DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2016/16

Greenland Mineral Resources Portal - Status 2016

Mineral Occurrences under the Greenland Portal

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GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
DANISH MINISTRY OF ENERGY, UTILITIES AND CLIMATE

GEUS

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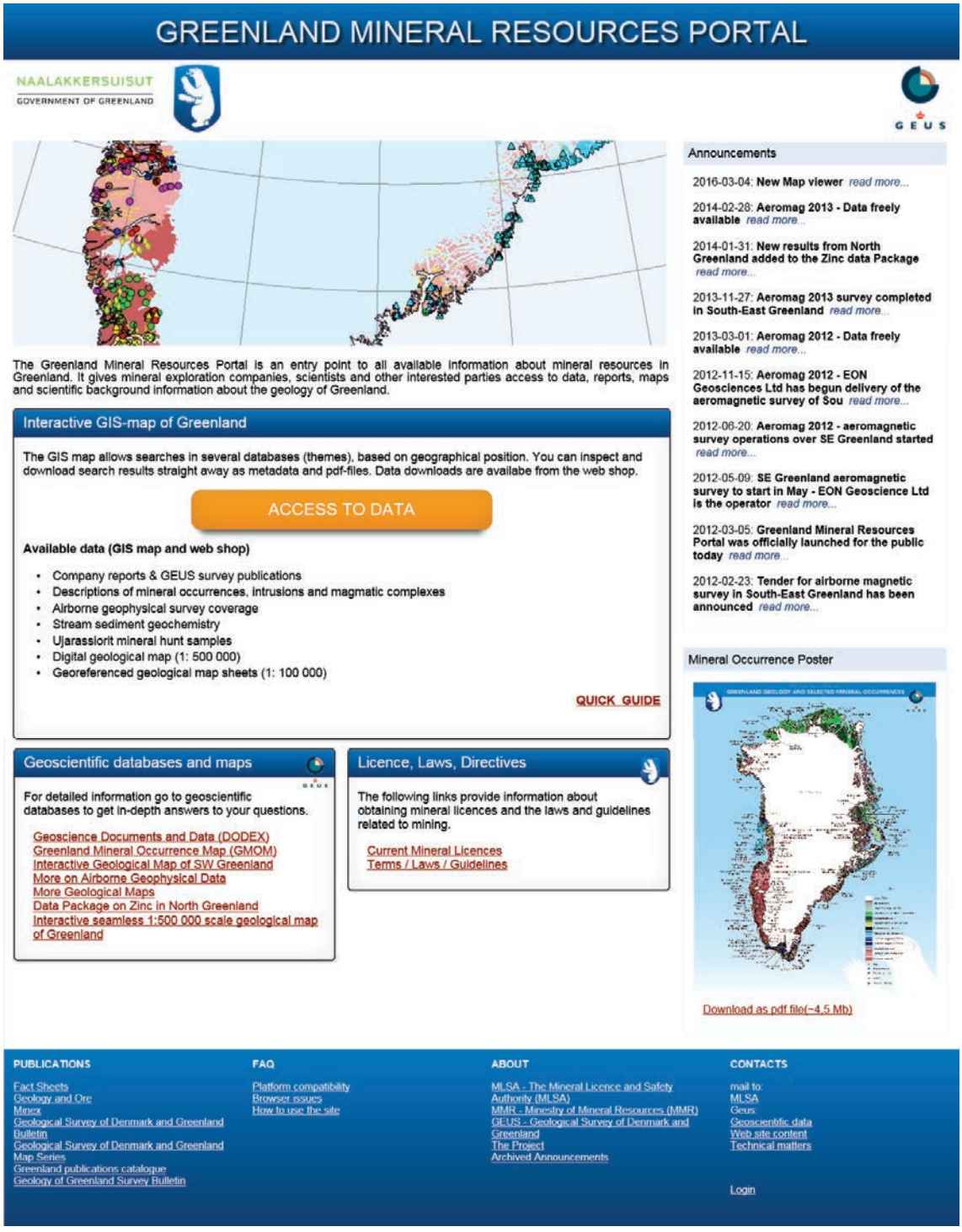

Frontispiece
The Greenland Mineral Resources Portal (GMRP, March 2016).

