Estimating Pre-Rift Bedrock Geology under Shelf Sediments of the Circumpolar Arctic

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Abstract

In the Arctic Ocean, almost 50% of the seafloor is underlain by continental shelf. However, the geology of the pre-rift continental crust that makes up the basement of the shelf is poorly constrained because it is overlain by thick Cenozoic sedimentary cover. This study explores the available data and methods for mapping the continental bedrock geology beneath the sediments. In a GIS framework, extrapolation of geological map units to the shelf edge was guided by onshore structure and offshore bathymetry. The compilation involved identification of data sources, development of a common legend for pre-rift basement geology, building attributes tables for analysis, and extrapolating geological contacts. As a first-order assessment of mineral resource potential of the continental shelf, permissive tracts for certain mineral deposit types were also identified. The analysis includes a case study of permissive geology for magmatic Ni-Cu deposits in the Taimyr Peninsula in northern Russia.

Résumé

Dans l'Arctique, le sous-sol continental occupe plus de 50% du socle rocheux au large des côtes. Par contre, l'étendu et la géologie de ce socle continental est encore méconnu. Les cartes géologiques publiées incluent seulement le couvert sédimentaire Cénozoïque. Ce projet explore les données et méthodes déjà accessibles pour étendre l'étude géologique de la plateforme continentale sous le couvert sédimentaire. L'extrapolation des unités géologiques fût guidée par les structures continentales et la bathymétrie. Cette compilation à impliquée l'identification de données, le développement d'une légende, et la construction de bases de données pour analyses. Pour produire une étude primaire des ressources minérales possibles, l'analyse contient aussi une estimation de la superficie totale des unités géologiques ayant une valeur économique probable au nord de la Russie, particulièrement les gîtes de Ni-Cu d'origine magmatique de la Péninsule de Taimyr datant du Permien et du Carbonifère.

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1.0 Introduction

The oceans cover over 70% of the Earth's surface and can be broadly subdivided into two major geological domains: oceanic crust, which dominates the deep abyssal plains, but also includes features such as mid-ocean ridges, oceanic trenches, and seamounts; and continental shelf, which represents the submerged portion of continental crust. These two geological domains constitute the largest geological environments on the planet. Oceanic crust covers a surface area of ~311,000,000 km^2, representing 86% of the total marine area, and is dominated by basalt overlain by sediments of varying thickness depending on the age of the crust and proximity to sediment sources (Harris and Baker, 2012; Harris et al., 2014). The continental shelf and slope cover the remaining 14% of the marine realm, including 32,000,000 km^2 of continental shelf and 20,000,000 km^2 of continental slope. They are composed of continental bedrock overlain by thick successions of much younger continent-derived sediments, typically 10-15 km thick but ranging from 0 to 22 km (Whittaker et al., 2013).

As the number of claims to the extended continental shelf increase, there is growing interest in the energy and mineral resources of those areas, as well as potential hazards and risks posed to the environment by their development. Some countries already exploit mineral resources "offshore" via mines and underground development that extend from land (e.g., coal resources in the United Kingdom and Nova Scotia; Precambrian orogenic gold deposits in China). By analogy with the land-based mineral resources, the vast areas of pre-rift continental basement offshore have the potential to host significant buried resources. However, almost all exploitation of marine minerals on the shelf is limited to dredging operations that target construction materials (sand, gravel) and near-shore placer deposits (e.g., diamonds, tin, gold: Rona, 2008). Several near-shore marine phosphorite deposits are also being considered for development. The thick sediments on the submerged continental shelf host a vast proportion of global petroleum reserves and currently account for as much as 1/3 of global oil and gas production. At greater depths, there is growing interest in manganese nodules, cobalt-rich crusts and seafloor massive sulfide deposits that occur on oceanic crust. Because the target resources in the shelf areas are hosted in relatively young sedimentary layers, most seismic data and exploration drill holes terminate before intersecting the deep bedrock or only penetrate a short distance into the basement. Therefore, there is little direct knowledge of the bedrock geology of the shelf (note that many seismic surveys refer to basement as "seismic basement", which may not correspond to the crystalline basement of the adjacent continent). Most knowledge of the offshore basement geology is gained from rocks of relevant ages exposed onshore. The assumption is that the continental shelf basement is likely very similar geologically to the adjacent land-based continental crust. From this, it can be postulated that the types and distribution of mineral deposits that occur on land should also occur within the offshore continental crust. In this case, land-based mineral resources can be used as predictors of offshore mineral potential on and beneath the extended continental shelf.

This thesis develops the workflow and first-order approaches to predictive mapping of the basement geology of the continental shelf. The challenge is similar to predicting geology under cover on land, except that the cover in this case is water and marine sediments. The geology of the continental shelf bedrock, from the coastline to the outer limit of the continental slope, is inferred from a combination of major lithostratigraphic assemblages on land that are manually extrapolated offshore following major onshore and offshore structures and bathymetry. A methodology is also presented for evaluating the mineral resource potential of the offshore permissive geology, following established mineral resource assessment techniques applied in remote areas on land (e.g., Singer and Menzie, 2010). For the purposes of illustration and to test these approaches, two maps at very different scales (1:25,000,000 and 1:5,000,000) were chosen in the Circumpolar Arctic (Fig. 1). This region is of particular interest to a number of nations that are currently making claims to the extended continental shelf (United Nations Commission on the Limits of the Continental Shelf). The workflow for analysis of offshore geology was developed as a large ArcGIS® project within which all available geological and resource data were compiled and overlain. Two compilations were used for the onshore geology: the Geological Map of the Arctic (Harrison et al., 2011) and the compilation by the Commission for the Geological Map of the World (hereafter CGMW, 2010). The offshore structure was developed from the International Bathymetric Chart of the Arctic Ocean (IBCAO; Fig. 2) (Jakobsson et al., 2012). The more detailed study at 1:5,000,000 was carried out in the Taimyr region of northern Russia, using available regional geological compilations, as an example of a possible assessment of resource potential under continental shelf sediments.

Major questions posed in the research were: Can we extrapolate basement geology and estimate resource potential under the shelf sediments? How far can we extrapolate coastal area geology offshore? What information is needed (or available) and where do we draw the lines? What platform is best used to manage the information? A variety of different approaches to "mapping under cover" are possible on land because of the level of detailed mapping available (1:500,000 geological base maps typical of national geological surveys:

e.g., United States Geological Survey portal "Energy Data Finder") and because of the abundant subsurface geophysical data, but similar approaches are generally impossible at the same scale offshore because the only readily available data are bathymetric surveys and satellite altimetry (in which the smallest observable objects are generally ~20 km in size). The approach used here is similar to that developed for mapping offshore marine habitat and natural hazard potential. The project borrows from habitat and hazard classification techniques that are similarly based on available bathymetric data (e.g., Dartnell and Gardner, 2004; Wilson et al., 2007; Harris and Baker, 2012; Chiocci and Ridente, 2011; Harris et al., 2014). Training sets (i.e., common rock legends) can be developed from the adjacent onshore geology at the appropriate scale and where enough structural, lithological, and stratigraphic information are available to extend the map polygons (units or assemblages) offshore. The onshore geology (established structure, stratigraphy, rock type, etc.) is the most important constraint on how to extend assemblages beyond the coastal exposures, with additional information about the offshore structure from textural analysis of digital terrain models (i.e., DTMs, based on the offshore bathymetry). From this, it is possible to compare offshore features related to the basement geology to the attributes of similar features exposed on land. This can include the known mineral deposits onshore. For example, an area of permissive geology for certain mineral deposit types can be defined as containing bedrock units of the appropriate composition, structure and age to host ore deposits of a particular type, usually with a clear link between rock type and the processes responsible for ore formation. Onshore mineral deposit databases are available from a number of different sources to guide this work: e.g., Geological Survey of Canada’s Mineral Deposit Map of the World Open File 2915 (OF2915); Promine and OneGeology in Europe. OF2915 was used to identify the major onshore mineral districts surrounding the Arctic basin that could potentially extend offshore.

1.1 Definition of the continental shelf and pre-rift basement

Most of the continental shelf area in the Arctic basin is contained within the Exclusive Economic Zones (EEZ) of Russia, Scandinavia, Denmark (Greenland), Canada, and the United States of America (Table 1 and Fig. 3). The major physiographic regions include the Barents Shelf, the Siberian and Chukchi Borderland, and the Canadian Arctic Archipelago; the oceanic domain is divided in the Eurasian Basin, which comprises the Amundsen and Nansen sub-basins, and the Amerasian Basin (Fig. 4). Large-scale structures that can be traced to the edge of the continental shelf define most of the sub-domains (Fig. 5). Most definitions of the continental shelf and continental slope are based solely on bathymetric criteria. The United Nations Convention on the Law of the Sea (UNCLOS) refers only to 200 nautical miles from the coastline as the Exclusive Economic Zone. The extended continental shelf is defined as 200 nautical miles (i.e., the existing EEZs) plus 150 nautical miles or 100 nautical miles from the 2500 m isobath, whichever is closest to the shoreline. Article 76 of the UNCLOS also stipulates that a coastal state can demonstrate that it possesses a wider margin if it satisfies particular “bathymetric and geological criteria” (Macnab, 2003).

Geologically, the continental shelf and slope represent the submerged portion of continental crust that extends seaward from all major continental landmasses and terminates at the transition from pre-rift continental basement to post-rift oceanic crust (Tarbuck, 2008). This transition is normally buried under several kilometers of sediment, making it difficult to define the exact location, width and geometry of this major geological contact. This study is restricted to the “pre-rift” regions of the Arctic Basin, which predate the formation of recent ocean crust in the Eurasian and Amerasian basins, as illustrated schematically in Figure 6. The project considers only the bedrock that existed prior to rifting of the ocean basins and is now buried by sediments.

Several definitions of the offshore continental shelf area are based on physical features, as opposed to the UNCLOS definition, that can be more meaningful for extrapolation of geology offshore (e.g., the 200 mi limit, the 2500 m isobath, etc.: Fig. 7). The International Hydrographic Organization (IHO) defines the continental shelf as “a zone adjacent to a continent (or around an island) and extending from the low water line to a depth at which there is a marked increase of slope towards the oceanic depths”; the continental slope is “the deepening sea floor out from the shelf edge to the upper limit of the continental rise” (IHO 2008). Other definitions include the thickness of the sedimentary wedge above the crystalline basement (the focus of this study). This can vary from several hundreds of meters of sediment to several kilometers of sediment, in part depending on the geometry of the basement (Fig. 8). The boundaries between continental shelf, slope, rise and abyssal plain also have been interpreted in different ways by different authors. Some authors have simply used only the 200 m isobath to define the edge of the shelf on geological maps (e.g., Bouysse et al., 2009).

Harris et al. (2014) divided the total ocean area of 361,883,510 km^2 into the hadal zone (3,437,930 km^2), the abyss (306,595,900 km^2), continental slope (19,606,260 km^2), and the shelf (32,242,540 km^2). They digitized the continental shelf at a spatial resolution of 1:500,000 in ArcGIS®, using 10 m, 50 m, and 100 m contours, depending on the slope. For the Circumpolar Arctic region, they used bathymetric data compiled for the International Bathymetric Chart of the Arctic Ocean (IBCAO, 2012) and a boundary delimited by a marked increase in the slope of the seafloor (Fig. 9). However, they did not include the entire slope or large areas of the shelf covered by glacial deposits.

These different definitions are compared in Figure 9. The outer limit of the slope has been used for this project and is redrawn in Figure 10. The oceanic crust, including where ridges impinge on the edge of the continental shelf, is shown in Figure 11, and the 1,000 m isobath is shown in inverse colour in Figure 12. The latter is used here as a close approximation of the location of the transition from continental to oceanic crust at the base of the slope. However, it is important to note that the bathymetric data were compiled from a number of different sources, including ship-borne multibeam surveys (Fig. 13) and satellite-derived gravity data (e.g., Sandwell et al., 2013, 2014). The ship-borne multibeam data cover only limited areas; most of the seabed structure is interpreted only from satellite altimetry. In this study, the volcanic platform around Iceland is excluded from the geological classification of continental shelf and slope, as are near-shore features such as carbonate atolls or other volcanic platforms that are not part of the continental basement.

1.2 Area of the global continental shelf

The global oceans as defined by Harris et al. (2014) have a total area of approximately 360 million km^2 (155,557,000 km^2 in the Pacific; 76,762,000 km^2 in the Atlantic; 68,556,000

km^2 in the Indian Ocean; 20,327,000 km^2 in the Southern Ocean; and 14,056,000 km^2 in the Arctic Ocean). About 280 million km^2 are deeper than 1000 m, and 230 million km^2 are deeper than 2500 m. The total area between the 0 m and the 1000 m isobath from the General Bathymetric Chart of the Oceans (GEBCO) 4 km-gridded data (Fig. 12) can be calculated by converting the ASCII data into raster format in ArcGIS®. In the attributes table, each isobath is accounted for explicitly and tallied. For example, the 314 m isobath is represented by 4215 pixels at that depth, and each pixel has an area of 16 km^2 (4 km x 4 km). The total area between 0 and 1000 m is represented by 5,071,437 pixels, corresponding to an area of 81,142,992 km^2 (this study). Thus, the area between the coast and 1000 m depth (the approximate limit of the outer slope) is equal to 22.4% of the global ocean area or 15.7% of the surface of the earth. The total area between 0 and 2500 m from the GEBCO 4 km-gridded data is represented by 8,174,251 pixels, corresponding to an area of 130,788,016 km^2 (36% of the global ocean area). However, the areas encompassed by the 1000 m and 2500 m isobaths include many features such as spreading ridges and other elevated areas of the ocean crust that are not underlain by continental basement.

Table 1: Areas and Coastlines in the Circumpolar Arctic

Country	**Coastline (km)**	**Area of EEZ (km^2)**
Norway	24,228	2,192,481
Sweden	2,679	54,341
Finland	2,694	65,476
Russia	57,392	4,777,769
Alaska (USA)	11,368	834,875
Canada	117,329	3,071,783
Greenland (Denmark)	52,290	1,966,093
Shetland Islands (UK)	820	115,893
Total	268,800	13,078,711
	Area (km^2)	Area %
Continental Land Mass	26,598,194	61
Ocean Basins	17,081,571	39
Total Area of the Circumpolar Arctic	43,679,765	
Ocean Basins that are EEZ	13,078,711	77
Unclaimed Continental shelf	4,002,860	23

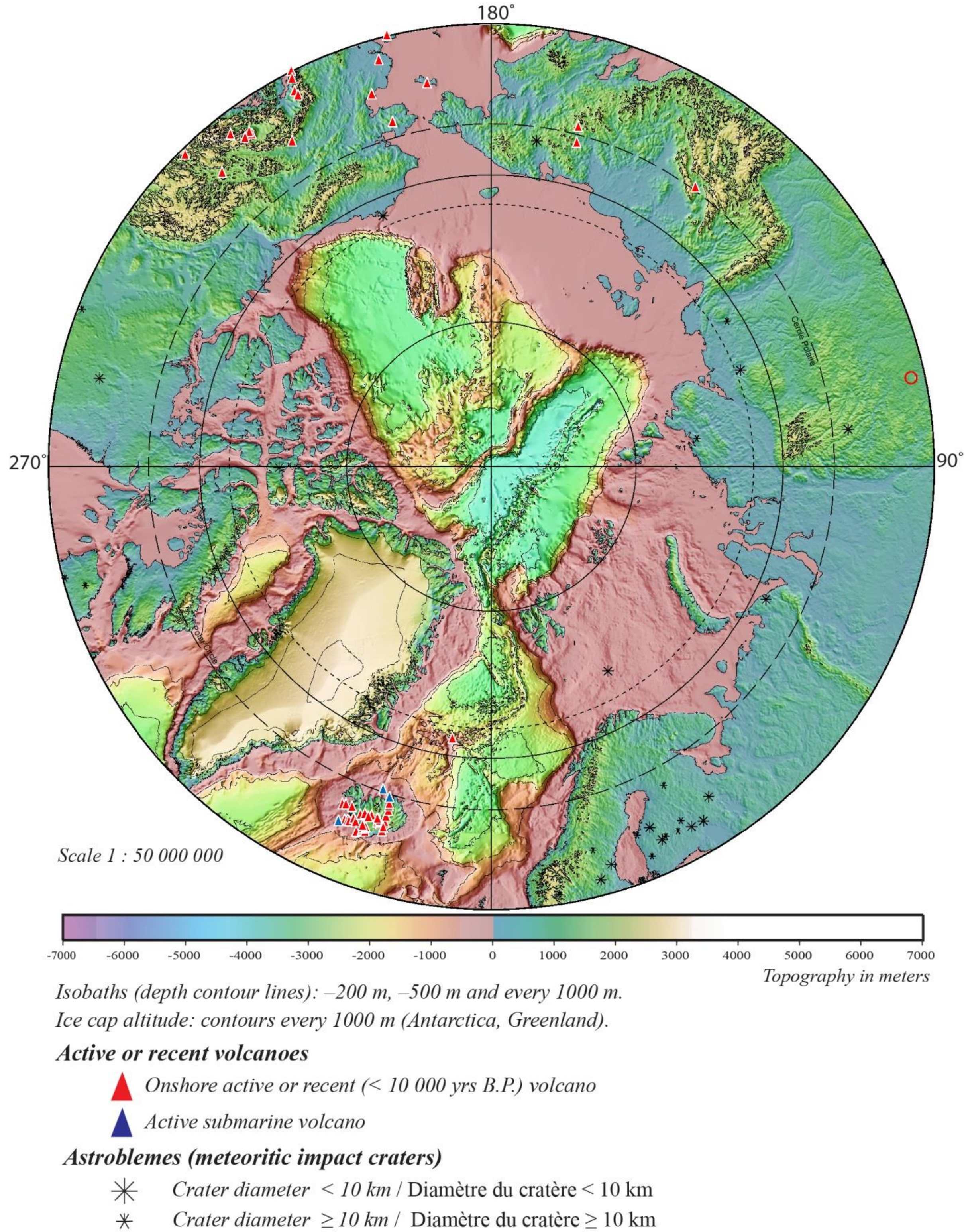

Figure 1: Physiography of the Arctic Basin. Polar projection from the Geological Map of the World (Bouysse, 2009, Commission for the Geological Map of the World).

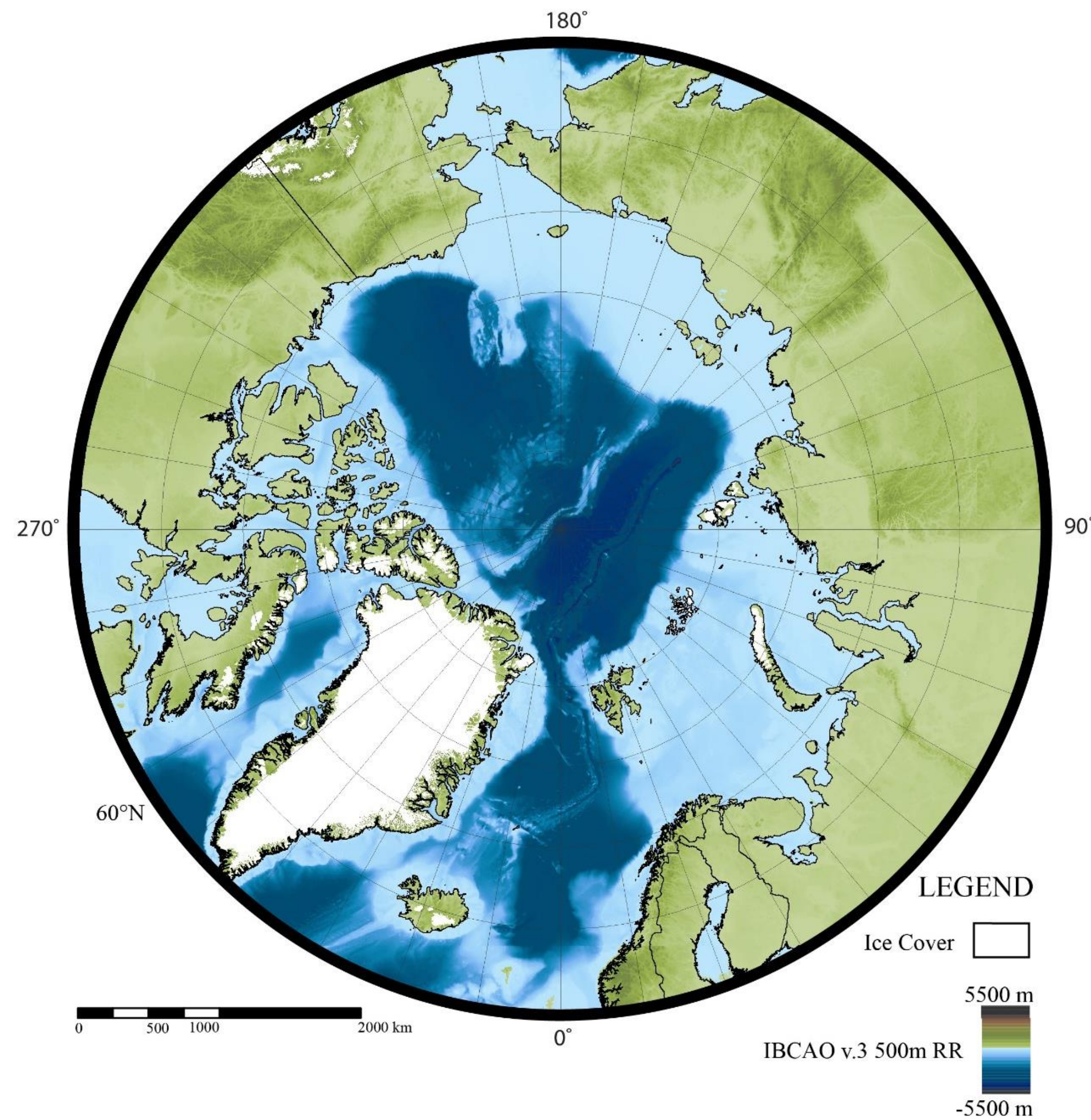

Figure 2: Combined topographic and bathymetric basemap of the Circumpolar Arctic region, created using data from the International Bathymetric Chart of the Arctic Ocean (IBCAO, v. 3; Jakobsson et al., 2012).

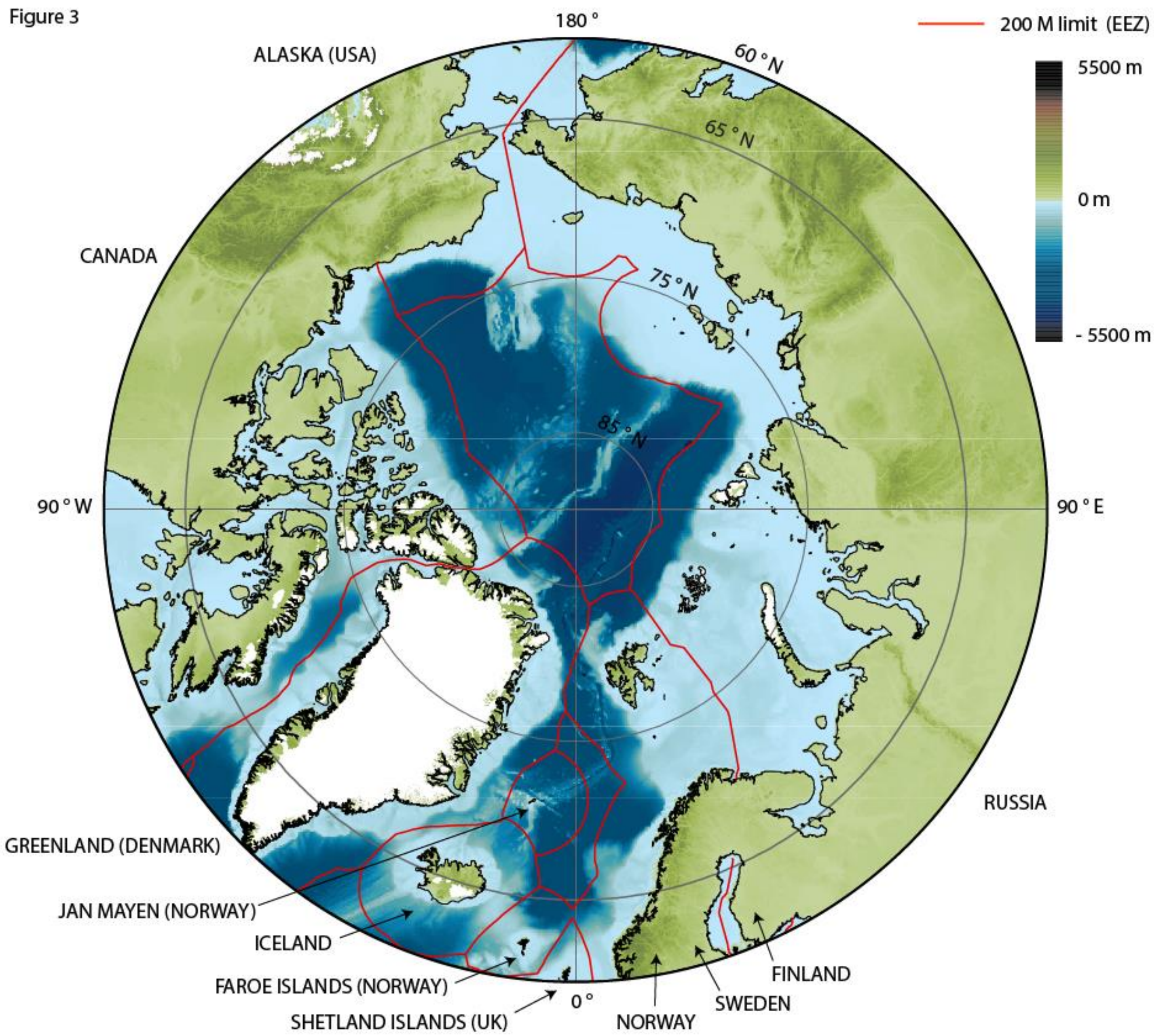

Figure 3: Map of the Circumpolar Arctic showing the current extent of country Exclusive Economic Zones (EEZ). Applications for extension of EEZs by all circumpolar countries have been submitted or are being prepared for submission to the United Nations Convention on the Law of the Sea (UNCLOS). Topographic and bathymetric data from IBCAO (see Fig. 2).

Figure 4: Names of geographic and physiographic features of the Arctic Basin. ESRI ArcGIS® Source: https://nordpil.com/portfolio/mapsgraphics/arctic-topography/

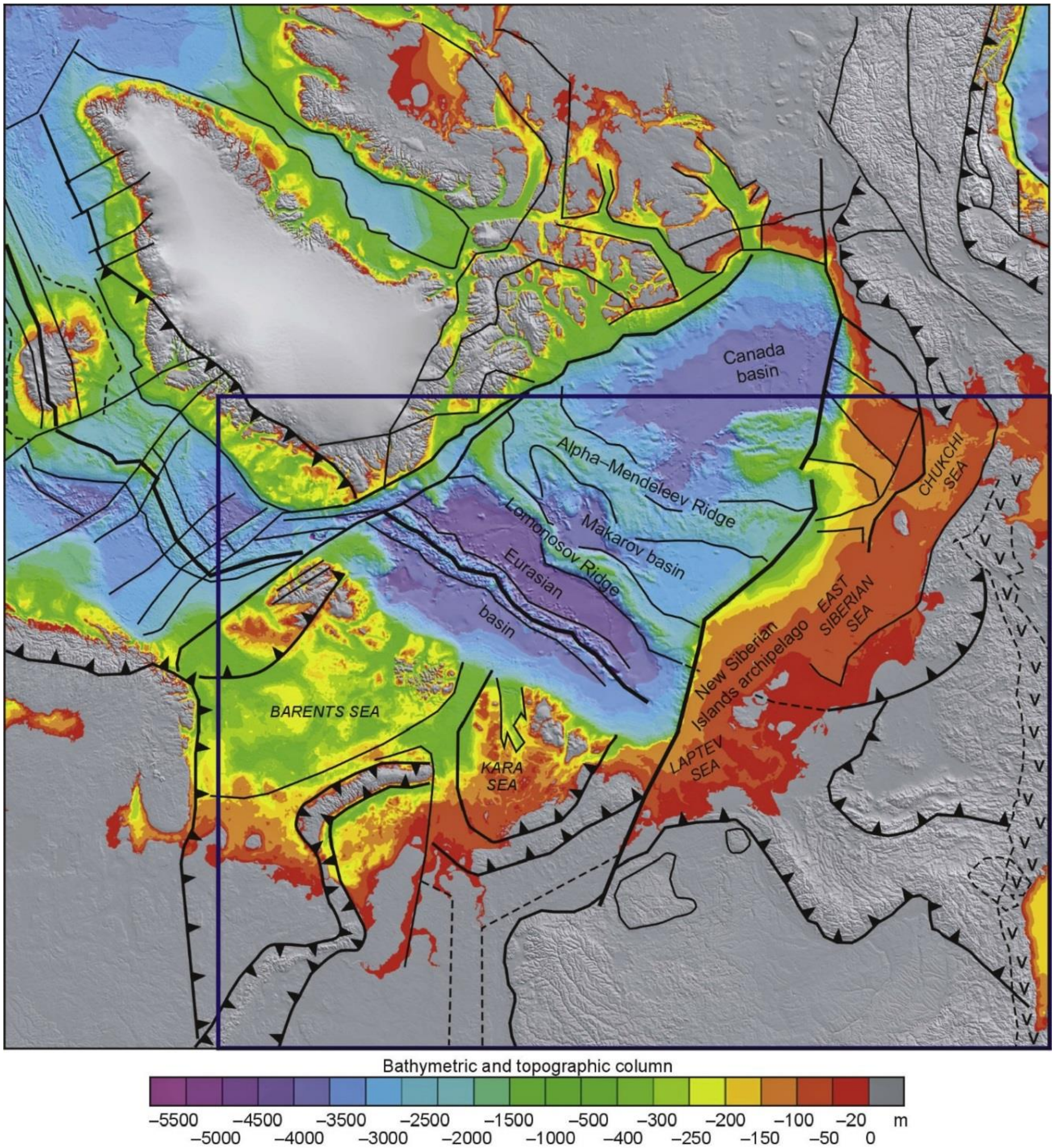

Figure 5A: Tectonic architecture of the Arctic Basin. Figure from Vernikovsky et al. (2013).

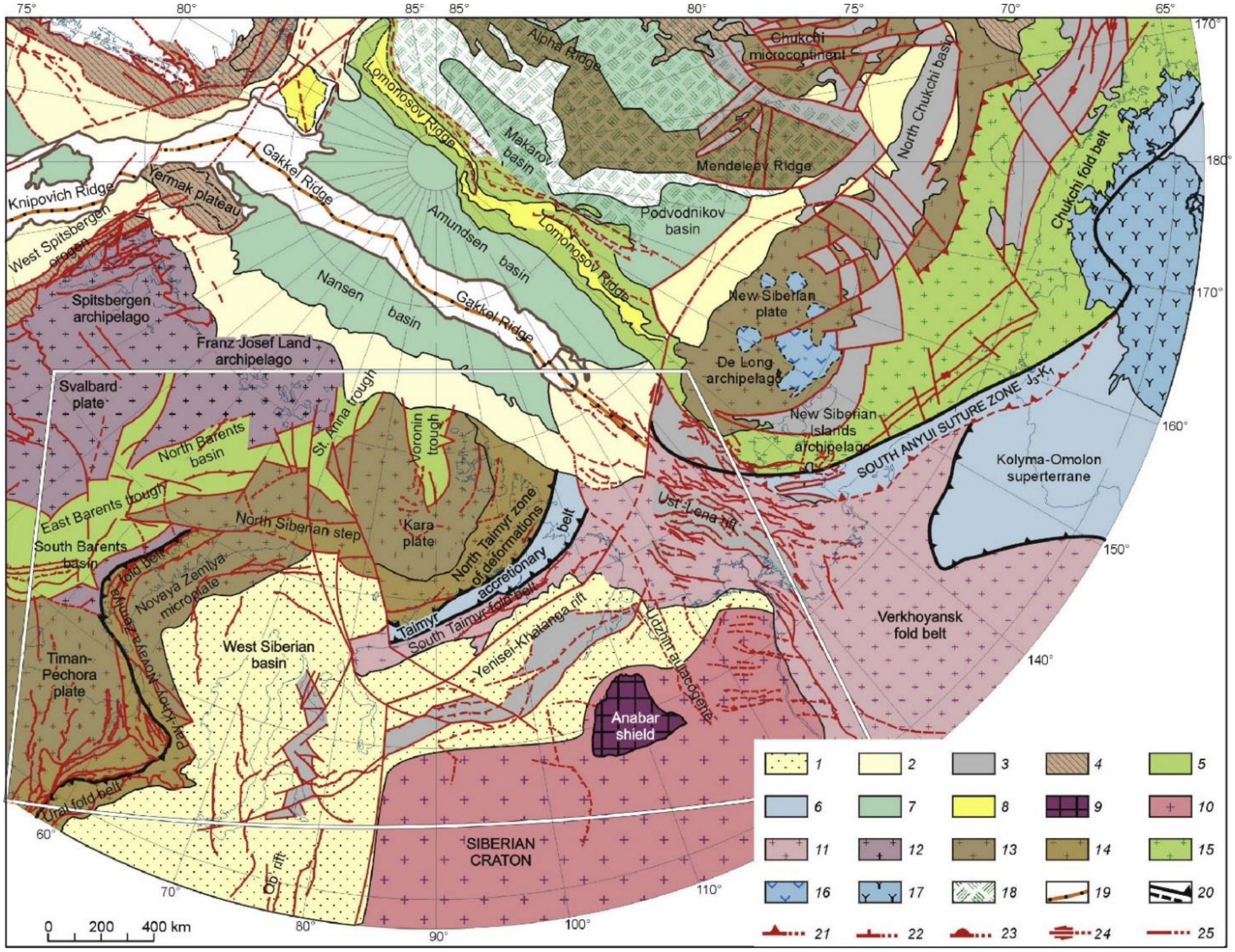

Figure 5B: Map of the main tectonic and geomorphologic elements of the Arctic (from Vernikovsky et al., 2013). *1*, young plates cover; *2*, modern continental slope; *3*, riftogenic and syn-strike-slip basins Mz–Cz; *4*, fragments of Caledonian orogenic belts; *5*, troughs and slopes with intermediate type crust; *6*, accretionary-collisional complexes; *7*, oceanic crust; *8*, blocks and ridges with continental crust; *9–11*, Siberian platform: *9*, basement metamorphic complexes (AR–PP); *10*, cover (undeformed); *11*, cover (deformed in the Mesozoic); *12–15*, lithospheric plates: *12*, with Grenvillian basement; *13*, with Late Precambrian basement; *14*, with Late Precambrian basement that was subjected to Hercynian tectonic deformations, *15*, with Late Precambrian basement that was subjected to Cimmerian tectonic deformations; *16*, basalts and bimodal volcanic associations of intraplate type (K1–N); *17*, Okhotsk–Chukchi volcanic-plutonic belt (K1–2); *18*, Alpha–Mendeleev large igneous province (alkaline basalts, 120–90 Ma); *19*, active spreading axis; *20*, sutures; *21*, thrusts and upthrows; *22*, normal faults; *23*, detachments; *24*, strike-slips; *25*, faults with unclear kinematics.

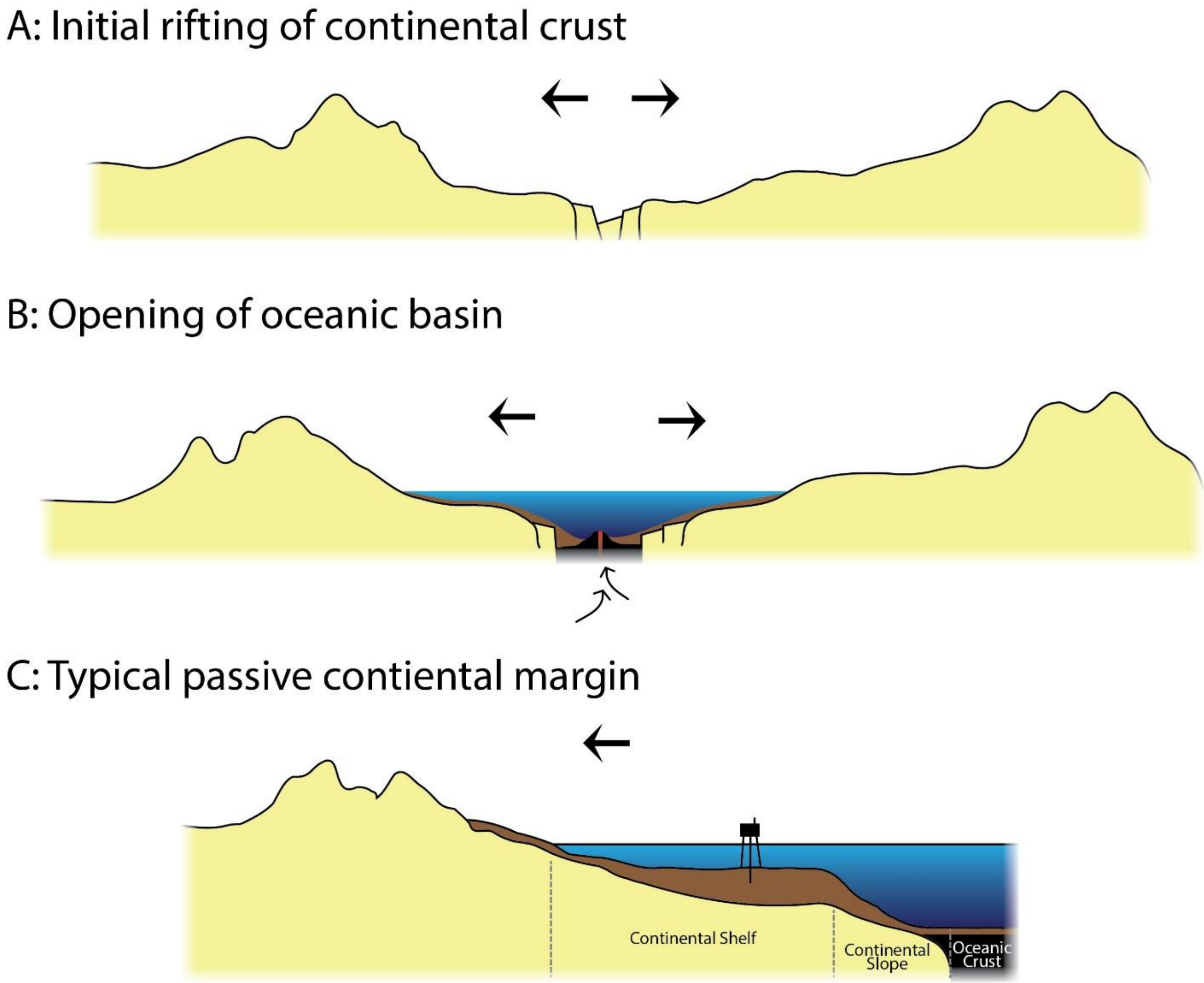

Figure 6: Schematic illustration of rifting of continental crust. The boundary between submerged, pre-rift continental crust and oceanic crust occurs at the base of the continental slope.

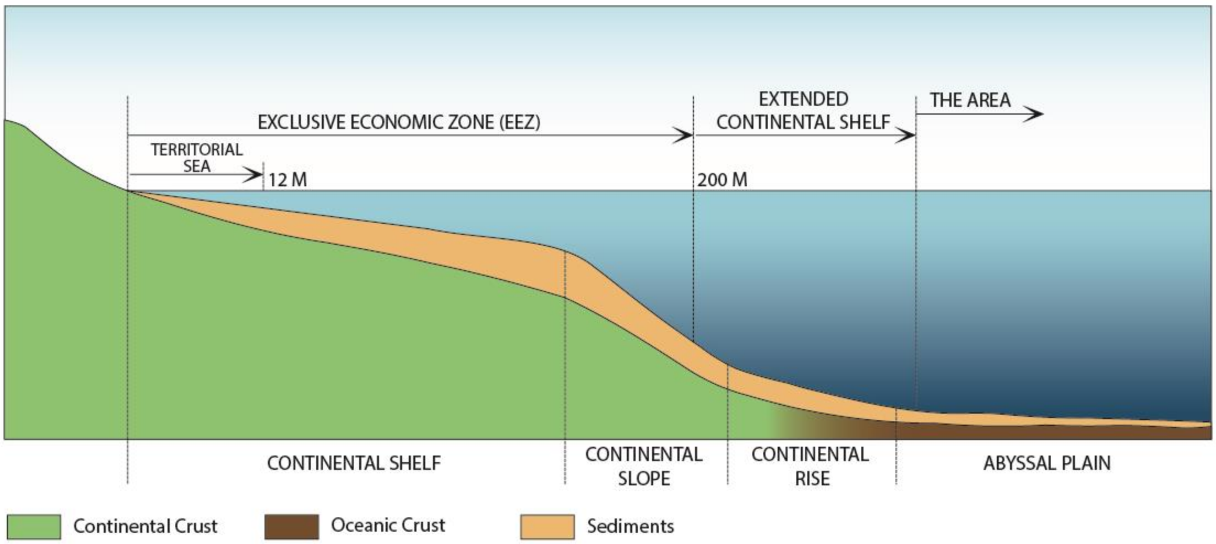

Figure 7: Cross-section through a typical continental shelf and slope, showing the extent of coastal state territorial seas, EEZ and possible extended continental shelf, as defined by UNCLOS. The transition between continental and oceanic crust is located at the base of the continental slope. See text for details.

