Publications of the Ministry of Economic Affairs and Employment
Enterprises • 2020:57

Study on Arctic Mining in Greenland

Ministry of Economic Affairs and Employment of Finland

Publications of the Ministry of Economic Affairs and Employment 2020:57

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Ministry of Economic Affairs and Employment of Finland, Helsinki 2020

Ministry of Economic Affairs and Employment of Finland

ISBN PDF: 978-952-327-567-6

Layout: Government Administration Unit, Publications

Helsinki 2020

Description sheet

Published by	Ministry of Economic Affairs and Employment		6 November 2020
Authors	Simon M. Thaarup, Majken D. Poulsen, Kisser Thorsøe, Jakob K. Keiding		
Title of publication	Study on Arctic Mining in Greenland		
Series and publication number	Publications of the Ministry of Economic Affairs and Employment 2020:57		
Subject	Enterprises		
ISBN PDF	978-952-327-567-6	**ISSN (PDF)**	1797-3562
Website address (URN)	http://urn.fi/URN:ISBN:978-952-327-567-6		
Pages	132	**Language**	English
Keywords	means of livelihood, enterprises, mining industry, arctic region		

Abstract

The Arctic region has a huge business potential and offers many possibilities, but to some extent, Arctic markets are not very familiar to most companies. It is therefore important to provide information about the markets, their characteristics and the operating context. This report gives an overview of the mining market and context in Greenland.

Mining activities have so far been limited in Greenland considering the potential. A relatively weak record of mining activity appears to contrast with the metal endowment and existence of numerous mineral occurrences and several world class mineral deposits.

Mineral exploration and mining in Greenland often occur in remote areas, usually far from existing infrastructure. This necessitates expensive transportation and establishment infrastructure. The remoteness, harsh Arctic climate and rugged terrain are negative factors often resulting in extra expenditures compared to most other jurisdictions.

The many deep fjords in Greenland offer excellent opportunities for deep-sea port and shipping capacity. The social license to operate is in general very favourable in Greenland, and an ambitious new mineral strategy can be instrumental to attract new investments to mining in Greenland. Currently, Greenland is undergoing a phase of rapid development, and large government-funded infrastructure projects are in progress including new airports.

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Publisher	Ministry of Economic Affairs and Employment
Distributed by/ publication sales	Electronic version: julkaisut.valtioneuvosto.fi Publication sales: vnjulkaisumyynti.fi

Kuvailulehti

Julkaisija	Työ- ja elinkeinoministeriö		6.11.2020
Tekijät	Simon M. Thaarup, Majken D. Poulsen, Kisser Thorsøe, Jakob K. Keiding		
Julkaisun nimi	Tutkimus: Arktinen kaivostoiminta Grönlannissa		
Julkaisusarjan nimi ja numero	Työ- ja elinkeinoministeriön julkaisuja 2020:57		
Teema	Yritykset		
ISBN PDF	978-952-327-567-6	**ISSN PDF**	1797-3562
URN-osoite	http://urn.fi/URN:ISBN:978-952-327-567-6		
Sivumäärä	132	**Kieli**	englanti
Asiasanat	elinkeinot, yritykset, kaivosteollisuus, arktinen alue		

Tiivistelmä

Arktisella alueella on valtavaa liiketoimintapotentiaalia ja se tarjoaa runsaasti mahdollisuuksia, mutta arktiset markkinat ovat jossain määrin melko vieraita useimmille yrityksille. Siksi on tärkeää tarjota tietoa näistä markkinoista ja niiden erityispiirteistä ja toimintaympäristöstä. Tämä raportti esittää yleiskatsauksen Grönlannin kaivostoimintamarkkinoihin ja toimintaympäristöön.

Toistaiseksi kaivostoiminta on Grönlannissa ollut melko rajallista sen potentiaaliin nähden. Kaivostoiminnan varsin alhainen taso näyttää olevan ristiriidassa metallivarantojen sekä lukuisien mineraaliesiintymien ja useiden maailmanluokan mineraalikerrostumien kanssa.

Grönlannissa mineraalien louhinta ja kaivaminen tapahtuu usein syrjäisillä alueilla, jotka yleensä ovat kaukana olemassa olevasta infrastruktuurista. Tämä vaatii kallista kuljetus - ja perustamisinfrastruktuuria. Syrjäisyys, ankara arktinen ilmasto ja vaikeakulkuinen maasto ovat kielteisiä tekijöitä, joista aiheutuu ylimääräisiä kustannuksia useimpiin muihin alueisiin verrattuna.

Grönlannin lukuisat vuonot tarjoavat loistavia mahdollisuuksia syväsatama- ja merenkulkukapasiteetille. Toiminnan yhteiskunnallinen hyväksyttävyys (social license to operate SLO) on ylipäätään varsin suotuisia Grönlannissa ja kunnianhimoinen uusi mineraalistrategia saattaa merkittävästi edistää uusien investointien houkuttelemista Grönlannin kaivostoimintaan Grönlannissa on parhaillaan meneillään nopean kehityksen vaihe ja käynnissä on suuria hallituksen rahoittamia hankkeita koskien mm. uusien lentokenttien rakentamista.

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Kustantaja	Työ- ja elinkeinoministeriö
Julkaisun jakaja/myynti	Sähköinen versio: julkaisut.valtioneuvosto.fi Julkaisumyynti: vnjulkaisumyynti.fi

Presentationsblad

Utgivare	Arbets- och näringsministeriet		6.11.2020
Författare	Simon M. Thaarup, Majken D. Poulsen, Kisser Thorsøe, Jakob K. Keiding		
Publikationens titel	Study on Arctic Mining in Greenland (Studie om gruvdrift i Arktis)		
Publikationsseriens namn och nummer	Arbets- och näringsministeriets publikationer 2020:57		
Tema	Företag		
ISBN PDF	978-952-327-567-6	**ISSN PDF**	1797-3562
URN-adress	http://urn.fi/URN:ISBN:978-952-327-567-6		
Sidantal	132	**Språk**	engelska
Nyckelord	näringsgrenar, företag, gruvindustri, arktiska regionen		

Referat

Den arktiska regionen har en enorm affärspotential och erbjuder många möjligheter, men samtidigt är de arktiska marknaderna inte så välkända för de flesta företag. Därför är det viktigt att förbättra informationen om marknaderna, vad som kännetecknar dem och deras verksamhetsmiljö. Denna rapport ger en översikt över gruvmarknaden och dess kontext på Grönland.

Gruvverksamheten har hittills varit begränsad på Grönland, i förhållande till potentialen. En relativt låg nivå av gruvverksamhet verkar stå i kontrast till naturresurserna i form av metall, talrika mineralförekomster och flera mineralfyndigheter i världsklass.

Mineralprospektering och mineralbrytning på Grönland försiggår ofta i avlägsna områden, i regel långt ifrån befintlig infrastruktur. Det gör att det krävs dyra transporter och etablering av infrastruktur. Det avlägsna läget, det stränga arktiska klimatet och den oländiga terrängen är negativa faktorer som ofta resulterar i extrakostnader jämfört med de flesta andra jurisdiktioner.

De många djupa fjordarna på Grönland erbjuder utomordentliga möjligheter till djuphavshamnar och fraktverksamhet. Den sociala licensen att bedriva verksamhet är i allmänhet gynnsam på Grönland och en ambitiös ny mineralstrategi kan i hög grad bidra till att locka nya investeringar till gruvdriften på Grönland. För närvarande genomgår Grönland en fas av snabb utveckling och stora statligt finansierade infrastrukturprojekt pågår, inklusive nya flygplatser.

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Förläggare	Arbets- och näringsministeriet
Distribution/ beställningar	Elektronisk version: julkaisut.valtioneuvosto.fi Beställningar: vnjulkaisumyynti.fi

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PREFACE

Mining industry interest in the Arctic region is growing for multiple reasons: new economic possibilities, climate change and the warming of the Arctic are making the region more accessible. Simultaneously these things make the region more vulnerable.

The new economic possibilities are various. They range from community infrastructure and digital public services to extraction of natural resources and opening of new northern trade routes. To seize these opportunities, understanding of the possibilities and value chains is required, e.g. the operating context and practical challenges encountered by organizations operating in the Arctic.

In this context, the Center for Minerals and Materials (MiMa) at the Geological Survey of Denmark and Greenland conducted a 'Study on Arctic mining in Greenland' for the Arctic Economic Dialogue project. This study provides mining and environment context of Greenland, and describes challenges and opportunities encountered during past mineral exploration and mining operations in Greenland.

Greenland in general are described in chapter 1. In chapter 2 the legal framework, challenges and opportunities related to mining in Greenland are described. Three advanced mining projects in Greenland are investigated. The case studies were chosen to reflect an active open pit mine (chapter 3), a potential large scale mine (chapter 0) and a historic underground mine with potential for reopening (chapter 5). A summary is provided in chapter 6.

This study is part of the Arctic Economic Dialogue (AED) project initiated by the Ministry of Economic Affairs and Employment of Finland. The project aims to provide a foundation for the new opportunities in the Arctic by shedding light on: 1) the context in which companies and organisations operate in the Arctic region, 2) the challenges that organisations encounter in their everyday work in the Arctic region, and 3) the wider ecosystem that supports and develops operations in the Arctic.

One goal is to familiarize Finland's exploration and mining industry stakeholders with Greenland's exploration and mining environment and ecosystem. This can pave the way for partnerships between Greenland and Finland and benefit the development of exploration and sustainable mining industry in both countries. A crucial starting point is to learn about the context, opportunities and challenges in Greenland: to engage in best practice comparisons and discussions and create a forum for companies and authorities to meet. This study is aimed to help to accomplish these goals.

The Arctic Economic Dialogue project has previously investigated other relevant arctic business areas. As a working method, the AED project has organized seminars and discussions around industries and topics like arctic mining, fish farming, tourism and northern sea routes. The aim of these seminars has been to bring together arctic experts to share and discuss the practical difficulties they encounter. As a result, common development agendas, future collaborations and new partnerships can be shaped to find solutions for the challenges recognized.

Unfortunately, due to on-going Covid-19 situation the project could not be fully executed but mutual future collaboration is still strongly envisaged.

The study was completed in the end of May 2020 and describes the situation up till that moment.

1 Greenland in general

1.1 Geography and Climate

Greenland, also known as Kalaallit Nunaat, is the largest island on Earth with an area of 2,166,086 km^2. It is located close to the North Pole between Iceland and Canada and is the 12th largest country in the world. 80% of the area is covered by ice, primarily the Inland Ice, which is up to 3 km thick. The ice-free area is 410,449 km^2 and is approx. the size of Norway. The distance from Cape Farewell in the South at latitude 59°50' to the Coffee Club Island in the North at latitude 83°40' is 2,670 km and it is 1,050 km from the widest point east to west (Statistics Greenland 2019). Deep fjords, high mountains and many small islands dominate Greenland, which is reflected in its 44,087 km long coastline.

Towns and settlements are located along the coast, mainly on the West and Southwest coast of Greenland; there are only two towns and five settlements on the East coast (Figure 1).

Figure 1. Map of Greenland with towns, a few settlements, airports, and airstrips. Modified from Kolb et al. (2016).

The southernmost part of Greenland is at the same latitude as Stockholm and Oslo, however the climate in Greenland is generally colder. The milder climate in Scandinavia is due to the warm oceanic currents from the North Atlantic Current that runs along the coast of Norway and influences the air temperature. However, the current shifts into deeper water and colder temperatures towards Greenland in the East Greenland Current and West Greenland Current, affecting the climate in Greenland (Figure 2).

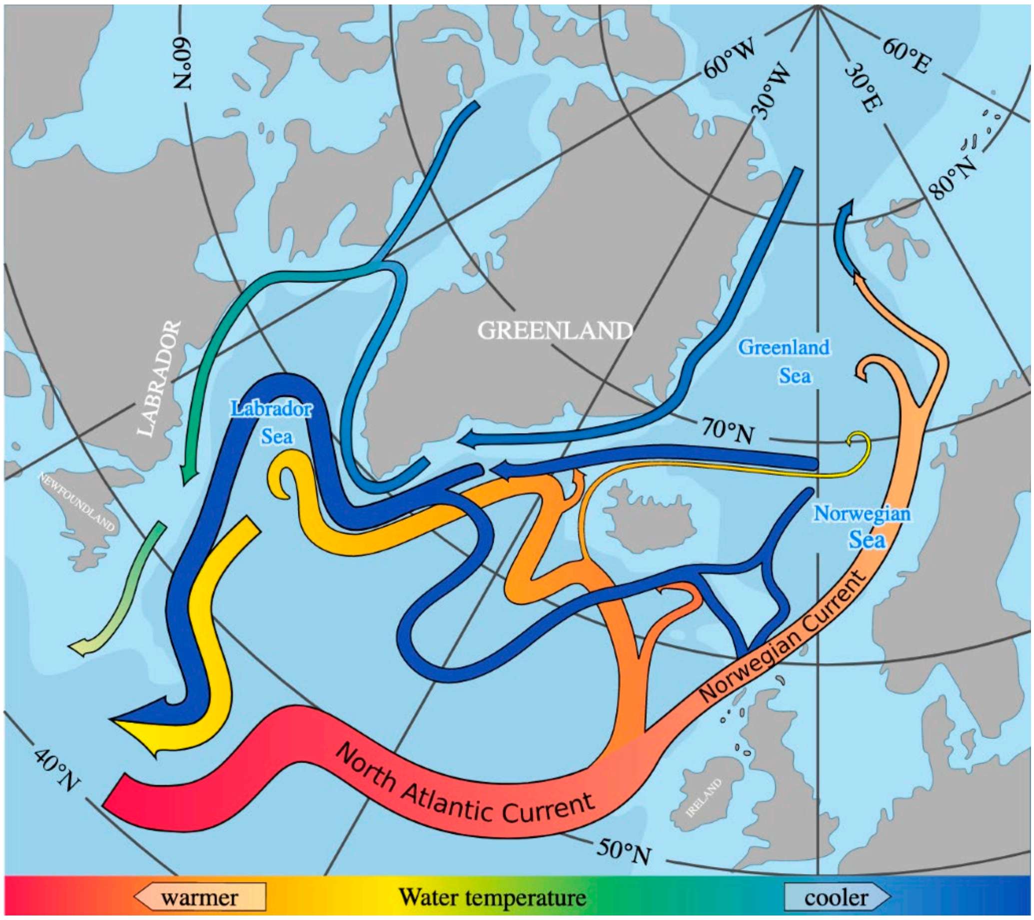

Figure 2. Schematic overview of the movement of the North Atlantic Current to North-western Europe and Greenland. Modified from Goddard Space Flight Center (2004).

The climate is Arctic to Subarctic with maximum temperatures around 10 °C in the summer (June-Aug) and around -10 °C (Oct-Apr.) during winter. Local variations occur due to Greenland's large size, as well as differences between coastal and inland climates in the deep fjords (see Table 1). During winter, parts of the sea ice, the fjords and the bays freeze. Along the East coast of Greenland there is pack ice in winter to spring, that often moves with the East Greenland Current towards Nanortalik in South Greenland. This can cause challenges for sailing in the area in early summer, because the pack ice can close the available sailing routes to towns and settlements.

Table 1. Weather data for several locations in Greenland. Annual values for the period 1981-2010. Source: Danish Meteorological Institute (2020).

Location	Annual precipitation (mm)	Average maximum temperature (°C)	Average temperature (°C)	Average minimum temperature (°C)
Pituffik	132	–	–10.8	–
Upernavik	–	–3.1	–7.8	–8.1
Ilulissat	–	–0.7	–4.3	–7.4
Nuuk	781.6	1.3	–1.4	–3.7
Narsarsuaq	650.7	5	1.0	–3
Qaqortoq	986.5	–	0.8	–
Tasiilaq	892.5	2.2	–0.9	–4
Ittoqqortoormiit	387.5	–2	–5.6	–8.6
Danmarkshavn	178.1	–8.2	–11.5	–15.1

The Arctic Circle runs through Greenland south of Sisimiut in West Greenland and north of Tasiilaq in East Greenland. North of the Arctic Circle, there is midnight sun (summer) and polar nights (winter) for varying periods of the year depending on the latitude.

1.2 History and politics

1.2.1 Before the Home Rule

During the last 4,500 years, Greenland has experienced intervals with populations of Arctic peoples (Saqqaq, Independence I, Independence II, Dorset and Thule cultures) migrating to Greenland from Arctic Canada and Alaska. The current, indigenous Greenlanders are descendants from the last migrants of the Thule culture (Gulløv et al. 2004). The indigenous Greenlanders call themselves Kalaallit and are related to the Inuit of Arctic Canada and Alaska (Raghavan et al. 2014; Moltke et al. 2015).

European influence is part of Greenland's history; the Norse (985–1400s), Dutch and Spanish whalers (1500–1700s), Danish-Norwegian missionaries (1721–1900s), the Moravian cChurch (1730–1900) and the American military presence and personnel from the 1940s an onwards. The Norse lived in Greenland from year 985 until the 1400s (Gulløv et al. 2004). There are several former settlements on the west coast showing their presence; these ruins are cultural heritage (http://lovgivning.gl/lov?rid={A8872163-73B9-4A97-91DF-872C10E4F15D}).

In 1721, the Norwegian priest Hans Egede came to Greenland to christen, and trade with, the Greenlanders (Amdrup et al. 1921; Bobé 1941). The Royal Greenland Trading Company (KGH) had exclusive rights on trade from 1774 to 1950 (Tejsen 1977; Sørensen 2012). The Moravian and Lutheran missionaries in Greenland established missionary stations (Kleivan 1983; Toft 2016) which became centres for towns and larger settlements (Sejersen 2010). Before this period, the Greenlandic people had more spread settlement pattern in smaller communities (Kleivan 1984; Sejersen 2010). From 1721, Greenland was ruled from Denmark-Norway. From 1814 to 1953 Greenland was a Danish colony and from 1953 to 1979 a Danish county (Fægteborg 2013; Gulløv et al. 2017).

The Fishing industry in Greenland began in the 1920s where Danes and Faroes fishing cutters were permitted on the banks of West Greenland. However, there was a demand from the Greenlander themselves, that any stations had to be away from the Greenlandic settlements. This resulted in the stations Ravns Storø and Færingehavn (Kangerluarsoruseq) (Mattox 1973) that is now abandoned.

During the 'Modernisation Period' (1945–1979) Danish workers and fishers from the Faroe Islands came to Greenland and interacted with the local population (Sørensen 2007, 2019). Today, many people from Denmark and the Faroe Islands continue to work in Greenland, but there are also large communities from Thailand, the Philippines and other countries working in Greenland. In 2019, 5,092 out of 56,081 (10.5%) of the inhabitants were born outside Greenland (Statistics Greenland 2019). The official language is Greenlandic, but Danish is still used in many places for everyday communication with and within public administration.

The Modernisation Period of Greenland changed the indigenous populations livelihoods from hunters and fishers to primarily fishers and employees (Heinrich 2012; Gulløv et al. 2017). There is still a strong connection to the hunting traditions in Greenland and the hunter and fisher organisations, such as the Association of Fishers and Hunters in Greenland (KNAPK).

1.2.2 History of politics in Greenland from 1970 to present

During the 1970s, the Greenlanders scepticism towards Denmark increased: some of the Greenlanders wanted more self-determination whilst some wanted full independence from Denmark (Loukacheva 2007, Dahl 2010). The path towards an independent Greenland is ongoing, and work was done on a draft constitution that could apply to a future independent Greenland (Forfatningskommissionen) (Grønlandsudvalget, 2016–17). From 2014 to 2017, the Reconciliation Commission (Forsoningskommissionen) studied the future effects of decolonization. The main goal was to increase knowledge of social issues and awareness of the past (Therkildsen et al. 2017).

Before 1979, many decisions about Greenland were taken in Denmark, but the increasing desire for independence flourished, and on May 1, 1979, the Greenland Home Rule came into effect (Brøsted & Gulløv 1977; Dahl 1986; Sørensen 2007). On June 21, 2009, the Greenland Self-Government Act replaced the Home Rule and allowed additional fields of responsibility to be transferred to the Self-Government authorities. As part of the Self-Government Act full authority of mineral resources was overtaken by Greenland from January 1, 2010, but besides this only a few fields of responsibility have been transferred. A few are excluded from being transferred, e.g. foreign affairs and defence (Statsministeriet. LOV nr 473 af 12/06/2009). Greenland has partial autonomy whilst at the same time is part of the Kingdom of Denmark as the Faroe Islands (https://um.dk/da/udenrigspolitik/lande-og-regioner/rigsfaellesskabet/), yet neither the Faroe Islands nor Greenland are part of the European Union. Queen Margrethe II of Denmark remains head of state and appoints a high commissioner in Greenland (Rigsombudsmand).

With the Home Rule in 1979 Greenland formed its own parliament, Inatsisartut, with 31 members (Sørensen 2007). The parliament appoints a premier who is head of the Government of Greenland, Naalakkersuisut.

Since the first election in 1979, the Siumut party (social democrats) has been in power continuously except from 2009–2013 when Inuit Atagatigiit was in power. In general, many voters in Greenland are very loyal to their parties, especially to Siumut that has many voters among the hunting and fishing people (personal comm. R. Leander 2020).

There are three classic parties in Greenland; Siumut, Inuit Atagatigiit and Atassut (personal comm. R. Leander 2020). All were founded before the election to the first parliament in Greenland in 1979 and the aim to represent Greenland in the Danish Parliament; see later.

Siumut was founded in 1977 as a classic social democratic party (https://siumut.gl/da/). There have almost continuously been internal differences of opinion within the party. Currently there are differences about when Greenland should become fully independent from Denmark. There will be internal discussions in the summer 2020 about who will become chair of the party (personal comm. R. Leander 2020).

Several splinter parties have been founded from Siumut. Currently three splinter parties are present in Inatsisartut: Nunatta Qitornai (founded 2018) (Pedersen 2017; Fievé & Petersen 2018), Partii Naleraq (founded in 2014) (Ritzau 2014) and Demokraatit (founded in 2002). Nunatta Qitornai and Partii Naleraq are very pro-independence.

Demokraatit (Greenland's Liberal Party) primarily started due to financial accountability issues (the founder was excluded from Siumut because he did not vote for additional allocation for a project) and financial accountability requirements were one of the party's main objectives when founded (personal comm. R. Leander 2020).

Inuit Atagatigiit (IA) was founded in 1978 as a classic left-wing party. Some of the older generations in IA find the direction set by the younger generation too social-liberal (personal comm. R. Leander 2020). The objective is to achieve financial and national independence for Greenland (https://ia.gl/).

Atassut was founded in 1978 as a classic conservative party. At times, they have shifted more to the left compared to their original ideology (personal comm. R. Leander 2020). Now they call themselves liberal conservative (https://atassut.gl/da/).

Suleqatigiissitsisut/Samarbejdspartiet is a splinter party from Demokraatit and was founded in 2018. They want Greenland to remain as part of the Kingdom of Denmark and focus on social policy (https://sulesam.gl/).

In order to understand the political situation in Greenland there are two axes to consider regarding the political dimensions: the usual left and right axis, but also the sovereignty versus association axis, where association refers to be a part of the Kingdom of Denmark. There are many opinions about if, and when, Greenland should become independent. These opinions are between the parties, internally within the parties and in the population (personal comm. R. Leander 2020).

Kim Kielsen from Siumut has been premier of Greenland since 2014. He was re-elected in April 2018. At present, seven parties are represented in Inatsisartut (number of members in brackets): Atassut (2), Demokraatit (6), Inuit Atagatigiit (8), Nunatta Qitornai (1), Partii Naleraq (3), Siumut (10), Suleqatigiissitsisut/Samarbejdspartiet (1) (https://ina.gl/).

Since the last election in April 2018 there have been more than 10 changes in Naalakkersuisut due to parties leaving the coalition, ministers disagreeing with the premier etc. Since Partii Naleraq left the coalition in September 2018, it has been the first minority government since the 1980s (personal comm. R. Leander 2020).

The Ministry of Mineral Resources has had different areas of responsibilities but is currently a ministry for mineral resources only. From 2013 to 2020, the position as Minister of Mineral Resources changed seven times; one of the ministers have held the position twice. The term length as Minster of Mineral Resources has ranged between 5 and 19 months, with an average of 13 months (Naalakkersuisut 2020); see Table 2.

Table 2. The ministers for Mineral Resources from 2013 to 2020.

Minister	Period	Months	Title/Resort Area	Political Party
J.E. Kirkegaard	Apr. 2013–Oct. 2014	19	Labour and Mineral Resources	Siumut
A. Uldum	Dec. 2014–Feb. 2016	14	Finances and Mineral Resources	Democrats
R.V. Evaldsen	Feb. 2016–Oct. 2016	8	Finances and Mineral Resources	Democrats
M.B. Egede	Oct. 2016–May 2018	19	Mineral Resources	Inuit Ataqatigiit
V. Qujaukitsoq	May 2018–Oct. 2018	5	Mineral Resources, Labour, Constitutional Issues and Independence	Nunatta Qitornai
E. Jensen	Oct. 2018–Nov. 2019	13	Mineral Resources and Labour	Siumut
V. Qujaukitsoq	Nov. 2019–present	6+	Finances and Mineral Resources	Nunatta Qitornai

Since June 2019 Mette Frederiksen (the Social Democratic) has been the Prime Minister of Denmark. There are 179 members in the Danish Parliament. Two are elected by Greenland and two by the Faroe Islands. Aaja Chemnitz Larsen from Inuit Ataqatigiit was first elected to the Danish Parliament in 2015 and was re-elected in 2019. Aki-Mathilda Høegh-Dam (Siumut) has been the other Greenland member of the Danish Parliament since the election in June 2019 (Schultz-Lorentzen 2019).

The Joint Arctic Command is part of the Danish Defence. The main tasks are surveillance and enforcement of sovereignty, the military defence of Greenland and Search and Rescue (Lindquist 2019).

Thule Air Base is an American military base in Greenland. The international airports in Kangerlussuaq and Narsarsuaq are former American bases (Sørensen 2006; Jensen et al. 2013).

There are several cooperation agreements between Greenland-Denmark and the United States of America. The first official agreement with the United States relating to Greenland was a defence agreement from 1951. In 2004, an amendment to this agreement was signed in Igaliku in South Greenland. This agreement confirmed the former agreement of economic and technical assistance between Greenland and US, as well as environmental cooperation (https://www.retsinformation.dk/eli/ltc/2005/6).

During the summer of 2019, Greenland received a great deal of international attention because the American president, Donald Trump, stated that he was interested in buying Greenland from Denmark. Following that statement, the Danish Prime Minister Mette Frederiksen proclaimed that buying Greenland is not possible. The Government of

Greenland replied that Greenland is 'open for business, not for sale' (Gronholt-Pedersen 2019). The Ministry of Foreign Affairs of Denmark announced in December 2019 that they had accepted the United States plan to open a consulate in Greenland (Ritzau 2019). On February 19, 2020 the Trump administration proposed to set aside 587,000 US$ for a consulate in Nuuk (Ritzau 2020a) and on April 23, 2020 it was reported that 12 million US$ are to be used for American consulting projects and advisory assistance for primarily tourism, mining industry and education in Greenland (Ritzau 2020b).

A milestone for Greenland (and Denmark) occurred on September 13, 2007 when the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) came into action, which includes the Inuit's of Greenland (Inuit Circumpolar Council 2007; Barten & Mortensen 2016). Greenland is now an autonomous territory within the Unity of the Realm in Denmark (also referred to as The Kingdom of Denmark). While Greenlanders are a minority group in Denmark, they constitute most of Greenland's population. Article 25–30 in UNDRIP concerns land territories and resources, which are relevant for the mining sector. In Greenland you cannot own the land, it is all Greenlanders land, which is different compared to for instance Canada and Alaska. Article 25–30 in UNDRIP discuss guidelines for usage of land, territories and resources, and includes the rights to the land areas for the indigenous peoples, compensation for re-establishment of the land after use, transparency in decision-making about the use of land areas, protection of the environment, and consultation before decisions about the use of the land areas (United Nations 2008).