Contents

1. Abstract

The Geological Survey of Denmark and Greenland has stored information about mineral occurrences since 1989. This information was made available on the web in 2004 for the first time as the Greenland Mineral Occurrence Map (GMOM). In 2011, the mineral occurrence data were moved from an Access to an Oracle database and in 2012 the Greenland Mineral Resource Portal was launched and has since grown to host numerous data sets including data about mineral occurrences from GMOM. This portal functions as a stepstone for industry as it holds a wealth of information and provides links to original resources. Our ambition is to add more datasets in the future and to continue to provide up-to-date information about Greenland's mineral resources.

This report describes the current status of the mineral resource datasets that have been compiled over the last 2 years, with new and updated mineral occurrences, intrusions and Mineral Assessment Workshops tracts, and presents the Greenland Mineral Resource Portal, the webpage that hosts these data.

2. Introduction

Access to relevant and up to date geological information is a central issue for industry, decision makers and the general public that is interested in mineral resources. Information about mineral occurrences has been available on the web since 2004. However, similar to scientific papers, reports or poster publications, data stored in databases soon loses relevance unless it kept up to date and is maintained.

The most recent data maintenance project has been concerned with the following issues:

- The wish to present the tracts defined at annual Mineral Assessment Workshops to the industry and the public
- Prominent mineral occurrences were not shown on the web
- Since the latest updates, some substantial changes have occurred and some mines closed, others opened, and projects have been developed from showing, to prospect or deposit
- Creating new occurrences, e.g. Isortoq

As the project developed it became apparent that further issues should be addressed:

- Many occurrences in the Paamiut area had been deleted
- Some Intrusions had either been omitted or were prevented from being shown

This status report documents these additions and changes of the Mineral Occurrence database which can now be viewed on the Greenland Mineral Resource Portal.

3. Historical Background

The Geological Survey of Greenland (GGU, later GEUS) has stored structured information about mineral occurrences in databases since 1989 (Schønwandt, 1990; Lind et al., 1994). When the internet became more commonly used, online access to these databases was facilitated by GEUS through the co-operation with Bureau of Minerals and Petroleum (BMP), now Ministry of Minerals and Resources (MMR; Thorning et al., 2004, 2011).

Because early versions of the database in the 90's were mostly used by few people, several databases emerged, which stored similar data in different ways (Schønwandt, 1990; Lind et al., 1994; Thorning et al., 2001). As it became apparent that managing the data in several databases required more resources than necessary, these projects were merged into a single database called GMOM (Greenland Mineral Occurrence Map) rather than many unequal and partly unrelated data bases. In the early 2000's much of the data was made available online as using ArcIMS which periodically extracted data from the GMOM access database (Thorning et al., 2004). In 2011 this mineral occurrence data was transferred to an Oracle database (Thorning et al., 2011) with the ability to show changes on-line instantly.

As interested parties from industry or the public require access to multiple datasets to make informed decisions about whether to become active or allow activities in a certain area, it became apparent that other potentially interesting datasets should be made available. MMR joined this collaboration early on, and has been a supporter of putting as much relevant data available on the web as possible. Thorning (2012) predicted that new data would become available including digitised maps (field and published), photographs (vertical and oblique have been added) and mineral licenses. The current GMRP shows many of these datasets, however the information provided by this system requires on-going maintenance and more datasets can be added so that it can continue to be a key resource for on-line users.

4. Greenland Mineral Resources Portal

The Greenland Mineral Resources Portal (GMRP) was launched in March 2012 (GEUS news 5th March 2012) and announced at the PDAC in Toronto, Canada (see also Thorning, 2012). The GMRP is focused on the Mineral Exploration Industry and Mining Companies with activities in Greenland. The GMRP has already become a step-stone with several thematic layers for data mining, where exploration and survey reports, maps and data are available online. The last addition includes the ability to buy airborne geophysical datasets on-line using a web-shop (Pedersen, 2016) together with many previously unavailable thematic layers. As this portal has not been described in detail before, this section provides a thorough description of the functionality and the capabilities of the GRMP. The portal is devided in three pages: an entry page which lists links to important resources, an interactive map that allows querying of the many datasets that are available and a webshop that lists the items that a user is interested in downloading or buying.