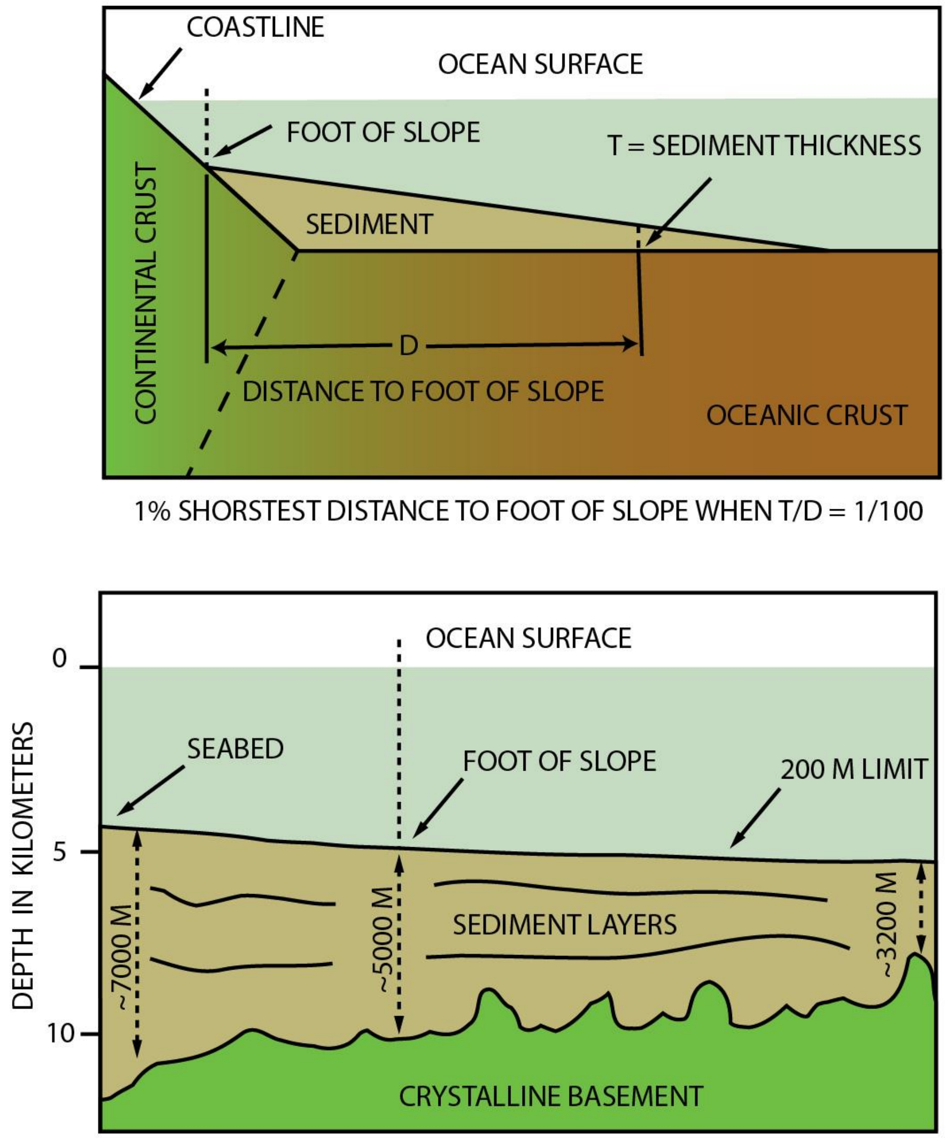

Figure 8: Cross-section of an idealized continental margin showing typical sediment thicknesses and the possible irregular geometry of the sediment-basement interface. Modified from Macnab (2003) (Developing outer continental shelf limits in the Arctic Ocean: Geoscience encounters UNCLOS Article 76; ICAM IV – The Fourth International Conference on Arctic Margins; pp. 189-198)

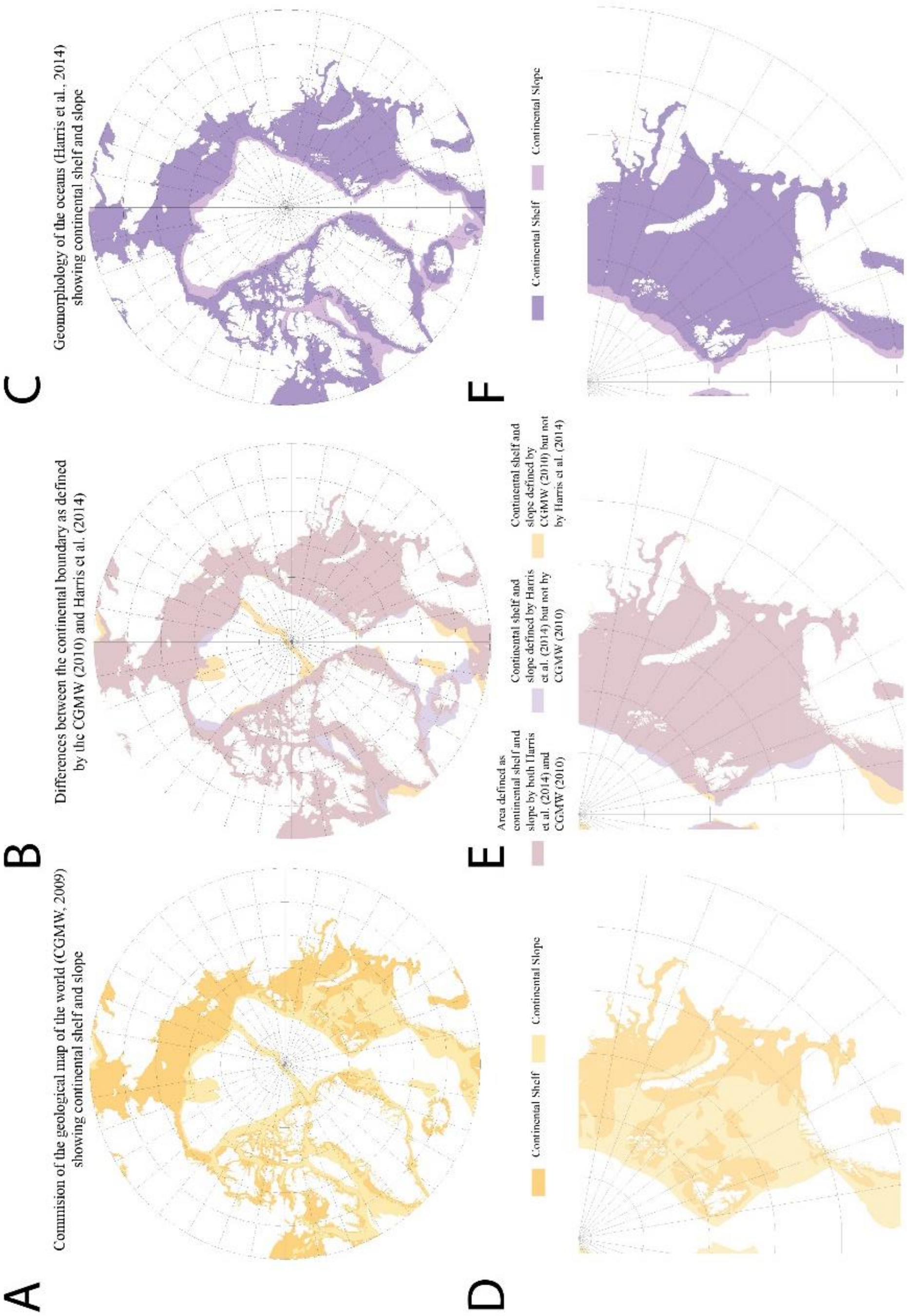

Figure 9: Comparisons of extent of continental shelf and slope in the Circumpolar Arctic (top) and Barents Sea region (bottom). The definition of continental shelf used by the CGMW (Bouysse et al., 2009) is the 200 m isobath (A, D). Harris et al (2014) use a geomorphological approach, where the outer limit of the continental shelf is defined by a marked increase in slope of the seafloor (C,F). Maps B and E show where these two definitions overlap. Maps were created using data from CGMW and Harris et al. (2014). See Appendix 1 for further details.

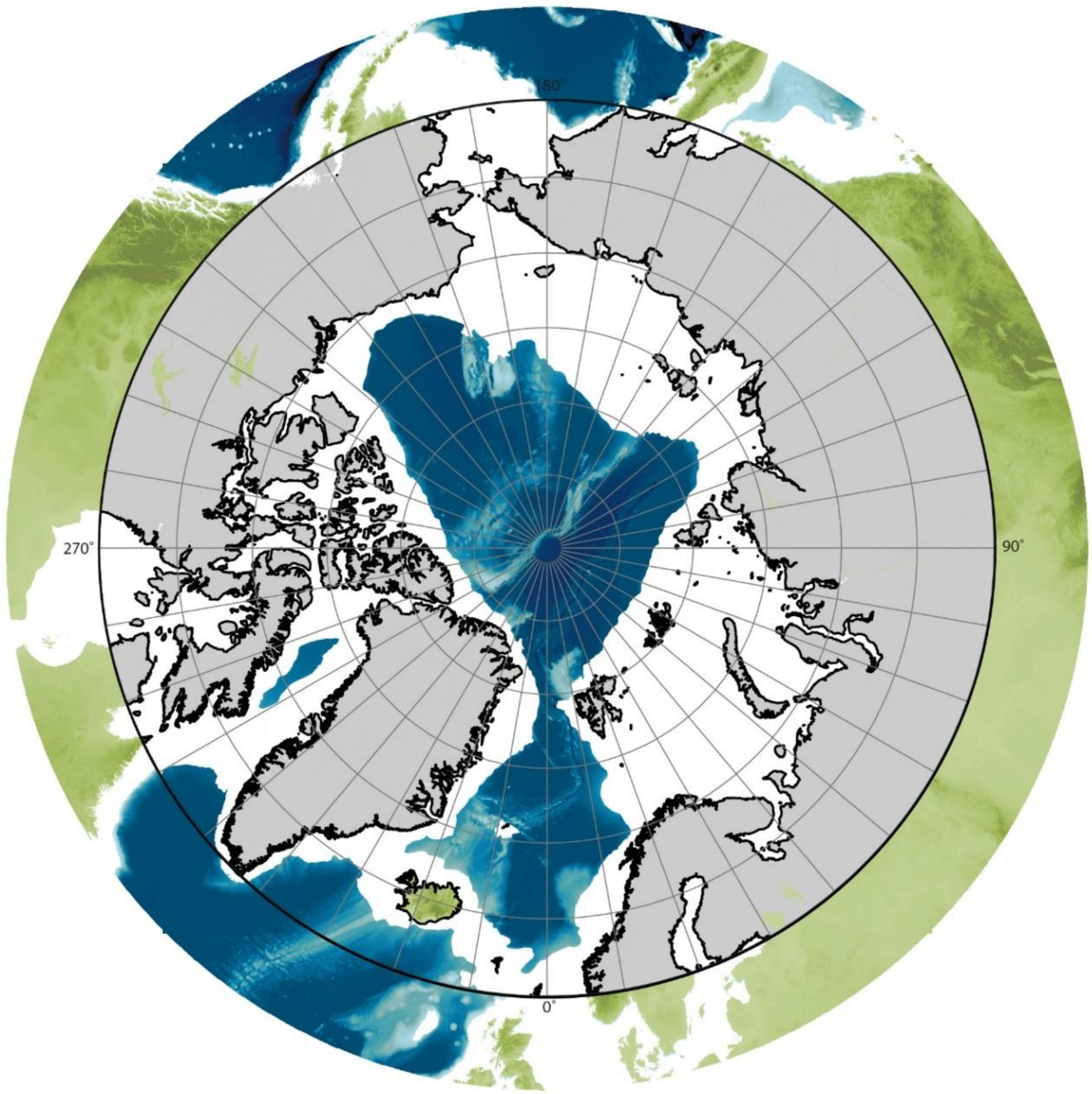

Figure 10: Map of the Circumpolar Arctic (polar stereographic projection). Grey area shows exposed continent north of 60°N, which is the southern limit of the map area for this study. The white area shows the extent of continental shelf and slope, as defined by Harris et al. (2014). This definition of the extent of continental shelf and slope is used for this project. Note that the volcanic terrace around Iceland is not included as continental shelf or slope, because it has a volcanic origin, and is not composed of pre-rifted continental crust. Map created using topography and bathymetry from IBCAO (v. 3).

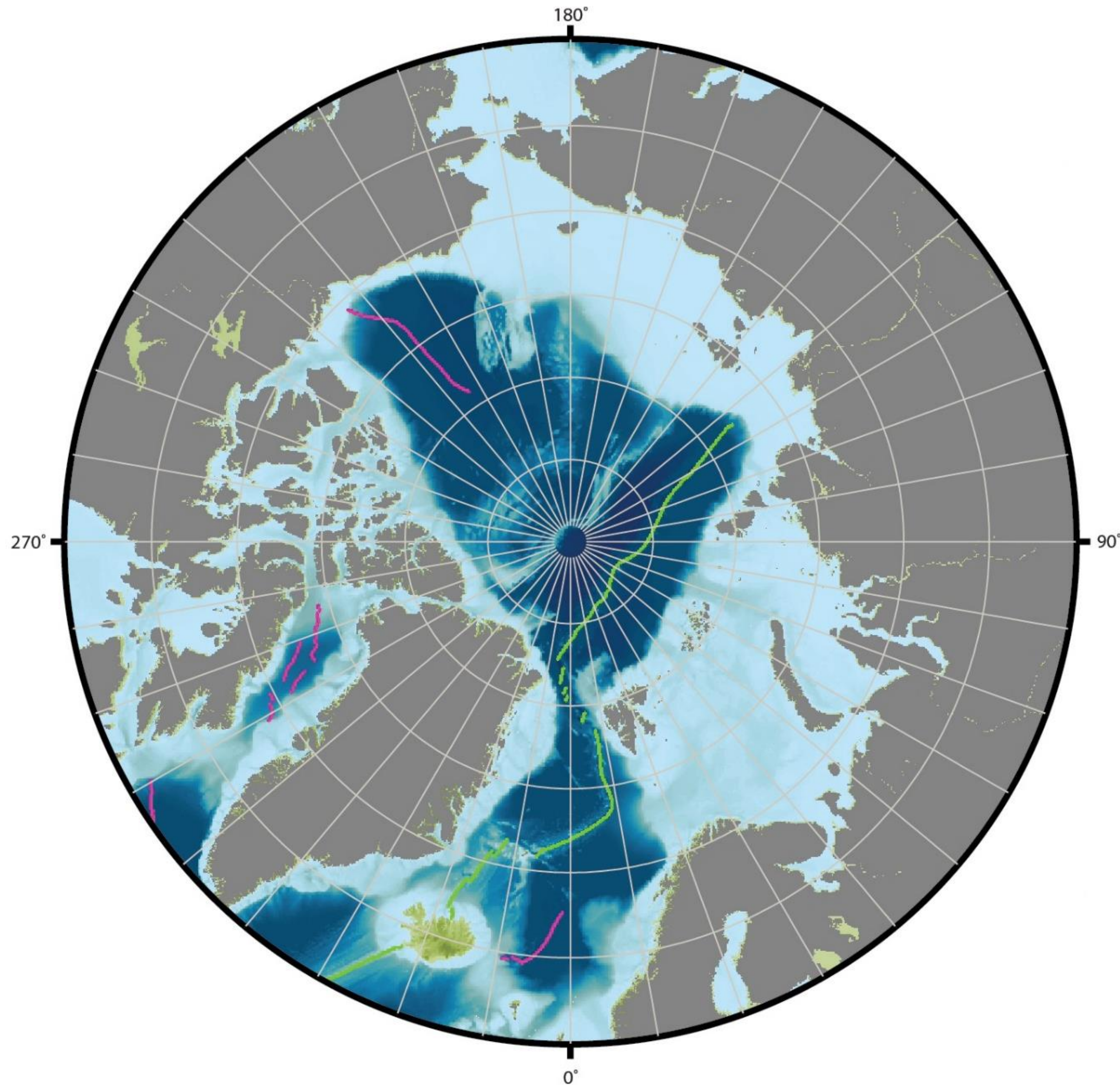

Figure 11: Bathymetric map of the Circumpolar Arctic (north of 60°N) showing active (green) and extinct (magenta) mid-ocean ridges. Ridge locations are derived from global satellite vertical gravity gradient (Sandwell and Smith, 2014) (Sandwell, D. T., R. D. Müller, W. H. F. Smith, E. Garcia, R. Francis, *New global marine gravity model from CryoSat-2 and Jason-1 reveals buried tectonic structure*, Science, Vol. 346, no. 6205, pp. 65-67, 2014). The termination of a spreading ridge at the foot of the continental slope indicates the limit of oceanic crust and transition to continental crust. Map created using IBCAO v.3 bathymetry.

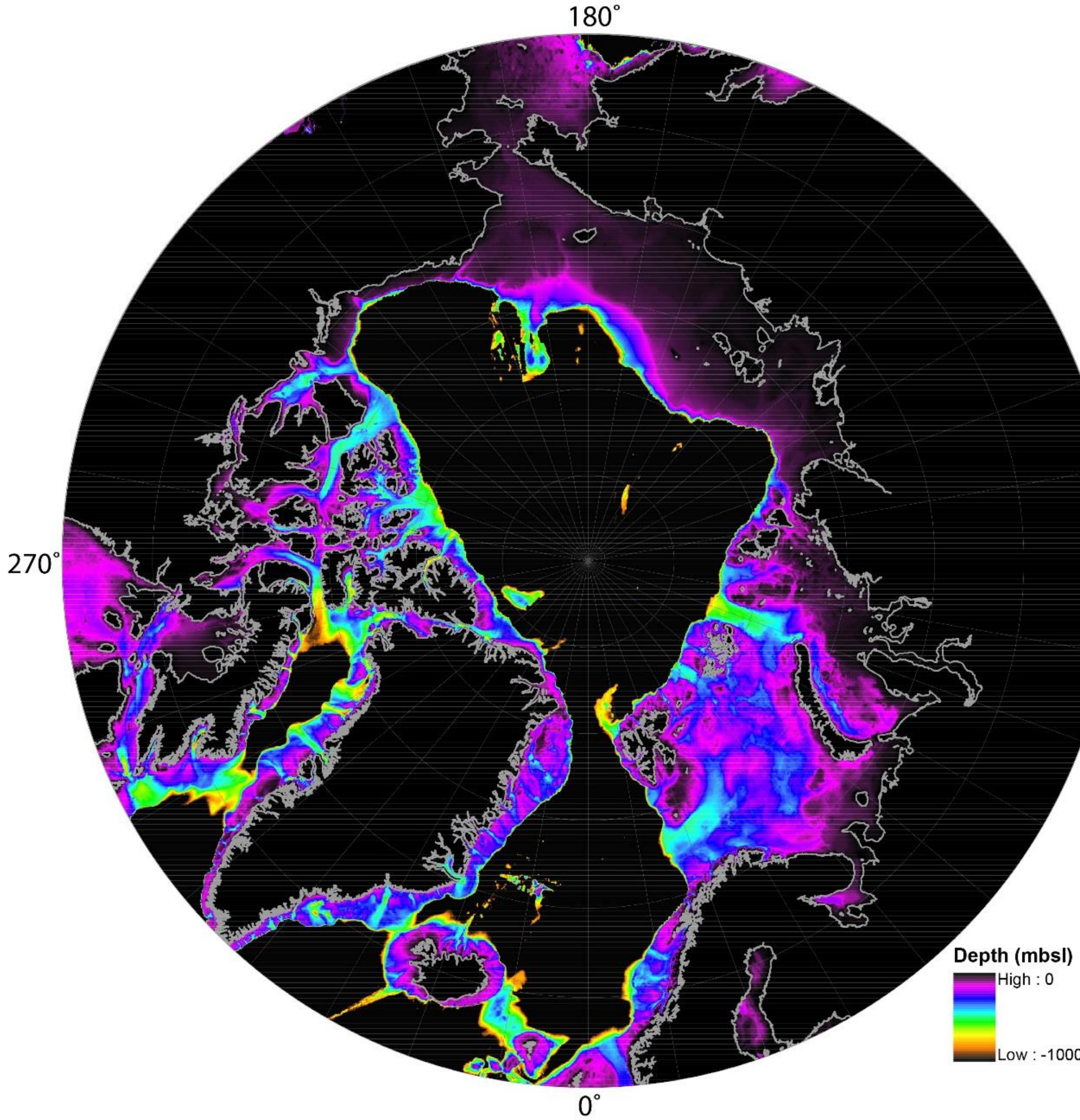

Figure 12: Image of the Arctic basin showing variable depths out to the limit of the continental slope used in this study. Map created using merged bathymetry from GEBCO and IBCAO v.3 (Jakobsson et al., 2012).

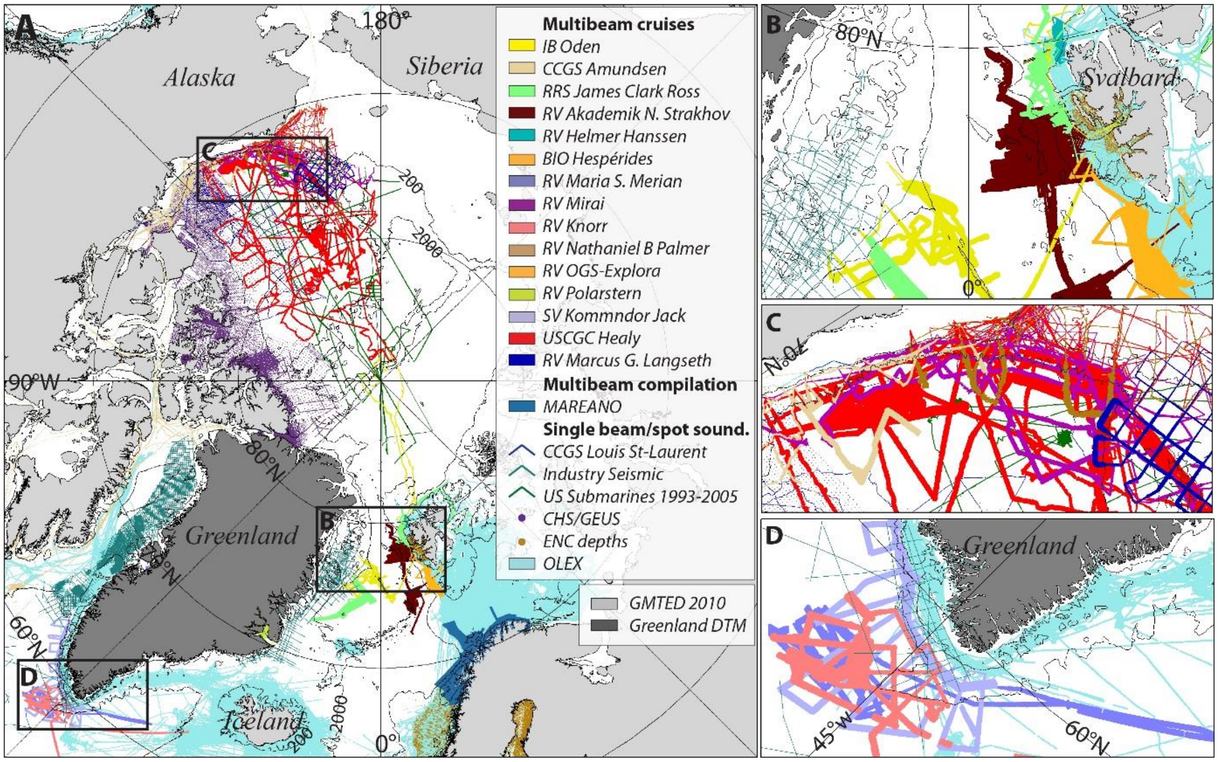

Figure 13: Map of the Arctic Basin, showing ship tracks of research vessels that provided multibeam bathymetric data that was merged with satellite-derived gravity data to produce the IBCAO bathymetric grid (from Jakobsson et al., 2012). Ship-derived bathymetry provides higher resolution data (e.g. 50 m grid instead of 500 m grid from satellite gravity data).

2.0 Regional geology of the Circumpolar Arctic

As a demonstration of the workflow and procedures that might be used to estimate the offshore bedrock geology of the continental shelf, an ArcGIS® project was constructed based on the onshore geology and offshore bathymetry of the Circumpolar Arctic region. The data layers imported into the project included shoreline geology, offshore structure where known, Tertiary cover (i.e., sediment thickness, type, geomorphology) and basement geology where known. The cover sequences are well known in many places, constrained by geophysics aimed at exploration for oil and gas, and these are included at a regional scale on the Geological Map of the Arctic – Map 2159A (Harrison et al., 2011) and the Commission for the Geological Map of the World (CGMW, 2010). The goal of the demonstration project was to “remove” those cover sequences and attempt to extrapolate the basement geology offshore by inferring extensions of older terranes on land to the edge of the shelf. The compilation involved identification of data types, assembly of map sheets and digital data, georeferencing, and development of a common legend and attributes table for analysis. Importantly, no single compilation of this type, including both onshore and offshore data sets, was previously available.

The regional geology of the Circumpolar Arctic is depicted in the Geological Map of the Arctic (Map 2159A, published in 2011), where units are defined at 1:5,000,000 scale. In the ArcGIS® project, this map was combined with the IBCAO bathymetric data in Figure 14. Larger-scale geological features, are depicted in the 1:25,000,000 generalized Geologic Map of the World (CGMW, 2010) in Figure 15, and the reduced legend is provided in Figure 16. The offshore units depicted on both maps are post-Cretaceous cover sequences (Fig. 17 and

Fig. 18); the continental basement in these areas is not exposed under this cover (e.g., Fig.19 and Fig. 20). A brief outline of the regional geology of 5 main sub-regions of the Circumpolar Arctic is provided below as a guide to features mentioned in the text. A more exhaustive summary of the geological history of each area is beyond the scope of this study.

2.1 Fennoscandia

The Fennoscandian region of Norway, Sweden, Finland, Karelia, and the Kola Peninsula is mainly underlain by the Baltic (Fennoscandia) shield, with the exception of the Norwegian coastline, which is bordered mainly by the Caledonian Fold Belt (Lahtinen et al., 2008). The shield areas are Precambrian plutonic, volcanic and sedimentary rocks that have undergone several stages of deformation and metamorphism. During the breakup of the Rodinian supercontinent in the Proterozoic, oceanic rocks, including clastic and carbonate sedimentary rocks formed in the Iapetus Ocean bordered by an Atlantic-type passive margin (Nairn and Stehli, 1974). The closure of Iapetus Ocean and collision between Laurentia and Baltica in the Silurian resulted in the formation of the Caledonian accretionary fold and thrust belt from these units which are now exposed along the western margin of the craton (Grenne et al., 1999; Watt and Thrane, 2001).

2.2 Russia

Russia dominates much of the Circumpolar Arctic, from the Fennoscandia Shield in the west to Alaska in the east, and includes the northern extension of the Urals Mountains, the Siberian Craton, and the West Siberian sedimentary basin. The Uralides comprise a N-S trending orogenic belt that subdivides these regions and extends from the islands of Novaya Zemlya to the Aral Sea (Pushkarev et al., 2013). They formed in the Paleozoic to Lower Jurassic and are dominated by mafic to ultramafic rocks of oceanic and island-arc origins. East of the Ural Mountains, the region is dominated by the West Siberian sedimentary basin. The Arctic coastline east of the Urals is dominated by the Taimyr fold and thrust belt, which comprises three separate terranes accreted between the Neoproterozoic and Mesozoic (Torsvik and Andersen, 2002). In the Jurassic, a large igneous event directly south and east of the Taimyr region formed the Siberian Traps flood basalts. Further to the east is the West Siberian Craton and the Yana-Kolyma fold and thrust belt, which includes an Upper Paleozoic to Mesozoic accretionary wedge referred to as the Kolyma-Olomon terrane. Furthest east, the region is dominated by the large Cretaceous Okhotsk-Chukotka volcanic-plutonic belt, which extends along the western margin of Sea of Okhotsk and across the Bering Strait to the Seward Peninsula. It overlies the southeastern margin of the North Asian Craton and the Kolyma-Omolon superterrane (Nokleberg et al., 2005).

2.3 Northern Alaska

On the Seward Peninsula, in northwestern Alaska, Paleozoic magmatic rocks similar to those of the Okhotsk-Chukotka region are exposed. The Seward Peninsula is considered to be the eastern extent of the Okhotsk-Chukotka volcanic-plutonic belt, which is extensively intruded by Late Cretaceous silicic granitoids (Nokleberg et al., 2005). The northern flank of Alaska is dominated by the Brooks Range, a strongly folded assemblage of Carboniferous chert, shale, limestone, and volcanic rock, and has been interpreted to have formed during rifting and back-arc spreading associated with a short-lived continental margin at this location (Nokleberg et al., 2005).

2.4 Canadian Arctic Archipelago

The Canadian Arctic Archipelago includes Archean and Paleoproterozoic basement rocks overlain by Mesoproterozoic and Paleozoic sedimentary sequences (Sherlock et al., 2004; Trettin, 1991). Sediments are the dominant lithologies exposed within the Arctic Basin. These include the Proterozoic Foxe River Belt on Baffin Island and the Melville Peninsula, lying within the northwestern margin of the Trans-Hudson Orogen, and the Mesoproterozoic Bylot Supergroup on the Borden Peninsula (Corrigan et al., 2001). Neoproterozoic sediments on Victoria Island are associated with rifting and passive continental margin deposition (Trettin, 1991). The Parry Island Fold Belt (Central Ellesmere Island) formed in the late Devonian to early Carboniferous and consists of platform carbonate rocks dominated by shallow-water shelf sequences. The Franklin Mobile Zone formed during the Ellesmere Orogeny in the late-Silurian to early-Carboniferous (Savard et al., 2000).

2.5 Greenland

Greenland formed the eastern part of the Laurentian craton that separated in the late Cretaceous from present day North America (Torsvik et al., 2001; Watt and Thrane, 2001). On the west side of Greenland, the Paleoproterozoic Rinkian Belt correlates with the Foxe Fold Belt in Canada (Wodicka et al., 2002; Connelly et al., 2006) and formed as a result of collision between Archean granitoids and the overlying Karrat Group Paleoproterozoic metasediments at 1.88-1.83 Ga (Connelly et al., 2006; Lahtinen et al., 2008). On the east side of Greenland, the Caledonian fold belt records the closure of the Iapetus Ocean (Higgins et al., 2000; Torsvik et al., 2001) and comprises a series of N-S trending west-verging thrust sheets that complement the east-verging structures of the Scandanavian Caledonides (Higgins et al., 2000; Kalsbeek, 1995). The Paleozoic sedimentary belts of Ellesmere Island are also exposed on North Greenland and are dominated by the E-W trending North Greenland Fold Belt that consist mainly of Ordovician shale and calcareous siltstone (Henriksen et al., 2009; Higgins et al., 2000). The youngest rocks on Greenland are Tertiary intrusive and extrusive igneous rocks of the Kangerlussuaq region, which are related to opening of the Atlantic and the emergence of the Iceland plume. Paleogene magmatic activity in this region included tholeiitic flood basalts, dyke swarms, and ultramafic to alkaline intrusions (Wittig et al., 2010; Holwell et al., 2012).

3.0 Regional metallogeny of the Circumpolar Arctic

The Circumpolar Arctic region is host to more than 180 documented mineral occurrences (Fig. 21 and Appendix 2), including orogenic vein-hosted deposits, felsic and mafic intrusion-related deposits, and sediment-hosted deposits (Fig. 22). The land-based mineral endowment of the region includes lode Au, IOCG (iron-oxide-copper-gold), MVT (Mississippi Valley-Type Pb-Zn), Ni-Cu-PGE, porphyry, sediment hosted Cu, SEDEX (sedimentary exhalative), Sn-W, and VMS (volcanogenic massive sulfide) (Geological Survey of Canada Mineral Deposits Database). However, many areas of the Arctic region remain poorly explored and significant potential for the discovery of mineral deposits remains. Based on the Geological Survey of Canada (GSC) World Mineral Deposits Database (2011), more than 30 different mineral districts are identified in the ArcGIS® project, with information on deposit type, commodity, grade, tonnage, host rock, lithology, age, lithotectonic domain type and number of occurrences (Table 2 and Fig. 23). This compilation includes more than 15 different deposit types reflecting a diversity of geological settings and a complex history of sedimentation, intrusive and extrusive igneous processes, metamorphism, rifting, and terrain accretion. Many of these terrain can be extended to the submerged portions of the continental crust, and an important premise of the thesis is that different types of continental basement rocks under the shelf areas could host mineral deposits similar to those on nearby land.

The Caledonian accretionary belt in Norway hosts several world class porphyry, SEDEX, Ni-Cu-PGE, and orogenic gold deposits (Grenne et al., 1999). Paleoproterozoic orogenic belts located within the Baltic shield areas of Northern Sweden and Finland contain volcanogenic massive sulfide (VMS), magmatic Ni-Cu-Co and platinum group element (PGE) deposits, and porphyry Cu-Au systems (Watt and Thrane, 2001). On the Kola Peninsula, large Precambrian Fe-Ti-V deposits are located in the Murmansk region, and mafic-hosted Ni-Cu-PGE deposits occur in the Lapland-Kola and Pechenga areas.

East of the Fennoscandia Shield, the northern extension of the Ural Mountains host a series Paleozoic sedimentary Cu deposits and mafic-ultramafic hosted Ni-Cu-PGE deposits. The Taimyr region, in particular, is host to numerous Carboniferous and early Triassic Ni-Cu-PGE occurrences associated with mafic intrusions into shallow marine clastic sediments. In the Yana-Kolyma fold and thrust belt of eastern Siberia there are numerous Triassic intrusion-related Sn-W deposits, Au quartz vein systems, and Sb-Au and sediment-hosted Hg deposits. These include deposits in widespread Permian to Triassic black shale (Nokleberg et al., 2005). The middle Triassic to Cretaceous magmatic arc assemblages of the Okhotsk-Chukotka volcanic-plutonic belt contain a large number of intrusion-related Sn-W, porphyry Cu-Sn, and polymetallic veins.

On the Seward Peninsula, in northwestern Alaska, intrusion related Sn-W deposits occur in similar Paleozoic magmatic rocks, which are considered to be the eastern extension of the Okhotsk-Chukotka volcanic-plutonic system. The Brooks Range is also an important metallogenic belt in northwestern Alaska. The carboniferous chert, shale, limestone, and volcanic rocks host a number of world-class Devonian and Carboniferous SEDEX Zn-Pb-Ag deposits including Red Dog.

The Arctic Islands of northern Canada include Neoproterozoic sediment-hosted copper occurrences on Victoria Island (Trettin, 1991), Paleoproterozoic SEDEX deposits in the Foxe River Belt on Baffin Island and Melville Peninsula (Corrigan et al., 2001), and Mesoproterozoic MVT-style mineralization at Nanisivik in the Bylot Supergroup (Sherlock et al., 2004). The Parry Island Fold Belt of Central Ellesmere Island hosts late Devonian to early Carboniferous MVT occurrences, including the Polaris MVT deposit on Cornwallis Island (Trettin, 1991).

The Rinkian Belt in West Greenland correlates with the Foxe Fold Belt and also hosts Paleoproterozoic SEDEX deposits (e.g., Black Angel), as well as Late Cretaceous to Paleocene magmatic sulfides in ultramafic rock (Connelly et al., 2006). The North Greenland Fold Belt hosts several important Ordovician shale-hosted SEDEX deposits (e.g., Citronen Fjord) similar to occurrences on Ellesmere Island (Henriksen et al., 2009; Higgins et al., 2000). The Greenland portion of the Caledonian Fold Belt is prospective for both SEDEX and VMS, and post-Caledonian sediments contain copper mineral occurrences. Tertiary intrusive and extrusive igneous rocks of the Kangerlussuaq region of East Greenland are host to Ni-Cu-PGE-Au deposits, including in the Skaergaard Intrusion (Holwell et al., 2012).

4.0 Tectonic history of the Arctic Basin

At 180 Ma, the entire northern hemisphere north of 55˚N was continuous continental crust, including the western margin of North America and the Siberian platform. During the middle Jurassic, opening of the Atlantic was initiated, eventually leading to the separation of Labrador and Greenland (Lawver et al., 1990). The Amerasian (Canada) Basin (Fig. 4) began opening at about 146 Ma by the detachment of the Chutcki block from the North American margin (Vernikovsky et al., 2013), representing the first major tectonic event in the formation of the Arctic Ocean Basin. After approximately 120 Ma, motion between Eurasia and North America in the eastern Siberian region ceased (Lawver et al., 1990; Rowley and Lottes, 1988), and continental rifting initiated between the Rockall Plateau and Eurasia at 80 Ma. By 60 Ma, Greenland was an independent plate, separated from both North America and Eurasia, and extension began between Greenland and Rockall Plateau/Eurasia. Seafloor spreading had shifted from the south Labrador Sea to the north Labrador Sea, and spreading between the Lomonosov Ridge (which now moves as a part of the North American Plate) and Eurasia begin at 56 Ma. This spreading, which propagated northward, resulted in the opening of the Eurasian Basin (including the Amundsen and Nansen sub-basins) and today forms the Nansen-Gakkel Ridge, which is the only present day plate boundary to cross the Arctic Ocean (Lawver et al., 1990; Rowley and Lottes, 1988). Continuing slow extension in the Eurasian Basin now amounts to less than 10 mm/year. The deep water passage between Greenland and Svalbard did not form until roughly 5 Ma (Lawver et al., 1990).

4.1 Post-rift cover sequences

The continental shelf area of the Arctic Superbasin defined by Harris et al. (2014) covers 6,727,440 km^2, representing 48% of the total seafloor area. This area does not include the slope or large areas of the Arctic shelf covered by glacial deposits. In the present study, the total area of the oceans north of 60°N, including the Arctic Basin, was calculated at 16,300,000 km^2 (the Arctic Basin alone is 14,056,000 km^2: Fig. 10). The shelf defined by the 1000 m isobath north of 60° and including the slope and areas under Quaternary cover has an area of 9,450,000 km^2, about 40% larger than the area defined by Harris et al. (2014) and comparable to the total land area north of 60°. In this calculation, about 58% of the total ocean area north of 60° is underlain by continental crust.

The margins of the Arctic Basin are covered by the "circum-Arctic sedimentary belt", which consists of syn- and post-rift sedimentary sequences up to 22 km in thicknesses. These sequences, composed of both hard sedimentary rock and unconsolidated sediments include mostly siliciclastic material sourced from the adjacent Eurasian and North American margins during the opening of the basin (Gramberg et al., 2001). Four major sedimentary provinces dominate the circum-Arctic basin: West Arctic, North Siberian, New Siberian-Alaskan, and North Canadian (Fig. 5; Gramberg et al., 2001). Geophysical data, compiled by Gramberg et al. (2001) from various sources including geophysical surveys, scientific publications and offshore exploration drilling programs, are the basis for the current understanding of the sedimentary cover of the Arctic. Of the four provinces, the West Arctic province, dominated by the Barents–North Kara megabasin, represents the thickest point of sediment accumulation (20-22 km). The Barents–North Kara megabasin is a rift-type basin that formed by north-northeast extension in the Late Devonian to the end of the Triassic. The basin now contains numerous large fragments of East European platform (Gramberg et al., 2001; Shipilov and Matishov, 2006). It spans an area of 1,500,000 km^2, which is twice as large as the next largest sedimentary basin (the North Siberian province at 600,000 km^2 , with a sediment thickness of 14-16 km: Gramberg et al., 2001). The North Siberian province includes the Yenisei-Khatanga megabasin, the Uedinenia and Lena-Anabar basins, and the Laptev basin (Fig. 5). Like the Barents−North Kara megabasin, most of these basins are associated with recently active rifts (Vernikovsky et al., 2013). The Laptev basin, for example, contains branching grabens that are thought to be projections of the Gakkel Ridge spreading center.

The New Siberian–Alaskan Province spans more than 2200 km with a width of at least 500 km and a sediment thickness of 10-15 km. It includes the Blagoverschensk, New Siberian, Toll, Ayonsk, North Wrangel, South Chukchi, Vilkitsky, Polkin, Coville, and Nuvuk basins (see Gramberg et al., 2001). Several of these basins in the far east are foredeeps of the North Alaskan foldbelt, with deformed basement rocks intruded by middle Cretaceous granitoids.

The North Canada province also spans about 2000 km with a width of 600 km and a sediment thickness of up to 14 km. It includes the Beaufort Sea–Mackenzie Delta, Canadian, Sverdrup, Lincoln, Wandel, Kron Prince Kristian, and Voring basins (Gramberg et al., 2001). The basement of the Beaufort–Mackenzie Delta basin consists of deformed lower Paleozoic rock and Precambrian metamorphic rocks of the Canadian Shield. The other basins are mainly underlain by deformed early to middle Paleozoic assemblages of the Innuit fold belt and Franklinian fold belt.

Although the general lithostratigraphy of the basement rocks in most of these sub-basins is known, there have been no attempts to systematically correlate onshore units with offshore basement geology at better than 1:25,000,000.