Article 26 states;

1. *Indigenous peoples have the right to the lands, territories and resources which they have traditionally owned, occupied or otherwise used or acquired.*
2. *Indigenous peoples have the right to own, use, develop and control the lands, territories and resources that they possess by reason of traditional ownership or other traditional occupation or use, as well as those which they have otherwise acquired.*
3. *States shall give legal recognition and protection to these lands, territories and resources. Such recognition shall be conducted with due respect to the customs, traditions and land tenure systems of the indigenous peoples concerned. (United Nations 2008).*

The allocation of land usage for projects, such as mining projects, must go through public hearings. However, there is a generally positive attitude towards mining in Greenland (Agneman 2018). The Indigenous peoples of Greenland have great knowledge of their land areas and oceans and there is a general wish to be more involved in the projects (Dahl & Hansen 2019).

In 1980 the non-government organisation 'Inuit Circumpolar Council' (ICC) was founded in Nuuk. They represent indigenous peoples of Alaska, Canada, Greenland and the Inuits of Tjukotka (Russia). The aim of the council was to draft an 'Inuit Arctic Policy', and to strengthen unity among the Arctic Inuit, and fight for the rights and interests of the Inuit in national, regional and international contexts, as well as strengthen the Inuit culture (Wilson & Smith 2011). Some of ICC's key issues are to ensure the given right in UNDRIP are followed. This includes concerns about environmental issues, transparency in decision-making and, importantly, consultation with the indigenous people in the affected areas before important decisions are made. An example of this was when Naalakkersuisut released the Greenlandic Oil Strategy 2020–2024. ICC criticised the strategy for not complying with the given rights in UNDRIP, regarding making important decisions with people living in the adjacent areas that could be affected by the new petroleum exploration activities and environmental concerns in the area (Kristiansen & Møller 2020). There have also been some objections from local people, who wanted to have rights to collect gemstones (such as tugtupite and rubies) within a certain mineral exploration/exploitation license area (Lowe & Doyle 2013), to which they have none in the current legal framework.

1.3 Demography

The population in Greenland was 56,081 on January 1, 2020 (Statistics Greenland 2019). Sixty percent of the population lives in the five largest towns in Greenland: Nuuk, Sisimiut, Ilulissat, Aasiaat and Qaqortoq.

Greenland have five municipalities (Figure 3):

- Kommune Kujalleq (Kujalleq Municipality)
- Kommuneqarfik Sermersooq (Sermersooq Municipality)
- Qeqqata Kommunia (Qeqqata Municipality)
- Kommune Qeqertalik (Qeqertalik Municipality)
- Avannaata Kommunia (Avannaata Municipality)

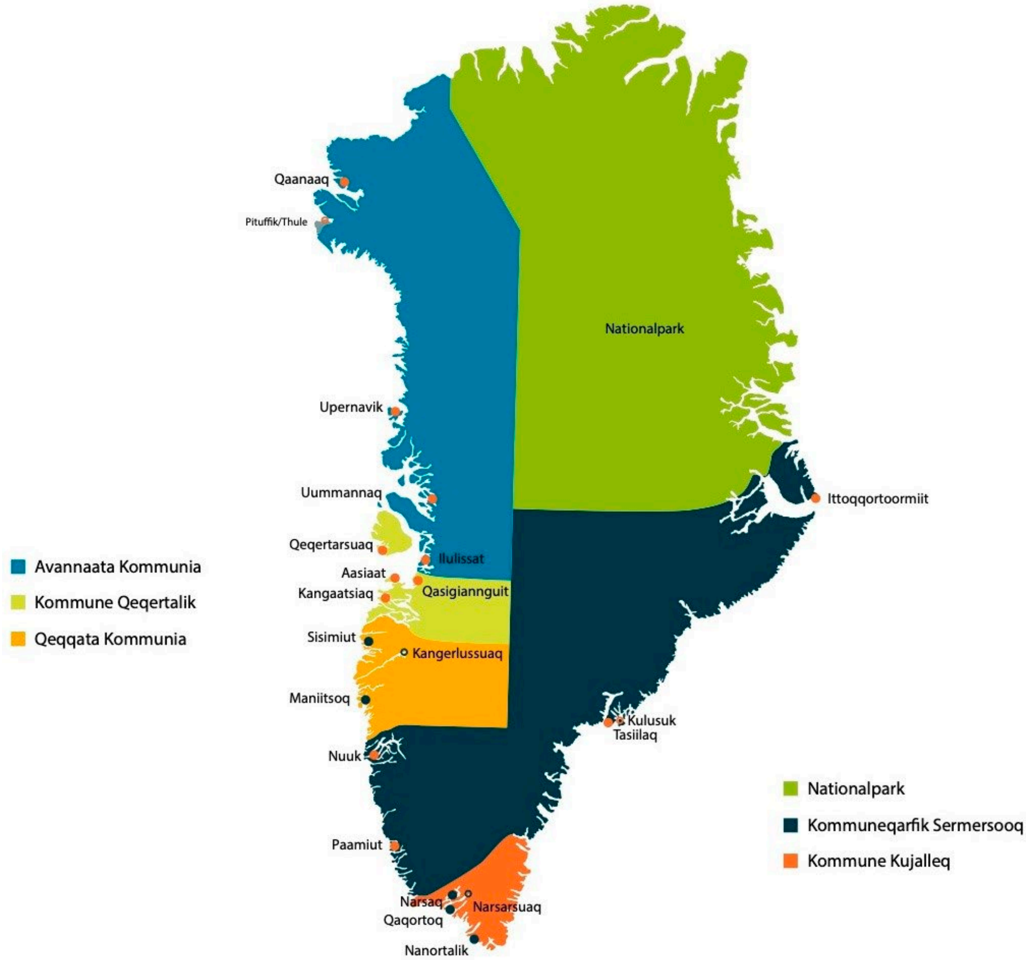

Figure 3. Locations of the municipalities, national park, towns, a few settlements and Thule Air Base. Source: Statistic Greenland (2019).

In 1977, one in four Greenlanders lived in settlements. In 2015 that number had decreased to one in seven (Kernn-Jespersen 2016; Statistics Greenland 2019).

1.4 Infrastructure

Greenland has 17 towns and 60 settlements (www.stat.gl). None are connected by roads, making the transport infrastructure in Greenland quite different from other countries.

A 130 km road connecting Sisimiut and Kangerlussuaq is in public consultation[1], making it the first potential road connecting two inhabited areas.

1.4.1 Transportation

As there are no roads between towns and settlements in Greenland, the main transport options are by plane, helicopter and boats. In some areas, sailing is not possible during winter and spring, and often snow mobiles or, to a lesser extent, dog sledges are used. Shuttle boats offer passenger transport from Qaqortoq in South Greenland to Ilulissat in Disko Bay for most of the year. Between East and West, regular passenger air traffic is available from Nuuk in West Greenland to Tasiilaq in East Greenland, or alternatively individual sailing routes via Prins Christian Sund in South Greenland.

Passenger transport between towns and settlements has since January 2017 been performed by companies that in 2016 won a service contract with the Government of Greenland. Disko Line A/S (www.diskoline.gl), a small shipping company, are responsible for transportation in Disko Bay, Mid Greenland and South Greenland (https://naalakkersuisut.gl/~/media/Nanoq/Files/Attached%20Files/Infrastruktur/Baggrund%20servicekontrakter%20DK.pdf). For some areas this service is only every second week.

Air Greenland, Greenland's national airline, links Greenland and Denmark (www.airgreenland.com). Air Greenland is responsible for passenger transport to and around Qaanaaq, Upernavik, Uummannaq and Tasiilaq, and between Ittoqqortoormiit and Constable Point in East Greenland (https://naalakkersuisut.gl/~/media/Nanoq/Files/Attached%20Files/Infrastruktur/Baggrund%20servicekontrakter%20DK.pdf). For some towns, there is only one flight per week; for some settlements, the air service is every second week. There are international flights from Copenhagen in Denmark to Kangerlussuaq in Greenland[2] with Air Greenland from October to May, normally four times per week. From June to September, there are five to eight weekly flights. Most of the year there is two weekly departures between Nuuk and Reykjavik in Iceland with Air Greenland. From mid-June until the beginning of September, Air Greenland has two weekly flights between Copenhagen and Narsarsuaq.

1 By February 2020

2 This information is from March 1, 2020 – before Covid-19.

Air Iceland Connect (http://www.airicelandconnect.com), is also flying shuttle to and from Greenland. Air Iceland Connect usually fly[3]:

- Reykjavik-Nuuk: Year-round – 2–3 weekly flights
- Reykjavik-Narsarsuaq: June to September – 2 weekly flights
- Reykjavik-Ilulissat: Year-round – 2–6 weekly flights
- Reykjavik-Kulusuk: Year-round – 1–7 weekly flights
- Reykjavik-Constable Point: August to September – 2 weekly flights

Norlandair (www.norlandair.is) won the 2016 traffic contract between Iceland and Constable Point in East Greenland. There are usually two flights per week.

Besides the mentioned civil airports and heliports/helipads there are several gravel airstrips around Greenland where smaller planes can land.

Mittarfeqarfiit, Greenland Airports, is responsible for air transportation of passengers and cargo in Greenland, and operates and maintains 13 civil airports and 43 heliports/helipads (https://www.mit.gl/en/).

Royal Arctic Line, www.ral.gl, have exclusive concession for the transportation of all sea cargo to and from Greenland and between the domestic towns and settlements. There are several conditions associated with the concession regarding frequency, capacity and security of supply for all the towns on both the East Coast and the West Coast.

1.4.2 Electricity, water and heat

The national company Nukissorfiit, www.nukissiorfiit.gl, is responsible for supplying electricity, drinking water and energy to all towns and settlements in Greenland.

Greenland has many rivers, lakes and glaciers. Therefore, hydroelectric power is one of the main energy sources in Greenland. Renewable energy from hydroelectric power and heat from waste incineration plants accounts for more than 70% of the total electricity and heat consumption (Nukissiorfiit 2018). Data for the five hydroelectric power plants in Greenland, supplying six towns with electricity, can be seen in Table 3.

3 This information is from March 1, 2020 – before Covid-19.

Table 3. Names of supplied towns, the years that production started and the capacity of Greenland's 5 hydroelectric power plants. Source: https://www.nukissiorfiit.gl/vedvarende-energi/vandkraft/.

Name	Supplied towns	Production start	Capacity (MW)
Buksefjorden	Nuuk	1993	45.0
Tasiilaq	Tasiilaq	2004	1.2
Qorlortorsuaq	Narsaq and Qaqortoq	2008	7.6
Sisimiut	Sisimiut	2010	15.0
Paakitsoq	Ilulissat	2013	22.5

Electricity from solar panels and windmills only constitutes a small part of the renewable energy. There are test sites for alternative energy sources in Greenland.

The rest of the energy is powered by fossil fuel (gas oil) (Statistics Greenland 2019), which is used as back-up for the hydroelectric power and in towns and settlements without hydroelectric power.

1.4.3 Telecommunication

The national telecom company Tele-Post A/S (www.telel.gl) is responsible for communication to all towns and settlements. From Nanortalik in South Greenland to Uummannaq in North Greenland the fundamental telecommunication infrastructure consists of a digital radio link. North and East Greenland are covered by satellites, both in terms of domestic and foreign telecommunications.

In March 2009 a marine cable for faster internet connection entered service. The cable runs from Newfoundland in Canada to Nuuk and continues to Qaqortoq and Iceland. In October 2017 an extension of the cable to Aasiaat was finalized (www.tele.gl).

1.5 Economy

Greenland receives a block grant, or subsidy, of 3.4 billion DKK from Denmark every year (2019 total). As part of the agreement of Self-Government in 2009, it was decided to lock the amount of subsidy, only adjusted to Danish inflation. This means that even if further fields of responsibility are transferred from Denmark to Greenland, the block grant does not rise. If the income from the oil and mining industry rises to above 75 million DKK (2009 value) special rules apply (https://ina.gl/media/2526795/d-inatsisartut-website-inatsisartutgl-media-10562-selvstyreloven-web-a4-dk.pdf). The politicians in Greenland aim to reduce Greenland's dependency on the subsidy from Denmark.

Besides the Danish subsidy, Greenland's main income stream is from the fishing industry, which accounts for up to 90% of exported goods and 12.6% of the GDP. As shown in Figure 4 the public sector in Greenland is substantial: almost 30% of GDP and 40% of jobs (Statistics Greenland 2019). From 2014 to 2017 the GDP increased by 2.5% on average, primarily driven by growth in the fishing, wholesale and retail, and construction industries (Statistics Greenland 2019). The GDP value generated from the extraction of raw materials is less than 0.1%. This is expected to rise in the coming years due to mining activities and mineral exploration.

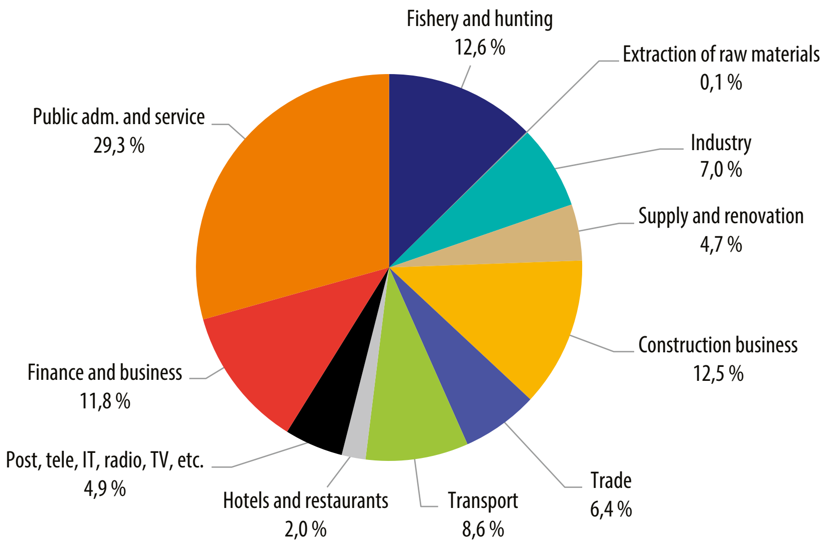

Figure 4. 2018 GDP by sector in 2010-values. Source: Statistics Greenland (2018).

1.6 Biodiversity

The biodiversity of species generally decreases as you move from the tropics towards the poles. The biodiversity in Greenland is thus sparse compared to countries further south. Within Greenland the biodiversity also declines as you move from south to north.

There are ca. 500 species of vascular plants, ca. 600 species of mosses, ca. 950 species of lichens, ca. 1,600 species of fungi (Born & Böcher 1999; Jensen et al. 1999) and ca. 1,200 species of insects (Böcher et al. 2015) in Greenland. Only seven species of terrestrial mammals are found in Greenland; caribou (*Rangifer tarandus*) and muskox (*Ovibos moschatus*), collared lemming (*Dicrostonyx groenlandicus*), arctic fox (*Vulpes lagopus*), arctic hare (*Lepus arcticus*), polar wolf (*Canis lupus arctos*) and stoat (*Mustela erminea*) (Born & Böcher 1999; Jensen et al. 1999). The Greenland sledge dog (*Canis lupus familiaris borealis*) came to Greenland with the Thule culture a thousand years ago (Ameen et al.

2019). In South Greenland non-native species including sheep, horses, chicken, goats, and cattle are part of the agricultural landscape.

There are a variety of birds and seabirds in Greenland (Born & Böcher 1999; Jensen et al. 1999).

The sea is rich in fish and invertebrates, especially along West Greenland. As with the terrestrial biodiversity the marine diversity is also sparse in the Arctic compared to the corresponding at lower latitudes. Approximately 260 species of fish are known from the waters surrounding Greenland (Møller et al. 2010). Marine mammals include seals (seven species including walrus) (Rosing-Asvid 2010), whales (11 species) and polar bears (*Ursus maritimus*) (Born & Böcher 1999). Many Greenlanders are still dependent on marine and terrestrial mammals for human consumption. Some have hunting and fishing as a profession (ca. 2,100 people in 2018) (Statistics Greenland 2019), while others hunt and fish for recreational purposes (ca. 5,100 people in 2018) (Statistics Greenland 2019).

Most vascular plants, mammals, and birds are included in the 'Greenland Red List' (Boertmann & Bay 2018). The red list includes information on vulnerability of individual species following the criteria by the International Union for Conservation of Nature. The list is available on the website of the Greenland Institute of Natural Resources' (https://natur.gl/raadgivning/roedliste/[4]).

1.7 Protected areas

There are three types of protected areas in Greenland according to Greenlandic legislation:

- National parks
- Nature reserves
- (Other) protected areas

The (other) protected areas are typically protected due to: a) the area contains historic monuments; b) the areas have special significance to animals, vegetation or birds, e.g. Ramsar Sites; or c) because they are UNESCO World Heritage sites. According to Naalakkersuisut there is in practice no difference for how the three types of protected areas are managed. In recent years there has been movement away from using the

4 Only the Danish version is updated.

designations of 'national park' and 'nature reserve' for new areas (for more information om protected areas see Due & Ingerslev 2000).

Protected areas are shown on the Greenland map portal http://naturemap.eamra.gl/ as well as information related to mineral resource activities. Some of the protected areas in Greenland in 2020 are listed here:

- The nature reserve in Melville Bay is protected due to a unique significance for narwhales that seek food close to the ice (http://lovgivning.gl/lov?rid={40C78374-0645-48B8-A846-1A50E9333611})
- Kitsissunnguit – Gønne Ejland – a Ramsar Area (http://lovgivning.gl/lov?rid={33A08E57-CE09-47A7-867A-9497651EC5F8})
- Ilulissat Ice Fjord is protected and included on UNESCO's World Heritage list because of a unique landscape and cultural monuments (https://whc.unesco.org/en/list/1149/)
- Arnangarnup Qoorua – Paradise Valley is a protected area because of its scenic beauty, and its cultural and scientific importance (http://lovgivning.gl/lov?rid={41CE08BB-2D47-4716-A02F-7A7436E7152B})
- An area around Arctic Station, Qeqertarsuaq, is protected for scientific purposes (http://docs.nunagis.gl/natur/KundgorelseomfredningafarealetomkringArktiskStationiGodhavn.pdf)
- The National Park in North and East Greenland is the world's largest national park, (http://lovgivning.gl/lov?rid={1FC9C99F-1BE0-494A-A663-4CA19ABEAF62})
- Austmannadalen is protected with the aim of preserving the area's appearance and historical relics (http://lovgivning.gl/lov?rid={5E3C668D-BEA7-4472-A8D9-520EEEF6C931})
- The island of Akilia is protected because of the geological formations on the island, which are of scientific importance (http://lovgivning.gl/lov?rid={AFDF9DF6-5515-41AE-9518-DFEE557829A9})
- An area outside the urban area in Ivittuut and Kangilinnguit is protected because of the landscape, historical relics. It includes the Ikaite columns in the Ikka Fjord. (http://lovgivning.gl/lov?rid={80A814FF-16FE-42E1-BCF0-6F0E7ED70768})
- Qinnguadalen, Qinngeq Kujalleq, Lake Tasersuaq is protected because of a unique vegetation in the area (http://lovgivning.gl/lov?rid={C6C459A4-3064-49AA-95B7-0A5C6E17D97E})
- Part of Uunartoq Island is protected with the aim of protecting the island's unique thermal springs (http://lovgivning.gl/lov?rid={2D76CCFA-8263-472C-BCB8-38257850596F})

- Klosterdalen is protected on conservation of forest and vegetation http://docs.nunagis.gl/sektorplan/Nalunaerutit_klosterdalen.doc
- Kujataa Greenland – 'Norse and Inuit Farming at the Edge of the Ice Cap' area is on the UNESCO World Heritage list. The area is protected because of Norse and Inuit farming history (https://whc.unesco.org/en/list/1536/).
- Aasivissuit Nipisat – 'Inuit Hunting Ground between Ice and Sea' is on the UNESCO World Heritage list, and is protected due to cultural traces for more than 4,200 years and extraordinary hunting sites (https://whc.unesco.org/en/list/1557/)
- Håbets Ø (Hope Colony) is protected for preservation of ancient monument (Hans Egedes first settlement) (https://da.nka.gl/fileadmin/user_upload/Haabets_OE.pdf).
- Uunnartorsuaq/Engelskmandens Havn is protected for preservation of unique geothermal springs (https://tidsskrift.dk/geografisktidsskrift/article/view/49592/63636)

The regulations and laws on protected areas can be found at the official homepage of Greenland legislation: www.lovgivning.gl[5]. In most of the regulations and laws about the protected areas, it is stated that mineral exploration/exploitation activities are excluded, but under special circumstances and if certain criteria are met, it is possible to get a mineral exploration/exploitation license.

1.8 Geology and mineral resources

Greenland consists of many geological environments such as orogens, islands arcs, sedimentary basins, magmatic intrusions and large igneous provinces. Most of these have potential for different mineral resources. The geological history spans 3.8 Ga, from the oldest rocks near Isua in West Greenland, through Proterozoic sedimentary basins in North-East Greenland and younger volcanic rocks associated with the opening of North Atlantic, to glacial sediments of the Quaternary period. This report only provides a short introduction to the geological history of Greenland, its mineral resources and a brief review of Greenland's mining history. Descriptions of mineral deposits and scientific reviews of economic geology of Greenland is beyond the scope of this study. Interested

5 Most of the descriptions are only in Danish and Greenlandic, some pertinent legislation can be found here: https://naalakkersuisut.gl/en/About-government-of-greenland/Travel-activities-in-remote-parts-of-Greenland/Legislation

readers are referred to Nielsen (1973, 1976), Henriksen (2006), Henriksen et al. (2009) and Kolb et al. (2015, 2016) for more in-depth description of these topics.

1.8.1 The crystalline basement and orogenic belts in Greenland

The majority of Greenland consists of crystalline basement with an Archaean block (3.8–2.5 Ga) and Palaeoproterozoic (2.5–1.6 Ga) rocks comprising almost 70% of the island (geological timescale is shown in Figure 5, geological map in Figure 6 and Figure 10). The Archaean mainly consists of two major cratons; the North Atlantic Craton (NAC) in the south and the Rae Craton in the north. The NAC in Greenland was once several smaller separate continental blocks that have amalgamated through convergence, subduction and continent-continent collisions (Escher & Watt 1976; Henriksen et al. 2009; Windley & Garde 2009). The NAC has been age-correlated to Labrador in Canada and the Lewisian Complex in northwest Scotland (St.-Onge et al. 2009; Kolb 2014;). The NAC consists of many different rock types such as orthogneisses, paragneisses, and magmatic rocks such as anorthosites, granites, amphibolites, kimberlites, carbonitites, and ultramafic rocks (McGregor et al. 1991; McGregor 1993; Friend & Nutman 2001, 2005; Nutman et al. 2004; Hollis et al. 2005a, b; Windley & Garde 2009; Keulen et al. 2011).

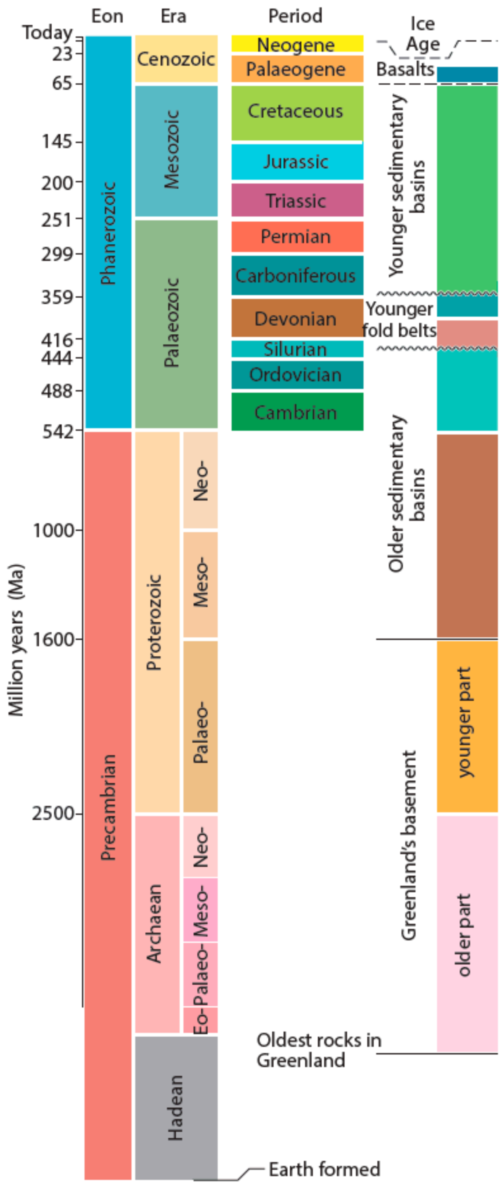

Figure 5. Geological timescale. Source: GEUS.

The Nuuk area contains the oldest rocks in Greenland (Baadsgaard et al. 1986; Nutman 1986; Frei & Rosing 2001), and they are among the oldest rocks in the world. The Isukasia area with rocks up to 3.8 Ga is where the Isua Banded Iron Formation (BIF) occur, a large iron deposit (see Chapter 4).

Younger gneisses in the crystalline basement range in age between 3.2 and 2.8 Ga (Escher & Watt 1976; Friend & Nutman 2001; Næraa et al. 2008; Henriksen et al. 2009; Keulen et al. 2014). A major magmatic event in the Nuuk to Maniitsoq area occurred at 2.56 Ga where granitic sheets and pegmatites intruded the older rocks (Friend et al. 1985; Nutman et al. 2010; Næraa et al. 2014). Later multiple Proterozoic and Palaeogene mafic dykes have intruded the basement in Greenland (Piper & Stearn 1977; Nielsen 1987; Mayborn & Lesher 2006; Nilsson et al. 2013, 2019; Bartels et al. 2015; Larsen et al. 2015).

The Ketilidian Orogen was formed by subduction of an oceanic plate under South Greenland at 1.85–1.72 Ga, at the southern edge of the Archaean NAC. Kilometre-thick layers of siltstone, mudstone, grey wacke and claystone from the ocean floor were metamorphosed into metasediments and were variably migmatised (partly melted). A large mass of intrusive igneous rock crystallized in the crust and formed the Julianehaab Batholith (1.87–1.79 Ga). Late granitic melts crystallized (1.75–1.72 Ga) south of the Julianehaab Batholith in the Ketildian Orogen (Garde et al. 2002, 2011).

Proterozoic crystalline basements in Greenland are found in the Ketilidian Orogen in South Greenland (Garde et al. 2002, 2011), the Nagssugtoqidian Orogen in southern West Greenland, across East Greenland and in the orogenic belts of central and northern West Greenland (Kalsbeek et al. 1987, 1993; van Gool et al. 2002; Kolb 2014).

Several hundred million years later a failed rift system produced the Gardar Province within the Ketilidian Orogen region in South Greenland at 1.3–1.14 Ga (Upton 2003; Sørensen 2006), where the crust was subjected to extensional stress, which created continental rifting, faulting, sedimentary deposits, and intrusion of basaltic and alkaline rocks. The Gardar Province contains several large rare earth element (REE) deposits (see section 1.8.6, speciality metals). The Gardar Province period has in more recent work been divided into two periods with igneous activity at 1.3–1.2 Ga and 1.18–1.14 Ga (Sørensen 2006; Upton 2013; Bartels et al. 2015). The Gardar period included major rifting of the continental crust with major dyke swarm with both a WNW–ESE to nearly NE–SW trending directions, where some of the dykes can be traced all the way to Canada.

In the early rifting phase, a few large magmatic intrusions crystallized in the area from Narsaq towards Arsuk, the Grønnedal-Ika Complex, the syenite Igaliko Complex near Narsarsuaq and the Cryolite-bearing Ivigtut granite (Piper et al. 1999; Hamala et al. 2003; Upton et al. 2003; Henriksen et al. 2009). It is estimated that the intrusions were crystallized in the crust in 2–5 km's depth and hence the 2–5 km of crusts has been removed and today the intrusions are exposed on the surface. The late phase from 1.18–1.14 Ga includes the Ilímaussaq Intrusion (Sørensen 2001, 2006), the Klokken syenite pluton and Paatusoq Syenite intrusion in South East Greenland (Upton et al. 2003; Upton 2013).

