



# A CHEMICAL ENVIRONMENTAL SCREENING STUDY AT THE FORMER QULLISSAT COAL MINE, WEST GREENLAND IN 2015

Scientific Report from DCE - Danish Centre for Environment and Energy

No. 230

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Abstract:	<p>The former Qullissat Coal Mine on the Disko Island in West Greenland operated between 1924 and 1972 and this study by DCE is the first to investigate the environment at Qullissat. The study was considered a screening study with the aim to identify possible significant pollution sources originating from remains at the mine site and mining town. Also, the study investigated the opportunities for studying effects of chronic exposure to e.g. PAHs (Polycyclic Aromatic Hydrocarbons) or other potential pollutants in the area. The study was conducted in August 2015 in connection with background studies for a Strategic Environmental Impact Assessment for the Disko-Nuusuaq area. During the study, a range of environmental samples was collected including surface soil, freshwater, lichens and marine sediment. Most samples were collected near the mine site and some samples were collected near the Qullissat mining town situated approximately 5 km to the north of the mine. All environmental samples were analysed for 63 elements and selected samples of surface soil and sediment were analysed for a total of 29 PAH compounds at DCE's accredited laboratory. Elevated concentrations of PAHs and some heavy metals were measured locally. However, based on the results from the analyses, it is DCE's assessment that there is no indication of any significant contamination of the surrounding environment at Qullissat neither from the Qullissat mine site nor from the Qullissat town. Also, due to the relatively low levels of PAHs and other pollutants found in the study, DCE does not find that the area has obvious research potential with regards to studying effects of chronic exposure. It shall be noted, however, that this conclusion is based on relatively few samples and sample types taken during a short period of time. For potential future and more comprehensive studies in the area, it could be relevant also to include off-shore sediment samples from deeper waters, marine biota and water samples taken at different times of the year.</p>
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## Eqikkaaneq

Qullissani Aamarsuorsiorfik, Kalaallit Nunaata kitaani Qeqertarsuarmittoq, 1924-miit 1972-imut pīaaaffigineqarpoq. Piffissap taassuma ingerlanerani aamarsuit katillugit 570.000 tonsit tunisassiarineqarput. Qullissani pīaaaneq 1960-ikkunni sukaruttormat aamarsuit ukiumut 30.000 pīarneqartarput, Qullissallu illoqarfiat aamarsuorsiorfiusoq 1.400 tikillugit inoqarpoq. 1972-imi aamarsuorsiorfiup matuneqarnera aammalu aningaasarsiornikkut pis-sutsit pissutigalugit illoqarfik inuerulluinnarpoq. Saliisoqanngilaq aammalu atortorissaarutit assigiinngitsut, illutat, atortut aamarsuillu sinnikui sulī aamarsuorsiorfimmippūt (2015-imi).

Danmarkimi Nukissiutinut Avatangiisinullu Misissuisoqarfik, (qaanganeruoq Danmarkimi Avatangiisinik misissuisoqarfiusimasoq kiisalu Kalaallit Nunaanni Avatangiisinik Misissuisoqarfiusimasoq) Kalaallit Nunaanni aats-itassarsiorfitoqqanik qassiinik avatangiisitigut ukiumi qulikkaani qassiini misissuisarsimavoq. Aatsitassarsiorfiit tamakku tassaappūt aatsitassarsiorfiit 1900-ikkunni matusimasut matuneqarnermillu nalaani avatangiisitigut pitsaanngivissumik inissisimasimasut (e.g. Johansen et al. 2008 & 2010). Avatangiisit malinnaavigineqarnerat maanna Pinngortitaleriffimmit Danmarkimilu Avatangiisinik Nukissiuteqarnermillu Misissuiveqarfimmit naammassineqarsimalerput. Misissuineri siunertaasut marloqiusaappūt: avatangiisit malinnaavigineqassappūt avatangiisit qanoq issusii pillugit innut-taasut oqartussallu paasissutissittarumallugit, kiisalu issittumi aats-itassarsiorfinni nunap akuisa toqunartullu allanngoriartortarneri pillugit ili-simasavut amerliartortinneqassappūt. Kalaallit Nunaanni aats-itassarsiorortoqartillugu avatangiisit annikinnerpaamik sunnerneqartarnissaat misissuisarnertigut paasiniarneqassaaq.

Misissuineri matumani Qullissani avatangiisit perngaammik misissuiffigineqarput. Misissuineq Danmarkimi Avatangiisinik Nukissiuuteqarnermillu Misissuisoqarfimmit ingerlanneqarpoq Qeqertarsuup Nuussullu Perisissiorfiusumik Avatangiisinut Sunniutissanik misissuiffigineqarnerannut atatillugu (Wegeberg & Boertmann 2016). Aatsitassarsiorfiusimasumiit aammalu illoqarfimmit aatsitassarsiorfiusimasumiit mingutsitsinerujunartut paasiniarniarlugit siammasissumik paasiniaanertut misissuineq isigineqarpoq. Aammattaq tamaani uuliap akuisa minguillu allat sunniusimajuarnerisa kinguneri misssorneqassappūt.

Misissuineri 2015-imi augustip ingerlanerani avatangiisiniit misissugassat assigiinngitsut Danmarkimi Avatangiisinik Nukissiuteqarnermillu Misissuisoqarfimmiit tigooqqarneqarput. Misissugassanik tigooraaviit tassaappūt issoq qalleq, imeq, qillinerit (ujaqqat naaneri) aammalu tinnuttagaani marraq. Immap naasui uillullu, Danmarkimi Avatangiisinik Nukissiuuteqarnermillu Misissuisoqarfiup avatangiisinik misissuinerini ilanngunneqartuartaaruartut misissuiffimmi tassani uluttagaani naammattuugassaannginnamik ilanngunneqanngillat. Misissugassatut tigooqqakkat amerlanerit aammarsuorsiorfiup eqqaaniit tigooqqarneqarput ilaallu Qullissat illoqarfiata avannanguani 5 km-inik ungasitsigisumiit tigooqqarneqarlutik (eqqaaviusimasoq ilanngullugu misissuiffigineqarpoq).

Avatangiisini misissugassatut tigooqqakkat tamarmik pinngooqqaatinut 63-inut misissuiffigineqarput (soorlu saffiugassat oqimaatsut, aatsitassat

qaqutigoortut il.il.) aammalu issumit marrarmillu tigooqqakkat aalajangersi-  
masut uuliap akuinut 29-inut misissuiffigineqarput, misissuineq Dan-  
markimi Avatangiisinik Nukissiuteqarnermillu Misissuisoqarfiup Ros-  
kildeme misissuisarfiani akuerisaasumi misissorneqarput.

Qullissani aamarsuorsiorfimmiit issup qalliup misissuiffigineqarnerani  
paasinarsivoq saffiugassanik oqimaatsunik akuat qaffassissoq, pingaartumik  
aqerloq eqqarsaatigalugu taama ippoq, kiisalu nunap manngertorniusaani  
aamarsuillu kinnganikuini uuliap akui naammattuugassaapput. Tama-  
tumalu kingunerisaanik aatsitassarsiorfimmiit mingutsitsinerup misis-  
sorneqarnerani saffiugassat oqimaatsut uuliallu akui annermik misissuiffigi-  
neqarput, tamannalu aatsitassarsiorfiit allat siusinnerusukkut misissuiffigi-  
neqartarnerannut naapertuuppoq.

Qullissani aamarsuorsiorfimmi kuup erngata misissuiffigineqarnerani saf-  
fiugassanik akuisa qaffasinnerunerannik takussutissaqanngilaq. Misissu-  
gassanilli tigusinerup nalaani sialuisaqaq piffiillu ilaanni nunap mannger-  
torniusaqarneratigut malunnarpoq ukiup ilaani sialoqarnerutillugu, ima-  
luunniit aputip aattornerata nalaani saffiugassat oqimaatsut seerisarsimassa-  
sut. Kisiannili nunap manngertorniusaqarfiusoq annertunngitsuinnaammat  
malunnarpoq saffiugassat annertunngitsuinnarmik siammarsimasut.

Qillinerit, ujaqqat naanerisa, misissoqqissaarneqarneranni saffiugassanik  
oqimaatsunik, soorlu krom-imik peqarnera takussutissaqarpoq, Qullissaniit-  
tulli sanilliussiviusumut sanilliullugit piffinni qassinnguaannarni qaffasinne-  
rupput. Tassuuna takuneqarsinnaavoq saffiugassat oqimaatsut pujoralatsigut  
siammartarsimassasut. Kisiannili annikitsuinnaanerat aammalu anoraakka-  
junnerusup oqquani qaffasinnerunnginnerat eqqarsaatigalugu saffiugassat  
oqimaatsut annerusumik mingutsitsisuunnginnerat takuneqarsinnaavoq.

Uluttagaani marraap misissuiffigineqarneratigut takuneqarsinaavoq Qullis-  
sani aamarsuorsiorfimmi aammalu Qullissat eqqaanni piiarnerlukunik  
eqqaavimmi marraap akui Qullissat avannaanni sanilliussivimmut sanil-  
liullugit qaffasinnerungaannngitsut. Taamaattorli piffimmi tamarmi kan-  
ngussak nikkililu Kalaallit Nunaata sinneranut sanilliullugu qaffasinnerup-  
put. Tamanna siusinnerusukkut misissuisarnertigut paasisanut naaper-  
tuuppoq, misissuisarsimanerimmi takutimmassuk Qeqertarsuup eqqaani  
marraq kanngussammik, nikkilimik saffiussanillu allanik allanit peqarneru-  
soq ujaqqat innermik anitsisartut arrornerinit pinngortunik. Norgemi mar-  
raap pitsaassusia pillugu najoqqutassiat atorneqaraluarpata (Kalaallit  
Nunaanni najoqqutassianik massakut soqanngilaq) Qullissani marraq  
'pitsaanngitsutut' taaneqassagaluarpoq kanngussaqaarnini nikkeleqaarnilu  
pillugu uumasunut marrarmiittartunut toqunartoqarami. Taamaattoqaralu-  
arpalli pinngortitap nammineq taamaassusiatut oqaatigineqassagaluarpoq  
aatsitassarsiornermut attuumassuteqarani.

Marraap immamiittup uuliap akoqassusianik misissuiffigineqarneratigut  
takuneqarsinnaavoq marraat ilaat aamarsuorsiorfimmut qanittumittut sanil-  
lissivimmut sanilliullugit qaffasinnerutsiartumik akoqartut. Misissugassani  
taakkunani uuliap akui Kalaallit Nunaata kitaani sumiiffinnut allanut sanil-  
liullugit qaffasingaatsiarput, kisiannili soorlu Danmarkimut sanilliullugit  
appasinnerullutik. Uuliap akui Qullissat marraaniittut aamarsuorsiorfimmiit  
aammalu pinngortitap nammineq seerineraniit pisuusimassasut naatsor-  
suutigineqarpoq. Norgemiut marraq pillugu najoqqutassiaat atorneqarsima-  
galuarpata Qullissat eqqaanni marraat tamarmik 'Nalinginnaasutut'



imaluunniit 'Pitsaasutut' oqaatigineqassagaluarput uuliap akuinik akoqasusiat naapertorlugu. Tassuuna takuneqarsinnaavoq Qullissani marraq uuliap akuanik akoqaalukkaluartoq akui taakku avatangiisinut sunniuteqangaarnaviannngitsut. Oqaatiginngitsoorneqassanngilaq naliliinermi tassani marraq sissamiittoq kisimi atorineqarmat avataaniittunik marrarmik tiguisoqarsimanngimmat.

Inerniliullugu oqaatigineqassaaq misissuinermit tassannga paasisat naapertorlugit Danmarkimi Avatangiisinik Nukissiuteqarnermillu misissuisoqarfiup naliliinera naapertorlugu Qullissani aamarsuarsiornikkut illoqarfimilluunniit annerusumik avatangiisinut mingutsitsisoqarneranik takussutissaqanngitsoq. Aamma uuliap akuisa minguilu allat misissuinermit nassaarineqartut annikitsuinnaanerat pissutigalugu avatangiisit mingutsitsinermit sunnersimaneqartuarnerannik misissuiffissaqqissutut Danmarkimi Avatangiisinik Nukissiuteqarnermillu Misissuisoqarfimmiit isigineqanngilaq. Kisiannili aamma misissugassatut tigooqqakkat ikittuinnaat kiisalu piffissami sikivikitsuinnarmi taamaallaat tigooqqarneqarsimasut naliliinermi tunngavigineqarsimanerat oqaatigisariaqarpoq. Siunissami tamanna sukumiinerusumik misissuiffigineqassappat marraat, uumassusillit avasinerusumiittut misissugassaqqissinnaapput aammalu imeq ukiup ingerlanerani piffissani allani misissorneqartarsinnaalluni.

Naggasiullugu oqaatigisariaqarpoq misissuinermit matumani avatangiisinit misissugassat akuinik uuttortaanerit taamaallaat naliliinermi tunngavigineqarmata. Nunap naanerisa aamarsuarsiornikkut illoqarfimilu illunit sinneruttunit innarlerneqarsimanerat, issup piiarneqarnera, nunap mann-gertornerata seerinerani allallu ilanngullugit misissuiffigineqanngillat.

## Sammenfatning

Den historiske Qullissat kulmine på Diskoøen i Vestgrønland var i drift i perioden 1924-1972. I løbet af den periode blev der brudt i alt 570.000 tons kul og minedriften var på sit højeste i 1960'erne med en årlig kulproduktion på 30.000 tons. Indbyggertallet i minebyen ved Qullissat, beliggende ca. 5 km nord for minen, nåede i disse år op på 1.400. I 1972 blev minen og minebyen af økonomiske årsager lukket og efterladt som alt stod, og bygninger, materiel og kulrester kan stadig (i 2015) ses i området.

DCE (tidligere DMU og endnu tidligere Grønlands Miljøundersøgelser) har gennem en længere årrække fulgt miljøtilstanden ved en række lukkede grønlandske miner fra forrige århundrede, hvor miljøet har været påvirket af fortidens synder (fx Johansen et al. 2008 & 2010). Disse undersøgelser udføres nu i et samarbejde mellem Grønlands Naturinstitut og DCE. Undersøgelserne udføres dels for at overvåge miljøtilstanden for de ansvarlige myndigheder, dels for gennem forskning at øge forståelsen for de geokemiske og toksikologiske processer i mineområder i et arktisk klima. Formålet er at opbygge viden, der kan bidrage til at sikre minimale miljøeffekter ved fremtidig minedrift.

Dette studie er det første til at undersøge miljøet i området omkring Qullissat. Studiet blev udført af DCE og gennemført i forbindelse med baggrundsundersøgelser til en strategisk miljøvurdering af Disko-Nuusuaq området (Wegeberg & Boertmann 2016). Studiet blev betragtet som et screening-studie til identifikation af mulige forureningskilder fra mineområdet og minebyen, og formålet med studiet var dels at fastslå, om der var væsentlig forurening i området, der stammer fra minedriften, dels at undersøge om området gav særlige muligheder for forskningsprojekter til belysning af effekter af kronisk eksponering til fx PAH-stoffer.

DCE indsamlede således i august 2015 miljøprøver af hhv. overfladejord, ferskvand, lav og marint sediment i tidevandszonen ved Qullissat. Tang og blåmuslinger, som normalt indgår i DCE's miljøovervågningsprogrammer i Grønland, forekom ikke i tidevandszonen i dette område og kunne derfor ikke indsamles. De fleste prøver blev indsamlet i området omkring minen, mens nogle få prøver også blev indsamlet nær minebyen (inkl. prøver fra en tidligere affaldsplads).

Alle miljøprøver blev analyseret for 63 grundstoffer (inkl. tungmetaller, sjældne jordarters metaller m.fl.) og udvalgte prøver af overfladejord og sediment blev desuden analyseret for 29 PAH-forbindelser (Polycykliske Aromatiske Hydrocarboner, dvs. oliestoffer). Alle analyser blev foretaget på DCE's akkrediterede laboratorium i Roskilde.

Analyserne af overfladejord fra mineområdet viste, at forhøjede koncentrationer af tungmetaller, især bly, samt PAH-forbindelser kunne findes i forbindelse med henholdsvis okkerudfældninger og kulrester på jordoverfladen. Det tyder på, at tungmetaller og PAH-forbindelser er de vigtigste potentielle kontaminanter fra dette område, hvilket også er i overensstemmelse med erfaringer fra miljøstudier i andre områder med kulminedrift.