Table 2: Deposit districts in the Circumpolar Arctic

Deposit District	Country	Deposit Type[1]	Geologic Age of Host Rock[2]
Grong	Norway	Porphyry; calc-alkaline	Cambrian to Devonian
Bleikvassli	Norway	SEDEX; sulphide plus exhalite	Cambrian to Devonian
Rana Intrusion	Norway	Ni-Cu-PGE; dissemination	Cambrian to Devonian
Bidjovagge	Norway	Au	Late Paleoproterozoic (Statherian)
Repparfjord	Norway	Sediment Hosted Cu	Paleoproterozoic (Rhyacian)
Skellefte	Sweden	VMS	Paleoproterozoic
Vasterbotten	Sweden	Porphyry Cu-Au	Early and Middle Paleoproterozoic (Siderian - Orosirian)
Vasterbotten	Sweden	Ni-Cu-Co	Early and Middle Paleoproterozoic (Siderian - Orosirian)
Lansi-Suomi	Finland	Ni-Cu-Co	Early and Middle Paleoproterozoic (Siderian - Orosirian)
Lappi	Finland, Sweden	PGE	Early and Middle Paleoproterozoic (Siderian - Orosirian)
Oulu	Finland	Ni-Cu-Co	Early and Middle Paleoproterozoic (Siderian - Orosirian)
Orijarvi (Southern Finland)	Finland	VMS; bimodal felsic	Early to late Paleoproterozoic (Siderian and Statherian)
Murmansk	Russia	Fe-Ti-V (Alkaline-Fe-Ti-P)	Mesoarchean and Neoarchean; middle Paleoproterozoic (Orosirian)
Murmansk	Russia	Fe-Ti	Middle Paleoproterozoic (Orosirian)
Lapland-Kola	Russia	Ni-Cu-PGE	Mesoarchean and paleoproterozoic archean; Middle and Late Devonian
Pechenga Area	Russia	Ni-Cu-PGE	Mesoarchean and paleoproterozoic archean
Arkhangelsk oblast	Russia	Magmatic Ni	middle and late Mesoproterozoic; Late Devonian
Musyur Range	Russia	Sediment Hosted Cu	Cambrian to Devonian; late Paleoproterozoic (Statherian) and Neoproterozoic
Taimyr Region	Russia	Magmatic Ni	Carboniferous and early Triassic; Ordovician and Silurian
Anabar-Olenek River Area	Russia	Placer Platinum	Early Cretaceous to Early Jurassic
Yakutiya (Sakha) Republic	Russia	Sn	Oligocene and Miocene
Yana-Kolyma fold thrust belt	Russia	Intrusion Related Sn-W	Middle triassic to Early Cretaceous
Yana-Kolyma fold thrust belt	Russia	Epithermal Gold	Middle Triassic
Okhotsk-Chukhotsk volcanic belt	Russia	Intrusion Related Sn-W	Triassic to Cretaceous
Okhotsk-Chukhotsk volcanic belt	Russia	Porphyry Cu-Sn-Ag	Late Cretaceous
Okhotsk-Chukhotsk volcanic belt	Russia	Intrusion Related Sn-W; Skarn	Middle Devonian to Early Cretaceous
Okhotsk-Chukhotsk volcanic belt	Russia	Intrusion Related Sn-W	Early Cretaceous to Late Triassic
Okhotsk-Chukhotsk volcanic belt	Russia	Au	Early to Middle Triassic

Deposit District	Country	Deposit Type[1]	Geologic Age of Host Rock[2]
Okhotsk-Chukhotsk volcanic belt	Russia	PGE; Hydrothermal	Late Triassic
Okhotsk-Chukhotsk volcanic belt	Russia	Hydrothermal; polymetallic vein	Early Cretaceous
Seward Penninsula	United States	Intrusion Related Sn/Placer	Proterozoic to Carboniferous
Brooks Range	United States	SEDEX	Devonian and Carboniferous
Brooks Range	United States	Cr	Neogene
Victoria Island Fold; Franklin LIP	Canada	Copper Redbed	Late Mesoproterozoic to Cryogenian
Parry Island fold belt	Canada	MVT	Cambrian to Permian
Borden Basin; Nanisivik District	Canada	MVT	Silurian
Foxe Fold Belt/Rinkian Belt	Canada/Greenland	VMS; mafic + SEDEX + magmatic	Mesoarchean to middle Paleoproterozoic
North Greenland Fold Belt	Greenland	SEDEX	Silurian to Devonian
Greenland Caledonian Fold Belt	Greenland	Sed-hosted Cu; Redbed	Cambrian to Jurassic
Southeast Greenland	Greenland	PGE-Au-Cu	Mesoarchean to Neoarchean
Ketilidian Mobile Belt	Greenland	Gold; Magmatic; PGE	Late Paleoproterozoic (Statherian)
Southwest Greenland	Greenland	Magmatic - Cr	Mesoarchean to Neoarchean
Southwest Greenland	Greenland	Vein/Replacement W	Mesoarchean to Neoarchean
Shetland Ophiolite Complex	United Kingdom	PGE; chromite magmatic	Cambrian and O+A1:D45rdovician

[1] Data from the GSC mineral deposits database

[2] Host rock ages from GSC Map 2159A (Harrison et al., 2011)

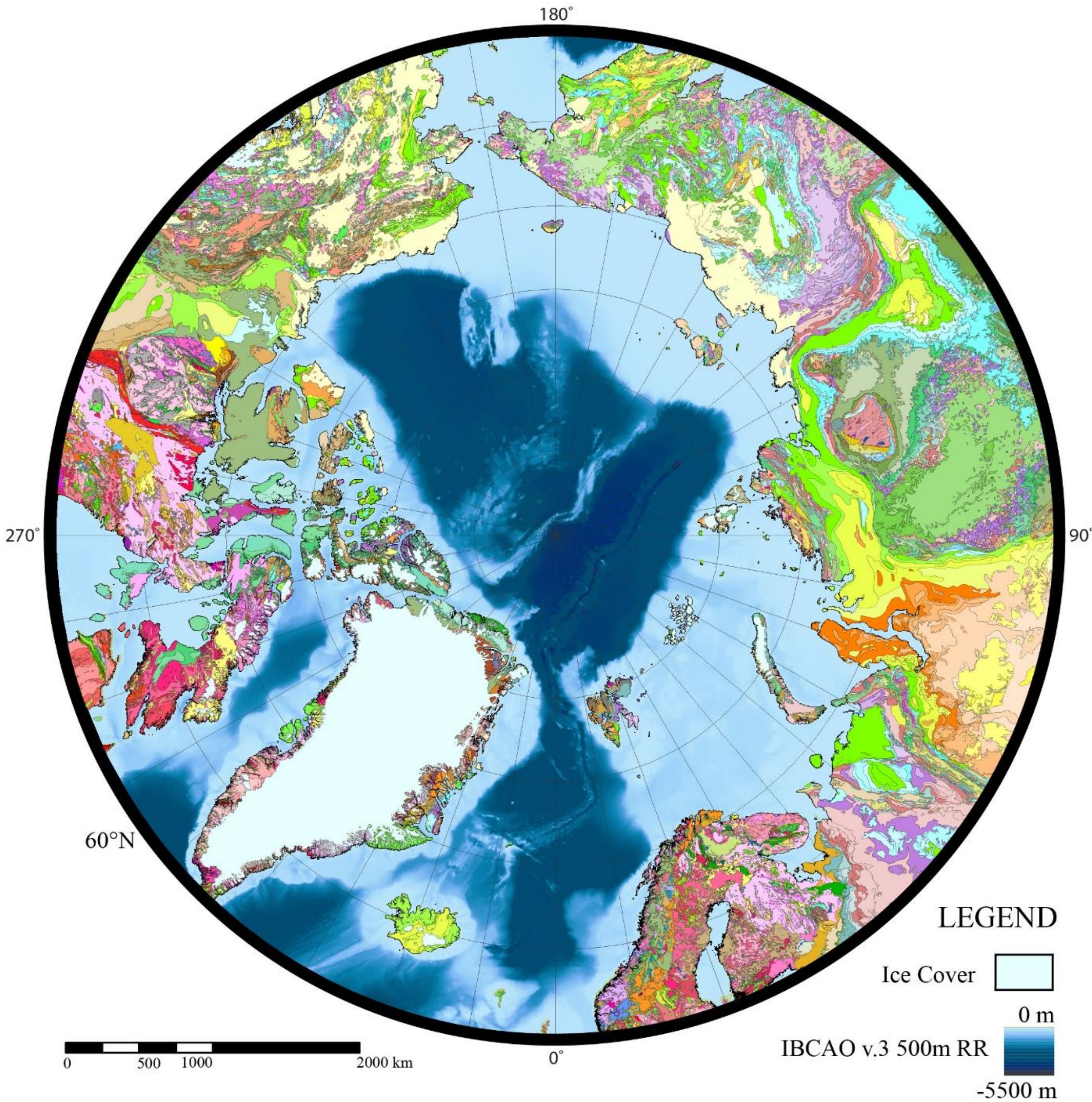

Figure 14: New combined geological and bathymetric map of the Circumpolar Arctic region. Land-based geology is from Geological Survey of Canada Map 2159A (Harrison et al., 2011) and is mapped at a scale of 1:5,000,000. Bathymetry is from IBCAO v.3 (Jakobsson et al., 2012). Legend for onshore geology can be found at:

http://ftp2.cits.rncan.gc.ca/pub/geott/ess_pubs/287/287868/as_2159.zip

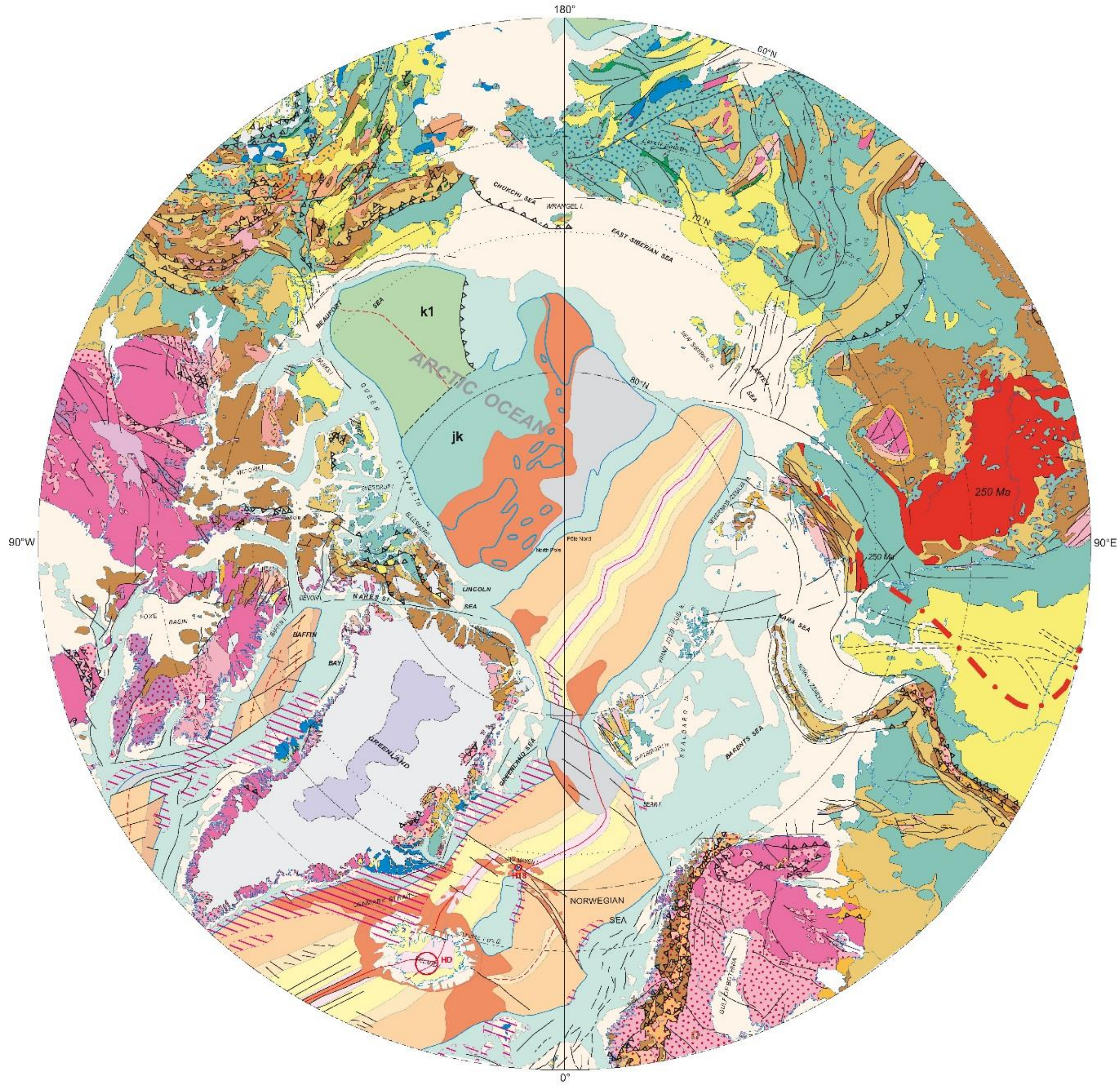

Figure 15: Polar stereographic projection of the Commission for the Geological Map of the World (CMGW) Geological map of the World, mapped at 1:25,000,000 (Bouysse, 2009). Mapped offshore geology represents age of seafloor (for oceanic crust) and undifferentiated continental shelf or slope (for submerged, pre-rift continental crust and overlying post-rift sediments). See Figure 16 for legend.

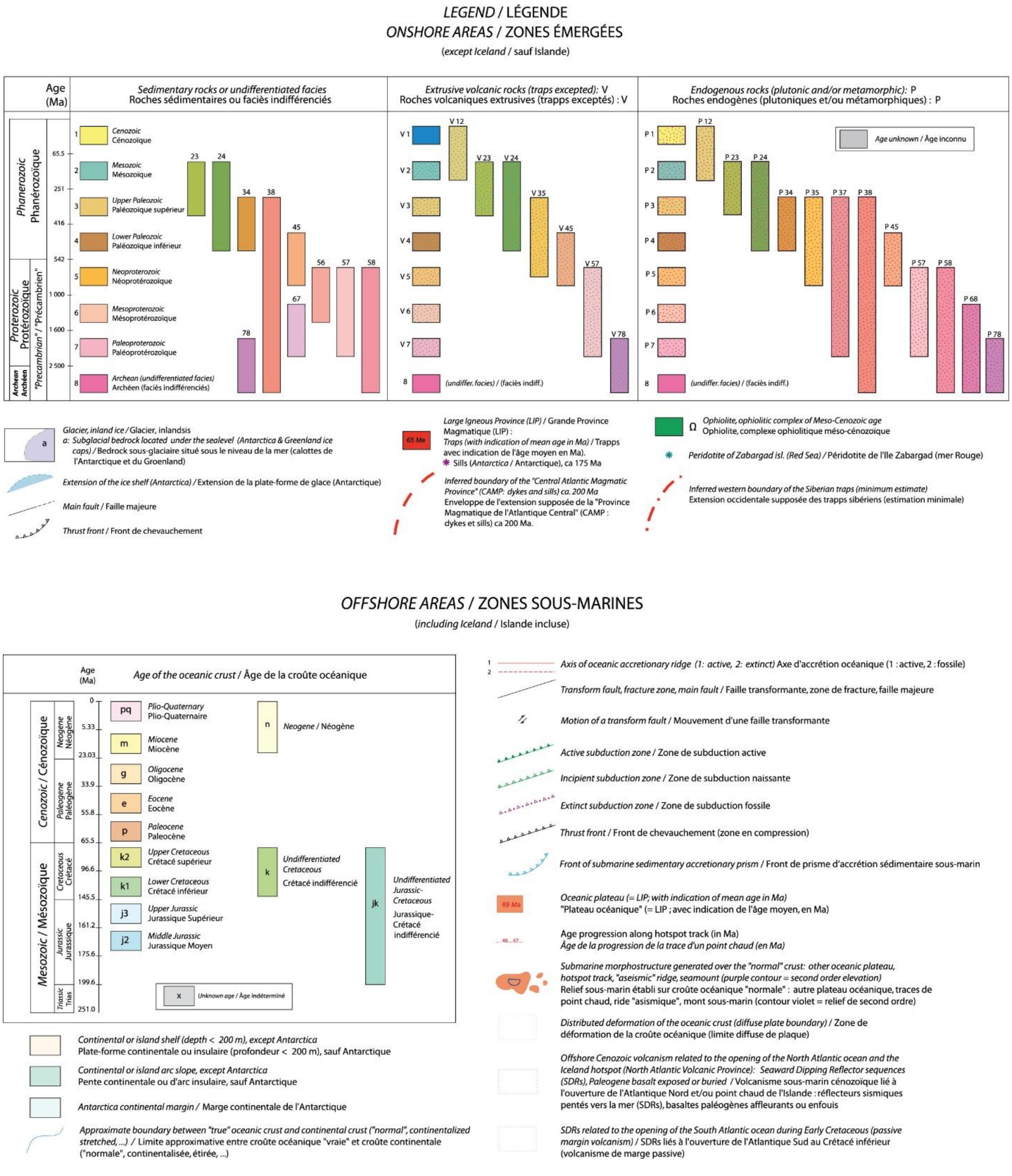

Figure 16: Legend for onshore and offshore geology of the circumpolar region depicted in Figure 15 (from the CGMW Geological Map of the World; Bouysse, 2009).

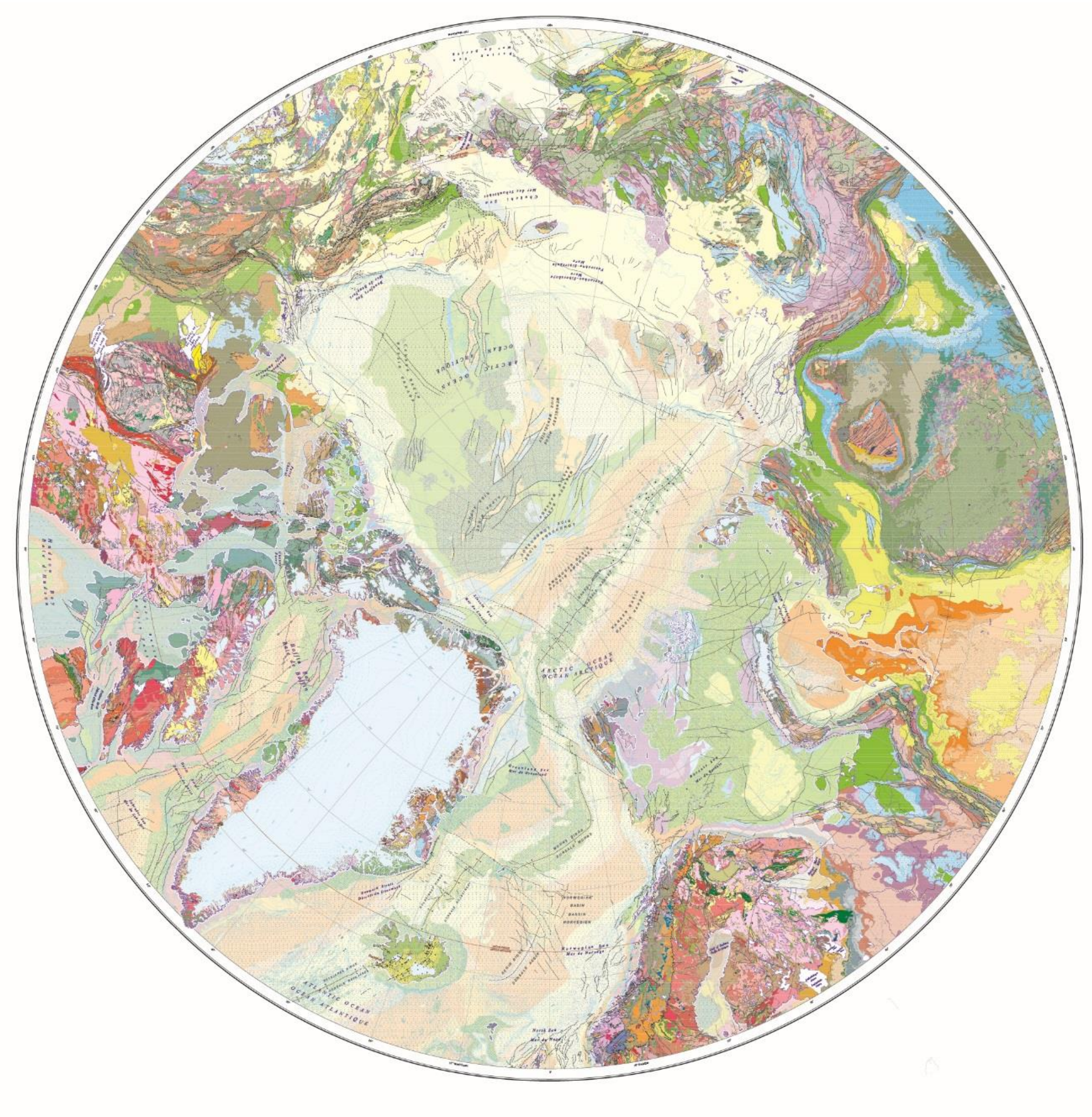

Figure 17: Geological Survey of Canada Map 2159A (polar stereographic projection) showing both onshore and offshore geology, mapped at 5X the scale (1:5,000,000) of the CGMW map (Harrison et al., 2011). Offshore units are subdivided based on age, rock type, and sediment source (e.g., continental or deep marine). See Figure 18 for legend.

PATTERN*	COMPOSITIONAL UNITS	EXAMPLE ROCK TYPES
	Supracrustal rocks	
CmD1	Sedimentary and/or volcanic: undivided	Sedimentary and/or volcanic rock: undivided
	Sedimentary	
Ng1	Sedimentary: undivided	Sandstone, siltstone, shale, limestone
Ng15	Clastic: continental	Redbeds, quartz arenite, arkose, conglomerate, evaporites
KPg3	Clastic: deltaic and nearshore	Sandstone, siltstone, shale, coal; plant fossils
D41	Clastic: shallow marine	Sandstone, siltstone, shale; marine fossils
D20	Evaporite	Salt, anhydrite, gypsum, dolostone
J40	Carbonate	Limestone, dolostone, shale, evaporites, chalk carbonate reefs
Ng24	Sedimentary: slope and deep water	Shale, chert, iron-formation, greywacke, turbidite, argillaceous limestone, matrix-supported conglomerate
SD7	Marine sedimentary: undivided	Limestone, dolostone, shale, evaporites, chalk, shale, iron-formation, gerywacke, turbidite, argillaceous limestone, matrix-supported conglomerate, carbonate reefs
	Igneous	
O26	Igneous: undivided	Igneous complex; volcanic and subvolcanic rocks
	Extrusive	
P30	Extrusive: undivided	Volcanic rocks, lava flows, pyroclastic debris
T51	Extrusive: alkalic	Trachyte, phonolite, carbonatitic lavas, leucitic volcanic rocks
D45	Extrusive: felsic	Rhyolite, felsic tuff, felsic pyroclastic rocks, felsic agglomerate
Pg40	Extrusive: intermediate	Dacite, latite, andesite, rhyolite, related pyroclastic rocks
K17	Extrusive: mafic	Basalt, olivine basalt, tholeiite, alkali basalt, basanite, pillow basalt, flood basalt
T7	Extrusive: ultramafic	Komatiite, nephelinite, picrite, basalt
	Intrusive	
CmD09	Intrusive: undivided	Plutonic rocks, intrusive complex, batholith
K18	Intrusive: granitic	Granite, monzogranite, quartz monzonite, leucogranite, alkalic granite, alaskite
P42	Intrusive: tonalitic-granodioritic	Monzonite, quartz monzonite, granodiorite, diorite, tonalite, granitoid rocks
SD11	Intrusive: gabbroic	Gabbro, olivine gabbro, diabase, norite, quartz norite, diorite, tonalite
PrD7	Intrusive: peridotitic	Pyroxenite, peridotite, dunite, harzburgite, wherlite, gabbro
i7	Intrusive: anorthositic	Anorthosite, gabbroic anorthosite
CmO11	Intrusive: syenitic	Syenite, lamprophyre, minette, foid syenite
K22	Intrusive: kimberlitic	Kimberlite, lamproite
T20	Intrusive: carbonatitic	Carbonatite
	Other compositions	
PzK12	Mélange	Mélange, polymict breccia, accretionary wedge complex
Pg53	Impact structure	Impact breccia, impact melt rock, crater fill
PrD8	Metamorphic: undivided	Schist, gneiss, migmatite, diatexite, tectonite, mylonite, granulite

* Certain compositional units have a distinctive pattern overlay as indicated in this column. Other units have a distinct colour fill only. Unit colours and labels shown only as examples.

Figure 18: Legend for offshore units from the Geological Survey of Canada Map 2159A (taken from Harrison et al., 2011).

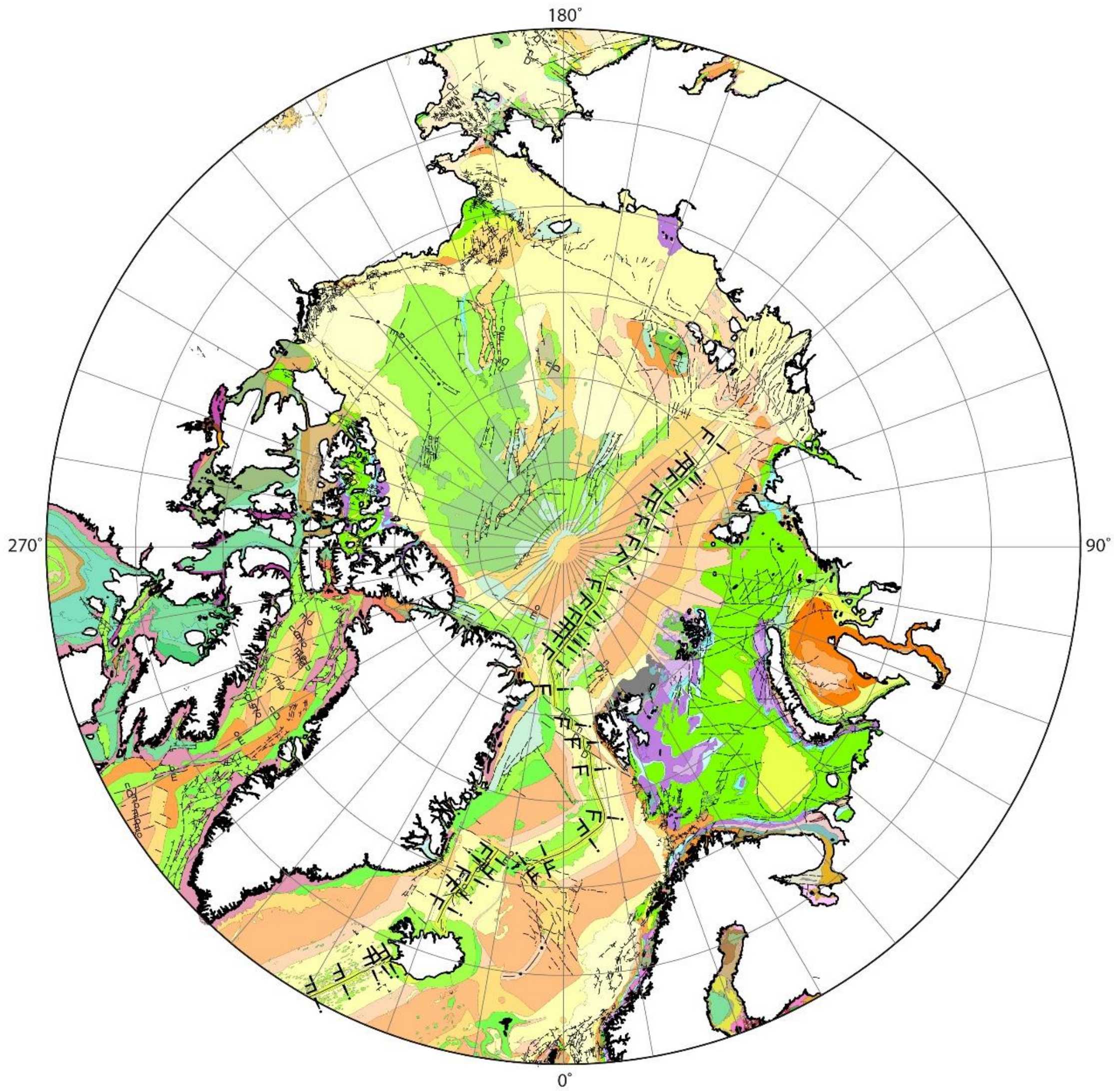

Figure 19: Offshore geology of the Circumpolar Arctic, from GSC Map 2159A (Harrison et al., 2011). Offshore geology of the continental shelf and slope area generally depicts the sediment cover only, and not the underlying basement rock. See Figure 18 for legend.

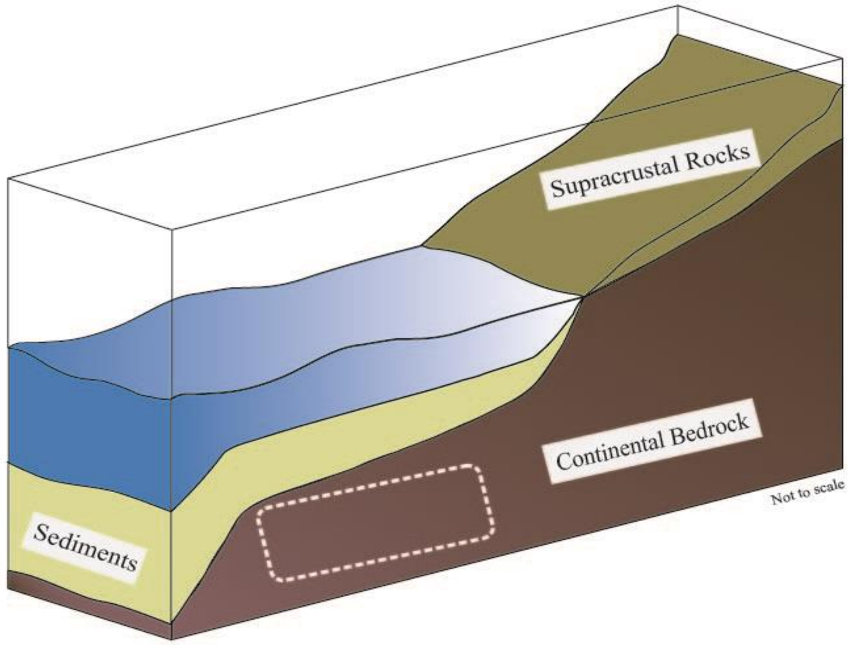

Figure 20: Schematic cross-section through a typical continental margin. On land, continental bedrock is variably covered by supracrustal sediments. However, on the continental shelf, continentally-derived sediments generally cover the entire underlying continental basement rock (area represented by dashed rectangle).

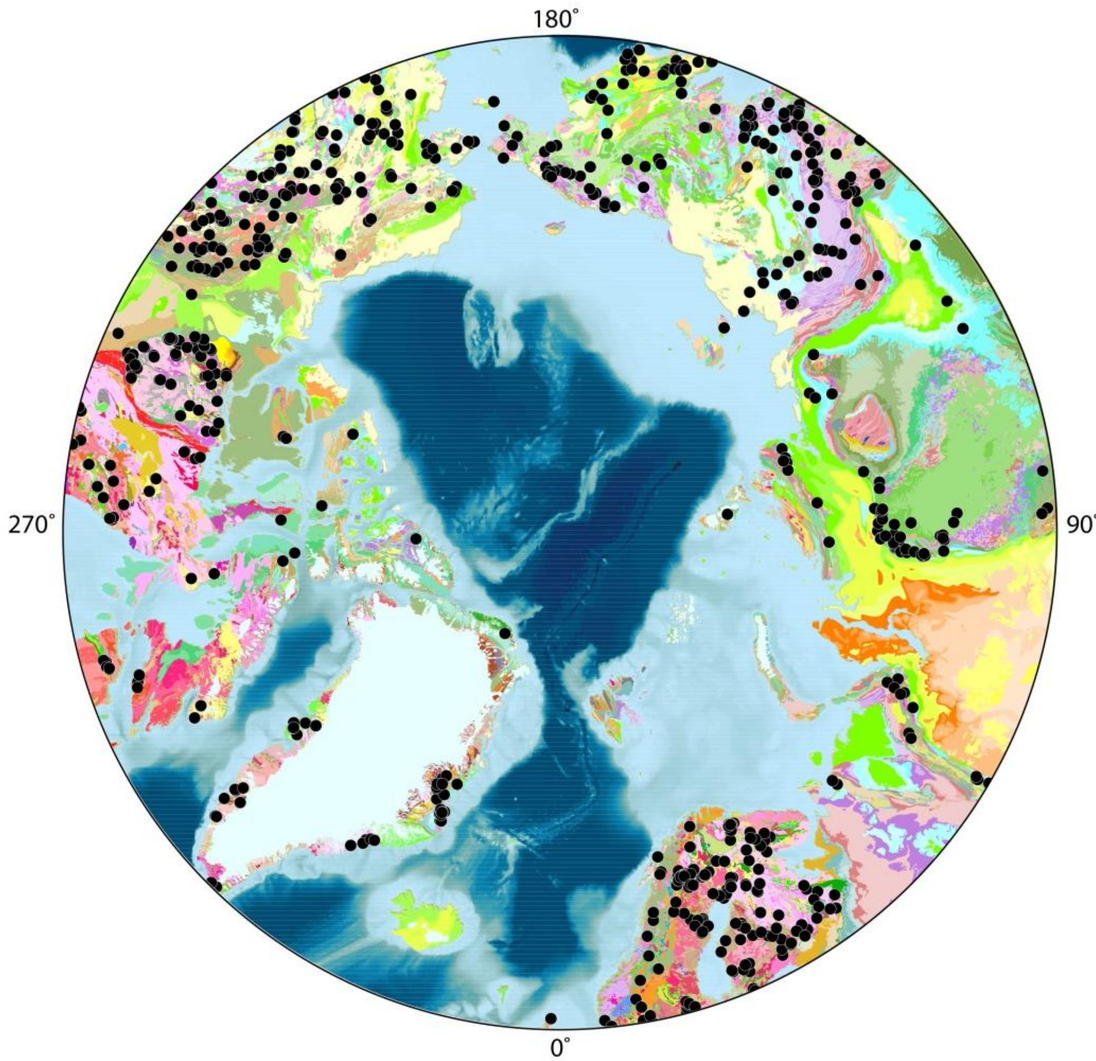

Figure 21: Geological map of the Circumpolar Arctic showing the locations of all known mineral deposits and mineral showings. Deposit data from unpublished GSC minerals database (see Appendix 2). Onshore geology from GSC Map 2159A (Harrison et al., 2011) and offshore bathymetry from IBCAO v.3 (Jakobsson et al., 2012).

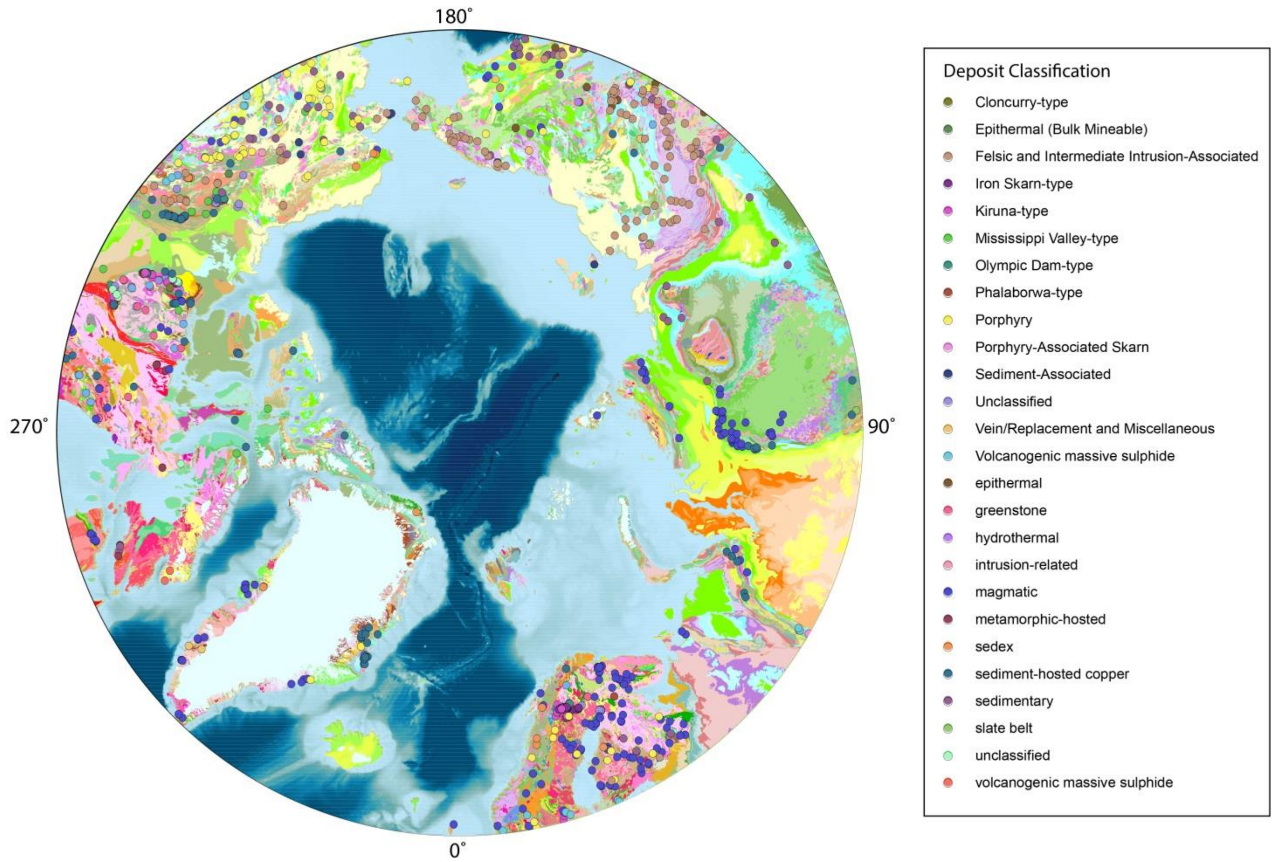

Figure 22: Mineral occurrences in the Circumpolar Arctic, classified by deposit type. See Figure 21 and Appendix 2 for source data.

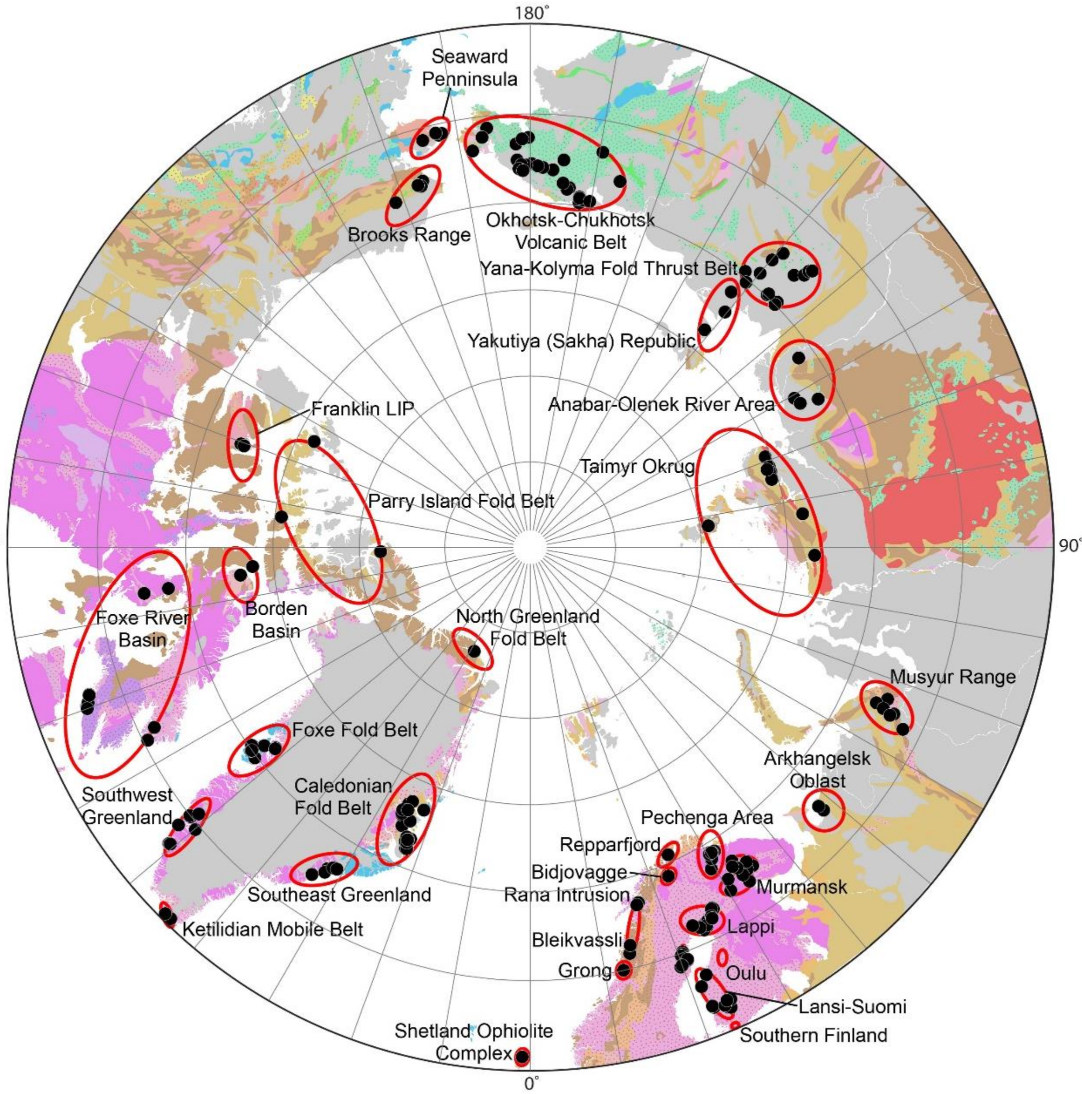

Figure 23: Locations of major mineral deposit districts in the circumpolar region north of 60°N (see Table 2).

5.0 Methods

This study explores methods for extrapolating pre-rift bedrock of the circumpolar continental shelf by the seaward extension of land-based geological units and structural features using a combination of 1:25,000,000 and 1:5,000,000 regional geological compilations and offshore bathymetric data. Bathymetric datasets are used to determine offshore structure, which is the most important constraint on how far individual map units can be drawn beyond the nearest coastal exposures. The derived maps are first-order estimates of the bedrock geology of the extended continental shelf. All maps are presented in the Polar Stereographic projection, as it conserves angles of the individual polygons. Areas of onshore and offshore polygons are calculated using the North Polar Lambert Azimuthal Equal Area projection. This projection preserves the area of individual polygons, regardless of its location from the standard parallel.

The area considered first is shown in white in Figure 24 and includes the entire Arctic Basin out to the 1,000 m isobath as the geological limit corresponding to the outer slope where oceanic and continental crust meet (Fig. 6 and Fig. 12). The total area is similar in size to that covered by post-Cretaceous sediments (or ice) on land, as shown in grey on Figure 24. The preliminary legend for the offshore extrapolation of bedrock geology is shown in Figure 25, adapted from the 1:25,000,000 compilation of the Commission for the Geological Map of the World (CGMW, 2010). The units correspond to lithostratigraphic assemblages (age, rock type) and include regional morphotectonic subdivisions developed onshore but generally excluding rock type (e.g., Vernikovsky et al., 2013: Fig. 5B).