Orogenic belts

The orogenic belts in central and northern West Greenland include the Nagssugtoqidian Orogen, the Rinkian Orogen, and the Inglefield Land Mobile Belt (van Gool et al. 2002; Crocott & McCaffrey 2017). The Nagssugtoqidian Orogen was contemporary with the Rinkian Orogen and was formed by continent-continent collision between Rae Craton in the North and the NAC around 1.9–1.8 Ga (Kalsbeek et al. 1993; Sanborn-Barrie et al. 2017). The Rae Craton in Greenland is correlated to Rae Craton in Canada (St-Onge et al. 2009; Kolb 2014) in the area from Kangerlussuaq to Disko Bay area. The orogen is inferred to continue under the Inland Ice to the Tasiilaq area in South East Greenland (Figure 6) (Kalsbeek et al. 1993; Nutman et al. 2008; Kolb 2014). The Palaeoproterozoic orogens consist primarily of folded Archaean gneisses and younger sedimentary rocks (Escher & Watt 1976; Henriksen et al., 2009).

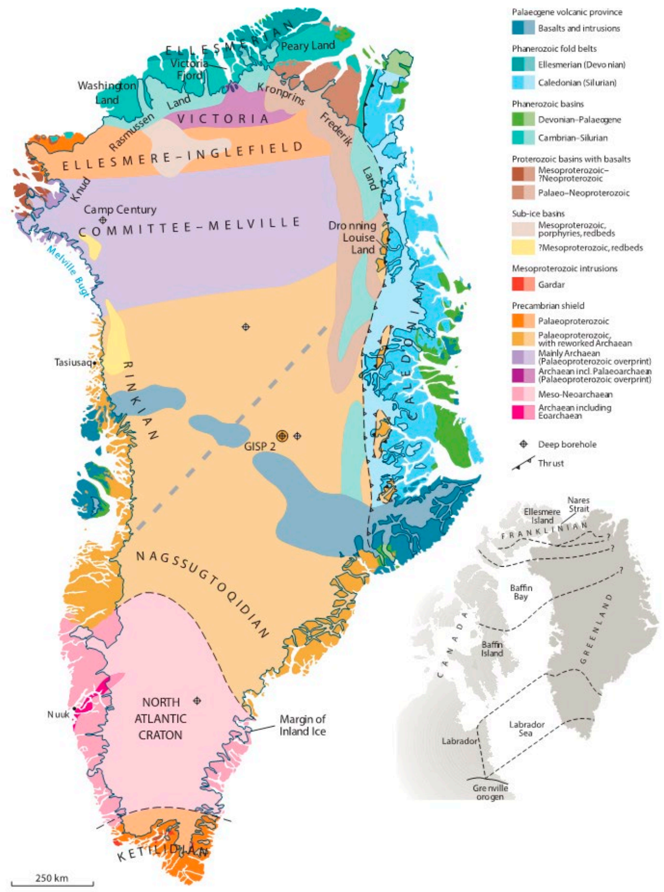

Figure 6. Geological map of Greenland and correlations to Canada. Source: Dawes (2009).

The Palaeozoic Caledonian fold belt is an approx. 1,300 km long, N-S oriented, belt from the Scoresbysund area towards Kronprins Christian Land in the north. The orogen was formed by collision between Greenland, North America, Scandinavia and Scotland around

420 Ma (Higgins & Frederiksen 1999; Higgins & Kalsbeek 2004; Higgins et al. 2008). The Caledonian rocks consists of both metamorphic, crystalline and sedimentary rocks in a thrust stack with gneisses, granites, various sedimentary units such as greywackes, marble, shales and metapelites (Higgins et al. 2008).

The Ellesmerian belt in North Greenland is an E-W trending belt along the margin of North Greenland, on top of the 2,000 km long and 4 km thick Franklinian Basin. (Soper and Higgins 1987, 1990; Higgins et al. 2000). The Ellesmerian belt is dominated by metamorphosed deep-water sediments and is assumed to be Late Devonian to Early Carboniferous (Escher & Watt 1976; Dawes 2004; Henriksen et al. 2009).

1.8.2 Sedimentary basins

The amalgamation of the Precambrian shield occurred around 1.7–1.6 Ga. shortly after sedimentary basins started to develop along the margins. The rate of subsidence of the basins was approx. equal to the amount of deposition of sediments into the basins. The thickest is the Eleonore Bay Basin, which is up to 20 km thick. Most of the basins were marginal marine, although some were continental basin-filled with fluvio-lacustrine sediments. The oldest, the Independence Fjord Basin in North East Greenland is around 1.7–1.6 Ga. The next period with major basin development was from approx. 1.5–0.5 Ga, when the Thule Basin, Hagen Fjord Basin, Hekla Sund Basin, Eleonore Bay Basin, Krummedal Basin were formed (Escher & Watt 1976; Peel & Sønderholm 1991; Dawes 1997; Henriksen et al. 2009). The youngest basins are Palaeozoic and include the Franklinian, Kong Oscar Fjord, Devonian and Wandel Sea, rift basins in East Greenland, and the Nuussuaq and Kangerlussuaq basins in Southeast Greenland (Escher & Watt 1976; Larsen et al. 2001; Dawes 2004; Dam et al. 2009; Henriksen et al. 2009) (Figure 7).

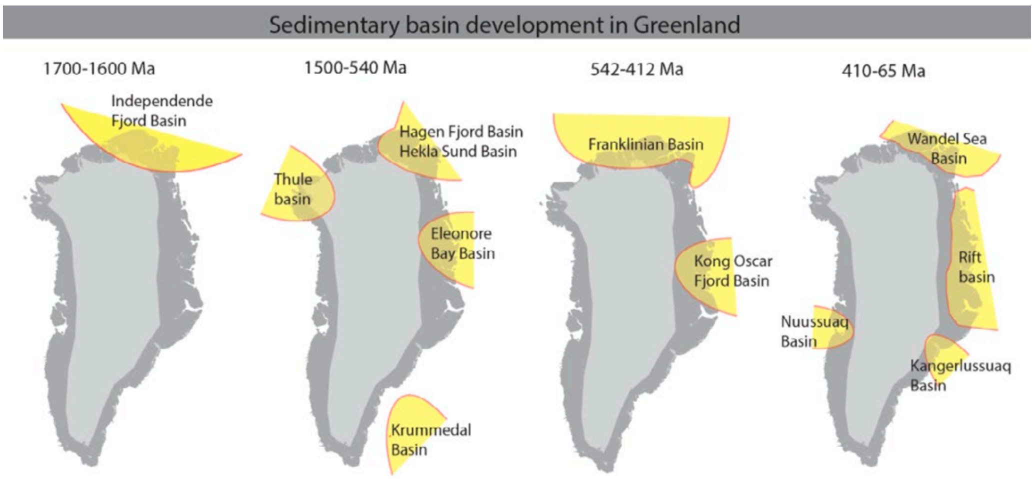

Figure 7. The sedimentary basins in Greenland. Modified after Henriksen 2006.

1.8.3 Palaeogene volcanism

Widespread volcanism from 63–13 Ma was related to the continental break-up and onset of Palaeogene seafloor spreading resulting in Greenland separating from North America and Scandinavia (Tegner et al. 1998, 2008; Nielsen 2009; Larsen et al. 2014, 2016; Pedersen et al. 2018). This Large Igneous Province (LIP) evolved during protracted but pulsating magmatism and was caused by a mantle plume, suggested to have originally been located beneath Greenland and today located underneath Iceland (White and McKenzie 1989; Saunders et al. 1997). Massive magmatism was associated with the still active LIP that extends for more than 3,000 km from Baffin Island across Greenland, Iceland and the Faeroe Islands to Scotland and Ireland. In Greenland, the province is manifested by magmatic rocks in the Disko Bay area in West Greenland and in East Greenland, where these Palaeogene rocks are exposed over a large area stretching from 66°N to 75°N in East Greenland. The most voluminous unit is the tholeiitic flood basalt sequence of East Greenland covering an area of more than 65,000 km^2 (Brooks and Nielsen 1982) followed by the picritic to basaltic volcanics on Disko Island and Nuussuaq and Svartenhuk peninsulas (Larsen and Pedersen 2000). More than 60 intrusions are found along the East Greenland margin (Figure 8). Mafic to ultramafic intrusions, dominates, but felsic intrusions also constitute an important component. Many of the intrusions hosts mineralisations including orthomagmatic PGE-Au mineralisations (e.g. Skaergaard intrusion, the Kap Edvard Holm intrusion, Miki Fjord macrodyke) (Bird et al. 1995; Holwell et al. 2012; Nielsen et al. 2015) as well as Mo-porphyry and Zn-Pb vein mineralisation, e.g. at Malmbjerg and Flammefjeld (Schassberger and Galey 1975; Geyti and Thomassen 1984).

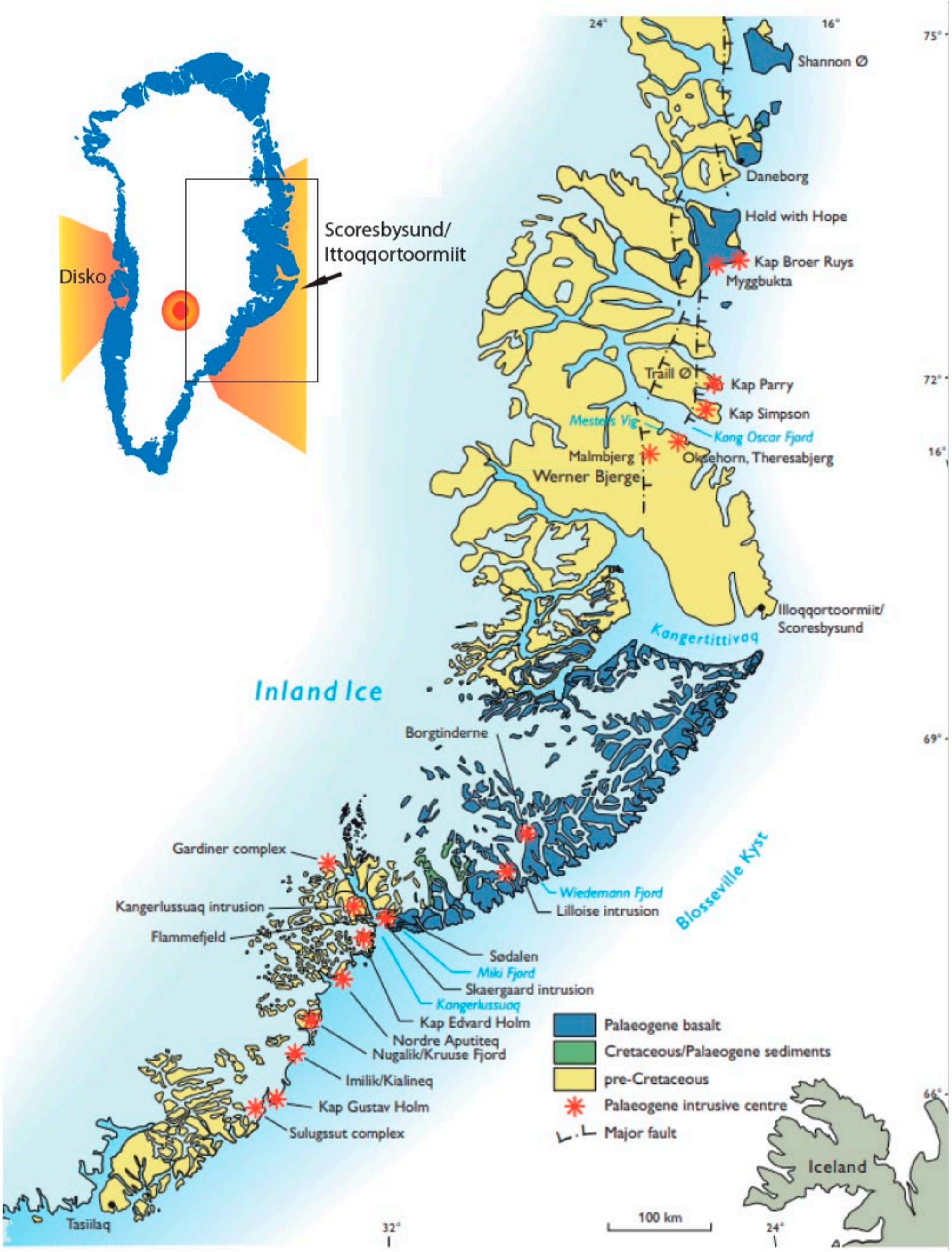

Figure 8. Small map: The Palaeogene North Atlantic Igneous Province in Greenland. Large map: The East Greenland Palaeogene. Map modified after Thomassen & Nielsen (2006). Source: GEUS.

1.8.4 The ice age and the Quaternary landscape

The Greenland ice sheet, which covers approx. 1,710,000 km^2, is the second largest ice body in the world after the Antarctic Ice Sheet. It has existed for the past 1.9 Ma (Funder et al. 2001, 2011; Born & Böcher 1999). The ice sheet has fluctuated in size through time and reached its maximum extent during the last ice age about 21,000 years ago, when Greenland was completely covered by ice, leaving only mountaintops (nunataks) ice-free. Currently the ice sheet is shrinking due to intense melting caused by the rapid global warming; a continued shrinkage of the ice cap is projected (Létriguilly et al. 1991; Funder et al. 2011) which might reveal new areas of interest for mineral exploration.

A temperature reconstruction for Greenland for the past 12,000 years based on proxy data, and observation data for the last ~140 years, is seen in Figure 9. It illustrates a dramatic warming during the last 150 years. The recent temperatures in Greenland are still likely below those experienced in the early Holocene but are clearly higher than those seen for the last two millennia and are warmer than during ~75% of the Holocene temperature history (Marcott et al. 2013).

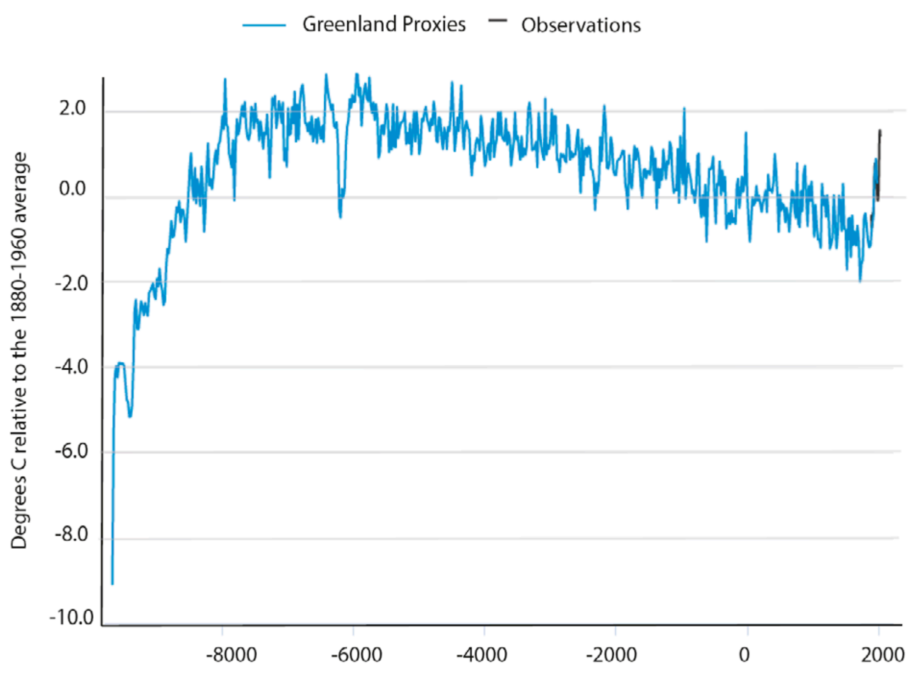

Figure 9. Greenland temperature reconstruction relative to 1880-1960 using proxy data from six ice cores (blue curve). The data spans 12,000 years back in time. The x-axis shows years where 2000 is present day. Observation temperature data from 1880-2018 is shown in black. Source: Hausfather (2019).

Glaciers connected to the ice sheet has carved the current glacio-geomorphologic landscape in Greenland where steep fjord systems were formed by glaciers. The landscape is generally dominated by glacial erosion, moraines and glacial till deposits in the crystalline basement of Greenland (Escher & Watt 1976; Henriksen 2006; Henriksen et al. 2009; Carriwick et al. 2017; Pearce et al. 2017).

1.8.5 Soil Conditions

Due to the Arctic climate in Greenland, outcrops of bedrock are common. Gneisses dominate the bedrock in Greenland, but some areas are dominated by sediments and basaltic rocks. Where present, the soil layer is thin, rocky and often under-developed with a depletion in humus soil with a sparse vegetation. Soils on top of gneisses are acidic, whereas soils in areas with basalt or sedimentary rocks are neutral to alkaline. Greenland is dominated by podzols, histosols and gelic gleysols. Along the coast, precipitation is high which leaches and depletes soils forming podzols, which are the most common soil type in South Greenland. In North Greenland and in the inner parts of long fjords in both West- and East Greenland the precipitation is low with dry soils and polar arenosols and under-developed luvisols. Tundra soils are frequent near streams and lower lying parts of the landscapes, where the soils are moist and often have a thicker vegetation cover. In areas with permafrost, the soils are under-developed and gelic gleysols are common (Born & Böcher 1999). North of the arctic circle the permafrost is coherent; south of the polar circle the permafrost is discontinuous and more scattered further towards the southern tip of Greenland (Tedrow et al. 1977; Born & Böcher 1999). In Greenland permafrost affect the soil formation by preventing organic material to decompose (Nielsen 2010).

1.8.6 Mineral resources

The complex and long geological evolution of Greenland has resulted in many different geological environments and mineralisations that are often linked to specific geological environments; see Figure 10. The location of the three case studies described in chapter 3, 4 and 5 are shown in Figure 10. All three are found in the crystalline basement rocks. Case 1 – White Mountain Project is in the Proterozoic Nagssugtoqidian Orogen near Kangerlussuaq. Case 2 – Isua Banded Iron Formation is in the Archaean banded iron formation near Nuuk. Case 3 – Nalunaq Gold Mine, Kirkespir Valley, is in the Ketilidian Orogen in South Greenland.

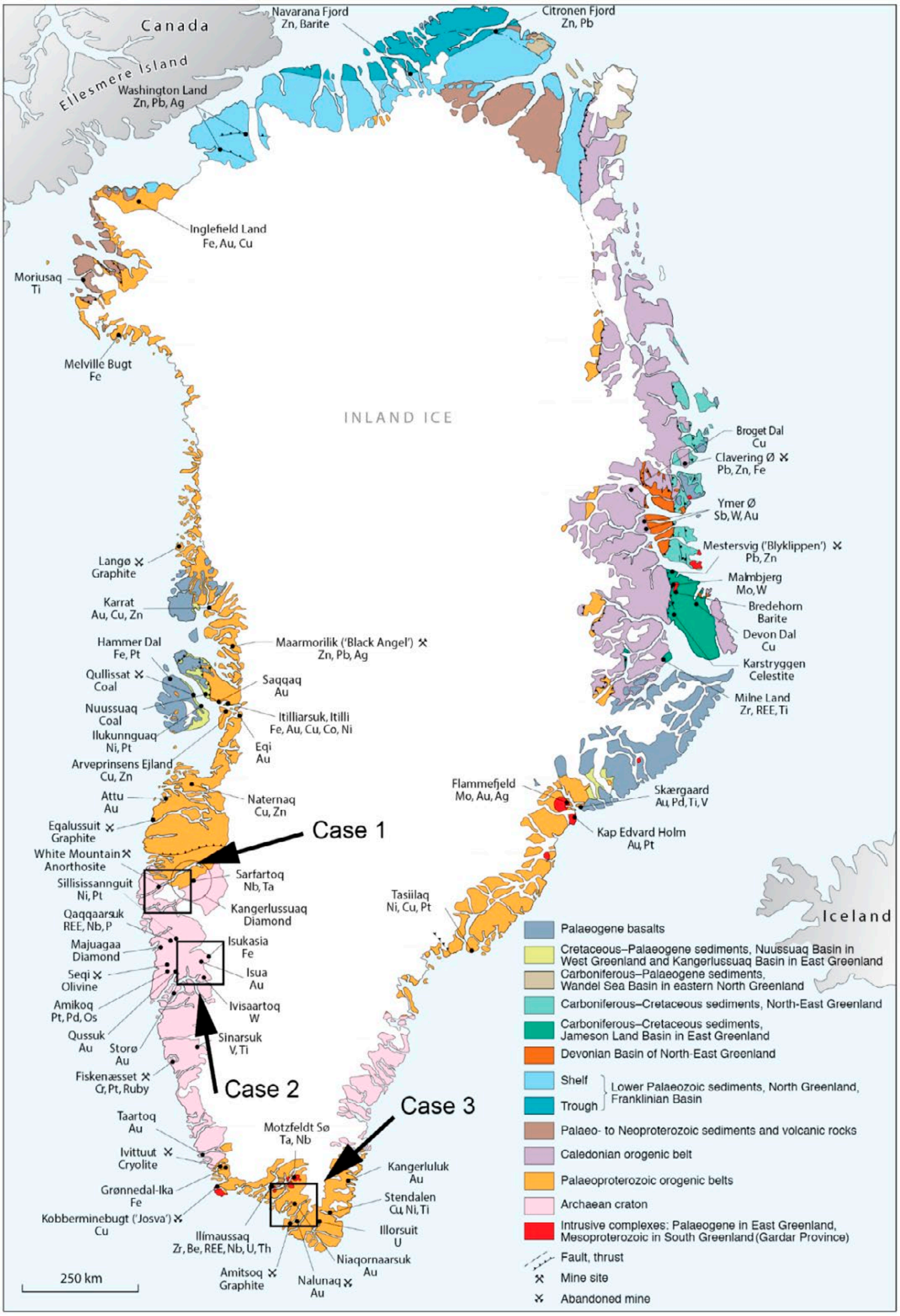

Figure 10. Simplified map of Greenland's geology and selected mineral occurrences. The boxes indicate the case study areas (chapter 3, 0 and 5). Modified from Henriksen et al. (2009).

The Iron and Ferroalloys

Iron, nickel, titanium, chromium, molybdenum and vanadium are known from the Archaean basement. Iron deposit are well known in the Isua iron deposit, the Baffin Bay area in West Greenland, and the Isortoq iron-titanium-vanadium occurrence in South Greenland. Nickel provinces are in West Greenland: the Norite belt near Maniitsoq, the Ikertoq occurrence near Sisimiut, nickel in Palaeogene intrusive rocks in the Disko Bay area, and in East Greenland: the Tasiilaq occurrence and the Palaeogene intrusive complexes. Molybdenum is known from Palaeogene intrusive complexes in East Greenland. In SW Greenland the Fiskenæsset gabbro-anorthosite complex chromium-vanadium-titanium are known (Keto 1998; Thomassen & Nielsen 2006; Secher et al. 2007; Secher & Stendal 2010; Stendal & Secher 2011; Stensgaard & Sørensen 2013). A deposit of titanium in ilmenite sand is found in the Thule-Moriusaq area in NW Greenland. Dundas Titanium A/S is currently investigating a titanium potential in heavy black sands close to the closed settlement Moriusaq near Thule Air Base (Weatherly 2015; Weatherly & Johannesen 2016). The company North American Nickel Inc. is investigating the norite belt near Maniitsoq for the nickel-cobalt potential (Garde et al. 2013; Rosa et al. 2013).

Precious Metals

Greenland has many gold showings and a significant potential for this commodity. The most prospective areas for gold are located within the Archaean and the Palaeoproterozoic of West and South Greenland. Gold occurs in various settings and localities and include the greenstone belt of the Tartoq Group, SW Greenland, the Godthåbsfjord Gold Province, in the vicinity of Nuuk, the Paamiut Gold Province, SW Greenland and finally the South Greenland Gold Province where the Nalunaq gold deposit, that was mined from 2004–2013, is located (see chapter 5) (Stendal & Secher 2002; Stensgaard & Stendal 2007; Secher et al. 2008; Kolb & Stensgaard 2009; Kolb et al. 2013; Kolb 2015).

The Platinum Group Elements (PGE) has attracted interests from the 1960s and have been part of Greenland exploration since the 1970s. PGE resources in Greenland encompass mineralisations in Precambrian to Palaeogene environments (Thomassen & Nielsen 2006; Secher et al. 2007; Stensgaard & Sørensen 2013). PGE occurrences found in the Archaean and the Palaeoproterozoic include mineralisations in the Fiskenæsset anorthosite complex (West Greenland), the Maniitsoq Norite Belt, layered ultramafic intrusions in the Fiskefjord-Amikoq region of West Greenland and parts of the Ammassalik Mobile Belt, East Greenland. Many PGE mineralisations have been observed both in the Palaeogene of West and East Greenland, with the most important being the world-class Platinova reef hosted in the Skaergaard intrusion (East Greenland) (Nielsen 2002; Thomassen & Nielsen 2006).

Base Metals

The base metals zinc, copper and lead are found in several of the sedimentary basins; the Franklinian Basin hosts the Citronen Fjord deposit in North Greenland with large deposits of zinc and lead (Peel & Sønderholm 1991; van der Stijl et al. 1998; Thomassen & Secher 2007). The Karrat Group in West Greenland and the Caledonian fold belt in NE Greenland also contains zinc and lead (Thomassen 1991, 2013; Thomassen et al. 2010; Thrane et al. 2011; Sørensen et al. 2012). The Phanerozioc sediments in Greenland are stratabound occurrences of base metals such as zinc, lead and copper from SEDEX (sedimentary exhalative) deposits and MVT (Mississippi Valley-Type) deposits (Thomassen et al. 1982; van der Stijl et al. 1998; Stensgaard 2011; Stensgaard & Sørensen 2013). Ironbark Zinc Ltd. has an exploitation license for the Citronen Fjord lead and zinc deposit.

Specialty Metals

A number of specialty metals, in particular rare earth elements (REE), niobium, tantalum and zirconium, are enriched in the rift-related alkaline and carbonatitic magmatic rocks from the Gardar Province in South Greenland (Tukianinen 1988; Sørensen 2001 2006; Sørensen et al. 2011; Sørensen & Kalvig 2011). The most investigated intrusive complex in the Gardar Province is the Ilímaussaq intrusive complex, which is enriched in REE, U, Th, Nb, Ta, Be, Zr, Li and F. It is a large intrusion that contains two world-class deposits with these specialty metals. The Kvanefjeld (Kunnersuit) deposit, located a few kilometers from Narsaq, is world famous for its wealth of minerals of which several are only found here. The deposit rich in REE, is hosted in the lujavrite enriched steenstrupine which also contains high concentrations of U and Th (Sørensen 2001).The deposit at Killavaat Alannguat (Kringlerne) is located in the southern part of the Ilímaussaq intrusion, and is hosted in the lower cumulates of layered kakortokite (agpaitic nepheline syenites). Eudialyte is the main economic mineral, which is enriched in REE as well as Zr, Nb and Ta. (Sørensen 2001, 2006). Greenland Minerals A/S and Tanbreez Mining Greenland A/S are at an advanced stage in negotiating their REE projects towards an exploitation license (Ministry of Mineral Resources 2020a). Another important deposit in the same area is the Motzfeldt Sø intrusive complex with large resources of niobium, tantalum and REE (Tukiainen 1988; Sørensen & Kalvig 2011).

The NAC is home to several carbonatitic intrusions including the Qaqarssuk Carbonatite Complex and the Sarfartoq Carbonatite Complex. Qaqqaarsuk (near Maniitsoq) and Sarfartooq (Kangerlussuaq) contain REE, tantalum, niobium, thorium and uranium (Secher & Larsen 1980; Knudsen 1991; Grice et al. 2006; Steenfelt et al. 2007; Secher et al. 2009; Stensgaard & Sørensen 2013). There are currently active exploration licenses for several of these areas.