The main page, see frontispiece of this report, shows three main boxes with links. The first is “Interactive GIS-map of Greenland”, where the link ‘Access to data’ is highlighted in orange and opens the interactive map Greenland Portal (URL: www.greenmin.gl/map.seam), that allows visualization of the geological data provided by MMR and GEUS. Beneath this one there are two smaller boxes; “Licence, Laws, Directives” that provides links to resources provided by MMR, e.g. to current mineral licenses and terms, laws and guidelines for obtaining one of these. The other box; “Geoscientific databases and maps” hold links to various resources that further describe the thematic layers. The links provided in the “License, Laws and Directives” box opens webpages under the Government of Greenland (URL: www.govmin.gl), where current licenses are posted, and terms, laws and guidelines for obtaining one of these can be found. Seven links are provided in the “Geoscientific databases and maps” box, and these link to various GEUS resources (from various GEUS URL’s, not listed here, but can be seen by hoovering over them and opened by clicking on them).

On the right-hand side of the GMRP announcements are listed. Where new announcements are posted on the top right and old ones are found further down. In the lower right of the page, a small mineral occurrence poster is shown. By clicking on the image a post-card size poster opens, showing mineral occurrences in Greenland.

Currently the interactive map (www.greenmin.gl/map.seam) allows viewing information from 14 thematic groups with 45 layers in addition to the background maps, which are a Topographic Map, 1:500 000 Geological Map or coastline. Each theme including the background can be made transparent to enhance other themes. Besides viewing the layers on the interactive map, the layers can also be viewed as a WMS or WFS (depending on the type of layer) in a client that allows importing such data such as ArcMap or QGis.

It has free text and geographic rectangle search functionality. Free text search can be done by writing a text string in the search box on the upper left of the window, geographic rectangle search can be done by clicking on the “search” button on top of the map panel. A given search is performed for all the thematic layers that are visible on the interactive map

(e.g. all layers marked with a tick). In principle all layers can be turned on and doing a search allows searching through all the layers at once. For example a user could search for a particular commodity such as gold or copper in reports together with mineral occurrences, when these layers are visible on the map. The items that are found from a search are shown in the lower left corner of the window and if necessary the results can be opened as an Excel file, where data from the individual layers occur as sheets. In the example of mineral occurrences and reports the Excel file opens with two sheets, one with mineral occurrences and the other with reports

Each item that is found in a search is listed with a globe-icon, an eye-icon and title. By clicking on the eye-icon an additional window opens in the lower right corner giving the title, author, and publications details of the report. By clicking on the globe-icon to the left of the eye-icon, the interactive map page zooms into the area that the report covers. The window that the eye-icon opens holds a link to the Report. The Report database holds Company reports, Survey reports, map explanations, publications etc. However, none of the series should be considered complete, as reports and publications are constantly added (Riisager et al., 2011).

4.1 Responsibility and User rights

It is obvious as the thematic layers grow in number; the responsibility for them will be decentralised and will therefore be maintained by several parties. Administration of online content is maintained by Geological Datacentre at GEUS. The Department of Petrology and Economic Geology is responsible for the larger part of the geological content, while Drill Core data, Geochronology and Licences is administrated and provided by MMR.

Currently only certain users with specific credentials can access the mineral resource databases at GEUS. This access is granted through web applications specifically created to maintain these databases, which connect to the database using a JDBC connection. Each user will have dedicated user account with which he or she logs in into the webapplication and the database. The applications are written in JAVA web frameworks and situated on open source web servers (JBOSS and Glassfish). In addition it is also common for developers or administrators to use the same user account with a database client such as SQLDeveloper or TOAD.

The database has three types of user roles: 1) Compiler, 2) Quality Controller and 3) Administrator. The Compiler has the ability to add data, the Quality Controller has the ability to add and release data and the Administrator currently has two roles: 1) Administrating issues related to the database and its structure and 2) Making the data available on the web.

4.2 Platform and display on web-browser

To view the data on the GMRP an internet browser is required. The view through a web-viewer may be limited as some browsers are rapidly undergoing changes. The GMRP is optimised for Mozilla Firefox and Google Chrome. The newest release of Internet Explorer and Microsoft Edge are likely to function as well.

Note also that data through-put may be limited by the client's computer memory or the data supplier's bandwidth as the size is quite substantial and may take time to open and view. A search however, is sent from the user's computer to the server, hosting the data, which fetches the relevant data and presents it on the user's screen.

