DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2016/12

Architecture and mineral potential of the Paleoproterozoic Karrat Group, West Greenland

Results of the 2015 season

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Abstract

Stratigraphic investigations revealed important new information on the nature and relationships between units of the meta-sedimentary and meta-volcanic Karrat Group. The oldest unit is the Qeqertarssuaq Formation, which is composed dominantly of quartzite and mica schist in contact with Archean crystalline basement rocks (“Archean basement,” herein). The Mârmorilik Formation, which consists dominantly of dolomite and calcite marbles, is also in depositional contact with Archean basement rocks, but not with the Qeqertarssuaq Formation. Therefore, the relative age of the Mârmorilik and Qeqertarssuaq formations is unclear. A new stratigraphic unit, the Qaarsukassak Formation, is formally established as a result of the field season’s mapping in Kangerluarsuk Fjord. The Qaarsukassak Formation occurs locally in depositional contact with Archean crystalline basement and stratigraphically below the youngest unit of the Karrat Group, the Nûkavsak Formation. Calcite marble horizons within the Qaarsukassak Formation appear to control the distribution of Zn-Pb mineralisation at the Discovery and Kangerluarsuup Sermia showings. The understanding of the distribution of this formation is therefore of significance for exploration work.

In Kangigdleq Fjord, a thick package of mainly mafic volcanic rocks occurs stratigraphically below the Nûkavsak Formation. Preliminary interpretations indicate that these meta-volcanic rocks are mainly subaqueous and transitional to alkaline in chemistry intra-plate basalts. Their thickness is variable through the region, with thicknesses of up to 850 m, at Qangattarsuaq, interpreted to be part of a larger submarine volcanic structure. The meta-volcanic rocks either have a LREE-enriched REE profile or a flat REE chondrite-normalized profile, comparable to samples from the Bravo Lake Formation (Baffin Island, Nunavut, Canada). Contact relationships between the Nûkavsak Formation and meta-volcanic rocks were observed to be transitional over several tens of metres, suggesting that there was no time break between the deposition of these two units. From these new observations, stratigraphic revisions are suggested, which would either elevate the meta-volcanic rocks to a standalone formation (the Kangigdleq Formation) separate from the Qeqertarssuaq Formation or would include the meta-volcanic rocks into the Nûkavsak Formation, since these units show conformable relationships in the field.

The Nûkavsak Formation contains primary sedimentary structures (including flute casts, scour structures, flame structures, and cross-bedding) and also contains abundant clasts of reworked, older Karrat Group rocks, including abundant meta-volcanic pebbles and cobbles. This was not previously reported, but provides important stratigraphic and basin tectonic constraints. The association between semi-massive sulfide horizons within the Nûkavsak Formation and the Kangigdleq Formation, suggests that the former are related to submarine volcanic activity and could correspond to volcanogenic massive sulphide systems (VMS). These horizons are anomalous, yet low in base metals and gold. However, these horizons and other related rusty-weathering horizons, including sulfidic cherts or siliceous meta-mudstones and gossanous meta-sandstone horizons, appear to account for several of the stream sediment and float base metal anomalies that have been previously reported.

An unconformity is inferred from field relationships between the Lower (Qeqertarssuaq Formation) and Upper (Kangigdleq-Nûkavsak formations) Karrat Group. The Qeqertarssuaq Formation records at least one more phase of deformation and is transposed, i.e. it is infolded with Archean basement. A post-Qeqertarssuaq Formation unconformity is also supported by two more observations: that meta-volcanic rocks of the Kangigdleq Formation

rest on different units of the Qeqertarssuaq Formation, and that clasts of recognized Qeqertarssuaq Formation were found to occur in the Nûkavsak Formation. Ongoing geochronological studies will better constrain the depositional age of the Karrat Group overall, test hypotheses regarding possible unconformities within the Karrat Group, and elucidate sedimentary provenance.

Some revisions to the existing map units are recommended. For example, rock units currently mapped as amphibolite with map code 'A' are not equated across the 71 V.2 South and 71 V.2 North map sheets (Henderson and Pulvertaft, 1987). Sometimes this map unit represents meta-volcanic rocks of the Kangigdleq Formation, which are stratigraphically above the Qeqertarssuaq Formation and are mostly in the greenschist facies, but sometimes this unit is amphibolite of uncertain protolith within the Qeqertarssuaq Formation.

The overall structural grain of the study area is characterized by complex interference of the structures related to four stages of deformation, D1 through D4. Early structures observed only in the Qeqertarsuaq Formation and the Umanak Gneiss pre-date the development of an unconformity and are attributed to the Qeqertarssuaq Stage (D1). The deformation post-dating the unconformity can be separated into three distinct stages named the Kigarsima Stage (D2), related to a WSW-ENE to SW-NE compression, the Maarmorilik Stage (D3), related to NW-SE compression and the Svartenhuk Stage (D4), with extension around intrusions and distal E-W compression. The area south of Kangilleq Fjord is characterized by fold structures with NW-trending axial traces that formed during the Kigarsima Stage (D2). The main regional overprint is by D4 (Svartenhuk Stage) folds with N-trending axials traces. The area between Umiammakku and Inngia Fjord is complex with also mainly D2 and D4 interference patterns. D1 (Qeqertarssuaq Stage), restricted to the Qeqertarsuaq Formation and the Umanak Gneiss, and D3 (Maarmorilik Stage) appear not to have a major influence on the regional-scale structural grain. The area between Inngia Fjord and Kangiusap Kuua is defined by N-trending structures related to extension proximal to intrusions in the west and E-vergent distal deformation.

Anomalous, but low, Au values were confirmed in quartz veins in Qeqertarssuaq Formation quartzites at Kussinersuup Aaffaa and at Inngia Fjord, and in quartz veins in Nûkavsak Formation metasandstoness and phyllites at Southern Kangiusap Kuua (Eastern Svartenhuk). These are interpreted to be related to a mesozonal orogenic gold mineral system, superimposed, at the former localities, on a Zr, Nb, Y, U, Th, lanthanide and, possibly, Au-enriched paleoplacer.

Background and logistical setup

The Paleoproterozoic-aged Karrat Group of West Greenland hosts one of the few deposits that have been mined in Greenland to date, the Black Angel Zn-Pb mine, which operated between 1973 and 1990. Attesting to its good potential for both SEDEX and MVT Zn-Pb-Ag mineralisation, the basin has been one of the areas highlighted by the expert panel assessing the zinc potential of Greenland in 2011 (Sørensen et al, 2013). However, while exploration has persisted and is still ongoing in parts of the basin, a basin-scale study has not been carried out since it was mapped in the 1960s, 1970s and 1980s, with only selected updates in the 1990s (stream sediment geochemistry) and 2001-3 (tectonic framework reconnaissance, aeromagnetic survey). Given this limited framework, the basin merits an updated and integrated approach focused on a detailed understanding of its architecture and its mineral system(s). Therefore, the Geological Survey of Denmark and Greenland (GEUS) and the Ministry of Mineral Resources of Greenland (MMR) agreed on a joint project. This project is forecast to last for at least two years, throughout 2015 and 2016, with a possible extension. As part of this project, between July 5th and August 4th, 2015, a total 10 of geologists conducted field work in the Karrat Fjord region (Figure 1). Six of these geologists spent the entire period in the region, while 4 either spent the first part or the second part, with a mid-season replacement (two in/two out) on July 20th.

Operations were based out of the chartered ship Minna Martek, which sailed off from Ilulissat with gear, provisions, fuel and participants on July 5th and, at the end of the season and after dropping the expedition participants in Qaarsut on August 3rd, sailed with gear, leftover fuel and samples, south to Nuuk, where it arrived on August 6th. In the meantime, the ship was used as a basecamp, setting anchor in three different anchorages (Figure 1; Anchorage 1, in Kangerdluarssuk at N71.2913 / W 51.7712; Anchorage 2 in NE Qeqertarssuaq at N 71.6671 / W 52.8115; and Anchorage 3 in Kangiussap imâ at N 71.7585 / W 53.8534), where fuel depots were established. Anchorages moves were done on July 15th and July 26th. From these anchorages, teams were put out on field camps or took off on reccos with an Air Greenland chartered AS 350 B3 helicopter (Joachim Haugland as pilot) or using zodiacs. Furthermore, on helicopter pilot rest days, Minna Martek was also used to sail along fjords, from which zodiacs were deployed for coastal recco. Figure 1 provides an overview of localities visited throughout the field season. The weather and snow conditions were good, for most of the time, with only occasional morning fog leading to some flying constraints.

The studied area is characterized by steep alpine terrain that, in many places, is completely inaccessible. This makes field work an extremely difficult task. A successful outcome is therefore highly dependent on remotely sensed observations in combination with reconnaissance observations. As such, an ongoing task throughout the field season was to collect and establish a framework of stereo-images which can be used by the project participants for subsequent 3D-mapping and interpretation purposes. A total of around 25000

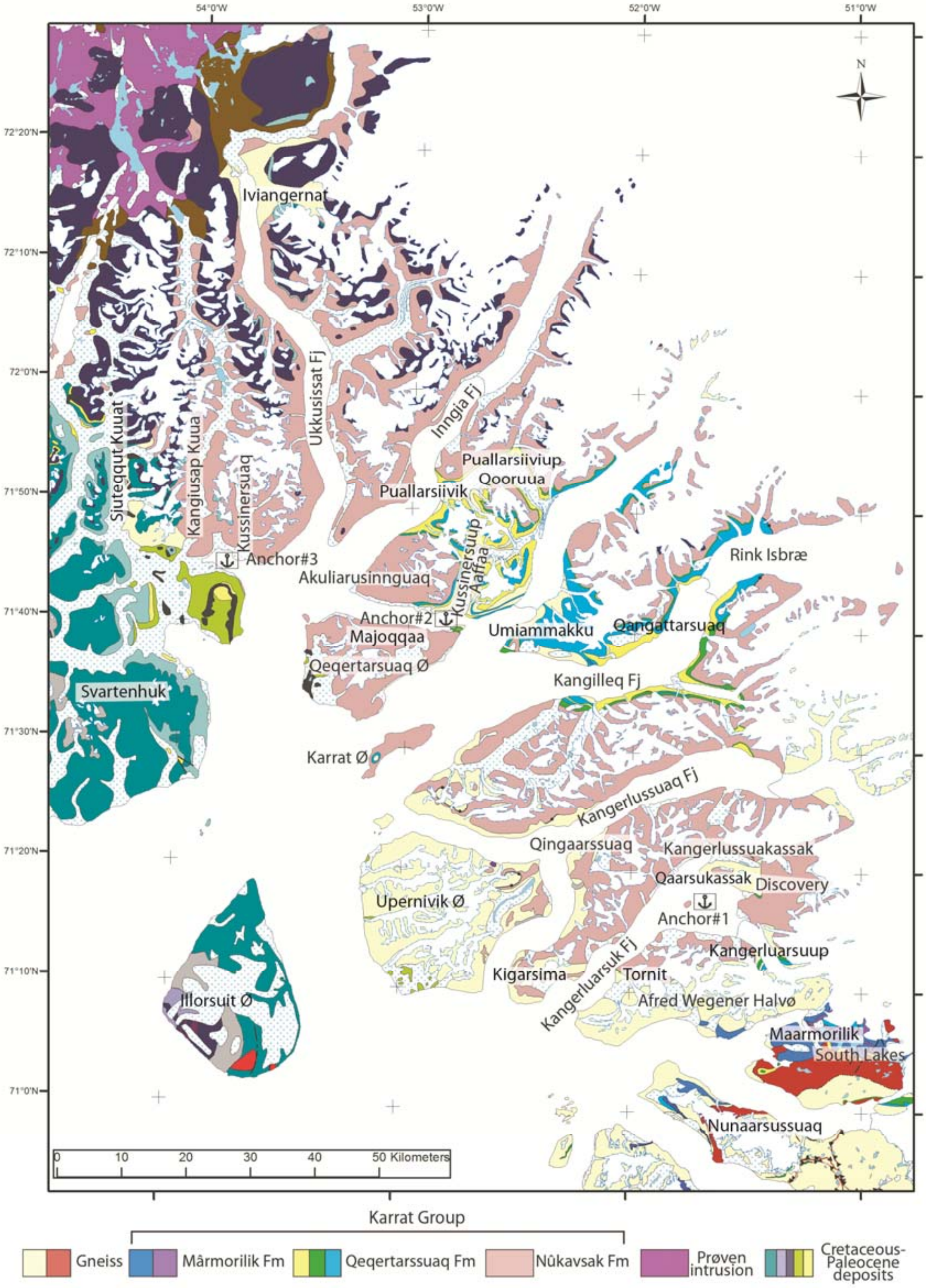


Figure 1. *Geological map of the study area (after Escher, 1980), showing anchorages and highlighting localities discussed in the text.*

images were collected with a 35 mm lens (mostly from the helicopter) and around 3000 with an 85 mm lens (mostly from the ship, while moving anchorage and on pilots rest days), as illustrated in Figure 2. This constitutes an advance to previous field observations, both by GEUS and by exploration companies, which were focused at or relatively close to sea-level since these were conducted mostly from ships, with limited helicopter support. Our modern photogrammetric approach applied during field work is a technological step forward compared to the previous approach. By collecting aerial photographs while flying anyway,

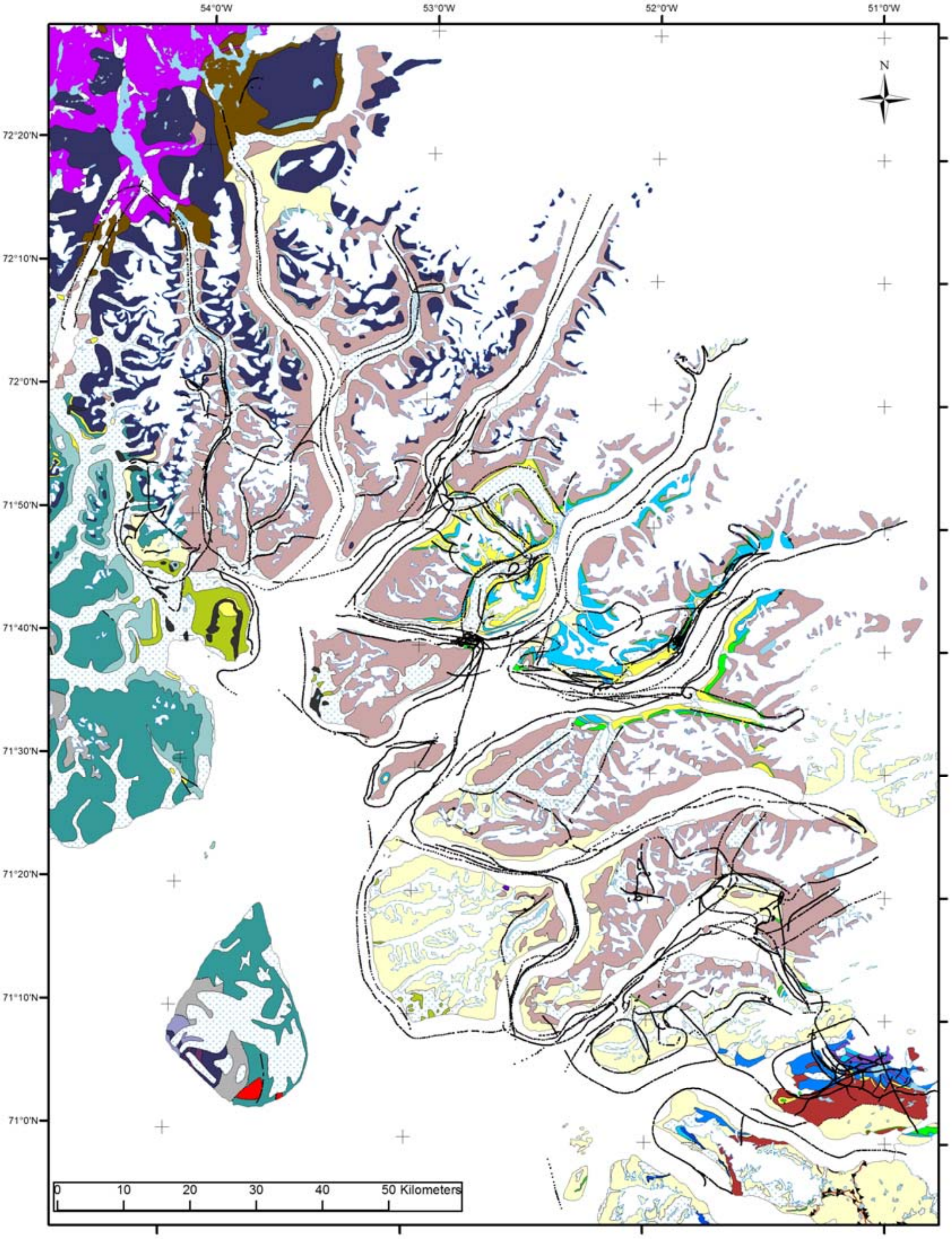


Figure 2. *Locations of collected stereo images (mostly from helicopter, but also from ship). Superimposed on geological map after Escher (1980).*

we are in a way able to take the field inside the lab where it they will form the basis for structural mapping, correlation between outcrops and structural restoration.
In the following sections the preliminary observations and results of the fieldwork are reported, organized along different disciplines. More definitive results should become available after a second field season in 2016, and as analytical data becomes progressively available.

Stratigraphy

A stratigraphic framework was described in previous work (Henderson and Pulvertaft, 1967; 1987), outlining the older Mârmorilik and Qeqertarssuaq formations that are overlain by the younger Nûkavsak Formation. In their framework, meta-volcanic rocks were considered to be part of the Qeqertarssuaq Formation. Observations made during the 2015 field season indicate that revisions to the Karrat Group stratigraphy are needed. These revisions have implications for understanding the tectonic setting and depositional environment of the Karrat Group. An overview of the stratigraphy in space and time as represented by field localities visited this field season is summarized in Figure 3. Although absolute age is poorly-constrained, the diagram graphically shows new ideas regarding the possibility of one or more unconformities within the Karrat Group. The relative age of the Qeqertarssuaq, Qaarsukassak, and Mârmorilik formations is uncertain. The Karrat Group might have been deposited in several sub-basins (Grocott and Pulvertaft, 1990). The Mârmorilik Formation is separated from the remainder of the Karrat Group by a topographic high of Archean basement, therefore it might represent a depocenter that was separated from the larger Karrat paleo-basin. Below, each stratigraphic unit is discussed in turn beginning with the oldest stratigraphic unit, drawing from observations made from localities in the Kangerluarsuk Fjord, Kangilleq Fjord, and Svartenhuk Halvø areas.

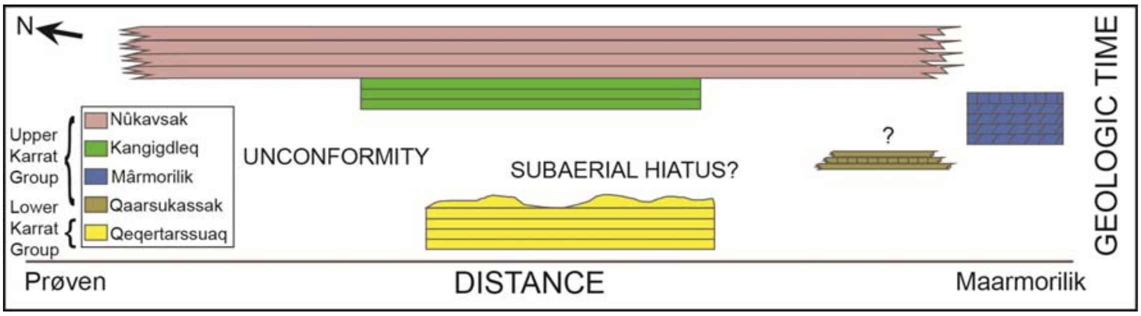


Figure 3. *A time-stratigraphy diagram (Wheeler diagram) hypothesizing spatial and temporal relationships for the five formations within the Karrat Group. White space represents areas of non-deposition or erosion. This diagram was constructed from approximate outcrop extents according to current geological maps. The y-axis represents geologic time, therefore stratigraphic thickness is not accurately represented.*

Qeqetarssuaq Formation

The Qeqertarssuaq Formation is a multiply-deformed and transposed meta-sedimentary (and meta-volcanic?) succession that is dominated by green and white quartzites and garnet schist, and semipelites, with minor calcite marble and amphibolite or garnet-amphibolite layers. The Qeqertarssuaq Formation is transposed and metamorphosed to the middle amphibolite facies, whereas the upper stratigraphy (Kangigdleq - Nûkavsak formations) is not. There appears to be a structural and stratigraphic break (angular unconformity) between the lower Karrat Group (Qeqertarssuaq Formation) and upper Karrat Group (Kangigdleq - Nukavsak formations) (Figure 3). In contrast to the Qaarsukassak and Nûkavsak formations described below, no primary sedimentary structures or depositional contacts were observed in the Qeqertarssuaq Formation. Only a tectonostratigraphy can be defined for the transposed Qeqertarssuaq Formation.