Industrial Minerals

Greenland is endowed with many occurrences of industrial minerals of which several have been mined (see section 1.8.7). Olivine is found in many ultramafic bodies such as in Fiskefjord where lens-shaped olivine rich peridotite (dunite) bodies occur, with some sized up to 0.5 x 1.5 km. The olivine at Seqi was mined from 2005 to 2010.

Recently there has been growing interest for anorthosites, that can be used in the production of fiberglass and aluminium. Some of the anorthosites in Greenland are characterized by high purity and are relatively large. An anorthosite in Fiskenæsset, West Greenland, is under exploration, and the White Mountain deposit, central West Greenland, has been mined since 2017 (see chapter 3).

Graphite is another important industrial mineral in Greenland. It is often associated with reworked, deformed and metamorphosed Palaeoproterozoic mobile belts, that can have relatively high abundance of graphitic material, mostly hosted in supracrustal rocks. Occurrences of graphite and graphite schist are reported from many localities in Greenland such as Amitsoq, South Greenland, Akuliaruseq (Eqalussuit), West Greenland and Aappaluttoq in East Greenland. The graphite potential in Greenland is considered to be good, although, graphite is still an underexplored commodity (Thrane & Kalvig 2019).

Sand and Aggregates

The freshwater runoff from Greenland represents only 1.1% of the Earth's freshwater flux. However, the amount of sediments running into the fjords from the melting Inland Ice is estimated as 8% of modern, fluvial suspended sediment to the global oceans (Overeem et al. 2017). A research project is looking at the potential for glacial flour as a mineral fertilizer for depleted soils for nutrients (Sarkars et al, 2018).

Bendixen et al. (2019) highlighted the opportunity of developing a sand mining industry in the deltas of Greenland, from the massive freshwater runoff. Those authors convincingly demonstrate a huge resource potential of sand and gravel. The global demand for sand is high and continues to increase worldwide which could result in increasing prices. However, sand and gravel are geologically abundant, low-value, raw material commodities for which transport costs are high. Assessment of the business potential for sand products from Greenland indicate that export of sediments to Europe or North America would not be economic in the present market (Kalvig and Keiding in press).

Gemstones

Gemstones such as rubies, sapphires and diamonds are found within the crystalline basement in NAC. Rubies and pink sapphires have been described in West Greenland in the Maniitsoq, Nuuk and Fiskenæsset areas, and in the Tasiilaq area in East Greenland (Keulen et al. 2014; Poulsen et al. 2015; Smith et al. 2016; Yakumchuk & Szilas 2018; Keulen et al. 2020). The deposits near Fiskenæsset contains more than 50 mineralisations (Keulen 2018; Keulen et al. 2020). Greenland Ruby A/S has two exploitation licenses near Fiskenæsset. Several small-scale licenses are owned by locals. A small-scale license enables Greenland residents to extract and sell gemstones. Diamonds have been found in kimberlites and lamprophyres in Greenland (Jensen et al. 2002, 2004a, b; Jensen & Secher 2004; Secher & Jensen 2004). A new diamond exploration dataset package was released by the Department of Geology within the Ministry of Mineral Resources in 2020. Other gemstones in Greenland include tugtupite, nuummite, greenlandite, agate, labradorites, quartz, amazonite, sodalite and lapis lazuli (Bøggild 1953; Petersen & Secher 1993; Secher & Appel 2007; Secher et al. 2006) and quarried by Greenlanders for local jewellery making.

1.8.7 Historic mining activities in Greenland

Extraction of raw materials such as soapstone, chert and metallic iron occurred in the earlier Inuit cultures in Greenland (Jensen et al. 1997; Lennert et al. 2018; Poulsen et al. 2018). Modern mineral exploration and mining activities started in the beginning of the 18th century but has been restricted to relatively few mines (Secher 2004; Fægteborg 2013; Sejersen 2013; Kolb et al. 2016).

Table 4 provides a summary of mining activities in Greenland from the late 18th century to the present. It includes metals, industrial minerals, coal and dimensional stones. In the following section, a short review of the most important mines is provided. Many of the quarries listed in Table 4 have been test-site operations or were very small-scale mines and will not be mentioned further here.

Table 4. Overview of mining operations in Greenland. Source: GEUS.

Locality	Commodity/raw material	Activity	Extracted ore (metric tonnes)
Disko	Coal	1782–1833	unknown
Langø, Upernavik	Graphite	1845; 1905; 1912	130
Frd. VII Copper mine, Qaqortoq	Copper, (silver)	1852; 1905; 1912	18
Josva Mine, Kobberminebugt	Copper, (gold)	1852–1954; 1905–1914	2,252
Ivittuut (old spelling Ivigtut)	Cryolite	1854–1987	3,700,000
Killavaat Alannguat, Kangerluarsuk	Zirconium	1888–1889; 1968	160
Qaarsuarsuk, Nuussuaq	Coal	1905–1924	25,000
Eqalussuit, Nassuttooq	Graphite	1912	50
Utoqqaaq, Sisimiut	Graphite	1914	80
Amitsoq, Nanortalik	Graphite	1915–1924	6,000
Qullissat, Disko	Coal	1924–1972	570,000
Auspiciedalen, Clavering Ø	Iron (gold)	1933	5
Appat, Uummannaq	Marble	1934–1966	621
Maarmorilik, Uummannaq	Marble	1936–1940; 1966–1971	8,949
Mestersvig, East Greenland	Lead, zinc	1956–1963	545,000
Ilimmaasaq, Narsaq	Uranium	1958–1962; 1978–1981	11,000
Isukasia, Godthåbsfjord	Iron	1965–1971	150
Black Angel, Maarmorilik	Lead, zinc, silver	1973–1990	11,300,000
Evighedsfjord, Kangaamiut	Olivine	1995–1996	300
Nalunaq, Nanortalik	Gold	2004–2013	>53,000
Seqi, Fiskefjord	Olivine	2005–2010	1,700,000
Aappaluttoq, Fiskenæsset	Ruby	2015–	unknown
White Mountain, Kangerlussuaq	Anorthosite	2017–	unknown

The most important mine in Greenland is without doubt the Ivigtut Cryolite Mine in South Greenland, which was operated for more than 130 years (1854–1987) (Secher 2004). The mine was economically successful, especially from around 1930 and until the closure. Cryolite (Na_3AlF_6) is an industrial mineral which was used first as an aluminium ore and then as flux in the electrolytic processing of aluminium from bauxite ore. The deposit occurs in a granite stock approx. 300 m in diameter. The ore was excavated by open pit mining. The deposit was the only one of its kind in the world, and critical for aluminium processing until the 1960s when cryolite was produced synthetically. The mine continued until exhaustion of the orebody, and most of the remaining tailings stored adjacent to the mine site also were processed (Thrane 2016). Ultra-pure quartz is located below the cryolite ore which in recent years has been a target for exploration (Pauly & Bailey 1999; Keto 1998; Kolb et al. 2016).

The Black Angel mine at Maarmorilik in West Greenland was a successful Pb-Zn mine operated between 1973 and 1990 and is so far the second most important mine in Greenland's mining history (Kolb et al. 2016). The mine took its name from a pelite outcrop that forms a dark angel-like figure on a precipitous cliff face of marble above Affarlikassaa Fjord, here ore and miners were transported between the adit at an elevation of 600 m above sea level and the camp on the opposite side of a fjord by a cable car. The Black Angel deposit comprised of ten ore bodies totalling 13.6 million tonnes of grades 12.3% Zn, 4.0% Pb and 29 ppm Ag. 11.2 million tonnes were extracted (Thomasson 1991). The massive sphalerite-galena-pyrite ore is hosted by calcitic and dolomitic marble with intercalations of anhydrite-bearing marble and pelitic schist of the Mârmorilik Formation of the Paleoproterozoic Karrat Group (Rosa 2016). The deposit was considered almost exhausted, but a re-establishment of the mine has been considered based on the remaining ore in pillars in the mine combined with other marble-hosted lead-zinc prospects in the area (Thomassen 2003; Henriksen et al. 2009).

Another small Pb-Zn mine was the Blyklippen mine in Mestervig, East Greenland. The deposit was found in 1954 after initial exploration work by Nordisk Mineselskab A/S dating back to 1948 (Thomassen 2005; Kolb et al. 2016). The original deposit formed a sulphide lens at 300 m to 490 m depth and consisted of 65% quartz, 15% sphalerite, 10% galena, 5–10% baryte with trace amounts of pyrite, chalcopyrite and tetrahedrite. The mine was in operation from 1956 to 1962 until the ore was considered exhausted. In total 560,000 tonnes of ore were mined at grades of 11.1% Pb and 8.6% Zn (Harpøth et al, 1986). The Blyklippen Pb-Zn mine is the only deposit mined in East Greenland.

Graphite was the first commodity to be mined in Greenland. It was mined in 1845 on Langø near Upernavik where graphite was quarried from shallow pits. Since then, several graphite mines have been open with the most important being the Amitsoq mine, South Greenland. The graphite deposit was discovered in 1911 and mined by Grønlandsk Minedrift A/S in cooperation with Grønlands Grafit Compagni A/S between 1915 and 1924 (Kolb et al. 2016). The ore reserves were estimated at 250,000 tonnes, yet only 6,000 tonnes of graphite ore, averaging 21% graphite, have been produced (Bondam 1992). The graphite mine was abandoned due to difficulties separating the graphite flakes (Thrane & Kalvig 2019).

An attempt to mine copper was made on one of the sulphide occurrences of the Ketilidian Orogen found in South Greenland. The Josva Copper mine, located 40 km south of Ivittuut, was worked from 1905 until 1914. 2,252 tonnes of ore were produced, yielding ~60 t Cu, ~50 kg Ag and 0.5 kg Au (Secher & Burchardt 2000). Inadequately known quantities of ore, simple technology and several ship losses were significant reasons why the copper mine was unsuccessful and had to be abandoned.

After 1990 Greenland experienced its first halt in mining since 1854. However, mining operations soon recommenced. Olivine has been mined in Evighedsfjorden (1995–1996) and at the Seqi deposit north of Nuuk from 2005 to 2010 (Table 4). The Nalunaq gold deposit was mined from 2004 to 2013 and is planned to reopen in 2021 (see case study 3, chapter 5). In Aappaluttoq at Fiskenæsset, West Greenland, a ruby mine opened in 2015 (see Figure 10). The White Mountain anorthosite mine at Qaqortorsuaq started operating in 2018 (see case study 1, chapter 3).

1.9 Licenses and mining in Greenland

As of February 2020, there are five mineral exploitation licenses (two are active mines), 13 prospecting licenses, 54 mineral exploration licenses, 23 scientific licenses, six exploration licenses on special conditions, 37 exclusive small-scale licenses and eight small-scale licenses without exclusive rights (extract www.govmin.gl). Figure 11 gives the current overview on the area under license as of February 2020. For more detail see www.govmin.gl.

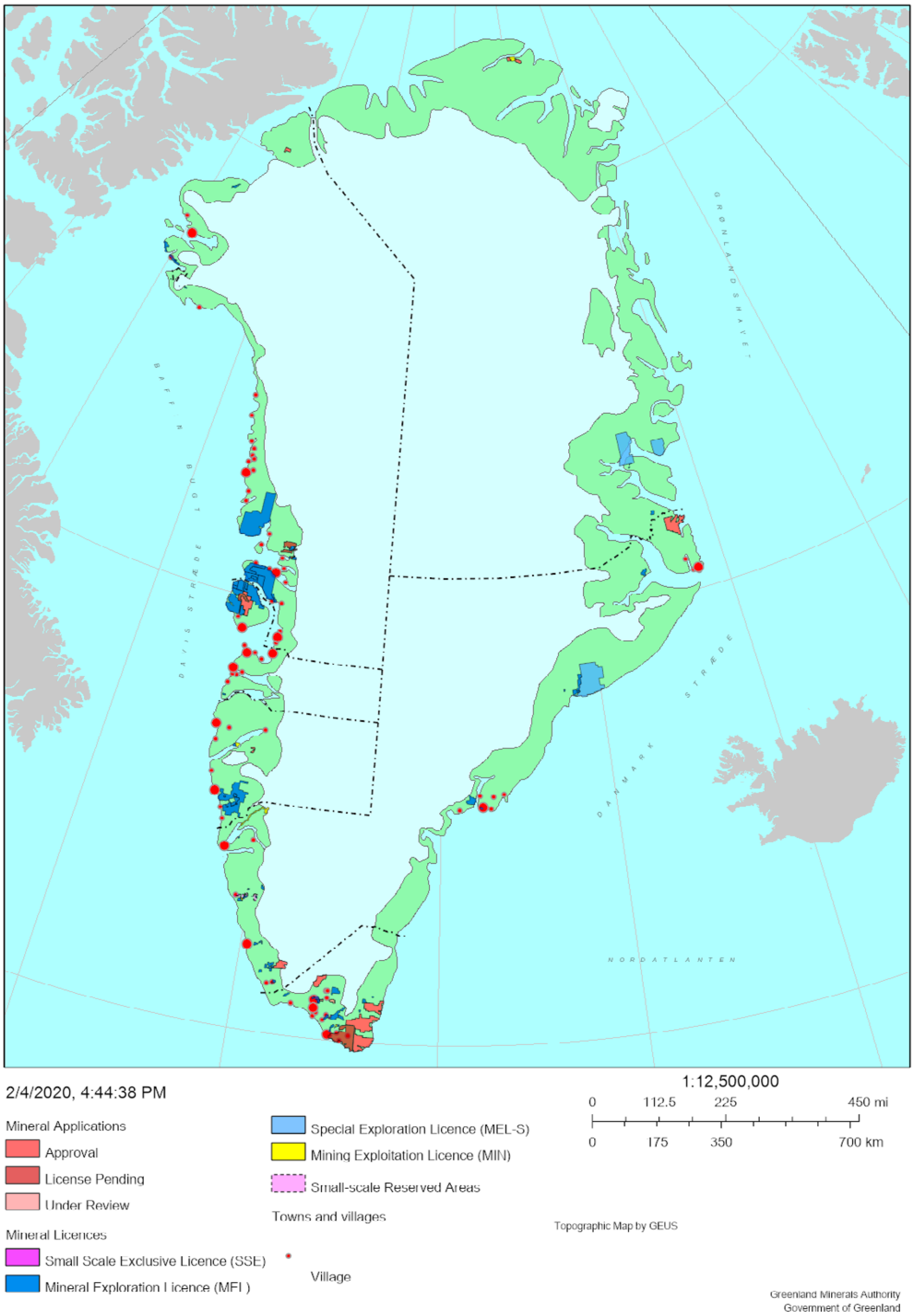

Figure 11. Greenland Licence Map. Status of mineral exploration in Greenland, February 4, 2020. Extract from www.govmin.gl. See more on www.govmin.gl.

One of the active mines is the Hudson Resources A/S anorthosite mine at White Mountain in the Kangerlussuaq Fjord in West Greenland (chapter 3). The other active mine is a ruby and pink sapphire mine at Aappaluttoq near Fiskenæsset in West Greenland, operated by Greenland Ruby A/S. Production started in 2017 and until the beginning of 2020 the mine mostly sells cut stones to jewellers in Denmark and Greenland (Turnowski 2018a, b). The company operations span the whole value chain from mining, transport, treatments, cutting, marketing and sales.

The Government of Greenland promotes the mineral resource potential in Greenland at numerous international conferences, marketing exhibition and trade fairs every year. The portals www.govmin.gl and www.greenmin.gl display much relevant information for applications, maps with active licenses, geological maps, mineral potential reports and other data from the Government of Greenland, the Geological Survey of Denmark and Greenland as well as published company reports.

Greenland received significant interest for mining activities from investors and explorations companies since 2000 (Figure 12). Exploration expenditures in Greenland increased to almost 700 million DKK in 2011, before Greenland was affected by the 2015–2018 downturn in the mining sector as the rest of the world (Figure 13). In recent years, there has been renewed interest for exploration in Greenland.

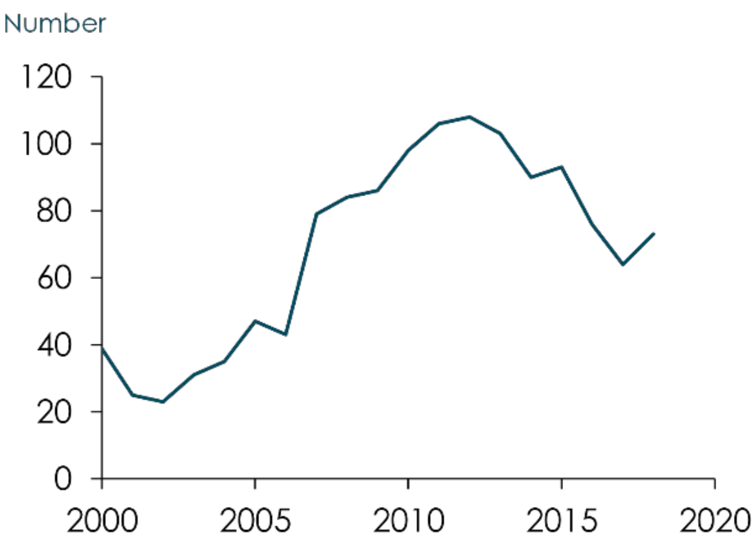

Figure 12. Number of exploration licenses in the mineral sector in Greenland from 2000 to 2018. Modified from Greenland's Mineral Strategy 2020-2024 (Ministry of Mineral Resources 2020b).

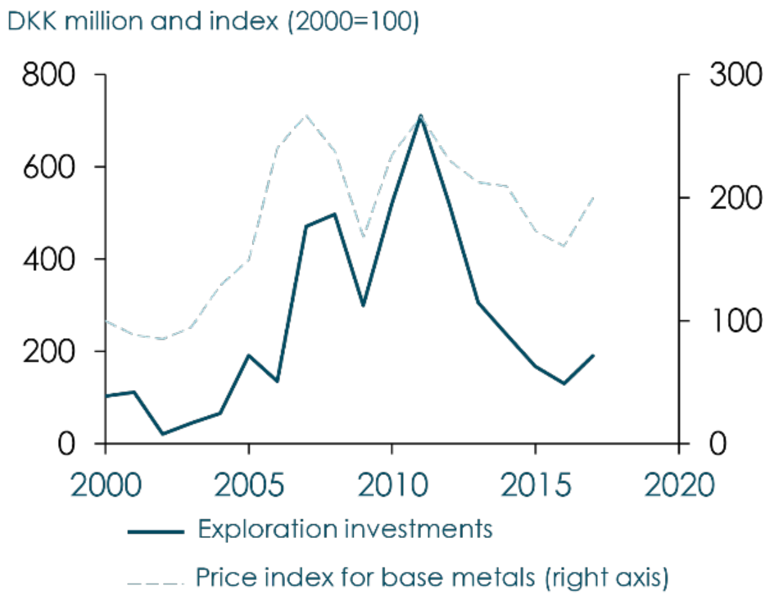

Figure 13. Exploration investments in the minerals sector in Greenland from 2000 to 2018. Modified from Greenland's Mineral Strategy 2020-2024 (Ministry of Mineral Resources 2020b).

The Fraser Institute annually evaluates the perceived attractiveness of approx. 100 jurisdictions for mining, including the mining potential, mineral attractiveness and policy attractiveness. Greenland's ranking fluctuates significantly year by year. Greenland's ranking is mostly dependent on its perceived mineralisation potential. Only 5 to 9 mining companies in Greenland responded to the 2019 survey invitation (Stedman et al. 2020). Given that low number of respondents, high fluctuations in the ranking can be expected.

2 Legal framework, challenges and opportunities for mining in Greenland

Mineral exploration is a prerequisite to mining activities. The mineral exploration phases aim to assess the mineral resource with respect to quantity, quality, mine and process design, and eventually the project feasibility. However, it is normally only a small percentage of the exploration projects that eventually go into production.

2.1 Regulatory framework

The mining industry in Greenland is regulated by the Mineral Resources Act 'Råstofloven', no. 7 that was passed in the Greenland Parliament, December 7, 2009. The Mineral Resources Act serves as the legal framework for all mineral resource related activities in Greenland. It has been amended several times since, the last time in November 2019. It aims to follow the best international practices for mining and regulation. In addition to the Mineral Resources Act, the document and its amendments 'Application Procedures and Standard Terms for Mineral Exploration and Prospecting Licenses in Greenland' sets the given terms and fees under which companies may apply for exploration licenses, and as such act as guidelines for the applicants. The current fees are seen in Table 5.

The administration regarding mineral resources is handled by the Mineral Licence and Safety Authority (MLSA) under the Ministry of Mineral Resources, acting within the framework of the Mineral Resources Act as part of the Mineral Resource Authority (MRA). The organisational structure of the MRA is shown in Figure 14.

Figure 14. Organisational structure of the Mineral Resources Authority in Greenland. Source: www.govmin.gl.

The Mineral Licence and Safety Authority (MLSA) is responsible for the application and administration of licenses, in addition to be the authority on technical matters. The MLSA may consult other departments within the ministries on specific matters such as geology, labour and environment. The Ministry of Mineral Resources (MMR) is responsible for all socio-economic aspects of the mineral resource application, such as Impact Benefit Agreements (IBA), Social Impact Assessments (SIA). It is the governing body for legal aspects of the mineral resources, in addition to strategy making. In a recent allocation of resource areas, the labour policies are currently handled by the Ministry of Industry, Energy, Research and Labour. All aspects relating to environmental concerns are handled by the Environmental Agency for Mineral Resource Activities (EAMRA) under the Ministry for Nature and Environment. The EAMRA handles and oversees all matters relating to the protection of the nature and environment, environmental liability and Environmental Impacts Assessments (EIA). Each application is in consultation within the ministries during processing, during which external partners such as the Department of Environment and Mineral Resources at the Greenland Institute of Natural Resources and the Danish Centre for Environment and Energy (DCE) at Aarhus University, Denmark, are often consulted.

The 'Application Procedures and Standard Terms for Mineral Exploration and Prospecting Licenses in Greenland'[6] differentiates between four types of mineral licenses, (a) the mineral prospecting license, (b) the mineral exploration license, (c) the special exploration license and (d) the mineral exploitation license. In addition to these licenses, inhabitants in Greenland can apply for small-scale licenses (under 1 km^2), exclusive and non-exclusive respectively, see Table 5.

The mineral prospecting license covers all minerals for a given area, unless stated otherwise in the license, and is non-exclusive. The license is granted for a five-year period

6 https://govmin.gl/exploration-prospecting/get-an-exploration-licence/standard-terms/

and cannot be renewed. Besides the application and granting fee as stipulated in Table 5, the mineral prospecting license requires no expenditure commitment.

A Mineral Exploration License (MEL) is similarly granted for a five-year period and covers all minerals, unless stated otherwise. The license is renewable. In addition to the application fee, the license holder obligates to yearly expenditure commitments which incrementally increase in expenditure. This is in many ways similar to the mineral rights and claims in British Columbia (BC), Canada, but is less expensive for larger license areas compared to BC. Obligations for exploration expenditure is also comparable to BC (Claims: Mineral & Placer Titles – Province of British Columbia 2020). A similar trend is seen when compared to Western Australia. In general, the standard fees such as registration and rent fee (only used in Western Australia) are considerably lower in Greenland compared to BC and Australia. However, when comparing license areas between 10–1,000 km^2 during the exploration years 1–8[7], the minimum exploration commitment is ca. 46% higher in Greenland compared to BC and Australia (see comparison in Appendix A). Taking into account that the general exploration cost is higher in Greenland compared to Canada and Australia, the amount of work or development required at a license in these countries are comparable.

7 Do not reflect the minimum-maximum extent of license areas

Table 5. General license fees for exploration in Greenland in 2020. Modified from www.govmin.gl. All prices are in DKK.

A. Prospecting license fees		
1	Application fee	3,000
2	Granting fee	24,900
3	Transfer fee	12,500

B. Exploration license fees		
1	Application fee	5,000
2	Granting fee (year 1–5)	36,300
2.a	Granting fee (Year 6–10)	36,300
2.b	Granting fee (Year 11–13, 14–16, 17–19)	36,300
3	Enlargement fee	20,800
3.a	Granting fee for transfer	20,800
4	Annual license fee (year 6 and forward)	41,500

C. Exploration license obligations		
1	Exploration obligation per license per calendar year	
1.a	Year 1–2	166,000
1.b	Year 3–5	332,000
1.c	Year 6–10	665,000
1.d*	Year 11–13	1,330,000
1.e*	Year 14–16	2,660,000
1.f*†	Year 17–19	5,320,000
2	Exploration obligation per km2 per calendar year	
2.a	Year 1–2	1,660
2.b	Year 3–5	8,310
2.c	Year 6–10	16,600
2.d*	Year 11–13	33,200
2.e*	Year 14–16	66,500
2.f*†	Year 17–19	133,000
3	Exploration obligation for large areas in East and North Greenland (special license)	
3.a	Exploration obligation per km2 831	

D. Exploitation license		
1	Granting fee	100,000
2	All related and factual expenses associated with processing by authorities in relation to the exploitation license	

* for licenses in year 11 or older and still active renewed prior to 2014 the exploration obligation is set in the license.
† for licenses in year 20 or older the obligation is multiplied by two (2) for every 3-year renewal. The obligation for licenses in year 20, 21 and 22 is therefore double of the rates for year 17–19. Licenses in year 23, 24 and 25 the obligation is therefore double of the obligation in years 20–22.

A special mineral exploration license (MEL-S) is granted for three years at a time and only applies for licenses in West Greenland north of 78°N and all areas in East Greenland east of

44°W and for license areas larger than 1,000 km^2. It was introduced to promote large area exploration in the less explored areas of Greenland, with fewer inhabitants, and with lower per square kilometre exploration fees compared to the rest of Greenland. The license is non-renewable but otherwise follows the same requirements and commitments as the MEL albeit at a much lower rate per square kilometre, and may be granted a MEL as a continuation of the MEL-S.

In a recent improvement to the Mineral Resource Act, applications for exploration permits can be made via the online portal https://portal.govmin.gl, in addition to the tradition application from. The application includes standard terms as:

- Technical and financial capabilities of the applicant
- Geographical area
- Target mineral(s)
- Description of planned activities for coming field season if granted
- Latest audited financial statement and company report
- A chart of the company ownership structure
- Coordinates and map of the exploration area sought.

The mineral exploitation license is exclusive for specific minerals and is granted for a period of 30 years and may be extended for up to 50 years. In order to be granted an exploitation license, the licensee must complete and approve a series of white papers, including SIA, EIA, IBA regulations, navigational safety investigations, and production and closure plans. The papers are subject to public consultations during which public meetings are held about the company's plans, often in collaboration with the Mineral Resources Authority.

The Government of Greenland has made several amendments in recent years to improve efficiency and quicken the transition from exploration to mining phases. One of the mechanisms is 'the one-door-shop' policy that allows companies to apply and contact the authorities through one portal/door only. Furthermore, the new web portal and associated application portals similarly offer easier access to vital documents, guidelines and contacts with the authorities. The government conducted a study on the average case handling times in Greenland compared to the Scandinavian countries, Canada, USA, Australia and others (Pedersen 2007). The study concluded that the application process time in Greenland is generally comparable to those mining jurisdictions, especially Sweden and Australia. However, process times in South Africa, Norway and Finland, were on average lower compared to Greenland (Pedersen 2017).

