ENVIRONMENTAL MONITORING AT THE NALUNAQ GOLD MINE, SOUTH GREENLAND, 2004-2019

Scientific Report from DCE – Danish Centre for Environment and Energy No. 386 2020

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Abstract: The Environmental monitoring was conducted yearly at Nalunaq from 2004 to 2019 to monitor the environmental impact from mining during (2004-2013) and after the mining operation (2014-2019). This report provides an overview of the monitoring results and major findings. The sampling programme included lichens, arctic char, sculpins, seaweed and blue mussels, which serve as key monitoring species in terrestrial and marine environments, respectively, supplemented with fresh water samples.

The environmental monitoring documented moderate pollution associated to the mining activities. In particular was elements as As, Co, Cr and Cu found to be dispersed in the environment as dust-borne from waste rock and ore stockpiles, from rock crushing and from driving on the road. Only minor impacts were observed in the freshwater and marine environments. During the mining period of 2009-2013, cyanide was used in the gold extraction process. No increased level of cyanide has been measured in Kirkespir River and no effects of cyanide has been detected in the environment.

An aerial mapping performed in 2019 identified old driving tracks in the terrain, which has been identified as remnants from the former mine activities. In general, relatively few pieces of waste/scrap were localized in the terrain and it is assessed that it does not pose any risk to the environment, but that the impact is related solely to esthetical matters.

Overall, DCE assess that the current environmental impact from the former mining activities to the environment at Nalunaq is insignificant and that no further actions are needed to reduce the environmental impact.

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Preface

Environmental monitoring was conducted at the former Nalunaq gold mine in South Greenland from 2004 to 2019. This report provides an overview of the monitoring results and major findings. Requirements for monitoring of the environment in relation to the mining activity have been set by the Mineral Resources Authority (MRA) of the Greenland Government. These requirements are described in the MRA exploitation license of 19 March 2010, Phase 6, §§19/43, Chapter 8.

The monitoring has been performed by Danish Centre for Environment and Energy (DCE) and from 2014 the Greenland Institute of Natural Resources (GINR) has participated.

This report also describes the major findings of an aerial mapping performed by GINR in 2020.

The report is requested by Environmental Agency for Mineral Resource Activities (EAMRA).

Summary

The Nalunaq gold mine is located in Kirkespir Valley, 40 km northeast of the town Nanortalik, at the southernmost tip of Greenland. The gold deposit at Nalunaq was discovered in 1992 and in 2004 the Nalunaq gold mine opened. The ore was broken and shipped first to Europe and later to Canada for processing. Rising oil prices and shipping costs made the economics progressively difficult and the mine closed with the last shipment of ore in March 2009. In medio 2009, the mine re-opened now with full production of doré[1] in Nalunaq. A processing chamber was constructed inside the mountain and involved the carbon-in-pulp technology, which included the use of carbon and cyanide. Due to the use of cyanide to extract gold from the ore, strict control with the outflow of cyanide from the mine to the Kirkespir Valley is performed. The mining company Angel Mining Gold A/S closed its gold production in the Nalunaq area in November 2013 after which the area was decommissioned with a clean-up and restoration period lasting until August 2014.

Associated to the mining activities, there were in particular two main environmental risks: I) The risk of spreading of released metals due to the crushing effects of the body rock, ore processing, stock piling, deposition of waste-rock and tailings and driving on the gravel road. The environmental risks were associated with discharge of waste water from the process and to spreading of metals as dust particles. II) The risk of discharge of cyanide in toxic concentrations to the environment during the mining period 2009-2013. The risks were associated with discharge of mining process waste water or accidental spills of cyanide, e.g. from traffic accidents or incorrect pumping of cyanide solutions. As a result of those risks, an environmental monitoring program was developed to discover and avoid unwanted impacts to the environment.

Environmental monitoring was conducted yearly at Nalunaq from 2004 to 2019 to monitor the environmental impact from mining during and after the mining operation. This report provides an overview of the monitoring results and major findings. The sampling programme included lichens, Arctic char, sculpins, seaweed and blue mussels, which serve as key monitoring species in terrestrial and marine environments, respectively, supplemented with fresh water samples.

The terrestrial environment was impacted by a moderate pollution of the elements arsenic (As), cobalt (Co), chromium (Cr) and cupper (Cu) dispersed as a result of dust spreading by wind from crushing of ore, waste rock and ore stockpiles, but also as a result from driving on the gravel road. Recommendations were given to minimise the dust pollution. After the restructuring of the mine production in 2009, the pollution decreased. This was a result of the processing of ore, including crushing, being placed inside the mountain, and that stockpiles of ore and crushed waste rock were removed from the terrestrial environment. The dust dispersal was then primarily related to traffic on the gravel road. Upon decommissioning of the mine in 2013, the dust pollution decreased even further and in 2017, four years after mine closure, the levels of elements measured in lichens were at or close to background levels. Based on the observed

[1] A doré bar is a semi-pure alloy of gold and silver. It is usually created at the site of a mine and then transported to a refinery for further purification.

dust pollution, it is recommended for new mining projects in the future that adequate environmental requirements are set to avoid such effects in the future.

In the freshwater system, only small impacts were documented in the Kirkespir River. The river was impacted by drainage from ore and waste rock, and from 2009-2013, by diluted waste water from the mine that potentially could contain cyanide residues and elevated levels of elements. While water samples taken at the waterfall station showed no elevated concentrations of elements, the Arctic char at the site appeared, however, to accumulate some elements and in particularly Cadmium (Cd) was found at consistently slightly elevated concentrations. It was assessed that the slightly elevated concentrations cause no harm to the fish or the freshwater system. Four years after mining, in 2017, all measured concentrations in the livers of Arctic char were found to be at the same level as background concentrations. Concerning cyanide, no water samples collected in Kirkespir River have had cyanide concentrations above instrument detection limits. Cyanide is and has not at any time been considered to pose any risk to the biota including the Arctic char or to the environment.

The marine environment was monitored by analysing mussels, seaweed and livers from sculpin fish. While mussels showed no elevated element concentrations, sculpin livers and in particular seaweed samples had slightly elevated or elevated element concentrations. In particular, Cu concentrations were found to be elevated in seaweed. As it primarily was the stations around the Kirkespir River mouth that were impacted, it is assessed that the marine impact was related to accumulation of elements from the mine processing water brought to the marine environment through the river. Four years after closure, in 2017, the element concentrations in seaweed were still slightly elevated, but the concentrations are assessed to pose no risk to the biota and it is likely that the concentrations will decrease further with time.

The aerial mapping performed in 2019 identified old driving tracks in the terrain as well as various waste elements of different origins. In general, relatively few pieces of waste/scrap was localised in the terrain and it is assessed that the waste/scrap does not pose any risk to the environment, but that the impact is related solely to esthetical matters.

Overall, DCE assesses that the current environmental impact from the former mining activities to the environment at Nalunaq is insignificant and that no further actions are needed to reduce the environmental impact. The EIAs developed before the mining was initiated proved to be adequate in the way that they identified the potential impacts of the mining project. The EIA and supporting environmental studies made it possible to set environmental requirements in the license and design, and implement a suitable and detailed monitoring program. Environmental monitoring is considered to be completed with the environmental studies in 2019. Consequently, DCE considers the Nalunaq gold mine to serve as an example of how adequate environmental requirements, together with detailed environmental monitoring and regulation, can result in a mine operation in Greenland with limited environmental impact.

Eqikkaaneq

Kuultisiorfik Nalunaq Iterlassuup qooruaniippoq Nanortallup illoqarfianit avannamut kangimut 40 km-inik ungasissuseqarluni Kalaallillu Nunaata kujammut isukannianiilluni. Kuulteqarfik Nalunaq 1992-imi nassaarineqarpoq, 2004-imilu Kuultisiorfik Nalunaq ammarneqarluni. Akuiagassaq piiarneqartarpoq aallaqqaammullu Europamut kingornalu Canadamut nassiunneqartarluni suliareqqitassanngortinneqartarluni. Uuliap akitsornera assartuinermilu aningaasartuutit qaffariartornerat pissutigalugu aningaasaqarniarneq ilungersunarsiartorpoq, 2009-imi martsimi akuiagassaq kingulleq nassiunneqareersorlu aatsitassarsiorfik matuvoq. 2009-ip qiteqqunnerani aatsitassarsiorfik aammaarluni ammarpoq Nalunami kuultiliassamik tamakkiisumik kuisisoqartalerluni. Akuiaavik qaqqap iluani sananeqarpoq aamarsuillu atorlugit pullartaasani akuiaanermik ilaqarluni, tassanilu aamarsuit akuiaqqissaakkat cyanidilu atorneqartarput. Akuiagassap cyanid atorlugu kuultitaajarneqartarnera pissutigalugu aatsitassarsiorfimmiit qooqqumut cyanidip aniatitap killiliussanik sippuinnginnissaa nakkutigeqqissaarneqartarpoq. November 2013-imi aatsitassarsioqatigiiffiup Angel Mining Gold A/S-ip Nalunami kuultisiorneq unitsippaa, taavalu aatsitassarsiorfik iluarsaqqinneqarpoq salinneqarlunilu 2014-imi augustip tungaanut ingerlanneqartumik.

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Ataatsimut isigalugu Danmarkimi Nukissiutinik Avatangiisinillu Misissuisoqarfik naliliivoq Kuultisiorfiusimasup Nalunap avatangiisinut sunniutai annikeqisut, aammalu avatangiisit sunnigaanerat annikillisarniarlugu suli annerusumik iliuuseqartoqartariaqanngitsoq. Aatsitassarsiorfiup ingerlalernissaa sioqqullugu avatangiisinut sunniutissanik nalunaarusiat suliarineqarsimasut paasinarsipput naammaginartuusut aatsitassarsiorfiup sunniutigiunnagaanik tikkuussiviunertik pissutigalugu. Avatangiisinut sunniutis-

sanik nalunaarusiat kiisalu avatangiisit imminni qanoq issusiinik misissuinerit tunngavigalugit akuersissummut atasumik avatangiisitigut piumasaqaasiornissaq ajornarunnaarsimavoq, kiisalu avatangiisit malinnaavigineqarnissaannut suleriaasissaq naleqquttoq sukumiisorlu suliarineqarsinnaasimalluni. Avatangiisit malinnaavigineqarnerat 2019-imi avatangiisinik misissuinikkut naggaserneqartutut isigineqarpoq. Tassalu Kuultisiorfik Nalunaq Danmarkimi Nukissiutinik Avatangiisinillu Misissuisoqarfimmit isigineqarpoq tassaasoq avatangiisitigut piumasaqaatit naammattut kiisalu avatangiisit sukumiisumik malinnaavigineqarnerat malittarisassiorfigineqarnerallu atorlugit Kalaallit Nunaanni avatangiisinut killilimmik sunniuteqartumik aatsitassarsiortoqarsinnaaneranut takussutissaq.

Sammenfatning

Guldminen Nalunaq ligger i Kirkespirdalen 40 km nordøst for byen, Nanortalik, på den sydligste spids af Grønland. Guldaflejringen i Nalunaq blev opdaget i 1992, og i 2004 åbnede Nalunaq guldminen. Malmen blev brudt og sendt først til Europa og senere til Canada for oparbejdning. Stigende oliepriser og fragtomkostninger gjorde økonomien vanskelig, og minen lukkedes med den sidste forsendelse af malm i marts 2009. I medio 2009 åbnede minen nu igen med fuld produktion af doré[2] i Nalunaq. Et oparbejdningsanlæg blev konstrueret inde i bjerget og involverede carbon-in-pulp-teknologien, der omfattede brugen af aktivt kul og cyanid. Grundet cyanidanvendelsen til udtrækning af guld fra malmen, blev der ført streng kontrol med, at udsivninger af cyanid fra minen ud i dalen holdt sig under de fastsatte grænseværdier. I november 2013 lukkede mineselskabet Angel Mining Gold A/S guldproduktionen i Nalunaq, hvorefter området blev reetableret med en oprydnings- og restaureringsperiode, der varede indtil august 2014.

I tilknytning til mineaktiviteterne var der især to miljørisici: I) Risikoen for spredning af frigivne metaller som følge af knusning, malmforarbejdning, lagring af malm før udskibning, deponering af gråbjerg samt kørsel på grusvejen. Miljørisikoen ved disse aktiviteter var forbundet med udvaskning af metaller fra malm depoter og gråbjerg, udledning af spildevand fra processen og spredning af metaller som støvpartikler. II) I mineperioden 2009-2013 var der risiko for udledning af cyanid i giftige koncentrationer til miljøet. Risikoen var forbundet med udledning af spildevand i mineprocessen eller utilsigtet spild af cyanid, f.eks. fra transportuheld eller forkert pumpning af cyanidopløsninger. Som et resultat af disse risici blev der udviklet et miljøovervågningsprogram for at opdage og undgå uønskede miljøpåvirkninger.

Der blev næsten årligt udført miljøovervågning i Nalunaq fra 2004 til 2019 for at overvåge miljøpåvirkninger fra minedrift. Denne rapport giver et overblik over overvågningsresultaterne og de vigtigste konklusioner. Prøveudtagningsprogrammet i miljøovervågningen omfattede lav, ørred, ulk, tang og blåmuslinger, der fungerer som indikatorarter i det terrestriske miljø, ferskvand og det marine miljø.

Det terrestriske miljø blev påvirket af en moderat forurening af elementerne arsen (As), kobolt (Co), krom (Cr) og kobber (Cu) som et resultat af støvspredning fra knusning af malm, gråbjergsdeponi og malmlagre, men også som et resultat af kørsel på grusvej. Som et resultat blev der givet anbefalinger til at minimere støvforureningen. Efter omstruktureringen af mineproduktionen i 2009 mindskedes forureningen. Dette var et resultat af, at forarbejdning af malm, inklusiv knusning, blev placeret inde i bjerget og lagre af malm og knust gråbjerg blev fjernet fra det terrestrisk miljø. Derefter var støvspredning primært relateret til trafik på grusvejen. Efter nedlukning af minen i 2013 faldt støvforureningen yderligere, og i 2017, fire år efter lukning af minen, var niveauerne af elementer

[2] En doré-bar er en semi-ren legering af guld og sølv. Det produceres sædvanligvis on site i mine området og transporteres derefter til et raffinaderi for yderligere rensning.

målt i lav på niveau eller tæt på baggrundsniveauet. På baggrund af den observerede støvforurening anbefales det fremadrettet at opstille miljøkrav ved nye mineprojekter til at mindske en sådan effekt i fremtiden.

I ferskvandssystemet blev der kun dokumenteret små påvirkninger i Kirkespirelven. Elven blev påvirket af udvaskning fra malm og gråbjerg, og fra 2009-2013 af fortyndet spildevand fra minen, som potentielt kunne indeholde cyanidrester og forhøjede niveauer af elementer. Mens vandprøver, taget i Kirkespirelv ved vandfaldet, ikke viste nogen forhøjede koncentrationer af elementer, var der tegn på akkumulering af enkelte metaller i ørred og især blev cadmium (Cd) målt i konstant let forhøjede koncentrationer. Det blev vurderet, at de let forhøjede koncentrationer ikke var til skade for fisken eller ferskvandssystemet. Fire år efter minedrift, i 2017, viste det sig, at alle målte koncentrationer i lever i ulk var på samme niveau som baggrundskoncentrationer. Angående cyanid, har ingen vandprøver indsamlet i Kirkespirelven haft cyanidkoncentrationer over detektionsgrænsen. Cyanid er ikke på noget tidspunkt blevet vurderet at udgøre nogen risiko for biota, herunder ørred, eller for miljøet.

Det marine miljø blev overvåget ved at analysere muslinger, tang og lever fra ulk. Mens muslinger ikke viste nogen forhøjede elementkoncentrationer, havde lever fra ulk og især tangprøver let forhøjede eller forhøjede elementkoncentrationer. Især blev der fundet forhøjede Cu-koncentrationer i tang. Da det primært var stationerne omkring Kirkespirelvens munding, der blev påvirket, vurderes det, at påvirkningen af det marine miljø var relateret til akkumulering af elementer fra spildevandet, der blev vasket ud i det marine miljø fra floden. Fire år efter lukningen af minen, i 2017, var elementkoncentrationerne i tang stadig lettere forhøjet, men koncentrationerne vurderes ikke at udgøre nogen risiko for biota, og det er sandsynligt, at koncentrationerne vil falde yderligere med tiden.

Overflyvningen, der blev udført i 2019, identificerede gamle kørespor i terrænet samt diverse affaldselementer af forskellig oprindelse. Generelt blev relativt få stykker affald/skrot lokaliseret i terrænet, og det vurderes, at affaldet/skrottet ikke udgør nogen risiko for miljøet, men at påvirkningen udelukkende er af æstetisk karakter.

Samlet vurderer DCE, at den aktuelle miljøpåvirkning fra de tidligere mineaktiviteter til miljøet i Nalunaq er ubetydelig, og at der ikke er behov for yderligere handlinger for at reducere miljøpåvirkningen. De VVM'er, der blev udarbejdet inden minedriften startede, viste sig at være tilfredsstillende på en sådan måde, at de identificerede de potentielle virkninger af mineprojektet. På baggrund af VVM'er samt baggrundsundersøgelser var det muligt at opstille miljøkrav i licensen til minedrift, samt udvikle og implementere et passende og detaljeret miljøovervågningsprogram. Miljøovervågningen anses for at være afsluttet med miljøundersøgelserne i 2019. Dermed betragter DCE Nalunaq guldminen som et eksempel på, hvordan tilstrækkelige miljøkrav sammen med detaljeret miljøovervågning og -regulering kan resultere i en minedrift i Grønland med begrænset miljøpåvirkning.

1 Introduction

'Nalunaq' is the Greenlandic name of Greenland's first gold mine and means 'the place that is hard to find'.

The Nalunaq gold mine is located in Kirkespir Valley in the license area 2003/05, ca. 40 km northeast of the town Nanortalik, at the southernmost tip of Greenland. The deposit is a Proterozoic narrow-vein, high-grade gold deposit. Nalunaq Mountain, which hosts the gold deposit, is located in a wide glacial valley reaching into the Saqqaa Fjord about 9 km from the mine site. The terrain is a glacial valley with mountain peaks reaching 1,200-1,600 m above sea level. A river, Kirkespir River, runs through the valley, fed by mountain streams of melting snow. For geological description of the area the reader is referred to Bell et al. (2017).

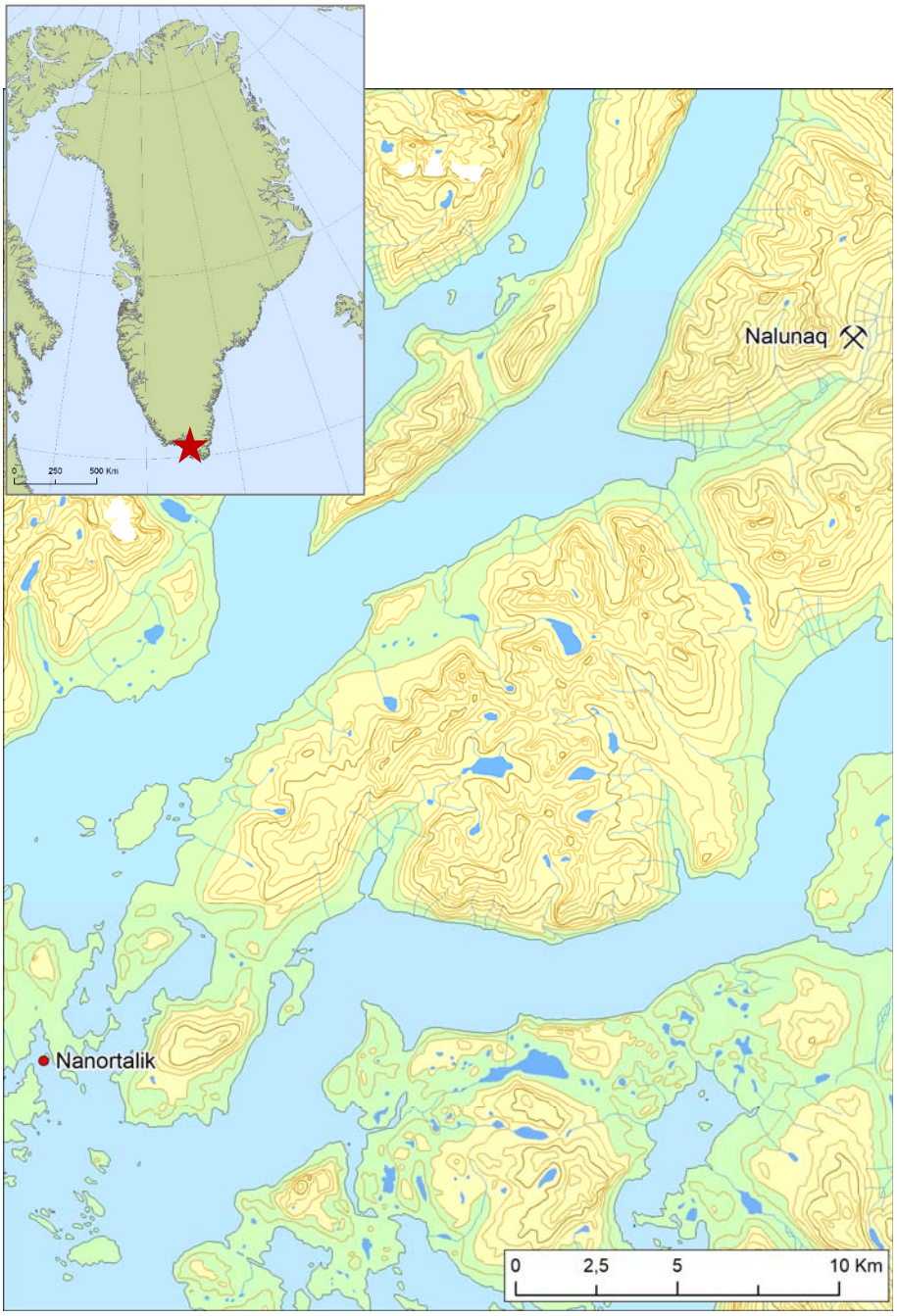

Figure 1. Map of Greenland in upper left corner showing the location of the area. The large map shows the location of Nanortalik and the Nalunaq gold mine. Source: Maps created with ESRI ArcMap 10.5.1. by D. Spelling, DCE.

The gold deposit at Nalunaq was discovered in 1992 (Secher et al. 2008). The data gathered on the gold mineralisation in Kirkespir Valley led to many finds of other gold occurrences in the region, and now the area is regarded as a major gold province. The opening of the mine in 2004 was a milestone for Greenland, being the first gold mine and the first new mine to be developed in the country for over 30 years. In 2004, the mining company Crew Gold Corporation was granted a license to exploit the gold deposit at Nalunaq. The license covered an area 16 km² around the mine site.