Analyserne af ferskvand indsamlet i mineområdet viste ingen tegn på forhøjede værdier af tungmetaller. Dog var perioden for indsamlingen meget tør,

og vand kunne kun indsamles ved et enkelt vandløb i mineområdet. Okkerudfældninger på jordoverfladen kunne ses flere steder i området, hvilket indikerer, at udvaskning af tungmetaller kan finde sted på andre og mere fugtige tidspunkter af året. Det begrænsede omfang af områder med okkerudfældninger indikerer imidlertid også, at udvaskningen med stor sandsynlighed er meget lokal.

Analyserne af lav viste, at nogle tungmetaller, især krom, var moderat forhøjede ved nogle lokaliteter i mineområdet i forhold til lav indsamlet ved en referencelokalitet. Det kan skyldes støvspredning med tungmetaller i mineområdet. Imidlertid indikerer de moderate niveauer, samt fraværet af koncentrationsgradienter i de dominerende vindretninger væk fra minen også, at en evt. støvspredning med tungmetaller i området med stor sandsynlighed er meget begrænset og ikke udgør et betydende miljøproblem.

Analyserne af tungmetaller i marint sediment indsamlet i tidevandszonen viste, at sediment indsamlet i nærheden af mineområdet og minebyen ikke indeholdt forhøjede værdier af tungmetaller sammenlignet med en referencelokalitet nord for minebyen. Imidlertid var koncentrationerne af kobber og nikkel i sedimentet generelt relativt høje i hele området sammenlignet med andre områder i Grønland. Det er på linje med tidligere studier, der har vist, at sediment nær Disko generelt indeholder forhøjede koncentrationer af bl.a. kobber og nikkel som følge af udvaskning fra vulkanske bjergarter. Anvendes norske miljøretningslinjer for sedimentkvalitet (der eksisterer p.t. ingen grønlandske) klassificeres sedimentprøverne fra Qullissat som 'dårlig' på baggrund af kobber- og nikkelkoncentrationerne (Bakke et al. 2010). Kobber- og nikkelindholdet i sedimentet ved Qullissat kan således have en betydning for især sedimentlevende organismer i området, men i givet fald betragtes det som en naturlig påvirkning og ikke en påvirkning relateret til mineaktiviteterne.

Analyserne af PAH-forbindelser i sediment indsamlet i tidevandszonen viste, at nogle af sedimentprøverne fra mineområdet indeholdt moderat forhøjede værdier i forhold til referencelokaliteten. PAH-niveauerne i disse prøver var relativt høje i forhold til tidligere rapporterede data for sedimenter i Vestgrønland, men lavere end i typiske sedimenter fra Danmark eller Østersøen. PAH-forbindelserne i sedimentet ved Qullissat stammer sandsynligvis fra både kulrester fra minedriften og fra udslip fra naturlige kilder i området. Anvendes de ovennævnte norske miljøretningslinjer for sedimentkvalitet klassificeres alle sedimentprøver fra Qullissat imidlertid som 'Baggrund' eller 'God' baseret på indholdet af PAH-forbindelser. Det indikerer, at niveauerne af PAH-forbindelser i det marine sediment ved Qullissat, selvom de er moderat forhøjede, ikke udgør et betydeligt miljøproblem.

Som konklusion på overstående er det DCE's vurdering, at der ikke er noget i dette studie, der tyder på en betydelig forurening af det omkringliggende miljø ved Qullissat, hverken ved mineområdet eller minebyen. På grund af de relativt lave niveauer med bl.a. PAH-stoffer finder DCE heller ikke, at området byder på oplagte muligheder for forskningsprojekter til belysning af effekter af kronisk eksponering. Det skal dog bemærkes, at studiet er baseret på relativt få prøver og prøvetyper. Ved evt. fremtidige studier i området kunne det være relevant også at inkludere sedimentprøver fra dybere vand, marint biota og vandprøver indsamlet på forskellige tidspunkter af året.

Natur- og miljøpåvirkninger så som mekanisk skade på vegetation og lignende ved mineområdet og ved minebyen som følge af bygningsrester, fjernelse af overfladejord, okkerudfældning mv. er ikke omfattet af undersøgelsen.

## Summary

The Qullissat Coal Mine on the Disko Island in West Greenland operated between 1924 and 1972. During this period, a total of 570,000 tons of coal was produced. The mining activity at Qullissat culminated during the 1960s with 30,000 tons of coal produced annually and the Qullissat mining town had a population of up to 1,400 people. In 1972, the mine was closed and the mining town was completely abandoned due to financial reasons. No clean-up was performed and remains of infrastructure, buildings, materials and coal residue are still (in 2015) present at the mine site.

DCE (formerly DMU and before that Grønlands Miljøundersøgelser) has monitored the environmental status of a number of old mining sites in Greenland for decades. These mining sites include closed mines from the last century with a bad environmental status at the time of closure (e.g. Johansen et al. 2008 & 2010). The monitoring studies are now done in a collaboration between the Greenland Institute of Natural Resources (GINR) and DCE. The objective of the studies are twofold: partly to monitor the environment to keep the public and authorities informed of the environmental status and recovery, and partly through research to increase our knowledge about geochemical and toxicological processes in arctic mining areas. The aim is to learn how to secure minimal environmental impact at future new mine sites in Greenland.

This study is the first to investigate the environment at Qullissat. The study was conducted by DCE in connection with background studies for a Strategic Environmental Impact Assessment for the Disko-Nuusuaq area (Wegeberg & Boertmann 2016). The study is considered a screening study with the aim to identify possible significant pollution sources originating from remains at the mine site and mining town. Also, the study investigates the opportunities for studying effects of chronic exposure to e.g. PAHs (Polycyclic Aromatic Hydrocarbons, i.e. oil compounds) or other potential pollutants in the area.

During the study, a range of environmental samples was collected during August 2015 by DCE. Samples included surface soil, freshwater, lichens and marine sediment collected in the tidal zone. Seaweed and blue mussel, which are normally included in DCE's environmental monitoring programmes in Greenland, were not present in the tidal zone at this site and could therefore not be collected. Most samples were collected near the mine site and some samples were collected near the Qullissat mining town situated approximately 5 km to the north of the mine.

All environmental samples were analysed for 63 elements (such as heavy metals, rare earth metals etc.) and selected samples of surface soil and sediment were analysed for a total of 29 PAH compounds at DCE's accredited laboratory in Roskilde, Denmark.

Surface soil analyses from the Qullissat mine site showed that elevated levels of some heavy metals, especially lead, as well as PAH compounds could be found associated with ochre precipitates and coal residues, respectively. Consequently, the main focus was on heavy metals and PAHs as potential sources of contamination from the site, which is in line with previously reported studies from other coal mine sites.



Analyses of freshwater collected at a stream at the Qullissat mine site did not show elevated heavy metal levels. Yet, the sampling period was very dry and ochre precipitates on the soil surface in some places indicate that leaching of heavy metals may occur during some (wetter) periods of the year, i.e. during rain events or thawing of the snow cover. Yet, the limited spatial extent of the ochre precipitates also indicates that this is only likely to be of local importance.

Lichen analyses showed that some heavy metals, such as chromium, were moderately elevated in lichens at a few locations within the Qullissat mine site compared to lichens collected at a reference site. This indicates that some dust dispersion with heavy metals may occur at the site. However, the moderate levels and an absence of concentration gradient reflecting the dominant wind pattern also indicate that dust dispersion with heavy metals is not likely to be a significant source of contamination at the site.

Analyses of heavy metals in marine sediment collected in the tidal zone showed that the heavy metal composition in sediment collected near the Qullissat mine site and adjacent to a waste dump in the Qullissat mining town did not differ markedly from sediment collected at a reference site north of Qullissat mining town. However, concentrations of copper and nickel were generally high in the entire area compared to other areas in Greenland. This is consistent with previous studies, which showed that sediment near Disko in general contains elevated levels of copper, nickel and some other metals due to leaching from tertiary volcanic rocks. If Norwegian guidelines for environmental sediment quality is applied (no present Greenlandic guidelines exist), sediment sampled at Qullissat can be classified as 'Bad' based on the copper and nickel concentrations. Consequently, it is possible that the copper and nickel content in the sediment at Qullissat can have ecotoxicological effects on especially the sediment-living organisms in the area. However, if this is the case, it is considered a natural impact not related to the mining activities.

Analyses of PAH compounds in marine sediment from the tidal zone showed that some of the sediments sampled close to the mine site were moderately elevated compared to sediment from the reference site. The PAH levels in these samples were relatively high compared to previously reported data from other parts of West Greenland but lower than for typical sediment in e.g. Denmark. The PAHs in the sediment at Qullissat are likely to originate both from coal residues from the mining activities and from natural seeps in the area. If the Norwegian guidelines for environmental sediment quality are applied, all sediment sampled at Qullissat can be classified as 'Background' or 'Good' based on the PAH content. This indicates that, despite the moderately elevated PAH levels in sediment at Qullissat, the PAH levels observed are not likely to be of significant environmental importance. It shall be noted that this assessment is only based on onshore sediment since no offshore sediment was sampled.

In conclusion, based on the results from this study, it is DCE's assessment that there is no indication of any significant contamination of the surrounding environment at Qullissat neither from the Qullissat mine site nor from the Qullissat town. Also, due to the relatively low levels of PAHs and other pollutants found in the study, DCE does not find that the area has obvious re-search potential with regards to studying effects of chronic exposure. It shall be noted, however, that this conclusion is based on relatively few samples and sample types taken during a short period of time. For potential future and

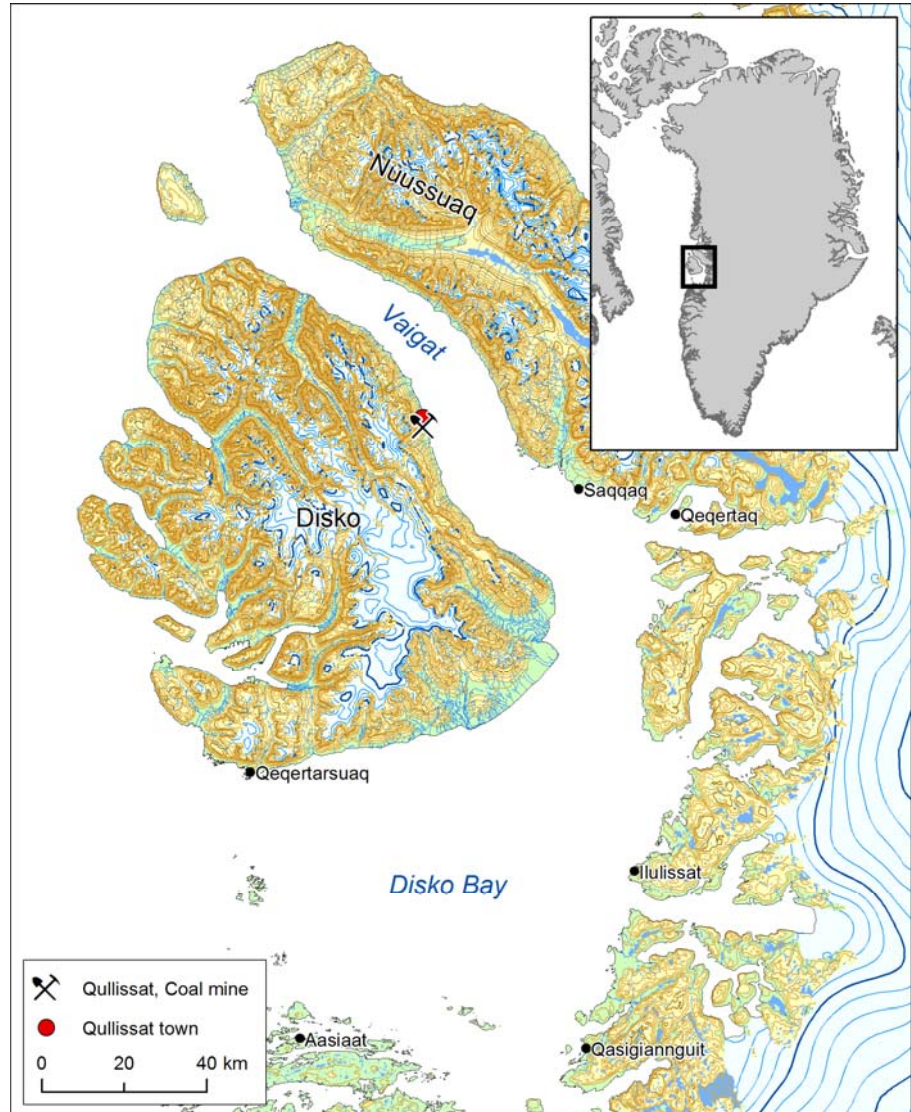
more comprehensive studies in the area, it could be relevant also to include offshore sediment samples from deeper waters, marine biota and water samples taken at different times of the year.

Finally, it shall be noted that this study is based solely on assessment of analysed chemical compositions in environmental samples. Local environmental impact such as mechanical damage to vegetation at the mine site and mining town due to remains of buildings, removal of surface soil, ochre precipitates etc. was not part of the study.

# 1 About the Qullissat coal mine

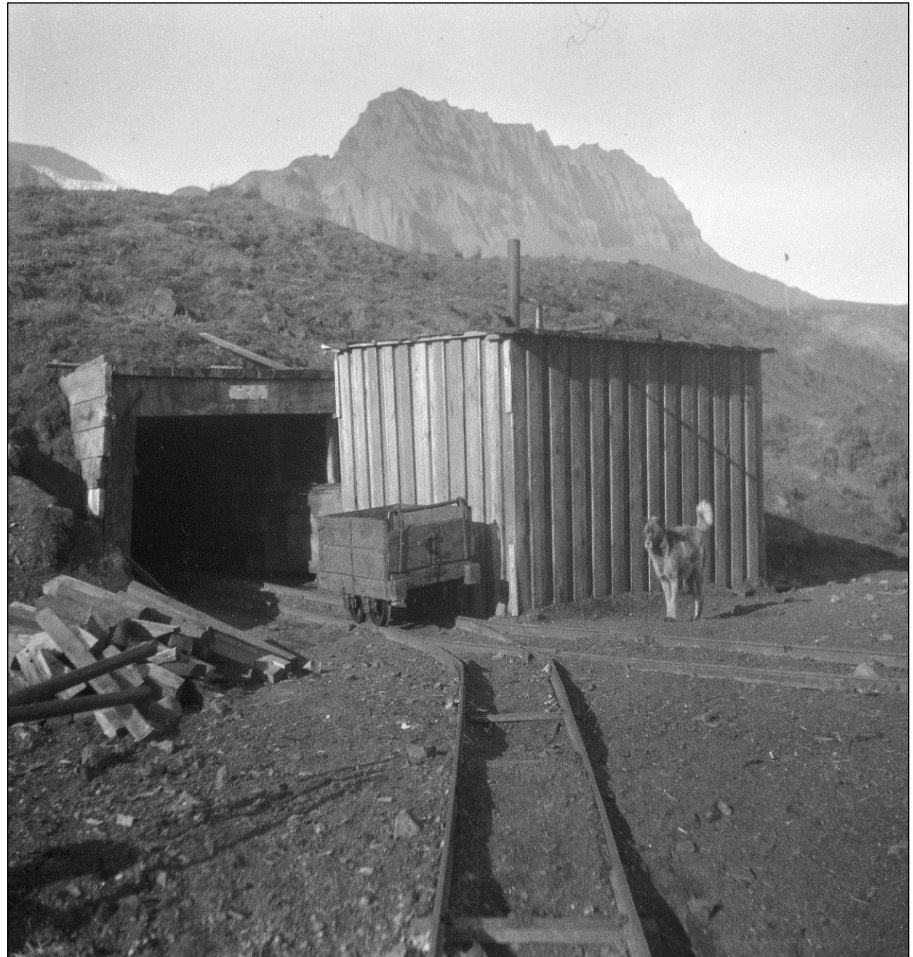
The former Qullissat coal mine and mining town is located on the northeast coast of the Disko Island in West Greenland (*Figure 1*).

**Figure 1.** Map of Greenland with the location of the former Qullissat coal mine (mining symbol) and mining town (red dot).



The coal production at Qullissat started in 1924, when the mining town was also founded, and continued for 48 years. The coal production and population size culminated in the 1960s with 30,000 tons of coal produced annually and a population size of 1,400 people. A total of 570,000 tons of coal was mined underground at Qullissat during the period 1924-1972 (Sejersen 2014). *Photo 1-3* were taken during the mining period and show the mine tunnel, the loading ramp and the mine site.

**Photo 1.** The entrance to the mine, anno 1927. Photo: Copyright Danish Arctic Institute.



**Photo 2.** The loading ramp, anno 1930. The coal was loaded into barges and sailed to ships anchored further from the coast. Photo: Copyright Danish Arctic Institute.



**Photo 3.** The Qullissat mine site, anno 1956. View from the railway track towards northeast and over the lower plateau. Almost the same view as in *Photo 6*. Photo: Jette Bang, copyright Danish Arctic Institute.