2.1.1 Impact Benefit Agreement (IBA)

The Impact Benefit Agreement (IBA) is a collaboration agreement between the company, the local municipality to be affected by the mining activity and the Government of Greenland. The Social Impact Assessment (SIA) report and the White Paper constitute the basis for the IBA. The IBA must be signed and approved before the mining project can be granted (Guidelines on the process and preparation of the SIA report for mineral projects 2016). The agreement regulates how initiatives stipulated in the SIA are carried out in specific and measurable incentives. The basis for the IBA is therefore the SIA. The IBA typically stipulates how or to which extent, the mining company should employ Greenland labour, engage with local enterprises; engage in knowledge transfer, training, education, socio-cultural values and traditions, etc. The companies typically commit to 50–80% of the workforce being Greenlanders (see definition of Greenland workforce below), a practice adopted from Nunavut, Canada. The extent of the IBA is project specific, but the legal sections and general provisions will, in principle, follow a common IBA model prepared by the Ministry of Industry, Energy, Research and Labour (Guidelines on the process and preparation of the SIA report for mineral projects 2016). The law describes what criteria are used when defining if an employee is Greenland labour. As per Landstingslov no. 27 of 1992, an individual born in Greenland, and who has had permanent residence in Greenland for minimum the first five years of the person's life, may be considered Greenland labour. Any other person is considered foreign labour, unless the person has had permanent residency in Greenland for seven of the past ten years or be married to a person which fulfil the two aforementioned requirements.

Private enterprises must compete for employees with national and state-funded building infrastructure projects. This results in a comprehensive demand for the Greenland workforce. The private enterprises (e.g. mining) are often at a disadvantage when competing against the salary rates of government-funded projects (personal comm. Hudson Resources Inc. 2020). This issue may deter foreign investments in Greenland, because the investors/mining companies may need to supply the project with foreign workers, adding to an already costly business. As such it can be difficult to meet the requirements set in the IBA regarding local workforce (Olsen 2018; personal comm. Hudson Resources Inc. 2020). Currently, the Greenland Ruby A/S's ruby mine at Aappaluttoq, employs more than 95% local workers, well above the minimum requirements (80%), whereas Hudson Greenland A/S White Mountain mine employs below 30%; well below the minimum requirement (personal comm. Hudson Resources Inc. 2020; personal comm. P. Madsen Greenland Ruby A/S 2020). The reason for this discrepancy is beyond the scope of this report, but potential neglect of the signed agreements poses a threat for attracting mining investments in Greenland (Olsen 2018).

Nonetheless, the IBA is not the cause of halted or failed projects. Factors including unfavourable timing, loss of supply-chain or market downturns are more influential.

However, people within the mining industry would like the IBA to be renegotiated every few years, e.g. to gradually increase the demand for local workforce in the agreement to suit the current market conditions and employee availability (personal comm. B. Olsvig, formerly Xploration Services A/S 2020).

2.2 Availability of labour

Ten years of primary school education is mandatory in Greenland. However, only 1 out of 7 children continue directly to upper secondary education (Statistic Greenland 2019). Among the 18–25 years old people only 4 out of 10 have finished high school or a vocational education (VET). As of 2017, for the age group 25–64, 54% have primary school as the highest education, 5% high school, 25% VET and 16% higher education (of which less than half have a master's degree or higher) (Figure 15). Education in Greenland is free of charge and people from Greenland can study in Denmark free of charge. Several initiatives have been invoked to increase the percentage of youths taking an education, and the numbers are gradually increasing. Still, many children are the first to take an education within their family.

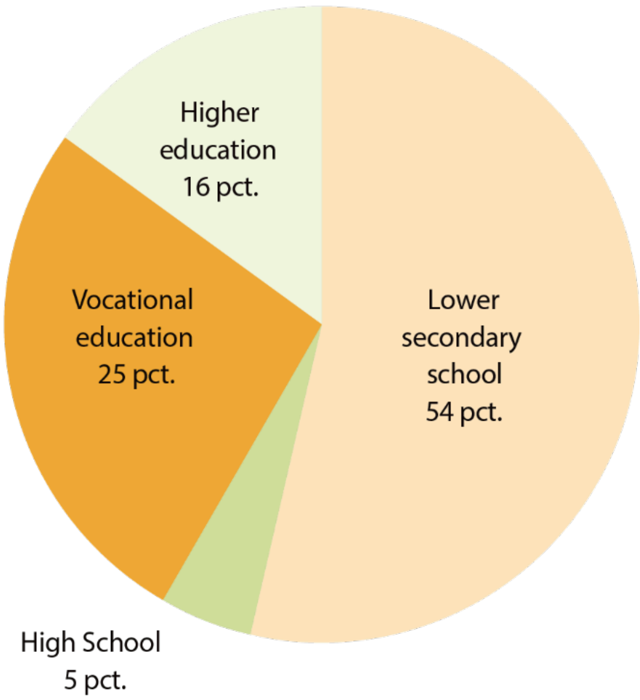

Figure 15. Educational level in Greenland. Highest completed education for the Greenlandic population in 2017 for the age 25-64 years old. Data from Statistic Greenland (2019).

In 2018, 95 residents in Greenland were employed in the mining and quarry sector, and 2,042 residents in the construction industry (Statistics Greenland 2018). The unemployment rate for permanent residents with VET in engineering, construction and manufacturing was 2% corresponding to 42 persons. Table 6 shows the number of students attending different short courses at the Greenland School of Minerals and Petroleum in Sisimiut from 2008 to 2019. The Greenland School of Minerals and Petroleum is dependent on additional funding for equipment and other resources to expand the current curriculum, which is necessary to satisfy industry skills needs (personal comm. H. Hinrichsen, Greenland School of Minerals and Petroleum 2020).

With the large national funded infrastructure projects, potential large mining projects such as the Greenland Minerals Ltd.'s REE-project in South Greenland and the potential Isua project (chapter 0), there is a risk of 'brain drain' from towns and settlements. In general, few people move from their hometowns and most women take an education. According to Statistic Greenland (2018), women outweigh men in higher education with more than 43%.

Table 6. Number of completed course participants from the Greenland School of Minerals and Petroleum. Note that the number of participants is not unique, i.e. one person can participate in several courses and will count as a participant in each. The number of completed supplementary courses can therefore not by summed. Source: Greenland School of Minerals and Petroleum, February 2020.

Course (supplementary)	Duration	Completed 2008–2019
Head of blasting	2 weeks	127
Machine Operator	5 weeks	256
Core driller	6 weeks	123
Drilling jumbo	3 weeks	74
Crushing and sorting	2 weeks	27
Rigger training	2 weeks	64
Common Core	10 weeks	396
Vibrations measurement	2 weeks	21
Caterpillar 777	2 weeks	6
Basic laboratory work	2 weeks	12

VET education	Duration	Completed 2016–2019
Skilled machinery operator	4 years	14
Skilled mine worker	4 years	8

2.3 Taxes and royalties

Exploitation licenses can generally only be granted to companies registered in Greenland. This is to ensure taxes are paid to Greenland. In addition to the corporate taxation and obligations to carry the expense of training of personnel within the government and the locals, the mining project must also pay a royalty fee of 2.5 to 5.5% of the value of the extracted minerals, depending and the commodity. Similar royalties or charges are set for the fishing industry. This addendum came in effect on July 1, 2014, and affects all licenses granted after July 1, 2014. For exploration and exploitation licenses granted earlier, this addendum does not apply if the exploration license has not been amended since granting or carry a plan related to royalties. The current royalty model is as follows (Schriver 2019):

- For exploiting rare earth elements, the licensee shall pay a sales royalty of 5% of the sales value.
- For exploiting gemstones, the licensee shall pay a sales royalty of 5.5% of the value of the gemstones and a surplus royalty of 15% based on gross profit exceeding 40%.
- For exploiting uranium, the licensee shall pay a sales royalty of 5% of the value of the uranium.

- For minerals other than REE, gemstones or uranium, the licensee shall pay a sales royalty of 2.5% of the value.

Sales values represents value of the minerals sold. The value may be the actual sales price to an independent party if based on an objective, informed and substantiated assessment equal to the free market. If the MRA determines that the actual sales price is not equal to the sale price obtained in the free market, the MRA may determine the value of the minerals sold, after consulting the licensee. The exploited minerals are considered sold, when loaded on a ship or vessel leaving Greenland, unless approved by the MRA. The freight costs may be deducted from the sales prices, depending on the delivery terms, albeit not for gemstones (Government of Greenland 2014a).

For other minerals and REE, the licensee may, on certain terms, offset an amount equal to paid corporate income tax and corporate dividend tax against the sales royalties to be paid (Schriver 2019).

When the royalty taxation regime was introduced in 2014, several companies raised concerns (e.g. when the Greenland Mineral Strategy 2014–2018 was in public consultation) about the sizes of the royalties, because it increased the total government offtake to higher levels compared to the global median on total government offtake on royalty taxes. However, concerns were raised when combining the effect on royalty tax and the overall high, albeit recently lowered, total effective mining tax in Greenland of 37–41% compared to the Nordic countries and Western Australia (Otto et al. 2006; comments on 'Oil and Mineral Strategy Report' Greenland Minerals and Energy Ltd. 2013; Hojem 2015).

The new Mineral Strategy 2020–2024 aims to optimise the total mining tax scheme in order to improve competitiveness, but otherwise concludes that the current royalty system is proportionate and competitive (Ministry of Mineral Resources 2020b). The 'one-door-shop' policy that was reintroduced in 2019 has been viewed positively by the industry because it offers a more effective and ease-of-access case handling for the mining companies, and thereby increases the competences of Greenland's rising mining industry (Ministry of Mineral Resources 2020b). Improving the competence in the ministries and maintaining the one-door principle, as suggested in the Mineral Strategy 2020–2024 could increase Greenland attractiveness for the mining industry and its investors.

2.4 Actions to attract investors

In order to attract investors, the corporate taxation for mining companies, with exploration or exploitation licenses, according to the Mineral Resource Act, is 25% as opposed to 26.5% for other industries. The tax on dividends for mining companies is 36%, significantly lower than for companies in other industries that pay 42–44% depending on the municipality (Schriver 2019). There is no statute of limitations for forwarding exploration/mining deficits, whereas other companies have a time limit of five years (Schriver 2019). The most recent amendment to the Mineral Resources Act removes the demand of a government-approved bankable feasibility study, this to lower the amount of case handling. An exploration/mining company therefore only needs to convince investors, and not the Government of Greenland, that the project could be profitable.

The Government of Greenland is adapting to the financial market demands with regards to the mineral resources sector. For example, during the market downturn of 2015–2018, mining companies with exploration licenses on standard terms for six years or more had their exploration obligations reduced to zero (personal comm. MRA 2020). This move was to incite interest from investors and maintain exploration companies with a substantial track record in Greenland and allowed them to maintain their licenses during difficult financial times. Due to Covid-19, the government offered similar relief for exploration commitments for the year 2020 (MLSA press release April 2, 2020). The downside is that potentially no work will be performed and the path towards production extends for the mining companies. Nonetheless, it is a valuable tool that is generally appreciated by the industry and investors (Jørgensen 2020).

The Government of Greenland aims to outline a strategy with a set of goals for the mineral resource sector every four years. While an in-depth analysis of the strategies and outcomes are beyond the timeframe of this study, the following paragraphs highlight some relevant aspects of the strategic aim to attract investors.

Setting the scene for mineral exploration in Greenland the Greenland Oil and Mineral Strategy 2014–2018 focussed on *Hydrocarbons*, *Minerals*, *GeoSurvey Greenland* and *Sustainable development*.

- Hydrocarbons are not the focus of this report.
- The focus for the *Minerals* component in the strategy was new targets for government survey programs with special emphasis on iron ore, copper, zinc, REE, gold and gemstones based on the market value, local mineral potential and attractiveness at the given time (Government of Greenland 2014b). In the strategy period a taxation model for mineral (and hydrocarbons) exploitation would be

initiated based on a benchmark analysis. The taxation model in the strategy largely follow the current model.

- A key recommendation within the strategy was the establishment of a *GeoSurvey Greenland* within five years of the strategy start. The GeoSurvey Greenland should handle geo-mapping activities (collection of geological and geophysical data), study of collected rocks in laboratories, management and storage of geo-data, and communication of collected information in marketing, etc.
- The *Sustainable development* theme aims for greater involvement of the Greenland business community in the mineral resource sector, and (a) examines the potential for public-private partnerships as alternative finance streams for large infrastructure facilities; (b) examines the possibility to promote utilization of hydroelectric power in the minerals sector on a commercial basis; (c) investigates the need and potential of current airports and locations of possible future airports and designs (mainly for the petroleum industry); (d) possible deregulation of telecommunications for the mineral industry; (e) focus on IBAs to develop the labour market, employment and training, and (f) promoting public consultations to increase awareness and understanding of the mining and mineral resource sector (Government of Greenland 2014b).

The initiatives forming this strategy was an aim to contribute towards Greenland having three to five active mines by 2018 (Government of Greenland 2014b). By 2018 only the Greenland Ruby A/S mine at Aappaluttoq was in operation. Another important intermediate goal was to establish a GeoSurvey Greenland within the strategy period. This goal was discarded as the estimated cost of operation and potential loss of knowledge from the Geological Survey of Denmark and Greenland, was deemed too high (Pedersen 2014). However, the implementation of the taxation model was achieved, and the IBA is now rooted within each exploitation license. During the strategy period, the sharing and marketing of geological data have increased and been made more readily available. Another key aspect was to separate the environmental protection aspects from the mineral sector to the Department of Environment and Nature. This has similarly been achieved, with the establishment of EAMRA that increased the knowledge and capabilities of the Greenland Institute of Natural Resources.

The Greenland Mineral Strategy 2020–2024 was originally meant to replace the former strategy, but it was delayed. The new strategy focusses only on the mineral sector; hydrocarbons are covered in a separate strategy (https://www.businessingreenland.gl/da/Erhverv/Oil-and-Gas/Olie-og-Gas-Strategi). The main priority in the new strategy is to improve sharing of geological knowledge. This should be done by providing high quality geological data via new geological maps, field-based studies, increased access to data, improving the usability of data, raising awareness of the data, providing online access (preferably as databases; e.g. the newly released diamond data package), and sharing data between the public and international partners. Another priority is the optimisation of case handling by: maintaining the one-door approach, improving knowledge and information on application procedures, shortening turnaround times by utilization of online portal, simplifying the Mineral Resource Act, simplifying guidelines and reporting requirements. Other aims include: a simpler transition from exploration to exploitation; extending the sustainable development of the mineral resource industry; maximizing the socio-economic benefits from mineral resource activities; improving information about consultation processes; aiming to increase the social license to operate; and improving the taxation and royalty model for competitiveness using benchmark analyses for both monitoring and optimizing the taxation and royalty model is mentioned (Ministry of Mineral Resources 2020b).

The MRA frequently participate in marketing events such as PDAC and AME Roundup in Canada to attract investors to the Greenland mineral industry.

There is continuing release of free data packages to the industry by the MMR, with datasets and overviews of: current and historic relevant exploration data, a gemstones database, and other geological and geophysical data and information, currently made available via www.govmin.gl and www.greenmin.gl. The aim is to give incentives for further exploration and attract additional investments. The new mineral strategy aims to expand and maintain this principle of promotion and marketing of freely available information. The effect of this focus will be revealed within the coming years.

Greenland Venture A/S, the Government of Greenland funded investment program, and Vækstfonden, the Danish Government investment fund, have entered a 220 million DKK partnership (2019) for business development in Greenland and has invested heavily in mining projects (more than 78 million DKK) since 2019. The apparent willingness of state-funded investment programs could be a valuable incentive for attracting foreign investments.

The recent opening of two mines in Greenland, the Aappaluttoq ruby mine by Greenland Ruby A/S and the White Mountain anorthosite mine by Hudson Greenland A/S, was a major step towards Greenland establishing an active mining sector that, in the long term, could generate a more stable economy being less dependent on the fishing industry. However, investors are driven towards profitability of mines. So far, neither the Aappaluttoq ruby mine nor the White Mountain anorthosite mine has become profitable (Hudson Resources Inc. 2019a, Danilov 2020. The success of these projects may prove vital for the evolving mining industry in Greenland (personal comm. B. Olsvig, formerly Xploration Services A/S 2020).

2.5 Infrastructure and logistics

The vast, uninhabited areas and the rugged terrain of Greenland can be a challenge for mineral exploration and exploitation. Transport wise, most areas cannot be reached by roads or fixed-winged aircraft, making reliance on helicopters and boats during early project stages. Consequently, some mining projects have suggested, or planned, to establish an air strip in connection to each planned mine site. Furthermore, mineral exploration and mining activities will have to provide for their own energy and water supplies and communication lines.

The remoteness can cause present-day challenges because in large parts of Greenland there are no infrastructure such as electricity, cell phone reception, roads and airstrips. All these crucial infrastructures would need to be constructed in order to get a mine into production.

The Inland Ice and associated lakes and runoff could provide hydroelectric power, and therefore some projects conduct hydroelectric power feasibility studies, which may be cost-effective over the mine's life span. This could also provide nearby communities with green power and give the mining projects a 'green signature'.

A recent amendment in the 'Storskala Act' allows mining companies to hire foreign contractors for the construction phase in large construction projects (above 1 billion DKK), provided that no Greenlandic contractors can comply with the tasks. The salaries in such projects are less than the minimum wage in Greenland and is legally accepted during the construction period (Government of Greenland 2012). This enables the mining and hydroelectric power industry to potentially complete mining related construction projects, that would otherwise have been delayed or rendered impossible given the shortage of workforce in the construction industry (see section 2.2).

Wind power is an alternative to the otherwise diesel-powered generators that run in most towns and settlements without hydroelectric power facilities. The potential of utilizing wind power in towns and settlements is currently being tested in Sisimiut. In Arctic Canada, it has proven viable in the Glencore Raglan Mine (Glencore Canada 2018).

Airstrips for fixed wing aircrafts are possible to construct in areas with gentle topography, typically near the coast. For instance, Dundas Titanium A/S is planning to construct an airstrip for their ilmenite project in NW Greenland (Dundas Titanium A/S 2019).

The numerous fjords in Greenland, often several hundreds of meters deep, offer natural deep-sea access ideal for construction of ports for large bulk carrier boats. This is the case for the White Mountain Project as described in chapter 3.

The cost of exploration in Greenland is considered relatively high in terms of logistics, infrastructure and goods (Taagholt & Brooks 2016). Many companies are apparently surprised by the cost of conducting exploration in Greenland (personal comm. B. Olsvig, formerly Xploration Services A/S 2020). The currently main issue for mining companies is the reluctance by investors to support and develop projects due to memories of the value destruction during the last downturn (Fowler 2019; PwC 2019). As such the transition from exploration to exploitation must be as simple and swift as possible, in order to meet the short timelines required by some companies and market forces. The Mineral Strategy 2020–2024 focuses on this transition. However, another concern expressed by the industry is the long case handling time and non-transparent application process (personal comm. B. Olsvig, formerly Xploration Services A/S 2020; Stedman et al. 2019).

2.6 Mining waste and waste management

Mining in Greenland must be carried out in accordance with good international practice and as stated in the approved EIA. For these matters, mining companies are legally required to apply Best Available Techniques (BAT), Best Environmental Practice and Best Practicable Control Technology. Similarly, discharges and emissions from power plants, incineration plants and process plants must comply with EU standards, or other standards if they represent a better solution regarding best practices (Johansen et al. 2015). Rules for waste management depend on the location and project. More information regarding environmental regulation is available at www.eamra.gl.

The closure plan in mining operations and certain exploration activities requires companies to set aside a specific monetary amount in an Escrow account that corresponds to the estimated cost of rehabilitation. This account is managed by the MRA. After the rehabilitation is complete the amount corresponding to the rehabilitation plan may be reimbursed to the company from the Escrow account by the authorities. This requirement to deposit a large monetary sum into the Escrow account before a project generates free cash flow makes a challenge for the mining companies to convince potential investors to invest. It can result in mines not being able to go into operation (personal comm. P.

Madsen, Greenland Ruby 2020; personal comm. B. Olsvig formerly Xploration Services A/S 2020). The importance of rehabilitation cannot and should not be lessened. However, the means by which companies must ensure proper rehabilitation could be changed from the current format (MonTec GmbH 2008). Several foreign insurance companies offer insurance for the rehabilitation guarantee, or security deposit as it is called in Greenland (e.g. Lombardins Insurance Company Ltd. and others). By amending the legislation to include the option of a third-party mining rehabilitation guarantee, the immediate risk for both the companies and its investors would be lowered whilst maintaining best practices for rehabilitation and closure plans (Lombardins 2019, MonTec GmbH 2008).

2.7 Social License to Operate (SLO)

A recent study by Agneman (2018) showed that the majority of the Greenlanders are positive towards mining. There are, however, concerns about: resultant limitations of the right to perform traditional ways of living in areas where mining activities occur (e.g. caribou hunting), and the impacts of a foreign workforce. Agneman (2018) showed that 53% of the Greenland population was positive towards mining and only 21% negative. Hansen & Johnstone (2019) found that distance to the mining project influences inhabitants' attitudes. The proximity to the Kvanefjeld REE project in South Greenland is a typical exemplification of the NIMBY (Not In My Back Yard) against mining (Hansen & Johnstone 2019). Conversely, Agneman & Leander (unpublished) conducted a public survey which clearly showed that, in general, the Greenland population is more positive towards mining the closer they are to a mine, with less positive views increasing with the distance to the mine. One flaw of the latter study is that there are no apparent consultations with people located within 20 km from a potential mine site. Therefore, the social acceptance of mining activities in Greenland is complicated and maybe project specific.

3 Case Study 1 – White Mountain Project

3.1 Discovery and description of the deposit

The White Mountain anorthosite (Figure 16) was first described in 1946 by Knud E. Rasmussen, during an expedition by the Geological Survey of Greenland to the Kangerlussuaq-Sisimiut area. The anorthosite body was at that time estimated to be 3 to 4 km^3 (Knudsen, Wanvik & Svahnberg 2012). The white colour of the 1,300 m high mountain led to its' Greenland name Qaqortorsuaq (The Great White). The area, roughly 80 km southwest of the international airport in Kangerlussuaq (Figure 17), was explored by Kryolitselskabet Øresund A/S in 1977. In 2007, Hudson Resources Inc. drilled the western part of the mountain in search of diamonds, which was unsuccessful. The area then laid dormant, until 2012 when interest in anorthosite for industrial uses and as a possible source for aluminium was renewed (Knudsen, Wanvik & Svahnberg 2012). Based on the 2007 drill cores, which revealed a substantial anorthosite resource, both Greenland Gold Resources and Hudson Resources Inc. started to explore the Qaqortorsuaq and surrounding areas in 2012 (Druecker & Simpson 2013). Greenland Gold Resources had an exploration license for the eastern part of the area while Hudson Resources Inc. focused on the western part of the mountain.

Figure 16. **The White Mountain seen from the air, Qaqortorsuaq in native spelling. Modified from Hudson Resources Inc. 2015a.**

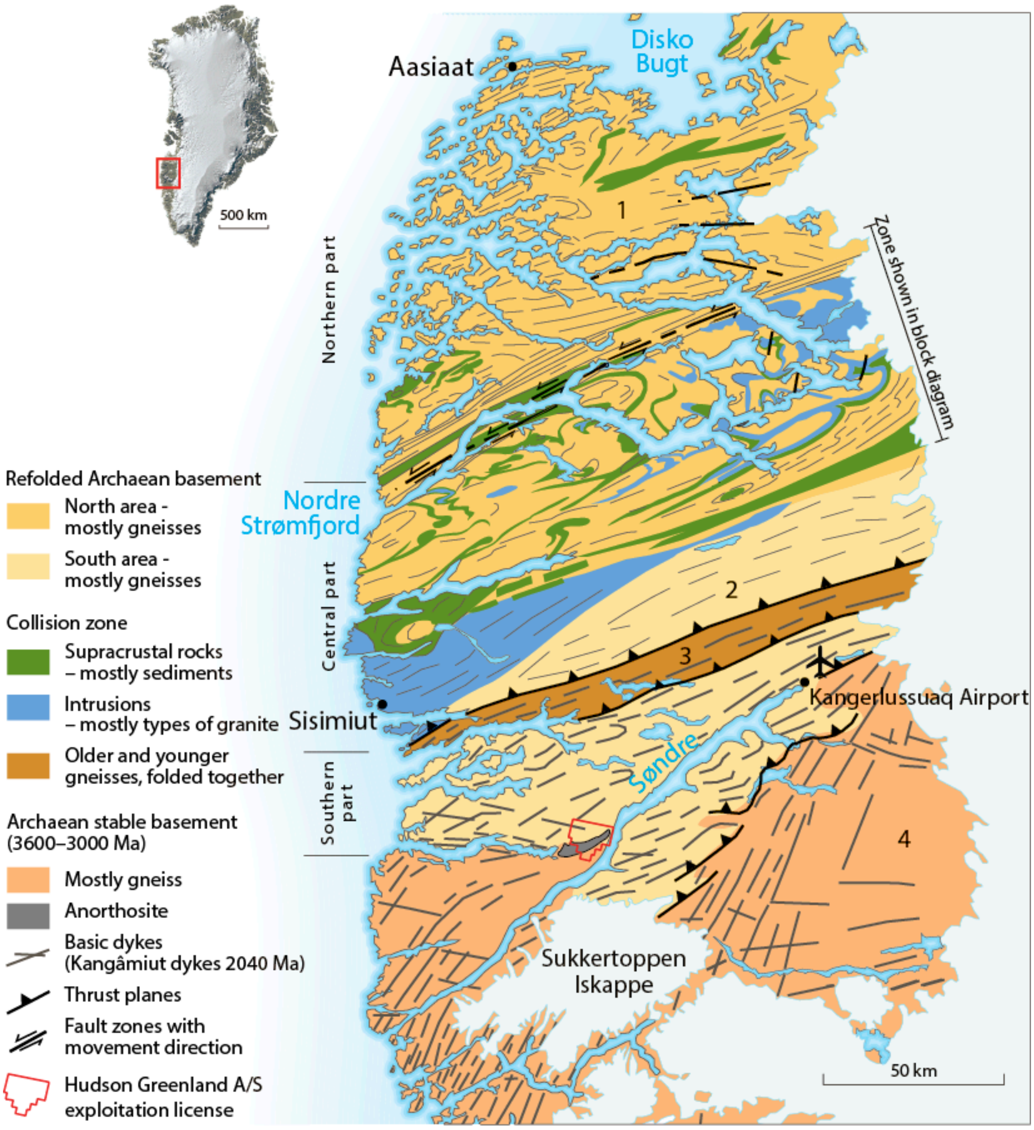

Figure 17. Simplified geological map of part of West Greenland. Hudson Greenland A/S' exploitation license at the White Mountain is marked with the red box. Modified from Henriksen (2006).

Anorthosite complexes are made up of more than 90% anorthite, a calcium rich feldspar. These complexes are relatively common in the Archaean basement in Greenland, where it regionally may constitute 5% of the bedrock (Knudsen, Wanvik & Svahnberg 2012). The anorthosite at Qaqortorsuaq is characteristically white, fine to medium grained and contains less than 8% darker minerals such as hornblende and biotite. The exact age of the rock is unknown, but from structural relationships with the surrounding rock, it is estimated that the anorthosite body formed more than 2,000 million years ago, probably in the Archaean (Lie & Østergaard 2014).

During two field seasons the Canadian based Hudson Resources Inc. identified a NI43-101 compliant resource of 27 million tonnes anorthosite (Hudson Resources Inc. 2013). For the necessary EIA, contemporarily environmental baseline studies were performed. In March 2015 the newly created company, Hudson Greenland A/S, based in Nuuk, applied for an exploitation permit. In just six months, September 2015, Naalakkersuisut (Government of Greenland) approved the application, paving the way for production. The company spent the following years securing investments and finalizing production and closure plans. All permits were eventually achieved in 2017. The construction of infrastructure was thereafter commenced, and included roads, production facilities, housing and a deep-sea port. The first official blasting and processing of the ore was in December 2018, and the first concentrate was shipped in fall 2019. The cost of the construction was 45 million CAD$, and was secured via capital from multiple funding's, including the Government of Greenland owned Greenland Venture A/S, who invested 4 million CAD$ in the project (4.49% ownership), in addition to debt financing (Hudson Resources Inc. 2019b). Hudson Greenland A/S sole owner is Hudson Resources Inc.