5.1 Base Maps

Commission for the Geological Map of the World

The 1:25,000,000 compilation of CGMW (2010) features geological/tectonic terrane assemblages classified as either sedimentary (or undifferentiated), extrusive volcanic, and plutonic/ metamorphic, subdivided by Period (Cenozoic, Mesozoic, Upper Paleozoic, Lower Paleozoic, Neoproterozoic, Mesoproterozoic, Paleoproterozoic, and Archean). For offshore geology, the continental shelf is drawn to the edge of the slope and oceanic rocks are designated according to age only (to early Jurassic). Where drawn, the boundary between continental and oceanic crust corresponds approximately to the base of the continental slope. CGMW is used here for the initial extrapolation of offshore bedrock geology at 1:25,000,000scale.

Geological Survey of Canada Map 2159A

The Geological Map of the Arctic - Map 2159A (Harrison et al., 2011) is a proper bedrock geology map of onshore and offshore areas located north of 60° latitude. This work was released in the north polar stereographic projection using the World Geodetic System (WGS) 84 datum at a scale of 1:5,000,000 as both a hardcopy map and digital map database to coincide with the International Polar Year in 2007/08 and 2008/09. Map 2159A was produced after its predecessor, the Circumpolar Geological Map of the Arctic (Okulitch et al. 1989), which was prepared at a scale 1:6,000,000 at 75° north. Both maps included comprehensive geological legends with full rock descriptions, divided by region and sub-Epoch level age classifications. However, the offshore geology is restricted to post-rift cover and recent oceanic crust. The technical challenges of creating Map 2159A at its published scale included conversion of numerous paper regional maps into digital data and a common database standard, as well as developing a method and rationale for the reclassification of thousands of geological units into a meaningful legend. The map distinguishes 9 sedimentary, 6 igneous extrusive, and 7 igneous intrusive lithotypes at the Age and Era levels, using an alphanumeric label to represent the different tectonic domains and rock types: e.g., impact-related (a), extrusive (e), intrusive (i), metamorphic (m), supracrustal (u), igneous (x), and sedimentary (z). Map 2159A is used here for more detailed extrapolation of lithostratigraphic units in the test case of the Taimyr region of northern Russia at 1:5,000,000 scale.

International Bathymetric Chart of the Arctic Ocean (Version 3.0)

The International Bathymetric Chart of the Ocean (IBCAO) was used to define the limits of the shelf and to guide the offshore extrapolation of units from CGMW and Map 2159A. IBCAO is a digital bathymetric model that is a compilation of a number of different bathymetric data sets for the Arctic Ocean north of 65˚N. First compiled in 1990, version 1.0 was gridded at a spacing of 2.5 km, followed in 2008 by version 2.0 gridded at 2 km spacing (Jakobsson et al., 2012). Version 3.0 (2012) contains new data sets that allowed a gridding at 500 meters. These datasets were provided by several Arctic countries, fishing vessels, national research vessels, and the US Navy (Fig. 13: Jakobsson et al., 2012). Soundings from U.S. Navy submarines were released as declassified bathymetric data from cruises between 1993-2005, providing depth information in sparsely mapped areas of the Canadian Basin. However, data from icebreakers USCGC Healy and CCGS Louis St-Laurent was the main source of multibeam in version 3.0. Despite the availability of these data, Version 2.0

had multibeam coverage for only 6% of the area; Version 3.0 has multibeam coverage for only 11% of the area (Jakobsson et al., 2012).

5.2 Elements of extrapolation

Because only the pre-rift geology is being estimated, only the onshore geology that pre-dates rifting is used for extrapolation; onshore Tertiary and Quaternary units are ignored. Initial rifting of the Gakkel Ridge occurred at ~65 Ma (e.g., Fig. 15), and therefore only onshore bedrock that is Cretaceous in age or older is used for offshore extrapolation in the region surrounding the Gakkel rift basin. The legend for the extrapolated units is based on the subdivisions for the onshore units, first subdivided by stratigraphic age, then by lithology (sedimentary/undifferentiated, volcanic, and plutonic/metamorphic rocks). The map legend for the CGMW Map of the World (Bouysse, 2009) is used at 1:25,000,000. The map legend scale of the GSC Map 2159A (Harrison et al., 2011) is used at 1:5,000,000 in the Taimyr region.

Onshore contacts between adjacent units are projected offshore, guided by the appropriate map legend, so that the general geometry of the onshore geology is maintained. Interpreting offshore continental units from the adjacent onshore units is first carried out using the broader geologic assemblages from the CGMW map, including sedimentary, plutonic and volcanic units at 1:25,000,000. The boundaries defined by the units at 1:25,000,000 scale are also used to guide extrapolation of units at 1:5,000,000 scale. Mapped offshore structures, in particular (e.g., faults, suture zones), from both the 1:25,000,000 and 1:5,000,000 compilations are used, extended to the limits of the continental shelf at the base of the continental slope where the transition to oceanic crust occurs. Major boundaries of the orogenic belts in the Hercynian, Caledonian, and Precambrian were also used to guide the extrapolations (Bouysse, 2009). Along rifted margins where the basement geology is exposed on both sides of the rift, the geology on one side also can be used to guide the extrapolation of the geology on the opposite side. However, as the distance from the coastline increases so too does the uncertainty in the positions of map unit contacts (see below).

6.0 Results for the Circumpolar Arctic Basin (1:25,000,000)

The extrapolated geology for the Circumpolar Arctic Basin, using the onshore geology of the 1:25,000,000 CGMW's Geological Map of the World is shown in Figures 24 and 25. The extrapolation of this geology was carried in an ArcGIS® project file generated in north polar stereographic projection using the WGS 1984 datum. A total of 491 polygons were drawn to depict the geology of the pre-rift continental basement (Fig. 26 and Fig. 27), and the attributes of the polygons are summarized in Table 3 (see Appendix 4 for full details). Areas of individual polygons were calculated using an area preserving projection called the North Polar Lambert Azimuthal Equal Area projection. The average area of the polygons is ~21,000 km^2 and the maximum polygon size is 1,216,913 km^2 (Lower Paleozoic undifferentiated crust off eastern Siberia and Alaska). The locations of the main mineral deposits of the region are overlain on the combined onshore and offshore geology in Figure 28.

6.1 Norwegian Sea

The continental shelf off Norway extends 130 to 270 km from the coast. The base of the continental slope merges with Eocene oceanic crust that formed during the initial rifting of the Mohns Ridge north of Jan Mayen and the now extinct Aegir Ridge south of Jan Mayen. The offshore basement is interpreted to be dominated by rocks of the Caledonian accretionary fold and thrust belt along the western margin of the Fennoscandia Shield (Fig. 26A). The margin consists mainly of thrust packages of Archean and Proterozoic metamorphic rocks and Lower Paleozoic sedimentary and metamorphic assemblages. The structural fabric is NNE-SSW and generally follows the coastline. The major part of the offshore continental basement is Paleoproterozoic and Lower Paleozoic intrusive and metamorphic rocks belonging to the coastal Caledonian accretionary fold belt from the closing of the Iapetus Sea (P7 and P4; Fig. 26A). Rocks of similar age occur on the eastern margin of Greenland on the opposite side of the rifted basin. At the southern limit of the mapping area, near the Shetland Islands, Neoproterozoic intrusive rocks and Upper Paleozoic sediments and volcanic rocks are also exposed. The Paleozoic and Neoproterozoic assemblages are separated by the NE-SW striking Great Glen strike-slip fault, which continues southwards into mainland Scotland. North of the Shetland Islands, the Neoproterozoic intrusive rocks occur mainly inland from the Norway coast, although they also outcrop along as much as 500 km of coastline.

6.2 Barents Sea

The Barents Sea lies to the north of Norway and the Kola Peninsula (Russia), and extends north to Svalbard (Norway) and the Franz Josef islands (Russia), and east to Novaya Zemlya (Russia). This entire region is underlain by continental crust that forms the Svalbard Plate, and is one of the most extensive areas of submerged continental crust in the world (Vernikovsky et al., 2013). This interpretation is supported by unpublished data from NPD (Norwegian Petroleum Directorate), including drill holes that hit the basement in the Barents Sea. The southwest margin of the shelf is defined by a major transform offset related to the opening of the Atlantic Ocean and includes the Lena Trough and Spitsbergen Fracture Zone, which connect the Mohns Ridge in the south to the Gakkel Ridge in the Arctic Ocean (e.g., Fig. 5). This major structure also forms the northern limit to the continental shelf north of

Greenland and the transition to oceanic crust that was generated during opening of the Eurasian Basin in the Eocene.

The southernmost part of the Barents Sea is likely underlain by the same Neoproterozoic intrusive rocks that dominate northern shore of Norway, bound to the south by a thrust contact between the Caledonian Fold Belt and the Archean and Paleoproterozoic craton. This contact is projected eastward along the coast to the Kola Peninsula (Bouysse, 2009; Harrison et al., 2011). Therefore, although the Kola Peninsula is dominated by Archean basement, the continental shelf in the Barents Sea immediately to the north is interpreted to be a continuation of Neoproterozoic rocks of the Caledonian Fold Belt. Rocks of similar age are exposed on the Svalbard Islands, but Svalbard is dominated by Early Paleozoic sedimentary rocks. The regional fabric on Svalbard, which is NNW-SSE, is markedly different from the Caledonian stratigraphy and suggests a major break or rotation of the continental basement rocks between Norway and Svalbard. The offshore geology of Svalbard is interpreted to be similar to that exposed on the islands.

The oldest rocks exposed on the Franz Josef Islands are Mesozoic extrusive rocks. No other igneous rocks of this age are found anywhere else in this region. The volcanism in this area may have been related to the St. Anna Trough, immediately east of the islands and forming a boundary between the Svalbard Plate to the west and Kara Plate to the East (e.g., Fig. 5: Shipilov et al., 2006). The Mesozoic volcanic rocks are interpreted to follow the general northeast-southwest trend of the St. Anna Trough (Vernikovsky et al., 2013).

The basement in the remainder of the Barents Sea, as well as the area surrounding Novaya Zemlya in the Kara Sea, is most likely dominated by Upper Paleozoic sediments, which are widespread on land in northwestern Russia (both exposed and underneath sedimentary cover). Lower Paleozoic sediments onshore in the immediate vicinity of Novaya Zemlya belong to the Novaya Zemlya fold and thrust belt, which is the northward continuation of the Ural Fold belt (Vernikovsky et al., 2013).

6.3 Eastern Kara Sea and Taimyr region

The Kara Plate is bounded by a major north-south linear tectonic belt that occurs on land between the West Siberian Basin and the Siberian Craton, along the Yenisei River Valley (Fig. 5). This major tectonic boundary is projected offshore as far as the Franz Josef Islands (Vernikovsky et al., 2013). The adjacent Taimyr region is dominated by a series of northeast-southwest trending accretionary belts at the north margin of the Siberian Craton (Torsvik and Andersen, 2002). The Taimyr fold belts have a strong structural pattern that likely continues onto the continental shelf and is an important guide for interpreting the offshore basement geology (Fig. 26B). The South and Central Taimyr fold belts are composed of Upper and Lower Paleozoic rocks that make up much of the on- and offshore basement geology. The North Taimyr belt is composed of older, Neoproterozoic sedimentary rocks that are extended here to the shelf margin. A second band of Lower Paleozoic rocks outcrop on the Severnaya archipelago, north of the Taimyr Peninsula, and these rocks are extrapolated along the same structural trend to the edge of the shelf. Beyond the shelf is the transition to oceanic crust generated by the Gakkel Ridge. The eastern boundary of the Taimyr fold belts is the Ust'-Lena rift zone in the Laptev Sea, which separates the Siberian Craton from other terranes to the east (Vernikovsky et al., 2013). This zone of extension represents the landward propagation of the Gakkel mid-ocean ridge.

6.4 East Siberian Sea, Chukchi Sea, and Northern Alaska

The basement geology of the extensive continental shelf region north of eastern Russia and Alaska is difficult to constrain due to a lack of exposed onshore geology (Fig. 26A). Much of eastern Russia is underlain by Mesozoic volcanic and plutonic rocks, but these rock types are not well exposed along the coast. Upper and Lower Paleozoic basement sediments outcrop on the major islands north of mainland Russia (New Siberian Islands and Wrangel Island), providing the only data points to which the offshore bedrock geology can be extrapolated. With this constraint, the entire shelf area is considered to be underlain by Paleozoic sedimentary rocks.

In the Bering Strait, sedimentary rocks of Paleozoic (as well as Proterozoic) age and Cenozoic volcanic rocks are extended onto the continental shelf.

6.5 Beaufort Sea, Canadian Arctic Archipelago and North Greenland

The continental shelf north of Alaska, Arctic Canada, and Greenland is much narrower than in other regions of the Circumpolar Arctic (on average ~150 km wide: Fig. 24). The exposed onshore basement along this stretch of the Arctic coast is again dominated by Paleozoic sedimentary rocks, and so the basement rocks of the offshore shelf area are interpreted to be Paleozoic sediments. Upper Paleozoic rocks dominate in the west, with Lower Paleozoic rocks (including volcanic rocks) along the northwest coast of Ellesmere Island.

Neoproterozoic intrusive and extrusive rocks associated with the Franklin magmatic event occur on Victoria Island. Archean rocks of the Canadian Shield occur on the mainland and Baffin and are interpreted to underlie the shelf in Baffin Bay, between Baffin Island and Greenland (Fig. 26A). Active mid-ocean ridge spreading within this basin in the Eocene resulting produced a small window of oceanic crust in Davis Strait.

6.6 Greenland Sea

The continental shelf along the eastern coast of Greenland is also very narrow. Because Greenland is covered by an icecap except along the coast, the geology on land is poorly known (Fig. 26A). Except for the northern coast (discussed above), most of the offshore continental basement is expected to be Archean and Proterozoic shield rocks. Cenozoic volcanic and intrusive rocks related to the opening of the Atlantic, however, are widespread on the eastern margin. Neoproterozoic and Paleozoic rocks belonging to the Caledonian Fold Belt are also exposed on the coast, but most of these rocks offshore may have been buried by volcanic flows during rifting.

6.7 Summary of results at 1:25,000,000

The circumpolar region north of 60°N latitude covers 43,679,571 km^2, of which 61% is continental landmass and 39% is covered by ocean. About 64% of the circumpolar continental landmass is covered by Cenozoic sediments and Quaternary cover. The remaining 36%, or 8,679,722 km^2, is exposed basement, of which 21% is Archean in age, 24% is Proterozoic, 46% is Paleozoic and 10% is Mesozoic:

	Onshore Area (km^2)	Area %	Offshore Area (km^2)	Area %	Ratio
Archean	1,794,854	21	1,209,305	12	1.5:1
Proterozoic	2,055,526	24	2,162,089	22	1:1
Paleozoic	3,985,721	46	5,273,277	53	0.8:1
Mesozoic	843,621	10	1,278,221	13	0.7:1
Cenozoic					
Total	**8,679,722**	**100**	**9,921,892**	**100**	**1:1**

The inferred basement architecture and offshore bedrock geology of each of the regions is depicted in Figure 26. In this interpretation, approximately 9,921,892 km^2, is underlain by continental shelf that is mostly covered by post-Cretaceous sediment. The bedrock geology to the edge of the shelf, estimated in this study, is strikingly similar to that on land in terms of area-age relationships, with 12% of the continental shelf underlain by Archean rocks, 22% by Proterozoic rocks, 53% by Paleozoic rocks and 13% by Mesozoic rocks. As expected, Archean basement, which comprises the cores of the continental land masses (i.e., the Canadian Shield and the Baltic Shield) is underrepresented on the continental shelf. It is also worth noting that the total area of continental crust covered by shelf sediments offshore is roughly equivalent to the area of the continents on land that are covered by Cenozoic and Mesozoic sedimentary rock, Quaternary sediments, and ice (e.g., Fig. 24).

7.0 Results for the Taimyr Peninsula (1:5,000,000)

Extrapolation of offshore bedrock geology at 1:5,000,000 is examined here for the Taimyr region of northern Russia (Fig. 29 and Fig. 30). This subproject, generated in north polar stereographic projection using the WGS 1984 datum, also shows that we can confidently extend basement geology offshore at a scale that is suitable for estimating resource potential under the shelf sediments. Well-documented lithostratigraphic units can be extended at least to the edge of the shelf, and rules can be set for different confidence limits for these extrapolations (e.g., where the distance to the shelf edge is no greater than the mapped strike length of the units on land; see below).

The major fold belts and large-scale structures of the Taimyr Peninsula are shown in Figures 31 and 32, as depicted on GSC's Map 2159A (Harrison et al., 2011) and from Trosvik and Andersen (2002). This region was chosen because of the excellent exposure of basement rock and the strong structural fabric of the onshore geology, which are two key features for offshore extrapolation of the bedrock geology at this scale. The known mineral occurrences in the region are shown in Figures 33 and 34 and listed in Table 4. The deposits are dominated by magmatic Ni-Cu-PGE mineralization, which occurs where mafic-ultramafic intrusions are present within the Permian and Carboniferous sedimentary rocks of the fold belt (Inger et al., 1999; Badania et al., 2014). The host rocks are shallow marine clastic and deltaic sediments that follow a strong tectonic fabric for more than 700 km (Fig. 35 and Fig. 36) related to the accretionary history of the Taimyr. The entire fold belt has an elevation of greater than 200 m above sea level (Fig. 37).

At 1:25,000,000, the offshore extrapolation includes 47 polygons, representing six map units (Fig. 38). At 1:5,000,000 scale, 157 polygons were drawn, representing 26 different map units (Fig. 39 to 42 and Table 5). The extrapolations are truncated to the west by the Yenisei River, to the east by the Ust'-Lena Rift Zone, and to the north by the outer limit of the continental slope. The strong structural control related to the South, Central and North Taimyr accretionary belts, and the fact that part of the coastline is perpendicular to the strike of the units, gives a high degree of confidence in the extensions of the units offshore. There is a much higher degree of uncertainty near the Ust'-Lena Rift Zone, which is an area of intense deformation. Here, the regional structure suggests that the offshore units likely wrap around the northeast edge of the Siberian Craton, and that the stratigraphy of the South Taimyr accretionary belt comes back onshore close to the Lena River Delta. The rock units that make up the North and Central Taimyr belts terminate at the northern shelf edge and are not exposed on land to the east of the Siberian Craton.

The orientations of map units on the Severnaya Islands, to the north of the Taimyr Peninsula, provide further constraints on the likely distribution of the North and Central Taimyr belts offshore. Proterozoic and Paleozoic rocks that make up the North Taimyr accretionary belt are exposed on southern Bolshevik Island, indicating that, in the eastern part of the map area, these units continue on a NE-SW strike, similar to the Central Taimyr accretionary belt. This strong regional structural fabric is lost between Bolshevik Island and the group of islands that lie to the northwest (Komsomolets Island, Pioneer Island and October Revolution Island; see Fig. 39).

8.0 Discussion of uncertainties

The offshore interpretations are based on limited published tectonic interpretations of the opening of the Arctic Basin, with the regional structure and major lithostratigtraphic assemblages compiled only from the Commission for the Geological Map of the World (CGMW, 2010) and the Geologic Map of the Arctic (GSC Map 2159A, 2011). The steps taken follow the general approach of identifying permissive geology in areas under cover, including in land-based resource assessments. In this study, tracts of similar structure and morphology are extended offshore and assigned geological attributes (i.e., age and lithotypes) similar to adjacent areas exposed on land. Uncertainties that are inherent in this process include the definition of the map units (e.g., unnecessarily grouping map units), uncertainties related to the scale of the maps used in the extrapolation (i.e., the map resolution), and uncertainties in how far to extrapolate features offshore. The limits of uncertainty for extrapolated bedrock geology are also partly a function of the choice of location for the edge of the continental shelf. A sensitivity analysis can be performed by testing different outcomes when some error is assigned to each step of the analysis (e.g., +/- 50% in estimating the distance that units are extrapolated offshore), as is done in remote predictive mapping on land (e.g., Harris et al., 1999; Chung and Joho, 2001; Chung et al., 2002; Harris 2006, 2008).

In this study, extrapolations that are less than 50% of the exposed strike length of equivalent geological units or structures on land are considered a reasonable first-order limit for estimating bedrock geology offshore. For example, in the Taimyr region, we assume that the units can be confidently extended at least to the edge of the shelf, a distance that is less than half of the observed strike length of the units on land. The Permian and Carboniferous sediments of the Taimyr Peninsula, which host the known magmatic Ni occurrences, have a minimum exposed strike length of ~700 km. The distance to the edge of the continental margin along-strike from these units is about 200 km. Extending the Permian and Carboniferous sediments to the edge of the shelf is an offshore extrapolation of less than 30% of their strike length on land. If these map units are incorrectly extended (e.g., an unknown fault terminates the geology at half the distance to the shelf edge), the error in the predicted offshore geology would be only 15% of the observable strike length. For most of the map units at 1:25,000,000 and 1:5,000,000 the extrapolation to the shelf edge is small in comparison to the total exposed areas of the units on land.

Because geological interpretations are governed by individual geologists, many projects of this type rely on averaging results from different groups of experts, each examining a common study area independently (e.g., Singer, 2010). This approach captures any variability in the likely interpretations. This uncertainty also can be minimized with training sets derived from the geological base maps or with additional external data (e.g., offshore geophysical surveys not used in this study). However, identifying and drawing map units is still a subjective process based on the interpretation of surrounding geological structures.

Table 3: Polygons of offshore continental basement geology larger than 10,000 km^2, with descriptions, based on the CGMW Geological Map of the World (Bouysse et al., 2009). Areas were calculated in the North Polar Lambert Azimuthal Equal Area projection. See Appendix 4 for complete list of polygons.

Polygon ID	Area (km2)	Setting	Age	Description
395	1,216,913	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
390	687,848	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
248	595,763	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
477	430,270	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
266	413,131	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
230	391,037	Sedimentary rocks or undifferentiated facies	Proterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic
399	381,748	Endogenous rocks (plutonic and/or metamorphic)	Mesozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesozoic
253	371,248	Extrusive volcanic rocks (traps exepted)	Mesozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Mesozoic
386	335,984	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
308	320,887	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
341	296,773	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
437	241,334	Extrusive volcanic rocks (traps exepted)	Mesozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Mesozoic
135	238,691	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
350	233,861	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
302	218,765	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
203	208,063	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
347	196,078	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
463	188,685	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
402	178,549	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
355	132,913	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
115	130,652	Endogenous rocks (plutonic and/or metamorphic)	Neoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Neoproterozoic
428	122,982	Endogenous rocks (plutonic and/or metamorphic)	Mesozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesozoic
17	113,448	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic
23	111,467	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
34	110,018	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
148	108,259	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
25	106,917	Endogenous rocks (plutonic and/or metamorphic)	Lower Paleozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Lower Paleozoic
356	104,111	Sedimentary rocks or undifferentiated facies	Proterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic
114	88,689	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic

Polygon ID	Area (km2)	Setting	Age	Description
161	85,667	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
464	80,682	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic to Archean	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic to Archean
215	79,314	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
424	78,486	Sedimentary rocks or undifferentiated facies	Neoproterozoic to lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic to lower Paleozoic
360	64,927	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
66	64,797	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic
52	63,512	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
387	51,823	Sedimentary rocks or undifferentiated facies	Neoproterozoic to Mesoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic to Mesoproterozoic
58	50,763	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
178	45,362	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic
396	44,099	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
457	43,927	Endogenous rocks (plutonic and/or metamorphic)	Mesozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesozoic
434	40,950	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic
429	38,738	Endogenous rocks (plutonic and/or metamorphic)	Mesozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesozoic
232	38,601	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
408	36,489	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
252	36,418	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
436	35,965	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic
14	35,339	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
465	33,739	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
489	33,724	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
78	30,844	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
63	30,567	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
426	28,846	Extrusive volcanic rocks (traps exepted)	Mesozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Mesozoic
225	27,911	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
371	23,243			Large Igneous Province (LIP): Traps with indication of mean age in Macc
229	22,334	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
397	21,274	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
235	21,216	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic to Archean	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic to Archean
123	21,104	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
239	19,912	Extrusive volcanic rocks (traps exepted)	Paleoproterozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Paleoproterozoic
28	19,289	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
134	18,935	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic

Polygon ID	Area (km2)	Setting	Age	Description
89	18,006	Sedimentary rocks or undifferentiated facies	Mesoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Mesoproterozoic
427	17,944	Endogenous rocks (plutonic and/or metamorphic)	Mesozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesozoic
41	17,764	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoicc
9	15,501	Endogenous rocks (plutonic and/or metamorphic)	Neoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Neoproterozoicc
364	15,087	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
174	15,032	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
249	14,548	Sedimentary rocks or undifferentiated facies	Mesoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Mesoproterozoic
306	13,519	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
56	13,376	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic
458	13,044	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
10	12,506	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
304	12,414	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
314	12,201	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
39	11,814	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
369	11,451	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
19	11,339	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
129	11,238	Endogenous rocks (plutonic and/or metamorphic)	Precambrian	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Precambrian
417	10,087	Extrusive volcanic rocks (traps exepted)	Mesozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Mesozoic

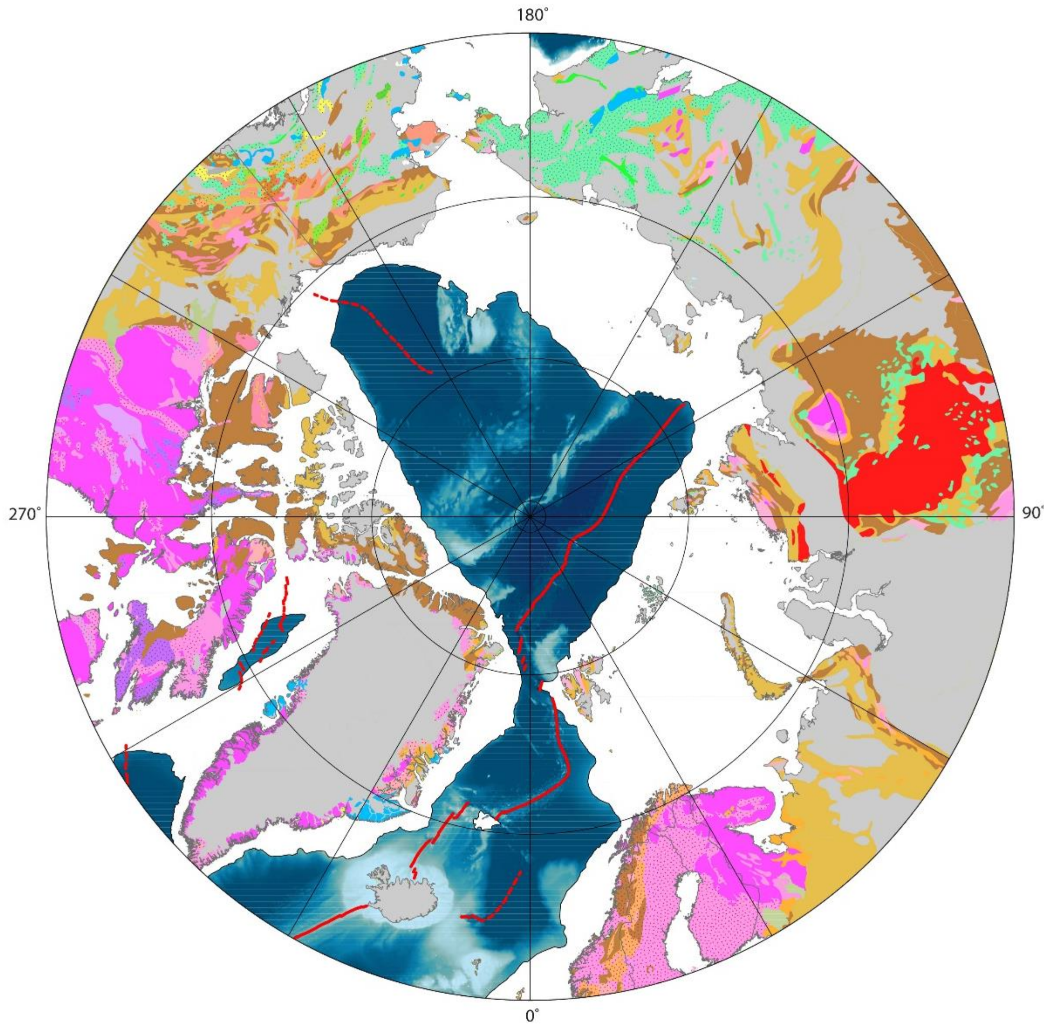

Figure 24: Map of the Circumpolar Arctic showing the extent of exposed continental basement rock on land, based on the CGMW's Geological Map of the World (Bouysse, 2009; see Fig. 16 for legend). Onshore areas covered by sediments or ice are coloured grey. The extent of submerged continental crust is outlined in white. Bathymetry of oceanic crust from IBCAO v.3 (Jakobsson et al., 2012).

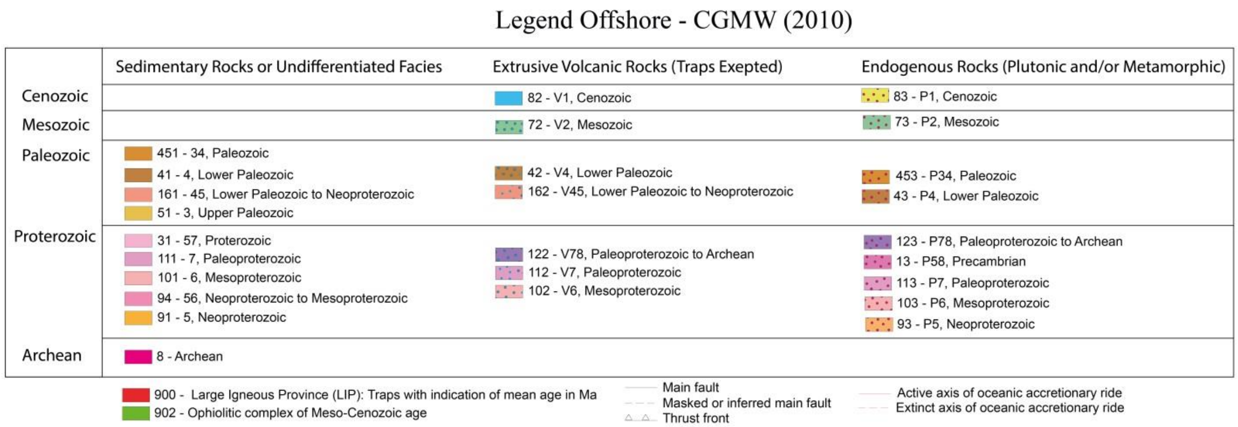

Figure 25: Legend for exposed continental basement rock in Figure 24 (from Bouysse et al., 2009). This legend also corresponds to the extrapolated offshore geology in Figure 26.

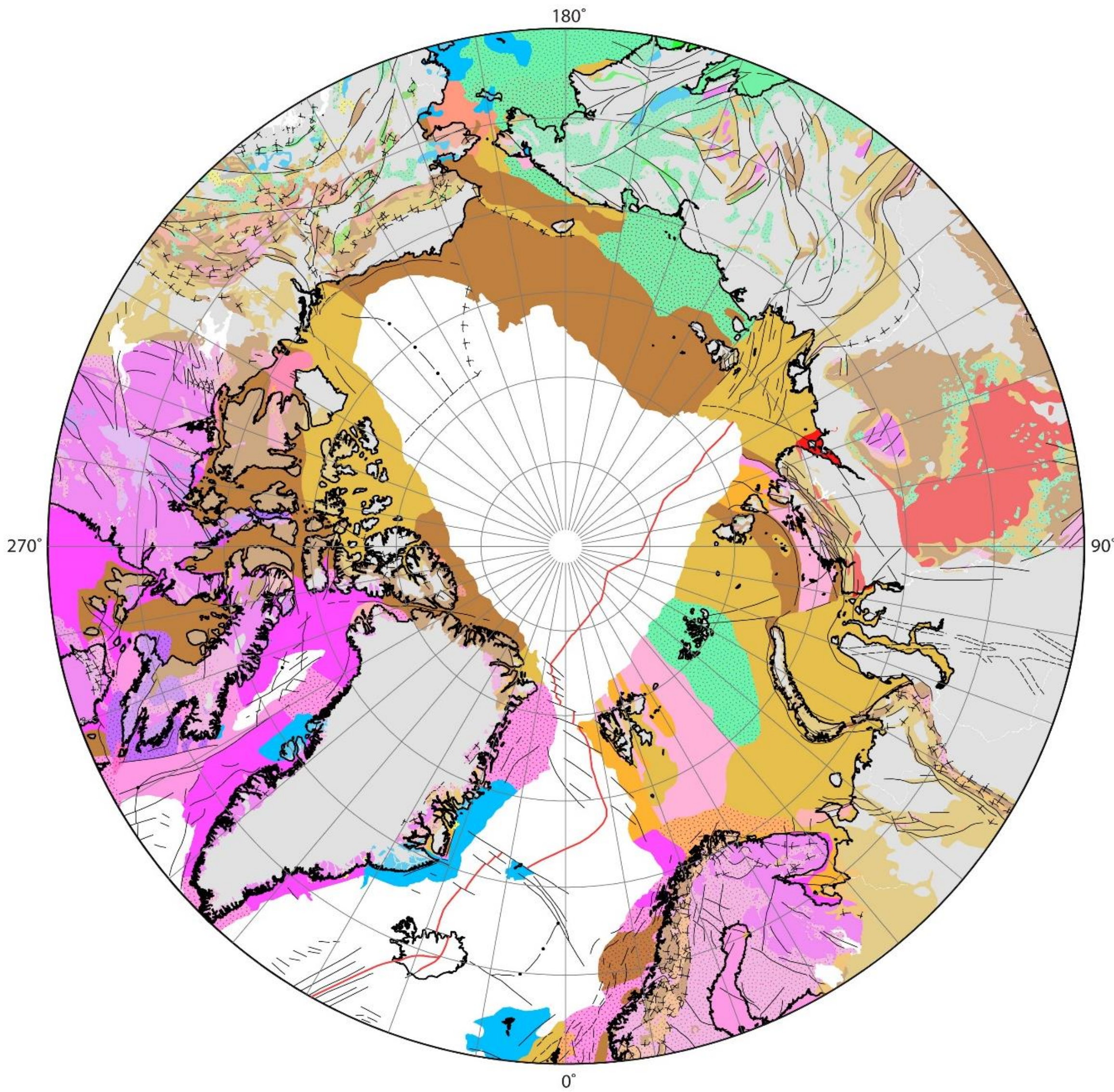

Figure 26A: Map of the Circumpolar Arctic, showing the geology of the pre-rift continental shelf basement, based on extrapolation of onshore geology from CGMW's Geological Map of the World (Bouysse et al., 2009). Offshore geology is mapped at the same scale as the CGMW map (1:25,000,000). See Figure 25 for legend and Appendix 3 for detailed examples of geological extrapolation.

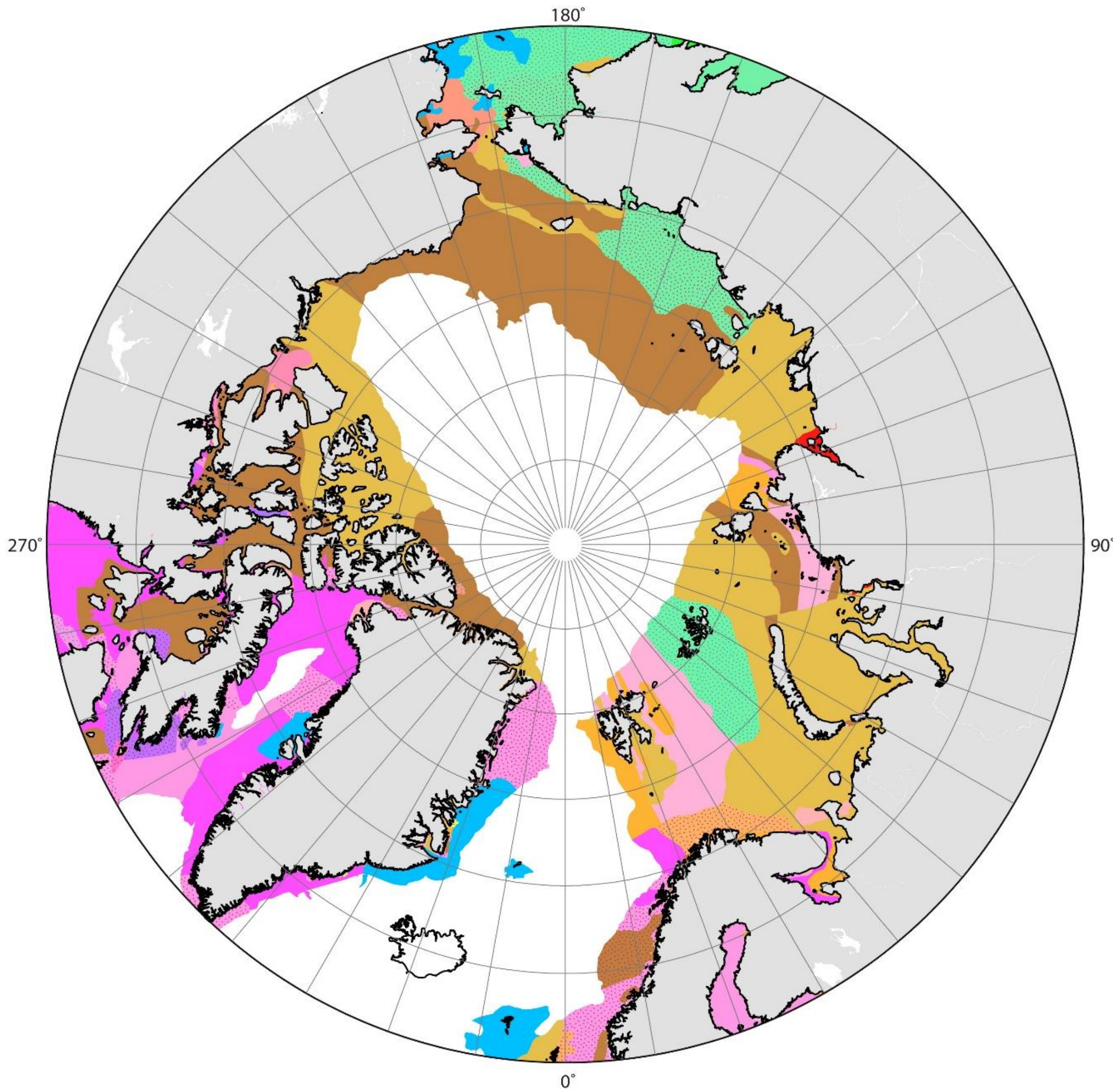

Figure 26B: Visual summary of extrapolated offshore continental basement rock. The limit of extrapolation represents the boundary between continental and oceanic crust, which occurs at the base of the continental slope (see Fig. 25 for legend). See Table 3 and Appendix 4 for details of individual polygons.

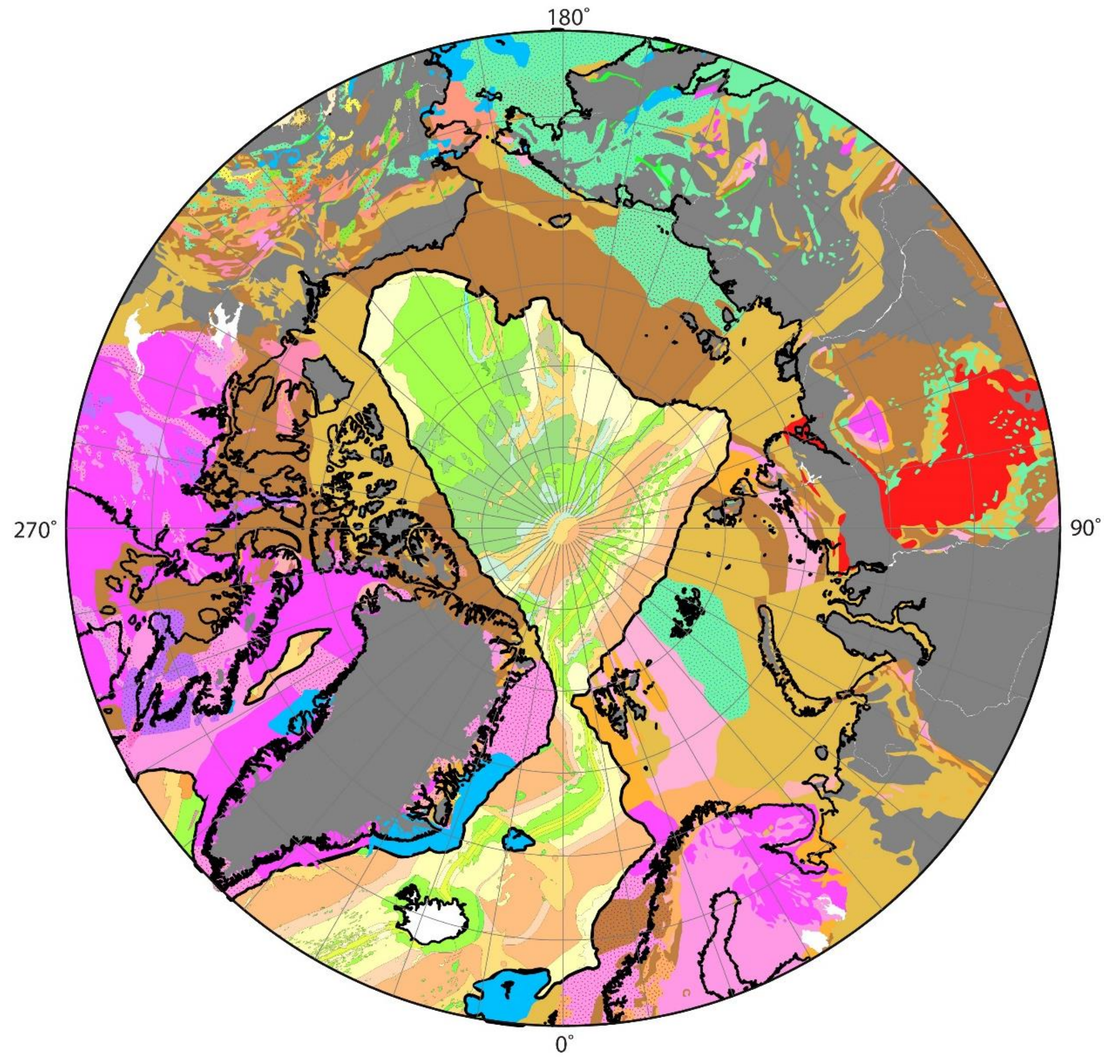

Figure 26C: Combined geological map of the Circumpolar Arctic showing pre-rift continental basement rock and post-rift oceanic crust. Onshore exposed basement geology is from the CGMW's Geological Map of the World (Bouysse et al., 2009; see Fig. 25 for legend). Sedimentary and ice cover is grey. Geology of the continental shelf pre-rift basement rock (i.e. they crystalline basement beneath the sedimentary cover) is also shown, using the same legend as the onshore geology. The geology of the oceanic crust beyond the limit of the continental slope is from the GSC Map 2159A (Harrison et al., 2011). Lines of latitude are in 5° intervals.