The Qeqertarssuaq Formation is best and most completely exposed at Umiammakku / Pyramidestubben in Kangilleq Fjord (Figure 4). It is one of the few places that one is physically able to walk from the Archean basement contact (Figure 5) to the stratigraphic top of the Qeqertarssuaq Formation, which is in contact with the Kangigdleq Formation. The basal quartzite is infolded with Archean basement, but then passes upwards into foliated to banded psammite to psammitic gneiss, semipelite, pelite, garnet mica schist (Figure 6), hornblende schist, a quartz-tremolite calcite marble, overlain again by quartzite, some of which is mylonitic (Figure 7). The total thickness of homoclinal rocks of the Qeqertarssuaq Formation in this locality is estimated to be ~200 m (no obvious structural repetitions were observed). In other areas, the Qeqertarssuaq Formation showed a distinctive green-coloured quartzite, which might be related to a fuchsite-bearing quartzite observed in other localities, and a magnetite-bearing quartzite. The magnetite-bearing quartzite could represent a fluvial or a foreshore (beach) deposit. The lack of finer-grained material overall in the Qeqertarssuaq Formation suggests a relatively shallow water depositional environment, but no cross-bedding was observed. The calcite marble unit could be used as a marker-bed for further tectonostratigraphic work, since this unit appeared to consistently occur within the mica schists (‘sp’ map unit) in the upper Qeqertarssuaq Formation. The calcite marble unit (1-3m) was observed in several localities (Figure 7).

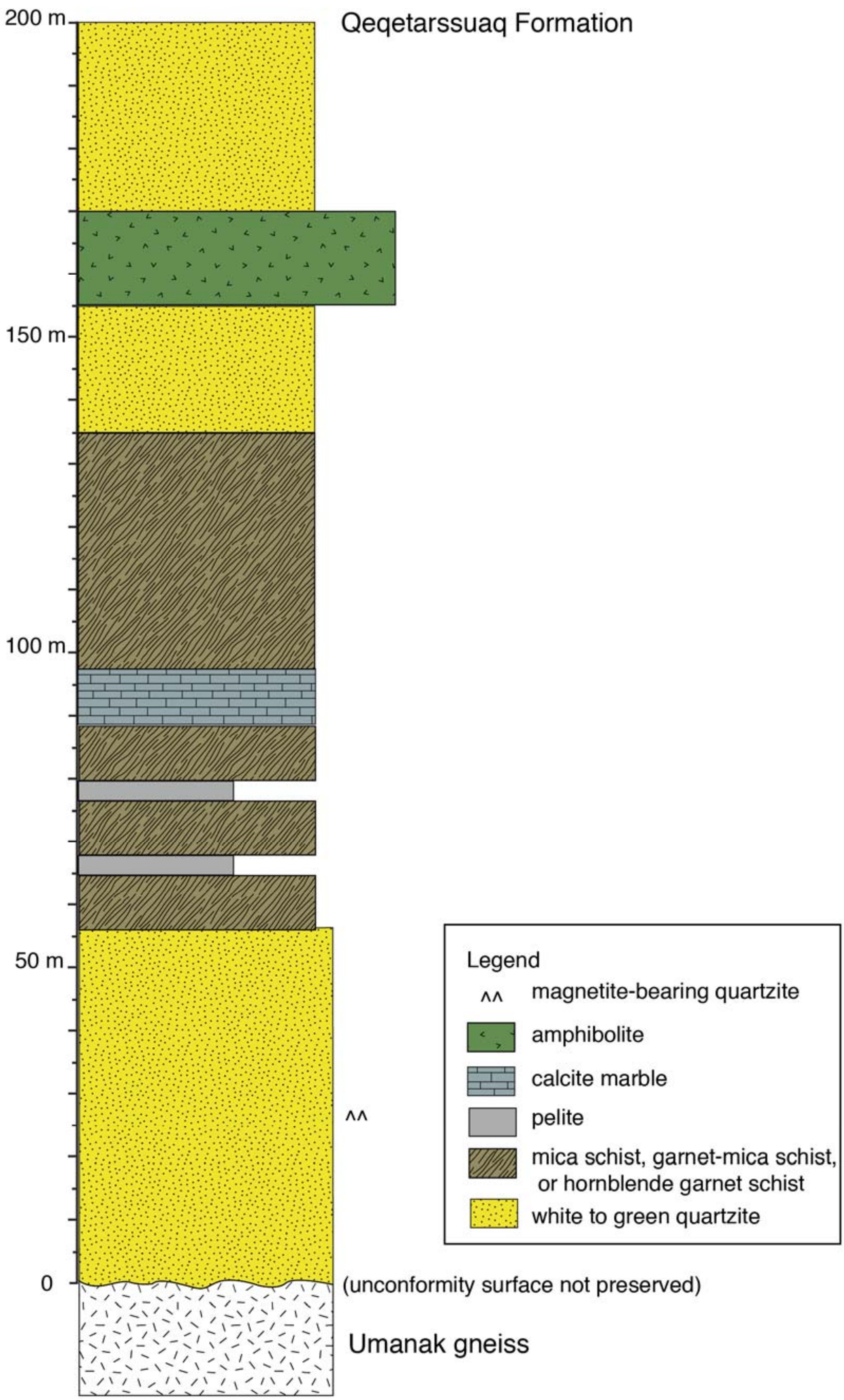


Figure 4. *Stratigraphic section of the Qeqetarssuaq Formation, as established at Umiammakku/ Pyramidestubben in Kangilleq Fjord. Thicknesses are approximate.*

Figure 5. *Transposed Qeqertarssuaq Formation at Umiammakku.*

Figure 6. *Garnet mica schist of the Qeqertarssuaq Formation at Umiammakku.*

Figure 7. *Quartzites of the upper Qeqertarssuaq Formation at Umiammakku (left: mylonitic quartzite).*

Figure 8. *Left: calcite marbles at Pyramidstubben; Right: calcite marbles at Umiammakku.*

The ‘A’ map unit, representing amphibolite as part of the Qeqertarssuaq Formation, is not equated across the 71 V.2 South and 71 V.2 North 1:100.000 map sheets (Henderson and Pulvertaft, 1987). In some places this unit is an amphibolite of uncertain protolith within the Qeqertarssuaq Formation, whereas other rock units with the ‘A’ map code are stratigraphically above the Qeqertarssuaq Formation and represent mafic meta-volcanic rocks. In many places the meta-volcanic rocks (Kangigdleq Formation) are only in the greenschist facies.

Although largely absent from the Svartenhuk Halvø area, the Qeqertarssuaq Formation is interpreted to be present in some places where Nûkavsak Formation is mapped, including Southern Kangiusap Kuua. We also visited the Qeqertarssuaq Formation at the Iviangernat locality (Archean basement - Qeqertarssuaq Formation contact). As discussed below in the ‘Kangigdleq Formation’ sub-section, the quartzite unit on this mapsheet does not represent Qeqertarssuaq Formation.

Qaarsukassak Formation

A new stratigraphic formation was established, named the Qaarsukassak Formation after the nearest geographical map feature, which occurs locally below the Nûkavsak Formation in the Discovery to Tornit area and is relatively thin. Qaarsukassak Formation replaces the field name of Discovery Formation, for its dominant occurrence in the (Rio Tinto) "Discovery" zinc occurrence (Coppard et al., 1992). This report describes a 30 to 66-m thick quartzite-metacarbonate succession with a mineralised zone occurring dominantly in calcite-bearing dolomite marbles bounded by Archean basement rocks and the Nûkavsak Formation, possibly occurring within the down-dropped block of a syndepositional fault.

A depositional contact is preserved between the Qaarsukassak Formation and Archean basement (Umanak gneiss) (Figure 9). The upper contact of the Qaarsukassak Formation with the younger Nûkavsak Formation is planar, but not well-exposed. A possible unconformable upper contact is supported by variable thickness of the Qaarsukassak Formation across the area, suggesting previous erosion, as well as the inclusion of a metacarbonate megaclast in the base of the Nûkavsak Formation that was likely derived from the Qaarsukassak Formation. It is unlikely that the Qaarsukassak Formation correlates with the Qeqertarssuaq Formation because of major differences in stratigraphy, thickness, and relative degree of deformation, e.g., the Qeqertarssuaq Formation is transposed and often infolded with Archean basement, whereas the Qaarsukassak Formation is not.

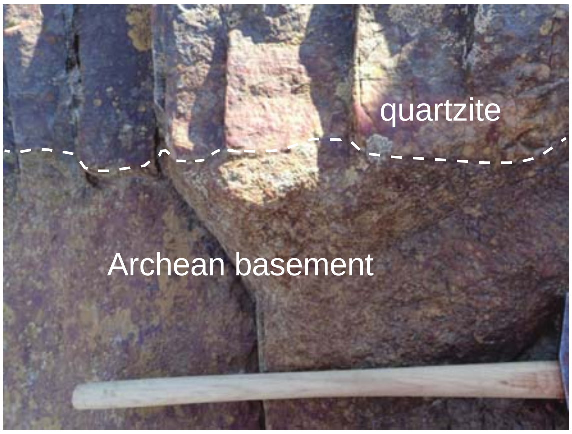


Figure 9. *Umanak gneiss (Archean basement)-Qaarsukassak Formation basal contact at the Discovery area.*

A stratigraphic section was measured from the base (Archean basement contact) to the inferred stratigraphic top of the sedimentary package, given the name Qaarsukassak Formation here (Figure 10). The actual stratigraphic thickness of the package is thin (< 20 metres) and is structurally-repeated to form a thicker map unit. Meta-carbonate rocks observed are composed primarily of calcite instead of dolomite (cf. Coppard et al., 1992); therefore only calcite marbles occur in the Qaarsukassak Formation. The presence of tremolite, though, suggests some primary Mg-rich carbonate minerals (dolomite or high Mg calcite). Sulfides occurring in the mineralised zone include pyrite ± pyrrhotite ± galena ± sphalerite.

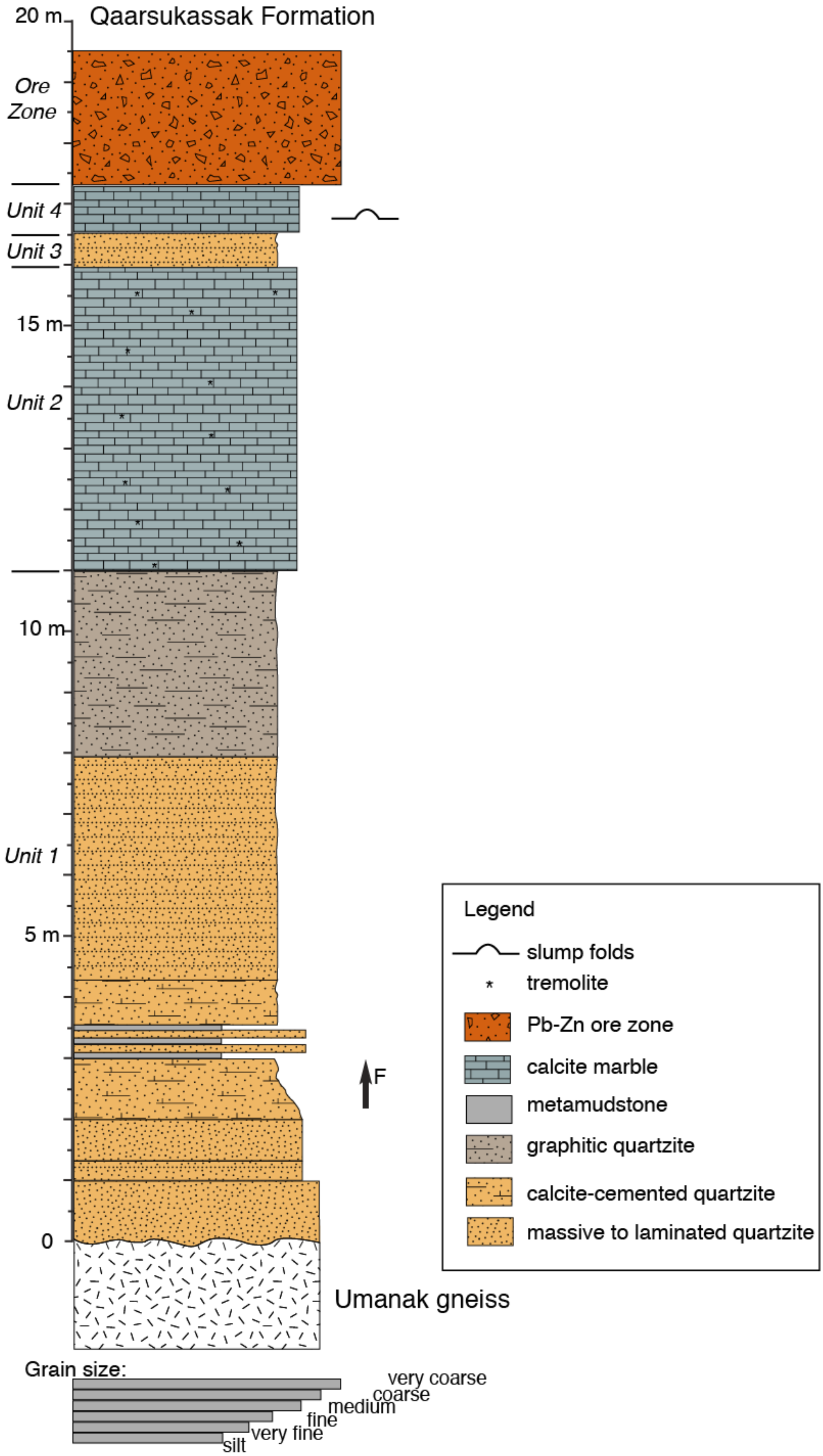


Figure 10. *Stratigraphic section of the Qaarsukassak Formation, measured at the Discovery area.*

The basal contact is planar to undulatory and preserves a depositional contact with Archean basement (Figure 9). Laminated to massive quartzite fines upward into finer-grained meta-sandstones and sandy meta-mudstones, including calcite-cemented quartzites and graphitic quartzites (Unit 1 in Figure 10). Metamorphic grade was not precisely determined, but meta-mudstone facies did not contain any mineral assemblages that would indicate metamorphism beyond the greenschist facies. The lower quartzites are overlain in sharp contact by light grey to white calcite marble, which has pods of tremolite and in some horizons, minor graphite (Unit 2). The marbles are overlain by another quartzite unit (Unit 3) followed by dark grey laminated calcite marble (Figure 11) with possible slump folds and minor tremolite veining (Unit 4). The overlying sedimentary rocks represent the ore zone (Unit 5), which is comprised of rusty meta-sedimentary rocks, including graphitic meta-mudstones and siliciclastic rocks.

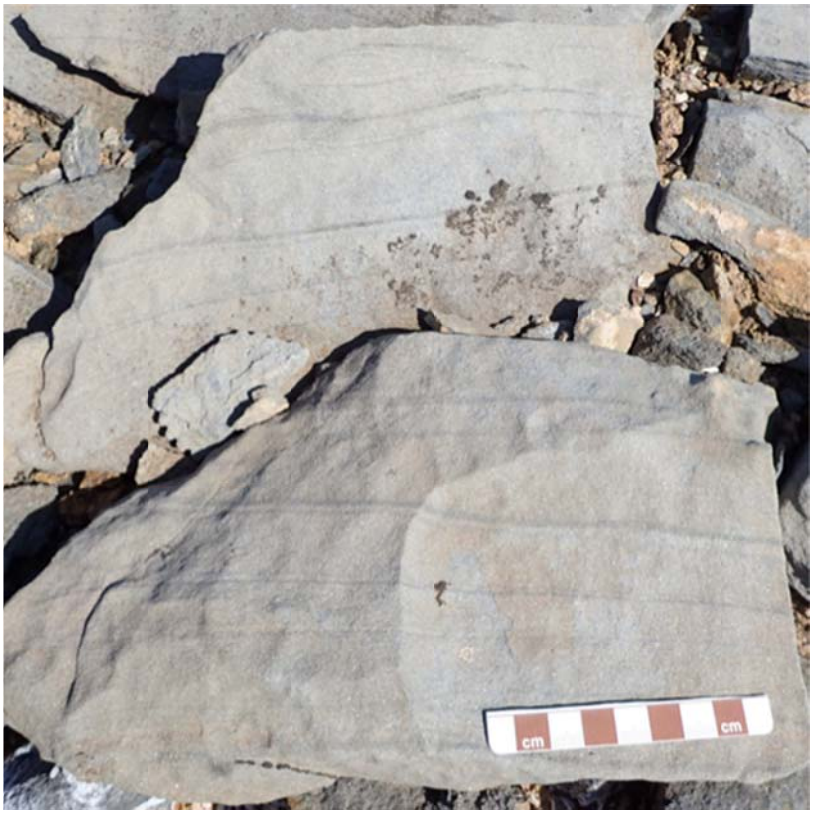


Figure 11. *Grey laminated calcite marble of the Qaarsukassak Formation at the Discovery area.*

Unit 1 of the Qaarsukassak Formation could represent a fluvial environment, but outcrops lack the sedimentary structures to confirm this; otherwise it likely represents a shallow marine environment since it is overlain by calcite marble, which is more commonly deposited in marine than in terrestrial (lacustrine) environments. The Qaarsukassak Formation shows variable thickness along strike, suggesting its deposition infilled pre-existing basement paleo-topography (see Structural Geology section).

The other side of the syndepositional fault reported by Coppard et al. (1992) was investigated briefly, but the contact with Archean basement was covered for ~10m. As a result. It could not be determined whether or not Units 1-4 of Qaarsukassak Formation also occur there. A ~5m thick fissile graphitic meta-mudstone unit occurs ~10 m below the contact with the Nukavsak Formation, Due to the nature of the contact, the meta-mudstone might be conformable with the Nûkavsak Formation.

The type section of Qaarsukassak Formation occurs in the Discovery area, as described above, but similar rocks that could possibly be attributed to the Qaarsukassak Formation also occur in two other localities, Tornit and Kangerluarsuup Sermia, though exposures are not laterally continuous. At Tornit, the Qaarsukassak Formation occurs between a thin amphibolite unit and the Nûkavsak Formation in a ~10m thick section comprising calcite marble, rusty clastic meta-sedimentary rocks, with occasional quartz pebbles, quartzites, and siliceous calcite marble (Figure 12). At Kangerluarsuup Sermia, an overturned section of dark grey tremolite-dolomite marble with an apparent thickness of ~30 to 40m occurs in thrust contact with Archean basement (Figure 13). The grey tremolite-dolomite marble contains interbeds of metamudstone (Figure 14).

Figure 12. *Thin Qaarsukassak Formation (calcite marble and rusty meta-sedimentary rocks) at Tornit.*

Figure 13. *Archean basement rocks thrust on grey tremolite-dolomite marble of the Qaarsukassak Formation at Kangerluarsuup Sermia.*

Figure 14. *Grey tremolite-dolomite marble of the Qaarsukassak Formation at Kangerluarsuup Sermia.*

Further investigation will determine 1) whether the Qaarsukassak Formation is time-correlative with the Mârmorilik Formation, 2) The relative conformity of the Qaarsukassak and Nûkavsak formations, and 3) Whether Pb-Zn mineralisation in various units, including the Qaarsukassak and Mârmorilik formations, are time-correlative.

Mârmorilik Formation

The base map and report by Garde (1978) served as an excellent foundation for reconnaissance work on the Mârmorilik Formation. Two of Garde's stratigraphic sections were followed to understand vertical and lateral variations in stratigraphy.

The quartzites at the base of the Mârmorilik Formation might represent a time-correlative unit of the Qeqetarssuaq Formation (Grocott and Pulvertaft, 1990). The quartzite/meta-conglomerate unit below the Mârmorilik Formation, however, shows several differences relative to the Qeqetarssuaq Formation, including thickness, sedimentologic character, and color. The lower Mârmorilik quartzite unit is thinner (30-60 m; Garde, 1978) as compared to the quartzites of the Qeqetarssuaq Formation, which are several hundred metres thick). Additionally, meta-conglomerates were not observed within the Qeqetarssuaq Formation, suggesting this might reflect a local process within the Mârmorilik sub-basin. Observations of this unit were made at the base of Garde's sections C and A, which are along-strike. Quartzites at the base of section C preserve a depositional contact with Archean basement rocks, with symmetrical wave ripples and a monomictic metaconglomerate at the base (Figure 15), with 3-15 cm long clasts of sedimentary rocks (a quartz-feldspar lithic wacke). The symmetrical ripples (Figure 16) are consistent with a NW or SE current direction in their present geometry. The lower dolomite marble unit was homogenous overall, only showing changing proportions of quartz or tremolite presence/absence. Dolomite marble was either rusty orange, grey, white, or a variegation of grey and white, or (Figures 17 & 18). The variegated nature of the dolomite marble (Figure 17) might be due to post-depositional fluids.