5. Additions to ‘Minerals’ on the Greenland Portal

The topmost thematic group of the Greenland Portal is termed ‘Minerals’. This thematic group consists of three layers: ‘Mineral Occurrences’, ‘Intrusions’ and the new ‘Mineral Assessment Tracts’ layer (see discussion below). Some mineral occurrences have been updated and a few new entries have been created. In addition, previously unavailable information about intrusions in North and West Greenland have been added to the intrusion layer. Schematically the data come from different sources as can be seen in the following flow diagram (Figure 1). The architecture for placing data on the web is the same for all layers.

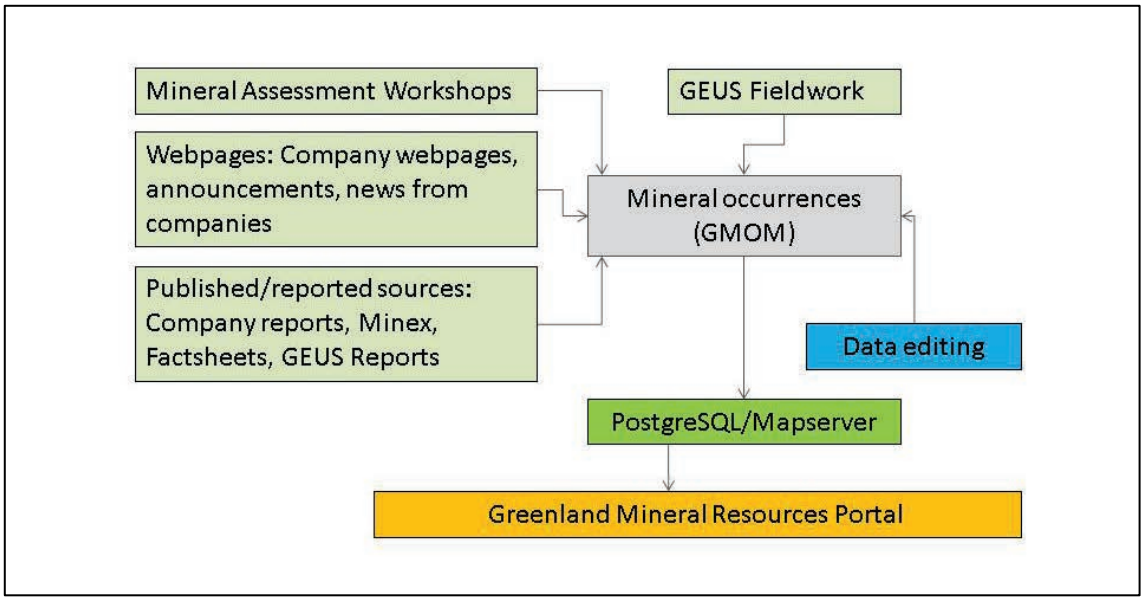

Figure 1. Data flow diagram of the data that enters the Mineral Occurrence data base (aka GMOM). The flow diagram is identic when it is Intrusion data that is entered and/or modified.

The mineral occurrence and intrusion data are both located in the mineral occurrence database, where the mineral occurrence data was derived from GMOM (Greenland Mineral Occurrence Map, see the simplified data model in Figure 3 and the full data model in Appendix 1). On the web-page however, the two are separated and shown as two individual layers as they deal with slightly different types of information. Intrusions only have a single symbol on the interactive map, while the Mineral Occurrences are classified by commodity groups. Figure 2, shows the Mineral Occurrence commodity groups.

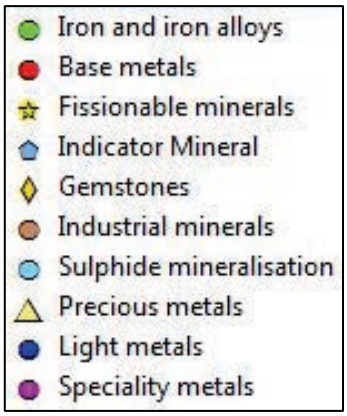

Figure 2. Legend of the Mineral Occurrence commodity groups shown in the Greenland Portal. Note that 'indicator Minerals' describes ruby indicator mineral, i.e. sapphirine and not kimberlite indicator mineral.

5.1 The new Mineral Assessment Tracts layer

The 'Mineral Assessment Tracts' holds the data from the annual Mineral Assessment Workshops held in Copenhagen from 2009 through 2015 (the tracts from 2015 workshop are not included).