In October 1972, the mine was closed due to financial reasons and the town of Qullissat was abandoned. The remains of the mine were later sold to an entrepreneur, who demolished the site. However, much of the mine infrastructure and many of the houses in the town are still there, although dilapidated, and some of the houses are still used as summer cottages. A tsunami generated by a mountain slide on the Nuussuaq peninsula, on the coast opposite of Qullissat in Vaigattet, in November 2000 (Pedersen et al. 2002) washed away all the houses close to the shore and also some of the infrastructure at the mine site.

The old mining area is located on two plateaus approximately 10 and 20 m above the beach (*Photo 4*). The mine entrance is located at the upper plateau whereas the lower plateau served as a loading plateau for shipping (*Photo 5*). The old railway trails for transportation of coal out of the mine and for ship loading, respectively, are still present at the site (*Photo 6*). A bank of coal residues originating from coal spills in connection with unloading the tippers or from coal stocks is also present and can be seen as a black band between the two plateaus (*Photo 4*).



**Photo 4.** The old mining area seen from the water side. The mining area is located at the foot of the mountain approximately 5 km SW of the Qullissat mining town. Buildings and other remains from the mine can be seen as well as a black bank of coal residues between the plateau with the mine shafts and the loading plateau just above the beach. Photo: David Boertmann.



**Photo 5.** The mining site seen from the hill above the site. Photo: David Boertmann.



**Photo 6.** Trails on the two plateau levels, from the mining shafts at the higher level and for shipment on the lower level. A bank of coal remains can be seen in between the two plateaus. Photo: David Boertmann.



## 2 Environmental studies

### 2.1 Background

The study in 2015 was aimed at identifying potential contamination from the remains of coal and other materials left at the mine site and gain knowledge about the environmental development of the old arctic coal mine. Also, contamination from a waste dump near the Qullissat mining town was included in the study.

The sampling programme was aimed at identifying any significant environmental issues, e.g. from leaching or dust dispersion. The intention was to expand the study at a later stage with a more comprehensive sampling programme if significant environmental problems were identified.

To identify potential contamination at the site, samples of water, biota, sediment and soil were collected as outlined below:

- Freshwater from streams close to the mine was sampled for identification of potential leaching from the coal remains and cinders.
- Lichens were sampled to identify possible contamination of the soil and vegetation near the mine area due to dust deposition.
- Marine sediments were sampled to identify possible contamination of the marine environment by leaching and subsequent dispersion of contaminants from the mine area.
- Finally, samples of surface soil at the mine site were taken for source-characterisation of any potential contamination.

Environmental problems in coal mining areas are often caused by development of acidic mine drainage originating from oxidation of sulfide minerals in the coal or in the waste rock. This causes acidic leach water and may result in release and dispersion of a range of heavy metals such as iron, aluminum, manganese, zinc and lead in the area downstream from the mine (Elberling et al. 2007; Søndergaard et al. 2007). Precipitation of ochre (primarily iron oxyhydroxides) at the soil surface at such sites is a visible result of this process. In addition to heavy metals, release and dispersion of PAH compounds contained in the coal have been shown to be a significant source of contamination in some areas (Achten & Hoffmann 2009; Bertrand et al. 2015).

Consequently, all samples collected in this study were analysed for element composition (including heavy metals) and selected samples also for PAH compounds.

### 2.2 Sampling

Sampling was carried out during 7-8 August 2015 and a total of 12 freshwater samples, 13 lichen samples, 8 marine sediment samples and 5 surface soil samples were collected. Geographical coordinates of the sampling site locations are shown in *Appendix 1*.

Freshwater samples were collected from a stream in the mine area (*Figure 2*). The stream ran through a deposit of cinders and samples were taken both upstream and downstream of the cinder deposit (Site 2 and 3, respectively). For reference purposes, a freshwater sample was collected approximately 500

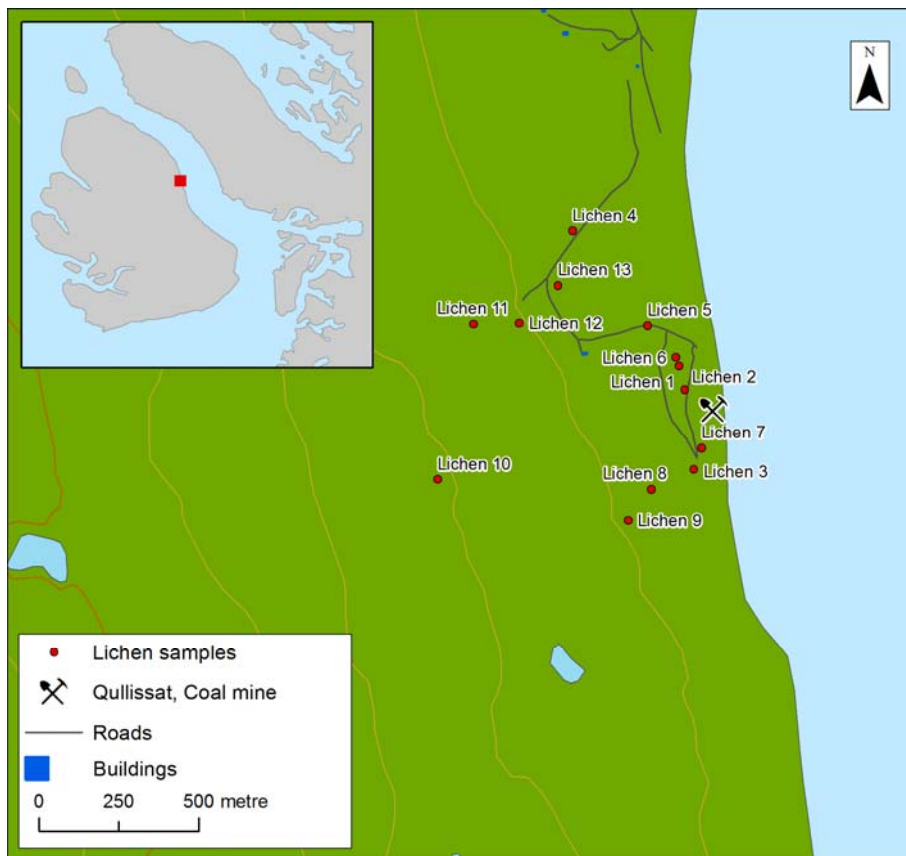
m north of the mine (Site 1). From the stock water samples, 4 subsamples were obtained of which 2 were filtered and 2 were unfiltered. These samples were brought to the laboratory for further analyses. At the sampling sites, water temperature was measured and each stock water sample was analysed for pH and conductivity in the camp.

**Figure 2.** Location of water samples collected near the former Qullissat coal mine (marked with mining symbol) in 2015.



Lichens samples of the lichen species, *Flavocetraria nivalis*, were collected in the area around the mine (*Figure 3* and *Photo 7*). The lichen sampling was designed to cover different heights/distances from the mine area with denser sampling S and NW of the mine area in the dominant wind directions. Site 10 was selected as a reference site as it was considered to have little or no impact from any dust deposition from the mining area. All lichen samples were dried and stored in zip plastic bags for laboratory analyses.

**Figure 3.** Location of lichen samples collected near the former Qullissat coal mine (marked with mining symbol) in 2015.



**Photo 7.** Lichens (*Flavocetraria nivalis*) were sampled in the vegetation behind the mine area. Photo: Caroline Engberg Simonsen.

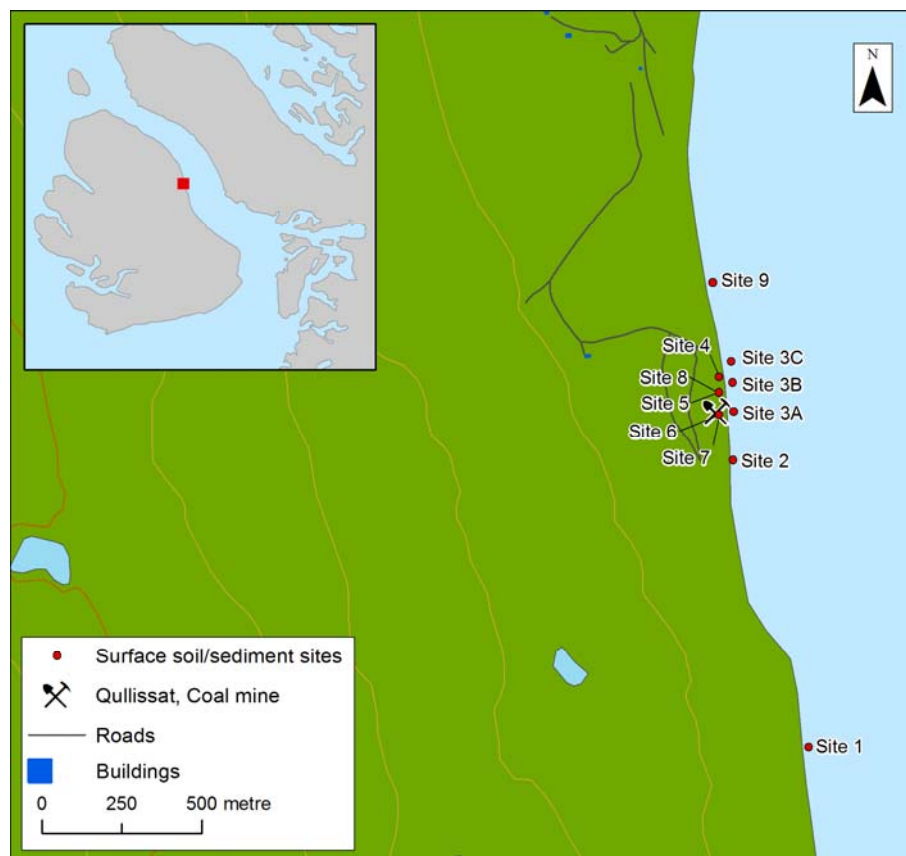


Six marine sediment samples were collected along the waterline in front of the mine and at other possible contamination sources (cinder deposits) (*Figure 4* and *Table 1*). In addition, two marine sediment samples were collected north of Qullissat, one adjacent to a waste dump and one further away, which was designated as an unpolluted reference site. All samples were collected and stored in RILSAN bags for laboratory analyses of PAHs (Polycyclic Aromatic Hydrocarbons, i.e. oil compounds) and metals.



Five soil surface samples were collected in the former mine area (*Figure 4*). Due to dry conditions in the area during the fieldwork, very little running water was present. However, traces of dried-out small streams and precipitated contaminants, primarily in the form of Fe-hydroxides (ochre), were found downstream from the coal deposits. Samples of these precipitates were collected from the dry soil at different locations (*Table 2*). Samples were collected and stored in zip-lock plastic bags for laboratory analyses of metals and in RILSAN bags for laboratory analyses of PAHs.

**Figure 4.** Location of surface soil samples (Sites 4-8) and sediment samples (Sites 1-3 and Site 9) collected near the former Qullissat coal mine (marked with mining symbol) in 2015. In addition, two marine sediment samples were collected north of the Qullissat mining town (not shown on map). One of these samples was collected near a small waste dump (Site 10) and the other sample was collected at a site further away, which is considered as an unpolluted reference site (Site 11).





**Table 1.** Marine sediment samples collected from the Qullissat mine site. Photo: David Boertmann.



Site 1	Site 2	Site 3a	Site 3b	Site 3c	Site 9
70° 03,650 N	70° 04,091 N	70° 04,172 N	70° 04,219 N	70° 04,253 N	70° 04,379 N
52° 58,515 W	52° 59,202 W	52° 59,255 W	52° 59,295 W	52° 59,325 W	52° 59,500 W
Black sand/gravel, right above the waterline	Below waste rock/cinders, at the waterline	Below the mine site, coarse sand	Coarse sand below the mine site and ochre leaching	Coarse sand below the mine site	Coarse sand, NW of the mine site



**Table 2.** Surface soil samples collected from the Qullissat mine site. Photo: David Boertmann.



Site 4	Site 5	Site 6	Site 7	Site 8
70° 04,223 N	70° 04,198 N	70° 04,161 N	70° 04,219 N	70° 04,253 N
52° 59,364 W	52° 59,347 W	52° 59,321 W	52° 59,295 W	52° 59,325 W
White precipitation	Ochre precipitation	Leachate from coal bank	Ochre precipitation	Coal bank



### 3 Analytical methods

The samples were analysed at Department for Bioscience and Department of Environmental Science at Aarhus University in Roskilde. All samples were analysed for element composition by Inductively Coupled Plasma Mass Spectrometry (ICP-MS). A selection of marine sediment and soil samples were also analysed for PAH compounds using Gas Chromatography coupled to Mass Spectrometry (GC-MS).

#### 3.1 Freshwater

Both unfiltered and filtered freshwater samples were taken and stored in 15 ml polyethylene vials. Filtered samples were filtered in the field using 0.45 µm nylon filters. Prior to the chemical analyses, 15 µl of concentrated Merck Suprapure nitric acid was added to the samples and left for a minimum of 24 hours before analyses.

#### 3.2 Lichens

Lichen samples were rinsed by hand using a pair of stainless steel tweezers and only fresh looking green/yellow parts of the lichens were selected. Remains of other plants, moss, soil or dead lichens were removed and the lichens were freeze-dried. A 300 mg sub-sample was then digested in a mixture of 4 ml concentrated Merck Suprapure nitric acid and 4 ml milliQ water in Teflon bombs in an Anton Paar Multiwave 3000 Microwave oven. After this treatment, the remaining solution was diluted to 25 g with milliQ water and stored in polyethylene bottles until analysed by ICP-MS.

#### 3.3 Soil and marine sediment

For element analyses: Soil and marine sediment samples were freeze-dried and 200 mg sub-samples were digested in a mixture of 0.25 ml/0.75 ml/3 ml Merck Suprapure HNO<sub>3</sub>/HCl/HF in Berghof bombs at 120°C for 4 hours. Then, the HF was neutralized with boric acid and the solution diluted to 50 g with milliQ water and stored in polyethylene bottles until analysed by ICP-MS.

For PAH analyses: 10 g homogenized wet soil or sediment sample spiked with isotope labelled recovery standards was extracted with toluene with activated copper on soxhlet for 20-24 hours. The samples were evaporated to approximately 1 ml and cleaned up on a silica column. The extract was evaporated to 1 ml in toluene. Finally, isotope-labelled injection standards were added.

#### 3.4 Element analyses

All samples were analysed for element composition using an Agilent 7500ce ICP-MS at Department of Bioscience. A total of 63 elements was analysed (elements are listed in *Appendix 2-4*).

Detection limits for the measured elements during the day of analyses were based on measurements of blank solutions and calculated as three times the standard deviation on these and reported in the appendices. The accredited detection limits are shown in *Table 3*.

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 digestions.

In addition to the blank solution, one duplicate sample (same sample ID but two different acid digestions) and at least one sample of certified reference material were analysed per series of digestions. The duplicate sample was analysed to check the repeatability of the measurements and the certified reference materials were analysed to check the accuracy. The certified reference materials used were PACS-2, HISS-1 and DORM-4 ([www.nrc-cnrc.gc.ca](http://www.nrc-cnrc.gc.ca)).

The laboratory at the Department of Bioscience is accredited by the Danish Accreditation Fund - DANAK for the analyses and parameters listed in *Table 3* with the shown detection limits and precisions.

The quality of the methods is further checked by participation in the international QUASIMEME laboratory intercalibration programme twice a year.

The elements that are not part of the accreditation by DANAK have a higher uncertainty as they have not been controlled by independent organisations like DANAK and QUASIMEME. We expect that the relative uncertainty for these elements in concentrations well above the detection limit is approximately 30% on a 95% confidence level.

**Table 3.** Accredited elements, detection limits (DL) and precisions for ICP-MS analyses of sediment, water and biota at the Department of Bioscience, Aarhus University.

Element	Sediment (mg kg <sup>-1</sup> )		Water (µg l <sup>-1</sup> )		Biota (mg kg <sup>-1</sup> )	
	DL	Precision	DL	Precision	DL	Precision
Li	1.6	15%	1.0	15%	-	-
Be	0.3	15%	0.2	5%	-	-
Na	200	15%	55	10%	-	-
Mg	15	15%	10	10%	-	-
Al	1000	15%	10	10%	-	-
P	30	15%	15	15%	-	-
K	650	20%	25	10%	-	-
V	0.2	15%	0.2	5%	-	-
Cr	0.5	35%	0.2	5%	0.4	20%
Mn	5.5	20%	2.5	15%	-	-
Fe	70	15%	10	5%	-	-
Co	0.2	10%	0.2	8%	-	-
Ni	0.3	15%	0.5	10%	0.3	15%
Cu	2.5	15%	0.8	10%	2	15%
Zn	1.0	15%	10	15%	5	15%
As	0.6	35%	1.0	20%	2	20%
Se	1.0	25%	0.5	10%	1	20%
Sr	0.4	50%	0.5	5%	-	-
Mo	0.7	25%	2.0	15%	-	-
Cd	0.3	15%	0.1	10%	0.1	15%
Sn	0.2	20%	2.0	-	-	-
Sb	0.9	20%	2.0	40%	-	-
Cs	0.2	10%	0.1	-	-	-
Ba	0.5	10%	1.0	5	-	-
Pb	1.4	20%	0.3	10%	0.3	20%

### 3.5 PAH analyses

A total of eight samples of marine sediment and soil was analysed for PAHs at the Department of Environmental Science. A total of 29 different PAHs was analysed.