Figure 15. Monomictic meta-conglomerate in the basal Marmorilik Formation Right, close-up of clast.

Symmetrical ripples observed in the basal quartzite unit are more consistent with swash in a marine environment than in a fluvial environment, which tends to produce asymmetrical ripples (Dalrymple and James, 2010). A shallow marine environment is inferred for these rocks. The overall structural thickness of the Mârmorilik Formation was estimated by Garde

(1978) to be no more than 2 km. The stratigraphic thickness could be much less, considering the possible repetition of units through the succession. More detailed mapping coupled with chemostratigraphy would be needed to test this. The presence of 'semipelite' beds (three, which could possibly represent a structurally repeated unit) suggests an occasional influx of siliclastics on the carbonate platform. The origin and water depth of the carbonate platform is uncertain, but could have originally represented microbial mats (perhaps stromatolites) in a shallow marine environment.

Figure 16. *Symmetric ripples in the basal Mârmorilik Formation.*

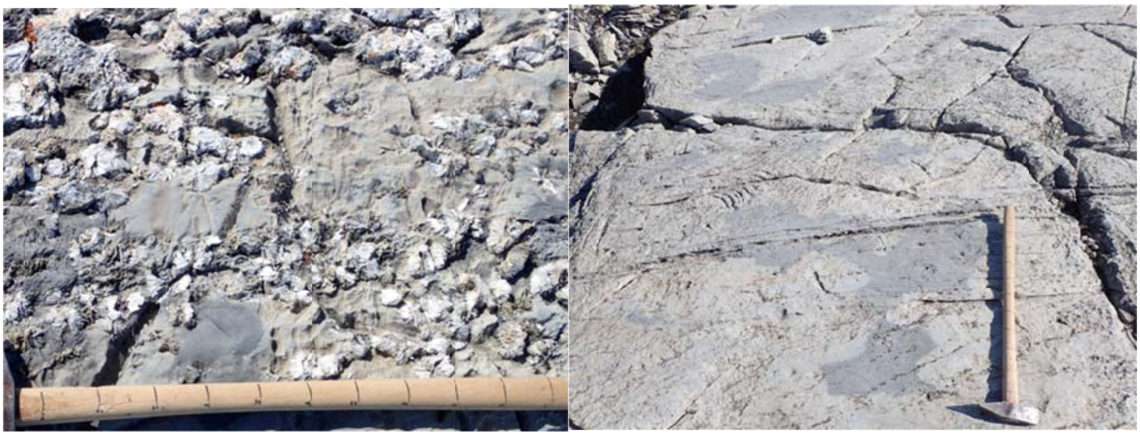


Figure 17. *Variegated grey tremolite dolomite marble of the lower Mârmorilik Formation.*

Figure 18. *Rusty orange-colored dolomite marble of the lower Mârmorilik Formation.*

Kangigdleq Formation

Meta-volcanic rocks, most likely attributed to an extrusive mafic-dominated volcanism, occur stratigraphically between the Qeqertarssuaq and Nûkavsak formations. These meta-volcanic rocks preserve primary volcanic features, including possible tuff beds, vesicles, flows, and pillow basalts (see Volcanic Rocks section for details). The meta-volcanic package occurs primarily on the 71 V.2 North 1:100.000 map sheet (Henderson and Pulvertaft, 1987), including Kangilleq Fjord, where the best exposures are found, especially at the Qangattarsuaq locality.

Meta-volcanic rocks, herein referred to as the Kangigdleq Formation, were previously grouped as part of the Qeqertarssuaq Formation. New stratigraphic observations suggest that the meta-volcanic rocks should be elevated to Formation status within the Karrat Group. Alternatively, the meta-volcanic rocks could be grouped as a Member of the Nûkavsak Formation. The lower contact of the Kangigdleq Formation is variable throughout the field area, since it was observed to rest on different units of the Qeqertarssuaq Formation. These units include: a mica schist at Qangattarsuaq and Kussinersuup Aaffaa; a quartzite on the opposite side of the fjord from Majoqqaa; and amphibolite on Qeqertarsuaq Island. The observation that the Kangigdleq Formation rests on different units of the Qeqertarssuaq Formation is consistent with an erosional unconformity between the Qeqertarssuaq and Kangigdleq - Nûkavsak formations (see Structural Geology section).

The stratigraphic thickness of the Kangigdleq Formation is variable throughout the area, but appears to be thickest in the Qangattarsuaq area in Kangilleq Fjord. The Kangigdleq Formation shows greater thickness (>500m) than previously mapped and shows a transitional contact with the younger Nûkavsak Formation (e.g., in Inngia Fjord). The meta-volcanic rocks in the Svartenhuk Halvø area are thinner overall, but do show well-preserved flows and flow textures, especially at Kangiusap Kuua. The 'quartzite' map unit is not a sedimentary quartzite, but more likely either a chert or silicified meta-sedimentary rocks. There is also vein quartz present. It does, however, provide a good marker of the localities where rocks have experienced hydrothermal alteration (three localities listed below).

In three areas (Siuteqqut Kuuat, and Northern and Central Kangiusap Kuua), extensive hydrothermal alteration marked by rusty weathering sulfides and hydrothermally-altered rocks were observed directly below the contact with the Nûkavsak Formation. For example, a garnet-dominated hydrothermal rock occurs at Siuteqqut Kuuat, whereas molybdenite occurs in an intrusive, but hydrothermally-altered, rock in Northern Kangiusap Kuua, and stockwork veining and massive sulfide (pyrite, pyrrhotite) occur at Central Kangiusap Kuua. If Re-Os dating of pyrite and molybdenite is successful then the timing and possible origin of hydrothermally-related mineralisations can be better delineated. Some hydrothermal activity could be synchronous with volcanic activity, since stockworks were observed in volcanic flow breccias at Central Kangiusap Kuua (see Economic Geology Section).

Field relationships, including onlap and differences in structural style, metamorphic grade, and number of deformation phases, suggest an unconformity between the Qeqertarssuaq and Kangigdleq-Nûkavsak formations. Detailed geochronology will provide more insight into the possibility and duration of unconformities within the Karrat Group (Figure 3). The variable thickness of the Kangigdleq Formation throughout the field area could be attributed to either: infilling pre-existing erosional paleo-topography, the infilling of grabens, or proximity to the volcano edifice or eruption site. The northernmost exposures of meta-volcanic rocks are in the Svartenuk Halvø area, which might represent the tapered edge of the volcanic basin or one of the above possibilities. Determining the depositional environment (e.g., subaerial, subaqueous, water depth) and tectonic setting of the Kangigdleq Formation (see Volcanic Rocks section) is critical to understanding the transition to the Nûkavsak Formation and the overall basin evolution through time.

Nûkavsak Formation

Excellent exposures of the Nûkavsak Formation were observed in the Kangerluarsuk Fjord area. A stratigraphic section was measured for several hundred metres from the Discovery zinc showing. The Nûkavsak Formation in this area did not yield many preserved sedimentary structures, but helped document vertical variations in the stratigraphy of the unit. Previously, only a ~6m stratigraphic section of Nûkavsak Formation was measured, so this field season's work far-surpassed this. The island at Anchorage #1 offers excellent sedimentary structures to help understand the depositional environment, but the island only contains Nûkavsak Formation, so its stratigraphic position (lower, middle, or upper

Nûkavsak Formation) is somewhat elusive. By correlation of similar features elsewhere, this island likely represents the to middle Nûkavsak Formation.

A ~325 m thick stratigraphic section was measured, beginning above the Qaarsukassak Formation in the Discovery area (Figure 19). The dominant lithology is a fine- to coarse-grained meta-sandstone (Figure 20), with variable proportions of biotite (5-20%) and feldspar (5-20%). Grain size did not vary systematically up-section, though normally-graded bedding was observed, which confirmed stratigraphic-up throughout the section. Bouma sequences were absent. Only one very coarse (granule-sized) horizon (greywacke) was observed and only limited meta-mudstone interbeds. Meta-sandstones were almost invariably non-calcareous. Near the base of the section, a laterally-discontinuous ~25 cm thick impure chaotic grey calcite marble bed occurs above a fine-grained calcite-cemented metasandstone. These represent the only calcareous sediments in the entire measured section. The origin of the calcite marble is unclear, but might represent a megaclast from the underlying Qaarsukassak Formation or re-sedimented (allodapic) limestone. It occurs laterally for about 50 m before pinching out.

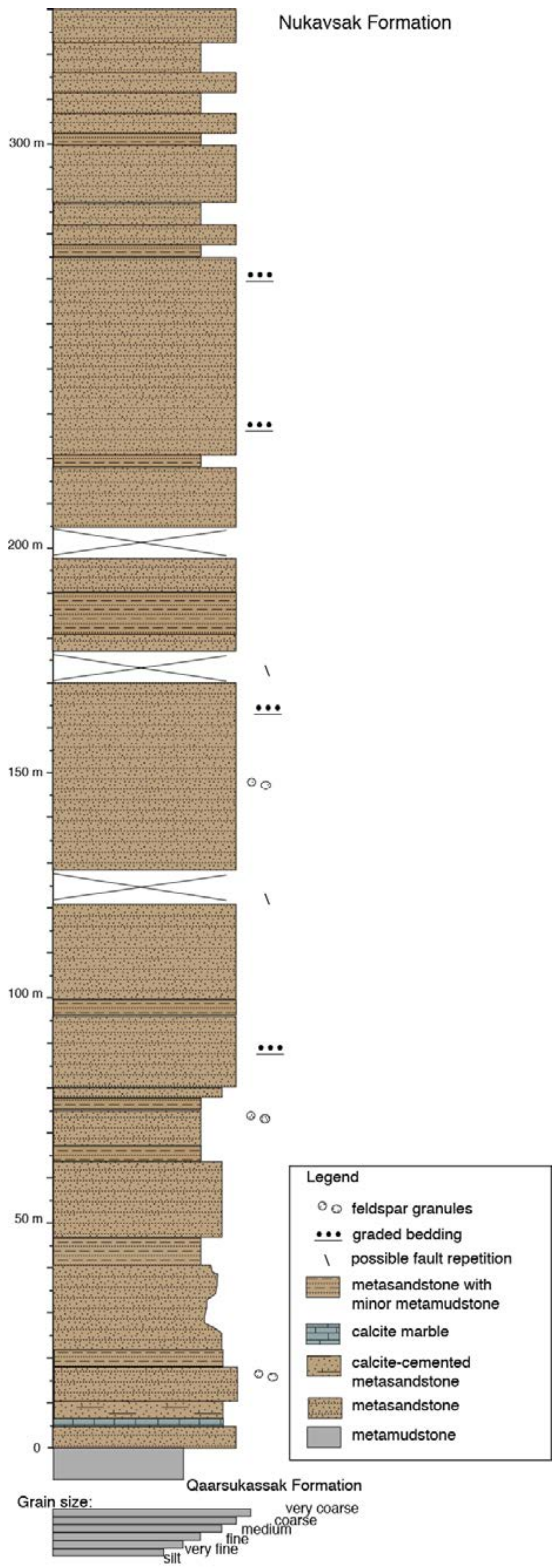


Figure 19. *Stratigraphic section of the Nûkavsak Formation, as established in the Discovery area.*


Figure 20. *Nûkavsak Formation outcrop near the Discovery area.*

Measuring a stratigraphic section of Nûkavsak Formation in the Qaarsukassak area highlighted the uncertainty associated with previous estimates of the stratigraphic thickness of the unit. Where the Nûkavsak Formation appears to be relatively homoclinal, it is actually tectonically-thickened by isoclinal folds and minor thrust faults. Conservatively, the stratigraphic thickness of the Nûkavsak Formation could be overestimated by as much as three times. Therefore, the succession is probably thinner than its estimated structural thickness of 5 km. Stratigraphic analysis from photogrammetry might help better quantify the true thickness of the Nûkavsak Formation.

Exposures of Nûkavsak Formation on the island of Anchorage #1 offered several intact sedimentary structures (Figure 21): graded bedding reminiscent of turbidites, flute casts, scour structures, planar cross-bedding, and intrabasinal clasts (Figure 22). These abundant clasts, likely derived from underlying/older sedimentary material, were not recognized in previous work. Clasts in order of descending abundance/occurrence include meta-volcanic rocks (mafic), semipelite (likely Qeqetarssuaq Formation), grey calcite marble, and quartz pebbles. Metavolcanic clasts in the Nûkavsak Formation ranged widely in size from a few centimeters to over 50 cm long. This section showed an overall coarsening upward trend. A metamudstone unit was also noted on the island of Anchorage #1 (Figure 23). Flute casts suggested current direction dominantly to the northeast. Previous work (e.g., Kalsbeek et al., 1998) was unable to determine a sediment transport direction, so this represents the first contribution to paleocurrent data for the Karrat Group. The abundance of meta-volcanic clasts (meter-scale) and pebbles suggests reworking of the underlying meta-volcanic rocks. Minor exposures of undeformed pegmatite intruding the Nûkavsak Formation occur on the east side of island of Anchorage #1. The only metamorphic indicator mineral observed in the Discovery area was biotite, consistent with greenschist facies conditions.

Figure 21. *Sedimentary structures in the Núkavsak Formation on the island of Anchorage #1: graded bedding (top, left and right), flute casts (bottom left), and scour structure (bottom right).*

Figure 22. *Top: Meta-volcanic clasts in Nûkavsak Formation (bedding perpendicular, left, and bedding plane, right). Bottom: basalt clasts in the Nûkavsak Formation on the island of Anchorage #1. Clasts are likely intrabasinal and derived from older Karrat Group units.*

Figure 23. *Meta-mudstone outcrop in the Nûkavsak Formation on the island of Anchorage #1.*

The Nûkavsak Formation is well-exposed in the area of Kangilleq Fjord, particularly on Qeqertarssuaq Island, Karrat Island, and Inngia Fjord. Access on Qeqertarssuaq Island is difficult, but exposures at sea level along the eastern shoreline are best, along with Majoqqaa on the north side. An ~1200 m thick section was traversed by rubber boat along the eastern shore of the island starting from Qeqertarssuaq peninsula, whereas only <80 m of section was possible to traverse at Majoqqaa on Qeqertarssuaq Island.

At Majoqqaa, the Nûkavsak Formation overall is a medium-grained meta-sandstone, with occasional elongate rounded cm-scale basalt clasts present or is a calcite-cemented, well-sorted meta-sandstone. Most of the outcrops at this locality lack mud (<2-5% for whole package). Flame structures (fluid escape structure) indicate the section was observed right way-up and also indicates relatively rapid deposition (Figure 24). Biotite was the only metamorphic mineral observed in outcrop.

On Qeqertarssuaq Island, the transition from meta-volcanic rocks to Nûkavsak Formation can be observed. The transition is characterized by a change from a volcanic-dominated to sediment-dominated succession, which shows a characteristic biotite-rich (25% biotite) purple meta-sandstone, sometimes lithic meta-sandstone, which passes upwards into meta-mudstone to meta-sandstone couplets and then into medium- to coarse-grained meta-sandstone. The Nûkavsak Formation is more mature than the transitional sediments (more quartz-rich, less biotite and feldspar) and contains large (15-30 cm) massive (rather than graded) beds.

On Karrat Island, the Nûkavsak Formation is typically a medium- to coarse grained meta-sandstone. Feldspar contents of the metasandstone range from ~15 to 25%. The meta-sandstone has occasional clasts of weathered meta-volcanic rocks (~20 cm long)—which is the same clast type seen on the island at Anchorage #1. This clast type is likely derived from the underlying meta-volcanic rocks. Also present here were small rounded pebbles of chlorite-epidote clasts (Figure 25). Where these have been weathered out, the rock appears pitted, which could explain this texture seen in other outcrops that were thought to be dissolution features associated with calcite-cemented meta-sandstone. Concentrated clast horizons occur on this part of Karrat Island, with 20-30% of beds comprised of pebbles in 1-10 cm thick beds. Semipelite clasts were observed here as part of the meta-volcanic package clast (Figure 26). The semipelite – meta-volcanic clasts are likely eroded from older units within the Karrat Group, including the Qeqertarssuaq and Kangigdleq formations. The abundance of these large clasts and the lack of mud indicates 1. Deposition on a slope from a relatively proximal source, and 2. Relatively high energy (no mud). Karrat Island is more proximal to the source of the eroded clasts than the island at Anchorage #1, since clasts are more abundant and larger than those observed at this island. Graded beds also occur here with very coarse (granule-size) to fine sand.

Figure 24. *Flame structure in Núkavsak Formation at Majoqqaa, Qeqertarssuaq Island.*

Figure 25. *Epidote-bearing pebbles common in the lower Nûkavsak Formation Location: Karrat Island.*

Figure 26. *Laterally-discontinuous and boudinaged semipelite layer (interpreted as a stretched clast) in the Nûkavsak Formation on Karrat Island.*

The depositional environment of the Nûkavsak Formation is consistent with a shallow marine setting, possibly on the slope of a continental shelf. An active tectonic setting is suggested by the influx of metre-scale intrabasinal clasts into the Nûkavsak Formation. The Nûkavsak Formation is relatively low metamorphic grade, usually greenschist and lower amphibolite facies, and is variably deformed. The Nûkavsak Formation could represent deposition in a foreland basin, but probably not in a foredeep setting, since rapid subsidence/increasing water depth is not implied by the stratigraphy. Instead the Nûkavsak Formation could represent more of a “molasse”-type sedimentation. Ongoing work (petrographic, stratigraphic, and geochronologic) will provide better constraints for the depositional environment and tectonic setting.

The contact between Nûkavsak Formation and meta-volcanic rocks is transitional over several tens of metres, suggesting that there was no hiatus between these two units. Importantly, two volcanic horizons within the lower Nûkavsak suggest that volcanism was waning, but still present, during the initial deposition of the Nûkavsak Formation. The meta-volcanic rocks show evidence of reworking, in the form of volcanic breccias; some of the volcanic material continued to be reworked during the deposition of the Nûkavsak Formation, resulting in the incorporation of abundant basalt clasts into the lower Nûkavsak Formation. This suggests active uplift in areas surrounding the basin.

The nature of the contact with the Kangigdleq Formation in the Svartenhuk Halvø area is typically a fault contact. This contact likely represents a minor translation of an original depositional contact. Therefore, sections of Nûkavsak Formation could be observed above the contact with the Kangigdleq Formation with a known-stratigraphic up context.

Undeformed basalt pebbles and boulders, in addition to possible mafic volcanic flows in the Nûkavsak Formation at Kangiusap Kuua, suggest a gradual transition from volcanic to clastic dominated sedimentation (Figures 27 & 28). These mafic volcanic flows observed in two places (Kangiusap Kuua and Inngia Fjord) suggest that the lowermost Nûkavsak Formation could be recording the final waning stages of volcanism.

Minor meta-mudstones occur at the base of the Nûkavsak Formation at Kangiusap Kuua, followed by characteristic transitional sediments (observed in other sections, including Inngia fjord and Qeqertarssuaq Island) of purple fine-grained lithic meta-sandstone that passes upwards into medium- to coarse-grained meta-sandstone with sporadic well-rounded basalt clasts and pebbles. Sedimentary structures are well-preserved in the Kangiusap Kuua area, including cross-bedding, undeformed clasts, and scour structures (Figure 29).

Granulite facies rocks (including previously mapped migmatitc metasandstone of the Nûkavsak Formation), as indicated by the Svartenhuk map sheet (Henderson and Pulvertaft, 1987), were not observed. Only greenschist and lower amphibolite facies rocks were observed. The lack of granulite facies or evidence of partial melt is important for the overall interpretation of the orogen. More detailed geothermobarometric studies are needed to more quantitatively constrain metamorphic P-T-t in different areas. This initial observation suggests overall lower metamorphic grade than the Piling and Penrhyn groups in Canada (Gagné et al., 2009).