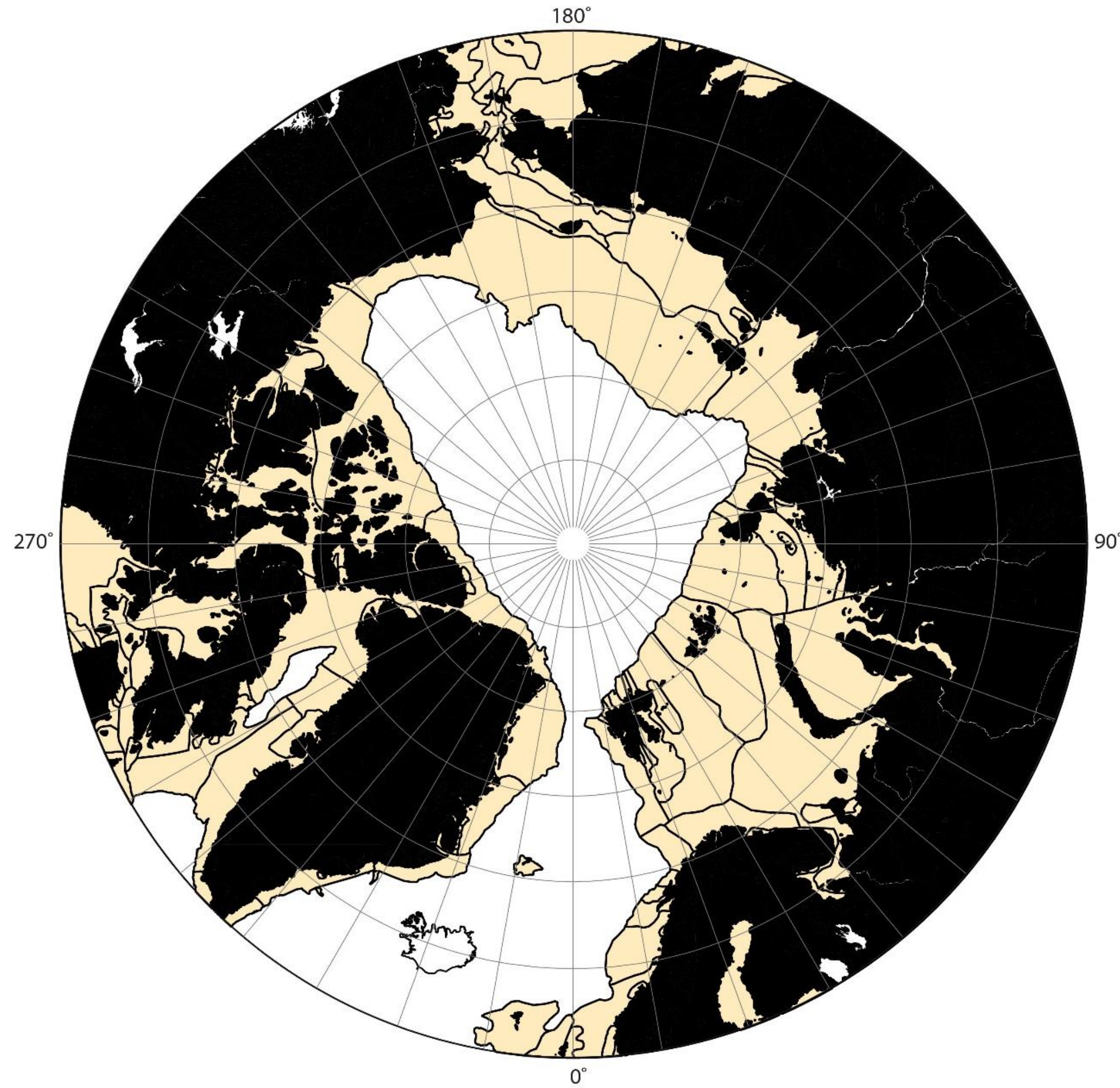

Figure 27: Outlines of the individual map polygons for the offshore continental basement geology. See Table 3 for details.

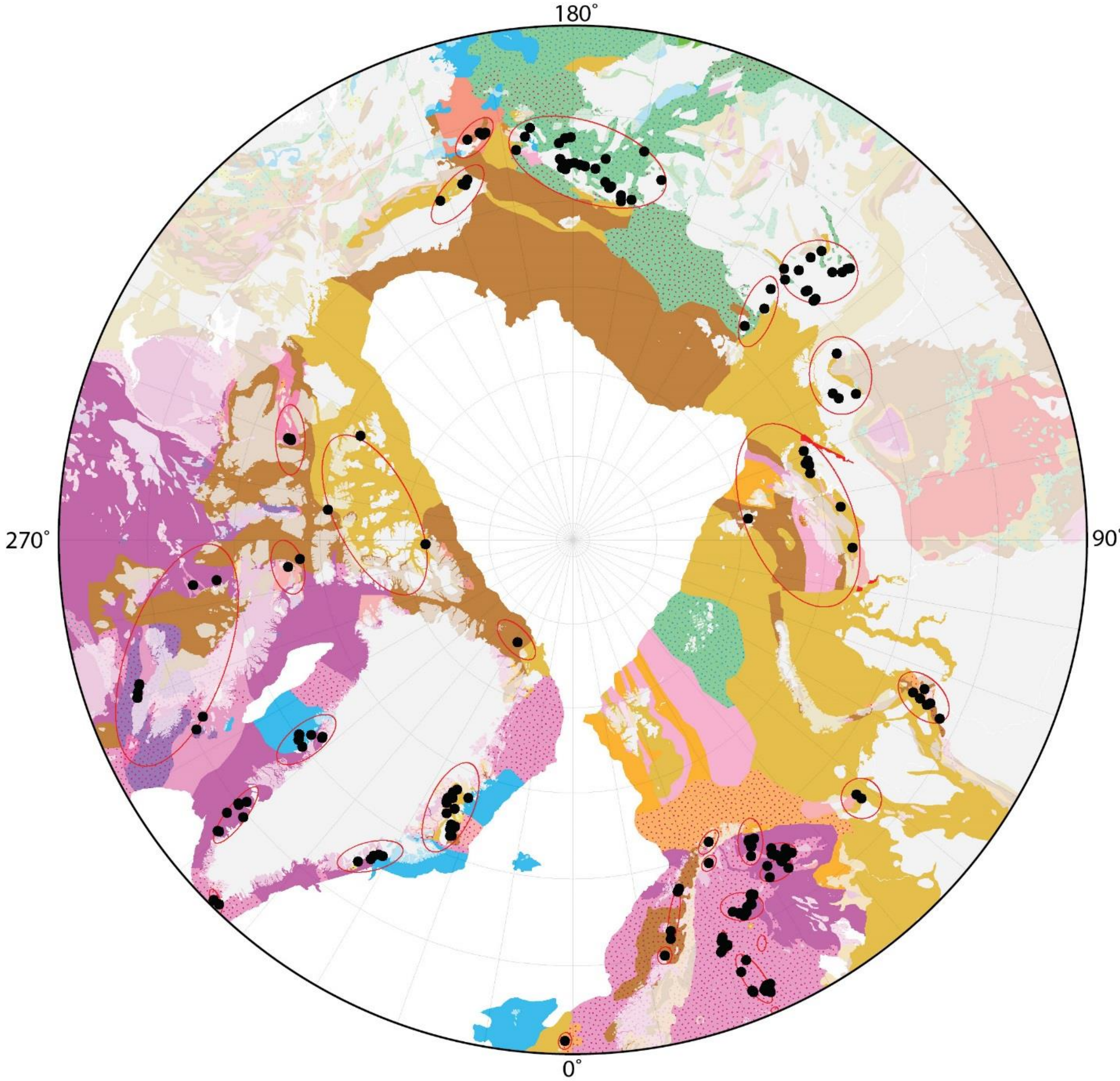

Figure 28: Locations of deposit districts and associated mineral deposits and occurrences in the Circumpolar Arctic (north of 60°N) with the CGMW basement geology (Bouysse, 2009) and extrapolated offshore continental shelf basement geology (this study).

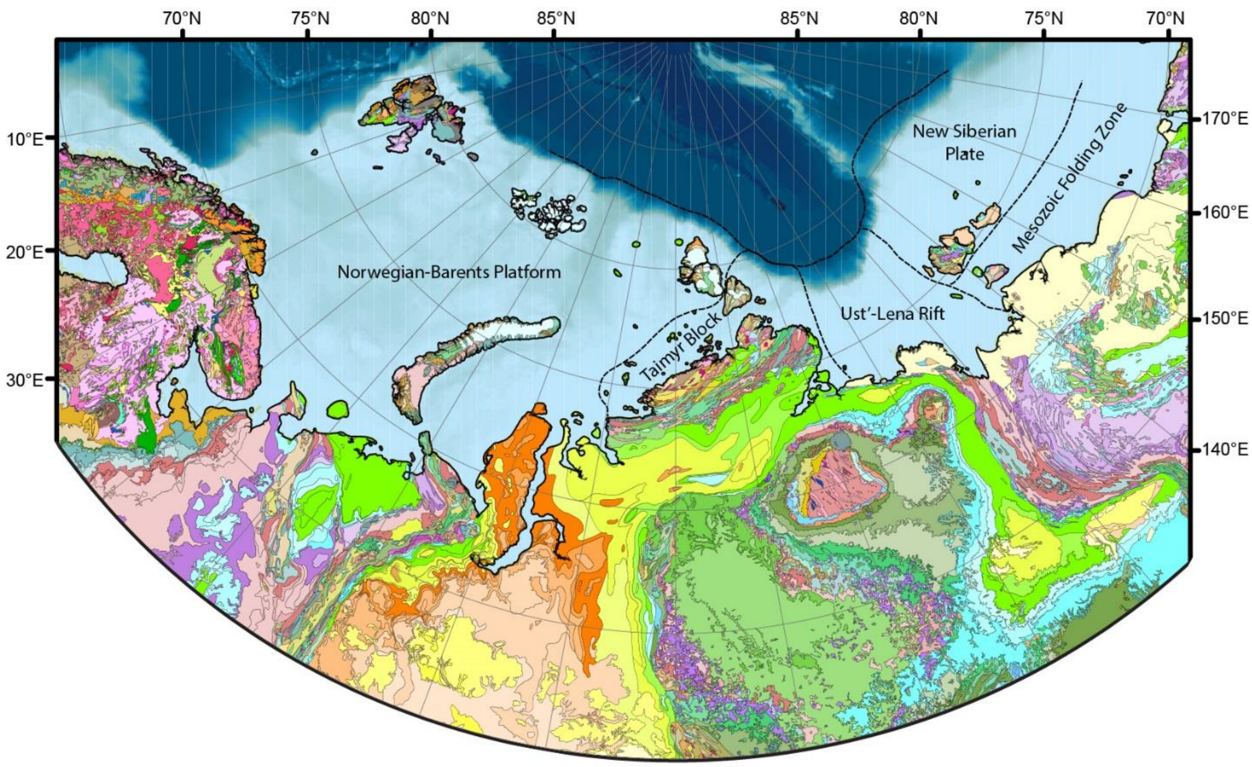

Figure 29: Regional geology of northern Siberia (geology from Harrison et al., 2011; offshore bathymetry from Jakobsson et al., 2012) with major offshore geological domains. These tectonic domains provide the first order boundaries used for extrapolating the onshore basement geology offshore.

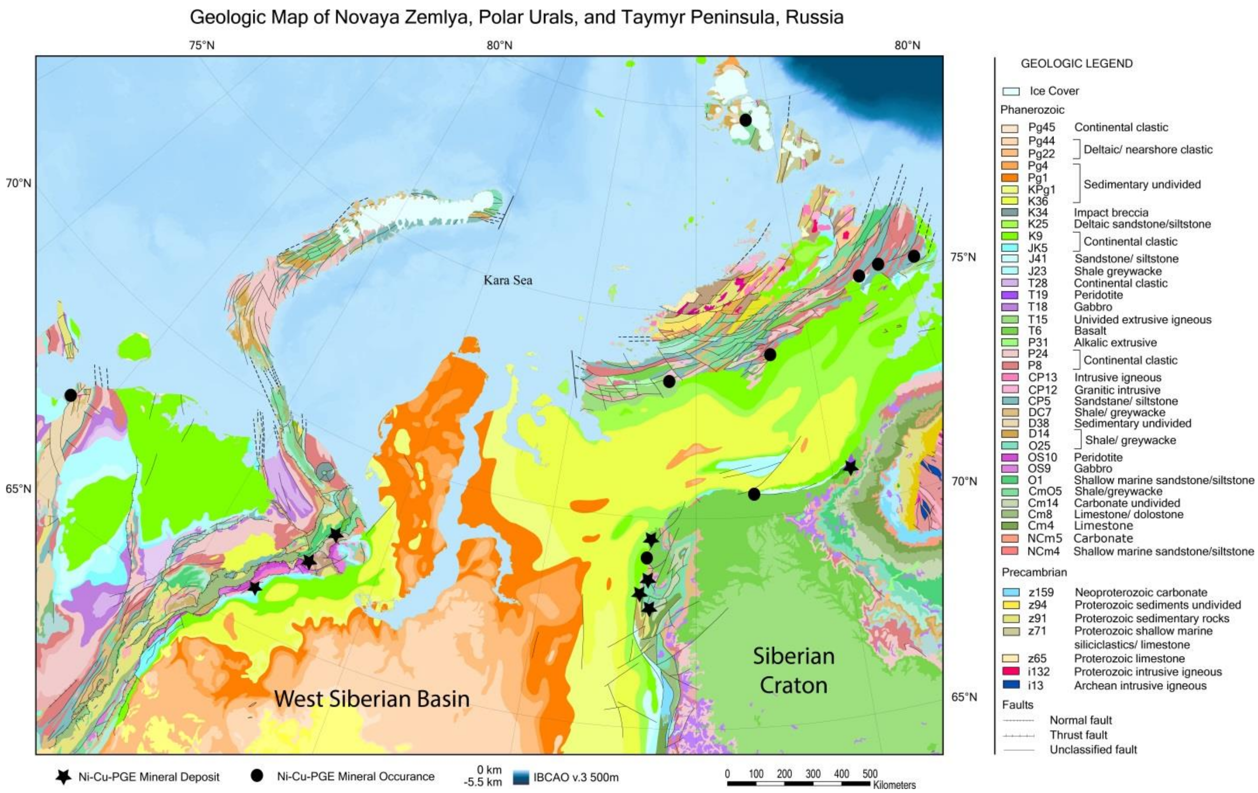

Figure 30: Geological map of the Taimyr and Kara Sea region with associated legend (from Harrison et al., 2011) showing the locations of mineral deposits and showings.

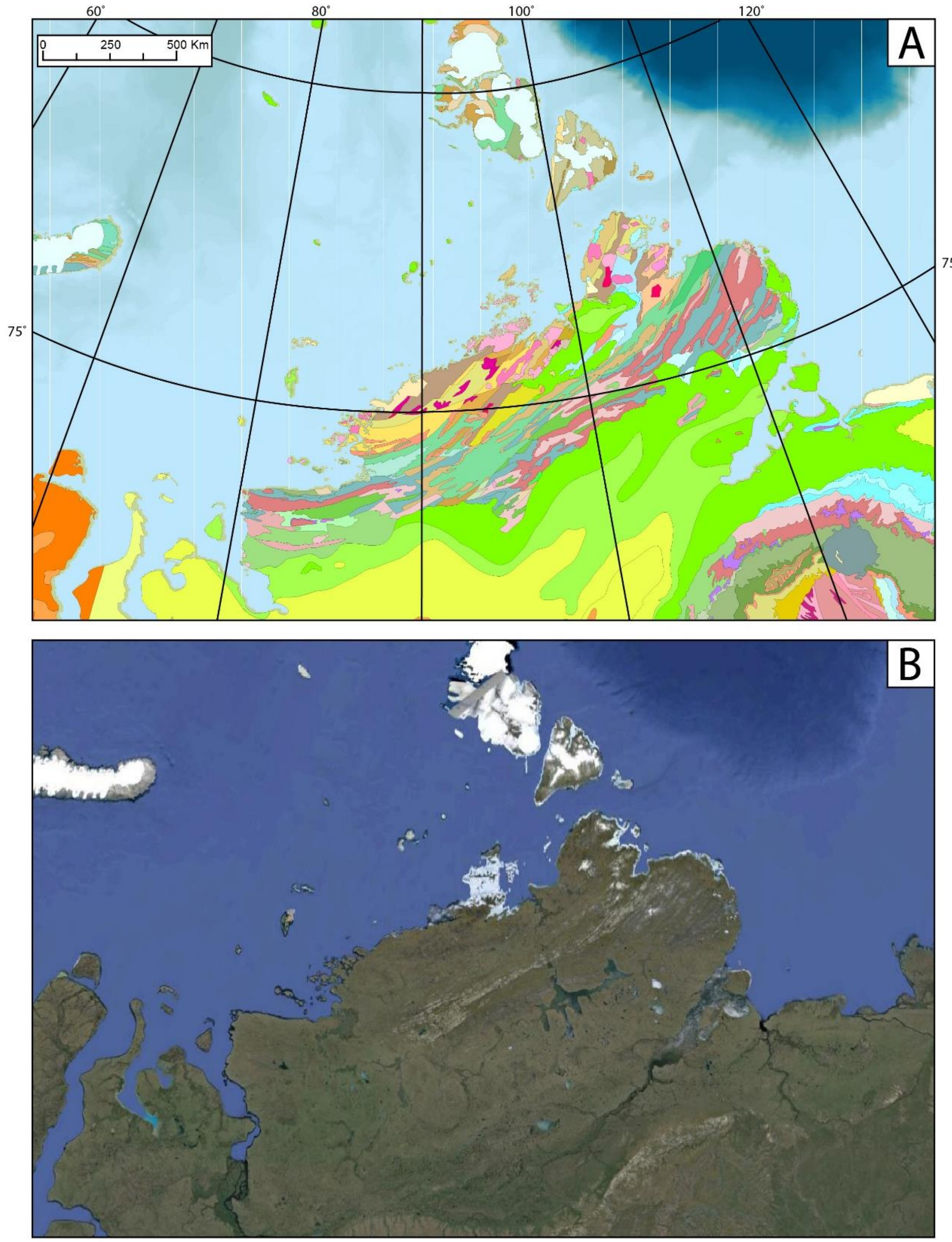

Figure 31: A: Geology of the Taimyr Region. Data source and legend same as Figure 30. B: Landsat image of the same area showing visible geological features that project onto the continental shelf. These land-based structural features are an important tool for projecting geological assemblages offshore.

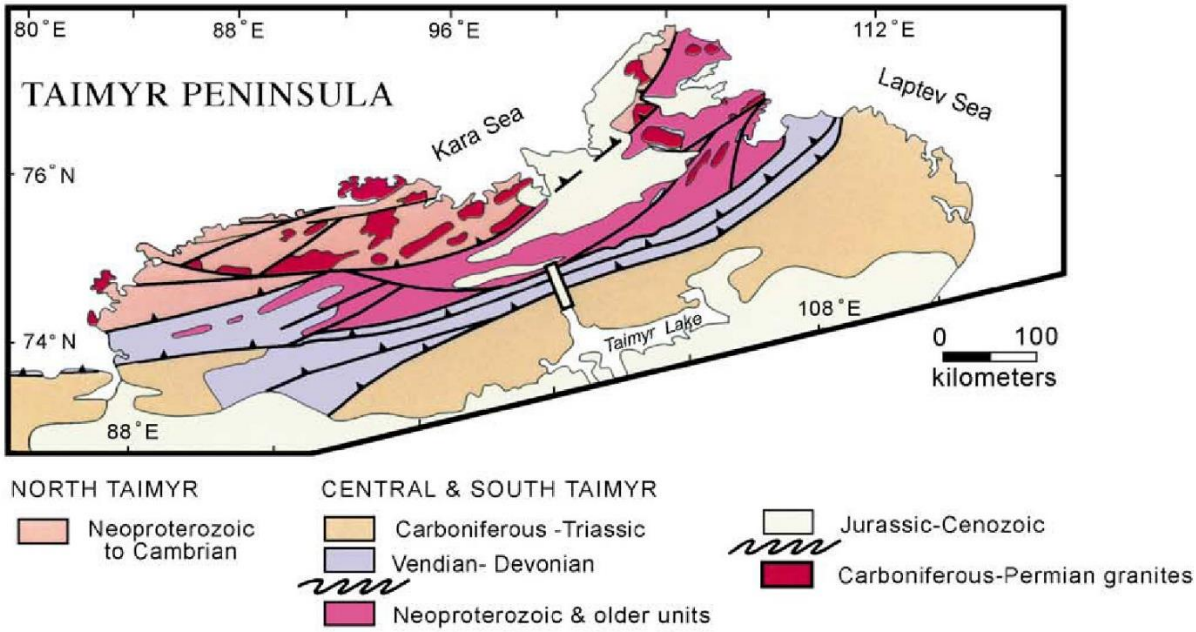

Figure 32: Geological map of the Taimyr Peninsula (modified from Torsvik and Andersen, 2002)

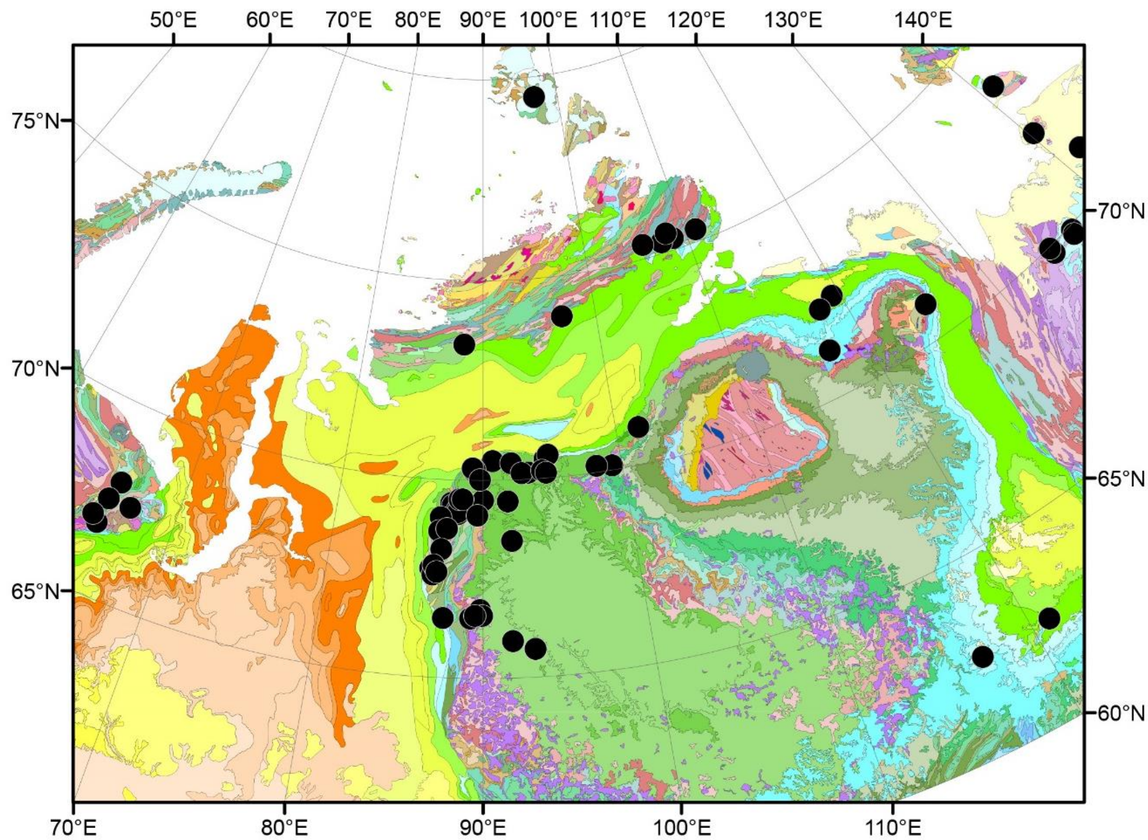

Figure 33: Geological map of the Taimyr region with locations of mineral deposits and showings (see Appendix 2 for details). Geology from Harrison et al. (2011) and locations of mineral deposits and occurrences from the Geological Survey of Canada global minerals database.

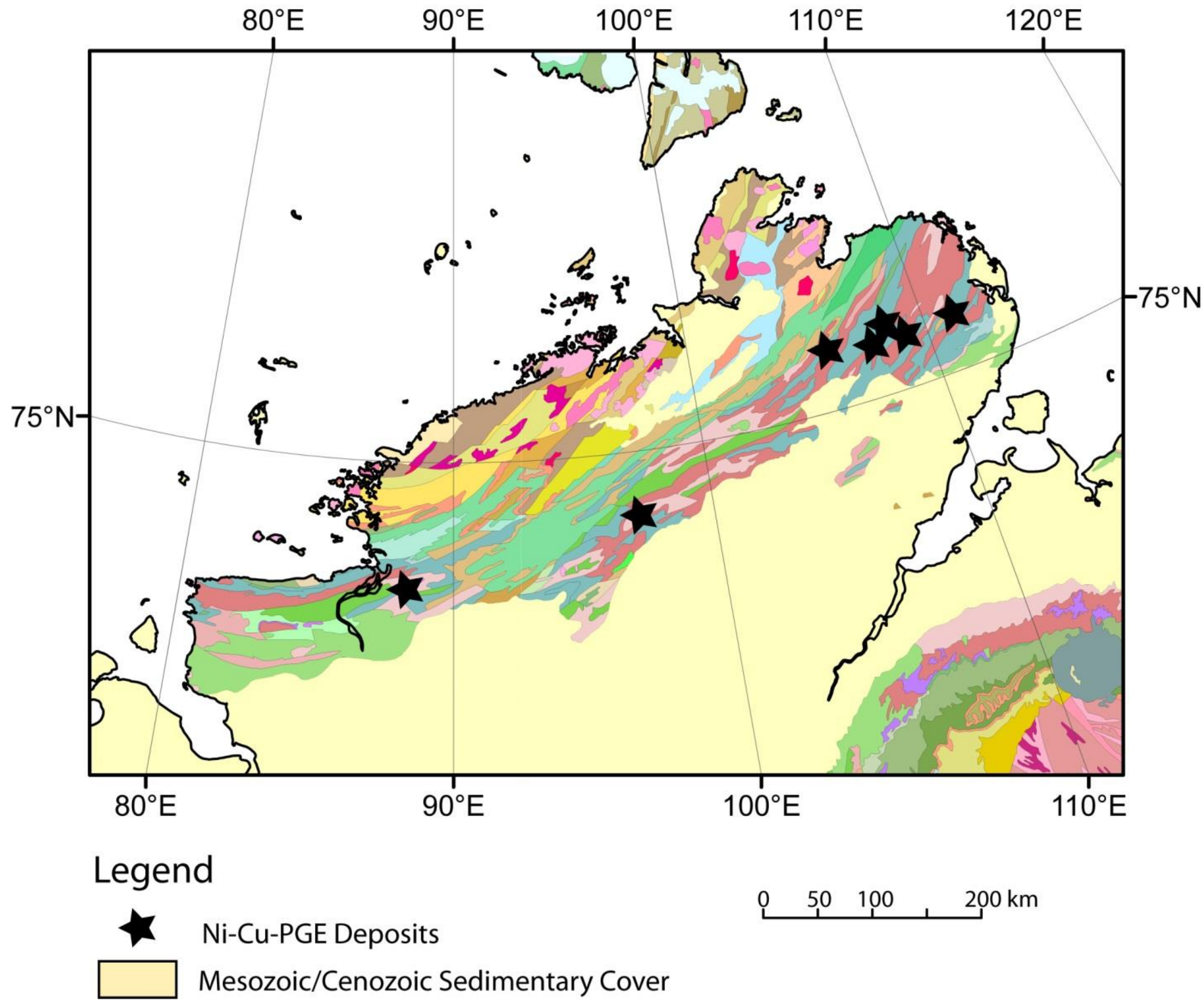

Figure 34: Distribution of Ni-Cu-PGE deposits and occurrences in the Taimyr region (Table 4). Deposits occur near the southern contact between Paleozoic metasediments and later Mesozoic and Cenozoic sediments. Geology from Harrison et al. (2011).

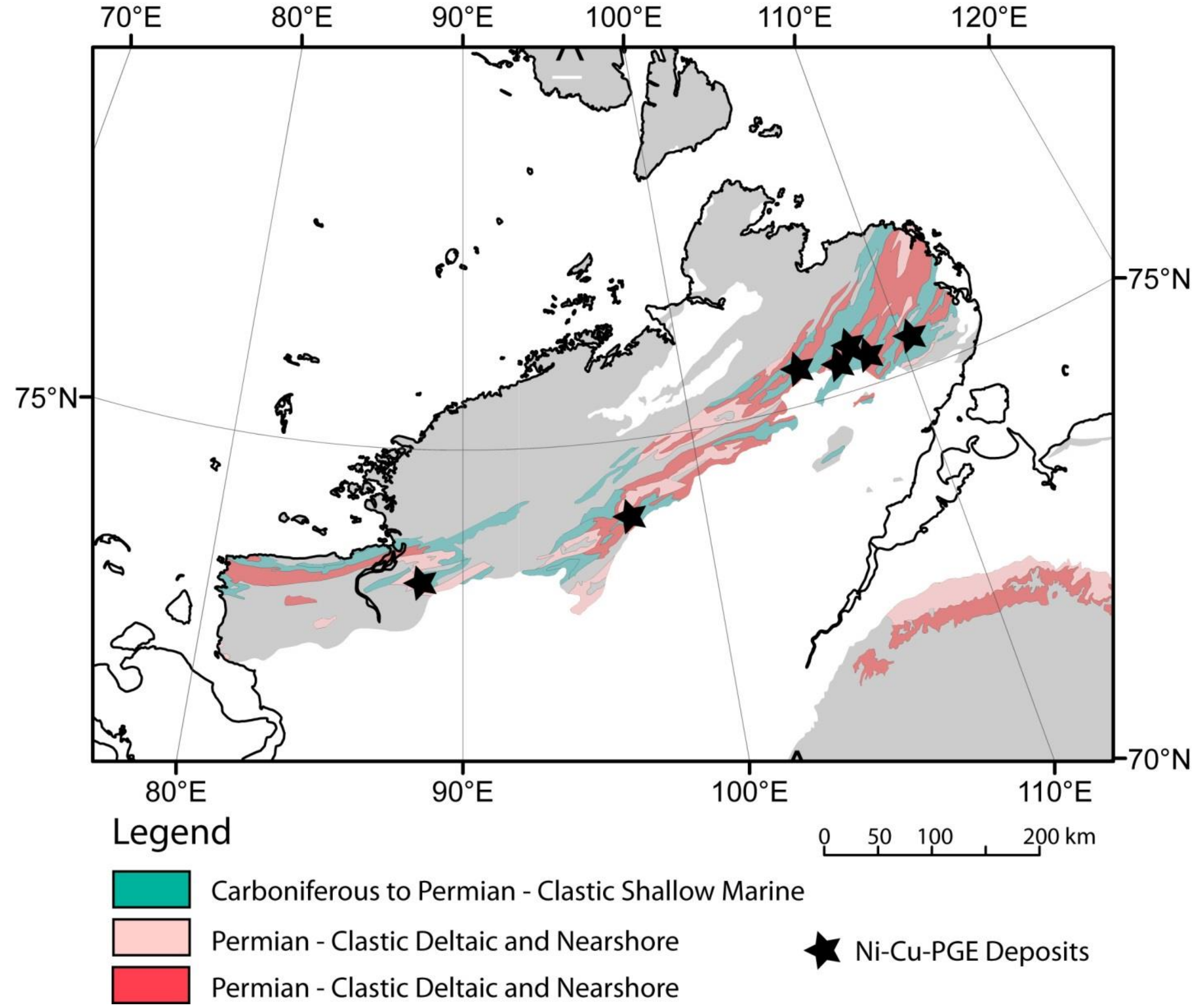

Figure 35: Distribution of permissive geology for Ni-Cu-PGE deposits in the Taimyr region.

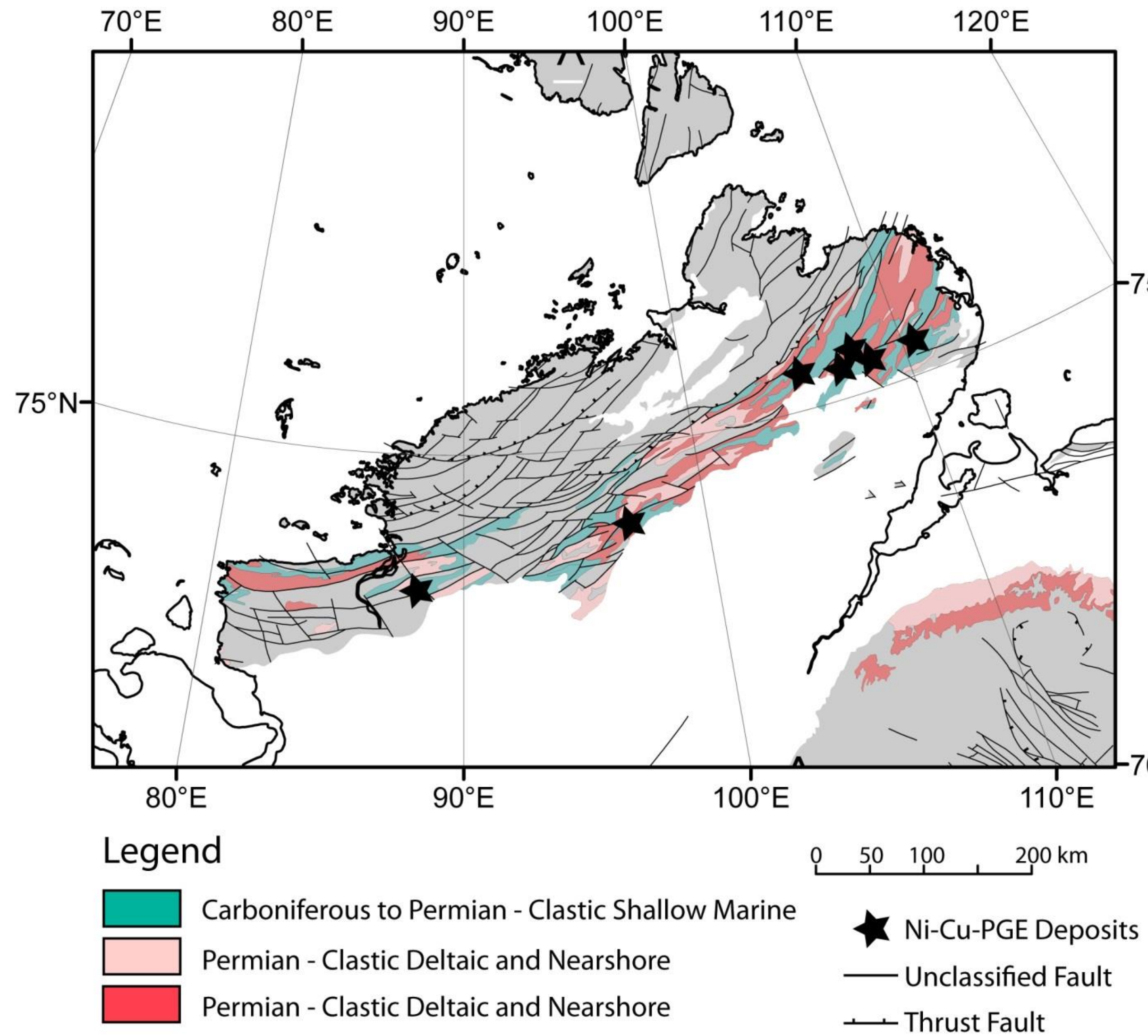

Figure 36: Map of the permissive geology for Ni-Cu-PGE deposits in the Taimyr region, with major structural features that are used to guide the extrapolation of onshore geology to the crystalline basement of the continental shelf.

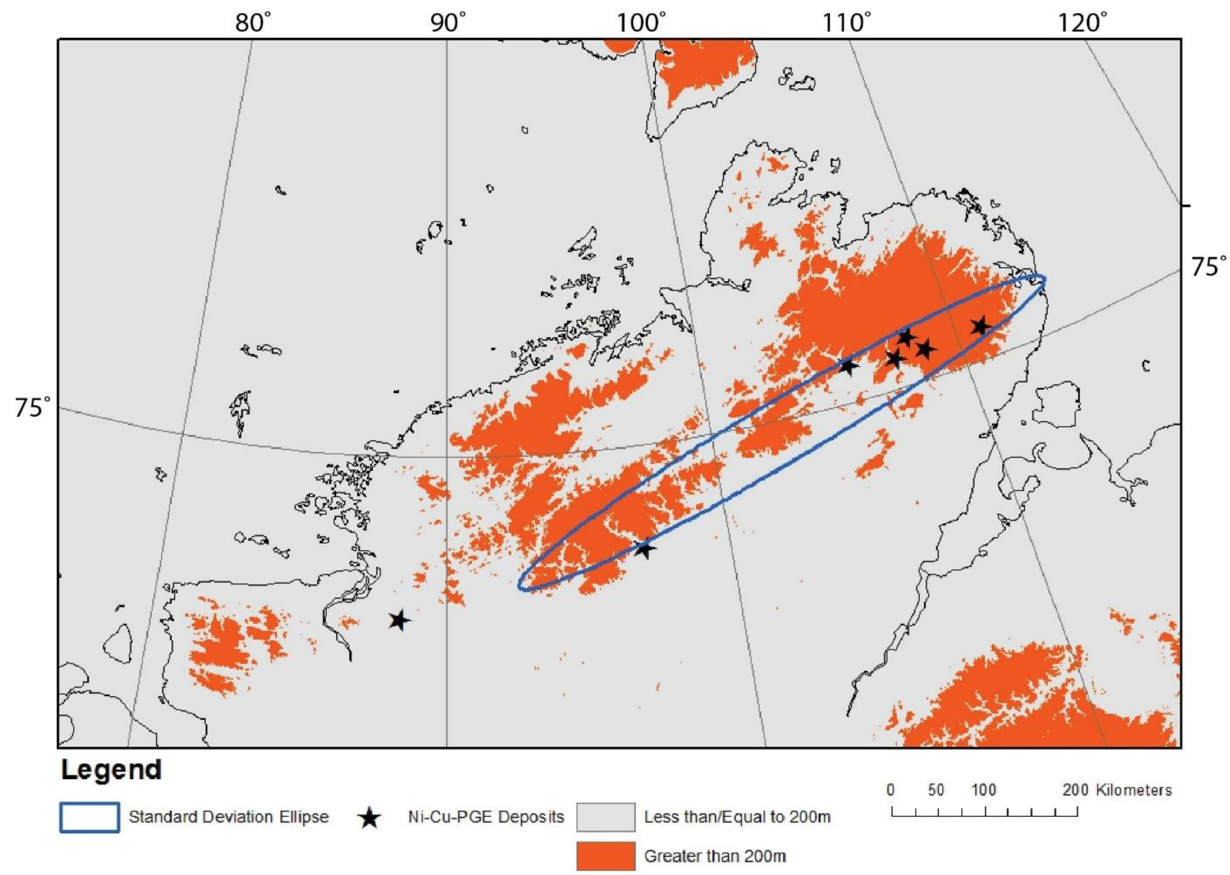

Figure 37: Map of the Taimyr region showing the distribution of elevation greater than 200 m above sea level. Higher elevations may show structural trends of more resistant exposed basement crust, which can be used to guide offshore extrapolation of basement geology. Blue ellipse represents the standard deviation of the distribution of Ni-Cu-PGE deposits along a ENE-SWS linear trend.