Samples were analysed using GC-MS in SIM mode and quantified against external calibration standards. GC column: HP5-MS, 30 m, diameter 0.25 mm, film thickness 0.25  $\mu\text{m}$ , temperature program: 90°C 1 min, increase 10°C/min to 200°C, increase 5°C/min to 240°C, 240°C 4 min, increase 20°C/min to 270°C, 270°C 18.5 min. Inlet temperature 280°C. Constant gas flow: 1 ml/min Helium.

The analytical method is accredited by DANAK, The Danish Accreditation Fund. All glassware was heated at 450°C for 2 hours before use.  $\text{Na}_2\text{SO}_4$ , glass wool and equipment that cannot tolerate high temperatures were cleaned by DCM before use. Blind samples and controls were analysed together with the environmental samples. Blind samples were true blinds, which followed the exact same analytical procedure as the environmental samples. The control was freeze-dried marine sediment. Detection limits ranged from 0.1 to 5  $\mu\text{g}/\text{kg}$  dry weight.

Dry matter percentage and LOI (loss on ignition) were determined in the samples according to the standard DS 204, 1980, Tørstof og gløderest.

## 4 Results and discussion

### 4.1 Freshwater

All results of chemical analyses of water samples are shown in *Appendix 2* and selected results are shown in *Table 4*.

Of the 63 elements analysed, none of the element concentrations were elevated in the water collected downstream from the mine as compared to water collected upstream and at the reference site. The pH of the water was neutral with low electrical conductivity. Concentrations of key elements in all water samples were below the established Greenland Water Quality Criteria for mining activities (MRA 2015) as shown in *Table 4*.

**Table 4.** Concentrations of selected dissolved elements ( $\mu\text{g l}^{-1}$ ), pH and electrical conductivity (EC) in freshwater collected upstream and downstream from the mine and at a reference site, respectively. Analytical detection limits and Greenland Water Quality Criteria for mining activities (GWQC) are also shown.

	Al	Cr	Mn	Fe	Ni	Cu	Zn	As	Se	Cd	Hg	Pb	pH	EC
Detection limit (DL)	0.3	0.3	0.07	0.7	1.3	0.1	0.1	0.4	0.1	0.02	0.03	0.04	-	-
Reference site (Site 1)	0.8-9.0	<DL	0.2-0.5	4.0-20	<DL	0.3-0.4	1.2-1.4	<DL	0.6-0.7	<DL	<DL	<DL-0.2	7.9	132
Upstream from mine (Site 2)	0.6-0.8	<DL	0.2-0.3	4.5-5.5	<DL	0.8-1.0	<DL	<DL	0.2-0.3	<DL	<DL	<DL	8.1	228
Downstream from mine (Site 3)	1.2-1.6	<DL	0.2-0.3	4.7-5.2	<DL	0.7-0.8	<DL-0.2	<DL	0.5-0.8	<DL	<DL	<DL	8.0	177
GWQC	-	3	-	300	5	2	10	4	-	0.1	0.05	1	-	-

The results show that the water collected in the stream downstream from the mine was not polluted, which indicate that there is currently little/no leaching of pollutants from the mine site. However, it shall be noted that the sampling period was very dry and that the stream was the only stream found at the mine site. Consequently, leaching of pollutants may occur at the site during more rainy periods of the year or in spring during thawing of the snow cover. The presence of ochre precipitates (mainly consisting of iron-oxyhydroxides) at the soil surface in some spots shows that formation of acid mine drainage has occurred in the past and may occur during some periods of the year. However, the limited spatial extent of the areas with ochre precipitates also indicates that this is only likely to be at a very local scale.

### 4.2 Lichens

All results of chemical analyses of lichen samples are shown in *Appendix 3* and selected results are shown in *Table 5*.

For evaluation of the lichen results, the chemical composition in lichens from the mine area was compared to the chemical composition in lichens sampled at Site 10 that was considered an adequate reference site. Since only one reference sample was used, and in order to account for natural variation in the lichen compositions, an element concentration of 10 times the concentration of the reference sample was chosen as an assessment criterion in the following. This was considered adequate based on experience from previous studies

(Søndergaard et al. 2011a; Søndergaard et al. 2011b; Søndergaard 2013). Subsequently, element concentrations in lichens that exceeded that assessment criterion were identified. In addition, the range in element concentrations measured in lichens at four locations undisturbed by mining and representing different areas/climate zone in Greenland (Avanersuaq, Nuuk, Qaqortoq and Tasilaq) and reported in Riget et al. (2000) were used for comparison.

Of the 63 elements analysed, only chromium (Cr) exceeded the assessment criterion in lichens sampled at the mine site (*Table 5*). However, concentrations of a range of other elements including aluminium (Al), manganese (Mn), iron (Fe), nickel (Ni), copper (Cu), zinc (Zn), cadmium (Cd), mercury (Hg) and lead (Pb) were generally higher in lichens at the mine site than at the reference site as well as lichens from Avanersuaq, Nuuk, Qaqortoq and Tasilaq.

The highest concentrations of those elements were found in lichens at Site 7 and Site 11. Site 7 is located close to the mine whereas Site 11 is the site furthest away from the mine. Site 11 is located uphill from the mine area and is considered the least affected site in terms of dust deposition from the mine area as the dominant wind direction is parallel to the coastline (*Figure 3*). This indicates that the relatively high concentrations of elements measured in lichens at Site 11 may not come from the mine area.

**Table 5.** Concentrations of selected elements in lichens at the 13 sampling sites (in mg kg<sup>-1</sup> dry weight). Sites 1-9 and Sites 11-13 are considered potentially influenced by dust deposition from the mine area whereas Site 10 is regarded as an unaffected reference site. Concentrations of 10 times the concentrations at the reference site were used as a criterion for assessment. Underlined values show element concentrations exceeding the assessment criterion value. Also, the ranges in element concentrations observed at four different areas undisturbed by mining (Avanersuaq, Nuuk, Qaqortoq and Tasilaq) and reported in Riget et al. (2000) were used for comparison (listed at the bottom of the table).

	Al	Cr	Mn	Fe	Ni	Cu	Zn	As	Se	Cd	Hg	Pb
Detection limit (DL)	26	0.23	1	1	0.22	0.13	0.2	0.7	0.026	0.033	0.014	0.037
Site 1	1224	2.36	139	698	3.06	1.25	12.2	<DL	0.083	0.081	0.041	0.786
Site 2	761	1.32	44	409	0.98	1.11	13.7	<DL	0.138	0.118	0.034	0.517
Site 3	888	1.18	42	251	0.74	0.91	17.9	<DL	0.111	0.110	0.029	0.547
Site 4	697	0.94	17	386	1.41	1.64	7.4	<DL	0.083	0.067	0.037	0.268
Site 5	958	1.21	32	400	1.15	1.48	13.7	<DL	0.107	0.109	0.039	0.575
Site 6	1294	2.63	143	974	2.38	1.87	17.4	<DL	0.085	0.084	0.039	0.976
Site 7	2353	<u>4.74</u>	62	1848	3.33	4.77	22.9	<DL	0.064	0.169	0.051	1.266
Site 8	918	1.81	45	597	1.64	1.63	22.6	<DL	0.083	0.115	0.043	0.567
Site 9	1182	2.55	23	1105	1.93	2.80	9.6	<DL	0.114	<DL	0.026	0.557
Site 11	2474	<u>4.62</u>	132	1525	4.06	2.49	12.8	<DL	0.097	0.147	0.045	1.139
Site 12	799	1.20	151	438	1.14	1.29	16.8	<DL	0.049	0.253	0.036	0.392
Site 13	815	1.94	71	716	1.78	1.60	20.5	<DL	0.109	0.097	0.040	0.551
Reference site (Site 10)	344	0.39	20	202	0.44	0.83	11.5	<DL	0.130	0.066	0.026	0.205
10x Reference site	<u>3436</u>	<u>3.88</u>	<u>195</u>	<u>2021</u>	<u>4.37</u>	<u>8.35</u>	<u>115.1</u>	-	<u>1.297</u>	<u>0.663</u>	<u>0.256</u>	<u>2.047</u>
Four non-mining areas in Greenland (Avanersuaq, Nuuk, Qaqortoq and Tasilaq)	79-710	0.12- 1.20	-	68-288	1.00- 1.80	0.45- 1.32	6.5-36.9	0.10- 0.16	-	0.047- 0.162	0.029- 0.089	0.32- 4.29

In Greenland, *Flavocetraria nivalis* lichens have been used as indicators of dust dispersion and deposition from mining for decades (Søndergaard et al. 2011b). These lichens are abundant, have no roots and take up nutrients and pollutants solely from the air, which makes them ideal for monitoring dust deposition. At recent mine sites in Greenland, *Flavocetraria nivalis* lichens have been collected at a number of sites before, during and after the mining activity. Subsequently, changes in element concentrations in the lichens before mining versus during and after mining at the specific sites have been used as a proxy for dust deposition of specific elements associated with the mining activity.

At Qullissat, no baseline data exist and the only way to evaluate dust deposition based on the lichen data is to compare lichens sampled close to the mine with lichens sampled some distance away. This will give an indication of dust deposition with elements originating from the mine but the comparison is not perfect since site-specific conditions such as orientation and wind exposure influence the dust deposition rates and subsequent lichen uptake at the sites. Consequently, the comparison should only be regarded as indicative.

Based on the above, and because of: 1) only slightly elevated concentrations of only a few elements and 2) the lack of pattern in the data between the sites (with relatively high concentration measured at Site 11, which is considered the least affected site with regards to dust from the mine area), we conclude that there is currently little dust dispersion and deposition of elements associated with the mine.

### 4.3 Soil and marine sediment

All results from the chemical analyses of surface soil and marine sediment are shown in *Appendix 4* (elements) and *Appendix 5* (PAHs) and selected results are presented in *Table 6, 7 and 9*.

#### Element composition in surface soil

For evaluation of the surface soil results, the chemical composition in surface soil from the mine area was compared to reported data on the average chemical composition in the Earth's upper continental crust (Taylor & McLennan 2002). This was done since no reference surface soil samples were collected at the site and was considered adequate for a rough comparison. A concentration of 10 times the concentration of upper continental crust was chosen as a criterion for assessment. Subsequently, element concentrations in the soil samples that exceeded that assessment criterion were identified.

Of the 63 elements analysed, only lead (Pb) exceeded the assessment criterion in the surface soil sampled at the mine site (*Table 6*). However, other elements including iron (Fe), nickel (Ni), copper (Cu) and zinc (Zn) were found in higher concentrations in surface soil within the mine area compared to the average continental crust. The highest concentrations of Pb (217 mg kg<sup>-1</sup>) and Zn (385 mg kg<sup>-1</sup>) were found in ochre precipitates at Site 7. This is not surprising since ochre, which consists mainly of Fe-oxyhydroxides, is known to concentrate a range of other heavy metals in its mineral structure (Elberling et al. 2007).



**Table 6.** Concentrations of selected elements in surface soil from 5 sites in the mine area (in mg kg<sup>-1</sup> dry weight). Since no reference surface soil sample was collected, the average element concentrations in the Earth's upper continental crust according to Taylor & McLennan (2002) are listed for a rough comparison. Concentrations of 10 times the concentrations in the upper continental crust were used as an assessment criterion (listed at the bottom of the table).

	Al	Cr	Mn	Fe	Ni	Cu	Zn	As	Se	Cd	Hg	Pb
Detection limit (DL)	422	4	7	18	2	1	1	8	0.37	0.75	0.27	0.8
Site 4	37362	59	179	16210	29	31	40	<DL	0.44	<DL	<DL	13.9
Site 5	48661	77	225	50144	44	39	53	<DL	<DL	<DL	<DL	12.7
Site 6	34478	63	236	18734	65	46	128	<DL	<DL	<DL	<DL	9.5
Site 7	31857	39	91	7093	27	18	385	<DL	<DL	<DL	<DL	217.4
Site 8	47408	89	313	34569	40	82	54	<DL	<DL	<DL	<DL	14.6
Upper continental crust	80400	85	600	35000	50	25	71	2	50	98	-	16
10x Upper continental crust	804000	850	6000	350000	500	250	710	15	500	980	-	160

The results from the soil surface samples indicate that some elements, especially Pb and to a lesser extent Zn, are present in elevated concentration in surface soil within the mine area. This will be discussed with the results from the marine sediments in the following. The few samples of surface soil collected in the mine area are not enough to evaluate the spatial extent of the soil surface contamination at the mine site.

#### Element composition in marine sediments

For evaluation of the sediment results, chemical compositions of the sediment sampled at the 7 sites in the mine area and adjacent to the waste dump in the Qullissat mining town were compared to the chemical composition in sediment at Site 11 north of Qullissat mining town, which was considered an adequate reference site. Since only one reference sample was used, and to account for natural variation in the sediment composition, an element concentration of 10 times the concentration of the reference sample was chosen as an assessment criterion in the following. In addition, the ranges of element concentrations in Arctic Shelf offshore sediments as reported in the Arctic Monitoring and Assessment Programme (AMAP, 2002) were used for comparison.

Of the 63 elements analysed, no elements in the onshore sediment samples from Qullissat exceeded the assessment criterion values (*Table 7*). Based on the results from soil surface samples, Pb and Zn were identified as potential contaminants from the mine area. Some of the sediment samples from the mine area did contain higher concentrations of Pb and Zn compared to the reference site and therefore some of these potential contaminants from the mine may have been dispersed. However, the differences in Pb and Zn sediment concentrations were relatively small (less than a factor of 3). A contributing factor is that Qullissat is situated along a high-energy coast and that any release of contaminants to the marine environment is likely to be greatly diluted.

**Table 7.** Concentrations of selected elements in onshore marine sediment at the 8 sampling sites at Qullissat (in mg kg<sup>-1</sup> dry weight). Site 11 situated north of Qullissat was used as reference site. Concentrations of 10 times the concentrations at the reference site were chosen as a criterion for assessment. Also shown is the range in mean element concentrations in offshore sediment from selected Arctic Shelf Regions as reported in AMAP (2002).

	Al	Cr	Mn	Fe	Ni	Cu	Zn	As	Se	Cd	Hg	Pb
Detection limit (DL)	422	4	7	18	2	1	1	8	0.37	0.75	0.27	0.8
Site 1	35159	74	741	45550	36	77	61	<DL	<DL	<DL	<DL	6.1
Site 2	56002	86	698	46112	45	73	68	<DL	0.54	<DL	<DL	9.8
Site 3A	27548	95	1158	44822	55	128	96	<DL	0.59	<DL	<DL	3.9
Site 3B	37818	89	1090	43946	51	116	82	<DL	<DL	<DL	<DL	6.4
Site 3C	33915	93	1022	43686	55	121	91	<DL	<DL	<DL	<DL	9.5
Site 9	40520	103	1041	41003	56	93	125	<DL	<DL	<DL	<DL	7.6
Site 10	29344	243	1063	45085	163	112	85	<DL	<DL	<DL	<DL	4.1
Reference site (Site 11)	27408	272	1043	58544	164	112	78	<DL	<DL	<DL	<DL	3.3
10x Reference site	274079	2722	10433	585438	1642	1118	778	-	-	-	-	33.2
Offshore sediments from selected Arctic Shelf Regions (AMAP 2002)	-	59-163	206-3747	33500-43900	18-82	11-49	56-115	15-33	-	0.06-0.27	0.017-0.074	8.5-24

To evaluate the sediment quality from an environmental perspective, concentrations of key elements in the sediment were compared with Norwegian sediment quality criteria (Bakke et al. 2010) (*Table 8*).

**Table 8.** Norwegian classification of environmental quality in sediments for selected elements (Bakke et al. 2010) compared to the concentration range measured in the Qullissat sediments (in mg kg<sup>-1</sup> dry weight).