3.1.1 Mining operation

The White Mountain Project is an open pit mine, from which anorthosite is directly drilled and blasted (using ammonium nitrate and diesel) from 10 m benches into the hillside; there is no overburden that needs to be removed. The mining and primary crushing at the pit is simple, and well-tested equipment such as excavators, drill rig and loaders are used (Inuplan 2015). The blasted rock is transported in 45-tonnes haul trucks to the primary mobile jaw and mobile cone crusher, which reduces the grain size to less than 35 mm, before feeding into the process facility. The mining operation will ensure that 285,000 tonnes of anorthosite is crushed and supplied to the process facility on an annual basis (Inuplan 2015) when production is fully scaled-up. The process facility including primary crushers are located downhill from the pit area.

3.1.2 Process facilities

The process facility (Figure 18) is located at the port site. The processing plant itself consists of a tertiary crusher and a magnetic separator. The processing will reduce grain size to 0.841 mm and 0.074 mm after de-dusting. The processed ore is fed into a dry magnetic separator to remove iron contamination. The plan is to operate the process plant 24/7 for 300 operating days per year, once production is fully scaled up. The plant will operate at an optimum 42 tonnes per hour with a 70% recovery rate with 15% loss from dust removal and 15% iron particles removed via magnetic separation. The tailings from the process facility, including the magnetic rejects, are expected to amount to approx. 85,000 tonnes per year. The tailings are pumped to a disposal site at the bottom of a nearby lake. The tailings contain no significant metal content, and no acid generating potential. As such the waste rock is classified as inert (Inuplan 2015). A simplified process design is seen in Figure 19.

Figure 18. Processing facility at the White Mountain Project. Notice the port nearby. Copyright Hudson Resources Inc.

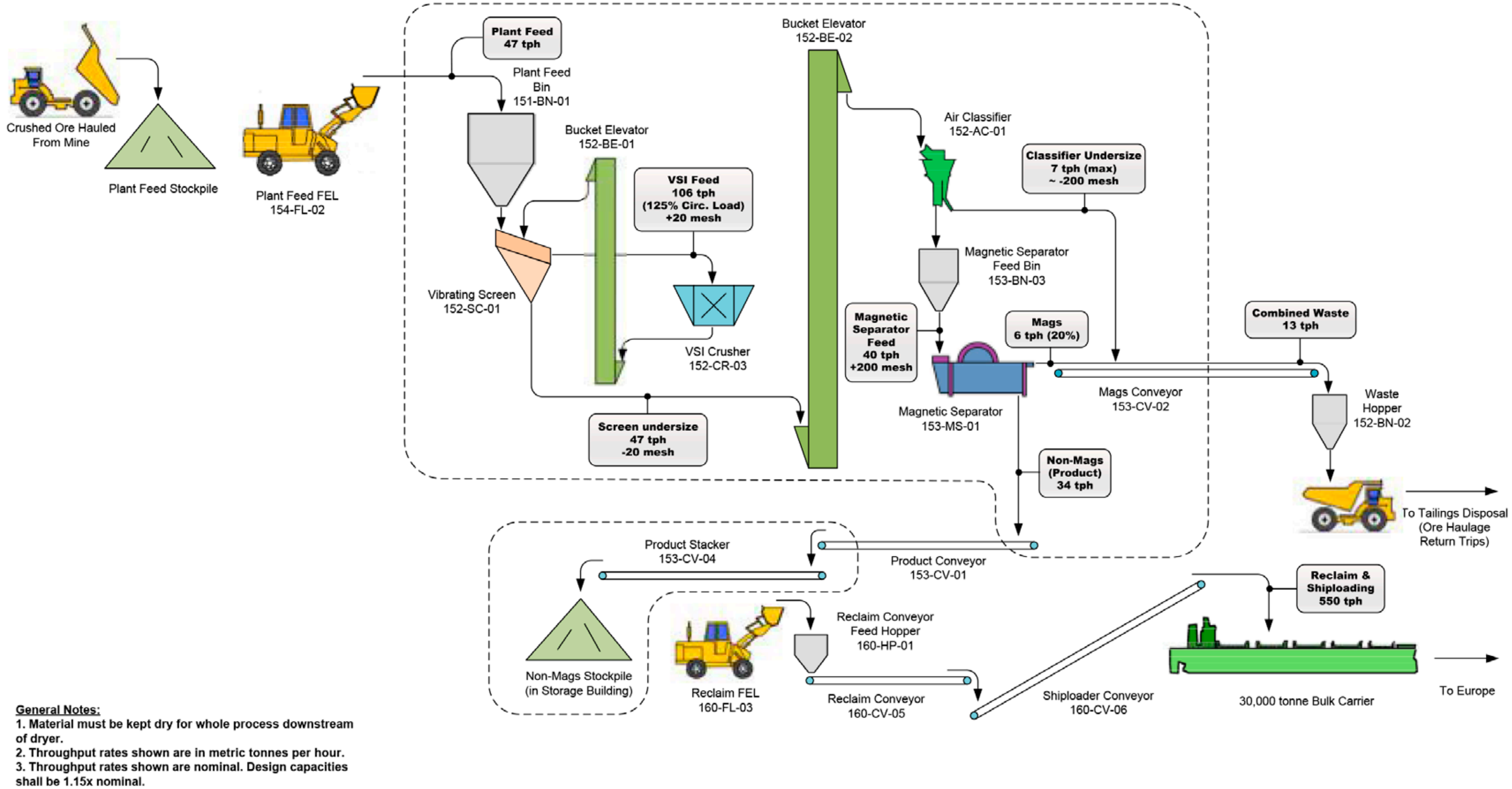

Figure 19. Simplified process design of the White Mountain Project. Modified from Hudson Resources Inc. (2015a).

3.1.3 Infrastructure

The process facilities as well as accommodation and administrative buildings are powered by two 400 kW diesel generators, suppling 750 kW in total. An additional 25 kW diesel generator is deployed at the quarry to power blasting and drilling operations. Alternative power supply such as wind and/or hydroelectric power have been investigated but proven inadequate. The discharge from the streams and rivers in the vicinity is too low for a run-off river hydroelectric power facility, and there are no suitable lakes. The nearest possible location is across the Kangerlussuaq Fjord, in the protected area known as 'Paradise Valley'. Similarly, the mean wind velocity in the area is well below the 5 m/s required for a traditional windmill (Inuplan 2015).

3.1.4 Water and waste management

Organic and hazardous waste is handled according to best international practices, as determined by the MRA's rules and guidelines. Organic and hazardous liquid waste is incinerated or disposed by other means if agreed with the EAMRA. According to the EIA for the project, two bio-film sewage treatment systems, compatible with EU-regulation, shall ensure that the discharge into the Kangerlussuaq Fjord is below threshold values. During the construction phase, temporary solutions are in place for waste management (Hudson Resources Inc 2015).

Water for both operation and personal consumption is supplied from a nearby lake. Drinking water is treated according to standards, e.g. by using particulate filters and UV sterilization systems.

3.1.5 Technical applications of GreenSpar

GreenSpar is the trade name of the anorthosite rock, which has been milled to less than 250 µm. Currently it is available as GreenSpar 250 and GreenSpar 90, with grainsizes less than 250 and 90 µm respectively. The GreenSpar products are to be used in E-fiberglass production as a replacement for kaolin, which could decrease energy cost by up to or more than 10%, lowering the heavy metal content and decreasing melt time. The use of GreenSpar can potentially, with additional development, result in white CO_2-free cement (Hudson Resources Inc 2019c). Adding phosphoric acid to the GreenSpar product results in a strong, heat resistant, white cement, which requires no addition of CO_2, contrary to common Portland white cement, while improving acid resistivity. Other applications of the GreenSpar product include as an extender or filler in paint and coatings, or as a primary source of aluminium metal (Hudson Resources Inc. 2019c).

3.1.6 Challenges Experienced

The lack of skilled labour in Greenland is critical. According to the IBA, Hudson Greenland A/S aim for 80% of the workforce to be Greenland labour; see section 2.1.1. However, the company have been unable to meet this obligation. At the start of the operation, 60% of the workforce were Greenland workers, but since the start of the nationally funded, major building projects for new international airports in Nuuk and Ilulissat, the company have lost 70% of its Greenland workforce. The company are unable to hire Greenland workers, as "There are virtually no skilled workers available anymore" (personal comm. Hudson Resources Inc. 2020) and therefore the Greenland workforce at the project is below 25%. Skilled workers are instead contracted from outside Greenland, typically Canada, which inevitably increases operating cost. Hudson Resources Inc. has estimated this to be up to 30%. Furthermore, work permits have proven difficult to obtain, and apparently some hired workers have even been detained at the airport, with all permits in order but evidently due to slow case handling by the Danish immigration authorities acting on behalf of Greenland (personal comm. Hudson Resources Inc, 2020).

The production plans were delayed due to technical and practical complications, as the secondary (High-Pressure Grinding Rolls) crusher was only operating at 55% capacity, this "… due to inadequate drivers supplied by the manufacturer" (Hudson Resources Inc 2019a). Waiting for a new motor and driver delayed the project for 12 weeks. Furthermore, hurricane Dorian in August 2019 destroyed port facilities in Florida, with whom the company had an agreement for shipping. Currently, production is on care and maintenance (December 2019) during the winter of 2019/2020, while awaiting new equipment (rotary drum dryer), that will heat the mined rock, as the cold temperatures have been found to lower the iron extraction and thereby degrade the purity of the GreenSpar product. With the purchase of a new rotary drum dryer, the company expects the process plant to achieve year-round production (Webb 2019).

By February 2020, more than 14,000 tonnes of the GreenSpar product have been shipped to the port facilities in Charleston, USA. In November 2019, the Company announced its first sale of 5,000 tonnes of its GreenSpar product, to a customer in the US. The company have signed a 10-year supply agreement with an E-fiberglass manufacturer, however with no guaranteed annual purchase.

3.1.7 Land and Conflicts

There is no apparent conflict on the license area with regards to cultural heritage. The White Paper states no concerns regarding hunting and fishing activities in the area, as these were already limited (Hudson Resources Inc. 2015).

4 Case Study 2 – Isua Banded Iron Formation

4.1 Discovery and description of the deposit

In 1965, a large area containing a rich, banded iron formation was discovered at Isua, approx. 150 km northwest of Nuuk, the capital of Greenland (Keto 1970) (Figure 20). The Isua deposit is part of the 3.7–3.8 Ga years old Isua Supracrustal Sequence and the deposit is hosted within the banded iron formation part of this sequence. The area hosts the most extensive occurrence of early Archaean supracrustal rocks known on earth (Henriksen et al. 2000). The orebody is dipping 45° to the East, and a substantial part of the deposit is covered by the Inland Ice, which is up to 200 m thick at the deposit. As such, almost 2/3 of the ore body is covered by the Inland Ice, which requires an immense redistribution of ice to access the ore (Orbicon A/S 2013).

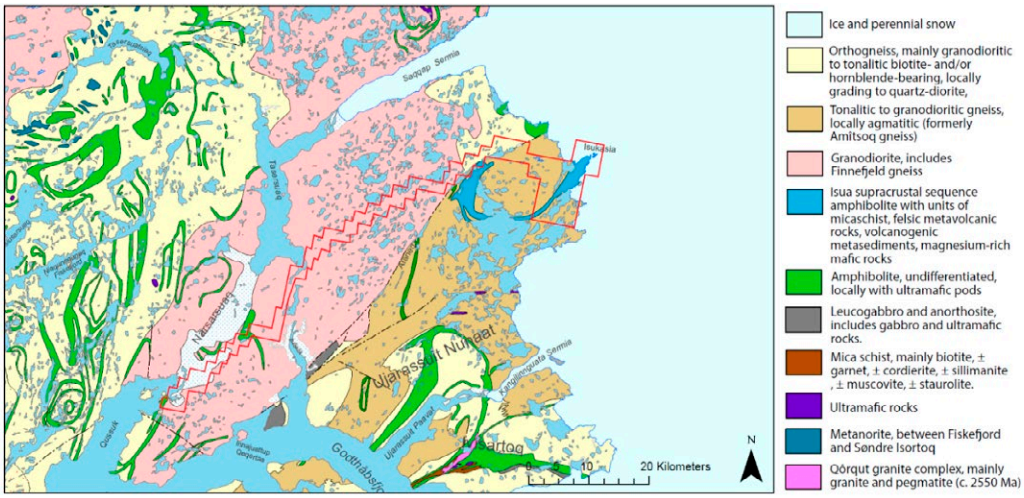

Figure 20. The location of the Isua Banded Iron Formation and Nuuk. License area in red. Source: GEUS.

Following its discovery, the area was then explored almost continuously by both researchers and industry for 40 years, and in 2005, London Mining Plc. acquired a sole interest in an exploration license covering the area. Over the next 6 years, 60 drill holes comprising more than 20,700 m of core were completed in the area, in addition to completing the required EIA, SIA and a bankable feasibility study (BFS). An indicated and inferred JORC-compliant resource (comparable to the NI-41-103) of 1,107 million tonnes of iron ore, averaging 32.3% Fe has been identified, of which, 380 million tonnes are in the indicated category. According to the proposed mine plan in the feasibility study, the ore will be processed on site to produce 15 million tonnes of iron-ore, grading 70% Fe annually, to be sold as Premium Blast Furnace pellet feed (London Mining Plc. 2012a).

The pre-feasibility study is based on 341 million tonnes of the indicated iron ore resource, and in order to extract this resource, 286 million tonnes of waste rock and 181 million tonnes of ice must be excavated/extracted in order to access the ore body. The production of iron concentrate from the 35-million- tonnes iron-ore mined annually is expected to generate 15 million tonnes of premium 70.2% Fe blast furnace pellet feed (London Mining Plc. 2012a).

On overview of the location of the mine relative to Nuuk, the port site and mine site can be seen in Figure 21.

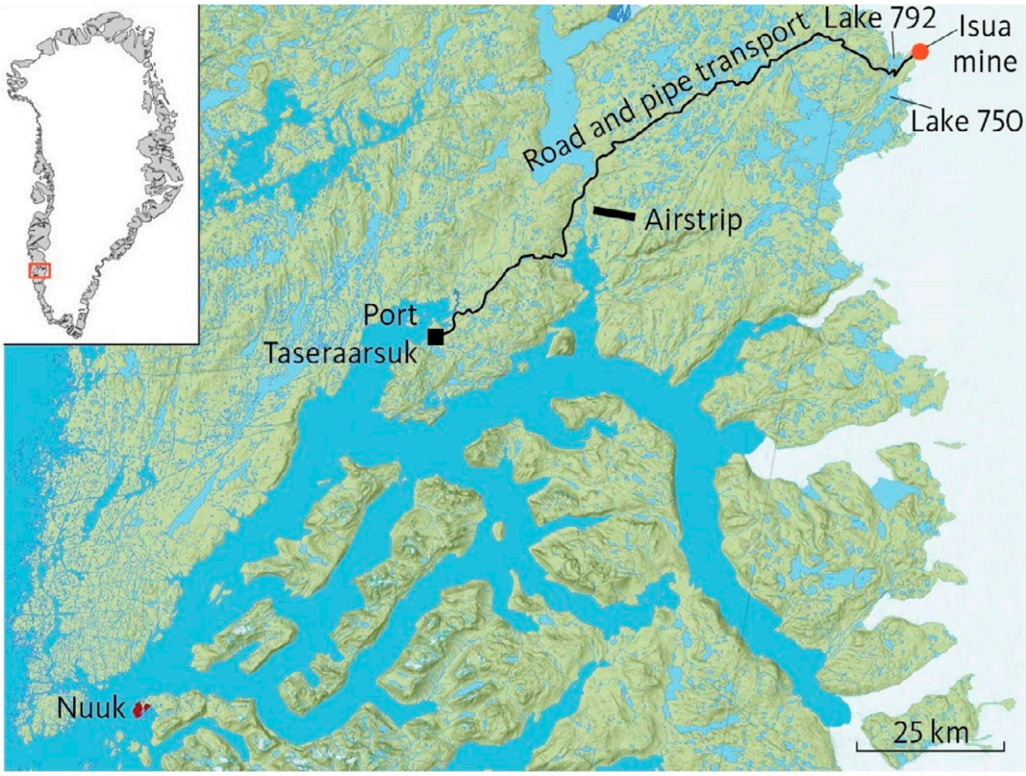

Figure 21. Infrastructure for the Isua project. Mine and process facilities are at the ice margin, 1,000 m above sea level and approx. 105 km from the port, where the iron ore will be shipped from. A long road, bridges, pipelines etc. need to be established from the mine to the port. After Orbicon A/S (2013).

4.2 Project status

The capital expenditure (CAPEX) is estimated to 2.35 billion US$ (London Mining Plc 2012a).

From 2011 to 2016, iron ore prices dropped 78%, well below the limit of 45 US$/t Fe, which is the operational cost of the mine, excluding freight cost (Fouche 2016). Iron ore prices has since partially rebounded and closed at 91 US$/t Fe on December 2, 2019. However, the current production capacity and expected falling demand for steel especially in China, suggest falling or stagnating iron ore prices towards 2030 (World Bank Group 2020). Therefore, it is unlikely that the project will be able to achieve enough funding to commence production within the coming years (Fouche 2016), especially considering the production cost which is more than double when compared to the iron ore producers in Australia (Du 2015). In 2015, the Government of Greenland approved the transfer of the ownership of London Mining A/S to General Nice Development Limited, a Hong Kong based conglomerate with more than 12,000 employees and an annual revenue of 18 billion US$. The hope was that General Nice Development Limited was able to acquire the necessary 2 billion US$ for CAPEX.

With an exploitation permit comes a requirement to start production within a specified period. The deadline for approval of production and closure plans has been postponed until the end of 2020, and the deadline for the start of production until 2025. The company awaits higher iron prices and substantial financial investments in the project before finalizing the IBA and commencing production.

As part of the exploitation license, the company must make a security deposit to cover the expense of rehabilitation of mining activity. These funds are locked in an Escrow account managed by the authorities. The company will be reimbursed for expenses to rehabilitation after approval.

4.2.1 Process facilities

In the original plan the construction phase for the Isua mine was stipulated to take three years.

Primary crushers will be installed near the open-pit and from there, the crushed rock will be transported to the process facility on a closed overland conveyor belt 3 km SW towards the process plant. The process plant consists of additional secondary cone and jaw crushers, a magnetic separation facility and flotation plant for iron enrichment (Figure 22).

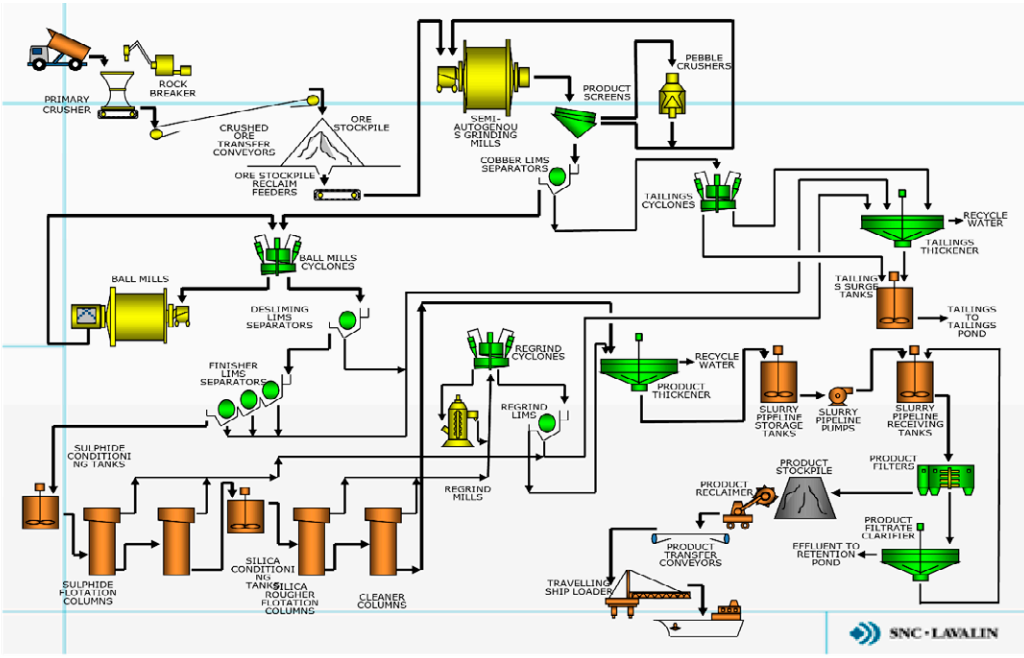

Figure 22. Simplified map of the Isua project process flow diagram. Source: Orbicon A/S (2013).

The crushed ore will be milled to less than 2 mm using semi-autogenous grinding. This material will then enter a ball mill for finer grinding. Both milling/grinding operations occur with the Fe-ore in suspension as slurries. Next, the milled ore is processed through a magnetic separator in which the non-magnetic fraction is discarded to the tailings. The residual high iron rich ore will enter the flotation facility in order to remove impurities such as silica and potentially sulphides. Impurities from this process will be deposited at the tailings depot for waste rock. The iron concentrate will be transported as a slurry in a 105 km long pipeline to the port that is planned to be constructed at the Taseraarsuk Bay (Orbicon A/S 2013).

The bankable feasibility study suggests no technical or economically viable alternatives to the suggested process steps as described above. Both ball mill crushing, and flotation is necessary to reduce the levels of silica and potentially sulphur in the iron ore concentrate (Orbicon A/S 2013).

4.2.2 Infrastructure

Energy

The process facilities, accommodation and similar facilities will be powered by a diesel power plant to be established near the process facilities. The power plant will have a nominal capacity of 130 MW. Furthermore, the port facilities will house a smaller 25 MW power plant, also powered by diesel generators, bringing the total capacity up to 155 MW.

In comparison the hydroelectric power plant at Buksefjorden, which supplies the capital with electricity and heating is only generating 45 MW (Table 3). The diesel fuel will be stored at the harbour and transported through a pipeline to the mine area (Orbicon A/S 2013)

The use of hydroelectric power as an alternative to the diesel-powered power plant, suggested in the study has also been investigated. The possibility for hydroelectric power is present, but not suitable since the added cost of construction of hydroelectric power (892 million US$) far out-weighs the reduction in operating costs (160 million US$). Furthermore, the installation and background studies would delay the project for an additional 3 years, not including negotiations with the authorities and the company which currently hold the right for the hydroelectric power potential in the area (Macedo & Kurktchiev 2012).

Mining area

The open pit mine will be excavated in 14 m tall benches, spiralling downwards; wide enough to carry two 227-tonnes dump trucks. The excavation will be done using drill rigs and explosives. Melt water from both the Inland Ice, permafrost, precipitation and the surroundings, will be redirected to the designated water supply lake (Figure 23) (Orbicon A/S 2013).

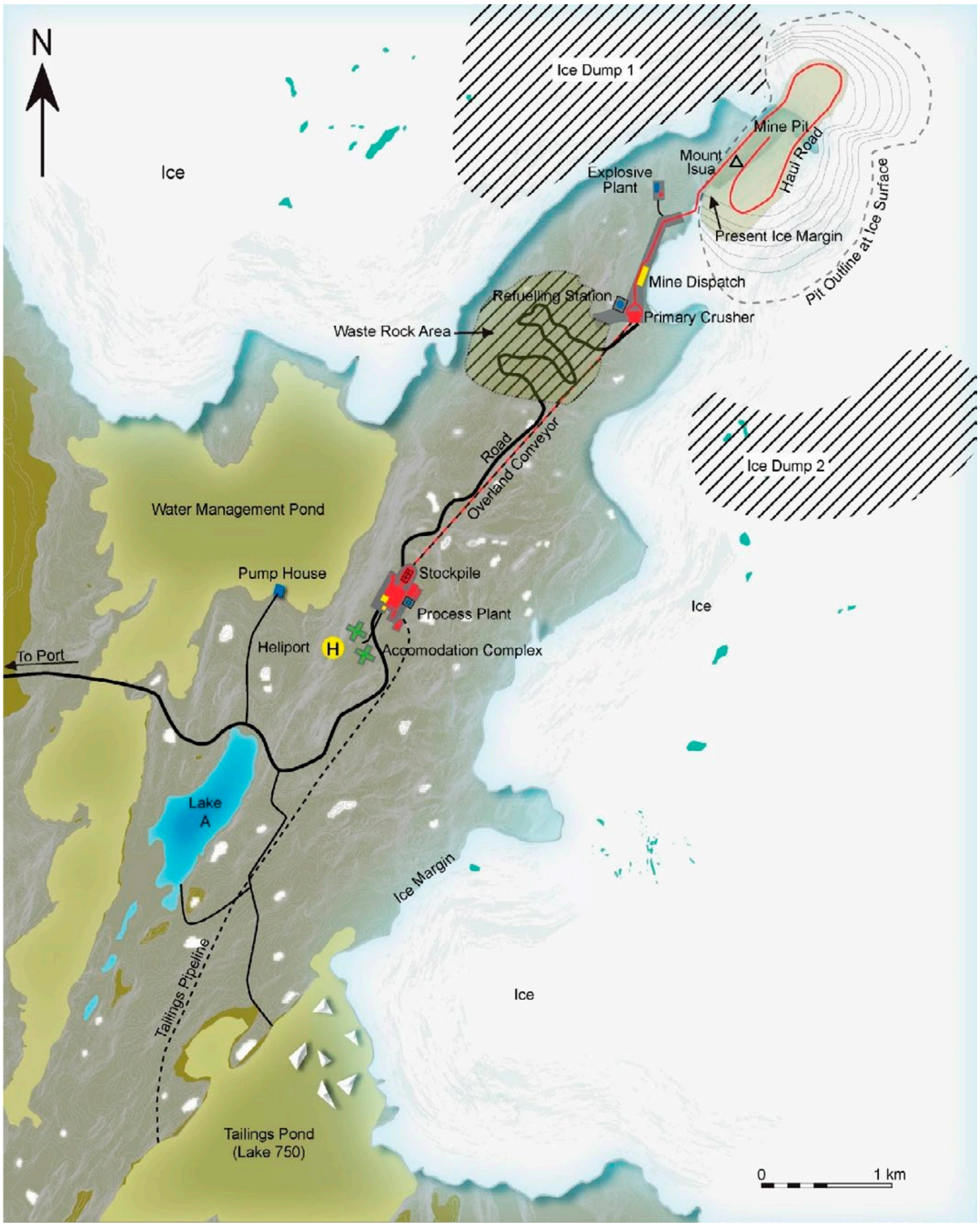

Figure 23. Map of a possible production of iron ore from Isua. The open mine will be surrounded by ice on three sides. Lake 750 is planned for tailings. After Orbicon A/S (2013).

Accommodation

Offices, sleeping quarters, kitchen and dining facilities, indoor areas for recreational activities and general service space are planned to accommodate 460 persons near the mine. Accommodation for a further 169 persons will be established at the port area.

Roads and access

A 105 km long gravel service road for trucks and vehicles will be established from the port area to the process facility. The bankable feasibility study furthermore holds an option to construct a minor airstrip (1,100 m) suitable for Dash type aircraft (Air Greenland's domestic aircrafts) and helicopters, mainly used for movement of personnel, baggage and supplies (Figure 23).

4.2.3 Waste management

The waste rock and ice comprising 585 million tonnes will be removed and deposited at three separate tailing sites. The waste rock is classified as inert waste per an ABA test (Acid-Base-Accounting). Solid waste will be collected and incinerated as per BMP (former name for MMR) guidelines. Hazardous waste is planned to be disposed of as per regulations in Sermersooq, Municipality and predominantly shipped to Denmark for further processing in accordance with EU regulations (Orbicon A/S 2013).