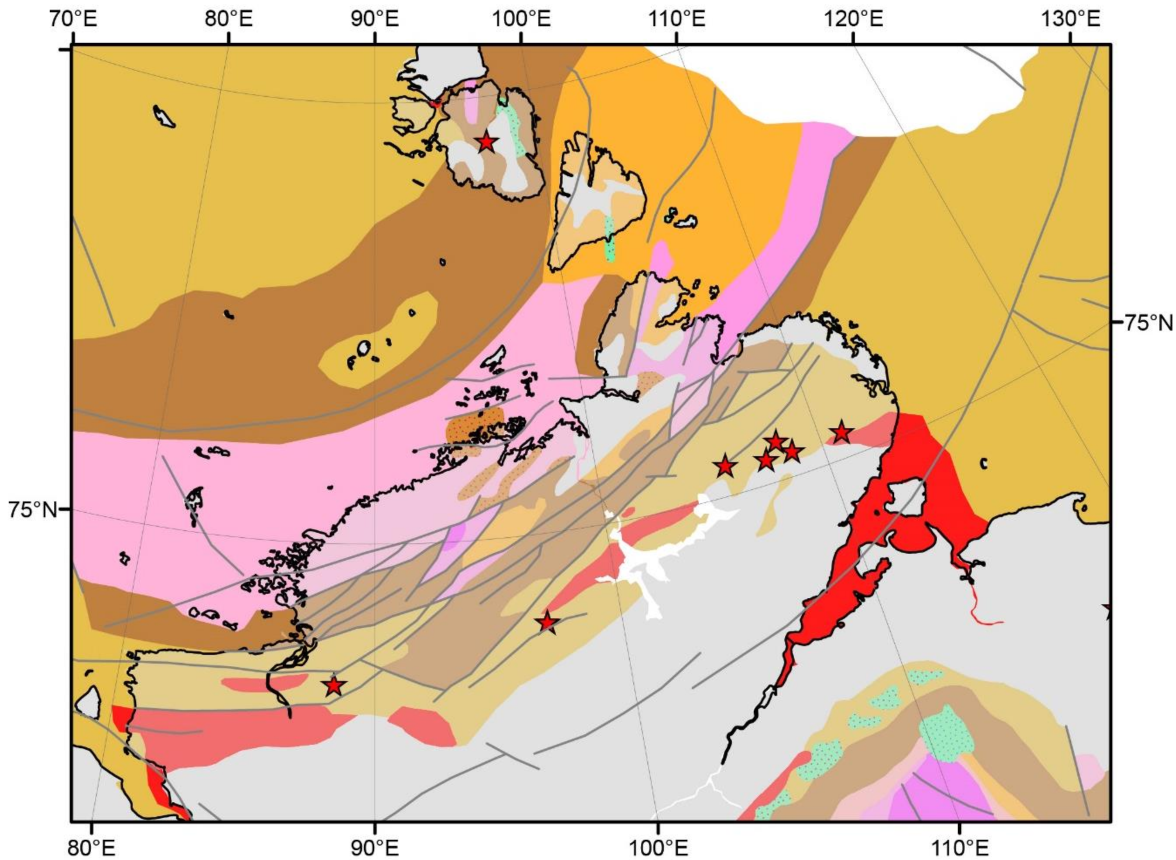

Figure 38: Geological map of the Taimyr region, mapped at 1:25,000,000 scale. Offshore geology is extrapolated to the limit of the continental slope using online geology and structural features from the CGMW Map of the World (Bouysse, 2009). Supracrustal onshore sediments are represented by the grey unit. Red stars show the locations of Ni-Cu-PGE deposits.

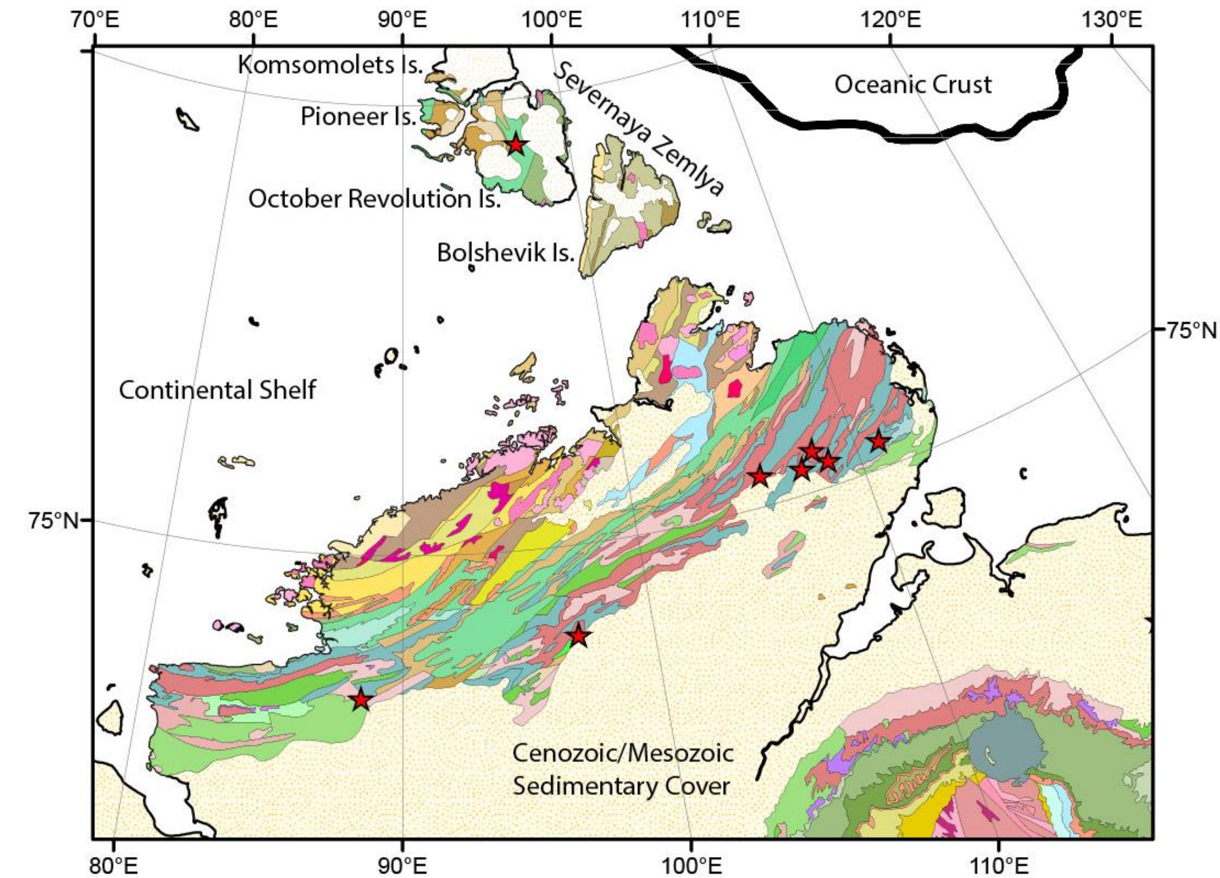

Figure 39: Geological basemap used for high resolution (1:5,000,000) extrapolation of basement geology (from GSC Map 2159A; Harrison et al., 2011) on to the continental shelf. Continental shelf limit is set as the base of the continental slope and represents the transition from continental to oceanic crust.

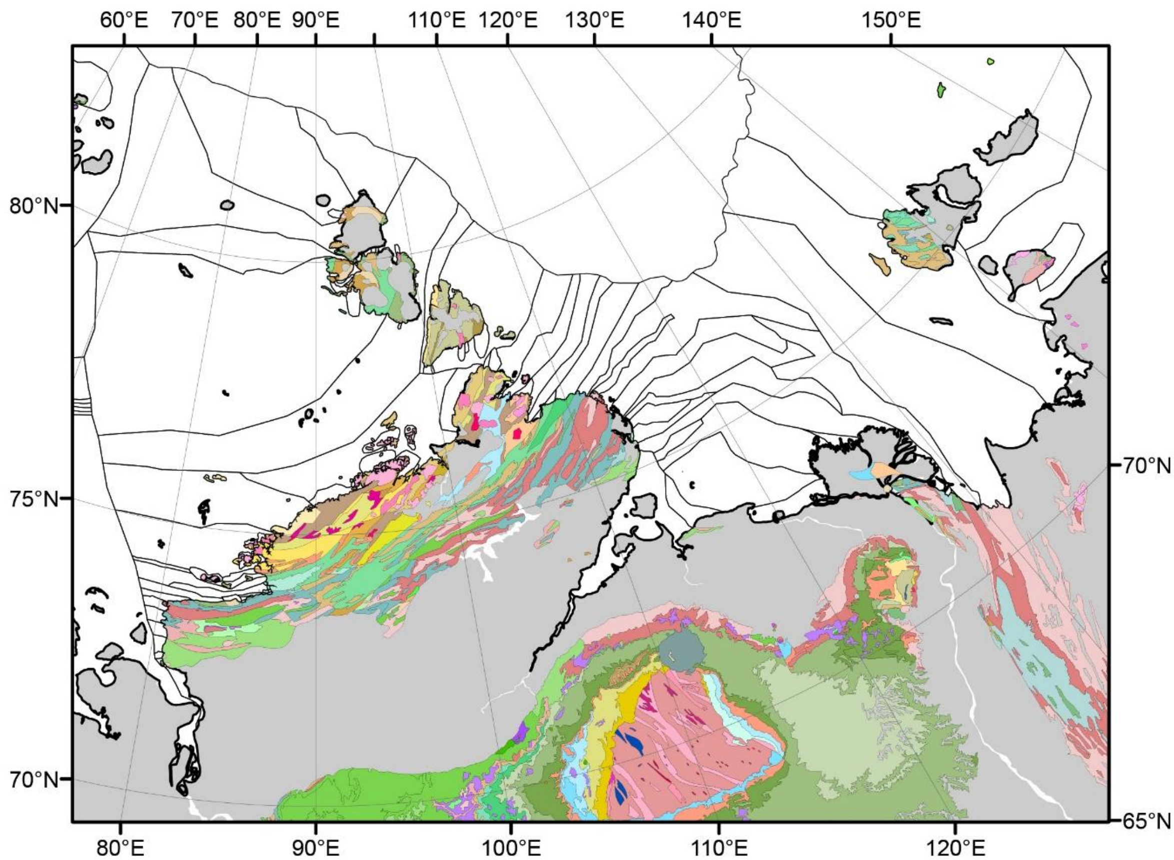

Figure 40: Polygons for the offshore extrapolation of individual map units from GSC Map 2159A (Harrison et al., 2011). See Table 5 and text for details.

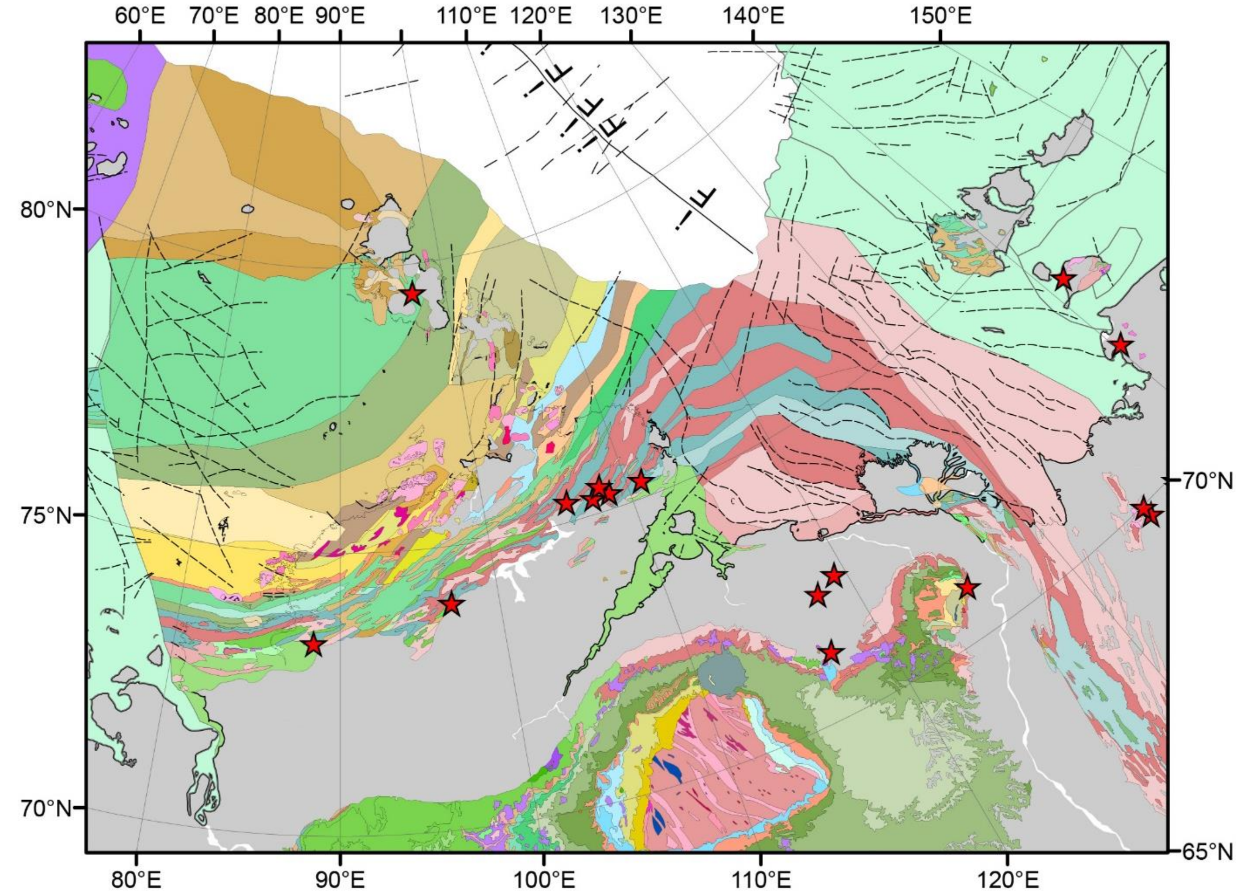

Figure 41: Geological map of the pre-rift continental shelf basement, mapped at 1:5,000,000 scale, based on extrapolation of exposed onshore basement geology from Harrison et al. (2011). Red stars show the locations of Ni-Cu-PGE deposits.

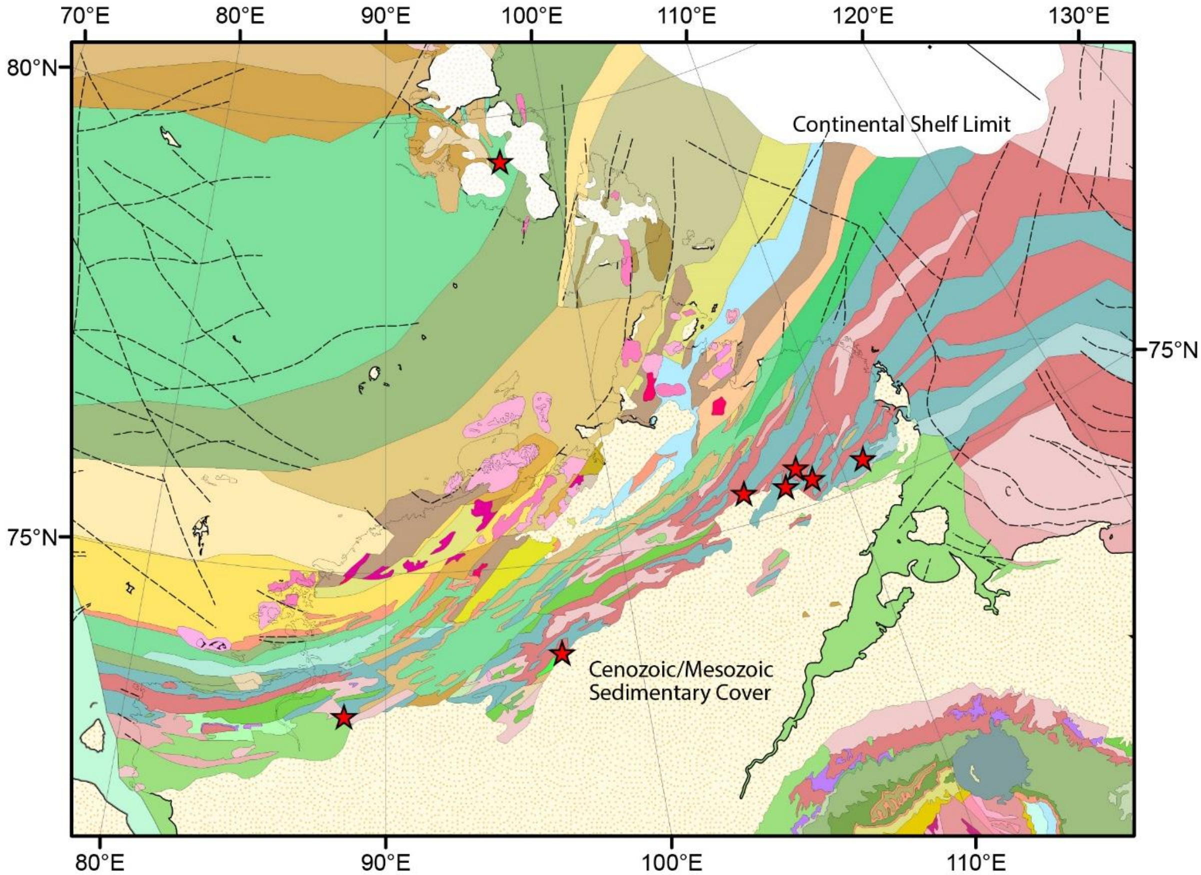

Figure 42: Close-up of the onshore and offshore basement geology of the Taimyr Region, with locations of Ni-Cu-PGE deposits (red stars). Onshore geology from Harrison et al. (2011) and offshore geology from this study.

9.0 Estimate of offshore mineral potential in the Taimyr region

The preliminary extrapolations of offshore bedrock geology of the Taimyr region presented here provide the basis for a first estimate of mineral potential of the continental shelf basement. Following the mineral assessment practice employed by the United States Geological Survey, the first step is an examination of geologic maps to determine the area that may be permissive for mineral deposits of different types. An area of permissive geology is defined as lithostratigraphic units of the appropriate composition, structure and age to host ore deposits of a particular type, usually with a clear link between the origin of the rocks and the processes responsible for ore formation. This is followed by an estimate of the number of undiscovered deposits in that area based on an analysis of deposit densities (i.e., numbers of known occurrences per km^2 of permissive geology) in areas considered to have been fully explored for that deposit type). Singer (2010) showed that estimates of deposit densities are always inversely correlated with map scale because larger maps tend to group permissive geology into larger areas, decreasing the density of known deposits. The map scale of 1:5,000,000 used here is at the limit suggested by Singer (2010), but maps of the sea floor with a larger scale (i.e., higher resolution) are not available.

In the Taimyr region, there are 7 magmatic Ni sulfide occurrences (Table 4 and Fig. 34). These deposits are associated with mafic intrusions within Upper Paleozoic clastic sediments of the South Taimyr accretionary belt. These units constitute the permissive geology where magmatic Ni deposits may be located (Fig. 35). This permissive geology on land covers 38,600 km^2, and represents ~20% of the exposed basement area of the mainland Taimyr region. Therefore, the deposit density is 1 occurrence per 5,500 km^2 of geologically permissive units, assuming that all of the significant mineral occurrences have been found. It is a fundamental assumption that the number of known occurrences represents the total number of deposits in the area used to estimate deposit density. This is a minimum number if undiscovered deposits still exist in unexplored parts of the Peninsula.

Assuming that the 7 known occurrences of magmatic Ni mineralization are representative of the mineral potential in equivalent units offshore, it is possible to estimate the number of occurrences that might be found in basement rocks of the shelf area. In this case, the permissive rocks that extend offshore to the east beneath the Laptev Sea and towards the Lena River Delta occupy ~40 % of the offshore shelf area (approx. 136,000 km^2 of a total area of 317,000 km^2). This area underlain by Permian and Carboniferous rocks is permissive for the occurrence of magmatic Ni sulfide deposits similar to those on the adjacent peninsula (Fig. 41). Based on the deposit density calculated onshore, an additional 25 magmatic Ni occurrences can be expected offshore. There are many uncertainties in this analysis, as noted above, but the example illustrates that first-order estimates of offshore mineral potential are possible and that significant numbers of mineral occurrences can be expected in the continental basement rocks of the shelf areas.

Table 4: Magmatic Ni deposits on the Taimyr Region (see Appendix 2 for complete list of deposits in the Circumpolar Arctic region).

Deposit Name	Latitude (DD)	Longitude (DD)	Deposit Status	Commodity	Host Rock Lithology	Geologic Age of Host Rock	Tectonic Setting
Binyuda	73.400013	88.400154	Showing	Ni	mafic-ultramafic suite: gabbro; peridotite	Late Paleozoic	craton
Central Taimyr	74.000012	97.000154	Showing	Ni; Cu; Pt	mafic-ultramafic suite: gabbro; peridotite	Late Paleozoic	craton
Dyabaka-Tari	74.000012	97.000154	Showing	Ni; Cu; pge	mafic-ultramafic; sub-alkaline	Late Permian - Early Triassic	epicontinental plume; crustal extension
Ozero Levinson-Lessinga	75.350011	105.666821	Showing	Ni; Cu	mafic-ultramafic suite	Late Permian - Early Triassic	continental plume; crustal extension
Kundgsalakh	75.283344	107.466821	Showing	Ni	ultramafic suite	Late Permian - Early Triassic	continental plume; crustal extension
Malakhai-Tari	75.450011	108.133487	Showing	Ni; Cu	intrusive; ultramafic suite	Late Permian - Early Triassic	continental plume; crustal extension
Murutumatari	75.283344	108.666821	Showing	Ni; Cu	mafic-ultramafic suite	Late Permian - Early Triassic	continental plume; crustal extension
Eastern Taimyr	75.300011	111.000154	Showing	Ni; Cu; Pt	mafic-ultramafic suite: gabbro, peridotite	Late Paleozoic	craton
Reka Ozernaya	79.500008	96.866821	Showing	Ni; Cu	(no information)	Late Permian - Early Triassic	craton

Source: Geological Survey of Canada Mineral Deposits Database

Table 5: Polygons (larger than 100 km^2) defining the offshore geology of the Taimyr Region, based on legend and descriptions from the GSC Map 2159A (Harrison et al., 2011).Areas were calculated in the North Polar Lambert Azimuthal Equal Area projection

Polygon ID	Area (km^2)	Description	Epoch	Age	Setting
152	173,080	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Ordovician and Silurian (488 - 416 Ma)	Carbonate
175	117,319	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Guadalupian and Lopingian (271 - 251 Ma)	Clastic: deltaic and nearshore
15	91,670	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic	Lower Paleozoic	Cambrian (542 - 488 Ma)	Slope and deep water
148	68,893	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Devonian (416 - 359 Ma)	Clastic: deltaic and nearshore
159	55,034	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Early and Middle Devonian (416 - 385 Ma)	Clastic: continental
12	37,754	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic	Proterozoic	late Paleoproterozoic (Statherian) and Neoproterozoic (1800 - 542 Ma)	Slope and deep water
22	34,572	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic	Neoproterozoic	late Paleoproterozoic (Statherian) and Neoproterozoic (1800 - 542 Ma)	Clastic: shallow marine
30	32,790	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Cisuralian (299 - 271 Ma)	Clastic: deltaic and nearshore
129	32,044	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic	Proterozoic	Mesoproterozoic (1600 - 1000 Ma)	Slope and deep water
158	28,060	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Early and Middle Devonian (416 - 385 Ma)	Carbonate
168	26,584	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Cisuralian (299 - 271 Ma)	Clastic: shallow marine
178	26,290	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Guadalupian and Lopingian (271 - 251 Ma)	Clastic: deltaic and nearshore
130	24,685	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic	Proterozoic	late Paleoproterozoic (Statherian) and Neoproterozoic (1800 - 542 Ma)	Sedimentary: undivided
165	23,285	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Pennsylvanian (318 - 299 Ma)	Clastic: shallow marine
162	22,599	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Cisuralian (299 - 271 Ma)	Clastic: deltaic and nearshore
28	21,665	Large Igneous Province (LIP): Traps with indication of mean age in Macc		Triassic (251.0 - 199.6 Ma)	Extrusive: undivided
157	20,115	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Devonian (416 - 359 Ma)	Clastic: deltaic and nearshore
161	16,521	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Cisuralian (299 - 271 Ma)	Clastic: deltaic and nearshore
163	14,738	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Carboniferous and Permian (359 - 251 Ma)	Clastic: shallow marine
169	12,905	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Carboniferous and Permian (359 - 251 Ma)	Clastic: shallow marine
90	12,372	Continental crust, Sedimentary rocks or undifferentiated facies -	Neoproterozoic	late Paleoproterozoic (Statherian) and Neoproterozoic (1800 - 542	

Polygon ID	Area (km^2)	Description	Epoch	Age	Setting
		Neoproterozoic		Ma)	
27	10,842	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic	Lower Paleozoic	Early and Middle Ordovician (488 - 461 Ma)	Slope and deep water
23	8,335	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic	Paleoproterozoic	Paleoproterozoic (2500 - 1600 Ma)	Sedimentary: undivided
36	8,293	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Carboniferous and Permian (359 - 251 Ma)	Clastic: shallow marine
86	8,088	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic	Neoproterozoic	late Paleoproterozoic (Statherian) and Neoproterozoic (1800 - 542 Ma)	Carbonate
51	7,280	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic	Neoproterozoic	Ediacaran (~635 - 542 Ma)	Clastic: shallow marine
53	6,122	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic	Paleoproterozoic	Archean (4000 - 2500 Ma)	
174	6,009	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Permian (299 - 251 Ma)	Clastic: shallow marine
0	5,450	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic	Lower Paleozoic	Ordovician and Silurian (488 - 416 Ma)	Slope and deep water
140	4,484	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic	Lower Paleozoic	Mesoproterozoic (1600 - 1000 Ma)	Slope and deep water
164	3,787	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Permian (299 - 251 Ma)	Clastic: shallow marine
187	3,521	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Cisuralian (299 - 271 Ma)	Clastic: deltaic and nearshore
186	3,521	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Carboniferous and Permian (359 - 251 Ma)	Clastic: shallow marine
29	3,321	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Guadalupian and Lopingian (271 - 251 Ma)	Clastic: shallow marine
1	2,753	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic	Lower Paleozoic	Silurian and Devonian (444 - 359 Ma)	Slope and deep water
71	2,569	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic	Lower Paleozoic	Cambrian to Devonian (542 - 359 Ma)	Carbonate
170	2,292	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Carboniferous and Permian (359 - 251 Ma)	Clastic: shallow marine
126	2,245	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic	Proterozoic	Paleoproterozoic (2500 - 1600 Ma)	Sedimentary: undivided
153	1,991	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Devonian (416 - 359 Ma)	Clastic: deltaic and nearshore
16	1,939	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleozoic	Paleozoic	Mesoproterozoic (1600 - 1000 Ma)	Slope and deep water
185	1,599	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Carboniferous (359 - 299 Ma)	Sedimentary: undivided
141	1,534	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic	Proterozoic	Carboniferous and Permian (359 - 251 Ma)	Intrusive: granitic
88	1,418	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic	Neoproterozoic	Mesoproterozoic (1600 - 1000 Ma)	Clastic: shallow marine

Polygon ID	Area (km^2)	Description	Epoch	Age	Setting
143	1,380	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic	Proterozoic	Mesoproterozoic (1600 - 1000 Ma)	Sedimentary: undivided
6	1,222	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Carboniferous and Permian (359 - 251 Ma)	Clastic: shallow marine
7	1,104	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic	Lower Paleozoic	Cambrian and Ordovician (542 - 444 Ma)	Slope and deep water
3	1,074	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Carboniferous and Permian (359 - 251 Ma)	Clastic: shallow marine
2	1,001	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Cisuralian (299 - 271 Ma)	Clastic: deltaic and nearshore
4	922	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Permian (299 - 251 Ma)	Clastic: deltaic and nearshore
131	890	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic	Proterozoic	Triassic and Jurassic (251.0 - 145.5 Ma)	Intrusive: syenitic
19	847	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic	Paleoproterozoic	Paleoproterozoic (2500 - 1600 Ma)	Sedimentary: undivided
132	772	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic	Proterozoic	Neoproterozoic and Cambrian (1000 - 488 Ma)	Sedimentary: undivided
5	740	Large Igneous Province (LIP): Traps with indication of mean age in Ma		Early Triassic (251.0 - 245.9 Ma)	Extrusive: undivided
142	668	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic	Proterozoic	Carboniferous and Permian (359 - 251 Ma)	Intrusive: granitic
52	645	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic	Paleoproterozoic	Archean (4000 - 2500 Ma)	Sedimentary: undivided
80	487	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic	Proterozoic	Permian (299 - 251 Ma)	Intrusive: syenitic
150	481	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Early and Middle Devonian (416 - 385 Ma)	Carbonate
149	439	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Late Devonian (385 - 359 Ma)	Clastic: continental
156	408	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Guadalupian and Lopingian (271 - 251 Ma)	Clastic: deltaic and nearshore
18	393	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesozoic	Mesozoic	Carboniferous and Permian (359 - 251 Ma)	Intrusive: tonalitic-granodioritic
68	385	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic	Lower Paleozoic	Late Devonian (385 - 359 Ma)	Slope and deep water
70	366	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic	Lower Paleozoic	Carboniferous and Permian (359 - 251 Ma)	Clastic: shallow marine
134	320	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleozoic	Paleozoic	Carboniferous and Permian (359 - 251 Ma)	Intrusive: granitic
26	316	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic	Lower Paleozoic	Ordovician and Silurian (488 - 416 Ma)	Slope and deep water
171	303	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Archean (4000 - 2500 Ma)	Sedimentary: undivided
49	282	Continental crust, Sedimentary rocks or undifferentiated facies -	Neoproterozoic	late Paleoproterozoic (Statherian) and Neoproterozoic (1800 - 542	Clastic: shallow marine

Polygon ID	Area (km^2)	Description	Epoch	Age	Setting
		Neoproterozoic		Ma)	
103	240	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Cambrian to Devonian (542 - 359 Ma)	Sedimentary: undivided
72	238	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic	Proterozoic	Carboniferous and Permian (359 - 251 Ma)	Intrusive: tonalitic-granodioritic
89	236	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic	Neoproterozoic	late Paleoproterozoic (Statherian) and Neoproterozoic (1800 - 542 Ma)	Sedimentary: undivided
176	224	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Guadalupian and Lopingian (271 - 251 Ma)	Clastic: deltaic and nearshore
125	212	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic	Proterozoic	late Paleoproterozoic (Statherian) and Neoproterozoic (1800 - 542 Ma)	Sedimentary: undivided
8	211	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Early Triassic (251.0 - 245.9 Ma)	Extrusive: mafic
94	206	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Permian and Triassic (299 - 199.6 Ma)	Extrusive: undivided
24	197	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic	Proterozoic	Archean (4000 - 2500 Ma)	
64	195	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Cisuralian (299 - 271 Ma)	Clastic: deltaic and nearshore
123	195	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic	Proterozoic	Carboniferous and Permian (359 - 251 Ma)	Intrusive: granitic
166	190	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Pennsylvanian (318 - 299 Ma)	Clastic: shallow marine
39	190	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic	Proterozoic	Paleoproterozoic (2500 - 1600 Ma)	Sedimentary: undivided
99	182	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Carboniferous (359 - 299 Ma)	Sedimentary: undivided
179	167	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Cisuralian (299 - 271 Ma)	Clastic: shallow marine
133	166	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Early Triassic (251.0 - 245.9 Ma)	Extrusive: undivided
112	165	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic	Proterozoic	Carboniferous and Permian (359 - 251 Ma)	Intrusive: granitic
74	164	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic	Proterozoic	Carboniferous and Permian (359 - 251 Ma)	Intrusive: tonalitic-granodioritic
87	161	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic	Neoproterozoic	Mesoproterozoic (1600 - 1000 Ma)	Clastic: shallow marine
13	157	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic	Lower Paleozoic	Devonian (416 - 359 Ma)	Clastic: deltaic and nearshore
146	155	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesozoic	Mesozoic	Carboniferous and Permian (359 - 251 Ma)	Intrusive: tonalitic-granodioritic
97	155	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Late Devonian (385 - 359 Ma)	Carbonate
83	148	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic	Neoproterozoic	Silurian and Devonian (444 - 359 Ma)	Intrusive: granitic

Polygon ID	Area (km^2)	Description	Epoch	Age	Setting
69	137	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic	Lower Paleozoic	Cambrian to Devonian (542 - 359 Ma)	Carbonate
42	135	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic	Lower Paleozoic	Devonian (416 - 359 Ma)	Carbonate
32	125	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Carboniferous and Permian (359 - 251 Ma)	Clastic: shallow marine
40	118	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic	Proterozoic	Proterozoic (2500 - 542 Ma)	Sedimentary: undivided
136	115	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic	Proterozoic	Permian (299 - 251 Ma)	Intrusive: syenitic
14	112	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic	Paleoproterozoic	Devonian (416 - 359 Ma)	Clastic: deltaic and nearshore
184	109	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Carboniferous (359 - 299 Ma)	Sedimentary: undivided
172	109	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	late Paleoproterozoic (Statherian) and Neoproterozoic (1800 - 542 Ma)	Carbonate
105	102	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic	Upper Paleozoic	Carboniferous (359 - 299 Ma)	Sedimentary: undivided

10.0 Conclusions

An ArcGIS® project of the Circumpolar Arctic shows that first-order estimates can be made of the bedrock geology of the extended continental shelf, and these results can be used to estimate resource potential under the shelf sediments. The analysis provides a first view of what the continents would look like if the position of the coastline is ignored and the basement geology is extended to the shelf edge. More than 50% of the Arctic Basin is underlain by continental crust; 12% is Archean, 22% is Proterozoic, 53% is Paleozoic, and 13% is Mesozoic (Fig. 43). Except for the Precambrian crystalline basement, most of the offshore continental crust comprises Paleozoic and Mesozoic sedimentary sequences. The analysis was carried out at two map scales guided initially by (1) regional tectonic assemblages at 1:25,000,000 resolution and then by (2) more detailed onshore lithostratigraphic map units at 1:5,000,000. As a demonstration project, the onshore and offshore geology of the Taimyr region of northern Russia was examined in detail, extrapolating older terranes exposed on land to the edge of the shelf. In this area, ~40 % of the shelf (approx. 136,000 km^2 of a total area of 317,000 km^2) is underlain by Permian and Carboniferous rocks considered to be permissive units for the occurrence of magmatic Ni sulfide deposits similar to those on the adjacent peninsula.

The approach for estimating the areas favourable for subsea mineral deposits requires the choice of a scale appropriate to the task, identifying the elements of extrapolation (ages, lithologies, structures related to the permissive geology), and assembling the constraints for offshore projection (digital terrain models from bathymetric data, gravity models). Offshore structure is the most important constraint on how far to draw the units beyond the nearest coastal exposures. Well-documented lithostratigraphic units can be extended at least to the edge of the shelf, and rules can be set for different confidence limits (e.g., extrapolations that are no greater than the mapped strike length of the units on land).

In the Taimyr region, a first-order approximation was made of the area of permissive geology for offshore Ni occurrences by comparison with the known deposits on land. While not a strict resource assessment following all of the criteria of Singer (2010), the approach clearly identifies the most favourable areas of continental shelf basement and gives a sense of the offshore potential. This can be repeated in any area of interest where there are known metallogenic belts near to the coast. Where sufficient numbers of deposits are known and well-characterized on land, probability models of deposit grade and tonnage could be used to estimate actual mineral endowment for a wide range of mineral deposit types that may occur on the continental shelf.

The results of this study also have important implications for models of area-age relationships of the continental crust, plate reconstructions, and hazard potential in the continental shelf region. The extrapolated bedrock geology also can be used in risk analysis, for example, associated with exposure of the marine environment to specific lithotypes (e.g., modelling shelf stability based on bedrock properties; estimating areas of Paleozoic shales that may be a source of mercury). Future research should include more sophisticated techniques for analysis of DTMs commonly used on land, application of weights of evidence to the map elements, and better criteria for categorizing seabed structure and geomorphology, including available geophysical data. However, it is noteworthy that even readily available data (i.e., satellite altimetry, multibeam bathymetry, acoustic backscatter, and magnetics) are rarely converted to geological maps. These data are interpretable at a range of scales, as shown here, and may also be analyzed using novel data processing techniques (e.g., terrain texture analysis) for the recognition of faults and lithological contacts, which can be used to improve predicted offshore geology.

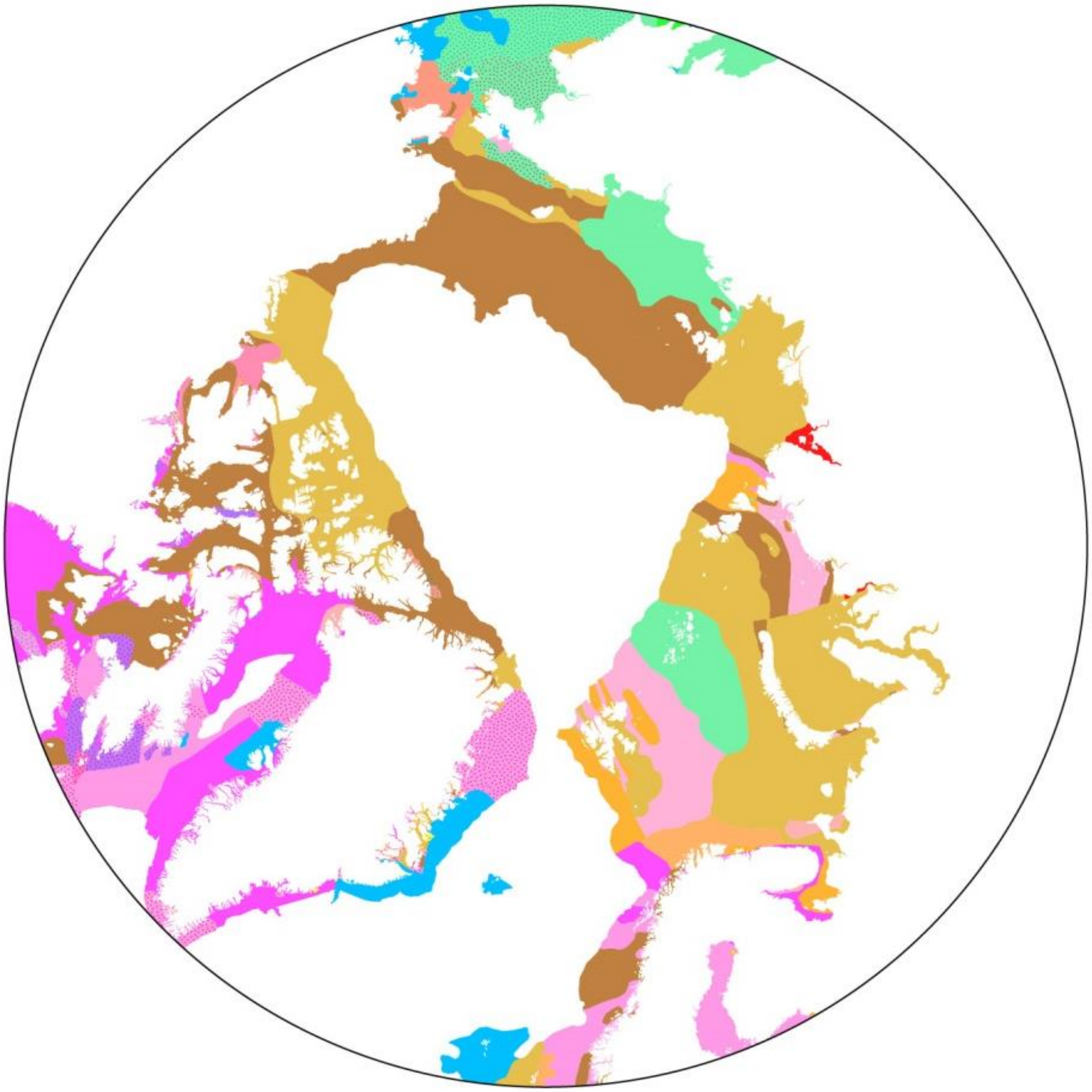

Figure 43: All polygons for extrapolated bedrock geology of the continental shelf north of 60° N

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Appendix 1: Examples of definitions of continental shelf.

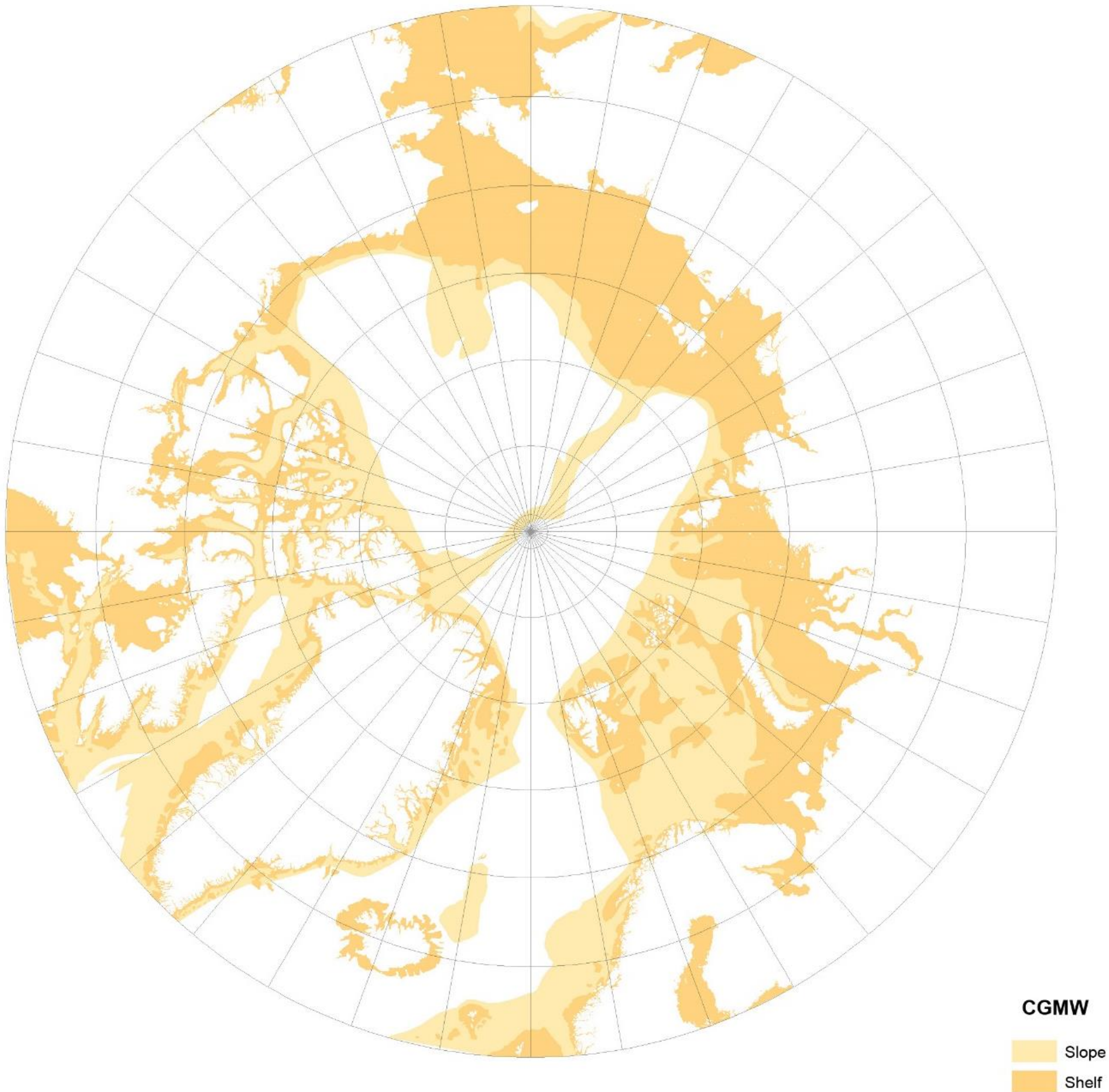

Figure A1-1: The definition of continental shelf used for the CGMW's Geological Map of the World is based on the 200 m isobath. Continental crust is any seafloor shallower than 200m. Using this definition, the crust below the Barents Sea is considered a combination of continental shelf and slope.

