bin**: Hard frozen ore is left. Iron scrap from the cable way terminal, the machine work shop, and autoprotection fence (autoværn) is also left there. It will be covered with clean marble
October 5	**The concentrate storage is filled with**: Steel and wood from this building, The walls from the lead storage area is blasted down and deposited here, Waste from the demolition of the mill is placed here. The rubbish is mixed with and covered with waste rock. The entire Zinc storage is filled with waste rock up to the level of the surrounding terrain. The lead storage is filled with waste rock to some metres above terrain. Some waste rock is deposited north west of the concentrate storage. Some big bags of calcium oxide is deposited at the bottom of the concentrate storage area. The wall between the zinc and the lead storage is partly blasted down.
October 6	The remains of the ore **cableway terminal** are covered by marble.
October 7	The polluted **surface layer on the ground** around the harbour and the concentrate storage was removed and deposited in the concentrate storage. Then the concentrate storage was covered with clean marble

Annex 4. Photos from Maarmorilik 1990

Maarmorilik June 22.

One of the storage buildings. June 30.

The mill and the concentrate conveyor belt. July 10.

Used machinery waiting for export. August 7.


Concentrate storage building during demolition partly filled with waste. August 29.

Concentrate storage building during demolition. August 29.

The mill during demolition. August 29

The concentrate storage building demolished containing a lot of waste and a small amount of ”Old waste rock Dump”. September 5.

The concentrate storage building with more waste rock dump. September 7.

The mill during demolition. September 7.

The mill during demolition. September 10.

The former concentrate storage building filled with waste and waste rock. September 10.

The mill during demolition. September 10.

A scoop tram goes through a house. September 10.

A scoop tram goes through a house. September 10.

Annex 5. Photos from Maarmorilik after mine closure

Maarmorilik after closure seen from above. The only buildings left are a hangar and the hotel, which are visible. Photo: Gert Asmund.

Maarmorrilik after closure seen from the fiord. Photo: Gert Asmund.

Maarmorrilik after closure seen from the fiord. Photo: Gert Asmund.

Maarmorrilik after closure seen from the fiord. The hangar and the hotel are visible. Photo: Gert Asmund.

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EVALUATION OF LOCAL CONTAMINATION SOURCES FROM THE FORMER MINING OPERATION IN MAARMORILIK

The company Angel Mining presently plans to re-open the Black Angel lead-zinc mine, which was operated by Greenex in Maarmorilik from 1973 to 1990. This report describes the closure activities, particularly how environmental issues were dealt with.

In 2008 NERI conducted a study to document the present environmental background conditions in the Maarmorilik camp site area. Soil and sediment samples were collected in August 2008 and analyzed for heavy metals and oil components. The results clearly indicate high metal pollution in the “concentrate storage area” of the former mine site. This is not surprising, since this area was used to store mineralized waste rock, when the mine closed. Levels of Polycyclic Aromatic Hydrocarbons (PAHs) in soil and fiord sediment samples were low, indicating that the soil and the fiord are not significantly polluted by oil.

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