5.1.a Workshop tracts

MMR and GEUS have held Mineral Assessment Workshops from 2009 to 2015. Lately the wish to access the assessed tracts appeared internally at GEUS with the urge to give online access to the workshop attendants as well as exploration industry and mining companies. The purpose is to supply the mining and exploration industry with these data and information, so that it in turn, may stimulate further exploration activities. Obviously, for newcomers these data are highly valuable. For companies that have worked in Greenland many years and perhaps participated in the workshops and have the workshop reports, online access allows using these data together with the other thematic layers. The background for the Mineral Assessment Workshops is as follows:

Global Mineral Resource Assessment Project
In 2002 the United States Geological Survey (USGS) initiated the project 'Global Mineral Resource Assessment Project' (GMRAP), with the primary objective to identify the principal areas in the world with potential for selected undiscovered mineral resources, in the uppermost one kilometre of the crust, using available compiled information and modern quantitative statistical models.

Three-part quantitative assessment
All of the workshops, excluding the one on Rare Earth Elements (REE), follow the processes and methodologies used in the 'three-part quantitative assessment' method of the U.S. Geological Survey described by Singer (1993): (1) areas delineated according to the types

of deposits permitted by the geology, (2) the amount of metal and some ore characterises are estimated using grade and tonnage models, and (3) the number of undiscovered deposits of each type is estimated. The objective is to produce a probabilistic estimate of unknown/undiscovered deposits and corresponding probabilistic estimates of the total amount of metals down to one kilometre depth. The estimates do not take into account economic, technical, social or environmental factors. The method does not define deposits or provide mineral resource or reserve estimates according to industrial or international recognised certified standards.

Monte Carlo simulation on consensus bids

In the 'three-part quantitative assessment' method, an expert panel reviews and discusses all available knowledge and data for a specific region (tract) to assess the possibility of finding new undiscovered deposits within this tract. The expert panels consist of geologists from universities, research institutions, surveys as well as private exploration and mining companies. The experts have either expertise in or worked with the deposit type of interest, with the regional and/or local geology relevant for the tracts being assessed or have expertise from exploration/mining projects for the deposit type in focus elsewhere in the world. One or two international top-experts on the mineral deposit type for the different workshops are also participating in the workshop. After reviewing the available knowledge and data, the members of the panel make their individual estimates (bids) of the number of undiscovered deposits they believe can be found under the best circumstances in a tract. The bids are based on the characteristics derived from descriptive mineral deposit models and a number of key-literature references on the mineralisation type. In several of the workshops, critical elements have also been considered in the mineralising system (e.g. McCuaig & Hronsky, 2014) associated with the deposit type in focus, when carrying out the bids. A panel discussion of the bids lead to a consensus bid, which is used as input to a statistical Monte Carlo simulation. Based on established grade-/tonnage models of e.g. known tungsten deposits worldwide, this simulation can provide a prediction on how much undiscovered tungsten can be found within a tract.

The Tracts dataset

To make the information about the tracts from the workshops available the tables that host their attributes needed to be harmonized. In addition to being made by different persons their attributes are also rather diverse and effort has to be put into creating a database that does not have duplicate information. After a coarse adjustment of the column headers and content they have all been through the AOMISHA software to narrow-down the adjustment of the content. AOMISHA (Et værktøj til **A**nalyse og **O**mstrukturering af store mængder **M**ap**I**nfo-filer eller **Sha**pe-filer) is an in-house built software package to homogenise large data sets in ArcGIS systems, where the software performs an analysis of the data and structure, edits the columns and converts the old data into tables (von Platen, 2015, pers. comm.).

The tracts dataset that is available online has 23 columns, where some are related to metals and others to rare earth elements. Columns for these two types of commodities should not be mixed, see Table 1, for readings of the various columns. The data held in the column *ESTIMATED_UNDISC_COMMODITY* (Estimated Undiscovered Commodity, in metric tonnes) may be misunderstood and hence misinterpreted and misused (Stensgaard et al.,

2011; Sørensen et al., 2011, 2012, 2013 & Rosa et al., 2014). The values in this column do not represent how many tonnes *are* in the ground, but they are the results of the Monte Carlo simulation from the EMINERS software and represent the maximum number of tonnes there can be under favourable conditions.