An EIA report was prepared in 2002 (SRK 2002) and described processing on site of 162,000 t ore/year with the use of the CIP (carbon in pulp) method. With respect to waste material, the non-acid generating waste rock would primarily be deposited on the mountain slope. Two alternatives were described for tailings disposal, where deep sea tailings disposal in Saqqaa fjord was found preferable over disposal on land due to both environmental and economic reasons (SRK 2002). The feasibility studies also described the possibility for a temporary shipping of the ore to Europe for processing, which was the basis for the application and the granted exploitation permit. The application thus excluded the on-site processing including tailings disposal temporarily and described instead coarse crushing and stockpiling of ore at a new built ship loading facility before shipment to Spain for processing (Nalunaq application 2003). After an operation period of four years, the aim was then to construct the processing facility at site and dispose the tailings into the Saqqaa fjord.

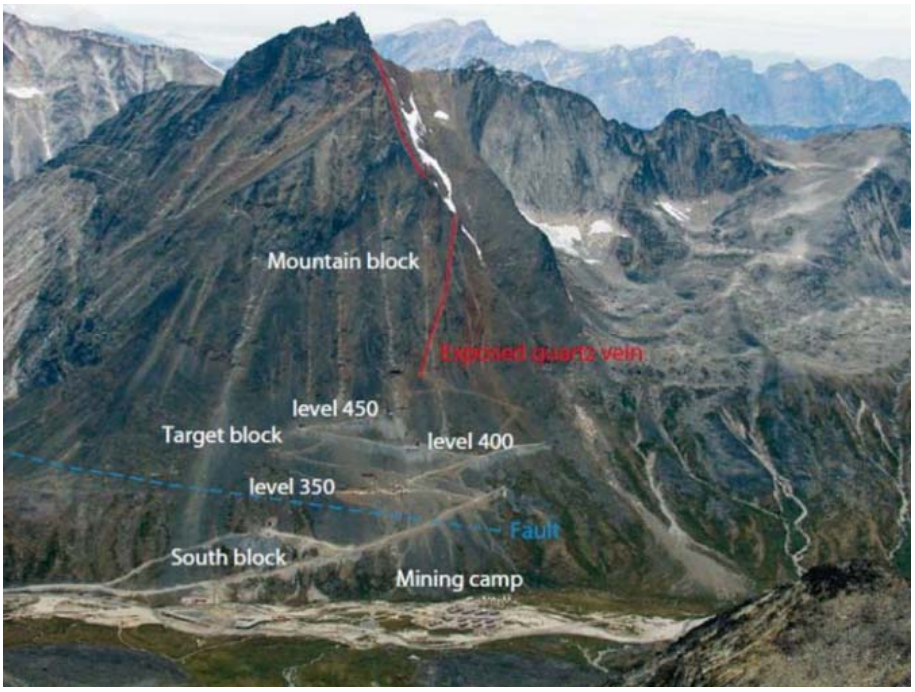

Figure 2. The target mountain. Source: Secher et al. 2008.

After the exploitation permit was granted, the area was prepared for the mining operations. A 12 km long road was constructed from the mine and to the fjord, where an ore store area was made with a capacity of at least 60,000 tons broken rock. A pier was constructed with a barge at the end, so it would reach to a depth of about 12 m, deep enough for large ships to approach. A ship loading facility was set up so that the ore, via conveyor belt, could be loaded on the ship. On the mountain block, the 300 m portal entrance and tunnel were excavated further to host the ore loading to the trucks. Fuel storage was constructed with

impermeable membranes and was constructed to hold at least 110% of the maximum content of the largest tank. The camp was upgraded from a temporary field camp to a more permanent camp for the approximately 90-100 workers. A dump area was placed along the road at a distance from the camp and an incinerator was constructed from a container. A sewage treatment plant for the accommodation and kitchen facilities was installed. The sewage treatment plant was an oxygenation system that degrades the organic matter before the cleaned water is discharged into a branch to the Kirkespir River. The discharged water should comply with the guidelines described for waste water in the Guidelines for preparing an Environmental Impact Assessment (EIA) report for mineral exploitation in Greenland (MRA 2015).

The mine officially opened August 2004. The mining included coarse rock crushing on site and stockpiling of ore at the pier area before shipment of the ore. Rising oil prices and shipping costs however made the economics progressively more difficult and the mine closed with the last shipment of ore in March 2009. Over the period, Crew completed more than 19,000 meters of tunneling and produced 8,000 kg of gold (Angel Mining 2009).

Figure 3. Photo showing the loading of ore to a ship during Crew Mining in 2008. Source: Aerial photo by DCE.

In medio 2009, Crew concluded the sale of Nalunaq Gold Mine to Angus and Ross plc (later Angel Mining Gold A/S). A new EIA was handed in November 2009 and described the full production of doré [3] in Nalunaq. Ore processing was aimed to be carried out using a combination of gravity processing and Carbon-in-Pulp (CiP) leaching which included the use of cyanide. All process tailings were to be backfilled underground in the previously mined out areas. While acid-generating waste rock was to be deposited underground, non-acid-generating waste rock was to be deposited on the mountain slope at the 300 m and 600 m portal to a maximum of 20,000 tons per year. Most of the mining work from 2009 and until the actual production included excavation

[3] A doré bar is a semi-pure alloy of gold and silver. It is usually created at the site of a mine and then transported to a refinery for further purification.

of a production chamber inside the mine. After initial testing of the gravity separation process, this method was discarded as the actual amount of gold was of a smaller size than what could be recovered by gravity. Angel Mining Gold had the first pure of gold in May 2011. Until the mine closure in 2014, a total of ~713,000 tons of ore, with an average grade of 15 g/t, were produced between 2004 and 2014, resulting in ca. 10.5 tons of gold (Bell et al. 2017).

An overview of the mining area with roads, buildings and quay areas is shown in figure 4.

Figure 4. Mine area, camp and workshop area in 2008. Source: Aerial photo by DCE.

1.1 Environmental consultancy

DCE has provided advisory services to the Greenland authorities; Bureau of Mineral and Petroleum (BMP) and later The Environmental Agency for Mineral Resource Activities (EAMRA) under the Ministry of Labour, Research and Environment. DCE (formerly known as NERI) has carried out a great amount of testing and analysis of environmental conditions and considerable data from environmental monitoring (2004-2019) has been gathered. DCE has been involved in the advisory work regarding the mining project since its beginning. DCE has provided recommendations and advisory services that included specific recommendations on: 1) Establishing baseline and background information on the environment of the area, and conditions of potential contaminants in the environment; 2) Designing the environmental monitoring programme according to the potential risks; 3) Establishing water quality criteria for cyanide etc. The subsequent advisory work included recommendations for setting environmental requirements and conditions for the project as part of the license.

The production decommissioned in October 2013 due to economic reasons. In 2014, the mine was closed and the area was cleaned up (removal of buildings, machines etc. – see figure 5). Soil and gravel that were contaminated by oil, for example the gravel under the former generator at the 350 m portal and the

gravel at the incinerator place that was impacted by smaller oil patches and small pieces of metal scrap, were excavated and stored safely in dry areas inside the mine. It was decided to leave the pier and one of the bridges crossing the Kirkespir River in place for potential future use

From 2014 and onwards, DCE has provided recommendations and advisory services in collaboration with the Greenland Institute of Natural Resources, Nuuk.

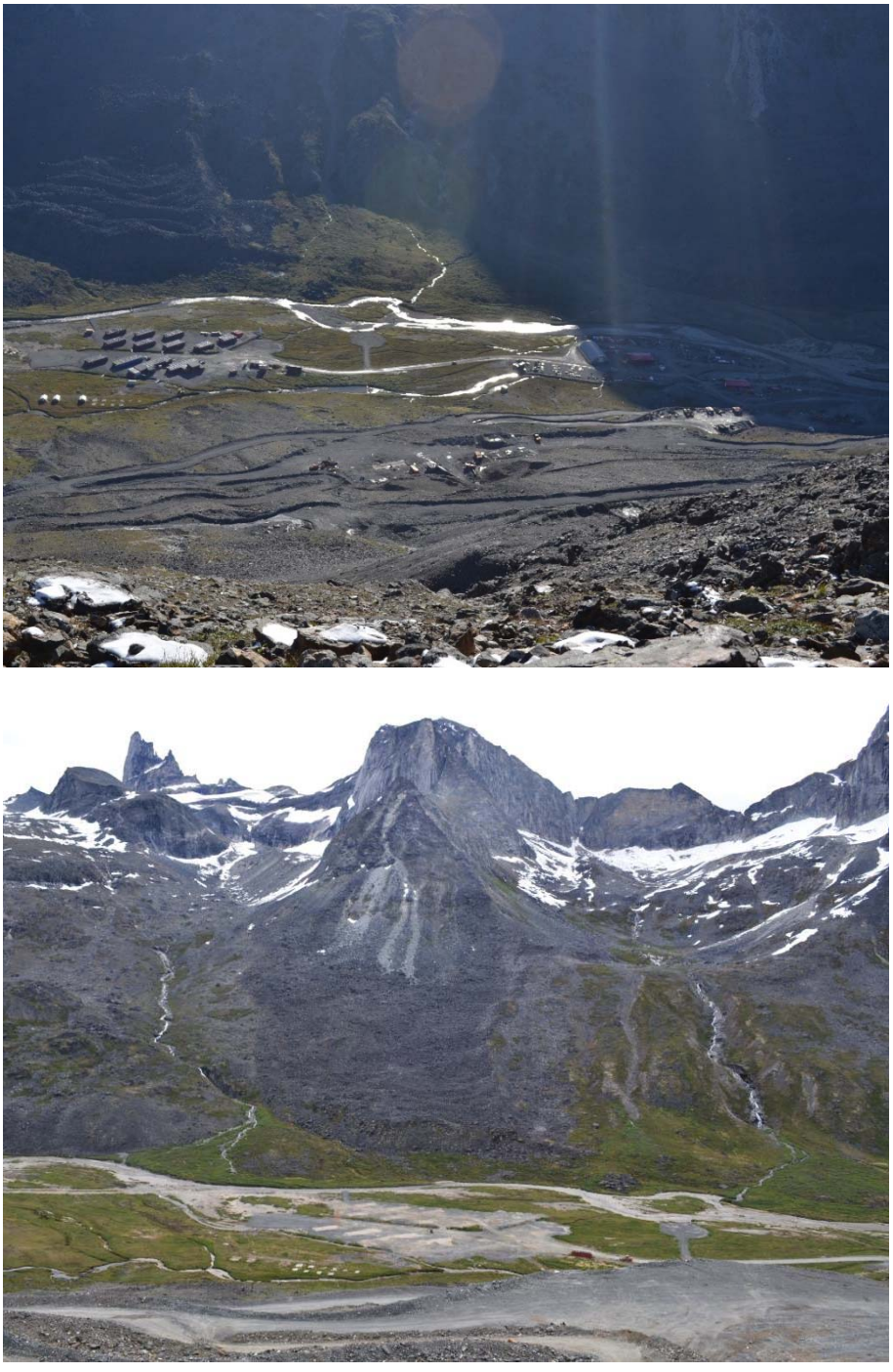

Figure 5. Overview of the camp area during Angel Mining in 2013 (above) and after decommission in 2014 (below). Source: Photos by L. Bach.

2 Environmental studies and monitoring

2.1 Environmental studies

Prior to mining, DCE conducted thorough baseline studies during 1998-2001 in the Nalunaq area (Glahder et al. 2005) for the proposed EIA. The baseline studies were carried out with the research vessel Adolf Jensen. The baseline studies included sampling of blue mussels, seaweed, cods, sculpins, lichens and marine sediments etc., as well as freshwater and Arctic chars from the Kirkespir River. In addition, a general survey of fish and shellfish was conducted in the fjord system (see Glahder et al. 2005). Other baseline studies included interview studies on fishing, hunting and tourism that were carried out in the Nanortalik district (Glahder 2001). Further, in relation to mineral exploration in the Kirkespir area, a semiquantitative study on the Arctic char population in the Kirkespir River was performed (Boje 1989).

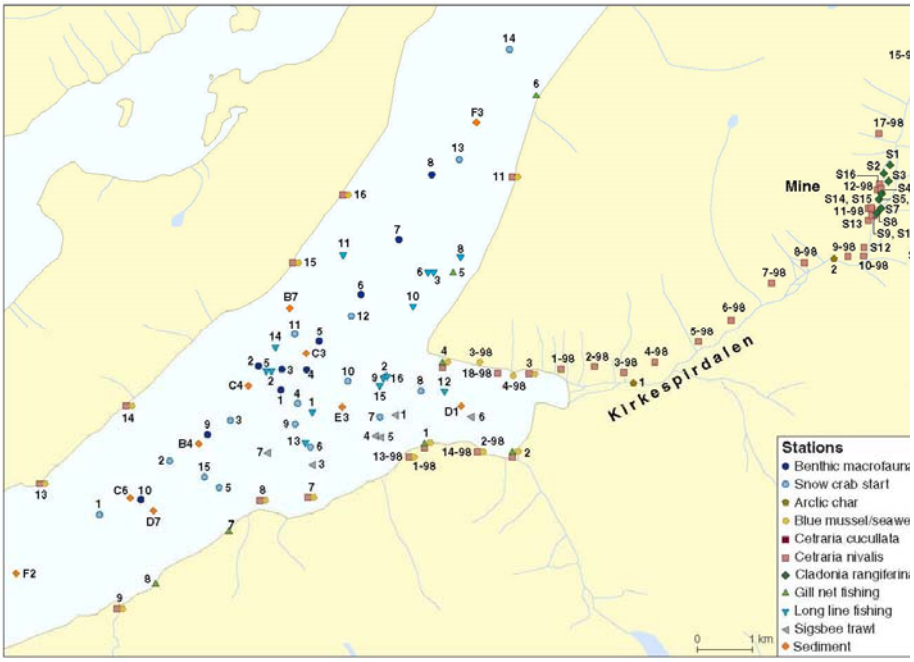

Figure 6. Sampling stations for the baseline study around the Nalunaq gold mine site in South Greenland. See Glahder et al. (2005) for details. Source: Glahder et al. (2005).

A study on freshwater samples from the Kirkespir River was performed by Nalunaq I/S. The samples were analysed for content of metals and general parameters (Lakefield 1998a, b, 1999a-d). A thorough bathymetric study in Saqqaa Fjord was performed in 1999, and in 2000 an oceanographic study was conducted in the Saqqaa Fjord, where as well as in Uunartoq Fjord benthic fauna was sampled and analysed (Greisman 2000). Further oceanographic studies in Saqqaa Fjord and measurements of the water flow of the Kirkespir River, were carried out in 2001 and 2002, and have been reported in an Environmental Impact Assessment (SRK Consulting 2002).

2.2 Environmental Monitoring

Based on the EIA report (SRK 2002) the main potential environmental impacts were identified as the risk of spreading of released metals due to crushing effects of the body rock, ore processing, stock piling, deposition of waste-rock

and tailings, and site traffic on the gravel road. The environmental risks were associated with drainage from waste rock and ore stockpiles, and with dust spreading of metals particles.

From 2009, when the processing took place on site with the use of CiP methodology, the risk of discharge of elements and cyanide residues in toxic concentrations to the environment was identified (EIA by Angel Mining 2009). The risks were associated with discharge of mining process waste water and accidental spills of cyanide, e.g. from traffic accidents or incorrect pumping of cyanide solutions. As a result of those risks an environmental monitoring programme was developed to discover and avoid unwanted impacts to the environment.

The environmental monitoring was conducted yearly by the authorities with DCE as consultants, while the daily and weekly analyses of water samples for cyanide residues were conducted as self-monitoring by the company. This self-monitoring program was reviewed and inspected yearly by DCE during the entire environmental monitoring programme. This report describes the methods and results from the authority monitoring, but due to the inspection and control measurements, the cyanide monitoring is briefly introduced.

Almost yearly, DCE carried out the environmental monitoring and from 2014 and onwards together with Greenland Institute of Natural Resources. The aim was to detect unintended effects on the local flora, particularly the lichens, and the freshwater and marine environment. During the Crew mining period from 2004 to 2009, the Angel Mining 2009-2013 as well as post mining 2014-2019, samples of selected types of biota identified as key monitoring organisms (lichens, Arctic char, blue mussels, seaweed, and sculpins) were collected together with freshwater samples, and the environmental impact of the mining activity was evaluated. The evaluation was based on concentrations of a long list of elements (e.g. As, Cd, Co, Cr, Cu, mercury (Hg), lead (Pb)) measured in the samples that were compared with the baseline samples. Full descriptions of the sampling performed and the results obtained between 2004 and 2013 can be found in: Glahder and Asmund 2005, 2006, 2007; Glahder et al. 2008, 2009, 2010, 2011; Bach et al. 2012, Bach & Asmund 2013, Bach et al. 2014.

After mine closure, the environmental monitoring programme continued to evaluate the environmental impacts of the mining activities. This programme was continued in 2014, 2015, 2017 and 2019 with modifications (Bach et al. 2015; Bach and Larsen 2016; Bach and Larsen 2018). The environmental monitoring program post mining was a reduced version of the programme conducted during the mining period, taking the previous results into account and focused on selected key monitoring organisms and sites. A final monitoring was conducted in 2019, where samples were collected as in the post mining program. Based on the results of previous years monitoring that showed no or only slightly increased element concentrations, it was decided that only water samples should be analysed. Consequently, the biota samples are stored at DCE for potential future analyses (Bach and Olsen 2020).

The monitoring programme at Nalunaq was beside freshwater samples focused on five species of biota: lichens (*Flavocetraria nivalis*), blue mussels (*Mytilus edulis*), brown seaweed (*Fucus vesiculosus*), common sculpin (*Myoxocephalus scorpius*) and the freshwater fish Arctic char (*Salvelinus alpinus*). These species were selected because they are well suited as monitoring organisms of mining contamination in the terrestrial, freshwater and marine environment, respectively, as described below. They are also widely used in other

monitoring programs at mine sites in Greenland (e.g. Johansen et al. 2008; Bach et al. 2014; Søndergaard 2020).

2.3 Monitoring organisms

Lichens bioaccumulate atmospheric contaminants, such as metals, and are abundant in the Arctic (Søndergaard 2019; Søndergaard 2020). Their lack of roots, a large surface area and a long life span enable lichens to effectively accumulate air contaminants. A number of studies have shown that lichens are adequate and sensitive monitors of contaminants from mining activities (Naeth and Wilkinson, 2008; Søndergaard et al. 2011a; Søndergaard 2020). The lichen species, *Flavocetraria nivalis*, is the preferred species for monitoring at Greenland mine sites since it is abundant, easily recognisable and has been shown to effectively accumulate mining contaminants (Søndergaard et al. 2011 and 2013).

Since the lifetime of *Flavocetraria nivalis* spans several years and due to a limited ability of lichens to excrete the bioaccumulated contaminants again, transplanted lichens have often been used as a supplement to or instead of resident lichens to assess the year-to-year variation in dust deposition (Søndergaard et al. 2013). Transplanted lichens are collected from uncontaminated reference sites and are typically placed at the monitoring sites for one year.

Figure 7. To assess dust deposition of contaminants from Greenland mine sites the lichen *Flavocetraria nivalis* is frequently used. This photo shows a lichen patch in Naunaq. Source: Photo by L. Bach.

Mussels are widely used as indicator organisms to monitor the health of aquatic environments in marine environments. In Greenland, the blue mussels are suitable as monitoring organisms since they are widely distributed and bioaccumulate metals in their tissue due to their feeding strategy based on filtration of large volumes of seawater (Rigét et al. 1997; Søndergaard et al. 2011). The contaminants accumulated in mussels are considered to be derived from both contaminants bound to particles and contaminants dissolved in the seawater (Rainbow, 1995). In Greenland, the growth of blue mussels is slow compared to temperate areas and the timespan of blue mussels can be 10-15 years for a typical 4-6 cm mussel (Theisen, 1973). Due to their limited ability

to excrete accumulated contaminants once they are taken up (Rigét et al. 1997), the concentrations of contaminants in resident blue mussels may continue to be elevated for some years after a contamination event.

Figure 8. 5831Blue mussels, *Mytilus edulis*, are widely used as biomonitor organisms in the marine environment and are used as a proxy for dissolved and particle bound contaminants. This photo shows a mussel bed in Northwest Greenland. Source: Photo by L. Bach.

Brown seaweed, including *Fucus vesiculosus,* also effectively accumulates contaminants such as metals, but in contrast to blue mussels, the contaminants accumulated in seaweed are considered to reflect only contaminants dissolved in the seawater (and not contaminants bound to particles) (Rainbow, 1995). When sampling only the annual fresh growth tips of the seaweed, the concentration of contaminants in the seaweed can be considered a proxy for the year-to-year variations in dissolved contaminants at the sampling sites.

Figure 9. The annual fresh growth tips of the seaweed, *Fucus vesiculosus*, is used as a proxy for the year-to-year variation in dissolved contaminants. This photo shows seaweed that becomes available for sampling at low tide. Source: Photo by L. Bach.

The shorthorn sculpin (*Myoxocephalus scorpius*) is a highly common species in the fjords of Greenland and is relatively sedentary at the seafloor (Muus 1990) and easy to catch. This makes the common sculpin an ideal indicator species for the marine environment. Although bivalves are known to be superior to fish in terms of bioaccumulation efficiency of most metals, predatory fish represent a higher trophic level. To apply fish as environmental monitor organism, analyses of the liver is often recommended, as it has an important role in contaminant storage, redistribution, detoxification or transformation, and it is an important site of pathological effects induced by contaminants (Ewans et al. 1993). Livers of the sculpins were used to assess the contamination level in the marine environment.

Figure 10. Shorthorn sculpins, *Myoxocephalus scorpius*, are easily caught in most fjords in Greenland, and as it is relatively sedentary, it is assessed as a proper indicator species for higher trophic level. Source: Photo by L. Bach.

Arctic char (*Salvelinus alpinus*) is used as a biological indicator species for the freshwater environment in Greenland. It is one of only two widespread freshwater fish species, and spends a large part of its life cycle in lakes or streams. It is a valuable edible fish and of commercial value for the local hunters. The Arctic char is known to accumulate metals and reflect the sources of bio-available metal (Glahder et al. 2010; Riget et al. 2000; 2010). Arctic chars were used to assess the contamination level in the Kirkespir River in the waterfall pond. This population consists of both non-migrating and migrating char and, if possible, non-migrating char are selected. Resident Arctic char stay all their life in the Kirkespir River, whereas the migratory char leave the river during May and return around August to spawn and winter. As with the sculpins, Arctic chars accumulate metals in the liver, therefore the livers were dissected and analysed.