Figure 27. *Clasts of meta-volcanic rocks (basalt?). Example on the right is possibly within a volcanic flow.*

Figure 28. *Flattened meta-volcanic clasts (lapilli?) overlain by mafic meta-volcanic flow (right).*

Figure 29. *Scour structure in the lowermost Nûkavsak Formation at the Kangiusap Kuua area.*

Volcanic rocks

Physical Volcanology

Rocks of volcanic origin are widely outcropping throughout the Karrat region. They form an important marker horizon that potentially can be used to correlate across the area. They have formerly been mapped as part of the Qeqertarssuaq Fm. This, however, requires revision, and it is suggested that they are included in the Kangigdleq Formation based on arguments presented in the Stratigraphy section (page 22). Preliminary results indicate that the thickness and preservation of primary textures through the region is variable. This however, may be biased due to difficulties in accessing outcrops in the steep cliffs and variable degrees of metamorphic overprinting. However, key observations from Kangilleq Fjord (Qangattarsuaq locality), Kussinersuup Aaffaa, Puallarsiiviup Qooruua, Niaqornakavsak (Anchorage #2) and Kangiussap Kuua, Salliarutsip Kangerlua (Inngia Fjord), where pillow lavas and/or pillow breccias as well as hyaloclastic textures were found, documents that the volcanic rocks were probably mainly of subaqueous (marine) origin. Pillow-lavas may form at variable depth and can only in certain instances be used as markers for water depth (Kawachi & Pringle 1988). However the shape and architecture of pillow lavas and related volcanic facies can be used to infer flow directions, “stratigraphic way-up” and the general volcanic environment. The discovery of a thick package of previously undescribed subaqueous volcanic rocks at Qangattarsuaq (Kangilleq Fjord) is, in this respect, important for the general understanding of the volcanic environment prior to the deposition of the Nûkavsak Formation. Most of the volcanic textures found throughout the Karrat region are also found in the Qangattarsuaq area, where these are better preserved and exposed. This makes it possible to put the volcanic textures into a more general context.

The meta-volcanic rocks at Qangattarsuaq are found in a synform in the steep cliffs of Kangilleq Fjord (Figure 30). Preliminary interpretation of this area suggests that the volcanic rocks are part of a larger volcanic structure. They rest on the quartzites of the Qeqertarsuaq Formation. The contact is generally sharp (Figure 31). However based on observation made from distance (photo flights) quartzites could be interbedded with the meta-volcanic rocks in places. It is recommended that this is investigated further by detailed 3D-mapping.

Variable degrees of structural deformation are found through the area. In the basal part, where inspected, the meta-volcanic rocks appear deformed and small tectonic folds have developed in places (Figure 31). The lower part of the meta-volcanic package at Qangattarsuaq is characterized by the frequent occurrence of quartz lenses. A range of primary volcanic textures are preserved in the area. Most noticeable is the relatively well preserved pillowed flows observed in different sections. Pillow shapes range from slightly flattened to flattened pillows (Figures 32-34). Other textures are pillow breccias and hyaloclastite (Figure 35 and 36). Also found in the cliffs at Qangattarsuaq are sheet flows a few meters thick to more massive 20 m thick sheet flows (Figure 37) that form marked terraces in the cliffs. It is in places possible to observe the flow stacking and interfingering of different flows. Preliminary mapping indicates that the pillowed flows are the lateral continuation of the sheet flows. The sheet flows generally dip 10-40° to the north, west of the axial part (Figure 30) of the synform, while lavas east of the axial part generally dip to the NW.

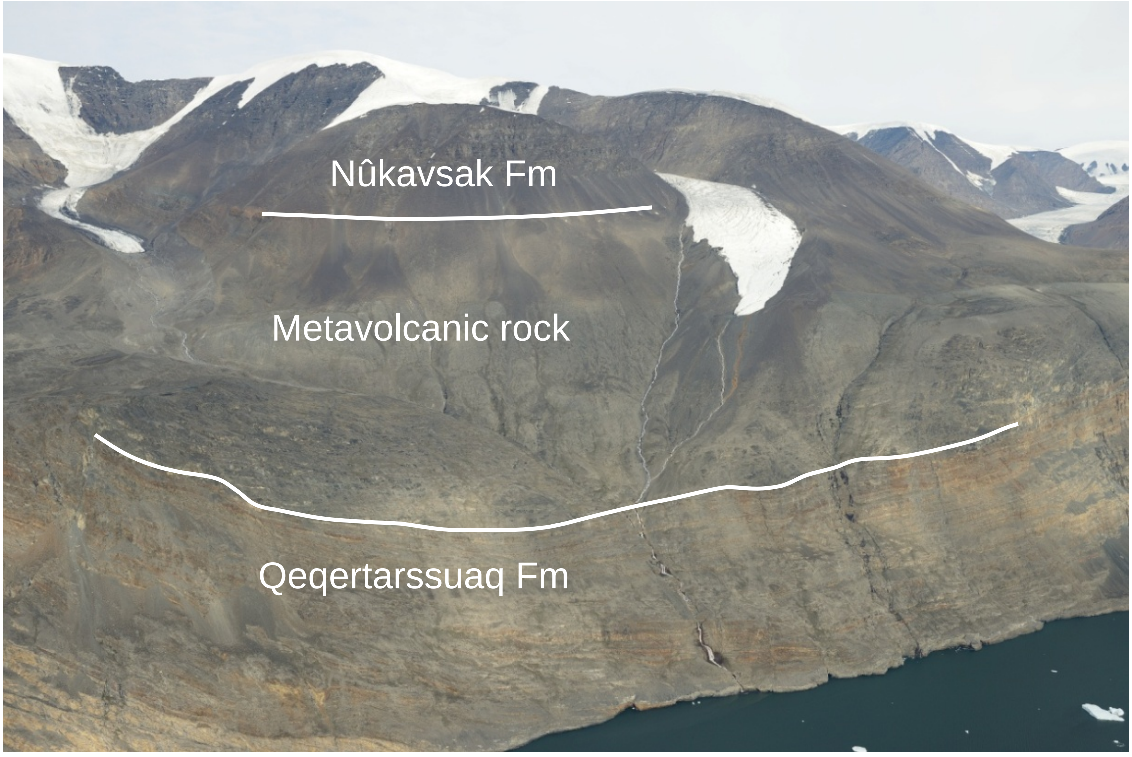


Figure 30. *Image showing the Kangigdleq Formation meta-volcanic rocks at Qangátarssuaq.*

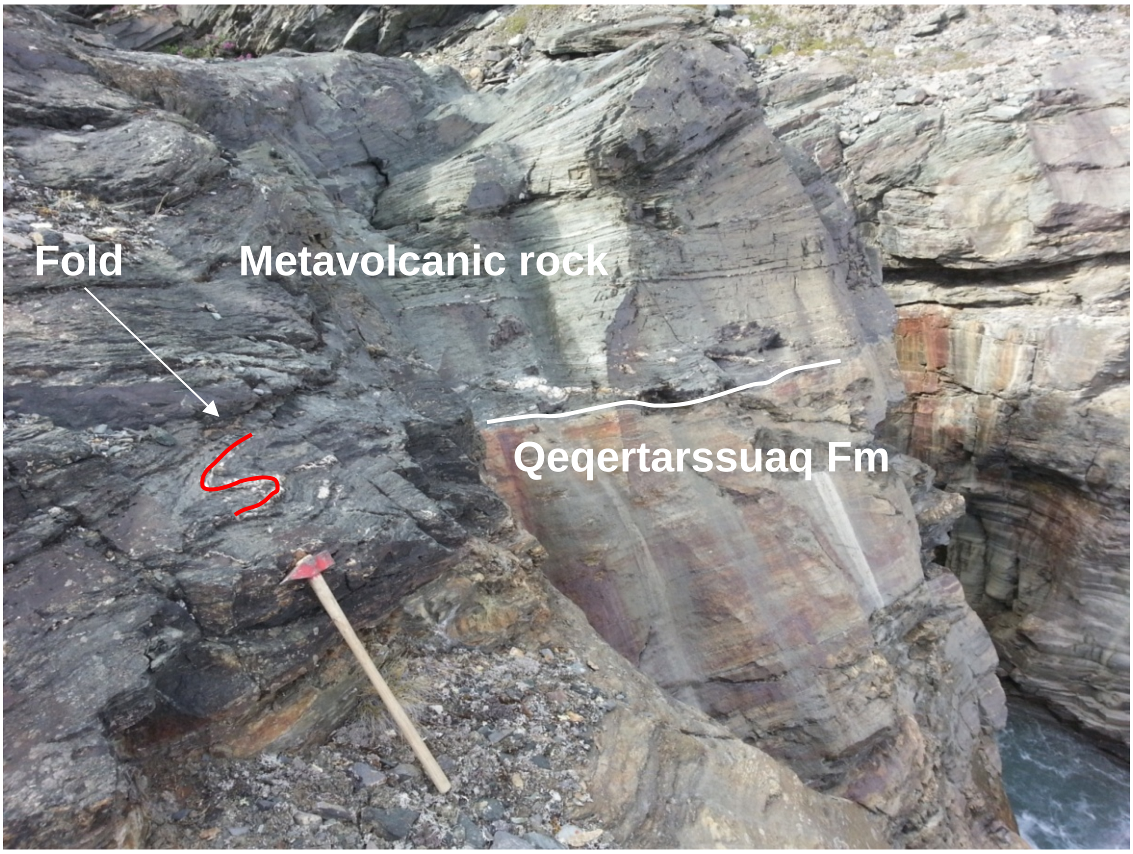


Figure 31. *Sharp basal contact between Kangigdleq Formation meta-volcanic rocks and the underlying quartzites of the Qeqertarssuaq Formation. Red line outlines fold structure in the lower part of the meta-volcanic rocks.*

Figure 32. *Image showing flattened smaller pillows (0-2 m).*

Figure 33. *Close-up image of close-packed pillows. White lines show the outline of pillows.*

Figure 34. *Pillows, highlighted by solid lines. Stippled lines show the outline of the chilled outer crust.*

Figure 35. *Image showing pillow breccia.*

Figure 36. *Hyaloclastite with jig-saw brecciated texture.*

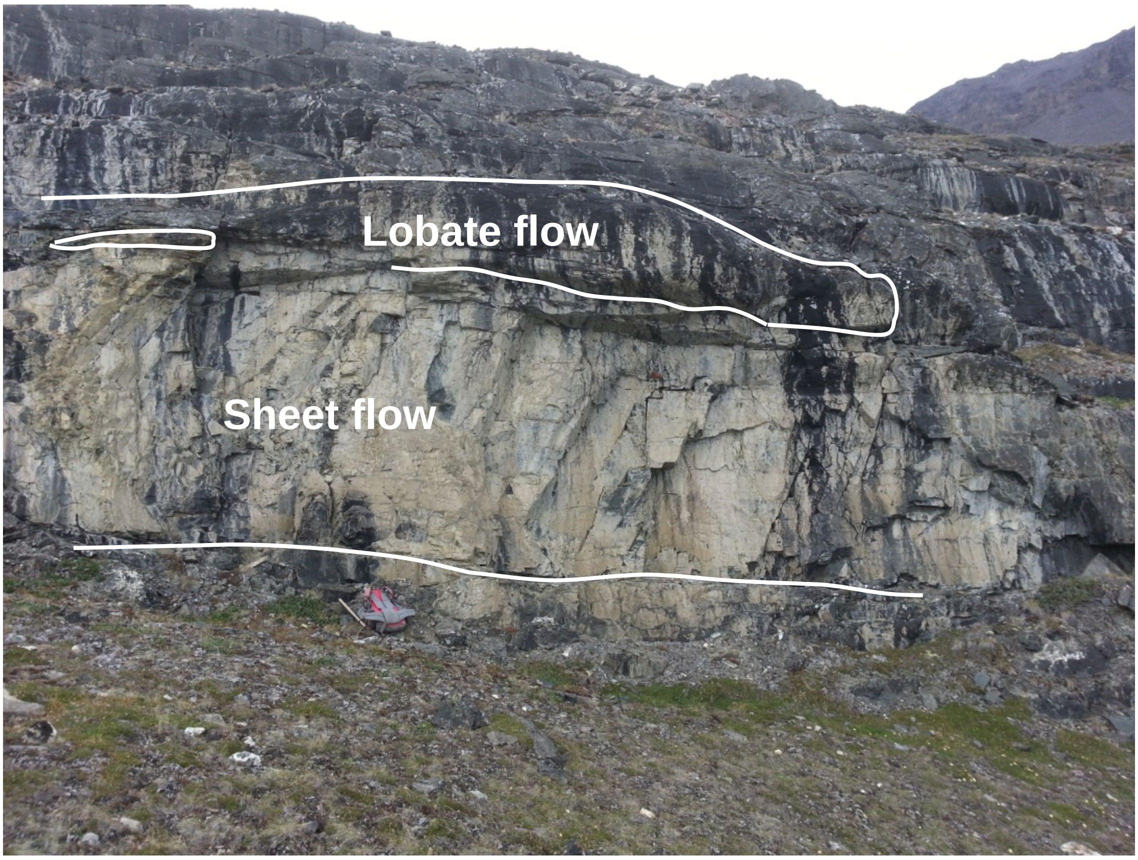


Figure 37. *Thick (20 m) massive sheet flow with lobate flow on top.*

We recommend that careful mapping of Qangattarsuaq area is undertaken in order to estimate flow/source direction as well as the general outline of the volcanic structure. A preliminary estimation of the thickness of the meta-volcanic rocks at Qangattarsuaq is that up to 850 m are preserved at this locality. Based on the observation that most of the volcanic textures found in the Karrat area (Kangigdleq Formation) are also found at Qangattarsuaq, where they can be put into context, suggests that lavas were erupted in a subaqueous setting. The Kangigdleq Formation meta-volcanic rocks are overlain by meta-sedimentary rocks of the Nûkavsak Formation and the transition appears gradual (see stratigraphy section p.32). The Nûkavsak Formation is characterized by the incorporation of clasts that are interpreted to be of volcanic origin. This gives the Nûkavsak Formation a striped appearance. The clastic material appears to have been available for erosion at the beginning of the deposition of the Nûkavsak Formation and throughout much of the formation of the Nûkavsak Formation. The periodic influx of volcanic material indicates that the material repeatedly was made available from a tectonic active hinterland with an unknown magmatic history. Careful examination of some of the larger clasts may shed light on the magmatic origin of these clasts.

Geochemistry

Eighteen samples of coherent mainly mafic rocks from the Karrat region have been analysed for major and trace elements at Actlabs, Canada. Samples were analysed using the 4Lithoresearch analytical package (www.actlabs.com), which involves a lithium metaborate/tetraborate fusion process that combines inductively coupled plasma optical emission spectrometry for major elements and inductively coupled plasma optical mass spectrometry for trace elements. The fusion process ensures total metals particularly for REE in resistate phases. The data exclude analysed fragmental volcanic rocks, cherts, carbonates, samples with more than 10 wt% LOI and mafic metasedimentary rocks that are not likely to yield geochemical data that reflect the geochemical character of their source magmas. All data is reported in Table 1.

Significant loss on ignition in some samples probably reflects a large carbonate component that will significantly influence the major element ratios. Also, chlorite identified in hand specimen in some samples may also reflect alteration, which again has probably significantly influenced major element ratios. Some of the samples identified in the field as being fine-grained mafic coherent volcanic rocks have very similar whole rock geochemistry to samples identified as fine-grained mafic meta-sedimentary rocks. A detailed petrographic work on representative thin sections is required to further assess the likely origin of some of these samples and therefore how the geochemistry should be interpreted. However, for the purposes of this preliminary report the original field descriptions and interpretations have been used to classify the rocks in the most general sense. These classifications need to be revisited after further work.

Table 1. Whole rock major and trace element geochemical data for meta-volcanic and associated (meta)sedimentary rocks of the Kangigdleq Fm.

Sample No.	Comments	Location	SiO2 %	TiO2 %	Al2O3 %	Fe2O3 %	MnO %	MgO %	CaO %	Na2O %	K2O %	P2O5 %	LOI %	Total %
COHERENT VOLCANIC ROCKS														
570105		Kangiusap Aaffaa	44.07	3.01	12.05	14.27	0.19	8.1	11.98	3.11	0.8	0.32	1.98	99.89
571725		Kangiusap Aaffaa	43.31	2.517	10.02	14.49	0.188	14.23	10.85	1.63	1.23	0.28	1.53	100.3
571726		Kangiusap Aaffaa	46.88	1.789	11.02	14.51	0.182	9.36	11.51	2.75	0.51	0.22	1.46	100.2
571727		Kangiusap Aaffaa	58.8	3.229	11.61	13.3	0.058	4.19	2.19	2.39	2.48	0.58	0.82	99.63
571716		Niaqornakavsak	40.81	2.381	8.1	12.6	0.19	10.32	16.13	1.12	0.94	0.18	6.45	99.2
570104		Niaqornakavsak	46.96	1.04	15.77	13.07	0.202	8.28	11.31	0.97	0.63	0.05	2.03	100.3
571718		Niaqornakavsak	52.9	2.974	10.4	11.78	0.188	6.4	10.94	2.52	0.14	0.37	1.65	100.3
571738		Qangattarsuaq	42.48	1.858	8.78	12.83	0.206	13.12	14.09	1.68	0.42	0.17	4.57	100.2
570128		Salliarutsip Kangerlua (Inngia Fjord)	41.73	3.056	11.29	13.09	0.164	10.24	12.26	2.32	0.87	0.77	4.33	100.1
570107		Salliarutsip Kangerlua (Inngia Fjord)	53	1.962	13.11	12.68	0.134	6.01	6.81	5.54	0.3	0.19	1.01	100.7
570109		Salliarutsip Kangerlua (Inngia Fjord)	62.83	0.604	21.64	6.4	0.058	1.69	1.07	1.32	3.23	0.05	1.59	100.5
571723		Umiammakku Nuuat	36.64	2.461	7.38	14.4	0.363	11.22	14.14	1.88	2.36	0.2	8.84	99.89
570102		Umiammakku Nuuat	37.87	3.079	10.47	17.23	0.506	8.84	8.91	1.88	3.71	0.4	5.82	98.71
571721		Umiammakku Nuuat	40.4	3.296	14.1	15.46	0.356	4.83	10.02	4.29	1.36	0.48	5.19	99.79
571719		Umiammakku Nuuat	41.04	3.168	12.7	16.03	0.271	5.68	11.16	2.95	2.17	0.32	4.84	100.3
571722		Umiammakku Nuuat	41.76	2.772	11.52	13.14	0.314	6.34	10.52	4.22	2.07	0.37	6.91	99.93
571754		Uparuaqqusuitsut Nunaat	39.89	5.542	14.18	20.23	0.19	8.83	2.6	0.54	6.51	0.63	1.35	100.5
571753		Uparuaqqusuitsut Nunaat	51.43	2.787	10.39	12.15	0.206	4.76	15.29	0.4	0.54	0.14	2.3	100.4
FRAGMENTAL VOLCANIC ROCKS. METASEDIMENTARY ROCKS. CHERT AND CARBONATE														
570106	carbonate-rich	Salliarutsip Kangerlua (Inngia Fjord)	60.6	0.51	9.74	4.62	0.276	2.62	13.17	0.82	0.43	0.09	7.74	100.6
571749	More than 10% LOI	Kangiusap Aaffaa	45.91	0.098	3.98	2.18	0.183	13.35	18.56	0.49	0.04	0.02	14.53	99.34
571746	clast dominated	Kangiusap Aaffaa	27.3	0.5	5.81	7.25	0.308	7.7	29.81	1	0.12	0.02	19.94	99.75
571744	clast dominated	Kangiusap Aaffaa	41.25	1.323	13.01	6.85	0.139	7.21	17.35	3.1	0.75	0.33	9.21	100.5
571728	More than 10% LOI	Niaqornakavsak	26.58	4.198	7.04	18.98	0.737	9.42	13.92	0.8	4.51	0.66	10.76	97.61
571717	More than 10% LOI	Niaqornakavsak	38.18	1.2	5.13	10.48	0.15	10.52	20.55	1.01	0.13	0.11	11.09	98.53
571734	metasedimentary rock	Niaqornakavsak	55.35	0.819	19.29	9.12	0.059	4.27	0.95	1.12	5.79	0.09	3.03	99.89
571730	metasedimentary rock	Niaqornakavsak	63.13	0.747	14.91	7.43	0.055	4.03	1.83	2.63	3.35	0.12	1.41	99.63
571732	cherty	Niaqornakavsak	65.07	0.649	14.39	6.75	0.052	2.94	1.6	1.54	3.8	0.08	3.26	100.1
571731	cherty	Niaqornakavsak	78.53	0.247	6.66	6.71	0.035	1.41	1.35	0.75	1.54	0.03	3.1	100.3
571729	chert	Niaqornakavsak	89.86	0.108	0.52	6.61	0.019	0.15	0.13	0.09	0.21	< 0.01	2.51	100.2
571733	chert	Niaqornakavsak	95.8	0.055	0.75	2.54	0.014	0.16	0.13	0.11	0.17	< 0.01	0.72	100.4
571747	clast dominated	Salliarutsip Kangerlua (Inngia Fjord)	39.59	1.819	7.73	13.27	0.189	14.89	15.11	0.99	0.1	0.13	6.34	100.2
571748	polymictic breccia	Salliarutsip Kangerlua (Inngia Fjord)	43.54	2.037	7.68	14.1	0.184	17.96	10.54	1.15	0.16	0.15	2.84	100.3
570110	metasedimentary rock	Salliarutsip Kangerlua (Inngia Fjord)	68.42	0.609	12.08	7.31	0.076	4.16	2.18	0.81	3.2	0.1	1.83	100.8
571720	More than 10% LOI	Umiammakku Nuuat	31.1	2.172	6.97	13.21	0.327	11.01	17.44	0.76	3.09	0.2	12.08	98.36
571752	More than 10% LOI	Uparuaqqusuitsut Nunaat	36.42	0.65	2.33	15.4	0.411	12.47	20.88	0.21	0.04	< 0.01	11.76	100.6
571750	carbonate		4.11	0.113	1.22	2.4	0.082	16.04	32.16	0.08	0.4	0.04	41.8	98.44