	Norwegian classification of metal and organic contaminants in sediments					Qullissat area
	I Background	II Good	III Moderate	IV Bad	V Very bad	All sediment samples
Cr	<70	70-560	560-5900	5900-59000	>59000	74-272
Ni	<30	30-46	46-120	120-840	>840	36-164
Cu	<35	35-51	51-55	55-220	>220	77-128
Zn	<150	150-360	360-590	590-4500	>4500	61-125
As	<20	20-52	52-76	76-580	>580	<8
Cd	<0.25	0.25-2.6	2.6-15	15-140	>140	<0.75
Hg	<0.15	0.15-0.63	0.63-0.86	0.86-2	>2	<0.27
Pb	>30	30-83	83-100	100-720	>720	3.9-9.8

As shown, with regard to Cr, Zn, As, Cd, Hg and Pb, all sediment samples were categorised as 'Background' or 'Good' in terms of sediment quality. With regard to Ni, however, the sediment ranged from 'Good' to 'Moderate' to 'Bad'. For Cu, all sediment samples were categorised as 'Bad' according to the Norwegian environmental classification system. This is notable, but is not considered a result of contamination from the mine area since sediment sampled at the reference site north of the Qullissat mining town had the highest Ni concentration of 164 mg kg<sup>-1</sup> as well as a high Cu concentration of 112 mg kg<sup>-1</sup>. High concentrations of Ni and Cu in sediment from the Disko area as compared to the other areas in Greenland as well as other Arctic Shelf Regions have previously been observed due to leaching from tertiary volcanic rocks near Disko (Loring & Asmund 1996; AMAP 2002).

In conclusion, since sediment is known to concentrate contaminants (e.g. Søndergaard et al. 2011a), the results presented above indicate that any current leaching of elements from the mine site and from the waste dump at the Qullissat mining town is likely to be low and insignificant in terms of environmental impact. However, naturally high Ni and Cu concentrations in the sediment in the entire Qullissat area may have an ecotoxicological effect on biota living in the sediment, which would require more studies to determine.

#### PAHs in surface soil and marine sediment

PAH concentrations in sediment collected in the tidal zone within the mine area and adjacent to the waste dump in the Qullissat mining town were compared to PAH concentrations in sediment from Site 11, north of the Qullissat mining town, which was considered unlikely to be influenced by contamination. Since only one reference sample was used, and to account for some natural variation in the sediment composition, an element concentration of 10 times the concentration of the reference sample was chosen as an assessment criteria in the following.

Only one of the soil surface samples collected within the mining area was analysed for PAHs (Site 8, *Table 2*). This sample was selected because it represented soil from the coal bank, which presumably would have the highest PAH concentrations and could therefore serve as source characterisation of any potential PAH contamination.

The summed PAH results from the soil surface sample and from the 8 sediment samples for all 29 PAHs analysed are shown in *Table 9*, whereas detailed results for all individual PAHs are given in *Appendix 5*.

**Table 9.** Sum of all 29 PAHs analysed in surface soil from a coal bank within the Qullissat mine area and in 8 marine sediment samples. Site 11 situated north of Qullissat was used as reference site. Concentrations of 10 times the concentrations at the reference site were used as an assessment criterion (listed at the bottom of the table). PAH values are both expressed per kg dry weight unit soil/sediment and per kg Loss On Ignition (LOI) unit (representing the organic matter content in the sample). LOI for the samples are also given.

	$\sum$ 29 PAH ( $\mu\text{g kg}^{-1}$ dry weight)	$\sum$ 29 PAH ( $\mu\text{g kg}^{-1}$ LOI)	LOI (%)
Soil surface			
Site 8 (coal bank)	10764	17361	62
Marine sediment			
Site 1	112	13950	0.8
Site 2	1009	34792	2.9
Site 3A	124	15515	0.8
Site 3B	176	16017	1.1
Site 3C	572	38114	1.5
Site 9	1031	36828	2.8
Site 10	202	20200	1
Marine reference site (Site 11)	100	12458	0.8
<i>10x Reference site</i>	<i>997</i>	<i>124580</i>	-

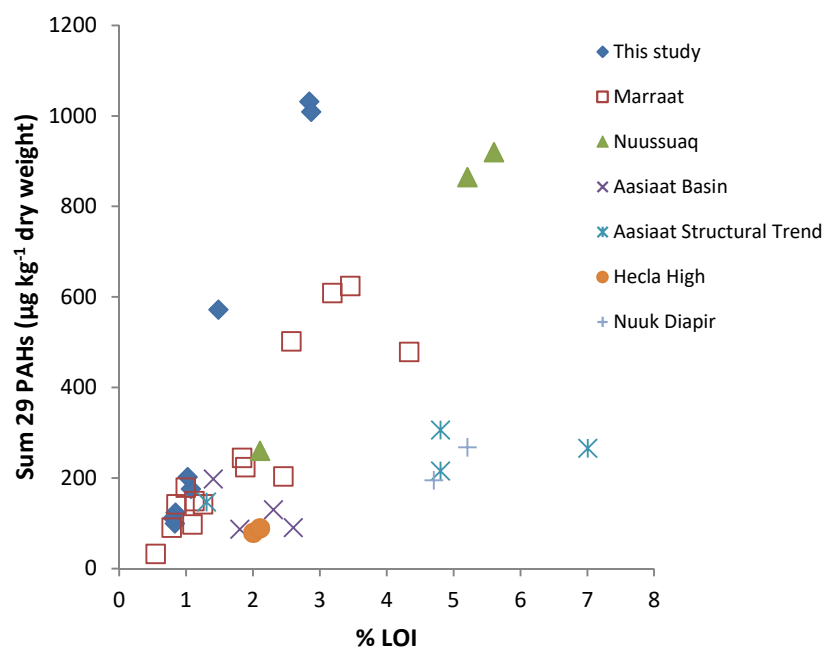
As shown, the soil surface sample from the coal bank contained the highest total PAH content per weight unit of 10764  $\mu\text{g PAH kg}^{-1}$  dry weight. This is not surprising since PAHs are known to be associated with coal (Achten & Hoffmann 2009; Bertrand et al. 2015).

PAH levels in marine sediment samples ranged from 100 to 1031  $\mu\text{g kg}^{-1}$  dry weight. The lowest value was observed at the reference site (Site 11). The highest values of 1009 and 1031  $\mu\text{g PAH kg}^{-1}$  dry weights were observed at Site 2 and 9, which also exceeded the assessment criterion of 10 times the concentration in the reference sample. Site 2 is located on the coast just downslope from the mining area whereas Site 9 is located approximately 500 meters to the north of the mine (Figure 4). Sediment collected at the other sites downslope from the mine area contained 112 to 572  $\mu\text{g PAH kg}^{-1}$  dry weight. The site situated near the waste dump in the Qullissat mining town (Site 10) contained 202  $\mu\text{g PAHs kg}^{-1}$  in total. The results indicate that moderately elevated PAH content in sediment is present near the Qullissat mine area but also that the PAH content vary markedly between the sites.

The PAH data were also calculated based on the organic content (estimated as Loss On Ignition – LOI) in the samples since PAHs are known to be primarily associated with particles rich in organic matter in the sediment (Mosbech et al. 2007). Applying this normalization of the PAH data to the organic matter content resulted in less variation in PAH content between the sites. However, the highest PAH values in marine sediment were still observed at Site 2, 3C and 9.

PAH results from Qullissat were compared with other data from West Greenland presented in Mosbech et al. (2007). These data consist of PAH results (including all 29 PAHs analysed in this study) from sediment collected at Marraat (both onshore and offshore sediments) and Nuussuaq Basin near Qullissat as well as from Aasiaat Basin and Aasiaat Structural Trend, Hecla High and Nuuk Diapir (all offshore sediments). The sums of all 29 PAHs versus LOI for the samples are plotted in Figure 5.

**Figure 5.** Plot of total PAH content versus Loss On Ignition (LOI) for Greenland west coast sediments including data from this study. Data from the other areas were taken from Mosbech et al. (2007).



The comparison showed that total PAH content in sediment per unit dry weight sediment collected at Qullissat at Site 2, 3C and 9 (the 3 highest values) was relatively high but close to PAH content in sediment previously reported from Nuussuaq Basin and Marraat. It also showed that the 3 sediment samples from Qullissat had a higher PAH/LOI ratio, i.e. a higher PAH content per mass unit organic matter than at the other sites. Altogether it illustrates that the PAH content in the 3 sediment samples from Qullissat is elevated for this part of Greenland. However, compared to sediment from e.g. Denmark and the Baltic Sea, the levels are down to a factor of 3 lower (Mosbech et al. 2007).

In order to assess the environmental importance of the observed PAH levels at Qullissat, PAH concentrations of 16 selected PAHs were compared to the Norwegian guidelines for sediment quality (Bakke et al. 2010). These 16 PAH compounds have been listed as priority pollutants by the United States Environmental Protection Agency (Achten & Hofmann 2009). The results are shown in *Table 8*.

**Table 8.** Norwegian classification of environmental quality in sediments for 16 selected PAHs listed as priority pollutants by the United States Environmental Protection Agency (Bakke et al. 2010) compared to the concentration range measured in the Qullissat sediments (in  $\mu\text{g kg}^{-1}$  dry weight).

	Norwegian guidelines on classification of metals and organic contaminants in sediments (Bakke et al. 2010)					Qullissat area
	I Background	II Good	III Moderate	IV Bad	V Very bad	All sediment samples
Naphthalene	<2	2- 290	290 - 1000	1000 - 2000	>2000	1.2 - 27
Acenaphthylene	<1.6	1.6 - 33	33 - 85	85 - 850	>850	<0.1 - 0.9
Acenaphthene	<4.8	2.4 - 160	160 - 360	360 - 3600	>3600	<0.2 - 31
Fluorene	<6.8	6.8 - 260	260 - 510	510 - 5100	>5100	<1 - 54
Phenanthrene	<6.8	6.8 - 500	500 - 1200	1200 - 2300	>2300	2.1 - 59
Anthracene	<1.2	1.2 - 31	31 - 100	100 - 1000	>1000	n.a. - 18
Fluoranthene	<8	8 - 170	170 - 1300	1300 - 2600	>2600	2.0 - 73
Pyrene	<5.2	5.2 - 280	280 - 2800	2800 - 5600	>5600	1.5 - 45
Benzo(a)anthracene	<3.6	3.6 - 60	60 - 90	90 - 900	>900	1.5 - 26
Chrysene	<4.4	4.4 - 280	280 - 280	280 - 560	>560	0.6 - 18 <sup>a</sup>
Benzo(b)fluoranthene	<46	46-240	240 - 490	490 - 4900	>4900	2.4 - 32 <sup>b</sup>
Benzo(k)fluoranthene	-	<210	210 - 480	480 - 4800	>4800	
Benzo(a)pyrene	<6	6 - 420	420 - 830	830 - 4200	>4200	<3 - 5.4
Indeno(1.2.3-cd)pyrene	<20	20 - 47	47 - 70	70 - 700	>700	<0.5 - 8.5
Benzo(ghi)perylene	<18	18 - 21	21 - 31	31 - 310	>310	<2 - 5.2
Dibenzo(ah)anthracene	<12	12 - 590	590 - 1200	1200 - 12000	>12000	<1 - 1.1
Sum 16 PAHs	<300	300 - 2000	2000 - 6000	6000 - 20000	>20000	<19 - 4 04

<sup>a</sup> Sum of the PAHs Chrysene and Triphenylene. Triphenylene is not included in the 16 selected PAHs.

<sup>b</sup> Values are for the sum of the PAHs Benzo(b)fluoranthene, Benzo(j)fluoranthene and Benzo(k)fluoranthene. Benzo(j)fluoranthene is not included in the 16 selected PAHs.

When comparing to the Norwegian guideline values, all the individual PAHs and the total 16 PAHs were found in levels of 'Background' or 'Good' sediment quality suggesting that the levels of PAH observed in the Qullissat sediment were not of environmental significance. In comparison to a recent study from the Sisimiut area, the sediment collected at Qullissat had <30 times lower total 16 PAHs values than found in Sisimiut harbour but higher than at uncontaminated reference sites in Sisimiut (Bach et al. 2009). It shall be noted that

the sediment in this study was only collected in the tidal zone and not at deep waters. Consequently, the sediment was relatively coarse grained. Since previous studies have shown a positive correlation between the percentages of fine-grained sediment, LOI and PAH content (Mosbech et al. 2007), it is possible that finer grained sediment collected at deep waters may have contained higher total PAH concentrations. The opposite may also be the case since Qullissat is situated at a high-energy coastal environment and any release of contaminants from the mining area to the marine environment is likely to be greatly diluted outside the close vicinity of the site.

In conclusion, the relatively low levels and varying PAH concentrations in marine sediment at Qullissat, with an absence of a concentration gradient away from the mine site, indicate that a major leaching of PAHs from the mine site, coming from remains of coal and other material left at the site, is not likely. Rather, it seems probable that only local occurrences of PAHs from coal remains, e.g. from past coal spills during loading of ships (*Photo 2*) and from natural sources, are present in the area around the mine site.

The results indicate little to no leaching of PAHs from the waste dump in the Qullissat mining town.

## 5 Conclusion and perspectives

This study was the first study to investigate the environment at the former Qullissat mine site and mining town in West Greenland.

The study was considered a screening study and the main purpose was to identify any potential significant contamination in the area. The study was based on collection of selected environmental samples in August 2015 and subsequent chemical analyses performed at DCE's accredited laboratory in Roskilde. Samples consisted of surface soil, freshwater, lichens and onshore marine sediment from the tidal zone.

Chemical analyses of surface soil showed that moderately elevated concentrations of some elements, especially lead, and PAH compounds were present in the surface soil at the Qullissat mine site. Lead and PAHs are considered to originate mainly from waste rock and coal residues at the mine site, respectively, although other remains at the mine site such as infrastructure and other waste products may also contribute.

Freshwater collected from the only observed stream in the mine area did not indicate any leaching of contaminants from the mine site. Yet, the sampling period in August 2015 was very dry and little running water was observed at the time. The presence of ochre precipitates at the soil surface shows that leaching of contaminants has occurred earlier and perhaps may happen during periods of the year with more precipitation. The limited spatial extent of the ochre precipitates, however, also indicates that this is only likely to be of local importance.

Lichens were collected to assess dust dispersion from the mine area. Subsequent chemical analyses of 63 major and trace elements showed that some elements, especially chromium, were moderately elevated in lichens at some sites near the mine compared to a reference site (suggesting some dust deposition with chromium). However, the lack of a pattern in concentration levels in the dominant wind directions as well as the concentration levels observed in general indicate that dust dispersion with elements is not likely to constitute a significant source of contamination in the area.

Marine sediments were sampled from the beach at 8 sites near the mine area and mining town and at a reference site considered unlikely to be affected by contamination. Results from analyses of 63 major and trace elements in the sediment showed no clear difference between the samples collected at the mine site and mining town compared to the reference site. This indicates that any significant leaching and dispersion of elements from the mine site or mining town is not likely. Notable, however, were relative high nickel and copper concentrations in all sediment samples. These high concentrations are considered to be naturally elevated levels in the Qullissat area. Previous studies have documented relatively high concentrations of nickel and copper in sediment in the Disko area compared to other areas in Greenland due to leaching from tertiary volcanic rocks.



In addition to the 63 major and trace elements, 29 PAH compounds were analysed in the sediment samples. The results revealed that some of the sediment samples near the mine area had PAH concentration levels that were elevated compared to the reference site as well as to other previously reported data from West Greenland. The elevated concentration levels of PAHs are considered a result of a naturally higher presence of coal and oil in the area and may originate from both anthropogenic activity and natural sources. However, the PAH levels were still quite low and all sediment samples could be classified as 'Background' or 'Good' using the Norwegian sediment quality guidelines, which suggests that the PAH levels observed are not of environmental importance. It should be noted, however, that this assessment is limited only to onshore sediments since no offshore sediments were collected.

In conclusion, we assess that this study does not indicate any significant chemical contamination from the Qullissat mine site or mining town to the surrounding area. Yet, the study is based on a relatively limited study programme composed of relatively few sample types collected during a short period of time. In case a more comprehensive study is to be conducted at Qullissat in future, it could be relevant to also include samples of marine offshore sediment, marine biota and freshwater runoff collected during different times of the year to assess any potential seasonal variations.

## 6 References

Achten C, Hofmann T (2009) Review: Native polycyclic aromatic hydrocarbons (PAH) in coals – A hardly recognized source of environmental contamination. *Science of the Total Environment* 407: 2461-2473.

AMAP 2002. AMAP Assessment (2002) Heavy metals in the Arctic. Arctic Monitoring and Assessment Programme (AMAP) 231 pp.

Bach L, Forbes VE, Dahllöf I (2009) The amphipod *Orchomenella pinguis* - A potential bioindicator for contamination in the Arctic. *Marine Pollution Bulletin* 58: 1664-1670.