Figure 11. Arctic chars were caught in the pool at the waterfall in Kirkespir River (upper photo) and the livers dissected for element analyses. Non-migrating fish, as the one in the lower photo, were selected for analyses. Source: Photos by L. Bach.

3 Monitoring sampling

3.1 Element monitoring programme

The monitoring of elements included three focus areas: the marine, the freshwater and the terrestrial environment. In the area around Nalunaq, a total of five marine stations were included for the monitoring purposes. One station at the waterfall in Kirkespir River served as the freshwater station for collection of freshwater and Arctic chars. In addition, 27 terrestrial stations were established for lichen sampling on land. The AMIT station was included as a reference site (figure 12).

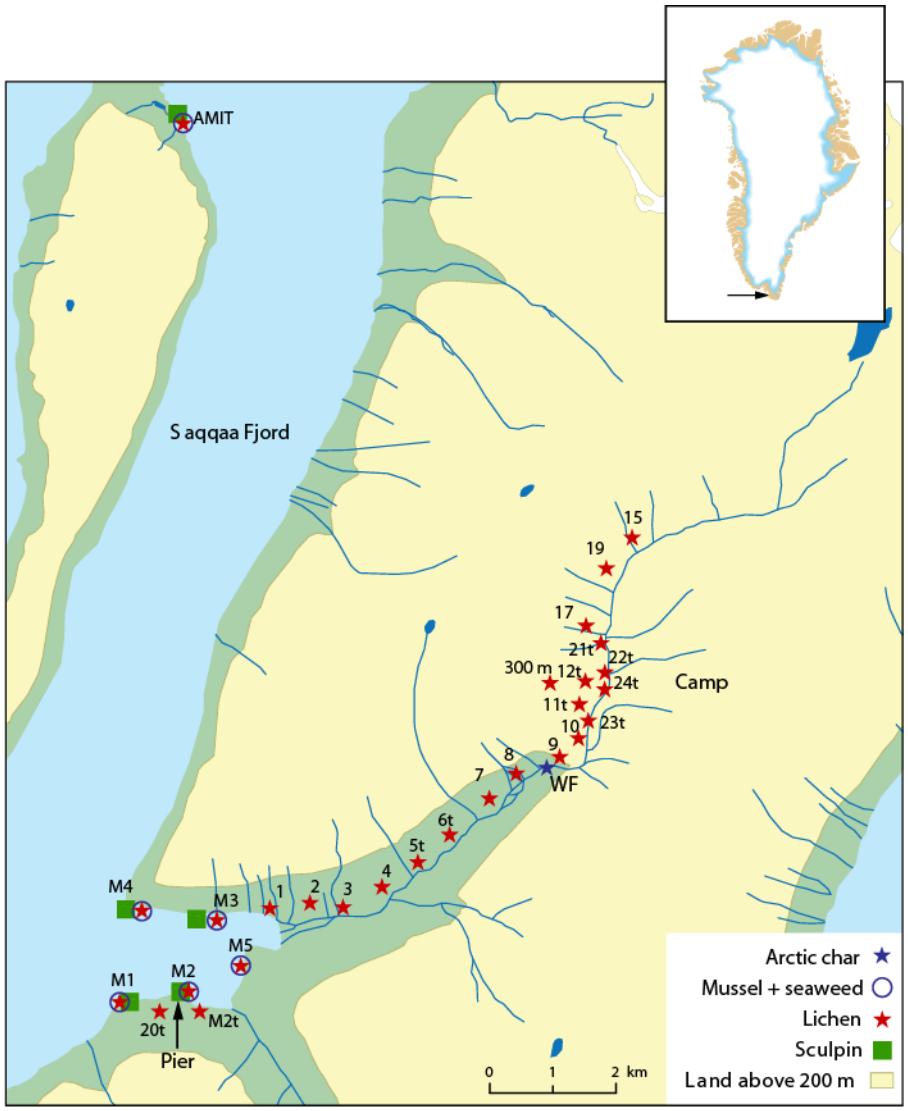

Figure 12. Sampling stations in the Nalunaq area. M: Marine stations: sculpins, blue mussel and brown seaweed. The terrestrial area is covered by lichen samples, where t-stations hold transplanted lichens initially collected at the AMIT station. Freshwater samples were collected at the waterfall (WF), upstream at station 22, downstream at station 23 and at the mine entrance at the position marked by '300 m'

3.1.1 Terrestrial environment

In the terrestrial environment, the lichen (*Flavocetraria nivalis*) stations are placed around existing and former ore stockpiles, along the road and in the area around the 300 m portal where waste rock was deposited and at areas where crushing took place. Lichens were sampled at M1, M2, M2t, M3, M4, M5

and 1, 2, 3, 4, 5t, 6t, 7, 8, 9, 10, 11t, 12t, 15, 17, 19, 20t, 21t, 22t, 23t and 24t (figure 12). The t-stations held lichens transplanted to the sites the previous year. The lichens for transplantation were collected at the reference station, AMIT. After sampling, new lichens collected at AMIT were placed for the next year collection. The collected lichen samples were stored in zip-lock bags and frozen at -20 °C until further preparation (sorting and freeze-drying).

3.1.2 Freshwater environment

Water samples were collected at four sites in the area (figure 13): at the outlet from the mine at the 300 m portal (1), upstream the mine in the small creek (2), and downstream the small creek after mine water had entered (3). Also, a sample was collected in the larger Kirkespir River (4). Two samples at each station were collected; one unfiltered and one filtered. The freshwater samples were in situ filtered through a 0.45 µm membrane filter immediately after sampling.

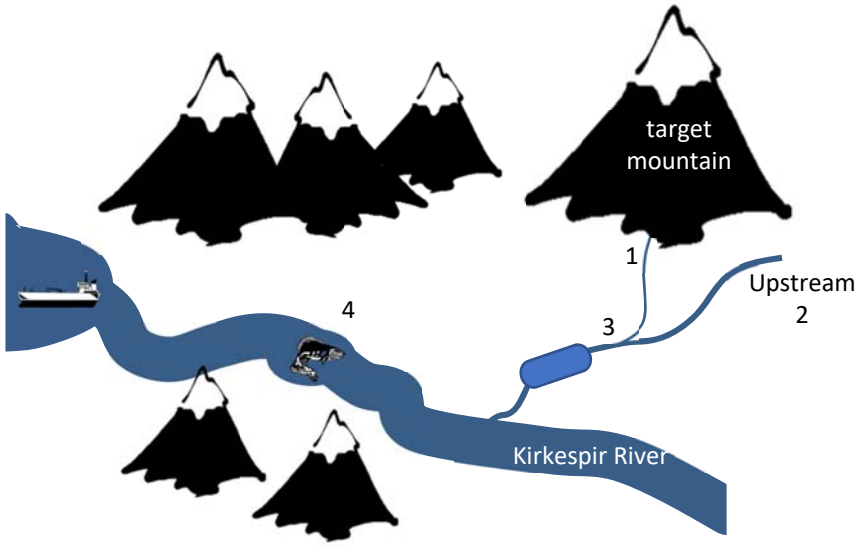

Figure 13. Illustration of freshwater sampling stations. Sample 1 was taken upstream, sample 2 was taken at the 300 m mine entrance, where process waste water is discharged. Sample 3 was taken after mine water was mixed with the little creek but before the settlement pond. Sample 4 was taken further down the Kirkespir River in the pool at the waterfall and is the first place in the Kirkespir River after mine water is admixed.

In the freshwater environment, the sampling of Arctic char was conducted at the the waterfall pond which is the first site downstream the mining area where resident Arctic char (*Salvelinus alpinus*) occur. This population consists of both non-migrating and migrating chars. Resident Arctic chars stay all their life in the Kirkespir River, whereas the migratory form leaves the river during May and returns around August to spawn and winter. Optimal 4 resident chars were preferred for analyses. Each fish was measured, weighed and the liver was dissected. The livers were stored in zip-lock bags and frozen at -20 °C.

3.1.3 Marine environment

For the marine environment, brown seaweed, blue mussel and shorthorn sculpin were sampled at four to five stations that present the harbor/shipping facility on one side of the bay and the outlet of Kirkespir River on the other side of the bay. The monitoring was initiated with four stations, but another station (st 5) was added to the program in 2011 and included sampling of mussel and seaweed.

Sampling of blue mussels and seaweed was performed in the Kirkespir Bay from land at low tide. Mussels of two different size groups were collected at each station. Each sample consisted of approximately 20 individuals. The mussels were opened with a scalpel and allowed to drain after which the soft parts were cut free and stored in zip-lock bags and frozen at -20 °C. The seaweed was collected at two spots within an area of approximately 20 m at each station. The current year's growth tips were cut, washed in freshwater and stored in zip-lock bags and frozen at -20 °C.

Shorthorn sculpins were jigged for from boat at the stations M1, M3, M4 and AMIT. Sculpins at M2 were caught from the barge at the pier. All sculpins were measured and weighed. The livers were dissected out and stored in zip-lock bags and frozen at -20 °C.

The coordinates of all the marine, freshwater and lichen stations are listed in table 1.

Table 1. Positions of sampling stations.

Station	Lat deg	Long deg	Sample type
1	60.32611	-44.92278	Lichen
2	60.32722	-44.91111	Lichen
3	60.32639	-44.90278	Lichen
4	60.32861	-44.89389	Lichen
5t	60.33247	-44.88003	Lichen
6-t	60.33603	-44.87183	Lichen
7	60.34222	-44.86028	Lichen
8	60.34556	-44.85194	Lichen
9	60.34694	-44.83722	Lichen
10	60.34750	-44.83278	Lichen
11t	60.35456	-44.83239	Lichen
12t	60.35783	-44.83058	Lichen
15	60.37861	-44.81889	Lichen
17	60.36639	-44.83111	Lichen
19	60.37500	-44.82528	Lichen
20t	60.31308	-44.95283	Lichen
21t	60.35587	-44.83097	Lichen
22t	60.35545	-44.83050	Lichen
23t	60.35303	-44.83108	Lichen
24t	60.35626	-44.82755	Lichen
M 1	60.31139	-44.96694	Lichen, blue mussel, seaweed, sculpin
M 2 and M2t	60.31253	-44.94639	Lichen, blue mussel, seaweed, sculpin
M 3	60.32472	-44.94681	Lichen, blue mussel, seaweed, sculpin
M 4	60.32639	-44.93750	Lichen, blue mussel, seaweed, sculpin
M 5	60.31567	-44.96028	Lichen, blue mussel, seaweed, sculpin
AMIT	60.43889	-44.95111	Lichen, blue mussel, seaweed, sculpin
Waterfall	60.34642	-44.84225	Arctic char, water sample
W 1 Upstream	60.35680	-44.82680	Water sample
W 2 Outflow mine	60.35573	-44.83399	Water sample
W 3 In sed. pond	60.35626	-44.82755	Water sample
W 4 Out sed. pond	60.35626	-44.82755	Water sample

3.2 Cyanide monitoring program

After the construction of the process plant in 2009 and the use of cyanide, cyanide was monitored in the freshwater system, as there was a risk associated with the discharge of mining process waste water and accidental spills of cyanide. Thus a strict monitoring program was developed to discover if cyanide residues accidentally were found at harmful concentrations in the freshwater system incl. Kirkespir River.

In the process plant, the gold was separated using the chemical Carbon-In-Pulp method. This method involved addition of cyanide. Cyanide is however a compound that exerts high acute toxic effects even in low concentrations. In the mining process, cyanide was added in the first extraction tank as sodium cyanide. After its use, the cyanide was treated by sodium meta-bisulphite and air in order to decompose the cyanide into cyanate. The cyanide was, however, not decomposed completely, and the rest of the cyanide followed the tailings into the underground tailings chamber where the water was subjected to recirculation to the process. The tailings chambers were outmined areas underground in the mine. A small amount of cyanide was discharged by waste water from the process. When cyanide entered the environment, it was expected to readily degrade to nontoxic levels as it is easily degraded under light and/or oxygen.

When the waste water left the mine, it entered a smaller creek and thus became diluted before entering a settlement pond. The settlement pond was constructed with an oil skimmer and acted to retain surface oil and delay the mine water before mixing with the large Kirkespir River. This enhanced the settlement of particles and degradation of cyanide residues originating from the waste water.

The cyanide monitoring programme consisted of scheduled frequent collection of water samples for analysis of free cyanide to ensure that cyanide concentrations in the environment did not exceed the limits set by EAMRA (identical with the Ontario Province Quality Objectives) – see table 2. To protect organisms, in particular the resident Arctic char, from toxic effects, the cyanide concentration in the Kirkespir River should not exceed 0.005 mg/l (measured as WAD CN, Weak Acid Dissociable cyanide). Due to dilution in Kirkespir River and the retention time facilitating natural degradation, the company was allowed to discharge water from the mine with a cyanide concentration of up to 0.20 mg/l.

At the closure of the mine, DCE recommended that water leaving the mine at the 300 m portal could comply with the limit of 0.20 mg/l.

As described above, the mining company was responsible for conducting the daily and weekly monitoring (i.e. sampling and sample analyses) and for forwarding the data on a regular basis to EAMRA, while DCE undertook a yearly monitoring. Water samples were collected at six sites in the area: inside the mine a water sample of the process water/tailings water (1) was collected. A sample was collected of the waste water leaving the mine at the 300 m portal (2), a water sample from the settlement pond, and two samples were collected of the two monitoring wells (4 and 5). Also, a sample was collected in the pool at the waterfall station in the Kirkespir River (6). See figure 14 for sample sites and table 2 for frequencies.

At few occasions after mine closure, DCE and GINR were permitted access to the underground mine. At those occasions several water samples inside the mine were collected and analysed for free and total cyanide.

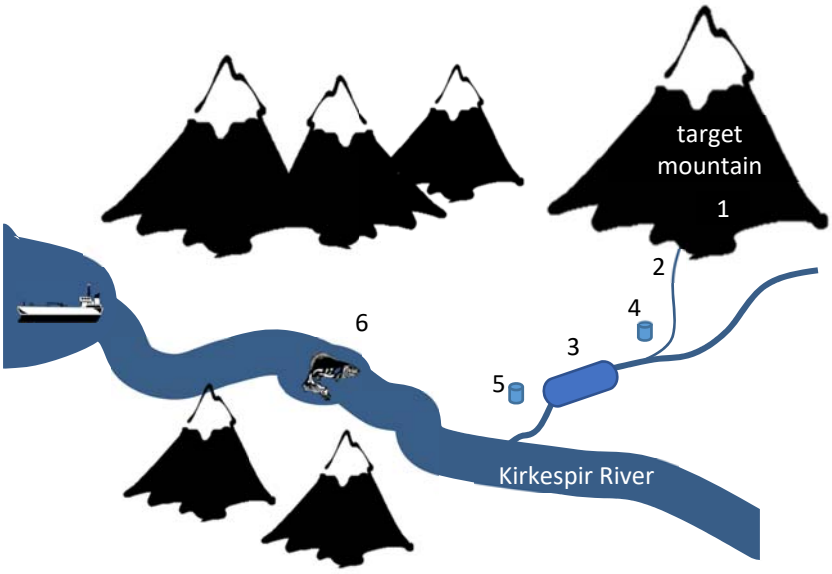

Figure 14. Illustration of sampling stations for cyanide monitoring. Sample 1 was taken from the tailings water, sample 2 was taken at the 300 m mine entrance, where process waste water is discharged. Sample 3 was taken at the settlement pond and sample 4 and 5 from monitoring wells. Sample 6 was taken further down the Kirkespir River at the first place in the Kirkespir River after mine water is admixed.

Table 2. Cyanide sampling program and allowed maximum limit values in ppm (parts per million or mg/l). Station 1-6 were included in the self-monitoring program by the company, while the authorities analysed samples from stations 2-6 yearly.* Monthly averages with maximum allowed value of 10.0 ppm of single samples.

Station	Location	Monitoring frequency	Maximum cyanide concentration
1	Process water/tailingswater inside mine	Daily	4.0 ppm in winter* / 2.0 ppm in summer*
2	Waste water discharge from mine process area/ditch	Daily	0.20 ppm
3	Settlement pond	Daily	0.20 ppm
4	Monitoring well a	Weekly	0.005 ppm
5	Monitoring well b	Weekly	0.005 ppm
6	Kirkespir River - waterfall	Weekly	0.005 ppm

Figure 15. A) Water from the mine enters the small creek before entering the settlement pond prior to mixing with the larger Kirkespir River. B) Settlement pond with oil skimmer. The settlement pond acted to retain surface oil and delay the mine water before mixing with the large Kirkespir River. This enhanced settlement of particles and degradation of cyanide residues originating from the mine process waste water. Source: Photos by L. Bach.

4 Monitoring analytical methods

4.1 Element analyses

All samples were analysed at the accredited Environmental Trace Element Laboratory at Department of Bioscience, Aarhus University in Roskilde, Denmark.

4.1.1 Soil, lichens, seaweed and blue mussels

Lichen samples were sorted by hand using plastic tweezers and only fresh looking green/yellow parts of the lichens were selected and freeze-dried. Seaweed and mussel soft parts were also freeze-dried and the samples homogenised in an agate mortar. Subsequently, 300 mg of freeze-dried sub-samples of soil, lichens, seaweed and mussels were digested in a mixture of 4 ml concentrated Merck Suprapure HNO_3 and 4 ml milliQ H_2O in Teflon bombs in an Anton Paar Multiwave 3000 Microwave Oven (following the DS259 method). Finally, the solution was diluted to 60 grams with milliQ water and stored in polyethylene bottles until analysis.

4.1.2 Arctic char and sculpin

The fish livers were thawed and homogenised prior to analyses. Dry weight of the livers were established upon weighing, heating the samples until dry and weighing. Sub-samples of liver and muscle tissues were digested following the same procedure described above with the exception of initial sample weight and dilution ratios; ~1 g frozen tissue was digested in 4 ml Merck Suprapure HNO_3 and 4 ml mQ H_2O and diluted to a final solution of 60 ml.

4.1.3 Freshwater

Freshwater samples (both filtered and unfiltered) were stored cool in 15 ml polyethylene vials. Prior to analysis, 15 µl of concentrated Merck Suprapure nitric acid was added to the samples and the acidified samples were left for a minimum of 24 hours.

4.1.4 Chemical analyses

The samples collected were analysed for at least the following elements: arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb) and zinc (Zn).

Detection limits for the measured elements on the day of analysis were determined based on measurements of blank solutions and calculated as three times the standard deviation on these. Blank solutions are the digestion solutions alone without the samples, treated in the Teflon bombs and diluted in the same way as the samples. At least one blank solution was prepared for every series of digestion (16 vials). Detection limits on the day of analysis have been reported in the data tables in the yearly monitoring reports.

In addition to the blank solution, one duplicate sample (same sample ID but two different digestions) and at least one sample of Certified Reference Material (CRM) were analysed per series of digestion. The duplicate sample was analysed to check the repeatability of the measurements and the CRMs were

analysed to check the accuracy. The CRMs used were: DORM-4, TORT-3, DOLT-5, MESS-4, PACS-2 and SLRS-6. (www.nrc-cnrc.gc.ca).

The laboratory at the Department of Bioscience is accredited by the Danish Accreditation Fund, DANAK. The quality of the methods is further checked by participation in the international QUASIMEME laboratory inter-calibration programme twice a year.

4.2 Cyanide analyses

Water samples for WAD cyanide determination were processed on site on the same day of the sampling. After filtration, the samples were analysed for free cyanide using the Hach-Lange LCK315 method and a Hach-Lange DR2800 spectrophotometer. This method is quick and effective and has a factory-guaranteed measuring range of 0.01-0.60 mg/l, within which precise results can be obtained. The practical detection limit is judged to be about 0.002 mg/l.

Figure 16. Water samples were collected for analyses of cyanide and elements. Source: Photo by L. Bach.

While samples for free cyanide was analysed by the Hach-Lange methods, the samples for total cyanide were sent to an accredited laboratory and analysed for total cyanide by ALS-Denmark after the DS/EN ISO 14403:2002.

5 Results of monitoring and discussion

This section provides an overview of the data generated by the environmental monitoring from 2004-2017. Monitoring data are discussed toward the knowledge of the activities related to the mining that could be associated with the possible effects. For concentrations of all analysed metals for each sample and statistics, the reader is referred to the monitoring reports: Glahder and Asmund 2005, 2006, 2007; Glahder et al. 2008, 2009, 2010; Bach et al. 2012, Bach & Asmund 2013; Bach et al., 2015; Bach and Larsen 2016; Bach and Larsen 2018.

Also results from a GINR report (Larsen 2020) from the overflying of the Nalunaq area by drone in 2019 will be described with respect to impacts to the terrain.

5.1 Terrestrial environment

Lichens were used as a proxy for dust contamination of the terrestrial environment. Resident lichens were sampled during the baseline studies in 1998-2002; during the first years of the mining operation in 2004-2009, while ore was shipped out; in the mining period where ore was processed on site 2010-2013; and after closure in 2014-2019.

Already at the first environmental monitoring in 2004, moderate pollution from the mine was documented with elevated concentrations of a few metals (As, Co, Cr and Cu) in lichens (Glahder and Asmund 2005). In particular three areas were found to be affected: the camp/mining area, down the valley where waste rock was stock piled and at the pier, where ore was stockpiled before ship loading. It became clear that these areas were of specific concern. For yearly comparison of concentrations for these three areas, see Bach and Larsen 2018 (figure 3.1, 3.2 and 3.3). To minimise the dust dispersal, it was recommended that prevention of dust from the two stockpile areas should be discussed with the mining company. An effect of dust in relation to the road was also observed. Subsequently, it was recommended that future use of waste rock for road maintenance should be reconsidered and based on chemical analyses of the fine-ground material.

Because metals are excreted from the lichens at a low rate if at all (Johansen et al. 2008), the reduction in the dust pollution was difficult to detect within a year or a few years period. Due to the dust pollution, it was decided to focus on the yearly deposition of dust in 2017, and the original lichen stations were replaced with transplanted lichen stations in these focus areas. Thus, lichens were collected from an uncontaminated area, e.g. northern Amitsoq, and transplanted to the Nalunaq area. There they were left until the next year for collection and analyses as a part of that years monitoring. The transplantation of lichens was initiated in the 2008 monitoring. The stations having transplanted lichens were named x-t stations. In the data presentation below, no distinction is made between normal lichen stations and t-stations.