Table 1. *Header of the of the attribute table tracts.*

TRACT_ID	RE-PORT	WORKSHOP	YEAR	TRACT_NAME	MINERALISATION_TYPE	GEOLOGY_AND_ORE
104	Link	Copper	2009	NE 1-9 Hagen Fjord Group	Basaltic	Link

Table 1. *continued…*

NUMBER_KNOWN_DEPOSITS	NUMBER_UNKNOWN_DEPOSITS	N90	N50	N10	N05	N01	DEPOSIT_DENSITY
		0	0	2	3	6	0

Table 1. *continued…*

ESTIMATED_UNDISC_COMMODITY	NUMBER_REE_PROSPECTS	NUMBER_REE_SHOWINGS	LOCAL_SETTING
0		0	0

Table 1. *continued.*

DISTRICT_SETTING	TOTAL_SCORE_REE	DEPOSIT_SETTING	RGB
2	3	6	40 240 140

Colour codes: Beige columns are related to both REE and the metals (Cu, Zn, Ni, W and Au). Green coloured columns relate the metals (Cu, Zn, Ni, W and Au), while blue columns are related to REE. Note that the columns are not coloured on the GMRP.

Colouring of Tracts

The individual workshops in their respective reports have their tracts (polygons) drawn in various colours, for purpose of illustration. These colours have not been retained when the tracts are transferred to the web. On the Greenland Portal the copper tracts are dark green, Rare Earth Elements are red, zinc is light green, nickel is violet, tungsten is dark blue and gold is light blue.

5.1.a.i Copper

The mineral assessment workshop about Sedimentary-hosted copper was held in March 2009. Four deposit models were assessed: Reduced-facies Copper, Redbed Copper, Revette Copper and Basaltic Copper. Grade and tonnage models are omitted for the Basaltic Copper deposit model. For further explanation of the general and detailed procedure and references, see Stensgaard et al., (2011). Three general areas were assessed: Central East-, North East- and North West Greenland.

5.1.a.ii Rare Earth Elements

The Rare Earth Element (REE) assessment workshop was held in 2011. The methods that were used are different from the standardised 'three-part quantitative assessment' methods that were used in the other workshops. The attribute table of REE is therefore different from that of copper and the other assessed commodities. Sørensen et al. (2011) outline the

mineral assessment method guidelines that were developed and utilised for the REE workshop.

Of these, tracts A3.1, A11.1 and A17 have been added. A11 existed as a combination of A11 and A11.1; the two were then separated to correspond to the report. Note that the scores of the REE bids have not been incorporated into the report or the attribute table that is online.

5.1.a.iii Zinc

The Zinc mineral assessment workshop was held in 2011 (Sørensen et al., 2013) and outlined two deposit types: Sedimentary Exhalative (SEDEX) and Mississippi Valley Type (MVT), worldwide these two account for more than 50% of all zinc deposits. A third deposit type exists that was not assessed in the workshop. Thirteen tracts were assessed during the Zinc workshop, 8 SEDEX tracts and 5 MVT.

5.1.a.iv Nickel

The tracts assessed under the Nickel workshop have had their name changed in the shape file, from a numbering system with postscript to a prescript where the type of tract C, K or I (according to Conduit, Komatiite or Intrusion, respectively) as it might ease recognition. Almost all of Greenland was covered in this workshop and 32 tracts were assessed.

5.1.a.v Tungsten

The Tungsten workshop was held in 2013 and assessed three areas of Greenland: Central East, Central West, and South Greenland. Eight tracts were assessed in the workshop, and include both skarn and vein type mineralisation; these number 16 in total, as every polygon is used twice.

5.1.a.vi Gold

Orogenic hosted gold was assessed in the workshop held in autumn 2014. South Greenland had previously been labelled a gold province from 2000 as gold exploration had grown and located several showings (Steenfelt, 2000), the workshop conclusion was that the areas proximate to the now-closed Nalunaq mine and areas in southern West and South Greenland have the highest potential for finding new orogenic gold deposits (Kolb, 2015). There are 28 gold tracts that cover most of Greenland. Only North Greenland has been omitted (excluding Kronprins Christian Land).

5.1.a.vii Titanium-Vanadium (Not included)

The workshop about the magmatic titanium-vanadium potential in Greenland was held in Copenhagen at GEUS in November 2015. Twenty Tracts were assessed at this workshop. The famous occurrences as the Skaergaard Intrusion were included. The results are not included on the Greenland Portal yet (March 2016) but can be seen in Geology and Ore issue no. 27 (Sørensen et al., 2016).