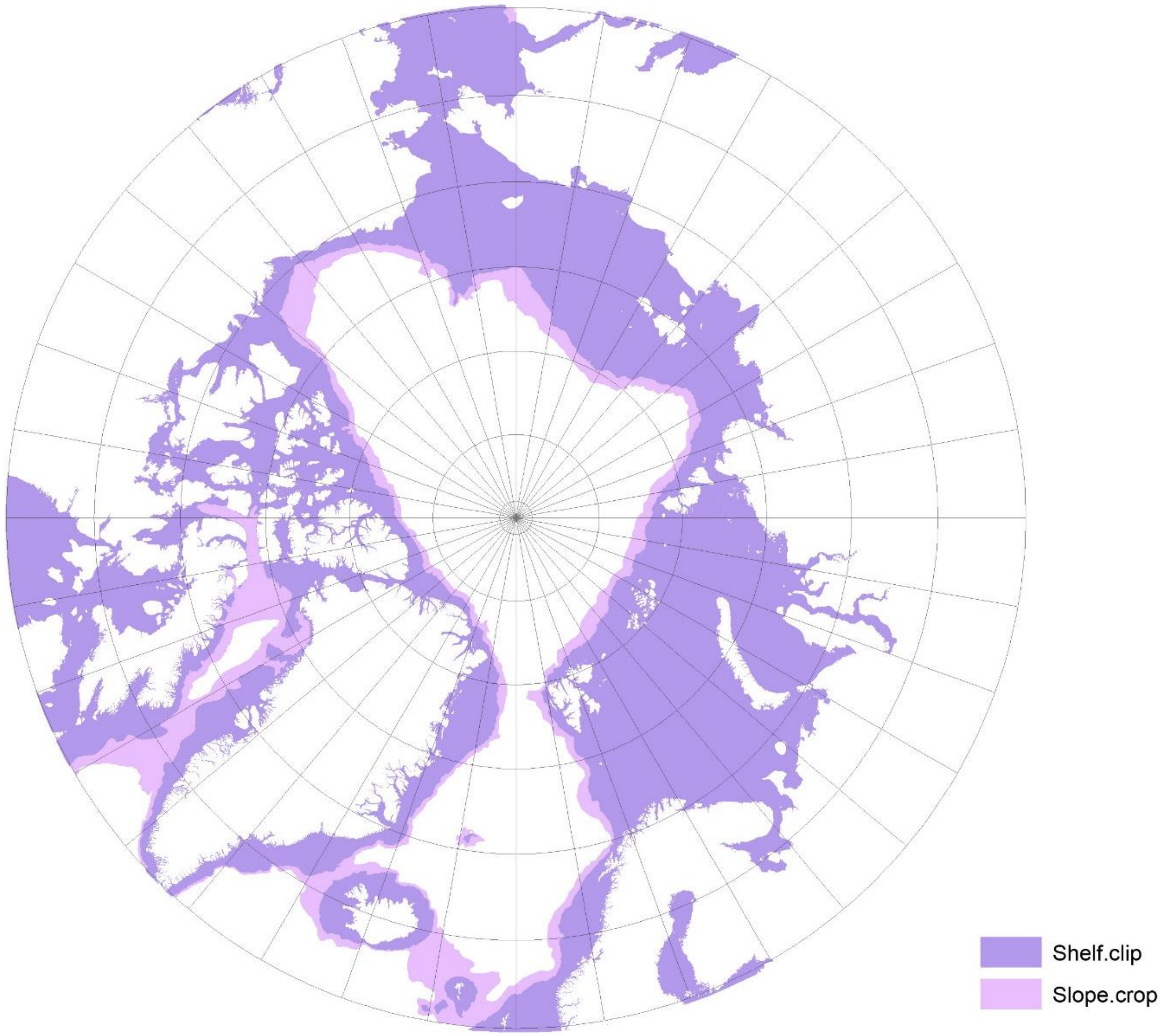

Figure A1-2: Continental shelf and slope, as defined by Harris et al. (2014). This definition is based on morphological features, primarily the slopes and slope breaks across continental margins. This definition is considered to be more representative of the underlying geology than the definition based purely on bathymetry. For example, the entire crust underneath the Barents Sea in this case is considered continental crust, up to the slope break down to the abyssal plain. However, this definition is not necessarily always representative of continental crust. The abyssal slope that extends eastward and westward from Iceland is classified as continental slope based on morphology. However, this region is a volcanic plateau on oceanic crust.

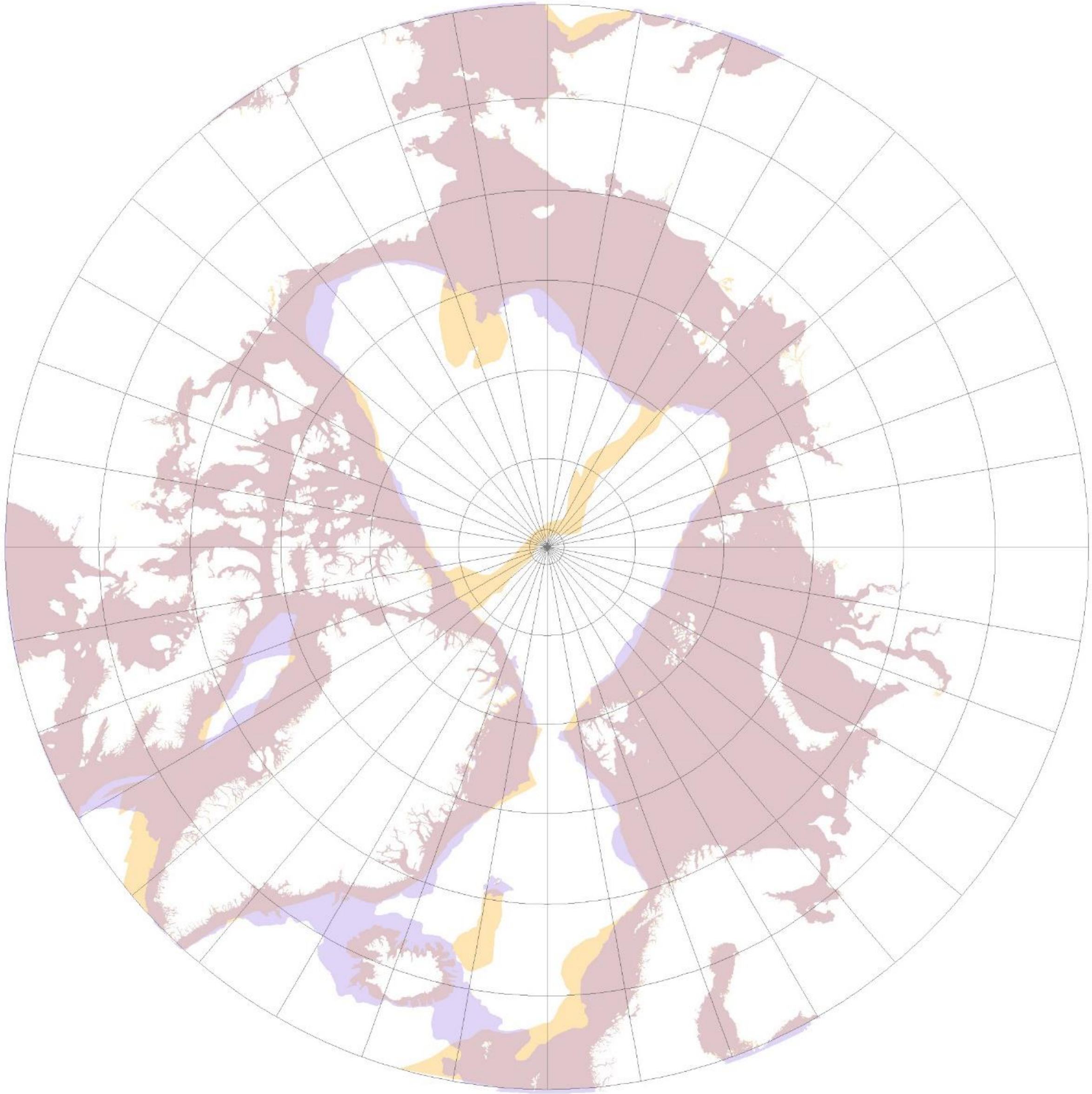

Figure A1-3: Map showing the difference in extent of continental shelf using the bathymetric definition (light orange) and the morphological definition (light purple).

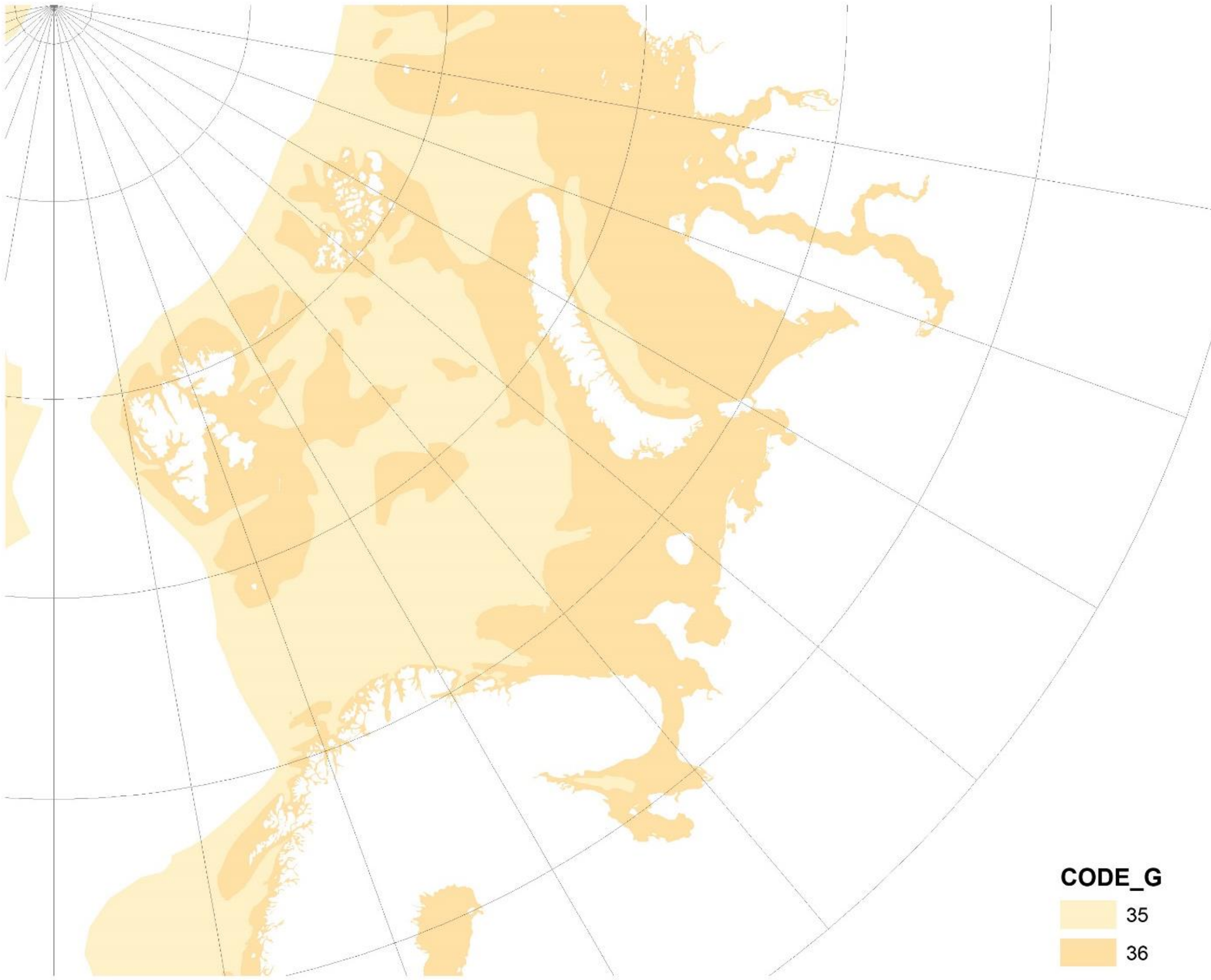

Figure A1-4: Close up of the Barents Sea region, with classification of continental shelf (code 36) and continental slope (code 35) based on the 200 m isobath (Bouysse, 2009).

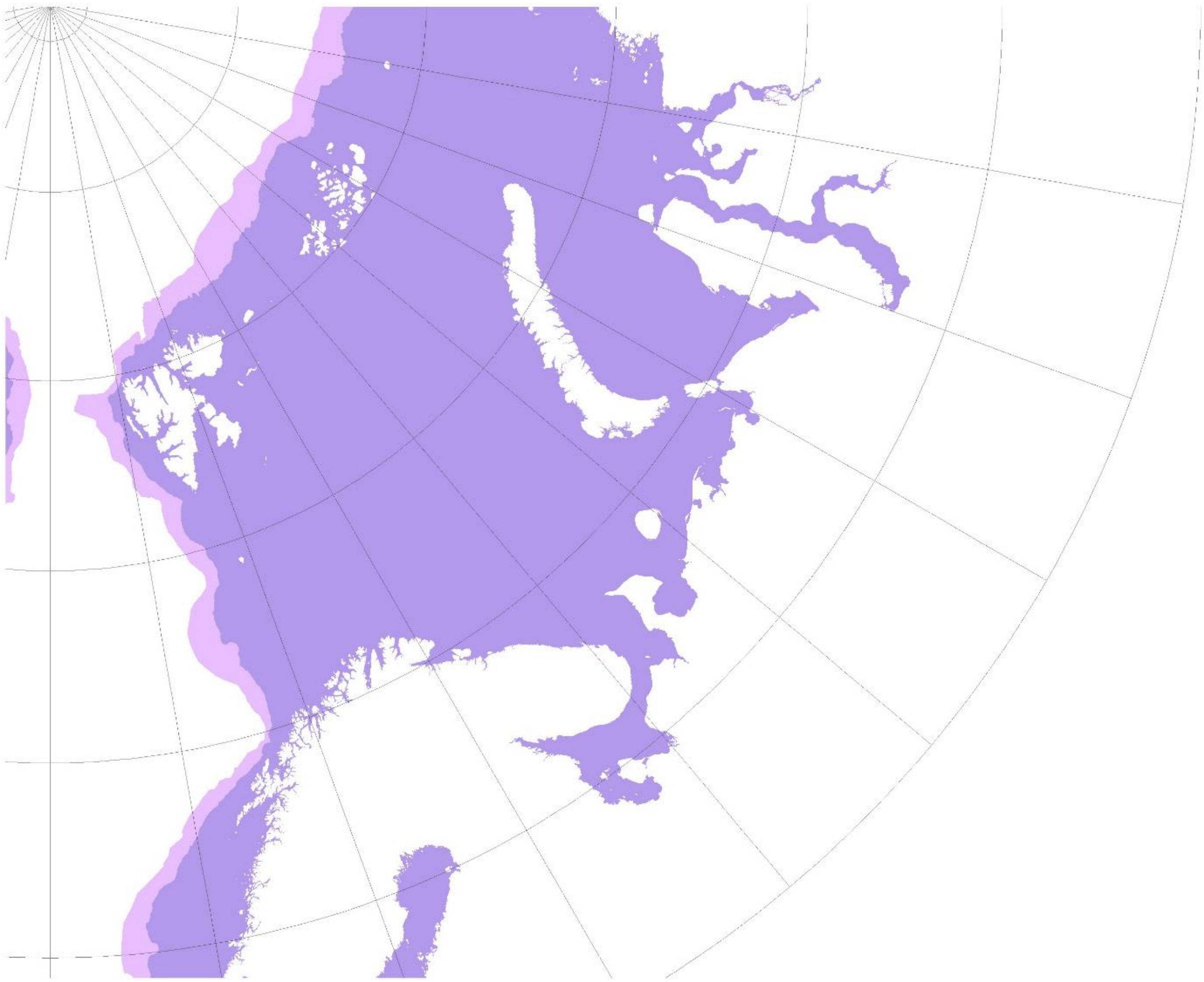

Figure A1-5: Close up of the Barents Sea region, with classification of continental shelf (purple) and slope (pink) based on morphology of the seafloor (Harris et al., 2014).

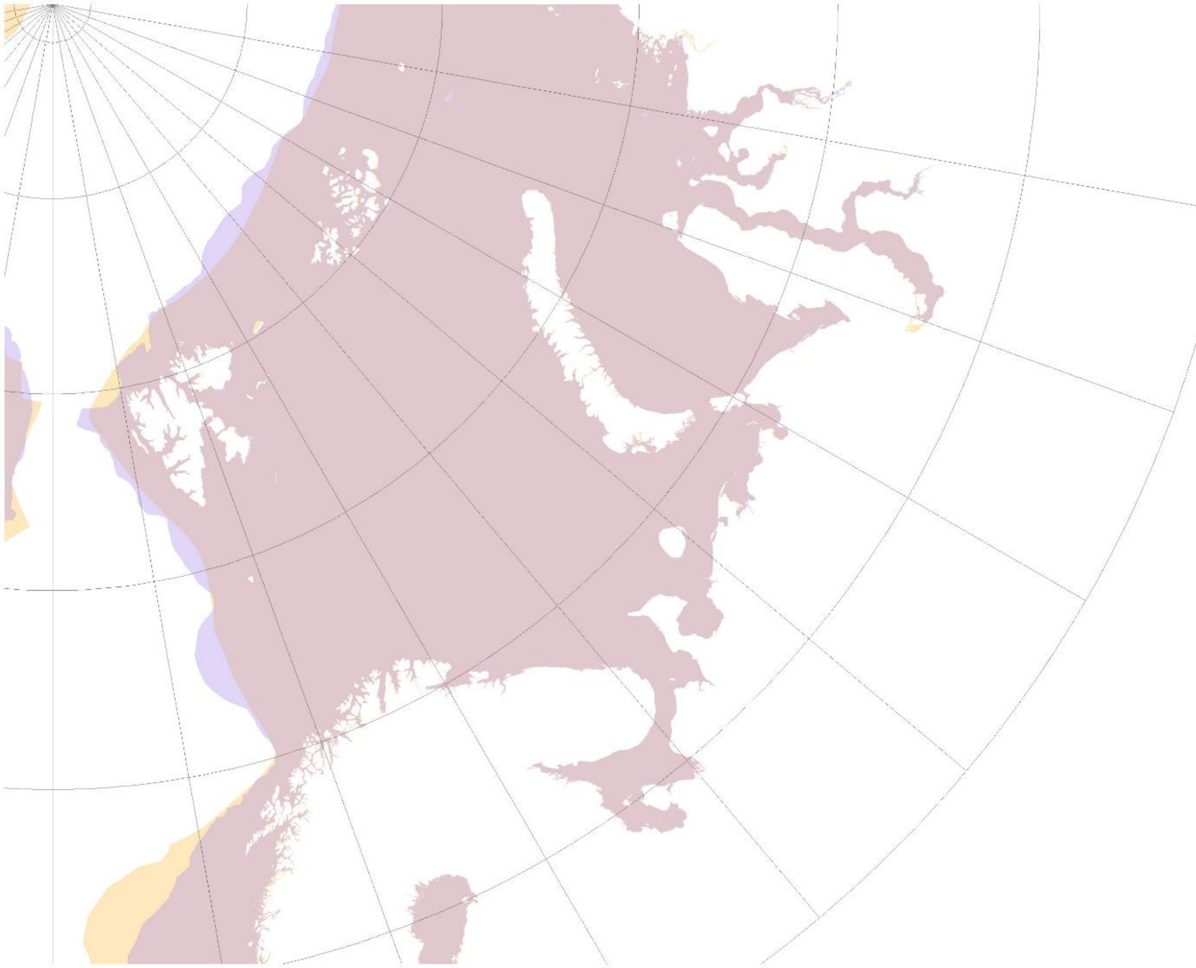

Figure A1-6: Close-up of the Barents Sea showing the difference in extent of continental shelf using the bathymetric definition (light orange) and morphological definition (light purple).

Appendix 2: Mineral deposits and occurrences in the Circumpolar Arctic, from GSC mineral deposits database.

Deposit Name	Deposit District	Country	Latitude (DD)	Longitude (DD)	Deposit Type	Deposit Status
Shetland Ophiolite Complex	Shetland Ophiolite Complex	United Kingdom	60.750021	-0.866513	PGE; chromite magmatic	Showing
Bleikvassli	Bleikvassli	Norway	65.833351	13.833487	SEDEX	Deposit
Mofjellet; Mofjell	Bleikvassli	Norway	66.283351	14.116821	SEDEX	Deposit
Skarnesdalen	Bleikvassli	Norway	68.366683	16.660154	SEDEX; Sulphide-only	Occurance
Bruvann	Rana Intrusion	Norway	68.483346	16.983488	Ni-Cu-PGE	Producer
Bidjovagge	Bidjovagge	Norway	69.300015	22.866821	Au	
Fremstfjell	Grong	Norway	65.000018	12.500154	Porphyry; calc-alkaline	
Repparfjord	Repparfjord	Norway	70.433348	24.216854	Sediment Hosted Cu	Deposit
Tallberg	Vasterbotten	Sweden	64.333352	20.000154	Porphyry Cu-Au	
Boliden	Skellefte	Sweden	64.866686	20.366821	VMS	Deposit
Bjorkdal	Skellefte	Sweden	64.953074	20.541154	VMS	Deposit
Akerberg	Skellefte	Sweden	65.050018	20.650154	VMS	Deposit
Rormyrberger	Vasterbotten	Sweden	64.283352	19.816822	Ni-Cu-Co	Deposit
Lappvattnet	Vasterbotten	Sweden	64.500019	20.716821	Ni-Cu-Co	Deposit
Brannorna	Vasterbotten	Sweden	64.500019	20.883487	Ni-Cu-Co	Deposit
Mjovattnet	Vasterbotten	Sweden	64.550022	20.950155	Ni-Cu-Co	Deposit
Oravainen	Lansi-Suomi	Finland	63.366685	22.416820	Ni-Cu-Co	Deposit
Petolahti	Lansi-Suomi	Finland	62.850018	21.350154	Ni-Cu-Co	Deposit
Hyvela	Lansi-Suomi	Finland	61.533354	21.816822	Ni-Cu-Co	Deposit
Sahakoski	Lansi-Suomi	Finland	61.633356	21.716821	Ni-Cu-Co	Deposit
Stormi intrusion; Vammala deposit	Lansi-Suomi	Finland	61.416688	23.066822	Ni-Cu-Co	Past producer
Kylmakoski	Lansi-Suomi	Finland	61.166689	23.650154	Ni-Cu-Co	Past producer
Kovera-oja	Lansi-Suomi	Finland	61.316687	23.183486	Ni-Cu-Co	
Kemi	Lappi	Finland	65.716685	24.500154	PGE	Producer
Kukasjarvi	Lappi	Sweden	66.200015	23.300153	PGE	Deposit
Ala-Penikka PGE Reef; AP Reef	Lappi	Finland	65.833354	25.033487	PGE	Deposit

Deposit Name	Deposit District	Country	Latitude (DD)	Longitude (DD)	Deposit Type	Deposit Status
Paasivaara PGE Reef; PV Reef	Lappi	Finland	65.883349	25.066821	PGE	Deposit
Kirakkajuppura	Lappi	Finland	65.966685	24.133487	PGE	Deposit
Sompujarvi PGE Reef; SJ Reef	Lappi	Finland	65.933352	24.100154	PGE	Deposit
Rytikangas Reef	Lappi	Finland	66.116685	26.166821	PGE	Deposit
Suhanko	Lappi	Finland	66.116687	26.166820	PGE	Deposit
Vaaralampi	Lappi	Finland	66.116687	26.166820	PGE	Deposit
Kilvenjarvi	Lappi	Finland	66.233348	26.166820	PGE	Deposit
Kuusijarvi	Lappi	Finland	65.850016	28.183486	PGE	Deposit
Porttivaara; Baabelinalkky deposit	Lappi	Finland	65.783351	28.116821	PGE	Deposit
Kusiaiskallio	Oulu	Finland	63.933352	25.183486	Ni-Cu-Co	
Hitura	Oulu	Finland	63.850017	25.016820	Ni-Cu-Co	Producer
Makola	Oulu	Finland	63.816685	25.000154	Ni-Cu-Co	Past producer
Pitkaneva	Oulu	Finland	63.766685	25.083488	Ni-Cu-Co	
Orijarvi	Orijarvi - (Southern Finland)	Finland	60.016722	23.350154	VMS	
Aijala	(Southern Finland)	Finland	60.166722	23.250154	VMS	
Metsamonttu	(Southern Finland)	Finland	60.166722	23.250154	VMS	
Lesnaya Varaka	Murmansk	Russia	67.383350	33.050154	Fe-Ti-V	Showing
Kovdorskoe	Murmansk	Russia	67.616684	30.816821	Fe-Ti-V	Producer
Kovdor	Murmansk	Russia	67.000017	30.333487	Alkaline-Fe-Ti-P	Producer
Afrikanda	Murmansk	Russia	67.466687	33.033484	Alkaline-Fe-Ti-P	Past producer
Zheleznyi	Murmansk	Russia	66.883350	33.333487	Fe-Ti	Showing
Imandra	Lapland-Kola	Russia	67.500017	34.000154	Ni-Cu-PGE	Deposit
Fedorovo-Panskoe	Lapland-Kola	Russia	67.500017	35.000154	Ni-Cu-PGE	Deposit
Bolshaya Varaka	Lapland-Kola	Russia	67.666684	34.000154	Ni-Cu-PGE	Deposit
Sopcha	Lapland-Kola	Russia	67.885016	32.807154	Ni-Cu-PGE	Deposit
Moroshkovoe ozero; Lake Moroshkovo	Lapland-Kola	Russia	67.866685	32.879154	Ni-Cu-PGE	Deposit
Revda	Lapland-Kola	Russia	67.883349	34.583487	Ni-Cu-PGE	

Deposit Name	Deposit District	Country	Latitude (DD)	Longitude (DD)	Deposit Type	Deposit Status
Kolozero	Lapland-Kola	Russia	68.383349	32.800154	Ni-Cu-PGE	Showing
Verlitovyi	Lapland-Kola	Russia	68.083349	32.366821	Ni-Cu-PGE	Showing
Nittis-Kumuzh'ya-Travyanaya; NKT	Lapland-Kola	Russia	67.920016	32.759154	Ni-Cu-PGE	Exhausted
Terrasa	Lapland-Kola	Russia	67.885016	32.879154	Ni-Cu-PGE	Showing
Nyud-2	Lapland-Kola	Russia	67.875016	32.870154	Ni-Cu-PGE	Exhausted
Sopcha ore bed; Bed 330; Layer 330	Lapland-Kola	Russia	67.890016	32.820154	Ni-Cu-PGE	Deposit
Kammikivi	Pechenga Area	Russia	69.395015	30.316821	Ni-Cu-PGE	Showing
Zhdanovskoe	Pechenga Area	Russia	69.400015	30.733487	Ni-Cu-PGE	Producer
Kaula	Pechenga Area	Russia	69.400015	30.316821	Ni-Cu-PGE	Producer
Kotselvaara	Pechenga Area	Russia	69.392793	30.333487	Ni-Cu-PGE	Producer
Ortoaivi	Pechenga Area	Russia	69.397515	30.345154	Ni-Cu-PGE	Showing
Promezhutochnoye; Intermediate	Pechenga Area	Russia	69.390293	30.266821	Ni-Cu-PGE	Deposit
Zapolyarnoe; Semiletka	Pechenga Area	Russia	69.383348	30.316821	Ni-Cu-PGE	Producer
Gora General'skaya; Luostari Massif	Pechenga Area	Russia	69.333348	30.500154	Ni-Cu-PGE	Deposit
Kierdzhipori	Pechenga Area	Russia	69.404459	30.650154	Ni-Cu-PGE	Showing
Bystrinskoe; Tundrovoe; Verkhnee; Sputnik	Pechenga Area	Russia	69.400015	30.733487	Ni-Cu-PGE	Deposit
Pilgujarvi deposits; Main Massif deposits	Pechenga Area	Russia	69.392793	30.750154	Ni-Cu-PGE	Deposit
Onki	Pechenga Area	Russia	69.359737	30.900154	Ni-Cu-PGE	Showing
Pilgujarvi northern deposit	Pechenga Area	Russia	69.466682	30.450155	Ni-Cu-PGE	Showing
Severnoe; Tsentralnoe; Zapadnoe	Pechenga Area	Russia	69.416682	30.500154	Ni-Cu-PGE	Producer
Karikyavr site	Pechenga Area	Russia	69.383346	31.300153	Ni-Cu-PGE	Showing
Pad - Yaga	Musyur Range	Russia	67.500017	65.500154	Sediment Hosted Cu	
Mount Sauri	Musyur Range	Russia	68.000016	65.833454	Sediment Hosted Cu	
Padyagin	Musyur Range	Russia	67.000017	65.000154	Sediment Hosted Cu	
Olenya/ Kamennaya	Arkhangelsk oblast	Russia	67.550017	48.116821	Magmatic Ni	Showing
Dalnyaya	Arkhangelsk oblast	Russia	67.183350	48.166821	Magmatic Ni	Showing
Binyuda	Taimyr Region	Russia	73.400013	88.400154	Magmatic Ni	Showing

Deposit Name	Deposit District	Country	Latitude (DD)	Longitude (DD)	Deposit Type	Deposit Status
Central Taimyr	Taimyr Region	Russia	74.000012	97.000154	Magmatic Ni	Showing
Dyabaka-Tari	Taimyr Region	Russia	74.000012	97.000154	Magmatic Ni	Showing
Ozero Levinson-Lessinga	Taimyr Region	Russia	75.350011	105.666821	Magmatic Ni	Showing
Kundgsalakh	Taimyr Region	Russia	75.283344	107.466821	Magmatic Ni	Showing
Malakhai-Tari	Taimyr Region	Russia	75.450011	108.133487	Magmatic Ni	Showing
Murutumatari	Taimyr Region	Russia	75.283344	108.666821	Magmatic Ni	Showing
Eastern Taimyr	Taimyr Region	Russia	75.300011	111.000154	Magmatic Ni	Showing
Boulkalakh River	Anabar-Olenek River Area	Russia	72.342813	119.364554	Placer Platinum	
Khatygyn-Uele River	Anabar-Olenek River Area	Russia	72.180013	118.000154	Placer Platinum	
Taas Eyeekit River	Anabar-Olenek River Area	Russia	70.900014	125.170154	Placer Platinum	
Udzha River	Anabar-Olenek River Area	Russia	71.162814	117.201854	Placer Platinum	
Chokurdak	Yakutiya (Sakha) Republic	Russia	72.228624	140.296821	Sn	
Churpunnya	Yakutiya (Sakha) Republic	Russia	71.105570	141.715432	Sn	
Northern Lyakhov district	Yakutiya (Sakha) Republic	Russia	73.750012	141.200154	Sn	
Kyuchus	Yana-Kolyma fold thrust belt	Russia	69.800015	134.750154	Epithermal Gold	Suspended
Odinokoe	Yana-Kolyma fold thrust belt	Russia	69.702515	142.011543	Intrusion Related Sn-W	
Deputatskoe; Deputatsky	Yana-Kolyma fold thrust belt	Russia	69.255293	139.971543	Intrusion Related Sn-W	Producer
Kester	Yana-Kolyma fold thrust belt	Russia	67.291406	134.644876	Intrusion Related Sn-W	Past producer
Ulakhan-Egelyakh	Yana-Kolyma fold thrust belt	Russia	67.147517	134.350710	Intrusion Related Sn-W	
Ege-Khaya	Yana-Kolyma fold thrust belt	Russia	67.635295	134.781543	Intrusion Related Sn-W	Past producer
Argin	Yana-Kolyma fold thrust belt	Russia	68.049183	135.835154	Intrusion Related Sn-W	
Nagornoe	Yana-Kolyma fold thrust belt	Russia	69.972237	134.725710	Intrusion Related Sn-W	
Sigilyakh	Yana-Kolyma fold thrust belt	Russia	69.904737	136.784321	Intrusion Related Sn-W	

Deposit Name	Deposit District	Country	Latitude (DD)	Longitude (DD)	Deposit Type	Deposit Status
Ulakhan-Sala	Yana-Kolyma fold thrust belt	Russia	69.791682	136.664321	Intrusion Related Sn-W	
Pavel-Chokhchurskoe	Yana-Kolyma fold thrust belt	Russia	70.161959	140.792932	Intrusion Related Sn-W	
Valkumey	Okhotsk-Chukhotsk volcanic belt	Russia	69.650571	170.207932	Intrusion Related Sn-W	
Perkakay	Okhotsk-Chukhotsk volcanic belt	Russia	69.489737	171.968765	Sn-W; Placer	
Pyrkakay	Okhotsk-Chukhotsk volcanic belt	Russia	69.557515	171.950432	Intrusion Related Sn-W	Deposit
Kekur	Okhotsk-Chukhotsk volcanic belt	Russia	69.815571	171.864876	Intrusion Related Sn-W	
Karalveem	Okhotsk-Chukhotsk volcanic belt	Russia	68.183349	166.150154	Au	Producer
Karalveem	Okhotsk-Chukhotsk volcanic belt	Russia	68.179183	166.154043	Intrusion Related Sn-W	
Lunnoe	Okhotsk-Chukhotsk volcanic belt	Russia	68.810849	174.821821	Intrusion Related Sn-W	
Kukeney	Okhotsk-Chukhotsk volcanic belt	Russia	69.130016	174.090987	Intrusion Related Sn-W	
Maiskoe; Mayskoye	Okhotsk-Chukhotsk volcanic belt	Russia	69.033349	173.733487	Au; Intrusion Related Sn-W	Under development
Maiskoe	Okhotsk-Chukhotsk volcanic belt	Russia	69.033349	173.733487	PGE; Hydrothermal	Deposit
Baimka; Baimskaya	Okhotsk-Chukhotsk volcanic belt	Russia	67.500017	175.000154	Porphyry Cu-Sn-Ag	
Velmay	Okhotsk-Chukhotsk volcanic belt	Russia	66.666684	-177.999846	Porphyry Cu-Sn-Ag	
Reechen	Okhotsk-Chukhotsk volcanic belt	Russia	64.953629	-172.487624	Intrusion Related Sn-W	

Deposit Name	Deposit District	Country	Latitude (DD)	Longitude (DD)	Deposit Type	Deposit Status
Tenkergin	Okhotsk-Chukhotsk volcanic belt	Russia	68.178905	-178.914568	Intrusion Related Sn-W	
Ekug	Okhotsk-Chukhotsk volcanic belt	Russia	67.571961	67.571961	Intrusion Related Sn-W	
Erulen	Okhotsk-Chukhotsk volcanic belt	Russia	66.154462	-173.285124	Intrusion Related Sn-W	
Serdtse-Kamen	Okhotsk-Chukhotsk volcanic belt	Russia	66.838073	-171.737624	Intrusion Related Sn-W	
Dioritovoe	Okhotsk-Chukhotsk volcanic belt	Russia	65.665574	-174.105679	Intrusion Related Sn-W	
Iultin	Okhotsk-Chukhotsk volcanic belt	Russia	67.856960	-178.726513	Intrusion Related Sn-W	Producer
Chaantal	Okhotsk-Chukhotsk volcanic belt	Russia	67.866683	-179.408735	Intrusion Related Sn-W	
Mymlerenet	Okhotsk-Chukhotsk volcanic belt	Russia	67.788350	179.770710	Intrusion Related Sn-W	
Svetloe	Okhotsk-Chukhotsk volcanic belt	Russia	68.066127	-178.317346	Intrusion Related Sn-W	
Vodorazdelnoe	Okhotsk-Chukhotsk volcanic belt	Russia	67.910849	178.853765	Intrusion Related Sn-W	
Vodorazdelnoe	Okhotsk-Chukhotsk volcanic belt	Russia	67.916683	178.850154	Hydrothermal	Deposit
Telekay	Okhotsk-Chukhotsk volcanic belt	Russia	67.990849	178.088210	Intrusion Related Sn-W	
Mramornoe	Okhotsk-Chukhotsk volcanic belt	Russia	68.104183	176.499876	Intrusion Related Sn-W	
Cape Creek	Seward Penninsula	United States	65.568074	-167.934013	Intrusion Related Sn/Placer	
Lost River	Seward Penninsula	United States	65.483351	-167.133179	Intrusion Related Sn/Placer	Deposit

Deposit Name	Deposit District	Country	Latitude (DD)	Longitude (DD)	Deposit Type	Deposit Status
Buck Creek; Potato Mountain	Seward Penninsula	United States	65.626685	-167.475679	Intrusion Related Sn/Placer	
Kougarok	Seward Penninsula	United States	65.703629	-165.232902	Intrusion Related Sn/Placer	Deposit
Iyikrok Mountain	Brooks Range	United States	67.900016	-163.666513	Cr	
Red Dog	Brooks Range	United States	68.066683	-162.799846	SEDEX	Deposit
Lik; Su-Lik	Brooks Range	United States	68.166683	-163.199846	SEDEX	Deposit
Drenchwater; Drenchwater Creek	Brooks Range	United States	68.566683	-158.683179	SEDEX	Deposit
Copper Creek	Victoria Island Fold; Franklin LIP	Canada	72.287513	-109.574846	Sed-hosted Cu	
Black Gossan - Laserich	Victoria Island Fold; Franklin LIP	Canada	72.275013	-109.516513	Sed-hosted Cu	
Muskox	Victoria Island Fold; Franklin LIP	Canada	72.136124	-109.627624	Sed-hosted Cu	
Green Hills	Victoria Island Fold; Franklin LIP	Canada	72.238902	-109.544290	Sed-hosted Cu	
Outlier	Victoria Island Fold; Franklin LIP	Canada	72.333346	-109.495679	Sed-hosted Cu	
Aj	Victoria Island Fold; Franklin LIP	Canada	72.268069	-109.674846	Sed-hosted Cu	
Canrobert Hills	Parry Island fold belt	Canada	75.966678	-116.083179	MVT	
Polaris	Parry Island fold belt	Canada	75.383344	-96.949846	MVT	Producer
Hvitland	Parry Island fold belt	Canada	81.250007	-88.249846	MVT	
Nanisivik	Borden Basin; Nanisivik District	Canada	73.061124	-84.508179	MVT	Producer
Aquitane Co. Permit 188 Zone Sc. 21-Duc	Foxe Fold Belt	Canada	67.493025	-83.200037	Ni; metamorphic hosted	Drilled Showing
Nanuk Showing	Foxe Fold Belt	Canada	65.255982	-63.263798	VMS	Drilled Showing
Black Angel; Marmorilik; Sorte Engel	Rinkian Belt (Foxe Fold Belt)	Greenland	71.166681	-51.749846	SEDEX	Deposit
Bil	Foxe Fold Belt	Canada	68.875016	-83.499846	unclassified	Drilled Showing
Hammers Dal Complex	Rinkian Belt (Foxe Fold Belt)	Greenland	70.154737	-54.576235	magmatic; low sulphide	Deposit
Nunngarut	Rinkian Belt (Foxe Fold Belt)	Greenland	71.125292	-51.696790	SEDEX	Deposit
Igdlukunguaq	Rinkian Belt (Foxe	Greenland	69.891682	-52.574846	magmatic; sulphide	Deposit

Deposit Name	Deposit District	Country	Latitude (DD)	Longitude (DD)	Deposit Type	Deposit Status
	Fold Belt)					
Citronen Fjord	North Greenland Fold Belt	Greenland	83.083338	-28.249846	SEDEX	Deposit
Ladderbjerg (Giesecke Bjerge)	Greenland Caledonian Fold Belt	Greenland	73.495845	-22.029046	Sed-hosted Cu	
Rubjerg Knude (Traill O)	Greenland Caledonian Fold Belt	Greenland	72.617235	-23.680446	Sed-hosted Cu	
Liverpool Land High	Greenland Caledonian Fold Belt	Greenland	71.083347	-22.249846	Sed-hosted Cu	
Paradigmabjerg	Greenland Caledonian Fold Belt	Greenland	71.607236	-22.685446	Sed-hosted Cu	
Andrees Land (Eremitdal)	Greenland Caledonian Fold Belt	Greenland	73.460012	-25.352046	Sed-hosted Cu	
Lyells Land (Kap Alfred)	Greenland Caledonian Fold Belt	Greenland	72.738902	-25.566546	Sed-hosted Cu	
Rubjerg Knude (Traill O)	Greenland Caledonian Fold Belt	Greenland	72.617235	-23.680446	Sed-hosted Cu	
Strindbergs Land	Greenland Caledonian Fold Belt	Greenland	73.698345	-24.839046	Sed-hosted Cu	
Suess Land - 1	Greenland Caledonian Fold Belt	Greenland	72.830569	-25.691546	Sed-hosted Cu	
Suess Land - 2	Greenland Caledonian Fold Belt	Greenland	73.026680	-25.869846	Sed-hosted Cu	
Ymers	Greenland Caledonian Fold Belt	Greenland	73.143069	-24.937346	Sed-hosted Cu	
Wegener Halvo	Greenland Caledonian Fold Belt	Greenland	71.666681	-22.783179	Sed-hosted Cu	
Canning Land	Greenland Caledonian Fold Belt	Greenland	71.669736	-22.260646	Sed-hosted Cu	

Deposit Name	Deposit District	Country	Latitude (DD)	Longitude (DD)	Deposit Type	Deposit Status
Devondal	Greenland Caledonian Fold Belt	Greenland	71.512514	-22.783146	Sed-hosted Cu	
Jameson Land; Graklint Beds	Greenland Caledonian Fold Belt	Greenland	71.066681	-22.456546	Sed-hosted Cu	
Kassen	Greenland Caledonian Fold Belt	Greenland	71.516681	-22.966546	Sed-hosted Cu	
Myalinadal	Greenland Caledonian Fold Belt	Greenland	71.437514	-22.999846	Sed-hosted Cu	
Orsted Dal Member	Greenland Caledonian Fold Belt	Greenland	71.700014	-23.083146	Sed-hosted Cu	
Pingel Dal Beds; Kap Biot - Carlsberg Fjord	Greenland Caledonian Fold Belt	Greenland	71.416681	-22.666546	Sed-hosted Cu	
Wegener Halvo	Greenland Caledonian Fold Belt	Greenland	71.566681	-22.733146	Sed-hosted Cu	
Platinova Reefs; Skaergaard Intrusion	Southeast Greenland	Greenland	68.195016	-31.617902	PGE-Au-Cu	Deposit
Kruuse Fjord	Southeast Greenland	Greenland	67.241684	-33.716513	Ni-Cu-PGE	Showing
Nordre Aputiteq Intrusion	Southeast Greenland	Greenland	67.750017	-32.296790	PGE-Au	Showing
Kap Edvard Holm Complex	Southeast Greenland	Greenland	68.000016	-32.227902	PGE-Au-Cu	Showing
Nalunaq	Ketilidian Mobile Belt	Greenland	60.350022	-44.833179	Gold	Producer
Sarqa	Ketilidian Mobile Belt	Greenland	60.345855	-44.899846	Magmatic; PGE	Showing
Amitsoq	Ketilidian Mobile Belt	Greenland	60.361182	-44.099846	Magmatic; PGE	Showing
Itipilua	Southwest Greenland	Greenland	64.984462	-51.557068	Magmatic - Cr	Deposit
Qeqertarssuatsiaq	Southwest Greenland	Greenland	63.150020	-50.499846	Magmatic - Cr	Deposit
Fiskenaesset	Southwest Greenland	Greenland	63.100020	-50.666513	Magmatic - Cr	Deposit
Malene	Southwest Greenland	Greenland	64.166686	-51.683179	Vein/Replacement W	Occurance

Deposit Name	Deposit District	Country	Latitude (DD)	Longitude (DD)	Deposit Type	Deposit Status
Ivisartoq	Southwest Greenland	Greenland	64.733352	-49.883179	Vein/Replacement W	Occurance

Appendix 3: Examples of extrapolation of onshore geology onto the continental shelf based on the CGMW Map of the World (Bouysse, 2009).