Bakke T, Källqvist T, Ruus A, Breedveld GD, Hylland K (2010) Development of sediment quality criteria in Norway. *Journal of Soild and Sediments* 10:172-178.

Bertrand O, Mondamert L, Grosbois C, Dhivert E, Bourrain X, Labanowski J, Desmet M (2015) Storage and source of polycyclic aromatic hydrocarbons in sediments downstream of a major coal district in France. *Environmental Pollution* 207:329-340.

Elberling B, Søndergaard J, Jensen LA, Schmidt LB, Hansen BU., Asmund G, Balic-Zunic T, Hollesen J, Hanson S, Jansson P-E, Friborg T (2007) Arctic vegetation damage by winter-generated coal mining pollution released upon thawing. *Environmental Science and Technology* 41:2407-2413.

Johansen P, Asmund G, Riget F, Johansen K (2008) Environmental monitoring at the cryolite mine in Ivittuut, South Greenland, 2007. National Environmental Research Institute, University of Aarhus. NERI Technical Report no. 674, 32 pp. <http://www.dmu.dk/Pub/FR674.pdf>

Johansen P, Asmund G, Rigét F, Johansen K, Schledermand H (2010) Environmental monitoring at the former lead-zinc mine in Maarmorilik, Northwest Greenland, in 2009. National Environmental Research Institute, Aarhus University. NERI Technical Report No. 775. 32 pp. <http://www.dmu.dk/Pub/FR775.pdf>

Loring DH, Asmund G (1996) Geochemical factors controlling accumulation of major and trace elements in Greenland coastal and fjord sediments. *Environmental Geology* 28:2-10.

Mosbech A, Hansen AB, Asmund G, Dahllöf I, Petersen DG, Strand J (2007) A chemical and biological study of the impact of a suspected oil seep at the coast of Marraat, Nuussuaq, Greenland – With a summary of other environmental studies of hydrocarbons in Greenland. NERI Technical Report no. 629. National Environmental Research Institute, University of Aarhus, Denmark, 56 pp.

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.

Pedersen SAS, Larsen LM, Dahl-Jensen T, Jepsen HF, Pedersen GK, Nielsen T, Pedersen AK, von Platen-Hallermund F, Weng W (2002) Tsunami-generating rock fall and landslide on the south coast of Nuussuaq, central West Greenland. *Geology of Greenland, Survey Bulletin* 191:73-83.

Riget F, Asmund G, Aastrup P (2000) The use of lichen (*Cetraria nivalis*) and moss (*Rhacomitrium lanuginosum*) as monitors for atmospheric deposition in Greenland. *The Science of the Total Environment* 245:137-148.

Sejersen F. (2014). Efterforskning og udnyttelse af råstoffer i Grønland i historisk perspektiv. Baggrundspapir, Udvalget for samfundsgavnlig udnyttelse af Grønlands naturressourcer, Københavns Universitet, 78 pp.

Søndergaard J, Elberling B, Asmund G, Gudum C, Iversen KM (2007) Temporal trends of dissolved weathering products released from a high Arctic coal mine waste rock pile in Svalbard (78°N). *Applied Geochemistry* 22: 1025-1038.

Søndergaard J, Asmund G, Johansen P, Riget F (2011a) Long-term response of an arctic fiord system to lead-zinc mining and submarine disposal of mine waste (Maarmorilik, West Greenland). *Marine Environmental Research* 71: 331-341.

Søndergaard J, Johansen P, Asmund A, Rigét F (2011b) 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: 4063-71.

Søndergaard J (2013) Dispersion and bioaccumulation of elements from an open-pit olivine mine in Southwest Greenland assessed using lichens, seaweeds, mussels and fish. *Environmental Monitoring and Assessment* 185(8): 7025-7035.

Taylor SR, Mclennan SM (2002) *Encyclopedia of Physical Sciences and Technology*. 3rd edition. Academic Press, Vol. 2, pp 697-719.

Wegeberg S, Boertmann D (2016) Disko Island and Nuussuaq Peninsula, West Greenland. A strategic environmental impact assessment of petroleum exploration and exploitation. Scientific Report from DCE, Danish Centre for Environment and Energy, Aarhus University No. 199. 108 p.  
<http://dce2.au.dk/pub/SR199.pdf>

## Appendix 1. Sampling data

ID no.	Station name	Sample type	Collection					
			date	Lat_deg	Lat_min	Long_deg	Long_min	W_E
53501	Water Site 1	Water	20150807	70,00	4,346	52,00	59,83	W
53502	Water Site 2	Water	20150807	70,00	4,044	52,00	59,39	W
53503	Water Site 3	Water	20150807	70,00	4,097	52,00	59,22	W
53504	Lichen Site 1	Lichen	20150807	70,00	4,223	52,00	59,55	W
53505	Lichen Site 2	Lichen	20150807	70,00	4,187	52,00	59,47	W
53506	Lichen Site 3	Lichen	20150807	70,00	4,059	52,00	59,36	W
53507	Lichen Site 4	Lichen	20150808	70,00	4,403	53,00	0,21	W
53508	Lichen Site 5	Lichen	20150808	70,00	4,277	52,00	59,75	W
53509	Lichen Site 6	Lichen	20150808	70,00	4,236	52,00	59,58	W
53510	Lichen Site 7	Lichen	20150808	70,00	4,097	52,00	59,35	W
53511	Lichen Site 8	Lichen	20150808	70,00	4,01	52,00	59,55	W
53512	Lichen Site 9	Lichen	20150808	70,00	3,95	52,00	59,62	W
53513	Lichen Site 10	Lichen	20150808	70,00	3,944	53,00	0,58	W
53514	Lichen Site 11	Lichen	20150808	70,00	4,213	53,00	0,58	W
53515	Lichen Site 12	Lichen	20150808	70,00	4,232	53,00	0,37	W
53516	Lichen Site 13	Lichen	20150808	70,00	4,308	53,00	0,22	W
53520	Soil/sediment Site 9	Beach sediment	20150807	70,00	43,76	53,00	59,50	W
53521	Soil/sediment Site 3C	Beach sediment	20150807	70,00	42,5346	53,00	59,32	W
53522	Soil/sediment Site 3A	Beach sediment	20150807	70,00	41,72	53,00	59,26	W
53523	Soil/sediment Site 3B	Beach sediment	20150807	70,00	42,1956	53,00	59,29	W
53524	Soil/sediment Site 2	Beach sediment	20150807	70,00	40,9188	53,00	59,20	W
53525	Soil/sediment Site 1	Beach sediment	20150807	70,00	36,504	53,00	58,52	W
53526	Soil/sediment Site 10	Beach sediment	20150808	70,00	5,5506	53,00	0,74	W
53527	Soil/sediment Site 11	Beach sediment	20150808	70,00	6,0348	53,00	16,26	W
53528	Soil/sediment Site 8	Soil with coal	20150807	70,00	41,98	53,00	59,35	W

## Appendix 2. Elemental analyses of freshwater

### Concentrations in µg/l.

ID no.	Lab no.	Notes	Li	Be	Na	Mg	Al	P	S	K	Ca	Sc	Ti	V	Cr	Mn	Fe
Detection limit (DL)			0,2	0,03	19	0	0,3	4	214	8	3	0,02	0,06	0,07	0,26	0,07	0,74
53501	-	Site 1, unfiltered	0,2	<DL	5175	4041	13,3	<DL	2691	273	11675	0,07	0,76	8,05	<DL	2,56	88,89
53501	-	Site 1, unfiltered	0,3	<DL	5350	4132	12,7	<DL	2953	294	11579	0,06	0,80	8,53	<DL	2,55	86,69
53501	-	Site 1, filtered	0,3	<DL	5337	4103	9,0	<DL	3070	320	11513	0,07	0,53	8,25	<DL	0,50	19,68
53501	-	Site 1, filtered	0,2	<DL	5361	4142	0,8	<DL	3452	314	11546	0,07	0,15	8,33	<DL	0,16	3,96
53502	-	Site 2, unfiltered	0,3	<DL	6359	9079	16,3	<DL	4982	535	24076	0,09	1,11	1,30	<DL	0,85	53,23
53502	-	Site 2, unfiltered	0,3	<DL	5995	8733	16,1	<DL	5121	517	21912	0,09	1,14	1,43	<DL	0,80	47,13
53502	-	Site 2, filtered	0,3	<DL	6145	8841	0,6	<DL	5237	521	21475	0,07	0,16	1,22	<DL	0,27	4,49
53502	-	Site 2, filtered	<DL	<DL	6104	8779	0,8	<DL	5319	516	22325	0,10	0,19	1,19	<DL	0,25	5,51
53503	-	Site 3, unfiltered	0,3	<DL	5543	6135	19,0	<DL	5064	322	17179	0,09	1,07	3,89	<DL	1,11	64,40
53503	-	Site 3, unfiltered	0,3	<DL	5402	6012	19,8	<DL	4832	323	17378	0,08	1,10	3,81	<DL	1,22	62,02
53503	-	Site 3, filtered	0,2	<DL	5140	5781	1,2	<DL	4520	319	17196	0,07	0,13	3,59	<DL	0,28	5,22
53503	-	Site 3, filtered	0,3	<DL	5403	5979	1,6	<DL	4709	329	17024	0,06	0,13	3,83	<DL	0,29	4,67

### Table continued

Ni	Co	Cu	Zn	Ga	As	Se	Rb	Sr	Y	Zr	Nb	Mo	Ru	Pd	Ag	Cd	Sn	Sb	Te	Cs
1,31	0,03	0,13	0,15	0,053	0,437	0,099	0,037	0,024	0,002	0,018	0,004	0,018	0,004	0,007	0,733	0,017	0,025	0,006	0,136	0,051
<DL	0,08	0,44	0,30	0,095	<DL	0,439	0,187	6,229	0,024	<DL	<DL	0,069	<DL	<DL	<DL	<DL	<DL	0,007	<DL	<DL
<DL	0,07	0,39	1,12	0,089	<DL	0,289	0,193	6,519	0,029	<DL	<DL	0,096	0,006	<DL	<DL	<DL	<DL	<DL	<DL	<DL
<DL	<DL	0,39	1,42	0,087	<DL	0,638	0,194	6,469	0,010	<DL	<DL	0,111	<DL	0,008	<DL	<DL	<DL	0,021	<DL	<DL
<DL	<DL	0,34	1,24	0,086	<DL	0,733	0,199	6,381	0,003	<DL	<DL	0,112	<DL	0,012	<DL	<DL	<DL	0,268	<DL	<DL
<DL	0,04	0,96	<DL	0,087	<DL	0,216	0,447	11,441	0,026	<DL	<DL	0,097	<DL	0,012	<DL	<DL	<DL	0,008	<DL	<DL
<DL	0,04	0,92	<DL	0,055	<DL	0,246	0,420	10,784	0,024	<DL	<DL	0,121	<DL	<DL	<DL	<DL	<DL	0,006	<DL	<DL
<DL	<DL	0,85	<DL	<DL	<DL	0,209	0,393	10,869	0,011	<DL	<DL	0,264	<DL	0,010	<DL	<DL	<DL	<DL	<DL	<DL
<DL	<DL	0,96	<DL	0,060	<DL	0,308	0,402	10,926	0,012	<DL	<DL	0,262	<DL	0,011	<DL	<DL	<DL	0,010	<DL	<DL
<DL	0,06	0,82	<DL	0,087	<DL	0,389	0,275	11,298	0,032	<DL	<DL	0,077	<DL	0,008	<DL	<DL	0,054	<DL	<DL	<DL
<DL	0,06	0,77	<DL	0,096	<DL	0,383	0,404	10,915	0,027	<DL	<DL	0,105	0,005	0,011	<DL	<DL	0,060	<DL	<DL	<DL
<DL	<DL	0,70	0,21	0,067	<DL	0,583	0,269	10,655	0,014	<DL	<DL	0,220	<DL	0,013	<DL	<DL	0,036	0,017	<DL	<DL
<DL	<DL	0,75	<DL	0,057	<DL	0,841	0,257	11,012	0,012	<DL	<DL	0,159	<DL	0,013	<DL	<DL	0,111	0,007	<DL	<DL

### Table continued

Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	W	Re	Pt
0,438	0,001	0,003	0,001	0,006	0,006	0,002	0,008	0,001	0,003	0,001	0,003	0,002	0,004	0,001	0,006	0,001	0,007	0,002	0,006
0,661	0,046	0,117	0,016	0,047	<DL	0,003	0,009	<DL	0,014	0,002	0,005	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
0,653	0,048	0,118	0,012	0,053	<DL	0,003	0,012	<DL	0,008	0,002	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
0,849	0,004	0,010	0,002	0,014	<DL	<DL	<DL	<DL	0,004	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0,004	<DL
0,699	0,002	0,003	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0,011	<DL
0,813	0,043	0,108	0,011	0,044	0,009	<DL	<DL	<DL	<DL	0,003	<DL	<DL	0,006	<DL	<DL	<DL	<DL	0,002	<DL
0,762	0,026	0,094	0,007	0,034	<DL	<DL	0,011	<DL	0,012	0,001	0,007	<DL	<DL	<DL	<DL	<DL	<DL	0,006	<DL
0,571	0,004	0,014	0,002	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
0,572	0,005	0,011	0,001	<DL	<DL	<DL	<DL	<DL	<DL	0,001	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
0,862	0,039	0,094	0,011	0,045	<DL	<DL	<DL	<DL	0,005	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
0,765	0,036	0,112	0,010	0,046	0,007	<DL	<DL	<DL	0,007	0,002	0,006	<DL	0,006	<DL	<DL	<DL	<DL	0,002	<DL
0,663	0,004	0,010	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0,001	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
0,656	0,004	0,010	0,002	0,012	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	0,005	<DL

*Table continued*

Pb	Bi	Th	U	Au	Hg	Tl
0,044	0,002	0,001	0,028	0,010	0,027	0,027
<DL	<DL	0,003	<DL	0,014	<DL	<DL
<DL	<DL	<DL	<DL	<DL	<DL	<DL
0,226	<DL	<DL	<DL	0,022	<DL	<DL
<DL	<DL	<DL	<DL	<DL	<DL	<DL
<DL	<DL	0,004	0,088	<DL	<DL	<DL
<DL	<DL	0,002	0,078	0,012	<DL	<DL
<DL	<DL	<DL	0,074	<DL	<DL	<DL
<DL	<DL	<DL	0,081	<DL	<DL	<DL
<DL	<DL	<DL	0,030	<DL	<DL	<DL
<DL	<DL	0,003	0,029	<DL	<DL	<DL
<DL	<DL	<DL	0,031	<DL	<DL	<DL
<DL	<DL	<DL	<DL	<DL	<DL	<DL



## Appendix 3. Elemental analyses of lichens

Concentrations in mg/kg dry weight.