Table 1. *cont.*

Sample No.	Comments	Location	Be ppm	Sc ppm	V ppm	Cr ppm	Co ppm	Ni ppm	Cu ppm	Zn ppm	Ga ppm	Ge ppm	As ppm	Rb ppm	Sr ppm
COHERENT VOLCANIC ROCKS															
570105		Kangiusap Aaffaa	2	29	312	520	49	210	110	100	19	1.5	< 5	21	551
571725		Kangiusap Aaffaa	2	32	326	1010	70	370	30	120	18	1.8	< 5	41	202
571726		Kangiusap Aaffaa	3	30	361	980	62	350	140	130	22	1.5	< 5	8	377
571727		Kangiusap Aaffaa	2	15	218	60	27	60	60	130	19	1.6	< 5	65	152
571716		Niaqornakavsak	3	55	309	1060	61	230	40	90	15	1.4	< 5	36	519
570104		Niaqornakavsak	< 1	38	266	340	43	90	30	100	17	1.7	< 5	23	150
571718		Niaqornakavsak	2	28	284	260	28	80	< 10	110	18	1.3	< 5	< 1	646
571738		Qangattarsuaq	1	28	259	910	63	430	150	80	14	1.8	< 5	11	1124
570128		Salliarutsip Kangerlua (Inngia Fjord)	3	24	352	300	53	170	90	120	21	1.5	< 5	19	333
570107		Salliarutsip Kangerlua (Inngia Fjord)	2	29	295	530	47	230	290	80	15	1.5	< 5	7	309
570109		Salliarutsip Kangerlua (Inngia Fjord)	2	12	68	150	18	80	50	70	28	1.2	< 5	132	65
571723		Umiammakku Nuuat	27	63	364	1180	74	290	10	290	15	1.3	85	80	1532
570102		Umiammakku Nuuat	30	44	334	440	53	190	70	410	20	1.6	< 5	88	3121
571721		Umiammakku Nuuat	15	16	386	< 20	44	30	50	220	24	1.4	< 5	35	1426
571719		Umiammakku Nuuat	5	23	269	40	47	70	< 10	140	20	1.2	< 5	45	790
571722		Umiammakku Nuuat	21	32	294	290	46	90	10	220	18	1.2	< 5	66	2097
571754		Uparuaqqusuitsut Nunaat	2	22	411	< 20	63	90	< 10	180	31	1.8	< 5	116	125
571753		Uparuaqqusuitsut Nunaat	3	18	305	50	30	60	70	100	20	2.6	10	11	211
FRAGMENTAL VOLCANIC ROCKS. METASEDIMENTARY ROCKS. CHERT AND CARBONATE															
570106	carbonate-rich	Salliarutsip Kangerlua (Ingia Fjord)	1	11	88	170	12	50	10	60	10	1.2	< 5	24	325
571749	More than 10% LOI	Kangiusap Aaffaa	6	2	248	< 20	1	30	10	90	6	1.4	< 5	< 1	134
571746	clast dominated	Kangiusap Aaffaa	< 1	16	145	380	37	210	90	40	7	1.1	23	2	225
571744	clast dominated	Kangiusap Aaffaa	< 1	35	295	620	85	210	150	50	15	0.9	9	9	183
571728	More than 10% LOI	Niaqornakavsak	14	31	321	270	46	120	20	500	21	1.7	< 5	89	3438
571717	More than 10% LOI	Niaqornakavsak	2	62	250	1190	65	290	< 10	70	10	1.6	< 5	2	544
571734	metasedimentary rock	Niaqornakassak	2	24	169	180	22	100	80	150	25	1.8	< 5	172	88
571730	metasedimentary rock	Niaqornakassak	2	19	136	170	15	50	40	130	19	1.8	< 5	110	95
571732	cherty	Niaqornakassak	2	16	175	180	7	30	50	100	17	1.6	< 5	122	137
571731	cherty	Niaqornakassak	1	6	106	110	8	40	110	160	7	1.2	< 5	37	76
571729	chert	Niaqornakassak	< 1	1	83	70	1	< 20	40	< 30	1	< 0.5	< 5	4	21
571733	chert	Niaqornakassak	< 1	1	20	70	2	< 20	90	< 30	1	0.9	< 5	6	10
571747	clast dominated	Salliarutsip Kangerlua (Inngia Fjord)	1	26	248	990	71	590	30	90	13	1.4	< 5	1	630
571748	polymictic breccia	Salliarutsip Kangerlua (Inngia Fjord)	1	30	258	1010	80	660	20	90	13	1.5	< 5	1	302
570110	metasedimentary rock	Salliarutsip Kangerlua (Inngia Fjord)	1	13	106	260	16	70	50	110	15	1.7	< 5	112	77
571720	More than 10% LOI	Umiammakku Nuuat	17	38	296	900	52	170	< 10	270	14	1.3	< 5	98	1791
571752	More than 10% LOI	Uparuaqqusuitsut Nunaat	< 1	5	67	40	21	40	< 10	70	5	2.6	< 5	< 1	365
571750	carbonate		< 1	4	64	60	2	40	10	50	2	< 0.5	< 5	8	126

Table 1. *cont.*

Sample No.	Comments	Location	Y ppm	Zr ppm	Nb ppm	Mo ppm	Ag ppm	In ppm	Sn ppm	Sb ppm	Cs ppm	Ba ppm	La ppm	Ce ppm	Pr ppm	Nd ppm
COHERENT VOLCANIC ROCKS																
570105		Kangiusap Aaffaa	23.6	209	43.6	< 2	0.7	0.1	2	< 0.2	0.5	316	35.4	77.7	9.62	38.8
571725		Kangiusap Aaffaa	20.8	166	36.5	< 2	< 0.5	< 0.1	1	< 0.2	7.6	332	27.3	61	7.61	32
571726		Kangiusap Aaffaa	16.6	119	25.7	< 2	< 0.5	< 0.1	2	< 0.2	0.2	142	18.9	42.1	5.37	22.1
571727		Kangiusap Aaffaa	34.2	332	86.3	< 2	1.3	< 0.1	7	< 0.2	2.1	492	69.6	142	16.3	63.5
571716		Niaqornakavsak	17.9	135	31.4	< 2	0.6	< 0.1	1	0.4	2.1	549	27.5	58	6.99	28.8
570104		Niaqornakavsak	19.6	67	6.2	< 2	< 0.5	< 0.1	< 1	< 0.2	1.3	125	4.92	12.3	1.77	8.43
571718		Niaqornakavsak	25.3	196	60.1	< 2	0.8	0.1	2	0.7	0.2	80	51	106	12.3	48
571738		Qangattarsuaq	18.3	124	25.3	< 2	< 0.5	< 0.1	1	0.2	4.1	176	20.5	45.7	5.65	23.6
570128		Salliarutsip Kangerlua (Inngia Fjord)	28.4	305	69.2	< 2	1.2	< 0.1	2	0.3	1.9	192	69.4	146	16.9	66.5
570107		Salliarutsip Kangerlua (Inngia Fjord)	21	155	28.1	< 2	< 0.5	< 0.1	1	< 0.2	0.7	149	35	66.9	7.49	30.4
570109		Salliarutsip Kangerlua (Inngia Fjord)	15.3	238	9.2	< 2	0.8	< 0.1	2	< 0.2	4.5	746	35.1	71.8	7.41	26
571723		Umiammakku Nuuat	70	156	83.6	6	0.6	0.1	7	0.5	3.4	2708	70.6	137	15.4	60.2
570102		Umiammakku Nuuat	130	386	184	20	1.5	0.2	17	0.3	1.8	5657	253	532	61.8	242
571721		Umiammakku Nuuat	41	239	86.1	6	1	0.1	4	0.3	2.4	1676	66.6	138	16	64.7
571719		Umiammakku Nuuat	26.8	212	90.7	< 2	0.9	0.1	3	0.3	0.8	814	44.6	91.4	10.7	41.9
571722		Umiammakku Nuuat	38.8	236	86.9	< 2	0.9	0.1	5	0.5	1.8	2253	61.1	132	15.7	63.3
571754		Uparuaqqusuitsut Nunaat	37.6	333	38.6	< 2	1.1	0.1	2	< 0.2	14.3	1172	47.7	113	14.7	62.8
571753		Uparuaqqusuitsut Nunaat	22.3	191	29.8	< 2	0.6	0.1	3	0.4	0.7	21	30	63.7	7.55	30.7
FRAGMENTAL VOLCANIC ROCKS. METASEDIMENTARY ROCKS. CHERT AND CARBONATE																
570106	carbonate-rich	Salliarutsip Kangerlua (Ingia Fjord)	23.3	190	6.8	< 2	0.6	< 0.1	< 1	< 0.2	1.7	146	26.5	52.6	6.01	23.4
571749	More than 10% LOI	Kangiusap Aaffaa	6.7	10	1.4	5	< 0.5	< 0.1	2	0.3	0.2	17	5.31	8.9	1.2	4.95
571746	clast dominated	Kangiusap Aaffaa	10.4	26	1.5	< 2	< 0.5	< 0.1	< 1	0.2	0.1	126	2.8	6.29	0.91	4.69
571744	clast dominated	Kangiusap Aaffaa	18.6	60	5.2	< 2	< 0.5	< 0.1	< 1	< 0.2	2.3	156	4.3	11.6	1.81	9.47
571728	More than 10% LOI	Niaqornakavsak	217	220	324	10	0.9	0.2	20	< 0.2	0.7	7984	541	1110	128	508
571717	More than 10% LOI	Niaqornakavsak	9.4	66	16.5	< 2	< 0.5	< 0.1	< 1	< 0.2	0.4	54	14.6	31.6	3.82	16.4
571734	metasedimentary rock	Niaqornakavsak	23.8	139	11.6	< 2	0.7	0.1	7	< 0.2	9.7	955	44.6	86.1	9.84	37.4
571730	metasedimentary rock	Niaqornakavsak	20.2	150	9.4	< 2	< 0.5	< 0.1	1	< 0.2	7.7	455	29.4	59.7	6.73	25.6
571732	cherty	Niaqornakavsak	12.3	153	11.5	3	< 0.5	< 0.1	1	< 0.2	7	709	21.1	39.5	4.35	15.8
571731	cherty	Niaqornakavsak	6.8	78	2.3	3	< 0.5	< 0.1	< 1	< 0.2	2	357	4.7	9.07	1.06	4.1
571729	chert	Niaqornakavsak	1.7	14	3.2	36	< 0.5	< 0.1	4	< 0.2	0.1	62	2.94	4.99	0.6	2.45
571733	chert	Niaqornakavsak	1.9	11	2.4	7	< 0.5	< 0.1	< 1	< 0.2	0.4	35	1.35	2.6	0.3	1.14
571747	clast dominated	Salliarutsip Kangerlua (Inngia Fjord)	15.7	117	19.2	< 2	< 0.5	< 0.1	< 1	< 0.2	0.2	15	17.5	40.7	5.1	21.8
571748	polymictic breccia	Salliarutsip Kangerlua (Inngia Fjord)	15	126	21.9	< 2	< 0.5	< 0.1	< 1	< 0.2	0.2	85	14.9	36.7	4.97	21.4
570110	metasedimentary rock	Salliarutsip Kangerlua (Inngia Fjord)	18.5	186	6.2	< 2	0.7	< 0.1	1	< 0.2	7.6	456	27.3	58.9	6.89	26.2
571720	More than 10% LOI	Umiammakku Nuuat	41.9	122	48.8	6	< 0.5	0.1	5	0.3	3.2	2829	48.8	98.1	11.4	45.7
571752	More than 10% LOI	Uparuaqqusuitsut Nunaat	5.5	49	5.6	< 2	< 0.5	< 0.1	< 1	0.2	< 0.1	< 3	10.7	19.7	1.98	8.05
571750	carbonate		22.8	10	0.4	< 2	< 0.5	< 0.1	< 1	0.2	0.6	60	3.82	2.77	0.7	3.59

Table 1. *cont.*

Sample No.	Comments	Location	Sm ppm	Eu ppm	Gd ppm	Tb ppm	Dy ppm	Ho ppm	Er ppm	Tm ppm	Yb ppm	Lu ppm	Hf ppm	Ta ppm	W ppm
COHERENT VOLCANIC ROCKS															
570105		Kangiusap Aaffaa	8.3	2.65	7.21	0.98	5.14	0.89	2.32	0.29	1.6	0.223	4.9	3.04	< 0.5
571725		Kangiusap Aaffaa	7.04	2.27	6.28	0.88	4.81	0.84	2.12	0.279	1.66	0.226	4	2.39	< 0.5
571726		Kangiusap Aaffaa	4.96	1.63	4.69	0.66	3.61	0.63	1.59	0.203	1.16	0.183	2.7	1.75	< 0.5
571727		Kangiusap Aaffaa	12.2	3.47	8.9	1.29	7.06	1.29	3.41	0.463	2.85	0.407	6.6	7.09	2.5
571716		Niaqornakavsak	5.69	1.8	4.96	0.73	3.71	0.66	1.76	0.232	1.39	0.179	3.5	2.29	0.9
570104		Niaqornakavsak	2.47	0.906	3.28	0.58	3.62	0.7	2.1	0.315	2.06	0.315	1.7	0.18	0.8
571718		Niaqornakavsak	9.67	2.77	7.91	1.07	5.78	0.98	2.45	0.307	1.8	0.251	4.6	4.4	4.7
571738		Qangattarsuaq	5.06	1.84	4.62	0.73	3.76	0.69	1.77	0.24	1.49	0.208	3	1.86	< 0.5
570128		Salliarutsip Kangerlua (Inngia Fjord)	13	3.64	10.1	1.33	6.6	1.09	2.7	0.348	1.96	0.278	6.4	4.91	< 0.5
570107		Salliarutsip Kangerlua (Inngia Fjord)	6.2	1.87	5.33	0.78	4.45	0.8	2.08	0.282	1.78	0.261	3.6	2.03	< 0.5
570109		Salliarutsip Kangerlua (Inngia Fjord)	4.3	0.855	3.51	0.52	2.97	0.56	1.59	0.24	1.56	0.231	5.8	0.89	1.9
571723		Umiammakku Nuuat	14.1	5.08	14.4	2.29	13.6	2.6	6.93	0.974	5.76	0.76	3.9	2.07	32.3
570102		Umiammakku Nuuat	50.3	16.4	38.5	5.23	28.5	5.07	13.2	1.73	10.9	1.44	7.7	4.07	23.9
571721		Umiammakku Nuuat	13.1	4.2	11.8	1.6	8.55	1.5	3.94	0.493	3.19	0.431	5.4	4.91	8.7
571719		Umiammakku Nuuat	8.25	2.49	6.78	1.01	5.52	0.98	2.54	0.321	1.91	0.267	5.1	4.76	1
571722		Umiammakku Nuuat	13.9	4.91	11.9	1.61	8.46	1.44	3.75	0.515	3.04	0.399	5.6	5.24	22.3
571754		Uparuaqqusuitsut Nunaat	13.7	4.23	11.9	1.63	8.72	1.47	3.64	0.471	2.77	0.373	7.6	2.86	0.7
571753		Uparuaqqusuitsut Nunaat	6.64	2.3	5.59	0.85	4.51	0.82	2.25	0.321	1.93	0.278	4.4	1.98	3
FRAGMENTAL VOLCANIC ROCKS. METASEDIMENTARY ROCKS. CHERT AND CARBONATE															
570106	carbonate-rich	Salliarutsip Kangerlua (Inngia Fjord)	4.72	1.16	4.36	0.67	3.83	0.76	2.14	0.319	2.15	0.331	4.5	0.54	1
571749	More than 10% LOI	Kangiusap Aaffaa	0.97	0.265	1.06	0.19	1.02	0.2	0.62	0.088	0.6	0.106	0.2	0.13	1.5
571746	clast dominated	Kangiusap Aaffaa	1.45	0.862	1.75	0.28	1.7	0.35	1.03	0.138	0.84	0.127	0.7	0.06	< 0.5
571744	clast dominated	Kangiusap Aaffaa	2.97	1.28	3.59	0.6	3.61	0.71	1.86	0.26	1.59	0.231	1.6	0.27	< 0.5
571728	More than 10% LOI	Niaqornakavsak	89.3	25.5	58.9	7.97	42.6	7.43	20.6	2.79	16.2	2.12	6.1	9.09	27.9
571717	More than 10% LOI	Niaqornakavsak	3.41	1.02	2.91	0.41	2.11	0.36	0.93	0.117	0.68	0.091	1.8	1.18	< 0.5
571734	metasedimentary rock	Niaqornakavsak	6.93	1.26	5.01	0.76	4.42	0.88	2.6	0.385	2.58	0.397	3.6	1.31	5.6
571730	metasedimentary rock	Niaqornakavsak	4.94	1.06	4.15	0.64	3.82	0.71	2.06	0.317	2.06	0.311	3.7	0.75	1.9
571732	cherty	Niaqornakavsak	3.14	0.899	2.39	0.36	2.26	0.43	1.4	0.218	1.52	0.238	3.6	0.77	3.5
571731	cherty	Niaqornakavsak	1	0.334	0.96	0.19	1.13	0.25	0.8	0.114	0.77	0.119	1.8	0.25	0.8
571729	chert	Niaqornakavsak	0.44	0.131	0.35	0.05	0.27	0.06	0.18	0.027	0.17	0.024	0.2	0.45	4.6
571733	chert	Niaqornakavsak	0.27	0.074	0.28	0.05	0.28	0.06	0.19	0.029	0.19	0.029	0.2	0.02	< 0.5
571747	clast dominated	Salliarutsip Kangerlua (Inngia Fjord)	4.77	1.92	4.28	0.63	3.46	0.59	1.54	0.194	1.18	0.174	2.5	1.39	< 0.5
571748	polymictic breccia	Salliarutsip Kangerlua (Inngia Fjord)	5	1.67	4.33	0.59	3.32	0.6	1.5	0.205	1.14	0.178	3	1.63	< 0.5
570110	metasedimentary rock	Salliarutsip Kangerlua (Inngia Fjord)	5.42	1.09	4.28	0.65	3.88	0.71	2	0.301	2.12	0.319	4.6	0.58	< 0.5
571720	More than 10% LOI	Umiammakku Nuuat	11.4	4.24	10.6	1.48	8.42	1.52	3.84	0.485	2.81	0.379	3.5	1.74	8.3
571752	More than 10% LOI	Uparuaqqusuitsut Nunaat	1.82	0.696	1.65	0.24	1.26	0.23	0.52	0.067	0.36	0.051	1	0.4	< 0.5
571750	carbonate		0.91	0.301	1.38	0.21	1.61	0.41	1.36	0.208	1.24	0.188	0.1	0.01	0.7