5.1.b New Ruby and sapphirine occurrences

Ruby Mine

Officially the Ruby mine in Aappaluttoq opened in October 2015. The ruby localities in the Fiskenæsset area have been known for a long time, and several exploration companies have been prospecting in the area. GEUS Report no. 2014/72 (Appel & Ghisler, 2014) gives the history of the findings and exploration of the area. In addition it describes 95 ruby and sapphirine occurrences; 44 ruby occurrences and 51 sapphirine. 87 occurrences are in the Qeqertarsuiatsiaat area, 3 in Kapisillit, 2 in Storø, and 1 in Maniitsoq, 1 in Tasiussaq and 1 in Ujarrassuit Nunaat.

In early 2015 the occurrences described in the GEUS Report 2014/72 became available on the web. Though the occurrences are stored in the Mineral occurrence database, the dynamic pdf shown on the Greenland Portal, are almost empty. The descriptions by Appel & Ghisler are available on the Ruby and sapphirine-portal (URL: http://data.geus.dk/geusmap/?mapname=greenland_ruby_sapphirine) which was made available on the web in April 2015.

These ruby localities are not as well described as other mineral occurrences from the mineral occurrence database, as they only have a short description of the locality, an occurrence number (a helicopter area name given to the area in the early 60-70's) before proper maps were available), geographic coordinates in decimal degrees, name(s), name of discoverer, description of the outcrop, references and optional field sketches or map details.

The Ruby and sapphirine-portal interactive map is much akin to the Greenland Portal, consisting of four individual layers, where the ruby/sapphirine layer is the topmost one, followed by field maps, mining licences and mineral exploration licences. The last two are dated from February 2015. The background layer is by default the topographic map, whose transparency can be altered by the displayed shooter. Additionally the coastline can be made visible, and the 1:500.000 official Geological Map can be turned on. The localities can also be seen on the Greenland Portal.

5.2 Data model

The full data model of the Mineral Occurrences is found in the end of this report in Appendix 1; Figure 3, shows a simplified relation between four of the most important tables of the Mineral Occurrences.