The concentrations of As, Co, Cr and Cu in lichens collected in the environment are shown in figure 19 for each of the three mining periods: A) 2004-2009; B) 2010-2013 and C) post mining 2014-2017. Also, to illustrate the effect of the road, the perpendicular distance to the gravel road is shown for comparison with the concentrations.

The camp and mining area was presented by stations 11t, 12t, and from 2013 also 21t, 22t, 23t and 24t (the latter four stations are not included in figure 19). This area was affected by dust dispersal from the rock crusher that in the first mining period 2004-2009 was placed at ground level and from stockpiles of the ore at ground. Later (2010-2013), rock crushing was now and then conducted in open air on the 300 m portal as back-up to the underground crusher. This was assessed to cause some dust dispersal. In both periods, driving and mine traffic on the roads would also cause dust dispersal, as the roads and working fields were constructed and maintained of crushed waste rock and gravel from the quarries in the area. Also, the waste rock disposed in the mountain slope (figure 17) was considered to contribute to the dust dispersal.

Figure 17. Target mountain with deposited waste rock on the mountain slope. Source: Photo by L Bach.

The area down the valley was presented by station 5t and 6t and reflected dust dispersal from stockpiles of crushed waste rock placed in this area. The dust effect was clearly highest in the first mining period compared to the second period and post mining. This was a result of removal of the crushed waste rock. As shown in the figure, there was however still an impact after the stockpiles were removed. When comparing to the distance to the road (figure 19D), the high concentrations at this area could be explained by an effect of the smaller distance from the lichen stations to the gravel road. Post mining, there has been only little traffic on the road. This was reflected by decreasing concentrations with time.

The ore was stored in large stockpiles at the pier area (station M2t and 20t) before it was ship loaded during the first mining period i.e. 2004-2009. The elevated concentrations of As, Co, Cr and Cu found in the lichens in this area were caused by dust dispersal from the ore stockpiles and the ship-loadings. After the Crew Mine closed, the remaining stockpiles were transported to the mining area for processing between 2011 and 2012. The dust impact at this area decreased as the stock piling ceased; and post mining, the metals were close to background concentrations.

As discussed above, driving on the gravel road was assessed to contribute to the dust dispersal (see figure 18). The road was constructed of crushed waste rock and maintained with gravel from the quarry between station 7 and 8. Dust was visually generated by road traffic on dry days and particularly during the first mining period (2004-2009), when ore was hauled on trucks to the pier area for stock piling the effect was high.

Figure 18. Dust generation by traffic on the gravel road. Source: Photo by L Bach.

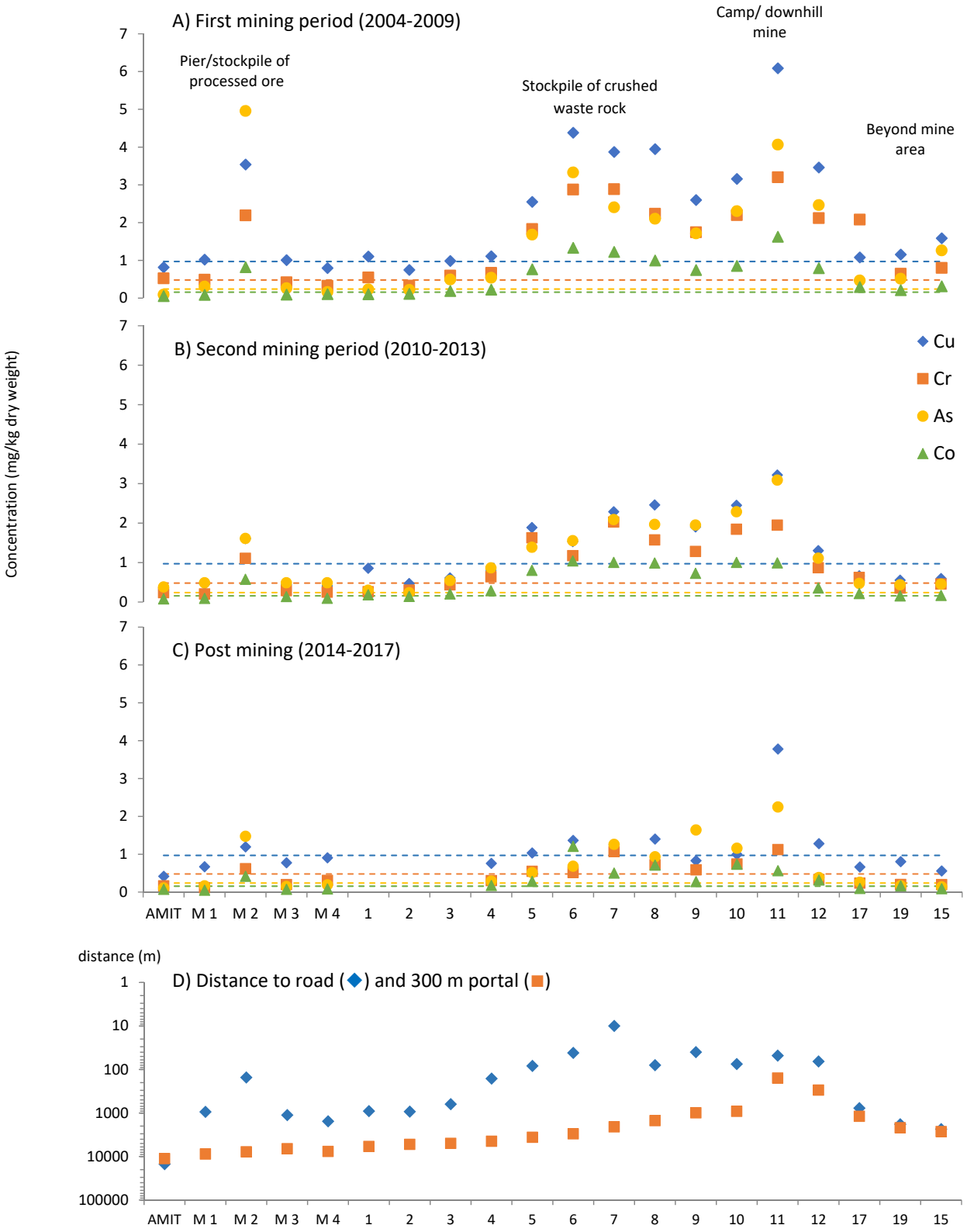

Figure 19. Concentrations of Cu (◆), Cr (■), As (●) and Co (▲) in the lichen *Flavocetraria nivalis* measured at the lichens stations A) during the first mining period, where ore was shipped out (2004-2009), B) during the second mining period, where ore was processed on site, and C) post closure. Also, the D) the distances (in meter on a log scale) from the lichen stations to the road (◆) and to the 300 m portal (■). Stations are arranged from the coast and up through the valley to the mine area and beyond the mine area. For localization of lichen stations see figure 12. The dashed horizontal lines in A-D indicate average background concentrations of the four metals.

Figure 20 shows how far from the road elevated concentrations of Cu, Cr, As and Co were found in the Kirkespir Valley for the three mining periods. For As, the background concentrations were met at about 3000, 5000 and 800 m from the road, respectively for the three periods. For Co the distances were ca. 1100, 1100 and 500 m. For Cr 2000, 550 and 100 m, while the background concentrations for Cu were met at 1500, 250 and 250 m, respectively, from the road. This indicates that the pollution effects of the road decrease with time. While the impact was most pronounced during the first mining period, the background concentrations were met at within 100-800 m post mining as a result of the ceased mining activities.

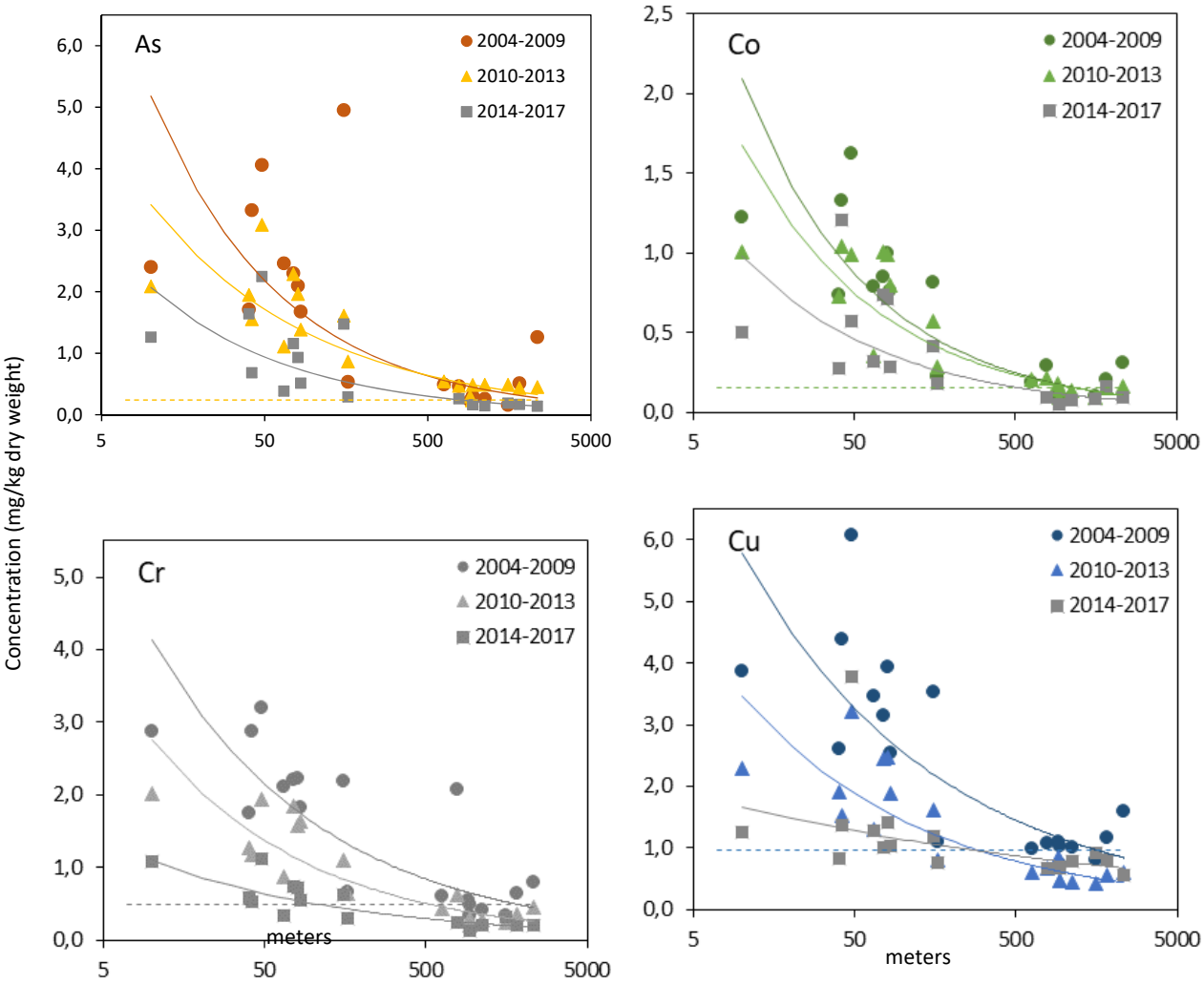

Figure 20. Concentrations of Cu, Cr, As and Co in the lichens, *Flavocetraria nivalis*, as a function of the stations' distances to the gravel road (in meters - on a log scale). Background average concentrations are shown with horizontal dashed lines.

5.1.1 Conclusions on the terrestrial environment

It is concluded that concentrations of Cu, Cr, As and Co in lichens during 2004-2010 were significantly elevated at the pier, at the waste rock stockpile and in the mine area compared to the background levels. Before 2009, the dust pollution was mainly an effect of the mine activities (crushing of rock, stock-piling etc.) rather than an effect of the road. The dust pollution decreased from 2010 due to structural changes in the mining process. From then on, the dust pollution was merely explained as an effect of the gravel road.

Overall, the dust deposition measured in the lichen samples reflected the activities related to the mining and logistics in the area. Even though the increased levels were found not to be harmful or cause any risk to the environment, recommendations were given to reduce the impact. The results from the monitoring in 2017, found that most elements were at background levels i.e. the levels measured in lichens before mining was initiated i.e. 1998-2002 (see Bach and Larsen, 2018 for detailed data).

5.2 Freshwater environment

The freshwater environment was monitored by analysing metal concentrations in water samples (2012-2019), and by analysing Arctic char livers for metal accumulation.

5.2.1 Water samples

Results of the element analyses for filtered freshwater samples are shown in table 3 relative to the Greenland Water Quality Criteria (GWQC).

As shown in table 3, elevated concentrations of As, Cu and Ni were found in the waste water sample from the mine exit (st 2) when compared to the GWQC. After mine closure, only As was found in elevated concentrations in the outflowing waste water, confirming that the previous high element concentrations were related to the mining process. At one point in 2014, a high concentration was found for Cu in the upstream water. This phenomenon was only observed once, and as it couldn't be explained by natural occurrence, it was possibly related to a contamination of the sample.

When the water flows out of the mine, it enters a small creek before it mixes with the Kirkespir River. The flow in Kirkespir River is roughly estimated to 350,000 m^3/d in average over a year based on data provided in the EIA (SRK 2002). At the waterfall station (st 4), most element concentrations were found in concentrations insignificantly different from the upstream water concentrations (see table 3 and figure 21). Only in 2012 was Cu detected at high concentrations in the Kirkespir River. Overall the data indicate that the high concentrations of elements in the mine waste water were diluted properly when mixing with the large Kirkespir River. After mine closure, all element concentrations at Kirkespir River (st 4) complied with the Greenland Water Quality Criteria (GWQC).

Table 3. Elements measured in filtered (<45 µm) freshwater samples at three stations 1: Upstream, 2: Outflow from the mine at the 300 m portal, and 4: Kirkespir River at the waterfall station (in µg/l). Values for Greenland Water Quality Criteria (GWQC) for filtered water for mining activities (MRA, 2015) are also shown. An asterisk (*) indicates slightly elevated concentrations (2-5 x background concentration), ** indicates elevated concentrations (5-10 x background concentration) and *** indicates highly elevated concentrations (>10 x background concentration) above GWQC. DL: detection limit. '-' indicates not analysed.

	As	Au	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
GWQC	*4*		*0.1*		*3*	*2*	*300*	*0.05*	*5*	*1*		*10*
2012												
Upstream (st 1)	0.862	0.001	0.005	0.012	0.102	1.86	2.62	0.013	0.289	0.030	0.232	1.06
Outflow mine (st 2)	70.1***	20.8	0.034	19.0	0.153	74.1***	22.5	0.049	19.8*	0.061	1.45	3.36
Kirkespir River (st 4)	1.65	0.016	0.008	0.155	0.121	3.65*	3.80	0.005	0.340	0.052	0.215	1.26
2013												
Upstream (st 1)	1.01	0.003	<DL	0.025	0.052	0.16	8.28	<DL	0.061	<DL	0.056	0.168
Outflow mine (st 2)	128***	26.8	0.016	50.3	0.070	65.6***	169	<DL	15.2**	0.018	0.956	0.926
Kirkespir River (st 4)	2.66	0.013	<DL	0.107	0.058	0.832	<DL	<DL	0.258	<DL	0.172	0.290
2014												
Upstream (st 1)	3.13	0.046	<DL	0.176	0.106	10.2**	12.5	<DL	0.282	0.321	<DL	4.48
Outflow mine (st 2)	273***	7.23	0.099	44.4	0.086	4.40*	387	0.030	4.90	0.008	0.576	2.56
Kirkespir River (st 4)	2.33	0.012	<DL	0.136	<DL	<DL	<DL	<DL	0.103	<DL	<DL	0.36
2015												
Upstream (st 1)	2.20	-	<DL	0.137	0.430	0.530	21.0	<DL	0.280	0.183	0.200	2.92
Outflow mine (st 2)	30.8***	-	0.018	0.205	0.415	1.40	6.05	0.004	1.29	0.089	0.160	4.34
Kirkespir River (st 4)	1.50	-	0.046	0.045	0.310	0.380	3.47	<DL	0.190	0.091	0.170	0.840
2017												
Upstream (st 1)	1.69	<DL	0.003	0.044	0.211	0.104	16.0	<DL	0.097	0.035	0.056	<DL
Outflow mine (st 2)	26.8***	<DL	0.009	0.059	0.347	0.762	3.65	<DL	0.749	0.011	0.148	1.77
Kirkespir River (st 4)	1.74	<DL	0.005	0.050	0.235	0.349	16.2	<DL	0.116	0.062	0.064	<DL
2019												
Upstream (st 1)	1.03	<DL	0.002	0.005	0.071	0.095	0.981	<DL	<DL	<DL	0.044	0.526
Outflow mine (st 2)*	157***	0.502	0.070	7.59	0.077	0.509	129	0.033	1.89	0.011	0.382	5.82
Kirkespir River (st 4)	1.77	0.011	0.002	0.057	0.087	0.208	9.96	<DL	0.085	0.004	0.092	0.606

* In 2019, the sample was taken inside the mine entrance as no water was flowing out of the mine.

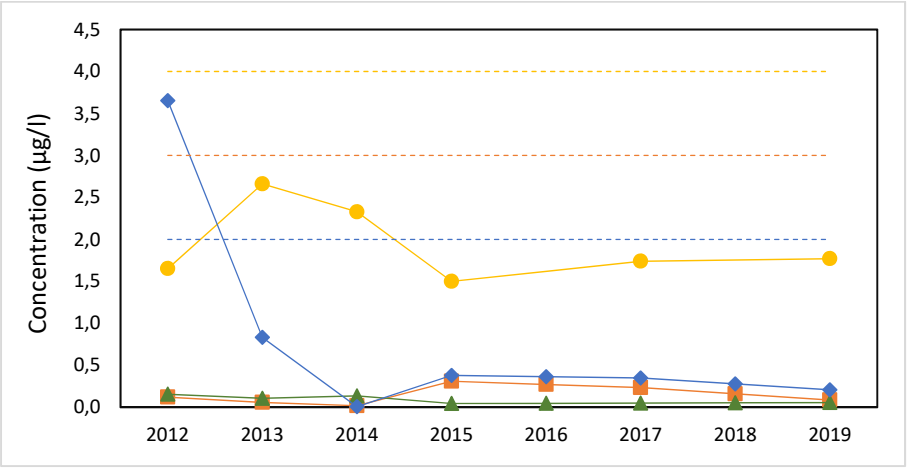

Figure 21. Concentrations of As (●),Co (▲),Cr (■) and Cu (◆) in water samples collected in Kirkespir River at the waterfall station (in µg/l). The dashed horizontal lines indicate GWQC for As, Cr and Cu.

Figure 22. Collection of water samples in the sedimentation pond. Source: Photo by L Bach.

5.2.2 Arctic char

Elements measured in the livers of Arctic char collected at the waterfall station in the Kirkespir River are shown in table 4. The waterfall station is the first place downstream from the mine where chars are found.

Compared to background concentrations, the data for metal load in livers of Arctic chars showed that there was a tendency for Cd to slightly accumulate in the fish. Especially during the period of Arctic Mining the measured concentrations found were slightly elevated. Cd is a heavy metal known to accumulate in livers and especially kidneys in organisms, incl. fish species, due to its lipophilic character (Dallinger et al., 1997). When comparing the Cd concentrations in the water samples (table 3 and figure 23) with the GWQC at 1 µg/l for cadmium, the water concentration appeared low. Thus, bioaccumulation occurred. The guideline maximum levels of Cd for food consumption is 0.05-0.1 mg/kg fish (Fødevaredirektoratet 2003). This level was exceeded by the liver concentrations in the Nalunaq chars. However, the guideline value is given for the fish muscle, and not the liver, which tend to accumulate metals to much greater extent than muscles. It was thus assessed that the maximum level was not reached for the fish in the Kirkespir River. The tolerable intake of cadmium per kg human body weight per week is set at 2.5 µg (Fødevarestyrelsen 2008) corresponding to ca. 200 µg per person and a tolerable intake of 800 g Arctic char liver a week. It is therefore assessed that there is no risk for human consumption of the Arctic chars or the livers.

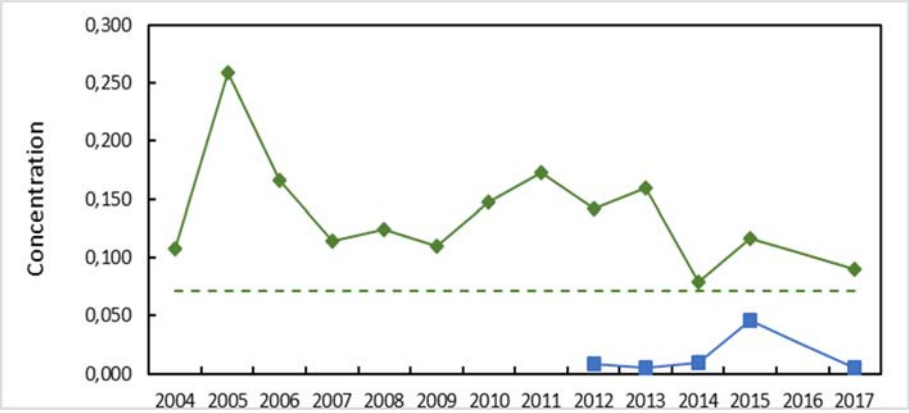

Figure 23. Concentrations of Cd in the Arctic char (◆) in mg/kg wet weight and in water samples (■) µg/l in the Kirkespir River at the waterfall station. Background average concentrations for the Arctic char are shown with horizontal dashed lines. The Greenland Water Quality Criteria (GWQC) for cadmium is 1 µg/l. Water samples were unfortunately not collected for analyses before 2012. .

Table 4. Average metal concentrations in livers of Arctic char, *Salvenius alpinus*, (mg/kg wet weight). Background concentrations are those from baseline studies. An asterisk (*) indicates slightly elevated concentrations (2 x background concentration). DL: detection limit.