Table 1. *cont.*

Sample No.	Comments	Location	Tl ppm	Pb ppm	Bi ppm	Th ppm	U ppm
COHERENT VOLCANIC ROCKS							
570105		Kangiusap Aaffaa	< 0.05	< 5	< 0.1	3.59	0.88
571725		Kangiusap Aaffaa	< 0.05	< 5	< 0.1	2.55	0.8
571726		Kangiusap Aaffaa	< 0.05	< 5	< 0.1	1.76	0.52
571727		Kangiusap Aaffaa	0.12	7	< 0.1	7.71	3.35
571716		Niaqornakavsak	0.06	< 5	< 0.1	2.74	1.01
570104		Niaqornakavsak	< 0.05	6	< 0.1	0.68	0.45
571718		Niaqornakavsak	< 0.05	8	< 0.1	5.15	1.2
571738		Qangattarsuaq	< 0.05	< 5	< 0.1	2.03	0.54
570128		Salliarutsip Kangerlua (Inngia Fjord)	< 0.05	11	0.2	6.94	3.53
570107		Salliarutsip Kangerlua (Inngia Fjord)	< 0.05	5	< 0.1	5.19	0.91
570109		Salliarutsip Kangerlua (Inngia Fjord)	0.59	17	< 0.1	10.3	2.38
571723		Umiammakku Nuuat	0.56	36	0.2	30.6	0.82
570102		Umiammakku Nuuat	0.72	45	0.2	102	2.36
571721		Umiammakku Nuuat	0.23	32	0.1	13.3	1.29
571719		Umiammakku Nuuat	< 0.05	9	< 0.1	4.74	0.99
571722		Umiammakku Nuuat	0.3	55	0.2	17.5	1.19
571754		Uparuaqqusuitsut Nunaat	0.09	< 5	< 0.1	3.59	1.1
571753		Uparuaqqusuitsut Nunaat	< 0.05	< 5	< 0.1	3.02	0.6
FRAGMENTAL VOLCANIC ROCKS. METASEDIMENTARY ROCKS. CHERT AND CARBONATE							
570106	carbonate-rich	Salliarutsip Kangerlua (Inngia Fjord)	< 0.05	18	< 0.1	8.03	1.46
571749	More than 10% LOI	Kangiusap Aaffaa	< 0.05	9	< 0.1	0.95	3.82
571746	clast dominated	Kangiusap Aaffaa	< 0.05	< 5	< 0.1	0.12	0.07
571744	clast dominated	Kangiusap Aaffaa	< 0.05	8	< 0.1	0.32	3.84
571728	More than 10% LOI	Niaqornakavsak	0.59	104	0.3	152	1.73
571717	More than 10% LOI	Niaqornakavsak	< 0.05	< 5	< 0.1	1.52	0.37
571734	metasedimentary rock	Niaqornakavsak	0.96	24	0.3	13.1	3.71
571730	metasedimentary rock	Niaqornakavsak	0.74	21	0.2	9.22	2.72
571732	cherty	Niaqornakavsak	0.89	19	< 0.1	9.84	2.95
571731	cherty	Niaqornakavsak	0.19	15	0.6	3.42	1.04
571729	chert	Niaqornakavsak	0.29	6	< 0.1	0.75	1.68
571733	chert	Niaqornakavsak	< 0.05	< 5	< 0.1	0.48	0.71
571747	clast dominated	Salliarutsip Kangerlua (Inngia Fjord)	< 0.05	< 5	< 0.1	1.63	0.42
571748	polymictic breccia	Salliarutsip Kangerlua (Inngia Fjord)	< 0.05	< 5	< 0.1	1.69	0.45
570110	metasedimentary rock	Salliarutsip Kangerlua (Inngia Fjord)	0.61	18	0.1	7.31	2.19
571720	More than 10% LOI	Umiammakku Nuuat	0.29	23	< 0.1	15.8	0.56
571752	More than 10% LOI	Uparuaqqusuitsut Nunaat	< 0.05	< 5	< 0.1	0.7	0.24
571750	carbonate		0.45	39	< 0.1	0.06	23.4

More consistent geochemical trends are indicated by the trace and REE chemistry. All but one of the analysed samples show light REE enrichment over a wide range of REE concentrations, from 10 times to more than 1600 times chondrite values (Figure 38). This includes samples from amphibolites at Niaqornakavsak, a known REE prospect. This LREE-enriched trend is consistent both with data of Mott et al (2012) from REE-mineralised amphibolites at Niaqornakavsak and also with the data of Johns et al (2006) from the Bravo Lake Formation on Baffin Island. The data available thus far indicate that the geochemistry of the majority of the mafic meta-volcanic rocks is very consistent over a large area, which lends weight to the interpretation that this LREE-enriched signature is related to the magmatic source composition. Alternatively, Mott et al. (2012) suggested that the REE deposit at Niaqornakavsak was produced by metasomatic alteration of the host amphibolites by a ferrocarbonatite-derived fluid. However, it is difficult to envisage why this LREE-enriched signature should be so consistent on a regional scale, including at the Niaqornakavsak deposit, if a carbonatitic fluid was the source. It is therefore viable that the basalts themselves are the source of the REE and that local enrichment has occurred by hydrothermal leaching of some parts of the volcanic stratigraphy with deposition occurring in other parts. Further work is required to investigate these questions.

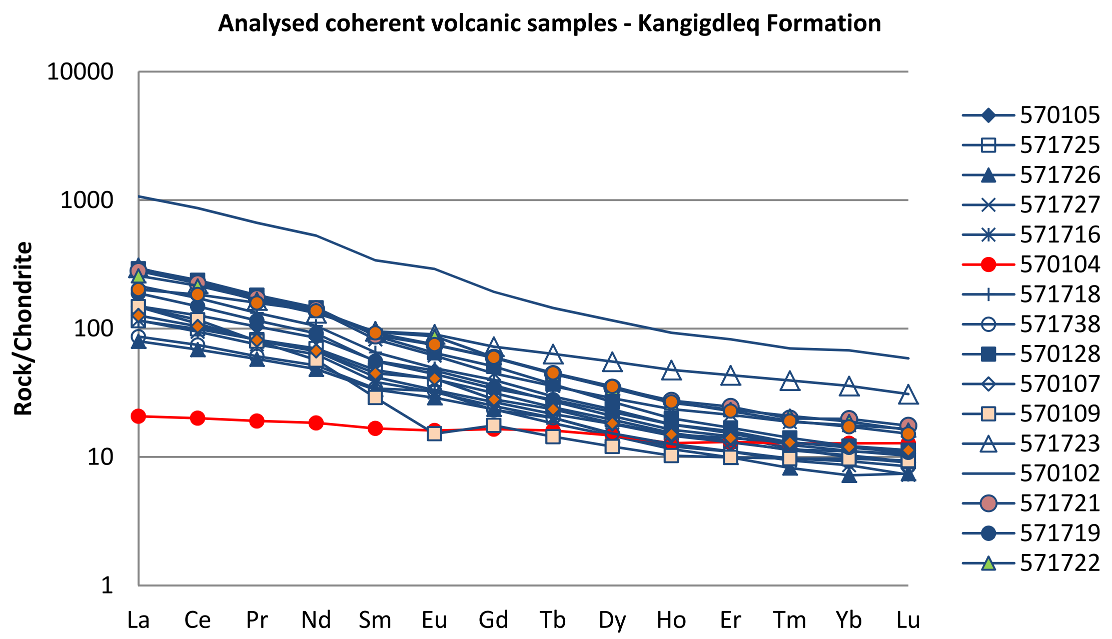


Figure 38. *Chondrite-normalised REE profiles for samples of coherent meta-volcanic rocks from the Karrat region. See Table 1 for locations. LREE enriched samples are coloured in blue lines. Sample with flat REE profile is coloured in red. Chondrite normalizing values are from McDonough and Sun (1995).*

The majority of these LREE-enriched samples cluster tightly in the alkali basalt field on a Zr/Ti-Nb/Y plot (Figure 39), in a similar manner as -the Bravo Lake Formation (Baffin Island, Nunavut, Canada), which is thought to be correlative (Johns et al., 2006). These samples also plot within the transitional to alkaline within plate basalt field on a Ti/Y vs. Nb/Y plot (Figure 40). Given this and the similarity with the Bravo Lake Formation (Figure 41), the geochemistry of the Karrat Group meta-volcanic rocks is consistent with the current models proposed for the formation of the Bravo Lake Formation (see below).

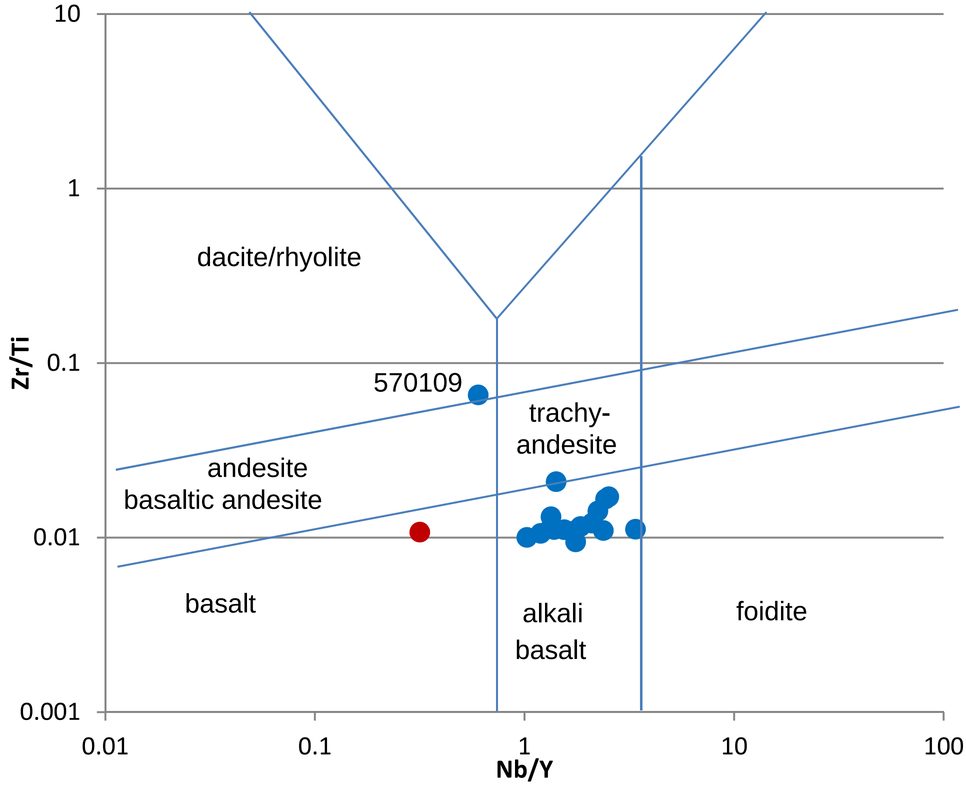


Figure 39. *Samples of coherent meta-volcanic rocks from the Karrat region plotted on the revised Zr/Ti-Nb/Y Winchester-Floyd diagram of Pearce (1996). LREE enriched samples are coloured in blue. Sample with flat REE profile is coloured in red. Most samples cluster tightly in the alkali-basalt field.*

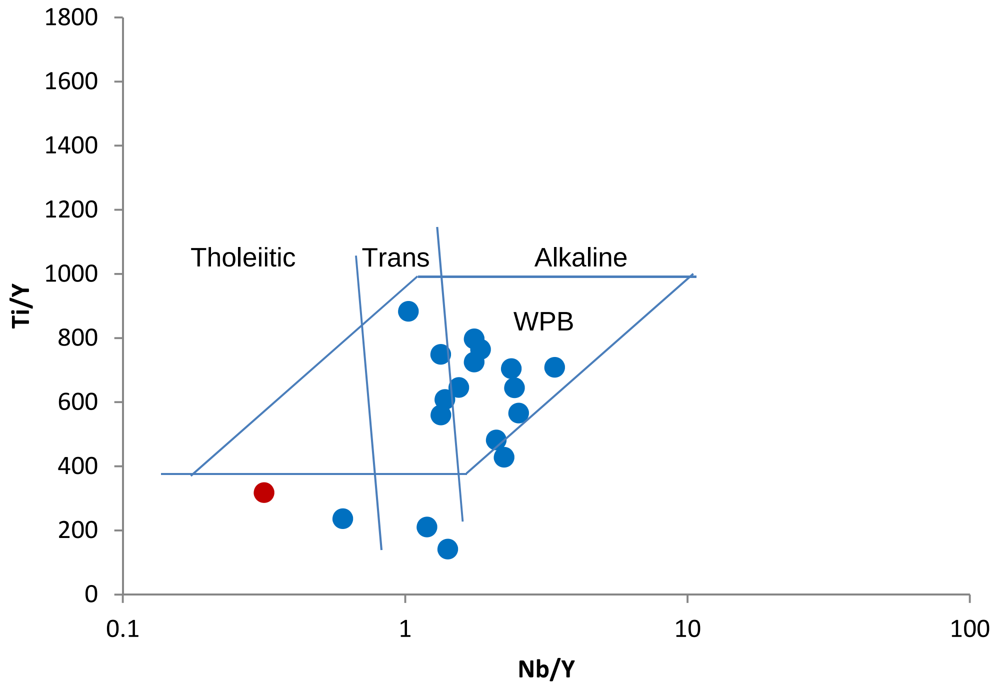


Figure 40. *Samples of coherent meta-volcanic rocks from the Karrat region plotted on the revised Ti/Y-Nb/Y diagram of Pearce (1982). Colour scheme follows that of Figure 39. Most samples plot within transitional to alkaline within plate basalt field (WPB).*

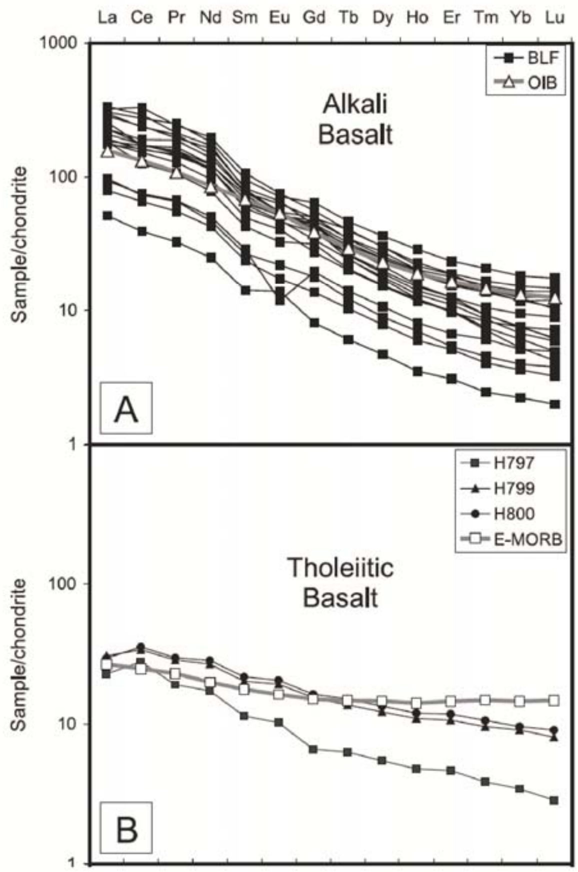


Figure 41. *Chondrite-normalised REE profiles for samples of the Bravo Lake Formation (Baffin Island, Nunavut, Canada) from Johns et al. (2006) showed for comparison with the Karrat meta-volcanic rocks (Figure 37).*

One exception to the LREE-enriched trend is a sample from Niaqornakavsak, which has a flat REE profile with only a slight enrichment in LREE. Interestingly this is similar to the REE patterns of subordinate tholeiitic basalts identified also in the Bravo Lake Formation (Johns et al., 2006). The significance of this one sample is currently unclear.

Broader perspectives

A linkage with the Paleoproterozoic meta-volcanic rocks in the intracratonic basin of the Archean Rae and Hearne provinces of the Canadian Shield has previously been discussed by Jackson & Berman 2000 and Shannon et al., 2006. The meta-volcanic rocks of the Karrat Group have comparable geochemistry with the Paleoproterozoic Bravo Lake Formation (part of the Piling Group) rocks from Baffin Bay, Nunavut, Canada (Johns et al. 2006). A mantle plume origin has previously been suggested for the Bravo Lake Formation (Anderson et al. 1997; Jackson 2000; Jackson and Berman 2000) while Johns et al., 2006 argued that the origin of Bravo Lake Formation was better explained by local strike-slip related rifting. In case of the meta-volcanic rocks of the Karrat Group, both a plume and local strike-slip related rifting episode is compatible with the data and it is probably difficult to resolve which model is more likely for the Karrat Group meta-volcanic rocks. One possibility may be to use geochronology to assess whether there is consistent regional age variation that may indicate movement of a plume. It is in this respect suggested that the extent of the meta-volcanic rocks is mapped based on the photo flights prior to new field work in order to establish the thickness of the meta-volcanic rocks. This will help to constrain areas with greater volcanic thickness that could be targets in future field work. The volcanic rocks of the Karrat region should be structurally restored. This would allow investigating for broad scale changes in thickness that could reflect hidden volcanic structures and or possible structural alignment of such structures. That this is important is well illustrated at the Qangattarsuaq locality where the Kangigdleq Formation is found in a synformal structure. Reconstruction of the synform to horizontal would give the volcanic rocks the geometry of a volcanic edifice instead of that of filling a depression.

Structural Geology

The most important element hitherto unrecognized in the Karrat Group is an unconformity visible from south to north that separates the Karrat Group into two sedimentary cycles. The stratigraphic character of this depositional feature is recognized in the Alfred Wegenr Halvø-Kangerlussuaq Fjord Domain where it separates the Umanak Gneiss below from pelites, meta-greywakes, quartzites and marbles of the Qaarsukassak Formation and Nukavsak Formation above (Figure 43). To the north, in the Umiammakku-Inngia Fjord Domain area the unconformity separates the Qeqertarssuaq Formation from the Nûkavsak Formation (Figure 43). In detail the meta-volcanic rocks of the Kangigdleq Formation appear to be stratigraphically above the unconformity and hence belong to the second cycle together with the Nûkavsak Formation.

This Paleoproterozoic unconformity becomes an important regional event separating two distinct tectonic cycles. It is used here together with the new stratigraphic and structural information, coupled with new photogeology, to re-define the tectonic evolution of the Paleoproterozoic Rinkian Belt.

Early deformation structures observed in the Qeqertarsuaq Formation and the Umanak Gneiss pre-date the development of the unconformity and are attributed to the Qeqertarssuaq Stage (D1). The deformation post-dating the unconformity can be separated into three distinct stages named the Kigarsima Stage (D2), related to a WSW-ENE to SW-NE oriented compression, the Maarmorilik Stage (D3), related to NW-SE compression and the Svartenhuk Stage (D4), with extension around intrusions and distal E-W compression.