4.2.4 Water management

Water for process facilities will be pumped from Lake 792, which is a large glacial lake with no or low biological activity. By testing, it has been found unsuitable for drinking. Water for consumption and similar will be pumped from local non-glacial lakes with a minimum requirement for water treatment (Orbicon A/S 2013)

4.2.5 Land and Conflicts

A large part of the license area and the area for planned infrastructure is in an area where locals hunt and where caribou's breed. The project is expected to have an impact on caribou migration paths, especially during the construction phase. Nevertheless, the EIA, after public consultation, was approved in 2012, to the dismay of local NGO's (Kleemann 2012; Nuttall 2012). A great deal of the comments in the white paper, both local, NGO's and public associations, involve the opt out of hydroelectric power in favour of diesel-powered generators, which would increase Greenland's CO_2-emissions by 89% (2012 numbers). For the critics, the use of hydroelectric power should be a prerequisite for approval in order to be in line with the national strategy on green energy consumption. However, as stated in section 4.2.2 this would lead to a substantial increase in CAPEX and time delays for the project. Some of the most critical comments are from 'Nuuk Fjords Venner' (the Friends of Nuup Kangerlua) a local NGO with focus on the environment and local use of the fjords around Nuuk. They are generally concerned about the public consultations and express doubts on the approved EIA (Nuttall 2012). Their worries relating to the EIA were rebutted by the authorities and environmental consultants. KANUKOKA (the former association of municipalities in Greenland) also raised concerns around the massive civil criticism of the public consultations, which criticized the hearing period as well as the nature of the meetings which were perceived as public information sessions, rather than public consultations (Nuttall 2012).

It is estimated that the project will need up to 3,300 workers in the construction phase and around 760 during operation (London Mining plc. 2012b). In the SIA, London Mining Greenland A/S mention the challenge of finding an available workforce (Grontmij 2013). The project will most likely invoke a conflict or competition for labour between the construction industry as well as the remaining mining industry and public sector. A large proportion of the workforce will be imported Chinese workers, especially during the construction phase, and it is still expected that around 45% of the workers will be from China during the operational phase; the remaining will be from Greenland or other western workers (London Mining plc. 2012b). The concerns regarding many foreign workers as well as the environmental concerns have been raised in the Greenland national news (Redaktionen Sermitsiaq 2011).

5 Case Study 3 – Nalunaq Gold Mine, Kirkespir Valley

5.1 Discovery of the deposit and deposit description

The Nalunaq Gold mine is located in South Greenland at 60º21'N and 44º50'W in Kujalleq Municipality near Nanortalik. The climate is mild in South-Greenland and the fjords are ice-free in the winter.

There have been gold investigations in the area around Nanortalik since the 1980s by Mineral Investment International (MDI) and Greenex, but it was not until the beginning of 1990 that a more systematic exploration was conducted in the area by the Greenland-Danish exploration company NunaOil A/S and later by NunaMinerals A/S (Dahl 2003; Secher et al. 2008; Gilbertsen et al. 2017). In 1992, in situ visible gold was located in quartz veins for a distance of 800 m and was named 'Nalunaq', which in Greenlandic means 'the unknown' or 'the place that is hard to find', because it had taken several years of fieldwork and geological reconnaissance to find source for the gold (Gowen et al. 1993). The exploration of the ore and the area in South Greenland continued for more than 10 years, and the first conduit were drilled in 1998 (Secher et al., 2008). The timeline with events regarding the Nalunaq Gold Mine is shown in Table 7.

Table 7. Timeline with events regarding the Nalunaq Gold Mine, from early exploration and mining to the present (Dahl 2003, 2008; Secher et al,. 2008; Watkinson 2009a, b; Gilbertson et al., 2017; Olafsson 2020).

Period	Timeline of events at Nalunaq Gold Mine
1954–1980s	Mapped by the Geological Survey of Greenland. Uranium exploration in South Greenland, and radiometric airborne surveys and a systematic analysis of stream sediment samples were carried out.
1979–1980	Investigation for uranium, and radiometric surveys from the air and analyses of stream sediments.
1986–1988	Mineral Development International MDI (Nanortalik Minerals) collaborates with Greenex (former owner of Maamorilik mine), finds placer-gold in stream sediments.
1989–1990	Sediment samples and sampling of the scree slopes in the area.

Period	Timeline of events at Nalunaq Gold Mine
1989	NunaOil A/S analyses the samples from older stream sediment samples from the uranium surveys in 1979–80 for gold anomalies.
1991	Nanortalik Minerals relinquished the concession and NunaOil A/S took over the concession.
1992	Intensive mapping, sampling of scree slopes, 14 g/ton gold grade was found in float sample. A quartz vein with visible gold was in situ at level 200 m a.s.l.
1993	Cyprus Minerals became partner with NunaOil A/S and drilled the first 13 boreholes (3,000 m). The company were not satisfied with the results and left the project.
1994	Sampling and mapping the ore.
1995	8 drill holes (848 m) is drilled.
1996	Systematic sampling of the vein and mapping.
1997	Norwegian Mindex became partners with NunaMinerals A/S; sampling and mapping continued.
1998	37 drill holes (5,134 m) and 288 m tunnel + 2 mineshafts was quarried at level 400 m a.s.l. NunaOil A/S was divided into two companies; NunaMinerals A/S and NunaOil A/S
1999	19 drill holes (2,520 m) was drilled and the gold vein is exposed at 468–775 m, rock samples are taken with rock saws. Mindex merged with Canadian Crew Gold Corporation.
2000	Level 350 m and level 450 m were started and level 400 continued, all three tunnels were 400 m in length, 12 mine shafts were started and test quarrying on level 350 m (Figure 25).
2001	13 drill holes, tunnels and level 300 m were finished, extension of other tunnels and 5 new mine shafts begun, test quarrying on level 400.
2002	Extension of tunnels and 4 new shafts, test quarrying on level 450 m, the roads were upgraded.
2003	Extension of tunnels, preparation for the mine started where the roads were upgraded, harbour facilities and a permanent basecamp are built.
2004	Greenland's first gold mine officially opens, shipments of ore to Spain.
2006	Crew Gold Corporation buys the gold process plant at Nugget Pond, and gold from Nalunaq were shipped and processed in Newfoundland.
2007	NunaMinerals A/S sold their Nalunaq Gold Mine shares (17.5 %) to Crew Gold Corp. Crew Gold Corporation builds their own Anfo-plant (production of explosives). Mining at Mountain block started.
2008	Crew Gold Corporation eased production of gold due to the global financial crisis, low gold prices and high oil prices, the latter increased expenses for shipping and other expenditures.
2009	The license is transferred from Crew Gold Corp. to Angus and Ross Plc. (A&R). The mine is sold for 1.5 million US$. Angel Mining Plc. Create a subsidiary company Arctic Mining.
2010	A cyanide process plant was built inside the mine. The first gold bars were produced onsite Nalunaq Gold Mine.
2012	6,855 oz of gold were produced in the cyanide process plant.
2013	The mine closed in December due to fallen global gold prices and suspension of payments from creditors.
2016	During fieldwork the Icelandic company ARC found ore at 800 m.
2017	ARC change name to Alopex Inc., geological investigations in Nalunaq continued.
2018	Alopex Inc. changed name to AEX Gold Inc., geological investigations in Nalunaq continued.
2019	Greenland Venture and Vækstfonden invested 2.2 million US$ into reopening of the Nalunaq project. Underground exploration still ongoing.
2020	Greenland Venture and Vækstfonden invested further 2.6 million US$ to the Nalunaq project.

The Nalunaq gold deposit license was owned by Crew Gold Corporation from 1999–2009 and by Angel Mining Plc from 2009–2013. The license has since 2017 been owned by AEX Gold Inc. and exploration has been carried out by them since 2017 with the aim of reopening the mine for gold production (Gilbertson et al. 2017; Olafsson 2020; Sommer & Sørensen 2020).

In 2017, the amount of exploration data was substantial and included 30,478 m of surface drilling, 5,572 m of underground drilling, 458 surface samples and 7,519 underground samples (Gilbertson et al. 2017). In 2019, two investment funds, Greenland Venture A/S and Vækstfonden, gave 2.2 million US$ in support to further exploration and development of the Nalunaq project (Schultz-Nielsen 2019). Inn2020 the investment funds increased the grant from 2.2 million US$ to 4.8 million US$ (Sommer & Sørensen 2020).

From 2004 to 2013 367,000 oz of gold (11.4 tonnes were produced (Edison Invest Research Limited 2018) (Figure 24).

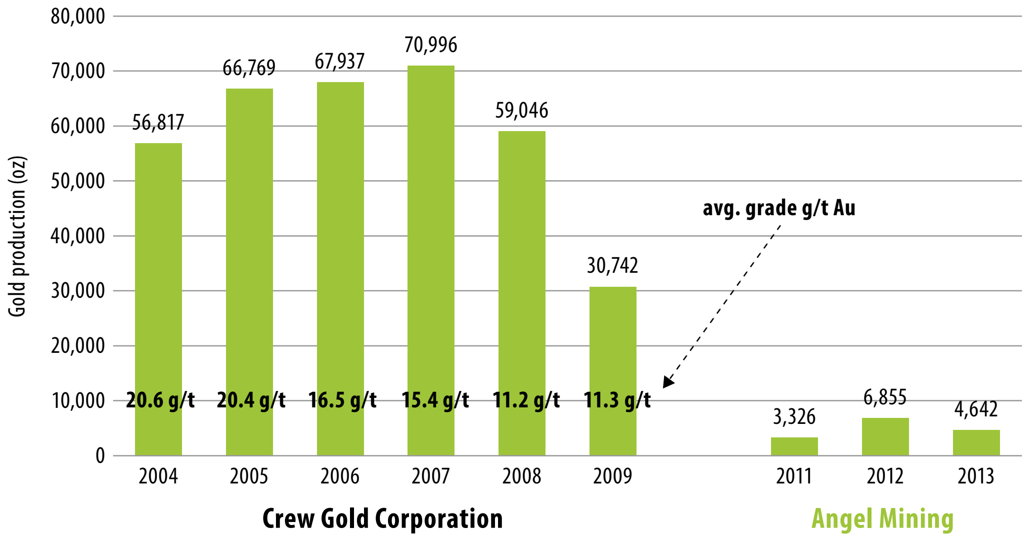

Figure 24. Gold production by Crew Gold Corporation (2004-2009) and Angel Mining (2009-2013). Source Edison Invest Research (2018).

Crew Gold Corporation 1999–2009

Crew Gold Corporation, a UK-based junior exploration company, took over the license of the area in 1999. The company owned 82.5% of the shares in the mine with 17.5% shares owned by NunaMinerals A/S. This setup continued until 2007, when NunaMinerals A/S sold their part to Crew Gold Corporation. In April 2004 the company were granted an exploitation license covering for 30 years and the mine officially opened.

Before the mine officially opened in 2004, Crew Gold Corporation estimated operation costs for two options: 1) shipping the ore to Europe or Canada and 2) to have a production facility in Nalunaq. The feasibility study showed the first option was the cheapest. In the two first years the ore concentrate was shipped to and processed at El Valle Plant of Rio Narcea Gold Mines Ltd. in Spain (Dahl 2003, 2008; Watkinson 2009b). Subsequent shipments were shipped to Nugget Pond in Newfoundland, which Crew Gold Corporation bought in 2006. In 2008, Crew Gold Corporation was financially constrained due to the global financial crisis affecting the global gold and oil prices, which ultimately made the expenses for shipping (and other goods) too high, and profit from gold too low (Rasmussen & Gjertsen 2018).

Out of 654,755 tonnes of milled ore, 352,307 oz of gold (11-tonnes gold) was produced, which gives an recovered gold grade of 16.7 g/ton (Gilbertson et al. 2017) (Figure 24). The mining method for both Crew Gold Corporation and Angel Mining Plc. was long-hole mining (Figure 25).

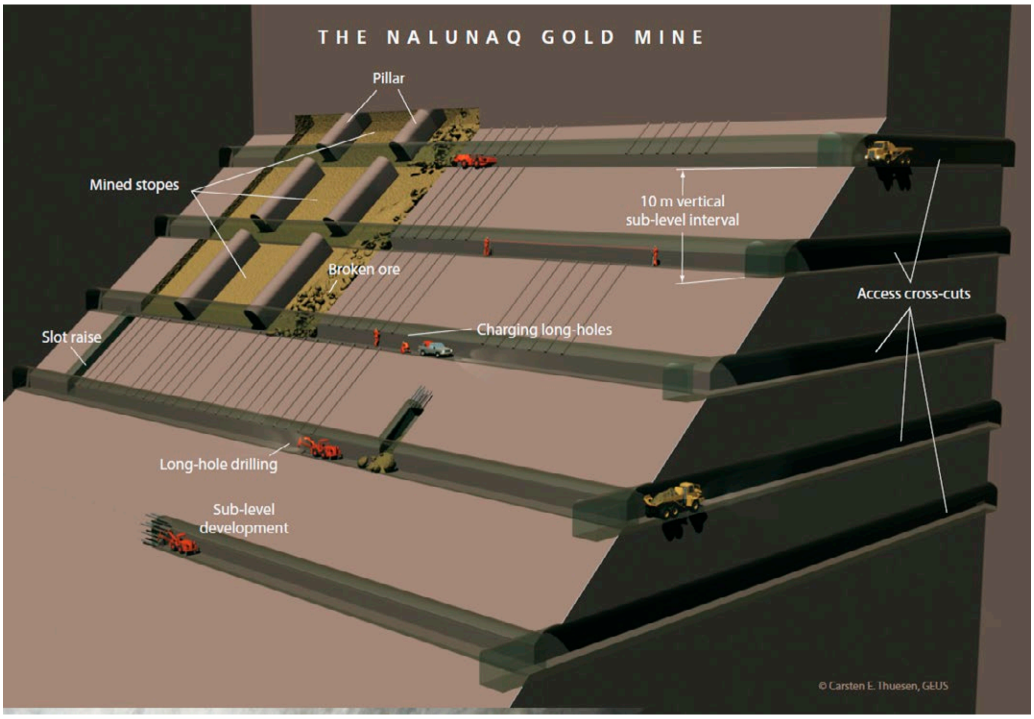

Figure 25. 3D model showing the applied mining method After: Secher et al., 2008.

When Crew Gold Corporation was operating the mine the labour force was on average 95 persons; 55% were Canadian, 35% Greenlanders, and approx. 10% Danish. The Greenland labour force were mainly from Nanortalik and Qaqortoq, and some of the local labour were educated to handle the different tasks in Nalunaq gold mine (Sejersen 2014).

NunaMinerals A/S wanted a production facility onsite. This and falling gold prices in 2007 led to the decision about selling their 17.5% shares in the Nalunaq Gold Mine for 13 million DKK to Crew Gold Corporation in 2007, and the license was then owned 100% by Crew Gold Corporation (Olsen 2007).

Angus & Ross Plc./Angel Mining Plc./Arctic Mining Ltd. 2009–2013

In 2009, the mine was sold to Angel Mining Plc. (daughter company to Angus & Ross Plc.) for 1.5 million US$ (Leftly 2009).

Angel Mining Plc. wanted to extract the gold inside the mine and designed and built a new mineral process plant before they could start to extract gold. The application granting permit process and installation of the process plant took approx. a year, but finally in 2010 the first gold bar was produced inside the mine tunnels using a cyanide leaching method (Watkinson 2009b; Edison Investment Research 2010) (Figure 26). However, by 2012 Angel Mining Inc. struggled to operate because the global gold price had declined by 17% (Sejersen 2014; Gilbertson et al. 2017).

Figure 26. **Smelting gold bars in the underground mine. Source: Edison Invest Research, (2010).**

5.1.1 Deposit description

The Nalunaq deposit (Nanortalik Gold Belt) in South Greenland is part of the Ketilidian Orogen formed by northward subduction of an oceanic plate under the southern margin of the Archaean craton in Palaeoproterozoic time (1,85–1,72 Ga). The Ketilidian Orogen is divided into domains from the foreland of the Archaean block: Border zone (Northern Domain), Julianehaab Batholith (Central Domain), the Psammite Zone + the Pelite zone (Southern Domain) (Garde et al. 2002, 2011) (Figure 27). The Nalunaq Gold Mine is in the Psammite Zone south of the Julianehaab Batholith (Figure 28). The quartz-vein is a mesothermal shear-zone-hosted narrow vein with high gold grades (Shlatter & Olsen 2011). The ore often has visible gold. The ductile shear zone is gold-bearing and cuts through the Nalunaq Mountain as a sheet with a strike of 45–50 degree and a dip of 36 degrees. The quartz vein is between 2 cm to 180 cm wide and pinches and swells; the average thickness is 30 cm. It consists of several quartz veins that are concentrated along the same shear zone (Dahl 2003, 2008; Secher et al. 2008; Hughes et al. 2013; Bell et al. 2017; Gilbertson et al. 2017) (see the lithologies in the Nalunaq mountain in Figure 29). The gold mineralisation is hosted in the Main Vein (MV). Crew Gold Corporation had defined three main areas of mineralisation, namely the South, Target and Mountain Blocks (Figure 30).

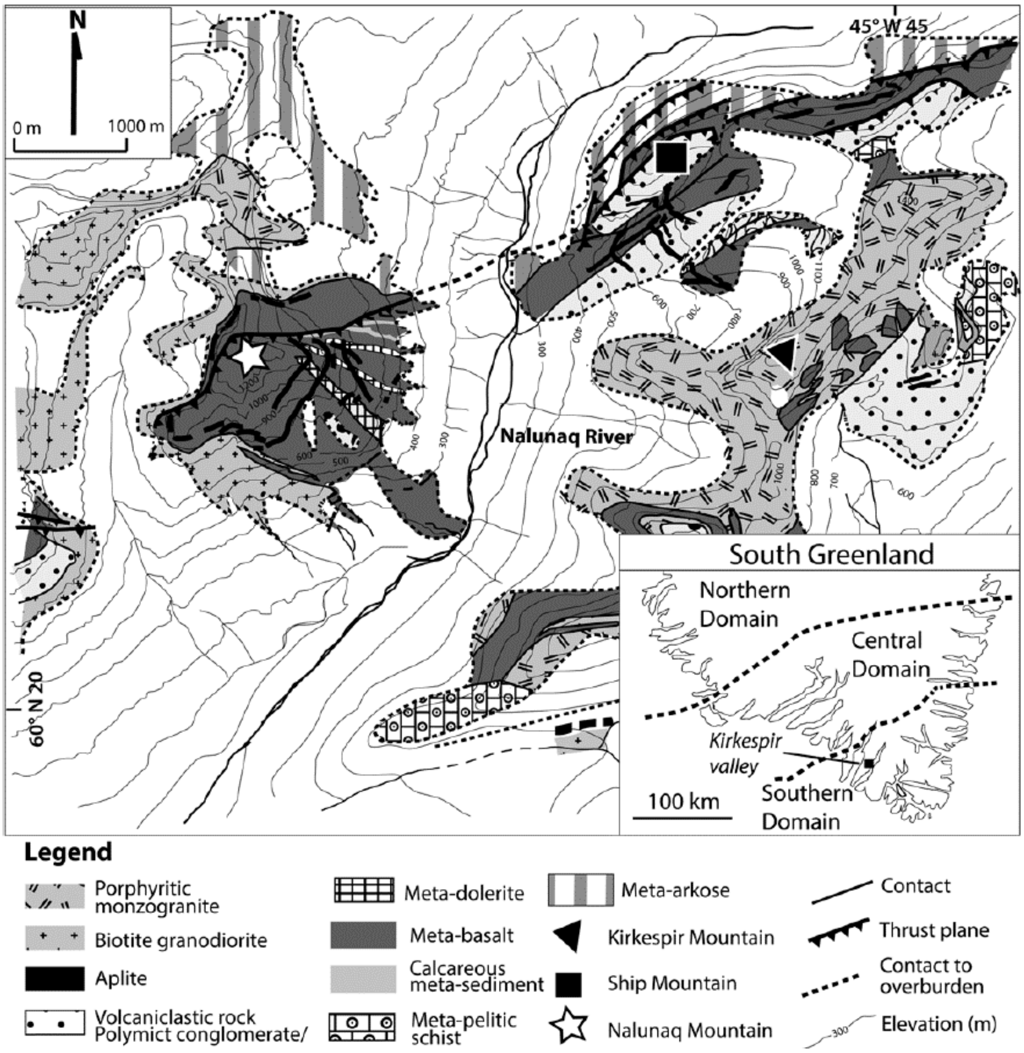

Figure 27. Geological map of Nalunaq Gold Mine in Kirkespir Valley area. The smaller map shows the Ketilidian Orogen and outline of the different domains (Bell et al. (2017).

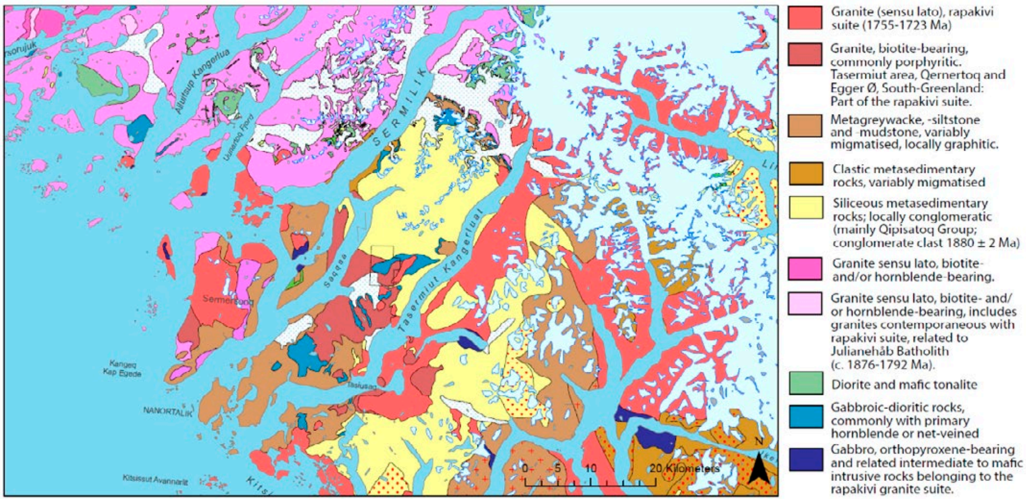

Figure 28. **Geological map of the area around Nalunaq Gold Mine. Source: GEUS.**

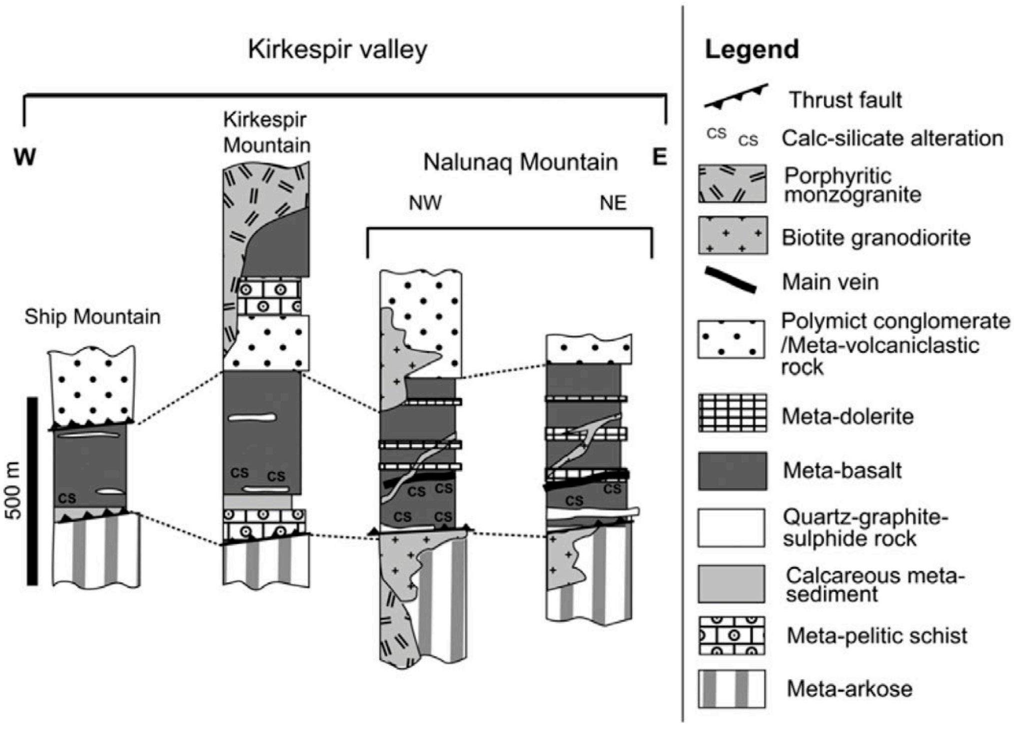

Figure 29. **Stratigraphic panel of the lithologies in the Kirkespir Valley (Bell et al. 2017).**

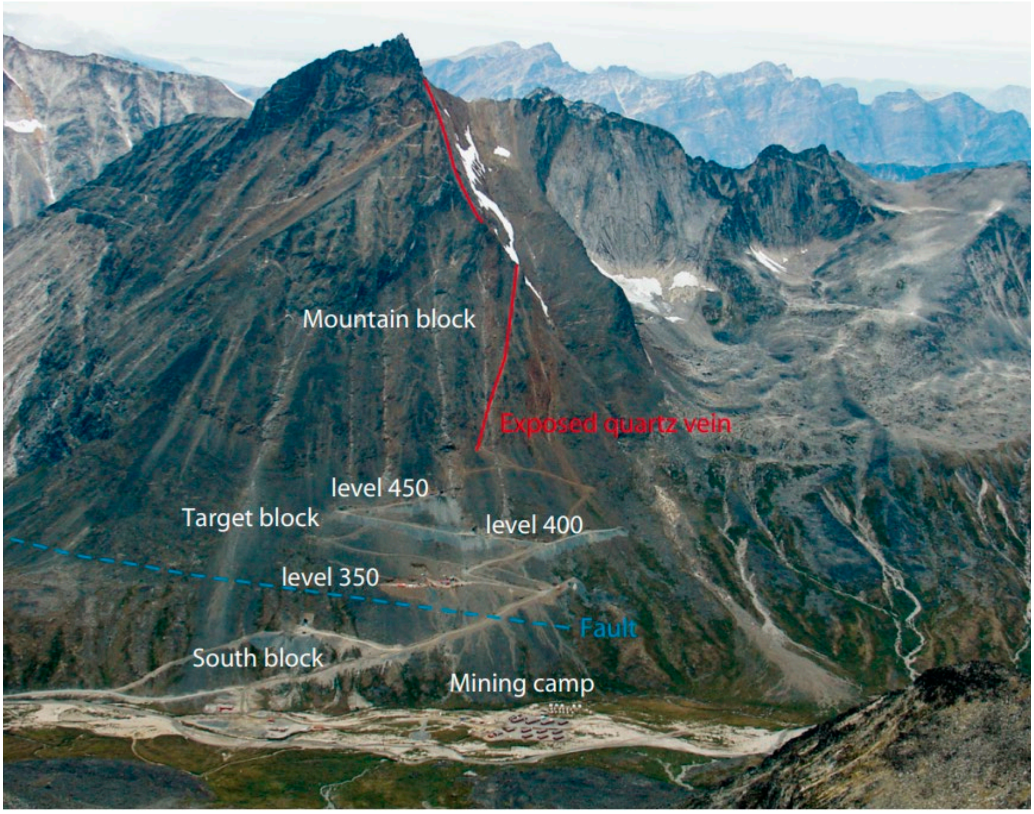

Figure 30. The Nalunaq Mountain. After Secher et al., 2008.

There is a zone of calc-silicate alteration minerals (mostly diopside) close to the quartz vein. The quartz vein with visible gold (Figure 31) can be followed on the surface of the mountain for 2 km. The quartz-vein has a high degree of nugget-effect which means the gold grade is very irregular, some places the grade is extremely high (Dahl 2003; Dominy & Petersen 2005; Gilbertson et al. 2017).

Figure 31. The quartz vein with high content of visible gold. After Secher et al., 2008.