		As	Au	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
Baseline mean		*0.448*		*0.071*	*0.042*	*0.026*	*9.88*		*0.025*		*0.006*		*34.8*
	std	*0.148*		*0.024*	*0.014*	*0.025*	*11.0*		*0.010*		*0.003*		*4.44*
Crew Mining													
2004	mean	0.243	-	0.108	0.114*	0.075*	12.3	-	0.033	0.188	0.008	2.78	21.2
	std	0.119	-	0.045	0.046	0.011	9.99	-	0.014	0.093	0.005	1.61	5.87
2005	mean	1.34*	0.001	0.258*	0.051	0.013	5.42	-	0.035	<DL	<DL	1.41	35.5
	std	0.935	0.001	0.220	0.045	0.011	7.63	-	0.025	-	-	1.05	11.5
2006	mean	0.192	0.047	0.167*	0.062	0.101*	7.82	-	0.054*	<DL	0.008	1.69	23.9
	std	0.052	0.023	0.053	0.045	0.014	3.94	-	0.005	-	0.003	0.67	2.56
2007	mean	0.295	0.001	0.114	0.062	0.012	7.73	-	0.039	0.111	0.001	2.81	33.3
	std	0.021	0.001	0.045	0.007	0.012	3.13	-	0.003	0.025	0.007	0.06	4.00
2008	mean	0.264	0.001	0.125	0.061	0.026	7.31	-	0.047	0.146	<DL	2.84	24.6
	std	0.094	0.000	0.067	0.024	0.011	3.42	-	0.016	0.024	-	1.30	2.26
2009	mean	0.208	0.009	0.110	0.062	0.017	8.53	221	0.031	0.037	0.009	0.87	23.0
	std	0.110	0.000	0.038	0.032	0.013	5.88	194	0.027	0.000	0.000	0.56	2.36
Angel Mining													
2010	mean	0.273	0.002	0.148*	0.069	0.026	22.3*	-	0.019	0.092	0.007	1.71	33.9
	std	0.086	0.001	0.068	0.025	0.016	25.2*	-	0.008	0.039	0.003	0.61	9.84
2011	mean	0.289	0.064	0.173*	0.068	0.048	19.6	279	0.039	0.021	0.027*	1.29	35.1
	std	0.210	0.091	0.102	0.033	0.027	17.2	225	0.025	0.009	0.021	0.56	6.45
2012	mean	0.322	0.035	0.142*	0.059	0.032	8.60	228	0.061*	0.011	<DL	0.91	32.5
	std	0.189	0.039	0.051	0.023	0.023	6.50	113	0.044	0.016	-	0.23	6.05
2013	mean	0.249	0.055	0.159*	0.051	0.015	9.37	68.4	0.020	0.014	0.008	0.94	29.6
	std	0.134	0.078	0.121	0.044	0.007	6.54	34.1	0.013	0.008	0.014	0.30	2.48
Post Mining													
2014	mean	0.203	0.529	0.079	0.097*	0.036	18.5	282	0.014	0.030	0.006	1.53	28.6
	std	0.038	0.208	0.028	0.004	0.010	6.03	157	0.006	0.001	0.004	0.27	2.11
2015	mean	0.534	-	0.117	0.047	0.022	4.62	119	0.018	0.001	0.002	0.89	28.1
	std	0.138	-	0.047	0.013	0.004	2.73	103	0.004	0.003	0.002	0.26	2.96
2017	mean	0.279	0.006	0.090	0.041	0.014	7.26	64.8	0.019	<DL	<DL	0.81	26.5
	std	0.137	0.002	0.010	0.026	0.009	7.09	30.4	0.002	-	-	0.22	2.39

Other metals – As, Co, Cr, Cu, Hg and Pb – were sporadically found slightly elevated on few occasions. These elevated concentrations are interpreted as natural variations.

Four years after mining, in 2017, all measured concentrations in the livers of Arctic char were found at the level of the background concentrations.

Figure 24. Arctic chars were dissected and the liver analysed for elements. Source: Photo by L Bach.

5.2.3 Cyanide

As cyanide was included in the extraction process during the Angel mining period, cyanide was monitored in the environment. The company performed daily checks for cyanide levels in the outflowing waste water from the mine and weekly at the waterfall station in Kirkespir River. During 2011, the company reported exceeded values a few times, and the company took action thereafter. It was evaluated that the cyanide in the measured concentrations would not cause risk to the environment. At no other times during the mining period did the company report cyanide concentrations that exceed the guideline values set by EAMRA at 0.005 mg/l at the waterfall station.

In addition to the self-monitoring by the company, cyanide was also monitored by DCE. The measured concentrations in Kirkespir River were at all times in compliance with the guideline values.

During the closure of the mine in 2013, DCE followed the closure closely, inspected the process and took water samples for cyanide analyses from all water bodies left inside the mine. After the closure of the mine, the cyanide levels were measured yearly in the water flowing out of the mine, in the monitoring wells and in Kirkespir River at the waterfall station. When possible samples from the underground mine were also collected for analyses. Samples collected underground in 2015 and 2019 were analysed for total cyanide in addition to free cyanide analyses. In 2015, the total cyanide concentration was 1.0 mg/l in the processing area and 0.003 mg/l in the old tailings chamber. Similarly, in 2019, the analysis of total cyanide showed a concentration of 0.36

mg/l in the sample collected inside the mine at the 300 m portal. This indicates that a minor part of the cyanide remains in the mine water as complex-bound cyanide. All water samples taken underground in the mine after closure contained cyanide in concentrations under the level of toxicity. The cyanide in the outflowing water from the mine was diluted greatly when entering the Kirkespir River and was expected to degrade naturally by exposure to light and oxygen in the environment. All monitoring of the water samples in the environment reported cyanide concentrations at levels that complied with the guideline values.

Based on the cyanide monitoring, cyanide was and is not considered to pose any risk to the biota including the Arctic char or to the surrounding environment.

5.2.4 Conclusions on freshwater environment

Few elements were found slightly elevated in the freshwater environment at the waterfall station in Kirkespir River (measured in water samples and Arctic char). The freshwater environment may have been impacted by outflow of waste water from the mine, drainage from ore and waste rock as described in Lakefield reports i.e. Lakefield Research Ltd 1998a,b, 1999a-d. It was expected that elevated concentrations of elements and possible cyanide residues would be found in the water flowing from the mine and that the concentrations would be diluted to low concentrations when the mine water mixed with the large Kirkespir River. Based on the data, this also appeared to be the case.

The Arctic char tended to slightly accumulate elements in the livers, but the concentrations were assessed to cause no risk.

Post mine closure, no cyanide or elevated concentrations of elements were found in water samples and in the Arctic chars in the Kirkespir River.

5.3 Marine environment

Mussels and seaweed were collected by hand from shore at four stations (M1-M4) in 2004-2010. From 2011, station M5 was included in the sampling program. Sculpins were angled from boat and when possible four sculpins were collected for analyses. In 2014 and 2015, a reduced sampling program was performed excluding the sculpins.

Station M3 and M5 were positioned on each site of the outlet from Kirkespir River and M2 close to the pier. Station M1 and M4 were further away and should provide an estimate for any possible spreading to the larger environment of the fjord.

Data presented are given as mean concentrations of the measured concentrations during the three mining periods: Crew mining, Angel mining and post mining. The data thus presents the mean of the means and standard deviations (std) are thus given of the means. For specific measured concentrations in each year, variations between years and statistics, the reader is referred to the yearly monitoring reports (Glahder and Asmund 2005, 2006, 2007; Glahder et al. 2008, 2009, 2010, 2011; Bach et al. 2012, Bach & Asmund 2013, Bach et al. 2014, 2015; Bach and Larsen 2016; Bach and Larsen 2018). Data were compared with the background data from 2000. Concentrations were considered slightly elevated when the mean of the measured concentrations exceeded the background levels

by a factor 2, elevated when concentrations were between 2-5 times the background concentrations and highly elevated when they were above 10 times background concentrations. As the data presented are mean concentrations over several years, higher concentrations could appear in one year but might be smoothed by lower concentrations in other years.

5.3.1 Blue mussels

Elements measured in blue mussels collected at the five marine stations in the Kirkespir Fjord are shown in table 6.

In blue mussels (*Mytilus edulis*), nearly all measured concentrations were considered normal and not elevated. As shown in table 6, Cr and Ni were found elevated at station M3 at one occasion (the numbers are marked with an asterisk).

With some level of fluctuation, the element concentrations in mussels are rather constant throughout the three periods, except for Au. The fact that the extraction of gold on site was initiated during the Angel mining period, was reflected in the gold concentrations in the mussels that increased about 10-fold from the period of Crew Mining to Angel Mining. Particularly the mussels at station M3, M4 and M5 had the highest concentrations, indicating that the origin from the impact was through the Kirkespir River and thus probably through waste water from the mine. Mussels are known to excrete elements at different rates. It is unknown whether the higher Au concentrations also measured post closure were relics of one or a few years high impact, or whether the mussels were constantly exposed to higher concentrations during 2009-2017. This uncertainty could be revealed by using the method of transplanting mussels from an un-impacted site to these stations for a year. However, as Au is considered not harmful at these concentrations this investigation has not been made.

Overall, the information on pollution level provided by mussel samples showed that there were no risk associated with the mining to the marine environment.

Table 6. Average element concentrations in blue mussels, *Mytilus edulis* (mg/kg dry weight) during the three periods, Crew Mining 2004-2009, Angel Mining 2010-2013, and post mining 2014-2017. Background concentrations are those from baseline studies. An asterisk (*) indicates slightly elevated concentrations (2 x background concentration). DL: detection limit.

		As	Au	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
baseline mean		*11.7*		*5.47*	*0.240*	*0.736*	*7.60*		*0.132*		*1.21*		*89.0*
	std	*1.8*		*2.01*	*0.040*	*0.356*	*0.831*		*0.029*		*0.424*		*13.0*
Crew Mining													
M1	mean	12.0	0.029	2.85	0.324	0.702	6.77	133	0.081	1.35	0.506	3.46	72.9
	std	0.864	0.035	1.78	0.105	0.209	1.00	-	0.022	0.333	0.161	0.715	6.66
M2	mean	13.8	0.015	3.23	0.392	0.900	7.80	233	0.076	1.61	0.589	3.97	80.5
	std	1.14	0.012	1.80	0.180	0.453	1.82	-	0.018	0.595	0.191	0.797	9.34
M3	mean	15.2	0.020	3.06	0.478	1.14	8.03	233	0.122	1.73*	0.669	4.12	79.0
	std	0.946	0.016	0.98	0.159	0.300	1.44	-	0.052	0.476	0.231	0.486	4.83
M4	mean	11.7	0.022	4.20	0.364	0.783	7.55	114	0.085	1.32	0.536	3.83	81.1
	std	0.544	0.017	2.20	0.108	0.229	1.43	-	0.047	0.253	0.169	0.690	10.8
Angel Mining													
M1	mean	12.0	0.093	3.36	0.335	0.776	6.12	157	0.094	1.14	0.578	3.14	61.8
	std	1.10	0.058	0.486	0.033	0.215	0.512	43.1	0.032	0.208	0.140	0.161	8.77
M2	mean	12.4	0.144	3.61	0.352	0.618	6.81	183	0.070	1.07	0.506	3.30	59.8
	std	2.07	0.112	1.35	0.069	0.074	0.432	28.5	0.031	0.106	0.123	0.467	6.40
M3	mean	12.8	0.354	3.76	0.446	1.61*	8.34	313	0.085	1.48	0.686	3.68	69.9
	std	0.965	0.273	0.530	0.043	1.29	1.94	161	0.036	0.625	0.123	0.609	17.9
M4	mean	11.0	0.309	5.48	0.385	0.720	7.82	166	0.134	1.09	0.588	4.08	67.0
	std	1.04	0.225	2.48	0.074	0.078	1.14	7.00	0.133	0.222	0.177	0.561	10.6
M5	mean	11.2	0.314	4.34	0.323	0.765	7.27	221	0.065	0.94	0.527	3.41	55.4
	std	0.839	0.154	1.62	0.028	0.218	0.989	35.0	0.010	0.033	0.093	0.453	6.61
Post mining													
M1	mean	11.9	0.122	4.22	0.353	0.578	6.77	114	0.071	1.20	0.528	3.96	76.0
	std	2.09	0.097	0.425	0.068	0.094	0.539	11.7	0.017	0.047	0.238	0.162	9.06
M2	mean	12.5	0.122	3.38	0.406	0.812	7.47	209	0.071	1.35	0.661	3.99	74.5
	std	1.48	0.093	0.341	0.123	0.356	1.35	161	0.013	0.393	0.210	0.929	15.5
M3	mean	11.8	0.466	3.97	0.369	0.739	7.26	175	0.064	1.10	0.615	3.79	69.2
	std	0.221	0.453	0.956	0.075	0.151	0.224	41.8	0.008	0.228	0.037	0.369	4.67
M4	mean	11.4	0.338	5.31	0.397	0.703	7.37	138	0.071	1.26	0.641	4.32	77.1
	std	0.667	0.197	2.28	0.126	0.119	0.335	34.5	0.011	0.375	0.137	0.801	3.42
M5	mean	14.6	0.435	4.21	0.463	0.836	7.83	213	0.070	1.22	0.614	4.64	69.7
	std	3.69	0.178	0.631	0.187	0.194	1.02	31.8	0.010	0.283	0.244	1.18	2.36

5.3.2 Seaweed

Element concentrations in seaweed collected at the five marine stations (M1-M5) in the Kirkespir Fjord are shown in table 7.

In brown seaweed (*Fucus vesiculosus*), elevated concentrations were found for Co, Cr, Hg, Pb and particularly Cu compared with background values.

Co was found slightly elevated around the outlet of Kirkespir River to the fjord (st M3 and M5). Hg and Pb were found elevated twice at different locations which was a result of individual high measurements (also indicated by high standard deviations). The elevated concentrations can't be explained and it can't be excluded that they were results of contamination of samples. Cr

was found slightly elevated at st M2, M3 and M4 during the first mining period under Crew, and at all sites after mining ceased. Most pronounced was Cu, which was found in concentrations higher than the background concentrations during all periods and at all sites. During the Angel Mining period, Cu was found elevated and highly elevated at the stations around the outflow of Kirkespir River to the fjord, while under Crew mining, the concentrations were only slightly elevated. To assess the risk of Cu the daily tolerable concentration for intake is taken into consideration. The daily tolerable concentration of Cu is 10-12 mg per day (Fødevarestyrelsen, 2008). Based on the highest measured concentration was ca. 12 mg/kg dry weight seaweed and the concentration post mining is at ca. 4 mg/kg dry weight, it is assessed that there is no risk associated to human consumption of the seaweed.

Post mining, slightly elevated concentrations were found for Co, Cr and Cu particularly around the outlet of Kirkespir River to the fjord (station M3 and M5).

Figure 25. At decommissioning of the mine, it was decided to leave the pier for potential future use. In August 2014, the barge was loaded with equipment and metal scrap to be shipped to Denmark. Source: Photo by L Bach.

Table 7. Average element concentrations in seaweed, *Fucus vesiculosus* (mg/kg dry weight) during the three periods, Crew Mining 2004-2009, Angel Mining 2010-2013, and post mining 2014-2017. Background concentrations are those from baseline studies. An asterisk (*) indicates slightly elevated concentrations (2-5 x background concentration), ** indicates elevated concentrations (5-10 x background concentration) and *** indicates highly elevated concentrations (>10 x background concentration). DL: detection limit.

		As	Au	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
baseline mean		*46.2*		*1.76*	*0.211*	*0.069*	*1.00*		*0.009*		*0.107*		*7.00*
	std	*8.43*		*0.576*	*0.046*	*0.076*	*0.237*		*0.006*		*0.043*		*2.09*
Crew Mining													
M1	mean	41.6	0.011	1.362	0.201	0.112	1.45	39.2	0.047**	1.01	0.043	0.136	7.71
	std	10.7	0.014	0.347	0.112	0.074	1.05	-	0.064	0.145	0.025	0.141	3.84
M2	mean	41.8	0.021	0.788	0.375	0.328*	3.30*	76.0	0.003	1.41	0.055	0.132	13.2
	std	11.3	0.038	0.280	0.135	0.344	3.76	-	0.005	0.419	0.060	0.201	8.56
M3	mean	46.9	0.208	0.907	0.663*	0.238*	2.43*	53.1	0.011	1.60	0.053	0.123	11.2
	std	6.88	0.418	0.147	0.331	0.265	1.96	-	0.021	0.390	0.048	0.174	5.02
M4	mean	47.5	0.056	1.461	0.359	0.339*	2.70*	39.8	0.002	1.61	0.064	0.211	10.8
	std	8.28	0.116	0.261	0.269	0.594	3.04	-	0.004	0.690	0.119	0.276	6.14
Angel Mining													
M1	mean	57.3	0.071	1.86	0.246	0.087	4.56*	21.3	<DL	0.785	0.249*	0.011	7.72
	std	6.61	0.046	0.389	0.027	0.019	3.38	2.46	-	0.188	0.334	0.020	1.90
M2	mean	64.6	0.136	1.40	0.302	0.072	5.78**	31.4	<DL	0.699	0.030	0.009	8.32
	std	5.33	0.113	0.522	0.057	0.063	4.73	9.88	-	0.140	0.024	0.015	2.25
M3	mean	60.4	0.777	1.13	0.564	0.087	12.3***	40.3	0.041**	1.10	0.065	0.013	10.3
	std	8.72	0.617	0.286	0.233	0.065	7.18	12.8	0.081	0.427	0.018	0.025	3.61
M4	mean	50.7	0.205	1.94	0.354	0.075	4.13*	27.8	0.003	1.06	0.053	0.015	7.81
	std	4.07	0.174	0.460	0.078	0.059	2.18	0.512	0.007	0.264	0.030	0.027	1.43
M5	mean	56.4	0.447	0.984	0.451*	0.104	10.3***	52.2	<DL	0.979	0.537**	0.014	10.6
	std	6.45	0.202	0.184	0.083	0.037	0.680	14.1	-	0.160	0.846	0.023	0.694
Post mining													
M1	mean	63.6	0.004	1.97	0.175	0.139*	2.50*	33.2	0.003	0.572	0.043	0.034	8.95
	std	11.7	0.008	0.173	0.013	0.064	1.58	19.5	0.004	0.065	0.013	0.008	1.05
M2	mean	63.6	0.014	1.30	0.269	0.201*	2.13*	66.1	0.003	0.654	0.051	0.064	9.77
	std	10.7	0.024	0.282	0.082	0.157	0.437	78.3	0.006	0.221	0.026	0.050	4.33
M3	mean	73.0	0.029	1.48	0.466*	0.213*	3.04*	39.1	0.003	0.849	0.047	0.058	9.87
	std	12.7	0.029	0.340	0.090	0.051	0.656	16.6	0.005	0.303	0.012	0.029	1.91
M4	mean	57.9	0.011	2.02	0.298	0.139*	2.19*	25.4	0.002	0.852	0.038	0.053	8.17
	std	4.75	0.019	0.522	0.130	0.051	0.439	12.6	0.003	0.349	0.012	0.032	1.73
M5	mean	51.2	0.021	1.20	0.387	0.333*	4.11*	198	0.001	0.835	0.149	0.052	11.4
	std	4.74	0.024	0.104	0.176	0.339	2.24	286	0.002	0.296	0.124	0.042	2.39

5.3.3 Sculpins

Elements measured in sculpin collected at the five marine stations (M1-M5) in the Kirkespir Fjord are shown in table 8.

In shorthorn sculpin (*Myoxocephalus scorpius*), slightly elevated concentrations were found for As, Co, Cr, Cu and Pb compared with background values. At one time Pb was found in fish liver in an elevated concentration.

The slightly elevated concentrations of Cr found at station M1 during the Crew mining period can only be explained by natural variations. The slightly elevated concentrations of other metals appeared at the stations around the outlet of Kirkespir River. As the concentrations appeared only to be slightly elevated and sporadically with no trend, it is assessed that there has been no risk related to the measured sculpin concentrations.

Table 8. Average element concentrations in sculpins, *Myoxocephalus scorpius*, (mg/kg wet weight) during the three periods, Crew Mining 2004-2009, Angel Mining 2010-2013, and post mining 2014-2017. Background concentrations are those from baseline studies. An asterisk (*) indicates slightly elevated concentrations (2-5 x background concentration). DL: detection limit.

		As	Au	Cd	Co	Cr	Cu	Fe	Hg	Ni	Pb	Se	Zn
baseline	*mean*	*2.75*		*1.09*	*0.017*	*0.017*	*1.88*		*0.026*		*0.004*		*31.8*
	std	*1.89*		*0.427*	*0.014*	*0.020*	*0.699*		*0.013*		*0.003*		*1.58*
Crew Mining													
M1	mean	2.11	0.028	0.775	0.026	0.050*	1.95	34.3	0.026	0.022	0.001	0.777	26.9
	std	0.38	0.052	0.165	0.029	0.064	0.54	-	0.012	0.023	0.002	0.193	4.39
M2	mean	3.14	0.031	0.389	0.021	0.022	1.52	43.2	0.018	0.025	0.006	0.689	31.2
	std	0.34	0.075	0.165	0.012	0.026	0.66	-	0.009	0.033	0.009	0.172	9.32
M3	mean	2.65	0.016	0.539	0.039*	0.024	2.40	75.2	0.025	0.056	0.008*	0.868	29.4
	std	0.77	0.023	0.103	0.022	0.031	1.07	-	0.008	0.057	0.013	0.187	5.88
M4	mean	2.51	0.011	0.531	0.022	0.018	2.57	64.6	0.031	0.088	0.006	0.613	25.9
	std	0.54	0.015	0.245	0.015	0.028	1.09	-	0.017	0.113	0.009	0.057	5.04
Angel Mining													
M1	mean	2.94	0.007	0.738	0.021	0.029	2.20	45.6	0.027	0.027	0.001	0.812	29.6
	std	1.04	0.004	0.232	0.007	0.003	1.49	4.25	0.019	0.024	0.001	0.138	4.64
M2	mean	3.05	0.003	0.404	0.019	0.026	1.46	44.3	0.027	0.020	0.002	0.854	29.9
	std	0.85	0.002	0.247	0.006	0.025	0.25	9.46	0.015	0.014	0.002	0.028	4.43
M3	mean	3.28	0.007	0.453	0.052*	0.036*	2.88	126.5	0.024	0.020	0.036**	0.878	30.9
	std	0.81	0.003	0.235	0.023	0.026	1.18	36.2	0.014	0.018	0.067	0.171	1.71
M4	mean	3.40	0.005	0.375	0.020	0.059*	1.52	37.9	0.034	0.024	0.003	0.707	26.0
	std	2.35	0.005	0.155	0.008	0.087	0.23	15.58	0.024	0.018	0.006	0.064	3.75
Post mining (2017 data available only)													
M1	mean	3.59	<DL	0.675	0.025	0.015	1.92	67.0	0.023	0.060	<DL	0.966	28.0
	std	-	-	-	-	-	-	-	-	-	-	-	-
M2	mean	5.60*	<DL	0.543	0.031	0.009	4.06*	62.4	0.024	0.077	<DL	0.948	30.8
	std	-	-	-	-	-	-	-	-	-	-	-	-
M3	mean	4.90	<DL	0.476	0.033*	0.005	5.13*	88.6	0.024	<DL	<DL	0.877	29.5
	std	-	-	-	-	-	-	-	-	-	-	-	-
M4	mean	5.48	<DL	0.299	0.013	0.002	1.65	48.0	0.029	<DL	<DL	1.07	31.5
	std	-	-	-	-	-	-	-	-	-	-	-	-
M5	mean	2.06	<DL	0.608	0.025	0.005	4.19*	36.8	0.016	<DL	<DL	0.878	29.9
	std	-	-	-	--	-	-	-	-	-	-	-	-

5.3.4 Conclusions on the marine environment

Kirkespir River runs out in Kirkespir Bay, where blue mussels, seaweed and sculpins were collected. The marine environment was generally only slightly affected by mining activities. Overall, as the data presented are mean concentrations over several years, higher concentrations could appear in one year but might be smoothed by lower concentrations other years. Seaweed was impacted by the outflow of elements by the Kirkespir River and had slightly elevated concentrations of several elements and particularly at the marine stations closest to the estuary. In contrast, only few sporadically and slightly elevated element concentrations were found in mussels and in sculpin livers at any of the marine stations. The pier area seemed not to contribute greatly to elevated concentrations in the marine environment.