ID no.	Lab no.	Notes	Dry matter													
			%	Li	Be	Na	Mg	Al	P	S	K	Ca	Sc	Ti	V	Cr
Detection limit (DL)			0,3	0,32	142	2	26	4	ND	27	24	0,12	3,28	0,06	0,23	
53504	5564	Lichen Site 1	100	0,5	<DL	553	1585	1224	672	ND	1432	3473	0,44	76,23	2,50	2,36
53505	5565	Lichen Site 2	100	0,3	<DL	424	1366	761	727	ND	1974	7062	0,29	56,94	1,53	1,32
53506	5566	Lichen Site 3	100	0,3	<DL	447	1329	888	495	ND	1442	6259	0,24	40,31	1,11	1,18
53507	5567	Lichen Site 4	100	<DL	<DL	468	410	697	583	ND	1560	1070	0,18	35,32	1,29	0,94
53508	5568	Lichen Site 5	100	<DL	<DL	710	1376	958	475	ND	1514	7196	0,27	51,91	1,34	1,21
53509	5569	Lichen Site 6	100	0,3	<DL	369	1419	892	446	ND	1741	3396	0,32	74,61	2,12	1,85
53509	5570	Lichen Site 6	100	0,4	<DL	458	1554	1294	434	ND	1628	3815	0,40	81,56	3,15	2,63
53510	5571	Lichen Site 7	100	1,3	<DL	569	1414	2353	776	ND	2151	8113	0,80	162,34	6,78	4,74
53511	5572	Lichen Site 8	100	0,3	<DL	264	2397	918	421	ND	1026	12009	0,34	73,43	1,95	1,81
53512	5573	Lichen Site 9	100	0,4	<DL	399	1516	1182	610	ND	1692	27716	0,44	82,08	4,13	2,55
53513	5574	Lichen Site 10	100	<DL	<DL	391	1584	344	328	ND	1422	4673	<DL	24,15	0,63	0,39
53514	5575	Lichen Site 11	100	0,6	<DL	403	1300	2474	534	ND	1221	4574	0,76	133,68	5,47	4,62
53515	5576	Lichen Site 12	100	<DL	<DL	483	1064	799	754	ND	2004	2493	0,18	43,02	1,44	1,20
53516	5577	Lichen Site 13	100	<DL	<DL	394	1293	815	734	ND	1746	2417	0,27	59,03	2,13	1,94
<b>Certified reference material analysed with the samples</b>																
Tort-2	5623		94,2	<DL	<DL	8655	1123	<DL	10258	ND	8327	3217	<DL	<DL	1,74	0,61
Tort-2, calc to 100% d.m.				<DL	<DL	9187	1192	<DL	10890	ND	8840	3415	<DL	<DL	1,84	0,65
Certified value															1,64	0,77
Certified uncertainty															0,19	0,15
Dorm-4	5578		92,84	0,9	<DL	10512	866	1193	7615	ND	12496	2153	<DL	10,57	1,56	1,67
Dorm-4, calc to 100% d.m.				0,9	<DL	11323	932	1285	8202	ND	13460	2319	<DL	11,39	1,68	1,80
Certified value															1,87	
Certified uncertainty															0,16	

Table continued

Mn	Fe	Ni	Co	Cu	Zn	Ga	As	Se	Rb	Sr	Y	Zr	Nb	Mo	Ru	Pd	Ag
0,57	1	0,22	0,06	0,13	0,18	0,072	0,698	0,026	0,069	0,678	0,003	0,959	0,049	0,030	0,002	0,006	0,031
138,68	698	3,06	1,99	1,25	12,18	1,841	<DL	0,083	1,348	13,500	1,072	<DL	0,063	0,035	<DL	0,026	0,041
43,69	409	0,98	0,47	1,11	13,74	0,964	<DL	0,138	1,157	13,352	0,619	<DL	0,050	<DL	<DL	0,016	<DL
41,86	251	0,74	0,28	0,91	17,91	0,926	<DL	0,111	1,402	11,381	0,408	<DL	<DL	<DL	<DL	0,008	<DL
17,31	386	1,41	0,42	1,64	7,39	0,397	<DL	0,083	1,119	3,318	0,293	<DL	<DL	<DL	<DL	0,010	<DL
32,40	400	1,15	0,43	1,48	13,74	0,799	<DL	0,107	0,835	14,534	0,677	<DL	<DL	<DL	<DL	0,012	<DL
110,63	613	1,84	0,91	1,50	15,37	1,382	<DL	0,205	2,193	12,926	0,692	<DL	0,059	<DL	<DL	0,013	<DL
143,38	974	2,38	1,11	1,87	17,36	1,736	<DL	0,085	2,150	13,524	0,819	<DL	0,062	0,040	<DL	0,017	0,033
62,46	1848	3,33	1,31	4,77	22,93	2,424	<DL	0,064	1,922	26,421	1,772	2,772	<DL	0,058	<DL	0,014	0,037
45,05	597	1,64	0,48	1,63	22,63	0,819	<DL	0,083	2,409	13,853	0,574	<DL	<DL	<DL	<DL	0,011	<DL
23,17	1105	1,93	0,61	2,80	9,55	0,910	<DL	0,114	2,442	23,905	0,826	0,963	<DL	<DL	<DL	0,012	<DL
19,53	202	0,44	0,18	0,83	11,51	0,321	<DL	0,130	0,786	14,021	0,192	<DL	<DL	<DL	<DL	<DL	<DL
132,21	1525	4,06	2,11	2,49	12,83	2,319	<DL	0,097	2,091	10,810	1,351	1,396	0,052	0,052	<DL	0,006	<DL
151,45	438	1,14	0,43	1,29	16,83	0,621	<DL	0,049	1,173	6,319	0,303	<DL	<DL	<DL	<DL	0,007	<DL
70,79	716	1,78	0,75	1,60	20,46	0,973	<DL	0,109	0,869	8,921	0,443	<DL	0,060	<DL	<DL	<DL	<DL
12,46	109	2,31	0,47	99,09	170,03	0,142	18,526	4,971	2,428	37,846	0,434	<DL	<DL	0,917	<DL	0,020	6,555
13,23	116	2,46	0,50	105,19	180,50	0,150	19,666	5,277	2,578	40,177	0,461	<DL	<DL	0,974	<DL	0,021	6,958
13,60	105		0,51	106,00	180,00		21,600	5,630									
1,20	13		0,09	10,00	6,00		1,800	0,670									
2,67	317	3,57	0,22	14,60	46,27	0,810	5,862	3,057	5,423	8,865	0,150	<DL	<DL	0,233	<DL	<DL	<DL
2,87	342	3,85	0,23	15,72	49,84	0,872	6,314	3,292	5,841	9,548	0,161	<DL	<DL	0,251	<DL	<DL	<DL
	341			15,90	52,20		6,800	3,560									
	27			0,90	3,20		0,640	0,340									

Table continued

Cd	Sn	Sb	Te	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
0,033	0,027	0,044	0,031	0,020	0,387	0,002	0,005	0,001	0,002	0,002	0,000	0,002	0,000	0,001	0,001	0,001	0,001	0,001
0,081	0,030	<DL	<DL	0,049	12,257	1,797	4,179	0,403	1,530	0,273	0,065	0,275	0,036	0,211	0,039	0,103	0,013	0,082
0,118	0,029	<DL	<DL	0,035	6,574	1,142	2,435	0,257	0,967	0,182	0,036	0,184	0,023	0,118	0,024	0,065	0,008	0,049
0,110	<DL	<DL	<DL	0,049	6,262	0,857	1,748	0,200	0,774	0,121	0,032	0,122	0,017	0,084	0,015	0,047	0,006	0,033
0,067	<DL	<DL	<DL	<DL	2,322	0,481	1,064	0,120	0,460	0,087	0,019	0,084	0,011	0,062	0,013	0,031	0,005	0,025
0,109	0,062	<DL	<DL	0,021	4,986	0,956	2,130	0,230	0,926	0,179	0,041	0,171	0,023	0,127	0,025	0,065	0,009	0,051
0,076	0,048	<DL	<DL	0,053	9,625	1,281	2,776	0,296	1,127	0,191	0,045	0,191	0,024	0,148	0,028	0,074	0,009	0,056
0,084	0,059	<DL	<DL	0,060	11,379	1,570	3,415	0,367	1,432	0,258	0,057	0,227	0,030	0,165	0,034	0,083	0,011	0,073
0,169	0,079	<DL	<DL	0,086	13,875	2,799	5,990	0,687	2,697	0,519	0,118	0,510	0,064	0,387	0,072	0,195	0,026	0,148
0,115	0,038	<DL	<DL	0,040	4,765	0,995	2,083	0,236	0,874	0,166	0,041	0,159	0,023	0,117	0,023	0,066	0,007	0,055
<DL	0,039	<DL	<DL	0,056	4,378	0,976	2,113	0,236	0,985	0,197	0,051	0,202	0,030	0,174	0,033	0,089	0,011	0,075
0,066	<DL	<DL	<DL	<DL	2,460	0,326	0,676	0,074	0,307	0,057	0,013	0,057	0,006	0,043	0,008	0,023	0,003	0,018
0,147	0,072	<DL	<DL	0,067	12,820	2,643	5,529	0,604	2,328	0,414	0,098	0,364	0,052	0,289	0,053	0,142	0,020	0,117
0,253	0,061	<DL	<DL	<DL	4,329	0,639	1,371	0,149	0,596	0,099	0,023	0,097	0,012	0,068	0,012	0,033	0,005	0,025
0,097	0,046	<DL	<DL	<DL	6,061	0,918	2,067	0,217	0,808	0,150	0,034	0,131	0,018	0,102	0,019	0,042	0,006	0,038
24,915	0,057	<DL	<DL	<DL	1,558	1,441	1,382	0,187	0,752	0,112	0,020	0,094	0,012	0,059	0,011	0,026	0,002	0,016
26,449	0,061	<DL	<DL	<DL	1,654	1,530	1,467	0,198	0,798	0,119	0,022	0,100	0,013	0,063	0,012	0,028	0,003	0,017
26,700																		
0,600																		
0,273	0,057	<DL	<DL	0,059	4,647	0,544	1,233	0,153	0,627	0,112	0,023	0,104	0,012	0,061	0,009	0,016	0,002	0,010
0,294	0,062	<DL	<DL	0,063	5,005	0,586	1,328	0,165	0,675	0,121	0,025	0,112	0,013	0,066	0,009	0,017	0,002	0,010
0,306	0,056																	
0,015	0,010																	

Table continued

Lu	Hf	Ta	W	Re	Pt	Au	Hg	Tl	Pb	Bi	Th	U
0,000	0,032	0,240	0,015	0,001	0,004	0,072	0,014	0,031	0,037	0,001	0,002	0,012
0,012	<DL	<DL	<DL	<DL	0,007	<DL	0,041	<DL	0,786	0,006	0,240	0,049
0,008	<DL	<DL	<DL	<DL	<DL	<DL	0,034	<DL	0,517	0,005	0,173	0,025
0,005	<DL	<DL	<DL	<DL	<DL	<DL	0,029	<DL	0,547	0,002	0,139	0,022
0,004	<DL	<DL	<DL	<DL	0,004	<DL	0,037	<DL	0,268	0,006	0,085	0,017
0,008	<DL	<DL	<DL	<DL	<DL	<DL	0,039	<DL	0,575	0,004	0,133	0,024
0,007	<DL	<DL	<DL	<DL	<DL	<DL	0,041	<DL	0,709	0,007	0,143	0,033
0,008	<DL	<DL	<DL	<DL	<DL	<DL	0,039	<DL	0,976	0,008	0,210	0,054
0,022	0,095	<DL	<DL	<DL	<DL	<DL	0,051	<DL	1,266	0,009	0,474	0,085
0,006	<DL	<DL	<DL	0,001	<DL	<DL	0,043	<DL	0,567	0,004	0,153	0,040
0,011	0,038	<DL	<DL	<DL	<DL	<DL	0,026	<DL	0,557	0,005	0,195	0,054
0,003	<DL	<DL	<DL	<DL	<DL	<DL	0,026	<DL	0,205	0,002	0,039	<DL
0,016	0,053	<DL	<DL	<DL	<DL	<DL	0,045	<DL	1,139	0,014	0,401	0,114
0,004	<DL	<DL	<DL	<DL	<DL	<DL	0,036	<DL	0,392	0,003	0,085	0,022
0,005	<DL	<DL	<DL	<DL	<DL	<DL	0,040	<DL	0,551	0,005	0,130	0,037
0,002	<DL	<DL	<DL	0,009	<DL	<DL	0,283	<DL	0,400	0,012	0,010	0,061
0,002	<DL	<DL	<DL	0,009	<DL	<DL	0,300	<DL	0,424	0,013	0,010	0,065
							0,270		0,350			
							0,060		0,130			
0,002	<DL	<DL	0,064	<DL	<DL	<DL	0,364	<DL	0,343	0,009	0,168	0,052
0,002	<DL	<DL	0,069	<DL	<DL	<DL	0,392	<DL	0,369	0,010	0,181	0,056
							0,410		0,416			

## Appendix 4. Elemental analyses of soil and marine sediment

Concentrations in mg/kg dry weight.

ID no.	Lab. no.	Notes	Dry matter													
			%	Li	Be	Na	Mg	Al	P	S	K	Ca	Sc	Ti	V	Cr
Detection limit (DL)				1,0	2,95	2170	4	422	44	ND	282	104	0,29	42	0,41	3,60
53520	5548	Site 9	100	10,2	<DL	6588	9928	40520	771	ND	5405	21347	11,10	7491	243,24	103,14
53521	5549	Site 3C	100	10,8	<DL	8911	10057	33915	782	ND	6320	24394	11,23	8566	273,10	93,02
53522	5550	Site 3A	100	6,7	<DL	8298	8787	27548	830	ND	4679	23706	10,25	10436	322,42	95,05
53523	5551	Site 3B	100	10,5	<DL	11412	16016	37818	698	ND	3261	35102	15,91	8747	287,21	89,11
53524	5552	Site 2	100	22,7	<DL	7785	9472	56002	557	ND	9767	21243	12,11	6261	195,52	86,31
53525	5553	Site 1	100	11,5	<DL	8867	10202	35159	547	ND	8903	22514	11,80	6627	198,97	74,04
53526	5554	Site 10	100	6,3	<DL	7757	16572	29344	699	ND	4258	26055	12,17	8352	277,23	243,50
53526	5555	Site 10	100	6,8	<DL	8901	20300	33880	615	ND	6306	28957	13,35	8104	263,02	245,15
53527	5556	Site 11	100	5,4	<DL	7901	17387	27408	599	ND	4412	25224	11,86	8083	277,44	272,16
53528	5557	Site 8	100	33,1	<DL	5836	5119	47408	372	ND	7858	10924	10,91	4313	174,08	88,63
53529	5558	Site 4	100	27,8	<DL	22777	6193	37362	467	ND	5885	22941	6,88	2401	72,65	58,64
53530	5559	Site 7	100	28,9	<DL	3073	2716	31857	460	ND	1318	6683	5,59	1674	59,17	39,01
53531	5560	Site 6	100	24,8	<DL	2901	3436	34478	519	ND	2503	8865	9,30	2726	133,20	63,13
53532	5561	Site 5	100	33,8	<DL	4352	4556	48661	358	ND	6768	9837	9,18	2896	208,53	76,55
<b>Certified reference material analysed with the samples</b>																
Mess-4	-		99,35	55,5	<DL	9874	12730	63578	929	ND	20179	11623	10,42	3002	194,18	85,45
Mess-4, calc to 100% d.m.				55,9	<DL	9939	12813	63994	936	ND	20312	11699	10,49	3022	195,45	86,01
Certified value				65,3		12600	15800	79100	1040		23800	13100		3840	216,00	94,30
Certified uncertainty				6,8		800	1200	2000	160		1000	600		220	8,00	1,80
Hiss-1	5563		99,59	6,7	<DL	5635	672	7330	61	ND	3325	10570	2,01	706	6,96	22,72
Hiss-1, calc to 100% d.m.				6,7	<DL	5658	675	7360	61	ND	3339	10613	2,02	709	6,98	22,81
Certified value				2,8		3700	800	7300			3300	11400			6,80	(30)
Certified uncertainty				0,5		300	200	500			100	100			0,78	(6,8)
Pacs-2	5562		98,45	31,1	<DL	28407	12100	56676	834	ND	11294	17721	10,88	3558	126,50	84,35
Pacs-2	-		98,45	26,4	<DL	27561	11227	52942	762	ND	10477	17109	9,23	3324	117,62	80,40
Pacs-2, calc to 100% d.m.				31,6	<DL	28854	12291	57568	847	ND	11472	18000	11,06	3614	128,49	85,68
Pacs-2, calc to 100% d.m.				26,8	<DL	27995	11403	53776	774	ND	10642	17379	9,37	3377	119,47	81,66
Certified value				32,2		34500	14700	66200	1000		12400	19600			133,00	90,70
Certified uncertainty				2,0		1700	1300	3200	-		500	1800			5,00	4,60