5.1.2 Project status

The Nalunaq Gold Mine exploitation license was from 2016 owned by ARC, which later changed its name to Alopex Inc. and then to AEX Gold Inc. AEX Gold Inc. owns Nalunaq A/S who has the exploitation license. The exploitation license was originally granted in April 2004 to Crew Gold Corp. and is valid until April 24, 2033 (Gilbertson et al. 2017).

According to AEX Gold Inc. and SRK Exploration Services there is an inferred resource of 446,900 tonnes of gold (NI 43-101 resource) with a grade of 18.7 g/ton at Nalunaq; the contained gold is estimated to 263,070 oz, and a cut-off grade of 5.5 g/ton (Gilbertson et al. 2017; Olafsson 2020). The ore is a high-grade ore. The company has announced they are interested in selling the gold as 'clean gold' by promoting special focus on environmental concerns, green energy and community engagements. Clean gold has 20–30% higher prices compared to other types (Turnowsky 2019). The company hope to refurbish the cyanide leach circuits and treat the historical tailings for a fast cash flow in the starting phase, as well as integrate the remnant material from earlier mining. The company plans to initiate EIA and SIA in 2020 (AEX Gold Inc. 2019). The company will test alternative mining methods for narrow vein mining.

5.1.3 Production facilities

Crew Gold Corporation

When Crew Gold Corporation operated the mine there were no mineral process plant onsite, but the ore were processed in a crushing and sampling plant in the valley near the camp area (Figure 32). The coarse-grained ore was loaded into a two-stage crushing circuit, where the ore were split into less than 20 mm fine ore. The crushed material was fed to the top of the sample tower by a conveyor belt and passed through three splitters. The rejects from the two first splitters were discharged to a pile beside the tower. A part of the ore from the second splitter went through a roll crusher to less than 6 mm particles. The third splitter would split the ore in two piles, where a sample of approx. 36 kg was obtained in one pile, while the material in the other pile would be stored as reference material. The 36 kg bulk sample were sent for analysis (Lind et al. 2001; Dominy & Petersen 2005) for grade control. The bulk rock samples were in the start-up phase sent outside Greenland for analyses, but later a laboratory was built onsite and the results for the gold grade could be analysed within one day (Dahl 2008). The tower rejects were hauled to either high or low-grade piles nearby, where the distinctions were based on the geological face mapping inside the mine after the blasting of the wall. The ore from the tower rejects were shipped to a gold process plant in Europe (2004–2006) every 3–4 months and later to Canada (2006–2009) every month. In 2006, Crew Gold Corporation had bought a gold processing plant in Canada, and instead of having a large shipment of ore every 3–4 months, a smaller load of shipment was sent to Canada every month, which increased the amount of cash flow to the mine from the gold production (Dah, 2008) (see section 5.1).

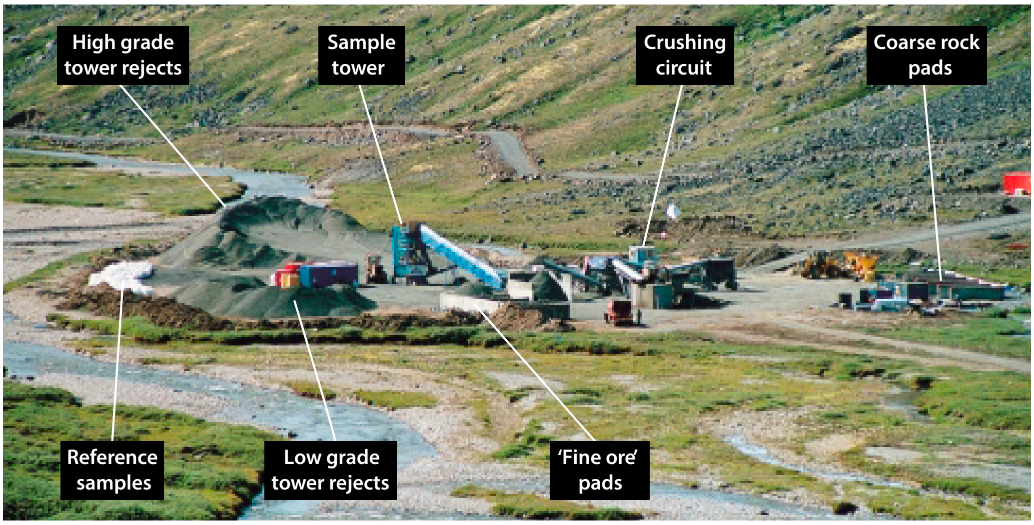

Figure 32. Crushing and sampling plant for the Crew Gold Corporation. The ore is separated in separate stockpiles in the mine camp area and shipped. After Lind et al. (2001).

Angel Mining Plc.

Angel Mining Plc. build a mineral process plant inside the mine and stored all the waste rock inside the mine as supporting pillars for the overlying roof in the tunnels. The ore were stored in a chamber 40 m above the mineral processing plant. According to the EIA the first phase in mineral process was a gravity based mineral processing and then a cyanide leaching mineral processing (Figure 33). The first step for the ore before the mineral separation process were crushing the ore to 50 mm size particles, and then to 10 mm sizes. The ore were then grinded by a steel-ball mill with water into particles less than 75-µm (Watkinson 2009b). The fine-grained material from the mill was pumped into concentrators in the gravity plant where the free gold would be removed. The ore were pumped through water onto a vibrating table with an inclination, that could concentrate the free gold on the table. The discharge from the table was collected in a bucket and dried and would later be melted in a crucible to gold Dore bars.

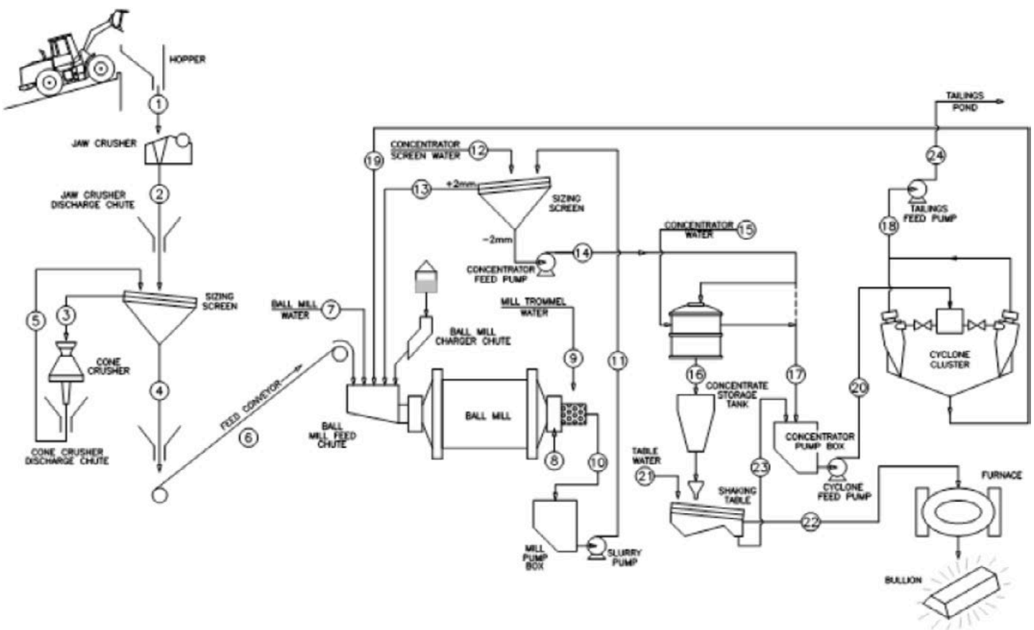

Figure 33. Process plant flow sheet for the Nalunaq Gold Mine in 2009. After Dominy et al. (2009).

Material that was rejected from the gravity plant, and still mixed with host rock (not free gold), was pumped into the Carbon in Pulp (CiP) leach circuit, which are a series of tanks with chemicals. Lime was added to maintain the pH to slightly alkaline level, then a liquid form of sodium cyanide was added to the slurry. The cyanide breaks the chemical bond between the host rock and the gold and releases the gold from the host rock to the liquid phase. The ore and chemicals were kept within the tank for 1–2 days before pouring the rock slurry, water and chemicals through a series of tanks; during this process carbon (charcoal) was added to the slurry.

Ideally the gold would have bonded to cyanide, and when they meet the carbon, the gold would bond to carbon instead. The slurry with carbon and gold were moved to tanks with strong acids, where gold would separate from the carbon again. The gold and water were pumped into another tank where electrodes were put in suspension and the electrodes and steel wool would concentrate the gold.

The gold from both the gravity plant and the gold-plated steel wool from the cyanide leaching plant were melted in a gold furnace (Dominy et al. 2009; Watkinson 2009b). The water from the tanks were cleaning through detoxification tanks and remained for reuse inside the mine. The gold Dore bars were transported to Europe for refinements into bullions (Watkinson 2009b). According to AEX Gold Inc. (Edison Invest Research 2018) the gravity gold separation phase by Angel Mining Inc. were skipped and instead only the CiP leach circuit process was applied for gold extraction.

5.1.4 Infrastructure

The Nalunaq Gold Mine is located in Kirkespir Valley about 33 km northeast of Nanortalik. The camp area was approx. 12 km up the valley from the coast.

Transport

The nearest accessible international airport is Narsarsuaq Airport. There are regular flights between Narsarsuaq and Kangerlussuaq and Nuuk year-round, and between Narsarsuaq and Iceland and Denmark from June to September (see section 1.4.1). Helicopters fly regularly from Narsarsuaq to Nanortalik. Passenger transport from Nanortalik to Nalunaq is by chartered boats.

Harbour and roads

In 2002–2003 the camp in the valley were build and a 12 km road from the coast to the camp area and to the 300 m level on the Nalunaq mountain. A harbour facility with a ramp and a storage area for up to 60,000 tonnes of ore were built prior to 2004, and also a ship loading system including a conveyor belt in order to load the ore into the ship.

Camp

The Nalunaq camp consisted of barracks, tents and containers designed for housing. Some of the barracks were: a canteen, field hospital, an office building, a changing room for the miners, a laboratory for analysis and one barrack were used for recreation purposes.

Service facilities

Catering and other services are available from Nanortalik, Qaqortoq and Nuuk.

Energy

The main source of power were large diesel generators to produce the amount of energy to run all the mine functions (Watkinsons 2009a)

5.1.5 Water management

Water management is an important factor for eliminating large environmental impacts from the mine area.

The water from the camp area was treated through an EcoLine 2N-BFK10 biological treatment plant provided by AEC International. The water was then discharged in fan-shaped drains in the gravel beds by the riverbed, which led into the river itself. The water leaving the plant was sampled and analysed monthly during summer and every second month during winter. The monitoring programme were planned in collaboration with the Government of Greenland (Watkinson 2009b).

Water was also used underground in the mining operations. Furthermore, water was used in the mineral process facility. The water used in the underground areas was reused for the processing plant, and the water did not leave the mine unless there were excess water. In these cases, the water went through various settling chambers and was sampled and analysed before being discharged.

5.1.6 Waste management

From 2004 to 2008 the waste rock was used as fills for roads and ramps outside the underground mine. After 2008 it was transported to the valley and dumped in stockpiles (Watkinson 2009b). The transportation of ore from the mining area to the valley and to the harbour generated dust that had a slight environmental impact on the plants in Kirkespir Valley and the sea in proximity of the mine (Bach et al. 2012; Bach & Larsen 2018).

Angel Mining Inc. tried to eliminate environmental effects by using the experiences that Crew Gold Corporation gained. The two most potential risks for pollution was dust from the roads and water from the mine that leads to the stream in the valley. According to the EIA (Watkinson 2009b), Angel Mining Inc. adjusted the storage of the ore to eliminate further environmental impacts. The plan was that no waste rock and tailings were deposited at external dumps, but instead put inside the mine as backfill in mined out areas (Watkinson 2009b). The process plant was also constructed inside the mine and the

CiP leaching with cyanide circuits were performed inside the mine. This had a minimum environmental effect on the plants and water in the mining area (Bach et al. 2012; Bach & Larsen 2018). Monitoring showed the metal pollution were lower in 2010 than during the operation (2004–2009) (Bach et al. 2012; Bach & Asmund 2013; Bach & Larsen 2018).

According to the EIA by Watkinson (2009b) all combustible waste from the mine camp was burned in a makeshift incinerator 3.5 km from the camp. There was no designed incinerator onsite and it was not required by the Bureau of Minerals and Petroleum (former MMR). All incombustible materials were packed into special rubbish containers and periodically shipped to the landfill area at Qaqortoq (Watkinson 2009b).

5.1.7 Earlier challenges in the Nalunaq Gold Mine

The ore was challenging for mining due to the slope and the geometry of the ore. The gold grade was erratic (the nugget effect), where some parts had very high grade and other parts lower grade (Dominy et al, 2006). The gold-bearing quartz vein is irregular and could be displaced by faults (Dahl 2003, 2008; Dominy et al. 2006; Gilbertsen et al. 2017). Exploration was carried out simultaneously while mining and following the ore; this could lead to missing the ore. This contrasts with normal practice, where the ore would have been drilled from side adits before the mining operations started, which could have given a higher control on the geometry of the ore.

Although the quartz vein with gold had a high grade, the rocks were sheared and in some areas the quartz vein were boudinaged. The thickness of the gold bearing ore was between 0.3 m and 1.8 m. From an economic point of view the optimal thickness when blasting was 1.2 m (Dahl 2008).

SRK Exploration Services suggested (Gilbertson et al. 2017) that the processing plant by Angel Mining Plc. was not properly adjusted to high grade ore, and therefore the gold recovery from Angel Mining Plc. was too low. Another point was also that Angel Mining Plc. did not make gravity separation of the ore; which would have caught a higher fraction of the gold, before the step with cyanide leaching were performed (Edison Invest Research 2018).

At the mine two very local challenges were present: 1) Snow avalanches near the mine site in winter-spring could bury the roads to the different mining levels or in worst case enclosure the staff inside the mine, and 2) Pack ice from East Greenland could lock the sea and fjords between Nanortalik and Qaqortoq with ice for days in spring-summer and could: delay the shipment of the ore, affect the shifts of labour force and fresh supplies of food and other goods to the mine (Dahl 2008).

Another challenge was when machines broke down. This could cease production for weeks while waiting for new supplies, spare parts or machines, and the long distance to neighbouring countries could be a constraint.

In 2008, the global financial crisis was evident. The gold price dropped from 1,000 US$ to 770 US$ per troy ounce from May 2008 to September 2009, and the global oil price increased; both were crucial for Crew Gold Corporation's economy.

Angel Mining Plc. struggled to reach the target production of 24,000 oz gold (746 kg) per year, but only reached 14,823 oz of gold (461 kg) in 2011 to 2013. The produced gold was mostly from old stockpiles, and minor parts from new development (Gilbertson et al. 2017).

5.1.8 Land and Conflicts

There have been no conflicts with the local population for the Nalunaq Gold Mine (Watkinson 2009a). The mining activities are not near vulnerable areas, areas with a unique geological significance, areas with an influence on animals, special plants or fauna, nor areas with a cultural or historical significance (Watkinson 2009b).

There were some concerns about the use of cyanide for extraction of the gold and possible negative environmental effects (Lyberth 2010). The environmental monitoring began before the mining started and were followed closely. Plants, seaweed, cod livers, and the water was analysed for arsenic, cadmium, cobalt, chromium, copper, gold, iron, lead, mercury, nickel, selenium and zinc during and after the mining operation; the effects of mining proved to be minimal (Bach & Larsen 2018).

Before 2009, the area was part of the Municipality of Nanortalik, but a reform in 2009 merged the three former municipalities Narsaq, Qaqortoq and Nanortalik into the Kujalleq Municipality. Crew Gold Corporation had contact to the Municipality of Nanortalik, and the municipality had tax income from the mine. The income from the mine and possibilities for jobs had an influence for the municipality and a positive mind-set towards the mine. The positive attitude towards the mine was very much dependant on the involvement in employment activities associated with the mine (local carpenters, catering, cleaning personnel etc). Local residents not involved in the mine had neither a positive nor negative view of the mine (Rasmussen & Gjertsen 2018). The Nalunaq Gold Mine created jobs and had a positive influence on the local economy (Greenland Venture 2009). The municipality of Nanortalik, and later the larger Kujalleq Municipality (from 2009), was unhappy to lose the tax income when the mine closed production in 2008 and again in 2013 (Thorin 2008; Mølgaard 2013). Today the Kujalleq Municipality is hoping for economic development and jobs in South Greenland in the mineral exploration and mining sector (Redaktionen Sermitsiaq 2020).

6 Summary

The geology of Greenland spans almost 4 billion years and includes many geological environments favourable for mineralisation. Nevertheless, mining activities have so far been very limited in Greenland considering the expected potential of such a large area. A relatively weak record of mining activity and mineral exploration success appears to contrast with the metal endowment, and existence of, numerous mineral occurrences and several world-class unexploited mineral deposits, of which several host commodities on the EU's list of critical raw materials. From an exploration point of view, the majority of Greenland can be considered greenfield and although the full potential is unknown it appears to have substantial, unrealized mineral possibilities.

Mineral exploration and mining in Greenland often occur in remote areas, usually far from municipalities and existing infrastructure (including energy supply and communication lines). This necessitates expensive helicopter and boat support for transportation and costly establishment of simple infrastructure. The remoteness, harsh Arctic climate and rugged terrain dominating Greenland are negative factors resulting in extra expenditures compared to most other jurisdictions. However, while the industry acknowledges this as a challenge, it is not necessarily the limiting factor for mining operations in Greenland. The profit of well-founded projects should be more than capable of managing these relatively higher expenses, and numerous mineral deposits developed in neighbouring Arctic countries suggest that the remote Arctic setting does not rule out mining in Greenland.

In order to obtain a license, a company must apply at the Mineral Resource Authority (e.g. through the online application portal https://portal.govmin.gl/dashboard) for various types of mineral exploration licenses; in line with the Nordic countries, Canada and Australia. Similarly, to BC, Canada, and Western Australia, companies are obligated to perform mineral exploration at a minimum expenditure depending on the size, location and standing of the license. In order to develop the mining project from exploration to exploitation, the Government of Greenland must approve a set of white papers, including social impact assessments, environmental impact assessments and impact benefit agreements etc.

In recent years, two mines have opened in Greenland, the Aappaluttoq ruby mine and the White Mountain anorthosite mine. Both mines are relatively small (estimated around 50 employees each from the third production year) and have yet to demonstrate profitability. Three additional companies have exploitation licenses; the Nalunaq gold project in South Greenland expects to commence production in 2021; the Citronen Fjord Zn-Pb project awaits further financing for construction of infrastructure; and the Isua iron project, which is unlikely to commence within the foreseeable future. One of the best ways to attract foreign investment is via proof of concept. The evolution of especially the Nalunaq gold mine or the Citronen Fjord project and their profitability may prove vital in this respect over the coming years. In addition to these projects with active exploitation licenses, three companies are close to submitting the final application for an exploitation permit or approving such. Greenland Minerals A/S' REE project Kvanefjeld in South Greenland is expected to deliver the final draft on their EIA soon. If compliant the next step is public consultation, a major steppingstone towards an exploitation license. Also, in South Greenland, Tanbreez Mining Greenland A/S are progressing on their negotiation towards an exploitation permit with submission of new material required for their REE project Kringlerne. Dundas Titanium A/S' Ilmenite project in North Greenland, have a compliant EIA and SIA pathing the way towards public consultation before final negotiation on the potential exploitation license within the near future.

The many deep fjords in Greenland offer excellent opportunities for deep-sea port and shipping capacity. Currently, Greenland is undergoing a phase of rapid development, and large government-funded infrastructure projects are in progress or set to start within the coming years, e.g. new Atlantic airports in Nuuk, Ilulissat and Qaqortoq, renovation and extensive replacement of housing and construction of new harbour facilities. Many construction companies are therefore at full capacity, limiting the mining industry's capacity to build infrastructure using local contractors. The construction phase of a mining project demands large investments in infrastructure and will possibly require a large workforce. Responding to this demand the Government of Greenland formulated the 'Storskala Act', which allows mining companies to hire foreign contractors for these tasks, if the Greenland contractors are unable to complete the task.

The Government of Greenland launched their latest mineral strategy in February 2020. Key focus in the ambitious new Greenland Mineral Strategy 2020–2024 is production and distribution/marketing of geoscience data and information relevant to the mining industry in order to attract new investments. The plan includes greater transparency and optimization of the administration, in order to streamline the application process and attract not only new investors but aid the existing industry in their endeavours for exploitation licensing and funding towards production.

With a workforce of 36,520 individuals and an unemployment rate of 5.8% (Statistics Greenland 2018), of which more than 84% have primary school as highest educational level, the resource for local Greenland labour is limited, despite the fact that a high percentage of local workforce is a prerequisite in the impact benefit agreements (IBA). As there are close to no workers available, only one of the two active mines in Greenland fulfil their commitment per the IBA to ensure a specific percentage of the workforce be local. Given that the current mines are relatively small, the prospect of large-scale mines such as the REE-projects in South Greenland with up to 1,000 workers for both mines, and the Citronen Fjord Zn-Pb mining project with 2–300 workers, reaching the standard goals of 80% local workforce as per IBA, will be a challenge.

The social license to operate is in general very favourable in Greenland, and except for radioactive minerals, both the local and remote inhabitants to the mines are generally in favour of mining, limiting the risk of local confrontation.

Taxation is more favourable for the mining industry compared to the rest of the business community, in order to attract investors. Currently the corporate tax for the mining industry is 25% as opposed to 26.5% for other sectors. However, in addition to the corporate taxation model, mining companies pay a royalty on the value of the extracted minerals of 2.5–5.5% depending on the commodity extracted; this is similar to the fishing industry.

Within the mining industry in Greenland, some advocate for a change in Standard Terms for Escrow and Pledge agreements, where companies must set aside a cash deposit for the rehabilitation or remediation of exploration or exploitation activities to ensure sufficient funds for restoration of the natural habitat in case of bankruptcy or similar. While the sentiment is good, and the protection of the environment should be a key component in any agreements and negotiations, the industry have found it challenging to set aside cash for such activities before any positive cash flow has occurred. In Finland, multiple companies offer to insure the mining companies' activities with regards to remediation of the natural environment. A similar amendment could be proposed in Greenland, to ensure that invested capital is utilised to the maximum extent by the mining companies working towards production.

The possibility of mining companies receiving several million DKK from the Danish-Greenland government-funded investment partnership between Vækstfonden and Greenland Venture, has been noticed by the industry, and to date three mining companies have received investments from this initiative; Bluejay Mining Plc., AEX Gold Inc. and Greenland Anorthosite Resources A/S. By opening government funded assets, the risk for foreign capital investments is lowered and could help to attract further investment.

Greenlandic politicians have a reputation within the industry to be forthcoming, listening and to some extent, willing to adapt the policies at the industry's request.

The Government of Greenland and GEUS continuously releases relevant geoscience information on various portals such as www.greenmin.gl where data and precompiled data packages (such as diamond, gemstone, nickel-zinc packages) are freely available. Information on application procedures and the most recent information regarding the mineral industry can be found at www.govmin.gl which includes all relevant information for the application procedure, policy, current license status etc. Business Greenland offer assistance, to any enterprises wishing to conduct business in Greenland, and much information can be found at www.greenlandbusiness.gl. Many mining companies similarly contact GEUS or the Department of Geology at the Ministry of Mineral Resources for information and aid on the geology and potential resources in Greenland (see more at www.geus.dk or www.govmin.gl).

Acknowledgement

This study has been supported by the Ministry of Economic Affairs and Employment of Finland (TEM). We acknowledge the Mineral Resource Authority and the Environment Agency for Mineral Resources Activities from the Government of Greenland for constructive comments that improved the text. From GEUS the authors are grateful for the careful remarks and comments by Per Kalvig and Stefan Bernstein on the draft and special thanks to Graham Banks and Nigel Jeremy Baker for proof-reading the manuscript. From the Greenland Institute of Natural Resources, the authors gratefully acknowledge the guidance and comments from Josephine Nymand, Katrine Raundrup, Lene Kielsen Holm, Ida B. Dyrholm Jacobsen and Karl Brix Zinglersen. Also, we would like to thank Mikko Martikainen from TEM and Pekka Tuomela from the Geological Survey of Finland for collaboration and valuable inputs. All contributions have greatly improved the quality of this report.

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Appendix A: Comparison of mineral claims in Greenland, British Colombia and Western Australia

	GREENLAND (GRL)		BRITISH COLOMBIA (BC)		WESTERN AUSTRALIA (W AUS)	
	Application fee	Granting fee	Application fee		Fees and Charges 2019-2020	Rent Fee
	DKK	DKK	CAD/ha	DKK/km2		DKK/km2
	5,000	35,800	1.75	894	Year 1-3	212
					Year 4-5	357
Cases (km2)	Application + granting fee			Registration fee	Year 6-7	488
10	40,800			8,943	Year 8-	922
50	40,800			44,713		
100	40,800			89,425		
200	40,800			178,850		
500	40,800			447,125		
1000	40,800			894,250		

GREENLAND (GRL)			BRITISH COLOMBIA (BC)			WESTERN AUSTRALIA (W AUS)			
	Annual Exploration obligations per license	**Annual Exploration obligations**	**Mineral claim - Annual Work requirement**			**Minimum Annual expenditure**			
		DKK/km2		CAD/ha	DKK/km2		DKK/km2		For 6-25 blocks**
Year 1-2	164,000	1,640	Year 1-2	5	2,555	Year 1- 3	1,533	Min.	92,000
Year 3-5	328,000	8,200	Year 3-4	10	5,110	Year 4-5	2,300	Min.	138,000
Year 6-10	656,000	16,400	Year 5-6	15	7,665	Year 6-7	3,067	Min.	230,000
Year 11-13	1,310,000	32,800	Year 7-	20	10,220	Year 8-	4,600	Min.	322,000
Year 14-16	2,620,000	65,600							
Year 17-19	5,250,000	131,000							

** 1 block = 3 km2

Cases (km2)	Annual Cost Year 1-2	Annual Cost Year 1-2	Annual Cost Year 1-3	Annual Cost GRL/BC %	Annual Cost GRL/W AUS %
10	180,400	25,550	69,000	86%	62%
50	246,000	127,750	92,000	48%	63%
100	328,000	255,500	153,333	22%	53%
200	492,000	511,000	306,667	-4%	38%
500	984,000	1,277,500	766,667	-30%	22%
1000	1,804,000	2,555,000	1,533,333	-42%	15%
	Annual Cost Year 3-5	**Annual Cost Year 3-4**	**Annual Cost Year 4-5**	**Annual Cost GRL/BC %**	**Annual Cost GRL/W AUS %**
	410,000	51,100	92,000	88%	78%
	738,000	255,500	138,000	65%	81%
	1,148,000	511,000	230,000	55%	80%
	1,968,000	1,022,000	460,000	48%	77%
	4,428,000	2,555,000	1,150,000	42%	74%
	8,528,000	5,110,000	2,300,000	40%	73%
	Annual Cost Year 6-10	**Annual Cost Year 7-**	**Annual Cost Year 6-7**	**Annual Cost GRL/BC %**	**Annual Cost GRL/W AUS %**
	820,000	76,650	138,000	91%	83%
	1,476,000	383,250	230,000	74%	84%
	2,296,000	766,500	306,667	67%	87%
	3,936,000	1,533,000	613,333	61%	84%
	8,856,000	3,832,500	1,533,333	57%	83%
	17,056,000	7,665,000	3,066,667	55%	82%

Average Difference in annual exploration requirement GRL vs. BC *	**46%**
Average Difference in annual exploration requirement GRL vs. W. AUS *	**68%**

* Not including differences in eligible overhead

Conversions:
1 ha = 0.01 km2
1 CAD = 5.11 DKK
1 AUD = 4.6 DKK

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Study on Arctic Mining in Greenland

Electronic publications
ISSN 1797-3562
ISBN 978-952-327-567-6

Electronic version: julkaisut.valtioneuvosto.fi
Publication sales: vnjulkaisumyynti.fi