Station M1 and M4, that were positioned 2.5-3 km away from the Kirkespir River outflow appeared only a little impacted, which indicates the extension of the coastal pollution. Thus, the length of coastline with elevated element concentrations can roughly be estimated to a maximum of 5 km.

6 Aerial mapping of terrain

Aerial mapping of the Nalunaq area with a drone was performed in August 2019. The purpose was to get a high quality baseline map of the present state and to document the impact on the terrain. Aerial photo can provide information about damage to vegetation, driving tracks, terrain changes, re-vegetation, etc.

The methods, results and conclusions of the mapping is described in a separate note (Larsen 2020 – provided in appendix A), while main findings and conclusions are described in this chapter with examples of the findings.

The mapping was focused on the former camp/workshop area and the mine area, but also the area around the harbour and around the former oil deposit now camp area for exploration team, as well as parts of the road from the harbour to the mine area (se figure 26).

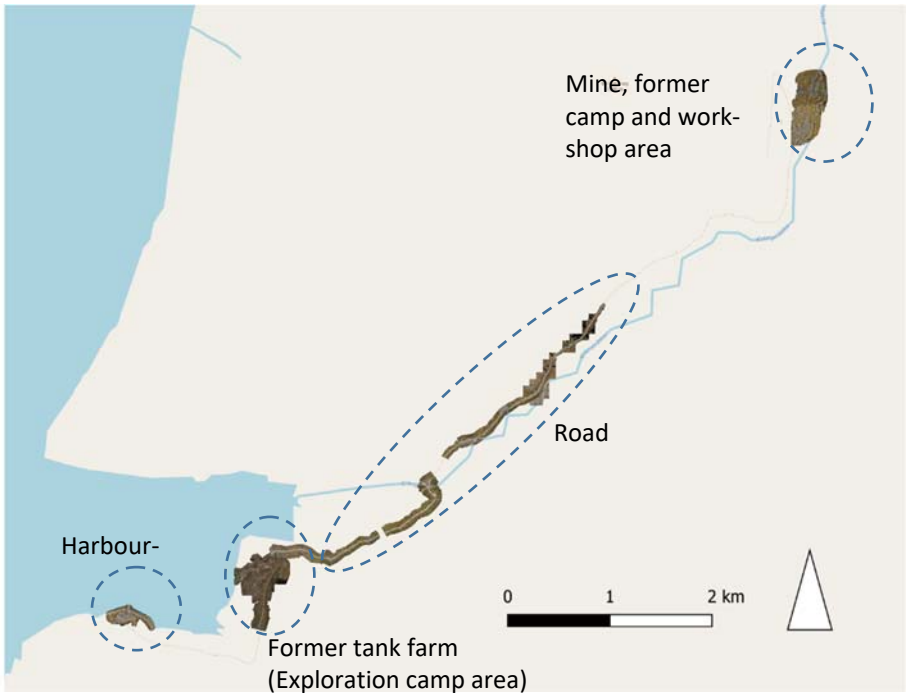

Figure 26. Areas with updated orthophoto with marked focus areas. The former tank farm area is presently used as camp area for the exploration team. Source: Revised figure from Larsen 2020.

Overall, the aerial mapping identified old driving tracks in the terrain, identified remnants from the former mine activities and provided an overview of equipment and supplies brought to the area by the present exploration team.

At the harbor site, small pieces of metal scrap were found at several places. A small pile of metal scrap was also located, possibly a remnant of the decommissioning of the mine where combustible waste was burnt in this area. At the area formerly used for tanks farm and where the exploration team has camp at present, a few pieces of waste were found close to the shore line. In general, the area seems tidy. Rope, fishing nets, wood etc. were identified on the shoreline but left out of the overall waste quantification in the report, as it could not be associated solely to the mining project. No waste was identified along the roadside. The aerial mapping documented the refurbishment of the road as well as the establishment of a number of culverts (see photos in the

report by Larsen 2020, appendix A). In the mine area and the former camp and workshop area, a total of 16 pieces of waste/scrap were identified including pipe lines, plastic items in the river and terrain, and blocks of concrete.

Figure 27. An overview of the mine area and mine portal at 300 m level. Source: Larsen 2020.

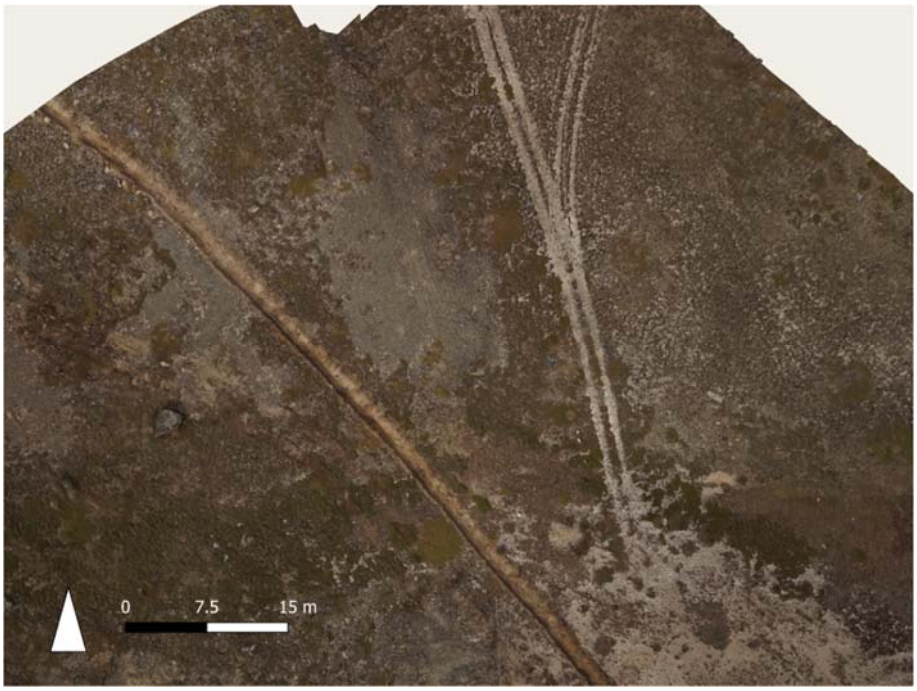

Figure 28. This photo shows a newly dug trench from the exploration camp down to the coast for waste water piping. Also an old driving track is visible. Source: Larsen 2020.

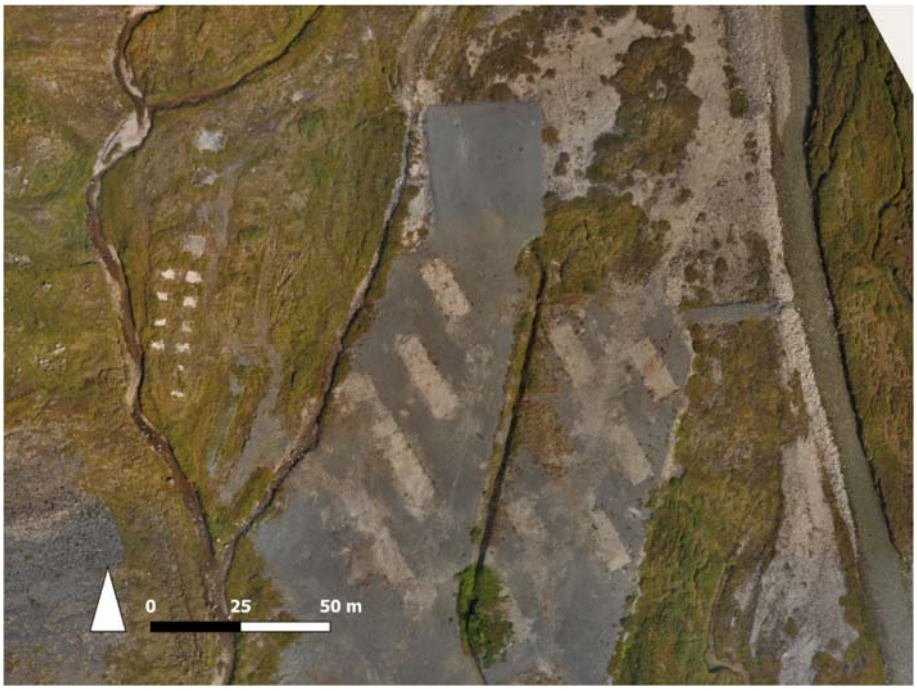

Figure 29. An overview of the former mine area. The former location of buildings and tents are visible. Source: Larsen 2020.

Figure 30. An example of waste in the terrain; here of a piece of orange PVC piping. Source: Larsen 2020.

6.1.1 Conclusion of the aerial mapping of the terrain

The drone flying and subsequent modelling of orthophotos carried out in the area around the Nalunaq gold mine, provided a good coverage of the area. A high resolution of the modelled photos was obtained so it was possible to see even relatively small impacts and disturbances in the terrain. This made it possible to identify also relatively small objects on the ground. In general, relatively few pieces of waste/scrap were localised in the terrain. It should, however, be noted, that not all waste could be localised in the photos, and besides

what was identified in the photos, it is known that more metal scrap is present around the mine site and the former camp/workshop area.

It is assessed that the localised waste items do not pose any risk to the environment in the Nalunaq area, but that the impact is related solely to esthetical matters.

7 Conclusion

Environmental monitoring was conducted at the former Nalunaq gold mine site from 2004 to 2019.

The results of the monitoring documented the impact from the mining to the local environment. Already at the first environmental monitoring in 2004, moderate pollution from the mine was documented with elevated concentrations of a few metals (As, Co, Cr and Cu) in lichens. The pollution was associated with the mining activities primarily as a result of dust spreading by wind from rock crushing, waste rock and ore stockpiles, but also as a result of driving on the gravel road. In particular three areas were found affected: I) The pier, where stockpiles of ore was placed before ship loading, II) The camp where processing of ore including crushing took place and the mining area where waste rock was deposited on the mountain slope. III) Down the valley, where waste rock stockpiles were placed. As a result, recommendations were given to minimise the dust pollution. The levels of dust dispersal had their maximum in 2007/2008. After the restructuring of the mine production in 2009, the pollution decreased. This was a result of the processing of ore (including crushing) taking place underground, and that stockpiles of ore and crushed waste rock were removed from the terrestrial environment. The dust dispersal could then primarily be related to driving on the gravel road. Upon decommissioning of the mine in 2013, the dust pollution decreased even further and in 2017, four years after mine closure, the levels of elements measured in lichens were at or close to background levels.

In the freshwater system, only slight impact was documented in the Kirkespir River. The river was impacted by drainage from ore and waste rock, and from 2009-2013 by diluted mine waste water flowing out of the mine potentially containing cyanide residues and elevated levels of elements. Water samples taken at the waterfall station showed no elevated concentrations of elements when compared to Greenland Water Quality Criteria (GWQC) guidelines. The Arctic chars at the site were shown, however, to accumulate some elements, and in particular Cd was found at consistently slightly elevated concentrations. It was assessed that the concentrations were too low to cause any harm to the fish or the freshwater system. All measured concentrations in the livers of Arctic char were found at the level of the background concentrations in 2017, four years after mine closure. Concerning cyanide, no water samples collected in Kirkespir River had documented cyanide concentrations above instrument detection limits. Cyanide is and was not at any time considered to pose any risk to the biota including the Arctic char or to the surrounding environment.

The marine environment was monitored by analysing mussels, seaweed and livers from sculpin fish. An impact to the marine environment could be the result of increased element concentrations carried to the marine environment by Kirkespir River and/or activities related to dust dispersal from stockpiling at the pier area and ship loading of ore in 2004-2009. While the mussels showed no elevated element concentrations, sculpin livers and in particular seaweed samples had slightly elevated or elevated element concentrations. In particular, Cu concentrations were found to be elevated in seaweed during 2010-2013. It was primarily the stations around the Kirkespir River mouth that were impacted. Therefore, it was assessed that the marine impact was related

to accumulation of elements most likely originating from the mine waste water brought to the marine environment by the river. Four years after mining, in 2017, the element concentrations in seaweed and particular Cu were still slightly elevated. The concentrations are, however, assessed to pose no risk to the biota and it is likely that the concentrations will decrease with time.

The aerial mapping was performed in 2019 and identified old driving tracks in the terrain and remnants from the former mine activities. In general, relatively few pieces of waste/scrap were localised in the terrain. It should, however, be noted, that not all waste could be localised in the photos due to size, color etc. Besides what was identified in the photos, it is known, that more metal scrap is present around the mine site and the former camp/workshop area. Regarding the localised waste/scrap, it is assessed that it does not pose any risk to the environment, but that the impact is related solely to esthetical matters. The aerial mapping further provided an overview of equipment and supplies brought to the area by the present exploration team. Since 2015, exploration activities have taken place in the area during the field seasons. The activities have included drilling, driving, establishment of working tents and re-establishment of roads among other things, but to date no significant environmental effects have been detected.

The possible environmental impacts identified in the EIA were identical to the observed. The impacts were primarily related to dust dispersal of elements and waste water discharge from mine activities. Despite that it was anticipated that mitigation measures could effectively minimise the impacts, considerable to minor impacts were found while the mine was active. After closure, however, the environmental impacts are assessed to be of insignificant character. The overall minor environmental impacts of the mine industry are considered to be a result of adequate environmental requirements set in the license, together with detailed and consistent environmental monitoring and regulation during the entire mine period from exploration, through exploitation and beyond closure. Thus, the environmental requirements and regulation that the company had to comply with proved to be sufficient and adequate.

Overall, DCE assesses the current environmental impact from the former mining activities to the environment at Nalunaq as insignificant and that no further actions are needed to reduce the environmental impact. The EIAs were adequate in the way that they identified the possible impacts of the mine. This made it possible to set environmental requirements in the license and to design and implement an appropriate and detailed monitoring program. Environmental monitoring is considered to be completed with the environmental studies in 2019. Consequently, DCE considers the Nalunaq gold mine to serve as an example of how adequate environmental requirements together with detailed environmental monitoring and regulation can result in a mine operation in Greenland with minimum environmental impact.

8 References

Angel Mining. 2009. Nalunaq Gold Mine. Environmental Impact Assessment – Revised, November 2009. 196 pp.

Bach, L., Asmund, G. & Søndergaard, J. 2012. Environmental Monitoring at the Nalunaq Gold Mine, South Greenland, 2011. Aarhus University, DCE – Danish Centre for Environment and Energy, 42 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 20.
http://www.dmu.dk/Pub/SR20.pdf

Bach, L. & Asmund, G. 2013. Environmental Monitoring at the Nalunaq Gold Mine, South Greenland, 2012. Aarhus University, DCE – Danish Centre for Environment and Energy, 42 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 55. http://www.dmu.dk/Pub/SR55.pdf

Bach, L., Olsen, M. & Asmund, G. 2014. Environmental Monitoring at the Nalunaq Gold Mine, South Greenland, 2013. Aarhus University, DCE – Danish Centre for Environment and Energy, 44 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 97.
http://dce2.au.dk/pub/SR97.pdf

Bach, L., Asmund, G. & Jia, Y. 2015. Nalunaq Environmental Monitoring 2014. Monitoring note from DCE – Danish Centre for Environment and Energy.

Bach, L., Asmund, G. & Riget, F. 2014. Environmental monitoring in 2013 at the cryolite mine in Ivittuut, South Greenland. Aarhus University, DCE – Danish Centre for Environment and Energy, 32 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 105.
http://dce2.au.dk/pub/SR105.pdf

Bach, L & Larsen, M. B. 2016. Environmental monitoring at the Nalunaq Gold Mine, South Greenland, 2015. Aarhus University, DCE – Danish Centre for Environment and Energy, 30 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 181. http://dce2.au.dk/pub/SR181.pdf

Bach, L. & Larsen, M.B. 2018. Environmental monitoring at the Nalunaq Gold Mine, South Greenland, 2017. Aarhus University, DCE – Danish Centre for Environment and Energy, 34 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 278. http://dce2.au.dk/pub/SR278.pdf

Bach, L. & Olsen, M. 2020. Environmental monitoring at the Nalunaq Gold Mine, South Greenland, 2019. Aarhus University, DCE – Danish Centre for Environment and Energy. Technical note from DCE – Danish Centre for Environment and Energy.

Bell, R.-M., J. Kolb, T. E. Waight, L. Bagas and T. B. Thomsen. 2017. A Palaeoproterozoic multi-stage hydrothermal alteration system at Nalunaq gold deposit, South Greenland. Mineralium Deposita 52(3): 383-404.

Boje, J. 1989. Fjeldørred undersøgelser ved Itillersuaq, Nanortalik 1988 (In Danish with English summary: Arctic char study at Itillersuaq, Nanortalik 1988). – Greenlands Environmental Research Institute, Denmark, 36 pp.

Dallinger, R., M. Egg, G. Köck and R. Hofer (1997). The role of metallothionein in cadmium accumulation of Arctic char (*Salvelinus alpinus*) from high alpine lakes. Aquatic Toxicology 38(1): 47-66.

Ewans D, Dodoo, K, Hanson, PJ. 1993. Trace element concentrations in fish livers: Implications of variations with fish size in pollution monitoring, Marine Pollution Bulletin, Volume 26, Issue 6, 329-334.
https://doi.org/10.1016/0025-326X(93)90576-6.

Fødevaredirektoratet 2003: Helhedssyn på fisk og fiskevarer. http://www.fodevarestyrelsen.dk/Publikationer/Alle_publikationer/2003/017.htm.

Fødevarestyrelsen 2008: Kemiske forureninger i fødevarer: Tjekliste. https://www.foedevarestyrelsen.dk/SiteCollectionDocuments/Kemi%20og%20foedevarekvalitet/Tjekliste%20til%20kemiske%20forureninger.pdf

Glahder, C. M. 2001. Natural resources in the Nanortalik district. An interview study on fishing, hunting and tourism in the area around the Nalunaq gold project. National Environmental Research Institute, Technical Report No. 384: 81 pp

Glahder, C. M. & Asmund, G. 2005. Environmental monitoring at the Nalunaq Gold Mine, South Greenland 2004. - National Environmental Research Institute, Technical Report No. 546, 34 pp.

Glahder, C. M. & Asmund, G. 2006. Environmental monitoring at the Nalunaq Gold Mine, South Greenland, 2005. - National Environmental Research Institute, Denmark, Technical Report No. 567, 37 pp.

Glahder, C. M. & Asmund, G. 2007. Environmental monitoring at the Nalunaq Gold Mine, South Greenland, 2006. - National Environmental Research Institute, Denmark, Technical Report No. 614, 26 pp.

Glahder, C. M., Asmund, G., Josefsen, A., Burmeister, A. D. & Jespersen, M. 2005. Nalunaq environmental baseline study 1998-2001. - National Environmental Research Institute, Technical Report No. 562, 90 pp.

Glahder, C. M., Asmund, G. & Riget, F. 2008. Environmental monitoring at the Nalunaq Gold Mine, South Greenland, 2007. - National Environmental Research Institute, Denmark, Technical Report No. 662, 32 pp.

Glahder, C. M., Asmund, G. & Riget, F. 2009. Environmental monitoring at the Nalunaq Gold Mine, South Greenland, 2008. - National Environmental Research Institute, Denmark, Technical Report No. 698, 30 pp.

Glahder, C. M., Asmund, G. & Riget, F. 2010. Environmental monitoring at the Nalunaq Gold Mine, South Greenland, 2009. - National Environmental Research Institute, Denmark, Technical Report No. 772, 32 pp.

Glahder, C. M., Søndergaard, J., Asmund, G. & Riget, F. 2011. Environmental monitoring at the Nalunaq Gold Mine, South Greenland, 2010. - National Environmental Research Institute, Denmark, Technical Report No. 811, 32 pp.

Greisman, P. 2000: Oceanography Report. Nalunaq field investigations. August to October 2000. Nalunaq Gold Project. For Crew Development Corporation. – URS Corporation, Vancouver, Canada, 35 pp.

Johansen, P., Asmund, G., Aastrup, P., Tamstorf, M., 2008. Environmental impact of the lead-zinc mine at Mestersvig, East Greenland. National Environmental Research Institute, University of Aarhus, Denmark. 30 pp. – Research Notes from NERI no. 241.

Lakefield 1998a. Progress Report No. 1, July 1998. Nalunaq Project, Environmental baseline, solids and liquids characterisation testing. Project No. L.R. 7777-452. Prepared for: Nunaoil A/S, Greenland. – Lakefield Research Limited, Canada, 60 pp.

Lakefield 1998b. Progress Report No. 2 (draft), June 1998. Nalunaq Project, Environmental baseline, solids and liquids characterisation testing. Report Prepared for: Nunaoil A/S, Pilestraede 52, DK-1112 Copenhagen K, Denmark. – Lakefield Research Limited, Canada, 7 pp.

Lakefield 1999a. Progress Report No. 3, February 1999. Nalunaq I/S, Environmental baseline study. Results of the phase 3 sampling program. Project No. L.R. 7777-452. Report Prepared for: Nunaoil A/S, Pilestraede 52, DK-1112 Copenhagen K, Denmark. – Lakefield Research Limited, Canada, 7 pp.

Lakefield 1999b. Progress Report No. 4, May 1999. Nalunaq I/S, Environmental baseline study. Results of the phase IV sampling program. Project No. L. R. 7777-565. Report Prepared for: Nalunaq I/S, O. H. Bangsvei 54-58, N-1363, Hovik, Norway. – Lakefield Research Limited, Canada, 3 pp.