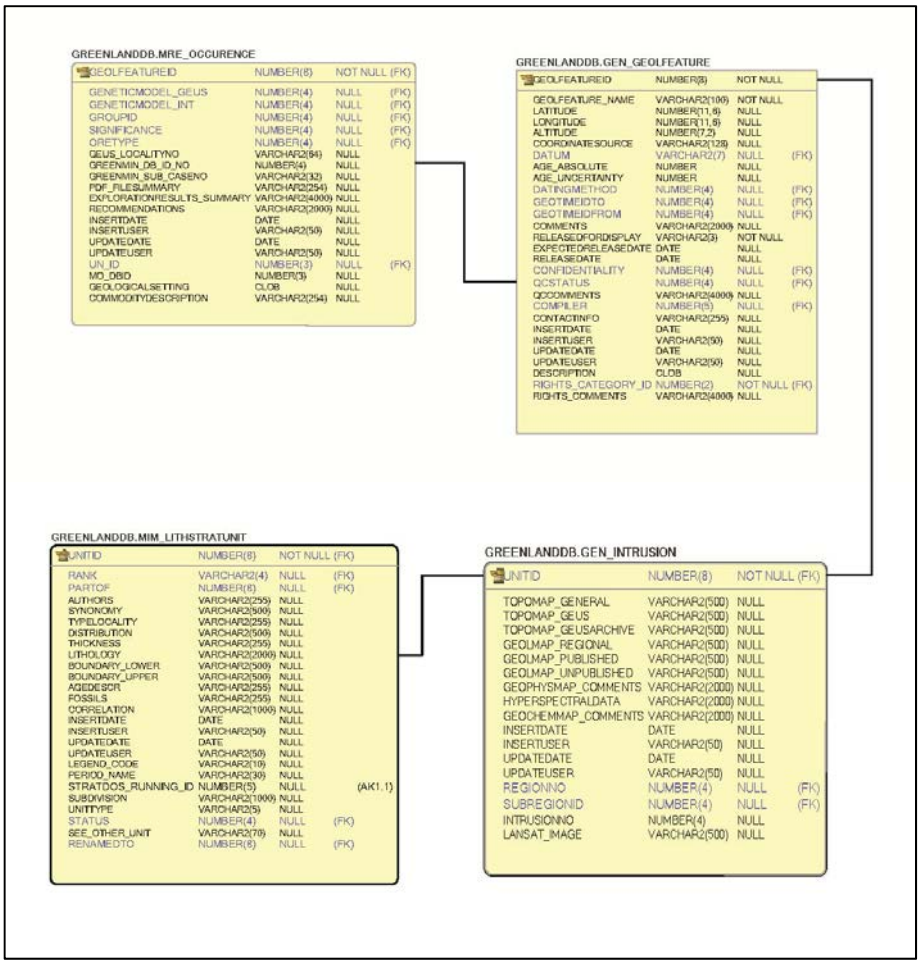

Figure 3. Simplified data model of Mineral Occurrences and Intrusions. See Appendix 1 for the full data model of Mineral Occurrences.

6. Missing occurrences

At the onset of this project, some prominent mineral occurrences were not visible on the web, even though they had been migrated from the Microsoft Access database to the new Oracle database. A few examples are the Seqi olivine deposit, Kvanefjeldet, Aappalutoq, Isua, Kringlerne, White Mountain, Maniitsoq Norite Belt and Citronen Fjord. The reason for these omissions is unclear. A possible and not very satisfying explanation is that something went wrong with the migration of data from the old system to the new. It appears that the most developed projects were missing. So it could have been the labelling as e.g. deposit rather than showing or occurrence that triggered some problem, so that the posting was stalled.

In the second Quarter of 2015 it became apparent that 315 Mineral occurrences were missing from the Oracle database, compared to the older Access database. A thorough search by the administrator in the database log, found that a SQL deletion had occurred, and wiped out occurrences in the Paamiut area. Luckily the occurrences could be restored from the database back-up, so that we did not need to enter the data manually again. In fourth Quarter of 2015 all the deleted occurrences were restored. This incidence emphasizes the need for tight user rights on the Quality Controller and Administrator roles, see discussion above. Several new entries about mineral occurrences in Southeast Greenland have been promised; these have not been delivered for various reasons, but will be posted in the near future.

7. Future work and data availability

According to the original plan with the GMRP and the Greenland Portal, more data is being made available thereto. Projects where old company data have been characterised optically will be made available through MMR and GEUS' cooperation.

Other data that could be made available are data about Kimberlite Indicator Mineral localities. Before the financial crisis in 2008 there was substantial diamonds exploration in Greenland, but as the demand for these gemstones has decreased, the exploration companies have turned to other commodities. However, it is difficult to predict future demand for this commodity and to be prepared for possible interest; GEUS and MMR should make this information available.

In addition to this the mineral occurrences found by the Northern Mining Company on East Greenland, and reported by Harpøth et al., 1986 should also be made available in the Mineral Occurrence layer on the GMRP. The data from this report can be quite easily added to the existing mineral occurrence dataset and modifications of the data model are not needed.

Concerning the deletions of the Mineral Occurrences in the Paamiut area: A point for database amendment, is that all SQL-statements with deletions are stored as well as the user that performs them.

8. Summary

The Greenland Mineral Resources Portal (GMRP) holds a wealth of online geological data on Greenland. Fourteen individual layers can be opened on the Greenland Portal, consisting of 45 sub-layers, ranging from Minerals, through Licenses, and geochemical and geophysical data, etc. Graphical search options and string-search make this portal a powerful tool for data mining and is highly relevant for the exploration industry and mining companies with interest in Greenland.

Mineral occurrences that were missing from the GMRP have been made available. Prominent mineral occurrences such as Aappalutoq, Isua, Kringlerne, Kvanefjeld, White Mountain, Maniitsoq, Citronen Fjord and others have been updated and made visible on the web and JORC or NI 43-101 resources updated. Several smaller mineral occurrences have been updated and a few new ones created, e.g. Isortoq. Missing Intrusions, especially in northern Greenland, have been added. Mineral Assessment Workshop Tracts from 2009 to 2014 have been made available online.

In accordance with the original plan for the GMRP more data will be made available and still much data exists that should be included, so that the portal still will remain a relevant tool for the exploration industry and mining companies with activities in Greenland.

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Appendix 1: Data model of Mineral occurrence