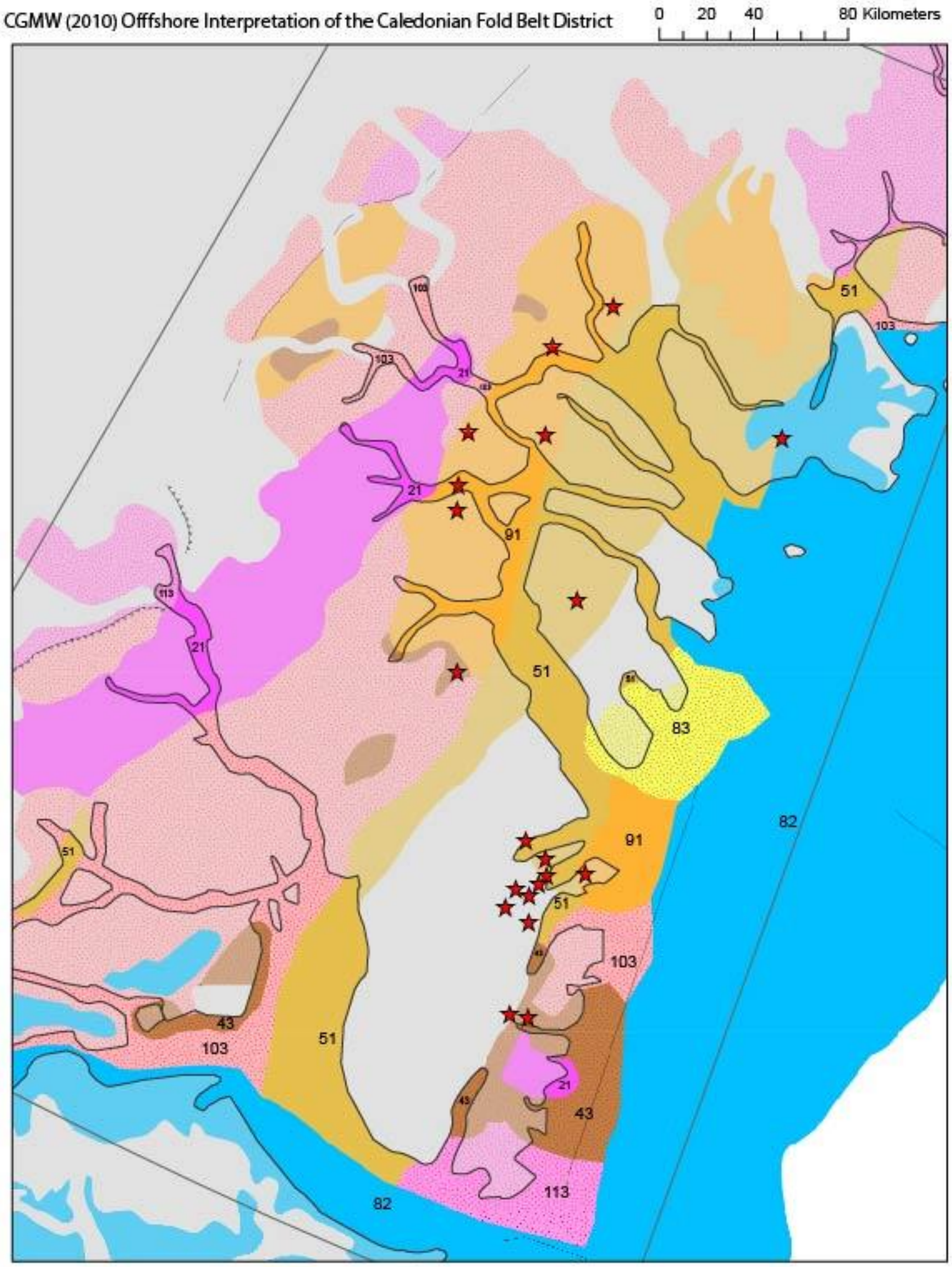

Figure A3-1: Extrapolation of bedrock geology off the east coast of Greenland

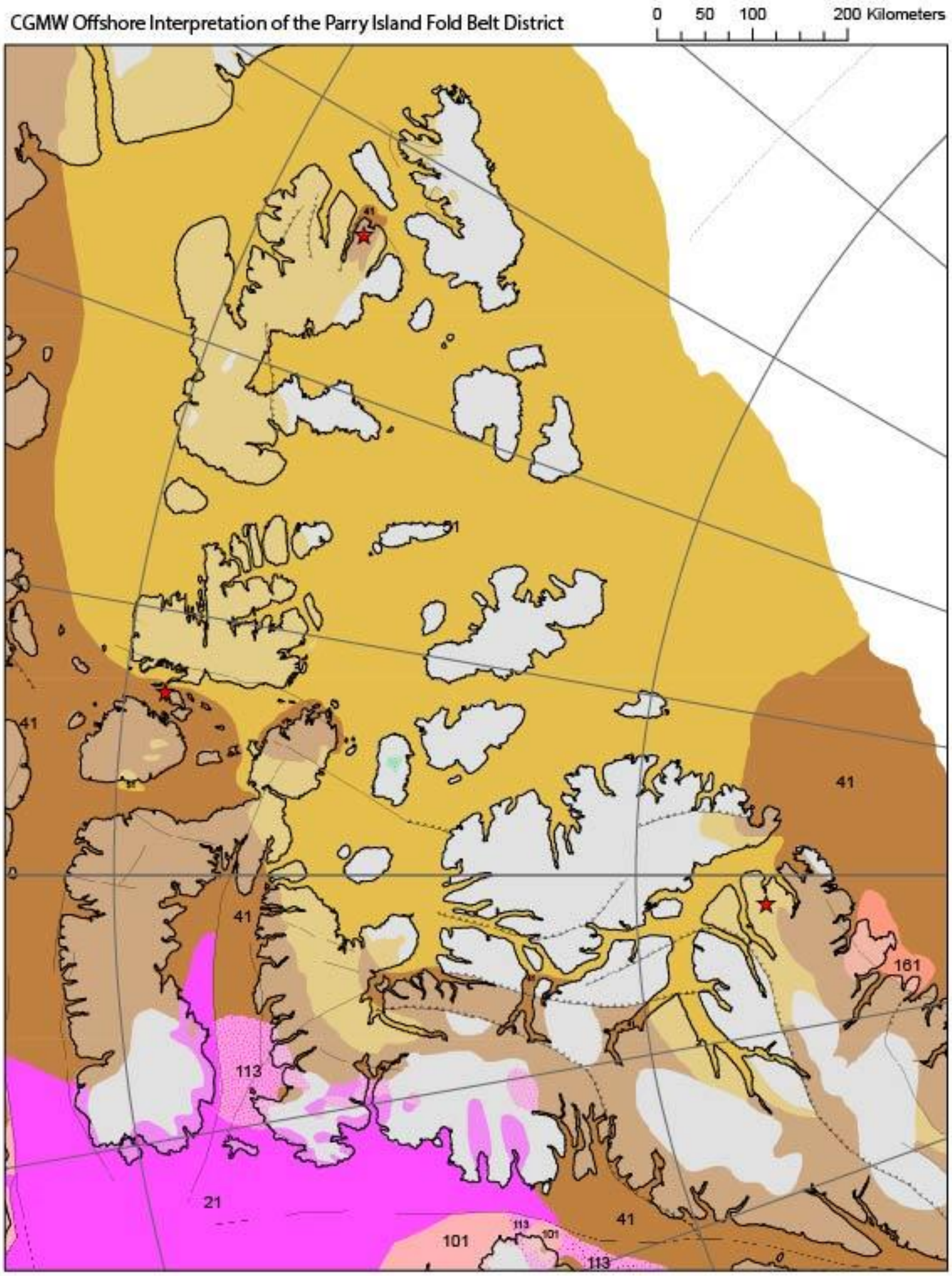

Figure A3-2: Onshore and offshore basement geology of the Canadian archipelago.

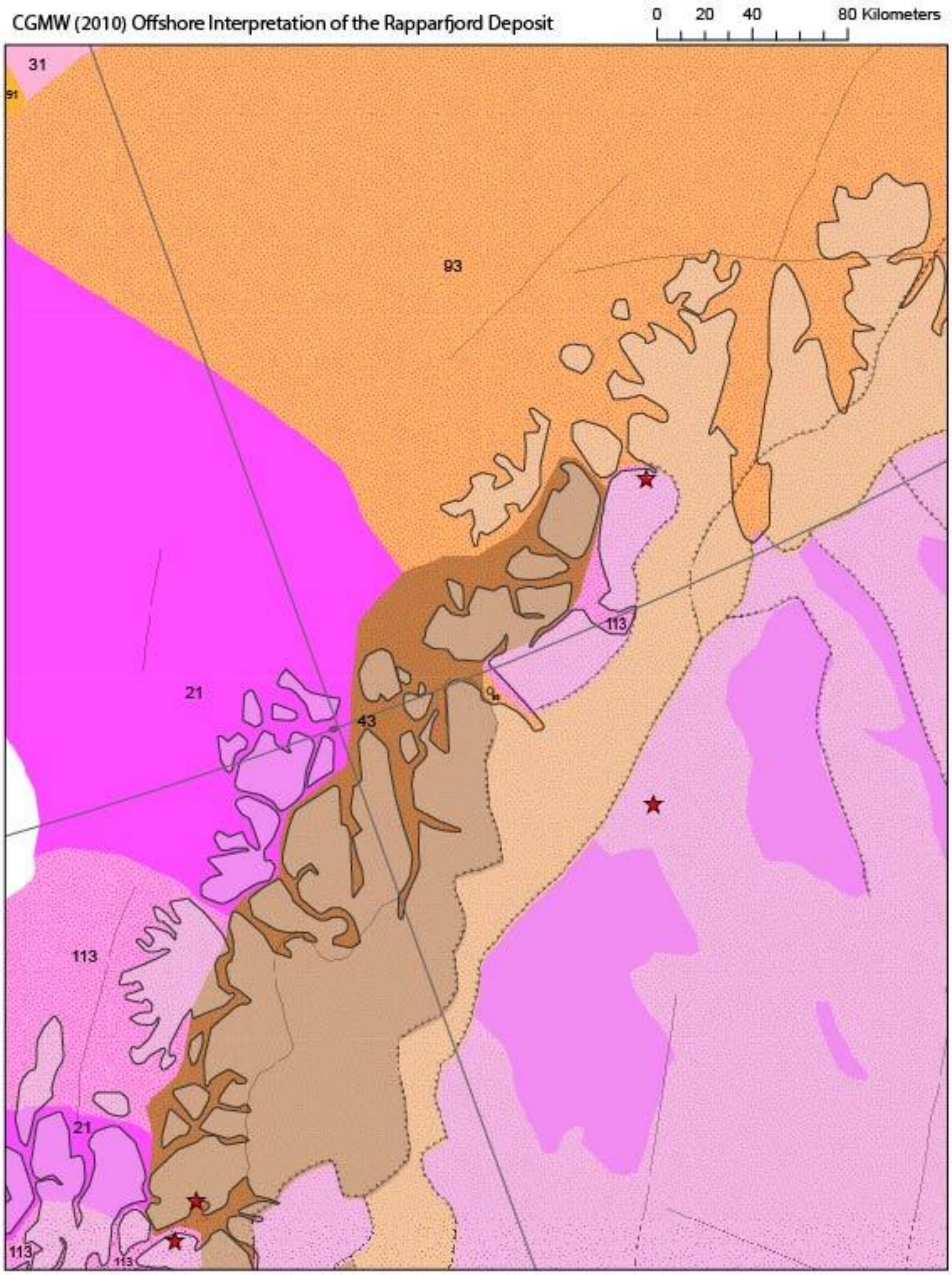

Figure A3-3: Onshore and offshore basement geology of the Rapparfjord district, northern Norway.

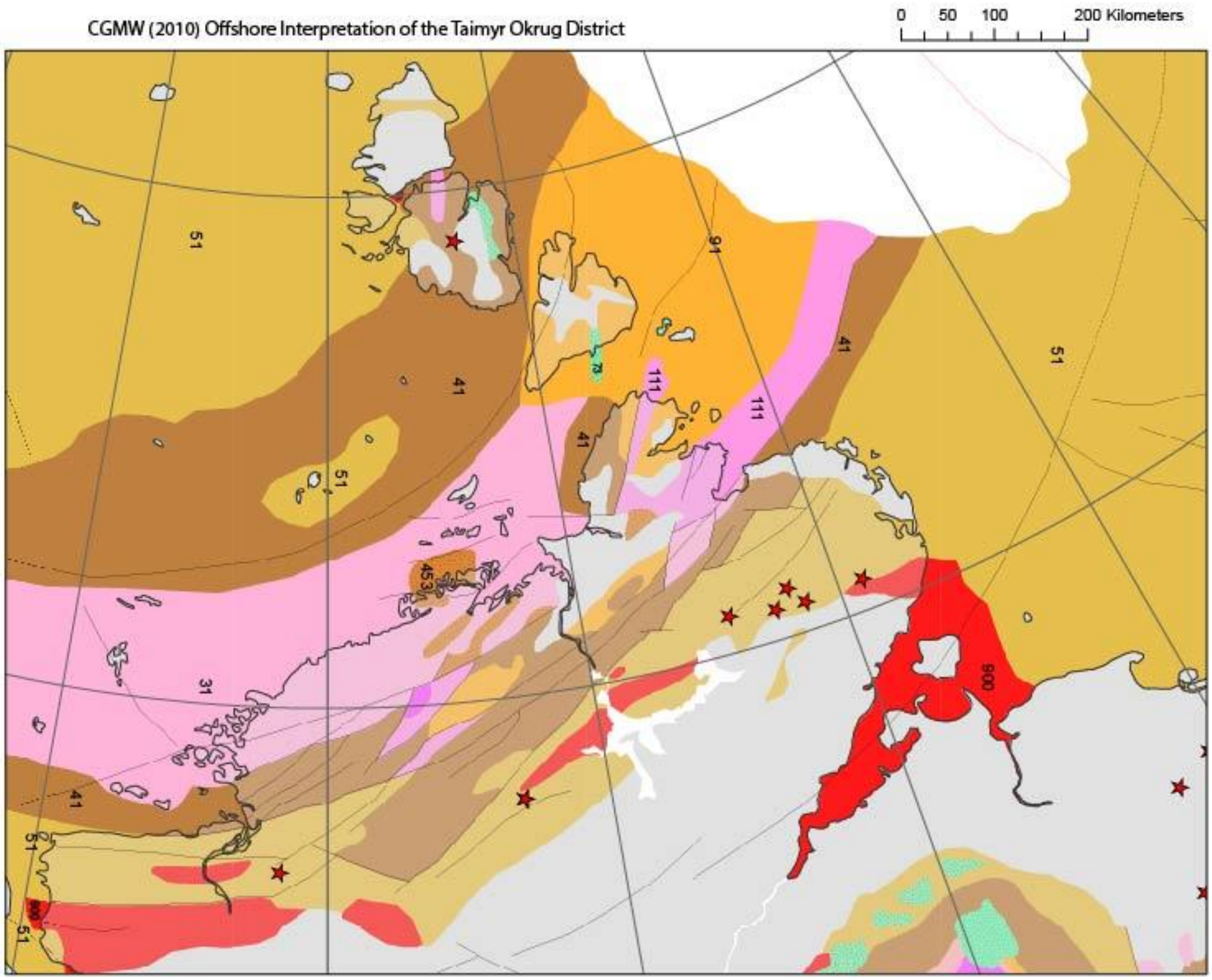

Figure A3-4: Onshore and offshore basement geology of the Taimyr region, northern Russia

Appendix 4: List of polygons for geology of the basement of the Circumpolar Arctic continental shelf, based on the map legend and descriptions from the CGMW Map of the World (Bouysse, 2009).

Polygon ID	Area (km^2)	Setting	Age	Description
0	19	Endogenous rocks (plutonic and/or metamorphic)	Neoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Neoproterozoic
1	231	Endogenous rocks (plutonic and/or metamorphic)	Lower Paleozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Lower Paleozoic
2	168	Endogenous rocks (plutonic and/or metamorphic)	Neoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Neoproterozoic
3	280	Endogenous rocks (plutonic and/or metamorphic)	Lower Paleozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Lower Paleozoic
4	61	Endogenous rocks (plutonic and/or metamorphic)	Neoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Neoproterozoic
5	9	Endogenous rocks (plutonic and/or metamorphic)	Neoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Neoproterozoic
6	6	Endogenous rocks (plutonic and/or metamorphic)	Neoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Neoproterozoic
7	15	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
8	65	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
9	15,501	Endogenous rocks (plutonic and/or metamorphic)	Neoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Neoproterozoicc
10	12,506	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
11	1	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
12	8	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
13	4	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
14	35,339	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
15	9	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
16	105	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
17	113,448	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic
18	465	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
19	11,339	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
20	540	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
21	2,006	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
22	383	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
23	111,467	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
24	33	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
25	106,917	Endogenous rocks (plutonic and/or metamorphic)	Lower Paleozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Lower Paleozoic
26	90	Endogenous rocks (plutonic and/or metamorphic)	Lower Paleozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Lower Paleozoic
27	25	Endogenous rocks (plutonic and/or metamorphic)	Lower Paleozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Lower Paleozoic
28	19,289	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
29	104	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
30		Endogenous rocks (plutonic	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or

Polygon ID	Area (km^2)	Setting	Age	Description
	9	and/or metamorphic)		metamorphic) - Paleoproterozoic
31	5	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
32	0	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
33	22	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
34	110,018	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
35	22	Endogenous rocks (plutonic and/or metamorphic)	Mesoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesoproterozoic
36	2	Endogenous rocks (plutonic and/or metamorphic)	Mesoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesoproterozoic
37	19	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
38	555	Endogenous rocks (plutonic and/or metamorphic)	Mesoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesoproterozoic
39	11,814	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
40	192	Endogenous rocks (plutonic and/or metamorphic)	Cenozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Cenozoic
41	17,764	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoicc
42	2,228	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
43	9,783	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
44	7	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
45	788	Endogenous rocks (plutonic and/or metamorphic)	Cenozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Cenozoic
46	11	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
47	1,880	Sedimentary rocks or undifferentiated facies	Mesoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Mesoproterozoic
48	2,336	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
49	0	Endogenous rocks (plutonic and/or metamorphic)	Cenozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Cenozoic
50	4	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
51	709	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
52	63,512	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
53	322	Endogenous rocks (plutonic and/or metamorphic)	Cenozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Cenozoic
54	125	Endogenous rocks (plutonic and/or metamorphic)	Neoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Neoproterozoic
55	29	Endogenous rocks (plutonic and/or metamorphic)	Cenozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Cenozoic
56	13,376	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic
57	0	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
58	50,763	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
59	417	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
60	11	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
61	478	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
62	6,219	Endogenous rocks (plutonic and/or metamorphic)	Lower Paleozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Lower Paleozoic
63	30,567	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic

Polygon ID	Area (km^2)	Setting	Age	Description
64	186	Endogenous rocks (plutonic and/or metamorphic)	Lower Paleozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Lower Paleozoic
65	135	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
66	64,797	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic
67	0	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
68	8	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
69	94	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
70	5	Endogenous rocks (plutonic and/or metamorphic)	Mesoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesoproterozoic
71	1,835	Endogenous rocks (plutonic and/or metamorphic)	Lower Paleozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Lower Paleozoic
72	813	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
73	67	Endogenous rocks (plutonic and/or metamorphic)	Lower Paleozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Lower Paleozoic
74	513	Endogenous rocks (plutonic and/or metamorphic)	Lower Paleozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Lower Paleozoic
75	182	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
76	3,438	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
77	247	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
78	30,844	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
79	65	Endogenous rocks (plutonic and/or metamorphic)	Mesoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesoproterozoic
80	1,464	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
81	4,663	Endogenous rocks (plutonic and/or metamorphic)	Mesoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesoproterozoic
82	39	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
83	2,281	Endogenous rocks (plutonic and/or metamorphic)	Cenozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Cenozoic
84	3	Endogenous rocks (plutonic and/or metamorphic)	Mesoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesoproterozoic
85	20	Endogenous rocks (plutonic and/or metamorphic)	Lower Paleozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Lower Paleozoic
86	18	Endogenous rocks (plutonic and/or metamorphic)	Mesoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesoproterozoic
87	503	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
88	134	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
89	18,006	Sedimentary rocks or undifferentiated facies	Mesoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Mesoproterozoic
90	4,847	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
91	297	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
92	2	Endogenous rocks (plutonic and/or metamorphic)	Mesoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesoproterozoic
93	7	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic
94	11	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
95	59	Endogenous rocks (plutonic and/or metamorphic)	Mesoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesoproterozoic
96	6,069	Sedimentary rocks or undifferentiated facies	Mesoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Mesoproterozoic
97	186	Endogenous rocks (plutonic and/or metamorphic)	Mesoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesoproterozoic

Polygon ID	Area (km^2)	Setting	Age	Description
98	93	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
99	209	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
100	5,348	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
101	177	Endogenous rocks (plutonic and/or metamorphic)	Mesoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesoproterozoic
102	29	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
103	159	Endogenous rocks (plutonic and/or metamorphic)	Mesoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesoproterozoic
104	377	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
105	7	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
106	189	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
107	17	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
108	42	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
109	246	Endogenous rocks (plutonic and/or metamorphic)	Mesoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesoproterozoic
110	199	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
111	114	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
112	89	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
113	501	Endogenous rocks (plutonic and/or metamorphic)	Lower Paleozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Lower Paleozoic
114	88,689	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic
115	130,652	Endogenous rocks (plutonic and/or metamorphic)	Neoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Neoproterozoic
116	1,789	Endogenous rocks (plutonic and/or metamorphic)	Mesoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesoproterozoic
117	30	Endogenous rocks (plutonic and/or metamorphic)	Mesoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesoproterozoic
118	1,228	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
119	267	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
120	32	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
121	3	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
122	682	Sedimentary rocks or undifferentiated facies	Proterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic
123	21,104	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
124	2,233	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
125	231	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
126	6,712	Sedimentary rocks or undifferentiated facies	Proterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic
127	15	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
128	564	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
129	11,238	Endogenous rocks (plutonic and/or metamorphic)	Precambrian	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Precambrian
130	5,926	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
131	2,972	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic to Archean	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic to Archean

Polygon ID	Area (km^2)	Setting	Age	Description
132	4,596	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic to Archean	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic to Archean
133	258	Sedimentary rocks or undifferentiated facies	Proterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic
134	18,935	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
135	238,691	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
136	1,849	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
137	10	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
138	14	Sedimentary rocks or undifferentiated facies	Proterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic
139	844	Sedimentary rocks or undifferentiated facies	Proterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoicccc
140	4,337	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
141	282	Extrusive volcanic rocks (traps exepted)	Paleoproterozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Paleoproterozoic
142	2,623	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic
143	5	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic
144	32	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic
145	108	Sedimentary rocks or undifferentiated facies	Proterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic
146	37	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
147	2,220	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
148	108,259	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
149	165	Sedimentary rocks or undifferentiated facies	Proterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic
150	1	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic
151	2,437	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
152	38	Sedimentary rocks or undifferentiated facies	Proterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic
153	453	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
154	997	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
155	36	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
156	3,248	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
157	448	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
158	145	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
159	1,531	Endogenous rocks (plutonic and/or metamorphic)	Neoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Neoproterozoic
160	2,074	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
161	85,667	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
162	3	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
163	102	Sedimentary rocks or undifferentiated facies	Proterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic
164	149	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
165	810	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic

Polygon ID	Area (km^2)	Setting	Age	Description
166	33	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
167	13	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
168	123	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
169	3,722	Sedimentary rocks or undifferentiated facies	Proterozoicc	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic
170	5	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
171	559	Sedimentary rocks or undifferentiated faciesc	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
172	74	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
173	18	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
174	15,032	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
175	5,158	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
176	58	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
177	9,961	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
178	45,362	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic
179	9,643	LITHO_EN Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
180	327	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
181	518	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
182	35	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
183	18	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
184	2,335	Extrusive volcanic rocks (traps exepted)	Paleoproterozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Paleoproterozoic
185	46	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
186	0	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
187	21	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
188	159	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoicc
189	1,884	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
190	8,302	Sedimentary rocks or undifferentiated facies	Proterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic
191	64	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
192	434	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic to Archean	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic to Archean
193	2	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
194	37	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
195	133	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic to Archean	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic to Archean
196	8	Endogenous rocks (plutonic and/or metamorphic)	Neoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Neoproterozoic
197	7	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
198	51	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
199	5	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean

Polygon ID	Area (km^2)	Setting	Age	Description
200	44	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
201	540	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
202	5,237	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
203	208,063	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
204	1,191	Endogenous rocks (plutonic and/or metamorphic)	Neoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Neoproterozoic
205	348	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
206	9,811	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
207	4,488	Sedimentary rocks or undifferentiated facies	Proterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic
208	93	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
209	9,918	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
210	240	Extrusive volcanic rocks (traps exepted)	Mesoproterozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Mesoproterozoic
211	6,633	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
212	5	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
213	496	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
214	262	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
215	79,314	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
216	8	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
217	997	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
218	73	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
219	4,048	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
220	1,102	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic to Archean	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic to Archean
221	24	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
222	402	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic to Archean	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic to Archean
223	1,436	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
224	315	Extrusive volcanic rocks (traps exepted)	Paleoproterozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Paleoproterozoic
225	27,911	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
226	926	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic to Archean	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic to Archean
227	827	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
228	0	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
229	22,334	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
230	391,037	Sedimentary rocks or undifferentiated facies	Proterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic
231	3	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
232	38,601	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
233	481	Extrusive volcanic rocks (traps exepted)	Paleoproterozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Paleoproterozoic

Polygon ID	Area (km^2)	Setting	Age	Description
234	57	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
235	21,216	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic to Archean	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic to Archean
236	7,831	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
237	704	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
238	3	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
239	19,912	Extrusive volcanic rocks (traps exepted)	Paleoproterozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Paleoproterozoic
240	32	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
241	2	Sedimentary rocks or undifferentiated facies	Mesoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Mesoproterozoic
242	43	Sedimentary rocks or undifferentiated facies	Mesoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Mesoproterozoic
243	3,300	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
244	830	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic to Archean	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic to Archean
245	7,495	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
246	180	Sedimentary rocks or undifferentiated facies	Mesoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Mesoproterozoic
247	615	Sedimentary rocks or undifferentiated facies	Mesoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Mesoproterozoic
248	595,763	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
249	14,548	Sedimentary rocks or undifferentiated facies	Mesoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Mesoproterozoic
250	492	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
251	48	Sedimentary rocks or undifferentiated facies	Mesoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Mesoproterozoic
252	36,418	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
253	371,248	Extrusive volcanic rocks (traps exepted)	Mesozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Mesozoic
254	9,034	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
255	589	Sedimentary rocks or undifferentiated facies	Mesoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Mesoproterozoic
256	134	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
257	22	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
258	1,075	Sedimentary rocks or undifferentiated facies	Mesoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Mesoproterozoic
259	12	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
260	11	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
261	72	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
262	16	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
263	4,709	Extrusive volcanic rocks (traps exepted)	Lower Paleozoic to Neoproterozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Lower Paleozoic to Neoproterozoic
264	29	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
265	58	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
266	413,131	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
267	107	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic

Polygon ID	Area (km^2)	Setting	Age	Description
268	867	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
269	217	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
270	79	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
271	37	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
272	470	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
273	4,141	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
274	64	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
275	192	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
276	80	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
277	32	Sedimentary rocks or undifferentiated facies	Mesoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Mesoproterozoic
278	101	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
279	141	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
280	204	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
281	7	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
282	1,066	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
283	4,996	Extrusive volcanic rocks (traps exepted)	Lower Paleozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Lower Paleozoic
284	6,726	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
285	31	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
286	4,086	Sedimentary rocks or undifferentiated facies	Mesoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Mesoproterozoic
287	793	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
288	1,188	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
289	726	Sedimentary rocks or undifferentiated facies	Mesoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Mesoproterozoic
290	860	Extrusive volcanic rocks (traps exepted)	Mesoproterozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Mesoproterozoic
291	38			Large Igneous Province (LIP): Traps with indication of mean age in Ma
292	582	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
293	1,683	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
294	2	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
295	255	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
296	143	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
297	89	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
298	22			Large Igneous Province (LIP): Traps with indication of mean age in Ma
299	1,449	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
300	515	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
301	1,512	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic

Polygon ID	Area (km^2)	Setting	Age	Description
302	218,765	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
303	8	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
304	12,414	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
305	440	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
306	13,519	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
307	14	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
308	320,887	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
309	78	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
310	2,144	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
311	3	Extrusive volcanic rocks (traps exepted)	Paleoproterozoic to Archean	Continental crust, Extrusive volcanic rocks (traps exepted) - Paleoproterozoic to Archean
312	1,186	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic to Archean	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic to Archean
313	927	Extrusive volcanic rocks (traps exepted)	Paleoproterozoic to Archean	Continental crust, Extrusive volcanic rocks (traps exepted) - Paleoproterozoic to Archean
314	12,201	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
315	869	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
316	19	Extrusive volcanic rocks (traps exepted)	Paleoproterozoic to Archean	Continental crust, Extrusive volcanic rocks (traps exepted) - Paleoproterozoic to Archean
317	520	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
318	1,484	Extrusive volcanic rocks (traps exepted)	Paleoproterozoic to Archean	Continental crust, Extrusive volcanic rocks (traps exepted) - Paleoproterozoic to Archean
319	112			Large Igneous Province (LIP): Traps with indication of mean age in Ma
320	274	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoiccc
321	423	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
322	3,827	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
323	183	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
324	133	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
325	6	Extrusive volcanic rocks (traps exepted)	Paleoproterozoic to Archean	Continental crust, Extrusive volcanic rocks (traps exepted) - Paleoproterozoic to Archean
326	11	Endogenous rocks (plutonic and/or metamorphic)	Paleozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleozoic
327	2,411	Endogenous rocks (plutonic and/or metamorphic)	Paleozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleozoic
328	118	Endogenous rocks (plutonic and/or metamorphic)	Mesozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesozoic
329	0	Extrusive volcanic rocks (traps exepted)	Paleoproterozoic to Archean	Continental crust, Extrusive volcanic rocks (traps exepted) - Paleoproterozoic to Archean
330	10	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
331	4	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
332	195	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
333	161	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic to Archean	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic to Archean
334	19	Extrusive volcanic rocks (traps exepted)	Paleoproterozoic to Archean	Continental crust, Extrusive volcanic rocks (traps exepted) - Paleoproterozoic to Archean
335	1,424	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic

Polygon ID	Area (km^2)	Setting	Age	Description
336	7	Endogenous rocks (plutonic and/or metamorphic)	Mesozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesozoic
337	420	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
338	207	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
339	45	Endogenous rocks (plutonic and/or metamorphic)	Paleozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleozoic
340	947	Sedimentary rocks or undifferentiated facies	Neoproterozoic to Mesoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic to Mesoproterozoic
341	296,773	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
342	8	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
343	19	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
344	24	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
345	89	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
346	516	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
347	196,078	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
348	9,295	Extrusive volcanic rocks (traps exepted)	Paleoproterozoic to Archean	Continental crust, Extrusive volcanic rocks (traps exepted) - Paleoproterozoic to Archean
349	55	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
350	233,861	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
351	1,017	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
352	2,950	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
353	66	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
354	409	Endogenous rocks (plutonic and/or metamorphic)	Mesozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesozoic
355	132,913	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
356	104,111	Sedimentary rocks or undifferentiated facies	Proterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic
357	424	Extrusive volcanic rocks (traps exepted)	Paleoproterozoic to Archean	Continental crust, Extrusive volcanic rocks (traps exepted) - Paleoproterozoic to Archean
358	192	Sedimentary rocks or undifferentiated facies	Proterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic
359	63	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
360	64,927	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
361	2,098	Extrusive volcanic rocks (traps exepted)	Paleoproterozoic to Archean	Continental crust, Extrusive volcanic rocks (traps exepted) - Paleoproterozoic to Archean
362	5,994	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
363	3,171	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
364	15,087	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
365	19	Endogenous rocks (plutonic and/or metamorphic)	Neoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Neoproterozoic
366	846	Sedimentary rocks or undifferentiated facies	Neoproterozoic to Mesoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic to Mesoproterozoic
367	2,209	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
368	394	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
369	11,451	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic

Polygon ID	Area (km^2)	Setting	Age	Description
370	177	Sedimentary rocks or undifferentiated facies	Mesoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Mesoproterozoic
371	23,243			Large Igneous Province (LIP): Traps with indication of mean age in Macc
372	521	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
373	518	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
374	522	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
375	1,228	Sedimentary rocks or undifferentiated facies	Neoproterozoic to Mesoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic to Mesoproterozoic
376	578	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
377	920	Sedimentary rocks or undifferentiated facies	Mesoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Mesoproterozoic
378	3,897	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
379	123	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
380	220	Endogenous rocks (plutonic and/or metamorphic)	Neoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Neoproterozoic
381	87	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
382	1,845	Undifferentiated facies	Archean	Continental crust, Undifferentiated facies - Archean
383	3,663	Extrusive volcanic rocks (traps exepted)	Mesoproterozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Mesoproterozoic
384	2,202	Endogenous rocks (plutonic and/or metamorphic)	Neoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Neoproterozoic
385	7,547	Sedimentary rocks or undifferentiated facies	Neoproterozoic to Mesoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic to Mesoproterozoic
386	335,984	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
387	51,823	Sedimentary rocks or undifferentiated facies	Neoproterozoic to Mesoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic to Mesoproterozoic
388	1,015	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
389	6,142	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
390	687,848	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
391	118	Endogenous rocks (plutonic and/or metamorphic)	Mesozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesozoic
392	10	Endogenous rocks (plutonic and/or metamorphic)	Mesozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesozoicc
393	422	Endogenous rocks (plutonic and/or metamorphic)	Mesozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesozoic
394	882	Extrusive volcanic rocks (traps exepted)	Mesozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Mesozoic
395	1,216,913	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
396	44,099	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
397	21,274	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
398	82	Extrusive volcanic rocks (traps exepted)	Mesozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Mesozoic
399	381,748	Endogenous rocks (plutonic and/or metamorphic)	Mesozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesozoic
400	92	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
401	2,611	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic
402	178,549	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic

Polygon ID	Area (km^2)	Setting	Age	Description
403	1,131	Sedimentary rocks or undifferentiated facies	Neoproterozoic to lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic to lower Paleozoic
404	8,287	Sedimentary rocks or undifferentiated facies	Proterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic
405	2,225	Extrusive volcanic rocks (traps exepted)	Mesozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Mesozoic
406	2,643	Extrusive volcanic rocks (traps exepted)	Mesozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Mesozoic
407	491	Sedimentary rocks or undifferentiated facies	Proterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic
408	36,489	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
409	2,176	Sedimentary rocks or undifferentiated facies	Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleozoic
410	3,054	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
411	6,189	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
412	16	Sedimentary rocks or undifferentiated facies	Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleozoic
413	2,140	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
414	1,433	Endogenous rocks (plutonic and/or metamorphic)	Mesozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesozoic
415	6,259	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic
416	2,016	Extrusive volcanic rocks (traps exepted)	Mesozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Mesozoic
417	10,087	Extrusive volcanic rocks (traps exepted)	Mesozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Mesozoic
418	8,324	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic
419	32	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
420	604	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic
421	33	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic
422	2,162	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic
423	128	Ophiolitic complex	Meso-Cenozoic	Ophiolitic complex of Meso-Cenozoic age
424	78,486	Sedimentary rocks or undifferentiated facies	Neoproterozoic to lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic to lower Paleozoic
425	4,890	Extrusive volcanic rocks (traps exepted)	Mesozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Mesozoic
426	28,846	Extrusive volcanic rocks (traps exepted)	Mesozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Mesozoic
427	17,944	Endogenous rocks (plutonic and/or metamorphic)	Mesozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesozoic
428	122,982	Endogenous rocks (plutonic and/or metamorphic)	Mesozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesozoic
429	38,738	Endogenous rocks (plutonic and/or metamorphic)	Mesozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesozoic
430	109	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic
431	177	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic
432	1,936	Ophiolitic complex		Ophiolitic complex of Meso-Cenozoic age
433	3,126	Ophiolitic complex	Meso-Cenozoic	Ophiolitic complex of Meso-Cenozoic age
434	40,950	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic
435	6,082	Extrusive volcanic rocks (traps exepted)	Mesozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Mesozoic
436	35,965	Extrusive volcanic rocks (traps exepted)	Cenozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Cenozoic

Polygon ID	Area (km^2)	Setting	Age	Description
437	241,334	Extrusive volcanic rocks (traps exepted)	Mesozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Mesozoic
438	1,922	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
439	438	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
440	30	Endogenous rocks (plutonic and/or metamorphic)	Mesozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesozoic
441	114	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
442	2,018	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
443	120	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
444	347	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
445	253	Extrusive volcanic rocks (traps exepted)	Mesoproterozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Mesoproterozoic
446	135	Extrusive volcanic rocks (traps exepted)	Mesoproterozoic	Continental crust, Extrusive volcanic rocks (traps exepted) - Mesoproterozoic
447	131	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoicccc
448	3,248	Sedimentary rocks or undifferentiated facies	Neoproterozoic to lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic to lower Paleozoic
449	30	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
450	733	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
451	1,316	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic to Archean	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic to Archean
452	50	Endogenous rocks (plutonic and/or metamorphic)	Mesoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesoproterozoic
453	8,191	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
454	623			Large Igneous Province (LIP): Traps with indication of mean age in Ma
455	1,438			Large Igneous Province (LIP): Traps with indication of mean age in Ma
456	1,016	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
457	43,927	Endogenous rocks (plutonic and/or metamorphic)	Mesozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesozoic
458	13,044	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
459	5,331	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
460	6,479	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
461	395	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
462	187	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
463	188,685	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
464	80,682	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic to Archean	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic to Archean
465	33,739	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
466	17	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
467	4	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
468	5	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
469	62	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
470	12	Sedimentary rocks or undifferentiated facies	Proterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic

Polygon ID	Area (km^2)	Setting	Age	Description
471	8	Sedimentary rocks or undifferentiated facies	Proterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic
472	56	Sedimentary rocks or undifferentiated facies	Proterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic
473	2	Sedimentary rocks or undifferentiated facies	Proterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic
474	13	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
475	38	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
476	5	Sedimentary rocks or undifferentiated facies	Paleoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Paleoproterozoic
477	430,270	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
478	27	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
479	52	Sedimentary rocks or undifferentiated facies	Upper Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Upper Paleozoic
480	1,987	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
481	31	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
482	12	Sedimentary rocks or undifferentiated facies	Proterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic
483	3	Sedimentary rocks or undifferentiated facies	Proterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic
484	22	Sedimentary rocks or undifferentiated facies	Proterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Proterozoic
485	3,854	Sedimentary rocks or undifferentiated facies	Lower Paleozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Lower Paleozoic
486	923	Endogenous rocks (plutonic and/or metamorphic)	Mesoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Mesoproterozoic
487	5,815	Sedimentary rocks or undifferentiated facies	Neoproterozoic	Continental crust, Sedimentary rocks or undifferentiated facies - Neoproterozoic
488	5,956	Endogenous rocks (plutonic and/or metamorphic)	Lower Paleozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Lower Paleozoic
489	33,724	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic
490	4,112	Endogenous rocks (plutonic and/or metamorphic)	Paleoproterozoic	Continental crust, Endogenous rocks (plutonic and/or metamorphic) - Paleoproterozoic