Lakefield 1999c. Progress Report No. 5, August 1999. Nalunaq I/S, Environmental baseline study. Results of the phase V sampling program. Project No. L.R. 7777-565. Report Prepared for: Nalunaq I/S, O. H. Bangsvei 54-58, N-1363, Hovik, Norway. – Lakefield Research Limited, Canada, 4 pp.

Lakefield 1999d. Progress Report No. 6, November 1999. Nalunaq I/S, Environmental baseline study. Results of the phase VI sampling program. Project No. L.R. 7777-565. Report Prepared for: Nalunaq I/S, O.H. Bangsvei 54-58, N-1363, Hovik, Norway. – Lakefield Research Limited, Canada, 16 pp.

Larsen M. 2020. Mapping at Nalunaq, 2020. Note from Greenland Institute of Natural Resources.

MRA, 2015. Guidelines for preparing an Environmental Impact Assessment (EIA) report for mineral exploitation in Greenland. Mineral Resources Authority (MRA), Government of Greenland. 24 pp

Muus, BJ. 1990. Grønlands Fauna: Fisk, Fugle og Pattedyr. Gyldendal, 2. udgave. 463 pp. ISBN 87-01-53160-3

Naeth, M.A., Wilkinson, S.R., 2008. Lichens as biomonitors of air quality around a diamond mine, Northwest Territories, Canada. Journal of Environmental Quality, 37, 1675-1684.

Rainbow, P.S., 1995. Biomonitoring of heavy metal availability in the marine environment. Marine Pollution Bulletin, 31, 183-192.

Rigét, F., Johansen, P., Asmund, G., 1997. Uptake and release of lead and zinc by blue mussels. Experience from transplantation experiments in Greenland. Marine Pollution Bulletin, 34 (10), 805-815.

Riget, F., Asmund, G., Aastrup, P., 2000. Mercury in Arctic char (*Salvelinus alpinus*) populations from Greenland. Sci. Total Environ. 245 (1–3), 161–172. https://doi.org/10.1016/S0048-9697(99)00441-6.

Rigét, F., Vorkamp, K., Muir, D., 2010. Temporal trends of contaminants in Arctic char (*Salvelinus alpinus*) from a small lake, southwest Greenland during a warming climate. J. Environ. Monit. 12 (12), 2252–2258.

Secher et al., The Nalunaq Gold Mine. Geology and Ore, GEUS No 11/2008

SRK Consulting 2002. Nalunaq Gold Project. Environmental Impact Assessment. Report prepared for Nalunaq I/S. - Steffen, Robertson & Kirsten (UK) Ltd., Windsor Court, 1-3 Windsor Place, CF103BX, United Kingdom.

Søndergaard, J., Hansson, S.V., Bach, L., Hansen, V., Sonne, C., Jørgensen, C.J., Nymand, J., Mosbech, A., 2020. Environmental monitoring at mine sites in Greenland. A review of research and monitoring practices and their role in minimising environmental impact. Aarhus University, DCE – Danish Centre for Environment and Energy, 44 pp. Scientific Report No. 364. http://dce2.au.dk/pub/SR364.pdf.

Søndergaard, J. 2019. Environmental monitoring at the former Seqi olivine mine, in Southwest Greenland 2011-2018. Aarhus University, DCE – Danish Centre for Environment and Energy, 36 pp. Scientific Report No. 319. http://dce2.au.dk/pub/SR319.pdf

Søndergaard, J., Bach, L. & Asmund, G. 2013. Modelling atmospheric bulk deposition of Pb, Zn and Cd near a former Pb-Zn mine in West Greenland using transplanted *Flavocetraria nivalis* lichens. Chemosphere 90: 2549-2556.

Søndergaard, J., Johansen, P., Asmund, G., Rigét, F., 2011. Trends of lead and zinc in resident and transplanted Flavocetraria nivalis lichens near a former lead–zinc mine in West Greenland. Science of the Total Environment, 409, 4063-4071.

Theisen, B.F., 1973. The growth of *Mytilus edulis* L. (bivalvia) from Disko and Thule district, Greenland. Ophelia, 12, 59-77.

Zhang, H. and M. Reynolds 2019. Cadmium exposure in living organisms: A short review. Science of The Total Environment 678: 761-767.

Appendix A

Note

Mapping at Nalunaq, 2019

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Background and purpose

In the summer of 2019, environmental monitoring and supervision were carried out at the decommissioned Nalunaq gold mine in South Greenland. In recent years, a company has conducted extensive research on the site on assessing whether it will be profitable to reopen the mine.

It was decided, that in connection with fieldwork in 2019, a mapping of the Nalunaq area with a drone should be performed. The purpose of this was to get a high quality base map, in order to be able to better assess possible impacts on the terrain if the project ends up with a reopening of the mine. In that case, aerial photo can provide better information about damage to vegetation, driving tracks, terrain changes, re-vegetation, etc.

Materials and methods

Nalunaq

The main focus of the mapping was the former camp area, the mine area, the area around the harbor, and around the current camp as well as parts of the road from the harbor to the mine area. Figure 1 shows a satellite photo of the Kirkespir Valley with location of harbor, the new camp and the former camp and mining area. Figure 2 shows the areas that has been updated with new orthophoto.

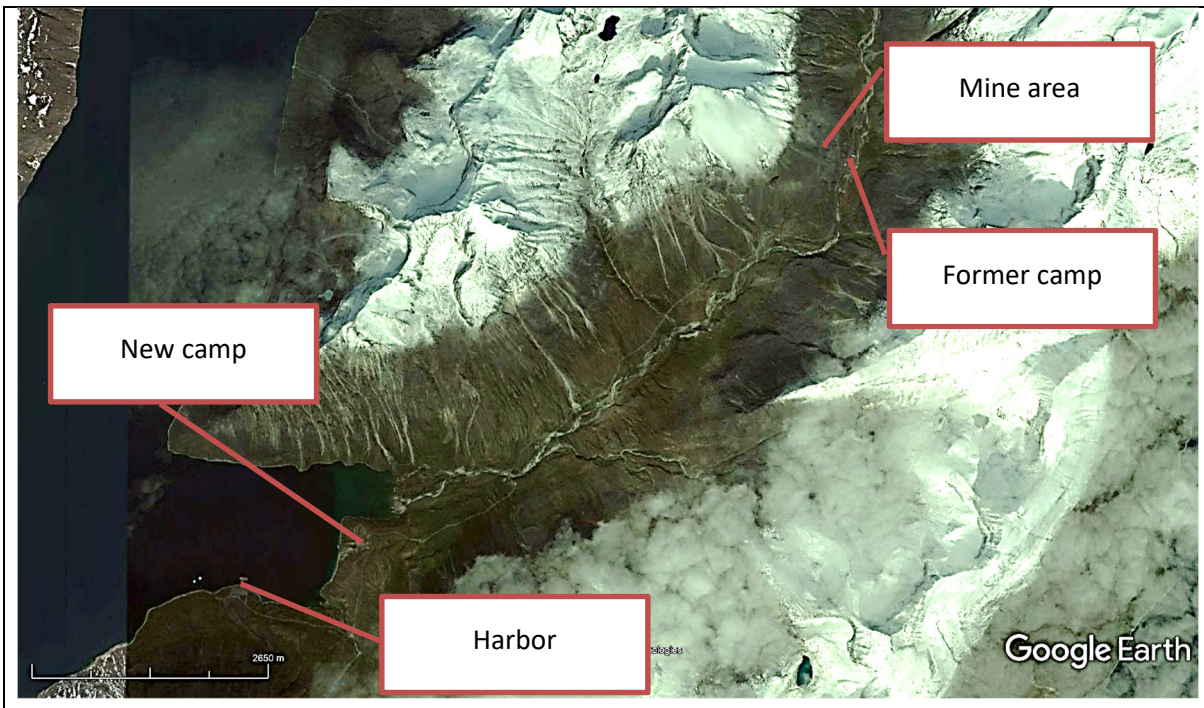


Figure 1. Satelite photo of the Kirkespir Valley

Figure 2. Areas with updated orthophoto

Fieldwork

Planning of the fieldwork as well as route planning was carried out as described in /1/. Table 1 shows the hardware and software used.

The flights were completed over 3 days, since recharging of batteries was necessary, to achieve a satisfying coverage of the area. The flights have been carried out in connection with environmental monitoring.

Table 1 . Hardware and software used for flight and data processing .

Hardware	
Drone	DJI Mavic Pro
Camera	1 / 2.3 ”12 mega pixel CMOS sensor
Software	
Control	Litchi
Data processing	Pix4Dmapper

Results

More than 4200 aerial photos have been taken, with a total amount of data exceeding 20 GB. It is difficult to model such large amounts of data, and the modeling was therefore divided into 11 sub-areas - see Table 2. An orthophoto and a terrain model have been modeled for each area. The files are in the range of 0.2-2.5 GB in size and it is recommended to open the files in a GIS programme – for example QGIS - as many photo programs have difficulties in handling files of this size.

When modeling, some of the images will be distorted, and if specific details need to be checked, it is therefore also advisable to review the original images. These are divided into folders for the 11 sub-areas.

Table 2. Modeled sub-areas and sizes of the orthophoto and the Digital Surface Model files.

Area	**Size (MB)**	
	Ortho	*DSM*
300 m portal	361	283
Camp I	1503	1363
Camp II	604	624
Harbour	770	1033
Mine Area	2482	1830
Road_1	1206	649
Road_2a	531	731
Road_2b	2251	1935
Road_2c	275	350
Road_2d	320	412
Road_2e	287	472

The appendix contains a number of examples of how the images can be used in relation to both environmental monitoring and environmental supervision.

Location of waste in the terrain

The orthophotos and the aerial photos have been examined to evaluate the amount of waste in the terrain. In general, only few pieces of waste are localized on the photos, but it should be noted, that waste, like cables, wires, metal scrap as well as smaller pieces of waste, in many cases will be overlooked on the pictures.

In the mine area and the former camp area, a total of 16 pieces of waste was localized. This includes pipe lines, plastic and concrete blocks. The localized waste is marked on the map in Figure 3.

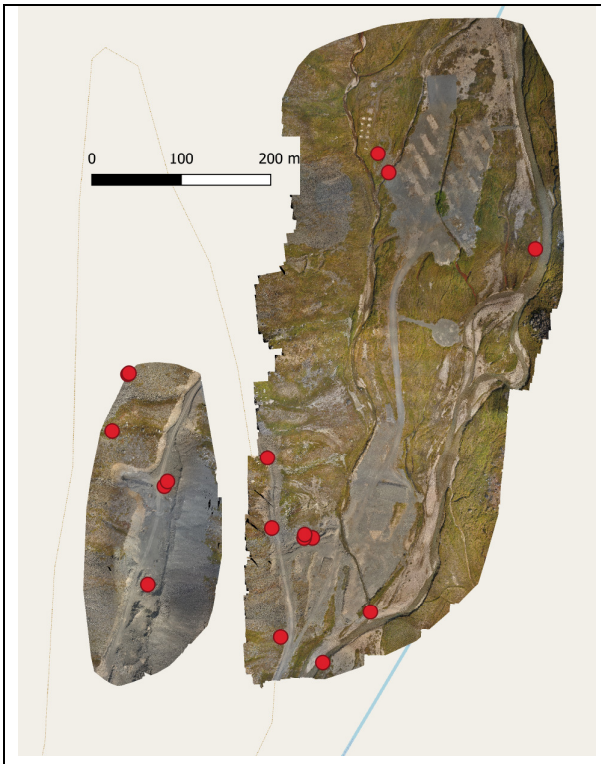


Figure 3. Localized waste in the mine area and the former camp area

In the new camp area, a few pieces of waste were found close to the shore line, while the area in general seems tidy - Figure 4. Waste found on the shore line (rope, fishing nets, wood etc.) is not included, since it probably does not have anything to do with the mining project.

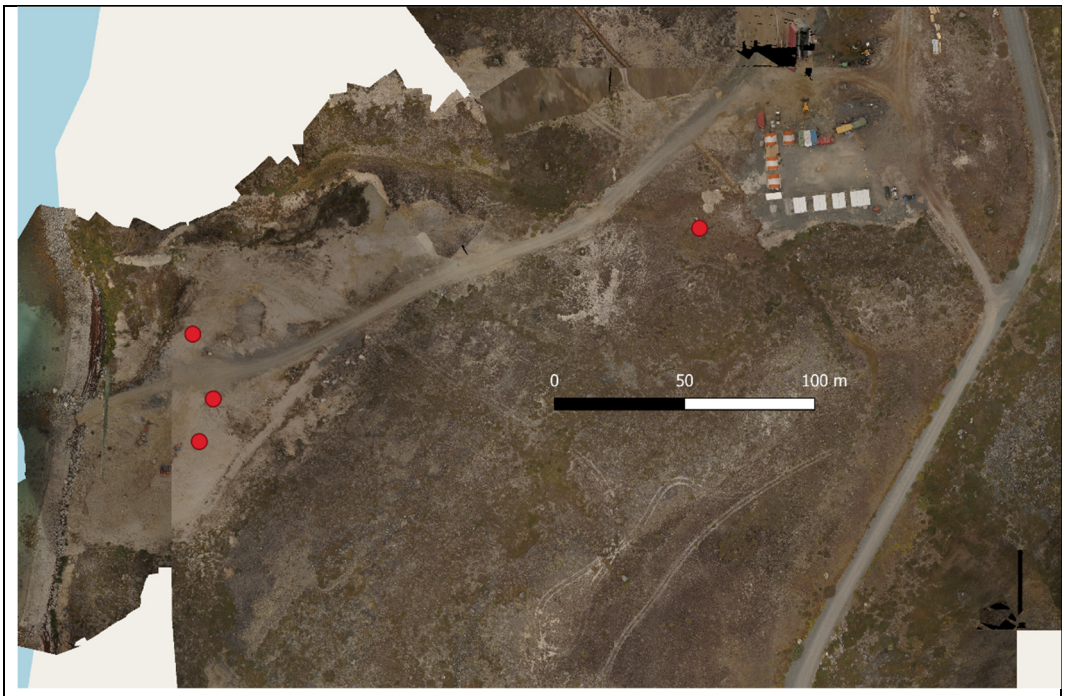


Figure 4. Waste found around the new camp area.

At the harbor site, metal scrap was found at several places - Figure 5. In most places only small pieces of metal were found, while a small pile of metal scrap also was found.

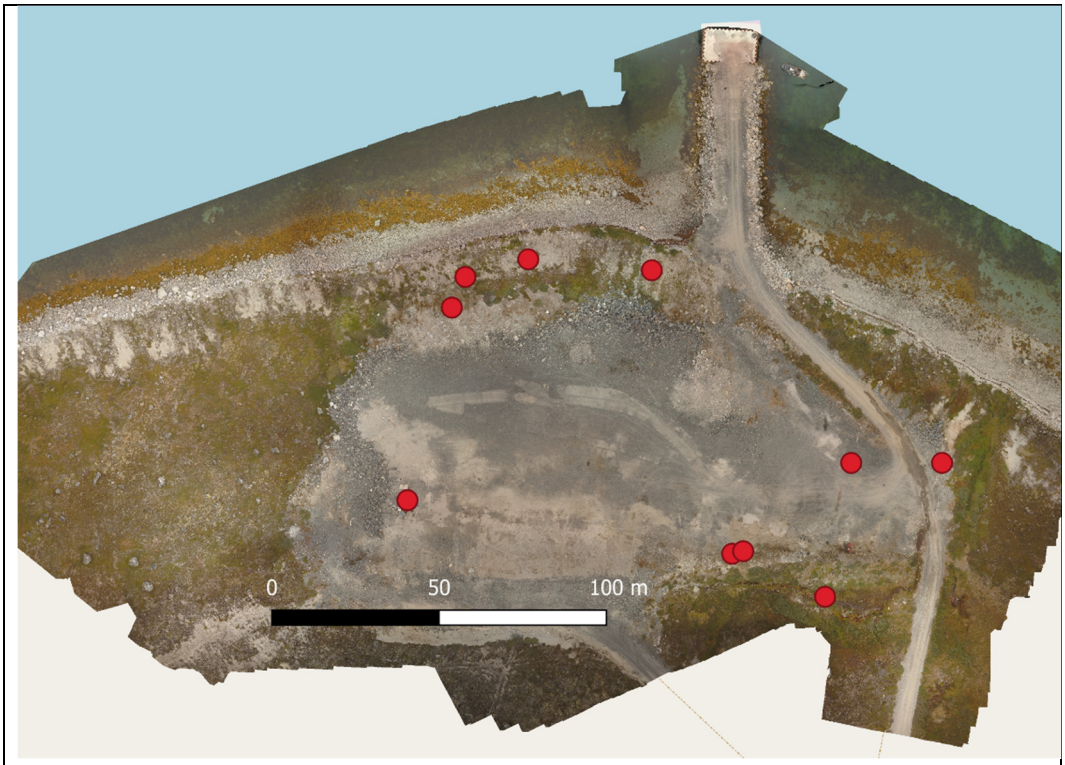


Figure 5. Waste found around the harbor site

No waste was found along the roadside, while a lot of construction work can be seen on the photos. This includes a general refurbishment of the road as well as the establishment of a number of culverts.

Conclusion

Drone flying and subsequent modeling of orthophotos have been carried out in the area around the Nalunaq gold mine.

In general, good coverage of the area has been achieved and the modeled photos have a sufficient resolution so that it is possible to see even relatively small impacts on the terrain and relatively small objects that are located on the ground. However, there are also examples of the modeling distorts the orthophotos, and there may be cases where it is necessary to look at the raw data instead of the modelled orthophotos.

The orthophotos were used to localize waste in the terrain. In general, relatively few pieces of waste were localized. The localized waste does not pose any risk to the environment in and around the Kirkespir Valley. The impact of the waste is only esthetical.

It should be noted, that not all waste can be localized on the photos. This is due to both the resolution of the camera, coverage by vegetation, and the color and size of the waste.

It is known, that more metal scrap is found around the mine site and the former camp site.

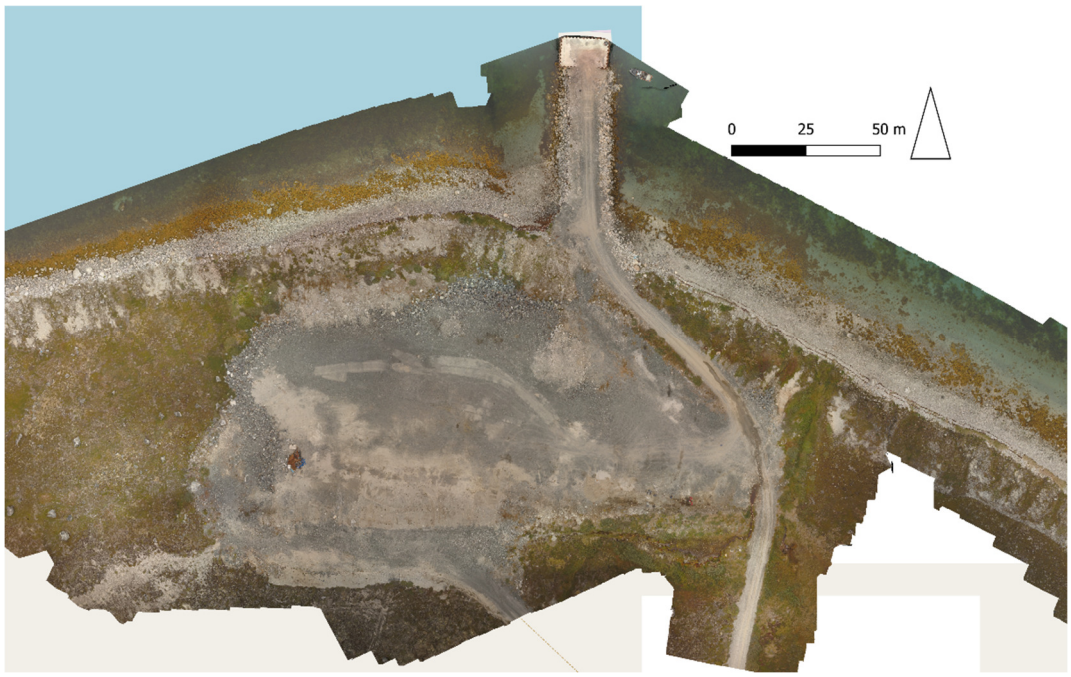
A number of examples of how mapping an area may be relevant, have also been highlighted.

References

/ 1 / Larsen, MB (2019). Use of drone for environmental supervision on small scale projects. Final report. Greenland Institute of Nature, July 24, 2019.