Table continued

Table continued

Mn	Fe	Ni	Co	Cu	Zn	Ga	As	Se	Rb	Sr	Y	Zr	Nb	Mo	Ru	Pd	Ag
7,31	18	1,52	0,36	1,05	0,99	1,187	7,532	0,374	1,406	0,573	0,017	12,491	0,671	0,421	0,054	0,072	0,172
1040,57	41003	55,91	28,81	93,09	124,57	29,496	<DL	<DL	11,381	102,120	10,810	92,215	5,883	0,862	<DL	0,073	<DL
1022,49	43686	54,53	30,04	120,54	90,80	27,960	<DL	<DL	11,213	115,560	10,445	117,264	6,056	0,971	<DL	<DL	<DL
1157,56	44822	55,10	34,48	128,06	95,74	21,577	<DL	0,594	4,880	103,351	9,398	132,217	6,807	0,858	<DL	<DL	<DL
1090,37	43946	51,02	32,03	115,81	82,21	21,102	<DL	<DL	6,578	142,523	13,691	124,854	4,985	0,802	<DL	<DL	<DL
698,40	46112	44,89	23,18	72,65	68,45	45,314	<DL	0,537	27,348	131,458	10,736	107,816	6,622	1,144	<DL	0,079	<DL
741,27	45550	35,60	21,72	77,41	60,59	38,336	<DL	<DL	21,416	122,571	10,901	126,233	5,322	1,113	<DL	<DL	<DL
1063,40	45085	163,02	37,12	111,86	85,44	19,571	<DL	<DL	7,058	97,019	11,390	107,674	5,006	0,766	<DL	<DL	<DL
1052,48	41116	178,13	36,85	119,70	77,30	23,977	<DL	<DL	11,688	121,493	11,237	103,739	4,582	0,694	<DL	<DL	<DL
1043,28	58544	164,18	36,86	111,84	77,79	20,213	<DL	<DL	7,314	106,132	9,661	102,375	4,417	3,972	<DL	<DL	<DL
313,37	34569	40,50	13,31	82,48	53,99	46,998	<DL	<DL	28,401	119,658	8,502	163,856	6,028	1,397	<DL	<DL	<DL
178,84	16210	29,19	9,16	31,33	40,42	39,045	<DL	0,437	24,999	196,967	6,278	131,863	4,885	1,319	<DL	<DL	<DL
91,41	7093	26,77	7,88	18,15	384,78	56,641	<DL	<DL	7,680	212,629	5,281	137,723	5,207	0,811	<DL	<DL	<DL
235,95	18734	64,85	19,41	46,49	127,66	31,935	<DL	<DL	11,246	205,609	9,973	214,804	6,367	0,812	<DL	0,101	<DL
225,37	50144	43,94	12,23	39,47	53,26	42,467	<DL	<DL	28,964	140,886	9,982	149,123	5,942	0,988	<DL	<DL	<DL
271,34	34001	38,78	11,13	29,48	161,80	96,092	15,763	0,677	117,071	121,623	15,395	84,899	11,547	2,540	<DL	0,097	<DL
273,11	34223	39,03	11,21	29,67	162,85	96,720	15,866	0,681	117,837	122,419	15,496	85,455	11,623	2,557	<DL	0,097	<DL
298,00	37900	42,80	13,00	32,90	147,00			21,700		132,000							0,161
14,00	1600	1,60	0,80	1,80	6,00			2,800		8,000							0,024
72,94	2458	8,94	0,64	2,66	6,03	18,736	<DL	<DL	10,919	104,538	2,183	69,158	1,581	2,119	<DL	<DL	<DL
73,24	2468	8,98	0,64	2,67	6,06	18,813	<DL	<DL	10,964	104,969	2,192	69,443	1,587	2,128	<DL	<DL	<DL
66,10	2500	2,16	(0.65)	2,29	4,94		0,801	0,050		96,900							0,016
4,20	100	0,29	-	0,37	0,79		0,099	0,007		11,200							0,002
414,42	37875	40,23	10,76	284	340,42	73,632	24,601	0,622	40,511	259,133	11,179	95,529	7,560	5,471	<DL	0,109	0,910
387,21	35309	34,17	10,06	263	345,90	88,187	19,568	0,741	37,428	244,086	10,566	53,785	7,010	4,664	<DL	<DL	1,079
420,94	38471	40,86	10,93	288	345,78	74,791	24,988	0,632	41,149	263,212	11,355	97,033	7,679	5,557	<DL	0,111	0,925
393,31	35865	34,71	10,22	267	351,35	89,575	19,876	0,753	38,017	247,929	10,732	54,632	7,120	4,737	<DL	<DL	1,096
440,00	40900	39,50	11,50	310	364,00		26,200	0,920		276,000							1,220
19,00	600	2,30	0,30	12	23,00		1,500	0,220		30,000							0,140

Table continued

Cd	Sn	Sb	Te	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	
0,748	6,247	0,613	0,172	0,468	5,223	0,041	0,103	0,010	0,037	0,007	0,003	0,013	0,006	0,009	0,009	0,006	0,005	0,013	
<DL	<DL	<DL	<DL	<DL	148,026	11,226	25,016	3,215	13,956	3,309	0,953	3,301	0,494	2,986	0,595	1,538	0,214	1,260	
<DL	<DL	<DL	<DL	<DL	139,153	9,146	18,385	2,787	12,608	2,926	0,851	3,035	0,452	2,882	0,543	1,456	0,213	1,328	
<DL	<DL	<DL	<DL	<DL	69,515	5,799	13,824	2,144	10,152	2,518	0,889	2,964	0,440	2,616	0,487	1,420	0,172	1,152	
<DL	<DL	<DL	<DL	<DL	70,603	6,714	16,832	2,451	12,160	3,130	1,124	3,864	0,633	3,715	0,728	1,868	0,259	1,560	
<DL	<DL	0,632	<DL	<DL	1,014	312,709	14,903	33,749	4,024	16,532	3,550	1,012	3,719	0,531	3,142	0,604	1,584	0,198	1,321
<DL	<DL	0,762	<DL	<DL	285,109	9,897	21,388	3,098	13,442	3,327	1,023	3,511	0,503	3,015	0,588	1,577	0,225	1,303	
<DL	<DL	<DL	<DL	<DL	81,921	7,205	16,275	2,426	11,696	2,952	0,958	3,360	0,517	3,172	0,606	1,610	0,208	1,270	
<DL	<DL	<DL	<DL	<DL	132,132	6,103	14,329	2,202	10,814	2,714	0,963	3,304	0,514	3,100	0,626	1,750	0,228	1,505	
<DL	<DL	<DL	<DL	<DL	89,488	4,883	12,652	1,919	9,435	2,502	0,814	3,100	0,431	2,709	0,515	1,408	0,173	1,194	
<DL	<DL	1,535	<DL	<DL	1,171	332,119	16,621	34,974	4,097	16,022	2,858	0,836	2,923	0,391	2,272	0,454	1,201	0,198	1,172
<DL	<DL	1,194	<DL	<DL	0,768	296,730	14,812	29,866	3,396	12,962	2,432	0,596	2,208	0,264	1,662	0,312	0,871	0,116	0,811
<DL	<DL	1,238	<DL	<DL	0,524	528,847	16,856	36,009	3,866	14,206	2,473	0,546	2,247	0,301	1,564	0,268	0,772	0,103	0,663
<DL	<DL	1,209	0,231	0,539	219,382	14,590	30,477	3,452	13,232	2,513	0,652	2,448	0,343	2,312	0,463	1,292	0,168	1,180	
<DL	<DL	1,133	<DL	<DL	1,320	314,371	19,743	41,627	4,676	17,474	3,128	0,823	3,175	0,401	2,435	0,511	1,453	0,191	1,293
<DL	<DL	0,843	<DL	<DL	7,565	889,845	32,297	61,480	7,172	27,788	5,031	1,169	4,846	0,649	3,755	0,728	2,130	0,318	2,214
<DL	<DL	0,848	<DL	<DL	7,614	895,667	32,508	61,882	7,219	27,970	5,064	1,176	4,877	0,654	3,780	0,733	2,144	0,320	2,229
0,280	2,350	1,070																	
0,040	0,120	0,160																	
<DL	<DL	1,256	<DL	<DL	194,999	3,488	7,643	0,812	3,198	0,597	0,160	0,521	0,071	0,485	0,109	0,319	0,046	0,320	
<DL	<DL	1,261	<DL	<DL	195,801	3,502	7,675	0,815	3,211	0,600	0,161	0,523	0,072	0,487	0,109	0,320	0,046	0,321	
0,024																			
0,009																			
2,256	22,081	14,544	<DL	<DL	2,202	669,187	15,222	31,147	3,881	15,843	3,405	0,931	3,361	0,457	2,838	0,572	1,556	0,230	1,408
1,820	24,892	12,826	<DL	<DL	1,905	881,034	15,469	31,508	3,838	15,114	3,139	0,945	3,207	0,467	2,749	0,531	1,604	0,222	1,450
2,292	22,429	14,773	<DL	<DL	2,237	679,723	15,462	31,638	3,942	16,092	3,459	0,946	3,414	0,464	2,883	0,581	1,581	0,233	1,430
1,849	25,284	13,028	<DL	<DL	1,935	894,905	15,712	32,004	3,899	15,352	3,189	0,960	3,257	0,475	2,793	0,540	1,629	0,225	1,473
2,110	19,800																		
0,150	2,500																		

Table continued

Lu	Hf	Ta	W	Re	Pt	Au	Hg	Tl	Pb	Bi	Th	U
0,004	0,410	2,997	0,200	0,007	0,054	1,007	0,273	0,185	0,767	0,017	0,026	0,077
0,194	3,391	<DL	0,223	<DL	<DL	<DL	<DL	<DL	7,640	0,045	1,637	0,801
0,179	4,325	<DL	<DL	<DL	<DL	<DL	<DL	<DL	9,515	0,022	1,340	0,630
0,155	4,944	<DL	<DL	<DL	<DL	<DL	<DL	<DL	3,865	<DL	0,703	0,397
0,230	4,465	<DL	<DL	<DL	<DL	<DL	<DL	<DL	6,379	<DL	0,920	0,378
0,189	3,896	<DL	0,243	<DL	<DL	<DL	<DL	0,224	9,793	0,058	3,616	1,321
0,186	4,454	<DL	<DL	<DL	<DL	<DL	<DL	<DL	6,125	<DL	1,632	0,610
0,198	4,009	<DL	<DL	<DL	<DL	<DL	<DL	<DL	4,099	0,025	0,959	0,394
0,212	3,736	<DL	<DL	<DL	<DL	<DL	<DL	<DL	4,366	0,021	0,688	0,295
0,184	3,809	<DL	0,341	<DL	<DL	<DL	<DL	<DL	3,325	<DL	0,744	0,290
0,171	5,080	<DL	0,398	<DL	<DL	<DL	<DL	0,185	14,578	0,050	4,690	1,395
0,123	3,872	<DL	0,295	<DL	<DL	<DL	<DL	<DL	13,888	0,047	3,026	1,096
0,094	3,512	<DL	0,296	<DL	<DL	<DL	<DL	<DL	217,353	0,039	3,863	0,988
0,173	5,495	<DL	0,452	<DL	<DL	<DL	<DL	<DL	9,470	0,033	3,306	1,266
0,200	4,538	<DL	0,367	<DL	<DL	<DL	<DL	<DL	12,681	0,042	6,207	1,727
0,330	3,394	<DL	1,231	<DL	<DL	<DL	<DL	0,650	20,577	0,381	9,702	3,163
0,332	3,416	<DL	1,239	<DL	<DL	<DL	<DL	0,654	20,711	0,384	9,766	3,184
								0,850	21,500			3,400
								0,100	1,200			0,400
0,052	2,210	<DL	<DL	<DL	<DL	<DL	<DL	<DL	5,033	<DL	0,790	0,294
0,052	2,219	<DL	<DL	<DL	<DL	<DL	<DL	<DL	5,054	<DL	0,793	0,295
									3,130			
									0,400			
0,223	3,312	<DL	1,258	<DL	<DL	<DL	2,820	0,495	181,483	0,321	3,849	2,478
0,221	2,067	<DL	1,092	<DL	<DL	<DL	2,647	0,497	175,748	0,356	3,989	2,380
0,227	3,364	<DL	1,278	<DL	<DL	<DL	2,864	0,503	184,341	0,326	3,909	2,517
0,224	2,099	<DL	1,109	<DL	<DL	<DL	2,689	0,505	178,515	0,361	4,051	2,417
							3,040		183,000			
							0,200		8,000			



## Appendix 5. PAH analyses of soil and marine sediment

Concentrations in µg/kg dry weight.

Sample name	Site 9	Site 3C	Site 3A	Site 3B	Site 2	Site 1	Site 10	Site 11	Site 8
ID no.	53520	53521	53522	53523	53524	53525	53526	53527	53528
MITO prøve no.	2015-14528	2015-14529	2015-14530	2015-14531	2015-14532	2015-14533	2015-14534	2015-14535	2015-14536
Sample type	beach sed.	beach sed.	beach sed.	beach sed.	beach sed.	beach sed.	beach sed.	beach sed.	soil with coal
Naphthalene	6,4	15,7	1,5	2,2	27,3	1,2	1,7	21,8	150,1
2-methylnaphthalene	7,2	35,0	3,1	3,0	42,5	1,9	3,5	11,4	299,5
1-methylnaphthalene	8,4	22,6	2,6	2,5	32,9	2,0	3,2	10,0	350,9
C2-naphthalenes	83,6	68,4	18,4	24,7	266,4	15,0	32,0	14,9	2527,6
C3-naphthalenes	152,5	39,4	17,4	10,8	188,5	10,0	28,4	8,4	4797,8
Acenaphthylene	0,4	0,9	<0,1	0,2	0,3	<0,1	0,5	0,2	28,9
Acenaphthene	24,5	3,0	1,3	24,9	4,2	<0,2	30,5	<0,2	23,3
Fluorene	24,2	<1	<1	34,7	<1	<1	53,9	<1	34,8
Dibenzothiophene	1,3	4,1	<0,5	<0,5	2,6	0,2	1,0	<0,5	15,3
C1-dibenzothiophenes	n.a.	4,0	<0,5	0,9	8,6	<0,5	n.a.	<0,5	n.a.
C2-dibenzothiophenes	<2	<2	<2	<2	4,0	<2	<2	<2	40,4
Phenanthrene	30,9	59,4	10,1	7,7	56,6	9,0	3,2	2,1	223,4
C1-phenanthrenes	35,1	30,0	10,4	14,6	65,5	10,1	7,8	<0,1	480,6
C2-phenanthrenes	46,6	19,9	8,1	6,1	60,9	5,9	<5	<5	221,1
C3-phenanthrenes	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Anthracene	4,7	17,5	n.a.	n.a.	10,5	n.a.	n.a.	n.a.	21,9
Benzo(a)fluorene	30,0	13,1	7,2	7,2	29,0	11,4	4,1	1,9	163,7
Fluoranthene	26,9	73,3	7,3	8,3	50,2	10,2	7,0	2,0	398,7
Pyrene	27,0	44,9	5,7	6,6	38,8	6,5	3,0	1,5	275,8
1-methylpyrene	7,3	4,0	2,1	1,1	7,2	1,5	0,6	0,3	47,8
Benzo(a)anthracene	18,2	26,4	7,2	3,2	18,8	4,5	2,3	1,5	57,3
Chrysene/Triphenylene	17,0	18,1	7,9	2,3	17,3	4,9	1,1	0,6	53,0
Benzo(b+j+k)fluoranthenes	21,4	22,0	5,7	5,3	32,3	8,4	3,3	2,4	171,8
Benzo(e)pyrene	5,8	4,9	1,1	1,1	6,5	1,6	<1	<1	31,3
Benzo(a)pyrene	5,4	3,4	<3	<3	<3	<3	<3	<3	19,7
Perylene	434,5	34,5	5,5	7,4	23,2	4,1	15,2	19,9	271,2
Indeno(1.2.3-cd)pyrene	7,0	4,4	1,5	1,4	8,5	3,3	<0,5	0,7	36,5
Benzo(ghi)perylene	5,0	2,7	<2	<2	5,2	<2	<2	<2	21,4
Dibenzo(ah)anthracene	<1	<1	<1	<1	1,1	<1	<1	<1	<1
Sum of all 29 PAHs	1031	572	124	176	1009	112	202	100	10764
% Loss On Ignition (LOI)	2,84	1,48	0,84	1,07	2,87	0,80	1,02	0,83	61,71

n.a.: Could not be quantified due to interference.

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## A CHEMICAL ENVIRONMENTAL SCREENING STUDY AT THE FORMER QULLISSAT COAL MINE, WEST GREENLAND IN 2015

The former Qullissat Coal Mine on the Disko Island in West Greenland operated between 1924 and 1972 and this study by DCE is the first to investigate the environment at Qullissat. The study was considered a screening study with the aim to identify possible significant pollution sources originating from remains at the mine site and mining town. Also, the study investigated the opportunities for studying effects of chronic exposure to e.g. PAHs (Polycyclic Aromatic Hydrocarbons) or other potential pollutants in the area.

The study was conducted in August 2015 in connection with background studies for a Strategic Environmental Impact Assessment for the Disko-Nuusuaq area. During the study, a range of environmental samples was collected including surface soil, freshwater, lichens and marine sediment. Most samples were collected near the mine site and some samples were collected near the Qullissat mining town situated approximately 5 km to the north of the mine. All environmental samples were analysed for 63 elements and selected samples of surface soil and sediment were analysed for a total of 29 PAH compounds at DCE's accredited laboratory. Elevated concentrations of PAHs and some heavy metals were measured locally. However, based on the results from the analyses, it is DCE's assessment that there is no indication of any significant contamination of the surrounding environment at Qullissat neither from the Qullissat mine site nor from the Qullissat town. Also, due to the relatively low levels of PAHs and other pollutants found in the study, DCE does not find that the area has obvious research potential with regards to studying effects of chronic exposure. It shall be noted, however, that this conclusion is based on relatively few samples and sample types taken during a short period of time. For potential future and more comprehensive studies in the area, it could be relevant also to include off-shore sediment samples from deeper waters, marine biota and water samples taken at different times of the year.