Based on the different types of rocks, meta-sedimentary covers, structures and basement-cover relationship, the Karrat region is subdivided from south to north into four structural domains (Figure 42):

- Nunaarsussuaq-Maarmorilik Domain
- Alfred Wegeners Halvø-Kangerlussuaq Fjord Domain
- Umiammakku-Inngia Fjord Domain
- Kangiusap Kuua-Ukkusissat Fjord Domain

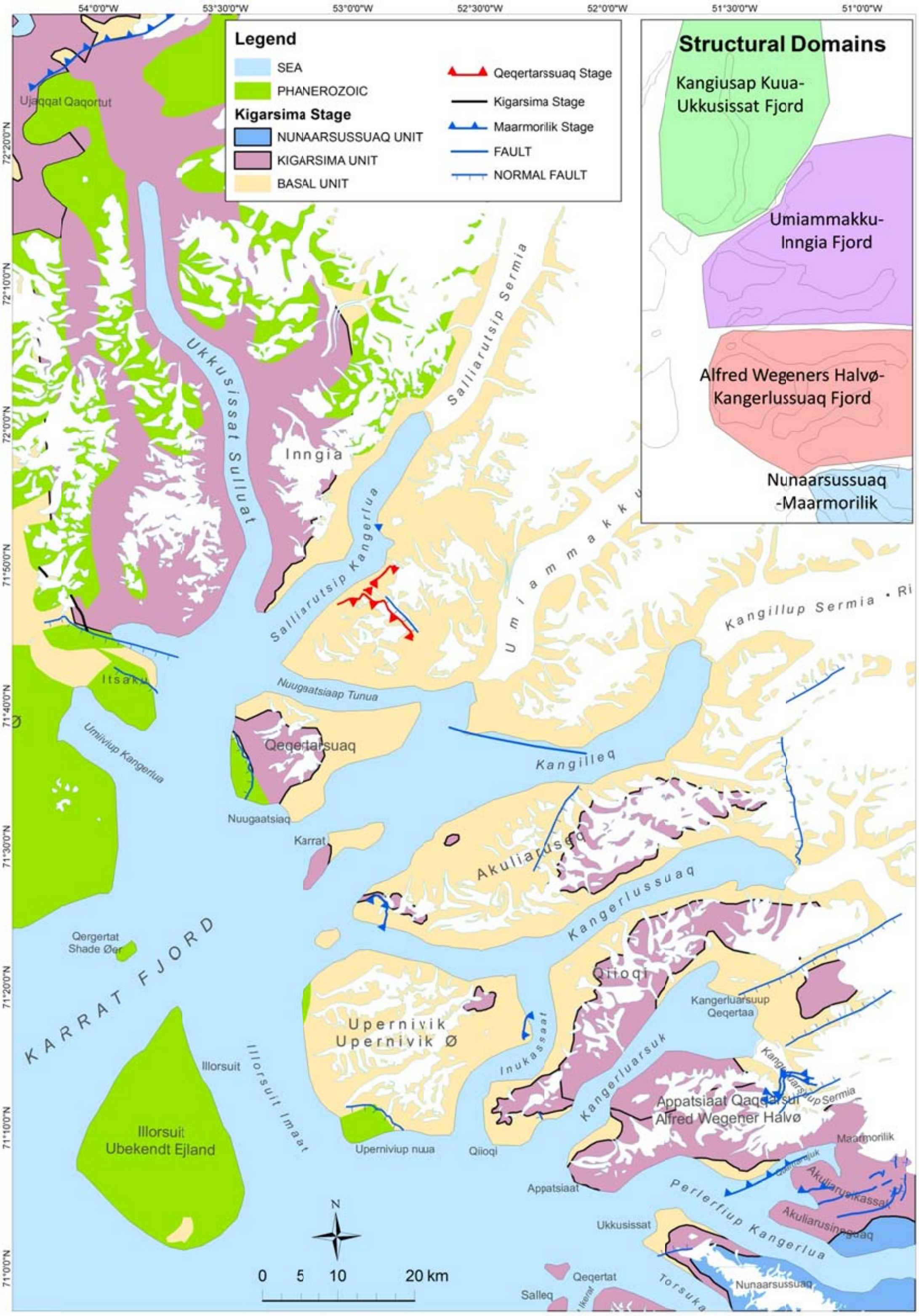


Figure 42. *Structural Map of the Karrat Fjord region. Inset map shows the Structural Domains.*

The Nunaarsussuaq-Maarmorilik Domain

In this structural domain, the meta-sedimentary cover is mainly represented by the Mârmorilik Formation that rests unconformably above a smooth surface onto the Umanak Gneiss. The basal sequence of the Mârmorilik Formation is represented by quartzites (Garde 1978), and the contact with the Umanak Gneiss is unconformable sedimentary. On the Nunaarsussuaq peninsula, as also noticed by Henderson and Pulvertaft (1987), two major thrust faults are observed (Figure 43). The thrust contacts separate a stack of three tectonic units. The uppermost unit corresponding to the Nunaarsussuaq Nappe (Grocott and Pulvertaft, 1990) continues to the south and is represented by an isoclinal antiform of Umanak Gneiss recognized by gently NNW-dipping axial planar cleavages; the intermediate unit, here named the Maarmorilik Unit, is represented by 500-600 metres of Umanak Gneiss and 300-400 metres of Mârmorilik Formation; the lower unit, here named the Basal Unit, represented by the Umanak Gneiss covered by a sequence of pelites folded together with a thin layer of marbles. The Ukkusissat Unit extends to the north, in the Alfred Wegeners Halvø, that in turn, is overthrust by basement rocks belonging to the Maarmorilik unit.

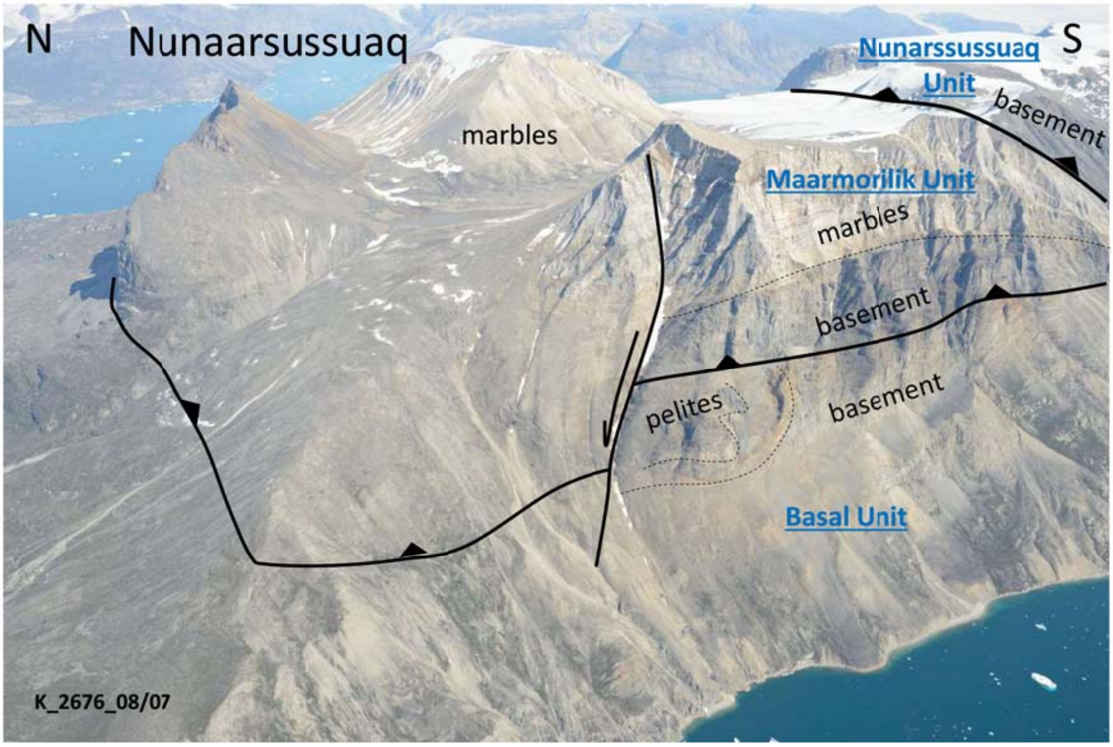


Figure 43. *Oblique photo of the Nunaarsussuaq peninsula showing the stack of three tectonic units: the Nunaarsussuaq Unit is the uppermost basement unit; the Maarmorilik Unit is the intermediate and represented by Umanak Gneiss and marbles of the Mârmorilik Formation; the lowest one, the Basal Unit, is represented by Umanak Gneiss covered by pelites and marble layers.*

In the Maarmorilik and Nunngarut areas, the Mârmorilik Formation is deformed with folds and thrusts (Figure 44), while in the easternmost part (the South Lakes) several faults are preserved. These normal faults, probably re-activated during the compressional stages, are folded in an upright fold together with the Umanak Gneiss. The normal offset along the faults and the apparent thickness variation across them (the South Lake Fault as an example) indicate a syn-sedimentary activity of these structures constituting the original architecture of a rift basin.

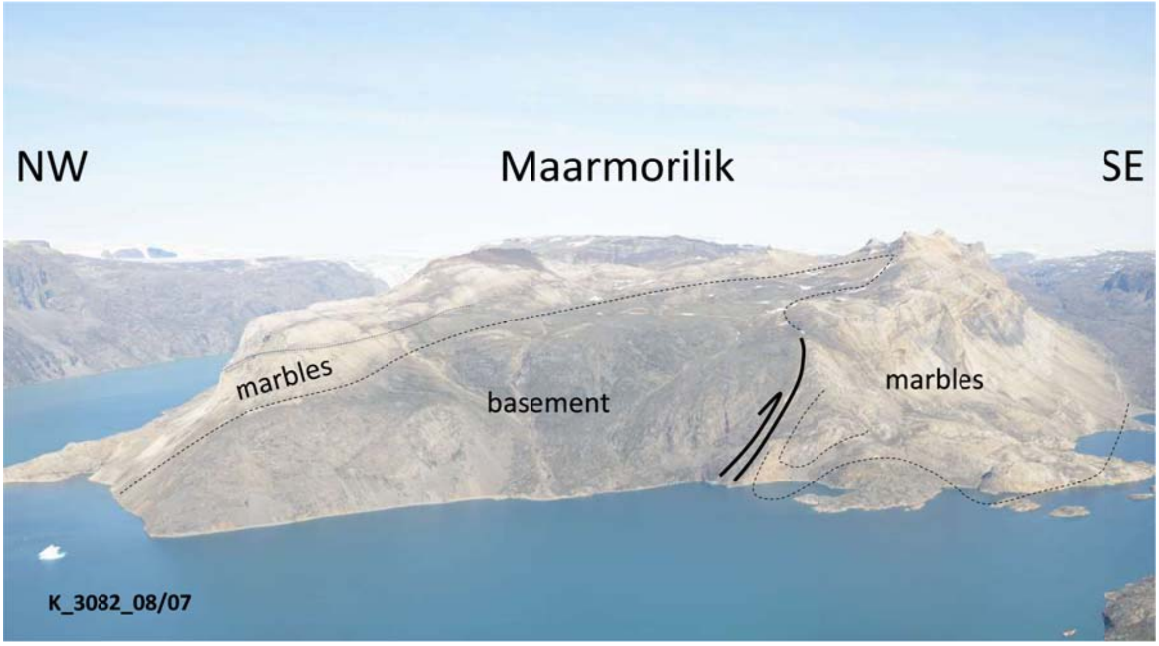
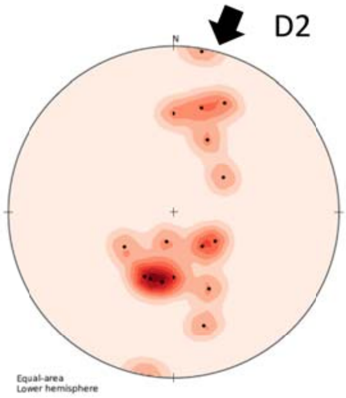
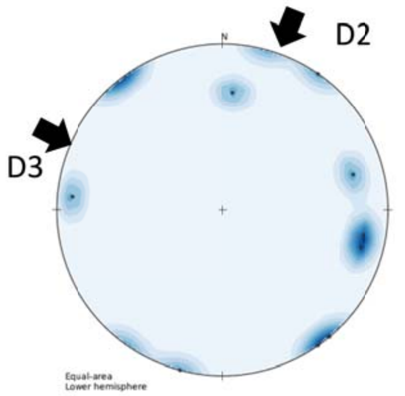


Figure 44. *Oblique photo of the Maarmorilik area showing the contact of Umanak Gneiss and the Mârmorilik Formation along a SE-verging thrust fault at Nunngarut, part of the Maarmorilik stage (D3).*

At least three major deformation stages were recognized in this domain:

- E-W to NW-SE extension characterized by N-S- and NE-SW-trending normal faults (rift stage);
- SSW-NNE to SW-NE compression, representing the main deformation stage, characterized by NW-SE- to WNW-ESE-oriented fold axes (D2 stage);
- NW-SE compression representing the last event and characterized by NNW-dipping thrusts, and locally by pressure solution cleavage overprinting the previous compressional event (Figure 45, D3 stage).





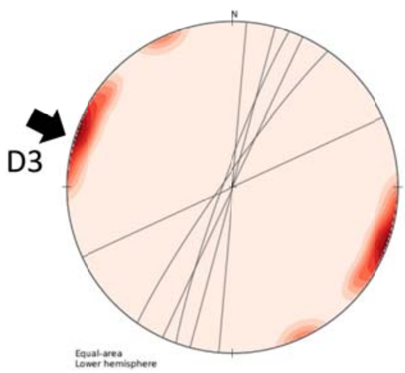


Figure 45. *Stereoplots of structural data collected in the Maarmorilik area (lower hemisphere, equal area). Top: poles to bedding of folded marbles showing a NNE-SSW compression (Kigarsima Stage); middle: fold axes showing two different orientations of the compression interpreted as the Kigarsima Stage (D2) overprinted by the Maarmorilik Stage (D3); lower: pressure solution cleavage (D3-stylolites) post-dating the folds related to the Kigarsima Stage, showing a coherent stress orientation with F3- fold axes.*

Alfred Wegeners Halvø-Kangerlussuaq Fjord Domain

This structural domain is characterized by the presence of a well-developed meta-sedimentary rock-Umanak Gneiss unconformity with paleovalleys incised in the Umanak Gneiss basement (Figures 46-48). This unconformity was previously interpreted as fault contact (Figure 46). The bottom of the paleovalleys is locally filled by meta-volcanic rocks and by the thin meta-sedimentary sequence constituting the Qaarsukassak Formation, while the meta-sandstone of the Nûkavsak Formation fills in the top part of the valleys (Figure 47 and 48).

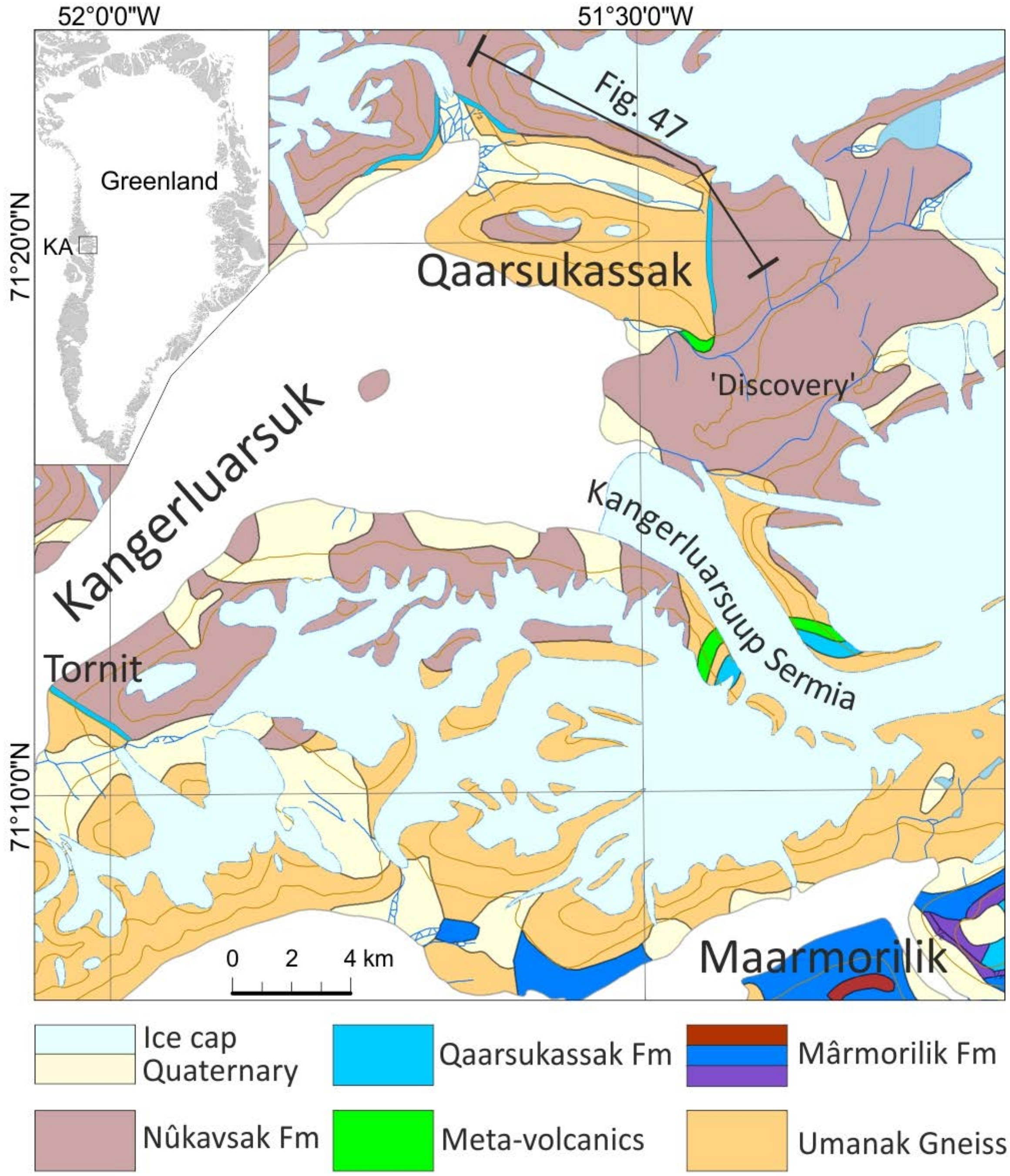


Figure 46. *Geological map of the "Discovery area" (modified after Escher, 1980). The meta-sedimentary rock-Umanak Gneiss contact had been interpreted as a series of faults. Black line A-B corresponds to the geological cross-section in Figure 47.*

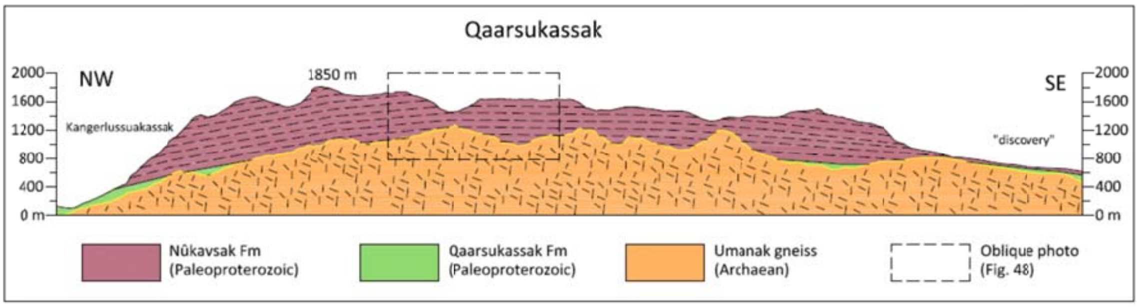


Figure 47. *Geological cross-section of Qaarsukassak showing the Paleoproterozoic incised valleys filled in by the Qaarsukassak Formation followed by the meta-greywakes of the Nûkavsak Formation. Inset corresponds to Figure 48.*

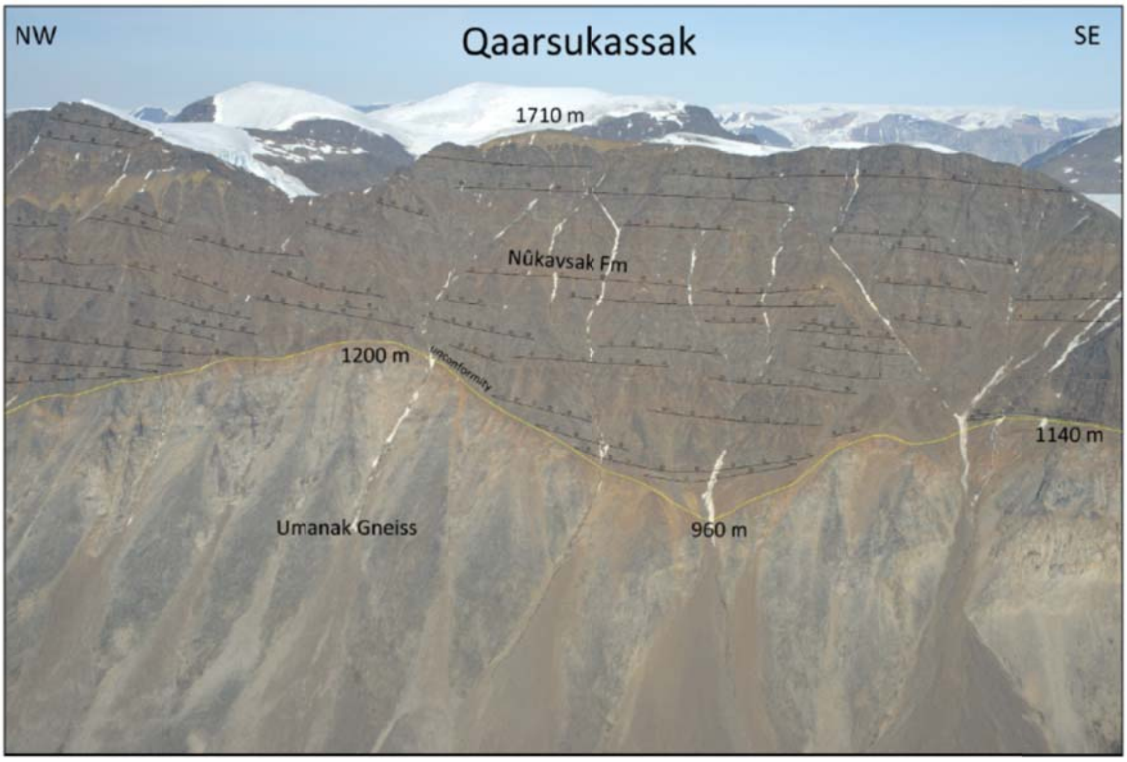


Figure 48. *Oblique photo of Qaarsukassak showing the stratigraphic relationship between paleovalleys incised in the Umanak gneiss and the on-lap geometry of the cover.*

Along the northern side of the Kangerluarsuk Fjord, a flat lying thrust separates the Kigarsima Nappe described by Henderson and Pulvertaft (1987) from a unit below represented by the Umanak Gneiss covered by a sequence of pelites. The Kigarsima Nappe is represented by a recumbent isoclinal fold of Umanak Gneiss and meta-sedimentary rocks. The thickness of the meta-sedimentary rocks in the basal unit shows strong lateral variation probably due to the presence of syn-rift faults. The basal unit is locally deformed by thrusts and upright folds that were interpreted as “dome” structures previously (Henderson & Pulvertaft, 1987) and here are considered as the effect of D3-deformation. The result is that the Kigarsima Nappe sole-thrust and the overall D2-structures are re-folded (Figure 49).