Appendix

a)



b)

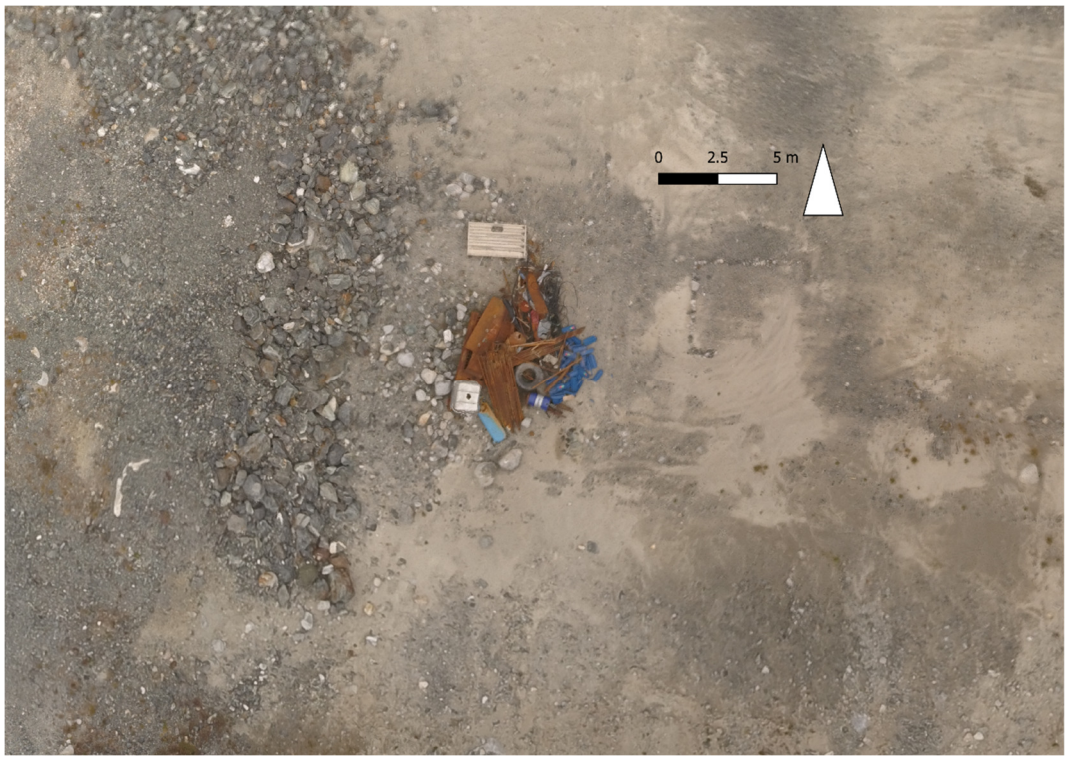
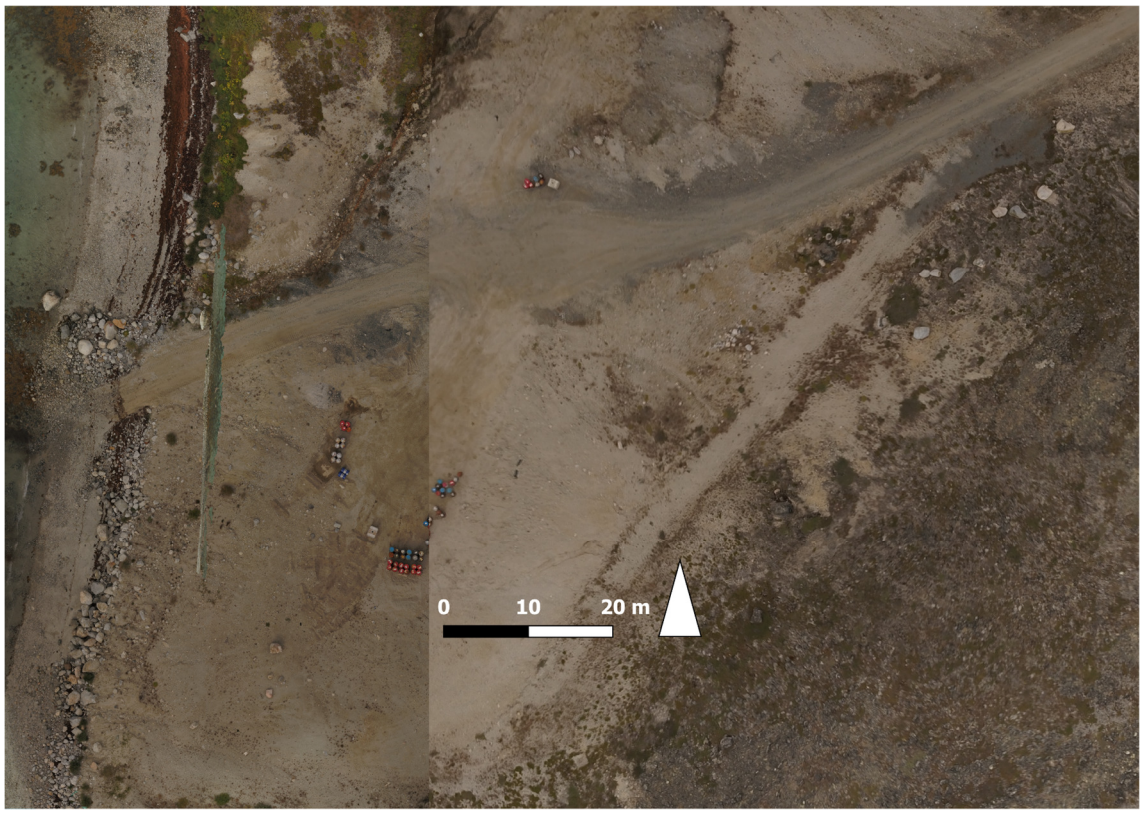


Figure A1-a and -b. Modeled orthophoto of port area (a) as well as zoom on waste pile located in the area (b).

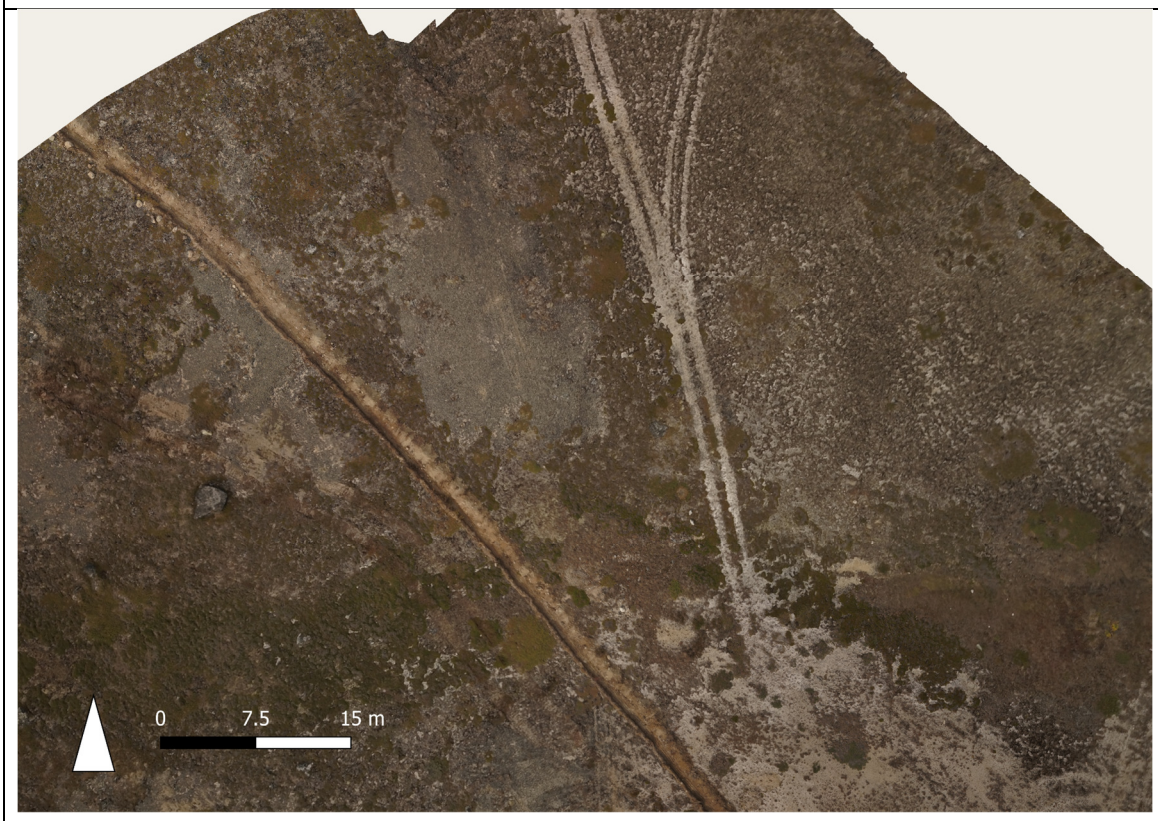
a)



b)

Figure A2-a and -b. Orthophoto from the beach area just west of the new camp, where heavy equipment is landed (a), as well as the actual photo of the area where the fuel barrels are located. At the top of the picture you see staining of the sand around the barrels, which may be due to a spill or possibly rain-water from the top of the barrels.

Figur A3. The new camp area. There is a distortion of the modeled orthophoto – clearly seen at the tents.



Figur A4. On the left side is the newly dug trench from the camp down to the coast for wastewater piping. To the right is an old driving track.

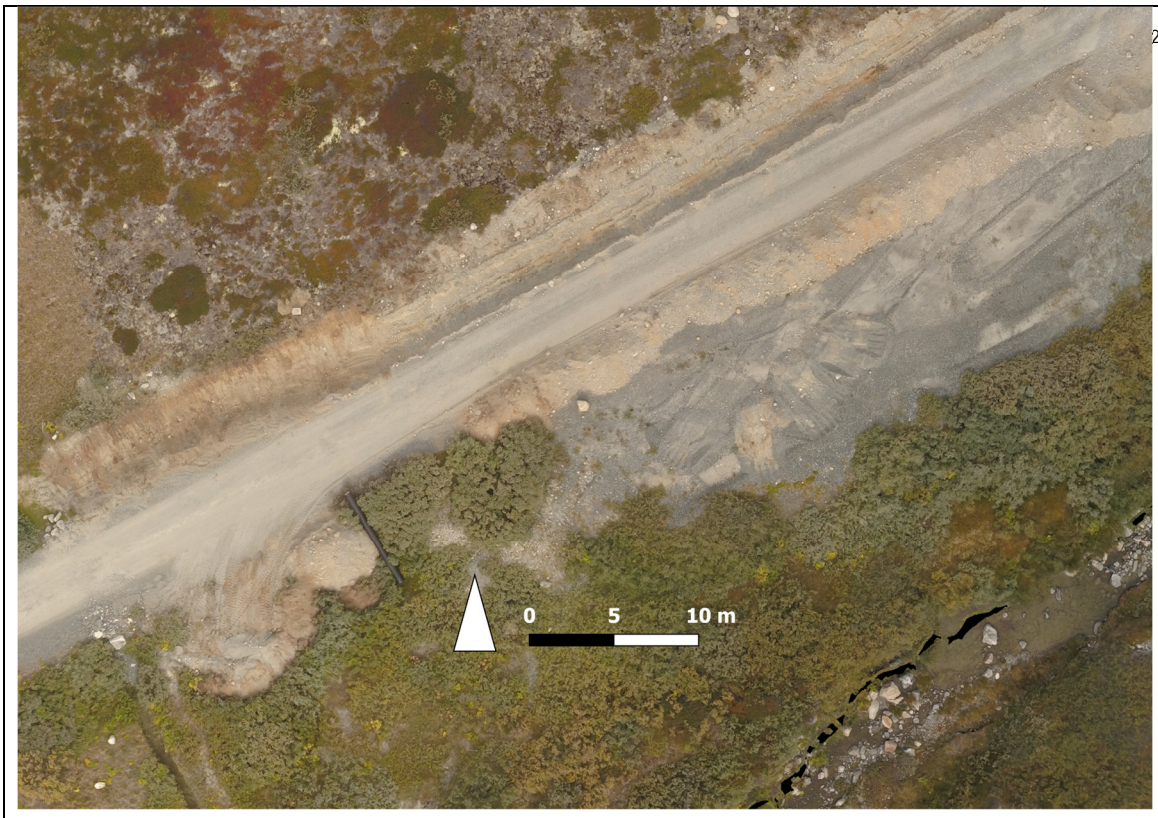
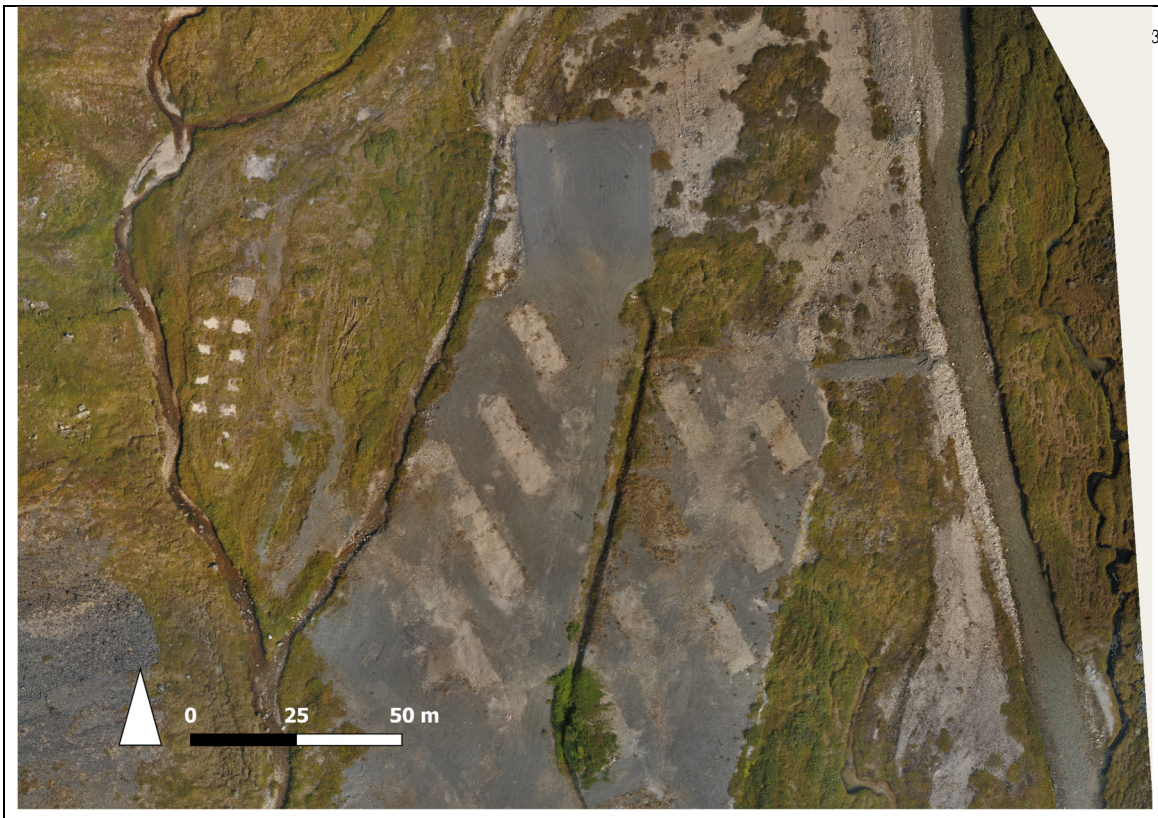
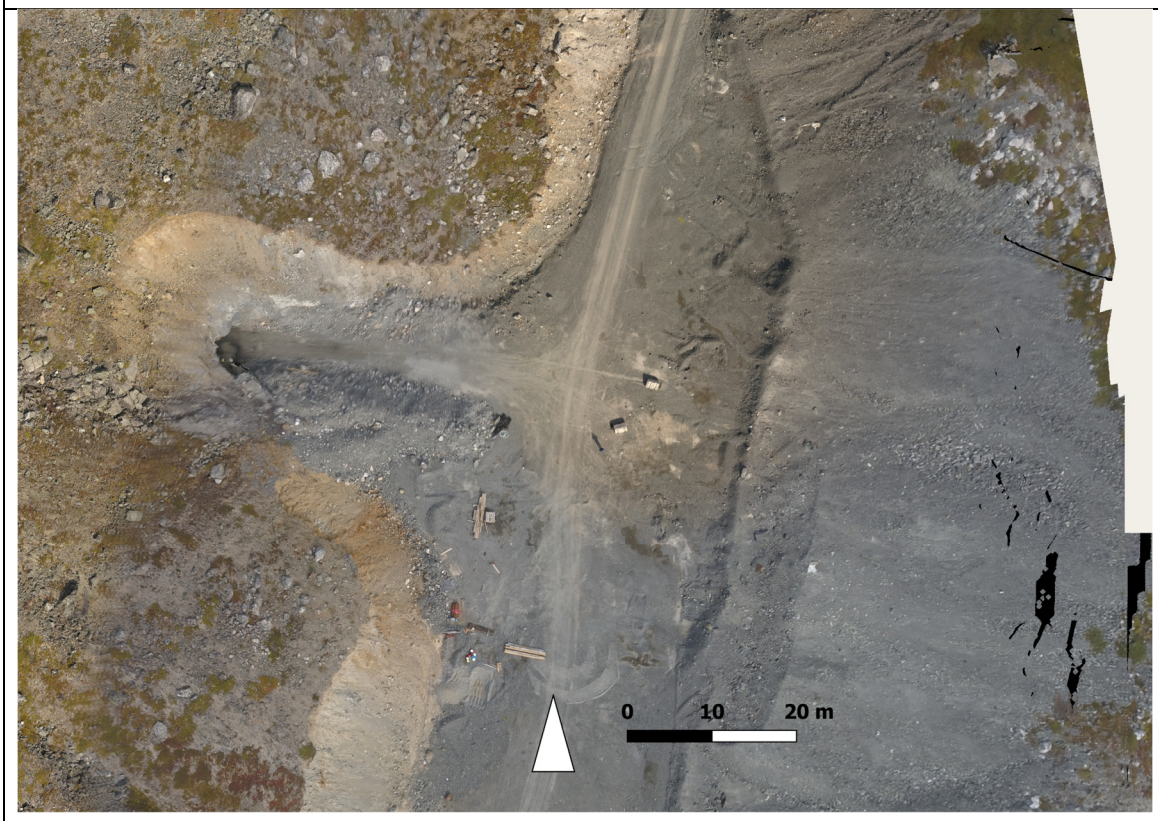


Figure A5. Road repair and trench excavation. Also seen is a plastic tube that is used for culverts.

Figure A6. Example of a newly placed culvert.



Figur A7. The former camp area, where the location of the buildings is clearly seen.

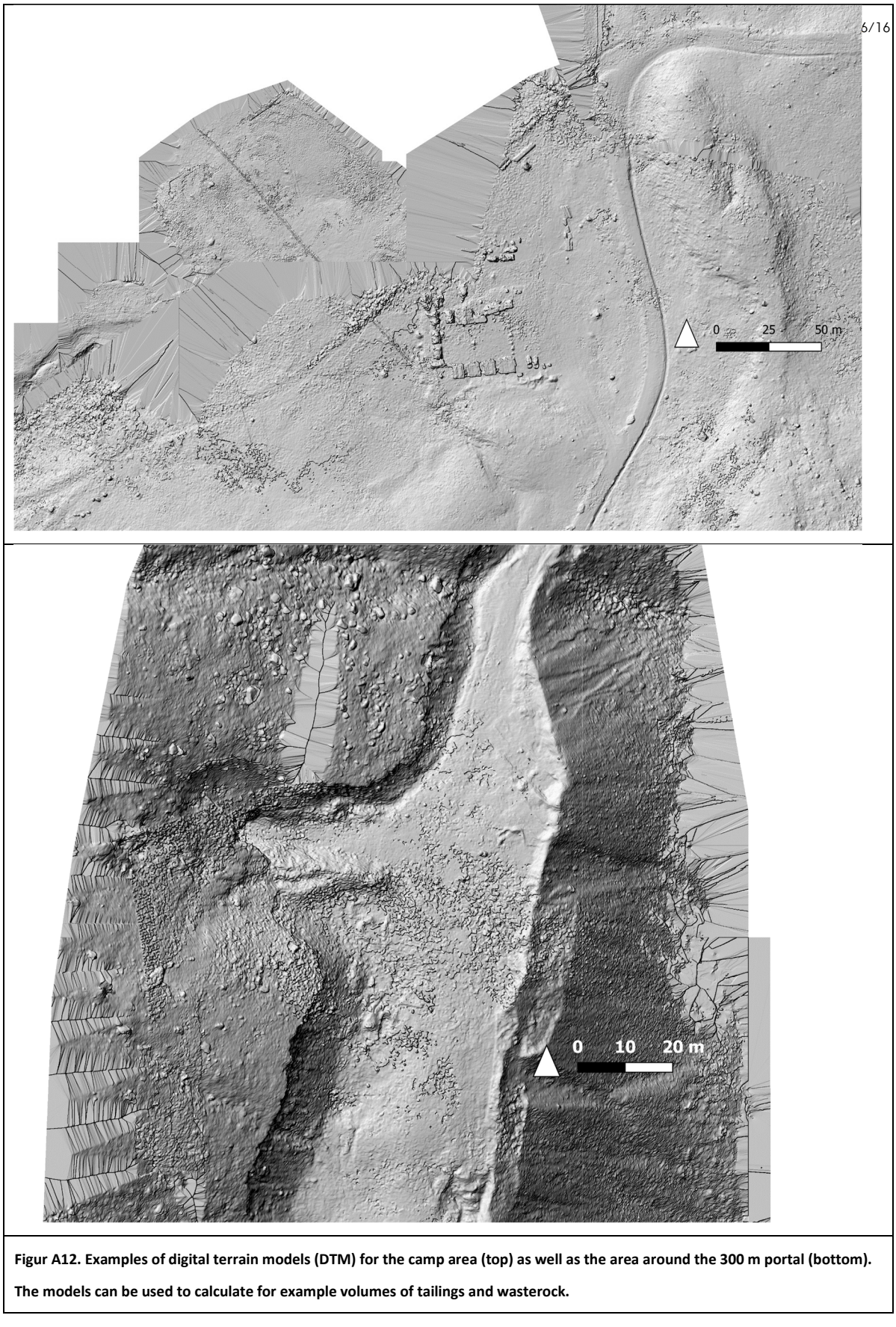


Figur A8. The 300 m portal and material placed outside of the portal.

Figur A9. Two examples of waste in the terrain. A piece of orange PVC piping (top) and a piece of blue plastic in the river (bottom).

Figur A10. Leaching of iron-rich water, which is seen several places at the former camp area.

Figur A11. In addition to the orthophotos taken with the camera (gimbal) aimed directly at the ground, a number of overview images were also taken, where the angle of the camera is minimized. These can be found in the folders with raw data.



Figur A12. Examples of digital terrain models (DTM) for the camp area (top) as well as the area around the 300 m portal (bottom). The models can be used to calculate for example volumes of tailings and wasterock.

ENVIRONMENTAL MONITORING AT THE NALUNAQ GOLD MINE, SOUTH GREENLAND, 2004-2019

The Environmental monitoring was conducted yearly at Nalunaq from 2004 to 2019 to monitor the environmental impact from mining during (2004-2013) and after the mining operation (2014-2019). This report provides an overview of the monitoring results and major findings. The sampling programme included lichens, arctic char, sculpins, seaweed and blue mussels, which serve as key monitoring species in terrestrial and marine environments, respectively, supplemented with fresh water samples.

The environmental monitoring documented moderate pollution associated to the mining activities. In particular was elements as As, Co, Cr and Cu found to be dispersed in the environment as dust-borne from waste rock and ore stockpiles, from rock crushing and from driving on the road. Only minor impacts were observed in the freshwater and marine environments. During the mining period of 2009-2013, cyanide was used in the gold extraction process. No increased level of cyanide has been measured in Kirkespir River and no effects of cyanide has been detected in the environment. An aerial mapping performed in 2019 identified old driving tracks in the terrain, which has been identified as remnants from the former mine activities. In general, relatively few pieces of waste/scrap were localized in the terrain and it is assessed that it does not pose any risk to the environment, but that the impact is related solely to esthetical matters.

Overall, DCE assess that the current environmental impact from the former mining activities to the environment at Nalunaq is insignificant and that no further actions are needed to reduce the environmental impact.

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