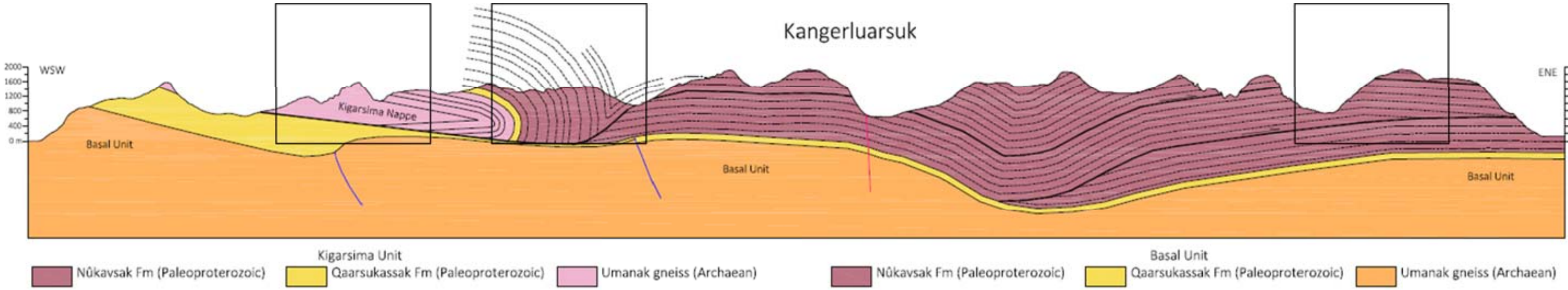


Figure 49. *Preliminary balanced cross-section along the Kangerluarsuk Fjord based on the new 3D-photogeology. Insets correspond to Figures 50, 51 and 52 respectively from west to east.*

Based on the geometry of bedding and the type of folds, the overall structure along the Kangerluarsuk Fjord is interpreted as fault-bend-fold (Figure 49). The Kigarsima Nappe sole-thrust shows a ramp-flat geometry, with a NE-ward piggy-back propagation of the thrust sheets that transfers the movement from a basal thrust (flat) located above the Qaarsukassak Formation (Figure 50) through a ramp (Figure 51) into an upper thrust (flat) that is located within the Nûkavsak Formation and marked by the presence of rusty-weathering horizons visible in the steep cliffs (Figure 52).

In this section, the Umanak Gneiss is repeated twice, (Kigarsima unit above the Basal Unit) while the Nûkavsak sequence is repeated in three tectonic units or thrust sheets in order to "balance" the cross-section.

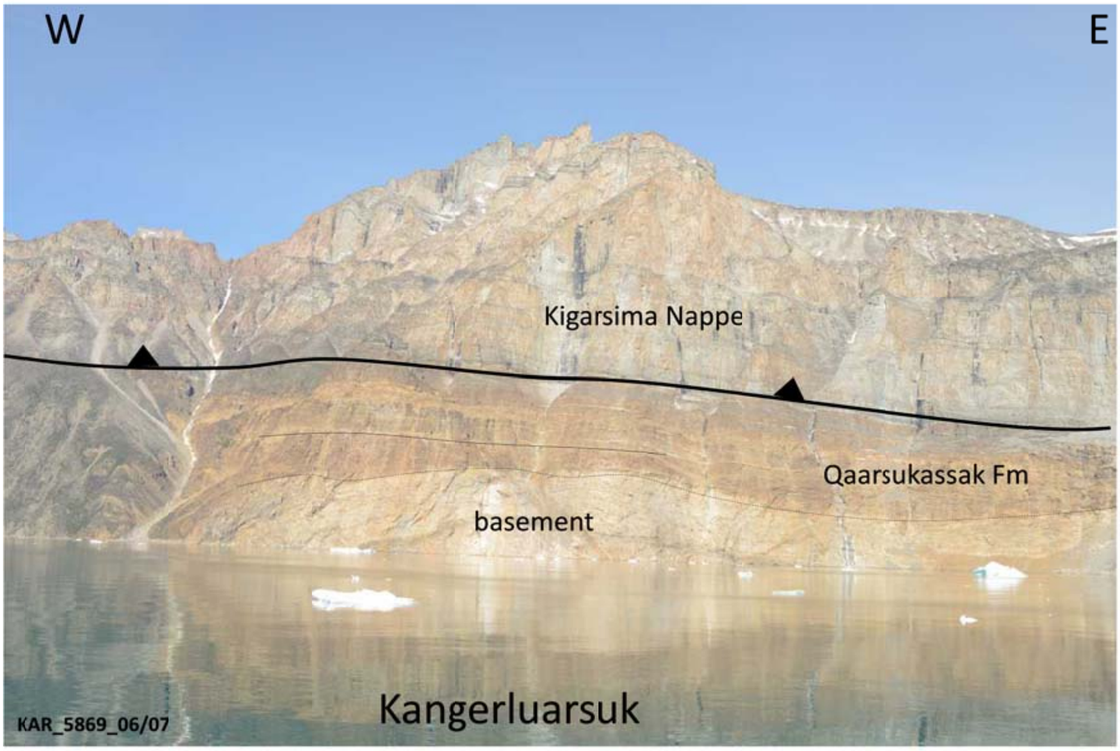


Figure 50. *The isoclinal folded Kigarsima Nappe above a flat-lying thrust fault onto the basal unit made by Umanak Gneiss covered by the Qaarsukassak Formation*

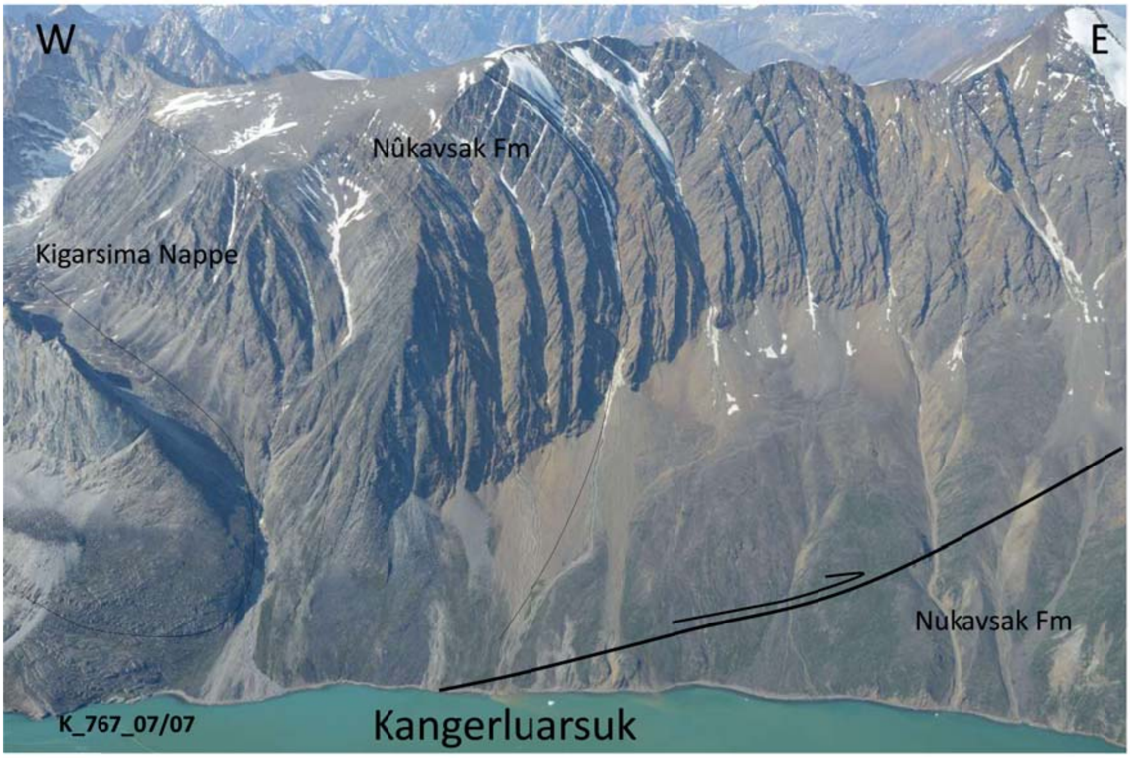


Figure 51. *The overturned limb of the Kigarsima Nappe together with the Nûkavsak Formation along a ramp-thrust.*

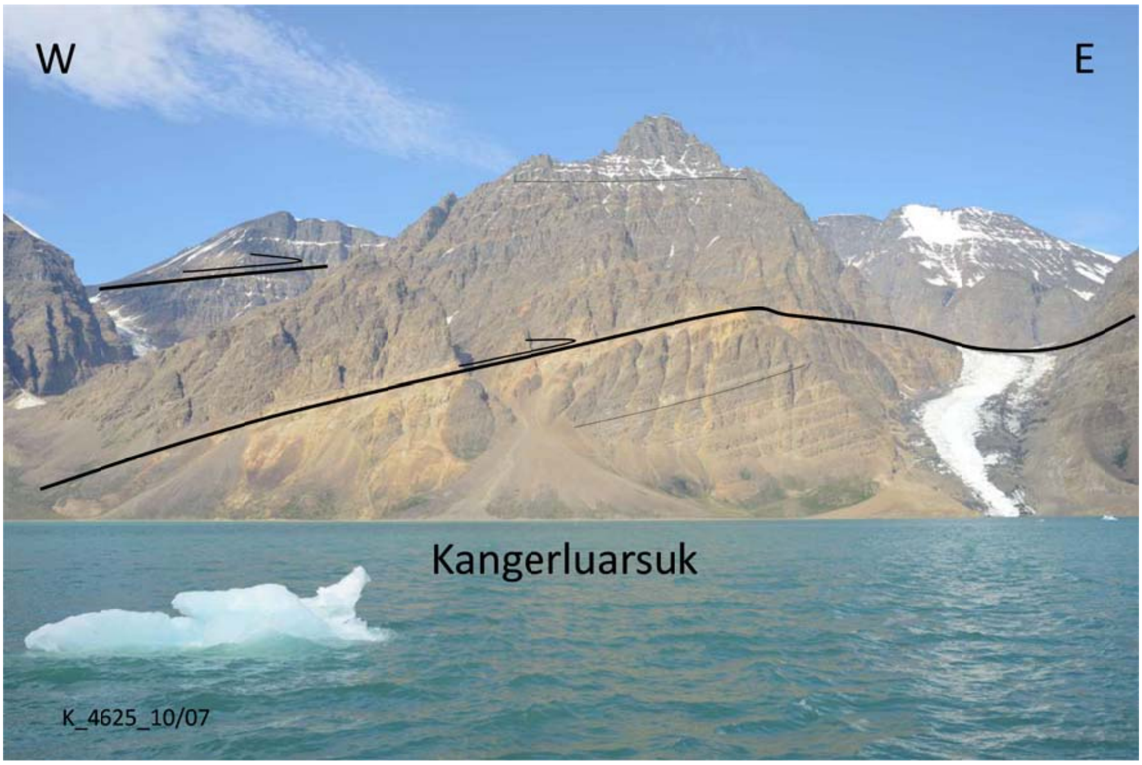


Figure 52. *A stack of three tectonic units of the Nûkavsak Formation separated by flat-lying thrusts. The thrust contact corresponds to the rusty-weathering layers visible in the foreground.*

At Tornit, a locality on the southern side of the Kangerluarsuk Fjord, the sub-vertical to overturned hinge of the Kigarsima Nappe was visited. Here, the Umanak gneiss is covered by almost 50 metres of meta-volcanic rocks passing upwards into the Qaarsukassak Formation, represented by 70-80 meters of folded pelites, mica schists and thin marbles.

Following the indications in the geological map along Kangerluarsuup Sermia, a stack of three tectonic units separated by two NW-dipping thrusts was recognized (Figure 53). The uppermost thrust sheet is represented by Umanak Gneiss carved by the characteristic paleotopography and filled in by the Qaarsukassak and Nûkavsak formations; the intermediate thrust sheet is represented by a sequence of pelites and mica schists stratigraphically above meta-volcanic rocks that in turn are unconformably above Umanak Gneiss; the lowermost unit is represented by folded pelites and marbles while the contact with the underlain Umanak Gneiss is covered by scree.

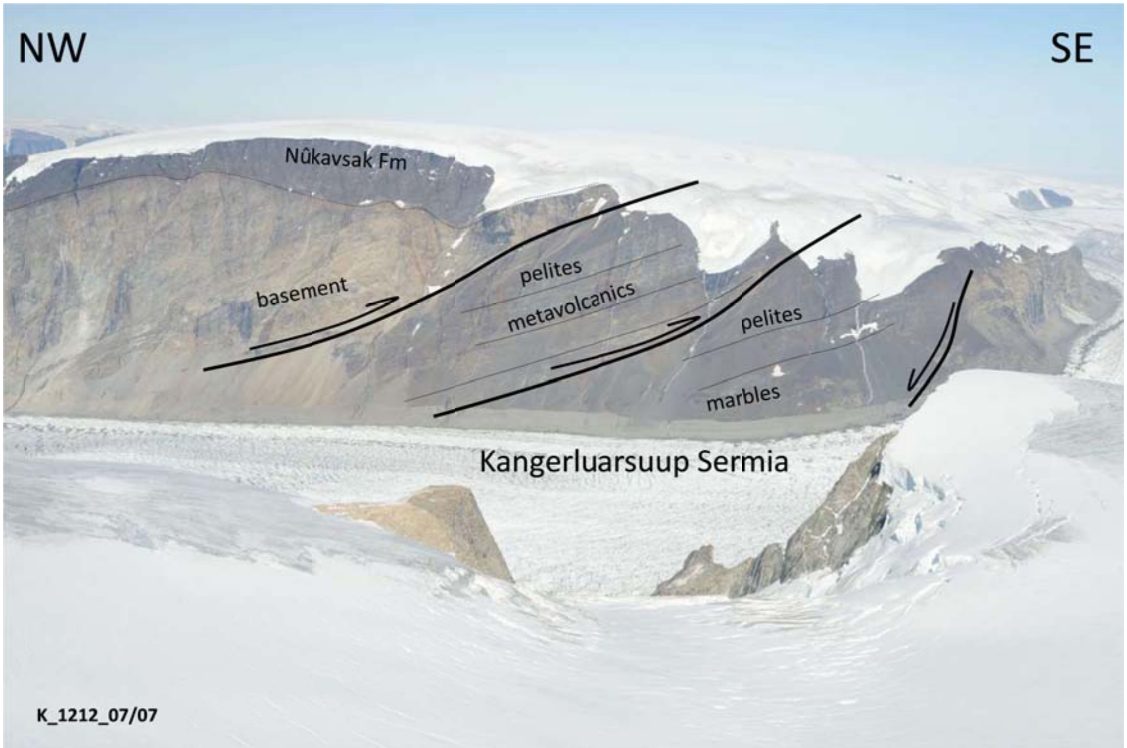


Figure 53. *Oblique photo of the Kangerluarsuup Sermia thrust system (D3 stage). To the NW, the Umanak Gneiss with the incised paleovalleys filled in by the Nûkavsak Formation is in tectonic contact along a NW-dipping thrust onto pelites, meta-volcanic rocks and Umanak Gneiss. The latter is in tectonic contact with a well-developed mylonite along another NW-dipping thrust onto pelites and marbles. To the SE, a NW-dipping normal fault, probably part of the original rift basin, separates Umanak Gneiss in the footwall from pelites and marbles in the hanging wall.*

Finally, along the eastern part of the same section, it is possible to observe a NE-SW-trending normal fault separating the Umanak Gneiss from pelites and marbles in the hanging wall (Figure 53).

At least three major deformation stages are recognized in this domain:

- E-W to NW-SE extension characterized by N-S and NE-SW trending normal faults (rift stage);
- SSW-NNE to SW-NE compression, representing the main deformation stage, characterized by NW-SE to WNW-ESE oriented isoclinal folds (D2 stage);
- NW-SE compression representing the last stage and characterized by NNW-dipping thrust faults responsible for structural culmination (D3 stage).

Umiammakku-Inngia Fjord Domain

This structural domain is characterized by the presence of the Qeqertarssuaq Formation that constitutes the lower part of the Karrat Group (Henderson and Pulvertaft, 1987) and a thicker sequence of meta-volcanic rocks that are distinguished and separated from the amphibolites commonly observed in the Qeqertarssuaq Formation

Along the southern side of the Kangilleq Fjord, below the Nûkavsak Formation, a sequence of meta-volcanic rocks crops out (Figure 54). The stratigraphic position of this package together with the presence of the regional unconformity below it indicates that this could be laterally equivalent to the Qaarsukassak Formation, occurring further West (Figure 55). Similar but thinner meta-volcanic rocks are observed in the previous domain in the same stratigraphic position. One interpretation could be that in the southern area, the meta-volcanic rocks filled only the bottom of the paleovalleys, while it is more widespread in the north, which would have been closer to the eruption site.

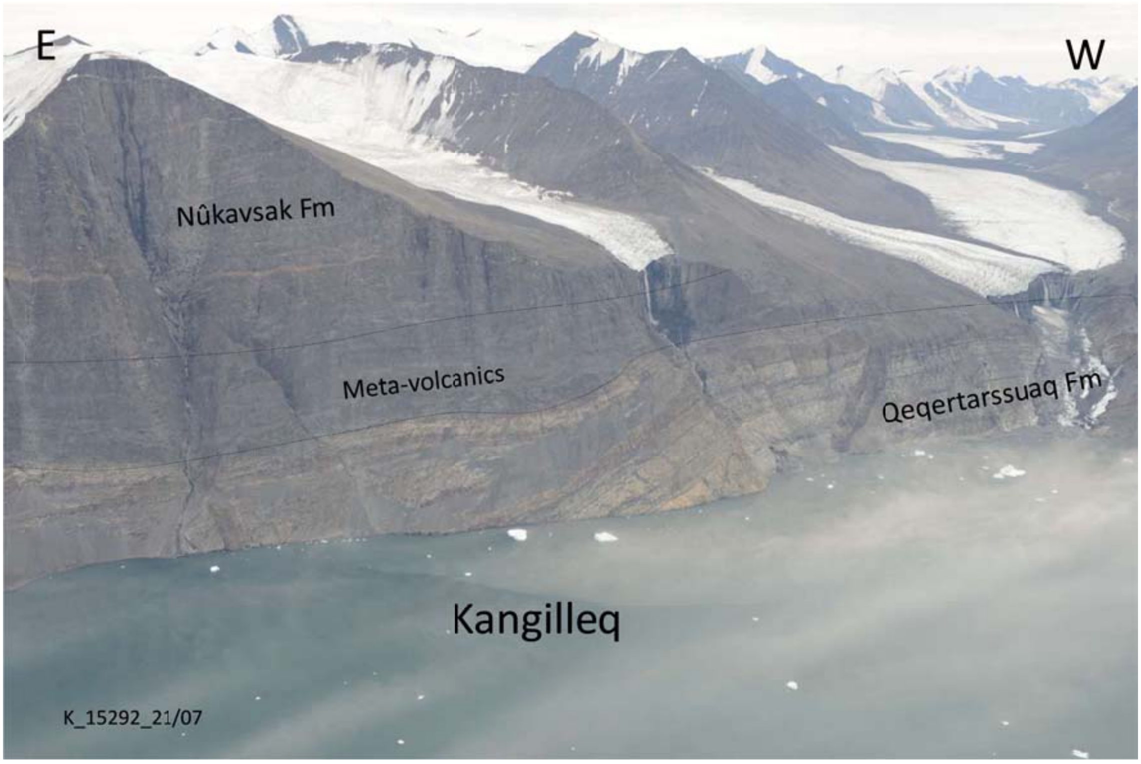


Figure 54. *Oblique photo of the southern side of Kangilleq Fjord showing the meta-volcanic rocks between the Qeqertarssuaq and the Nûkavsak formations.*

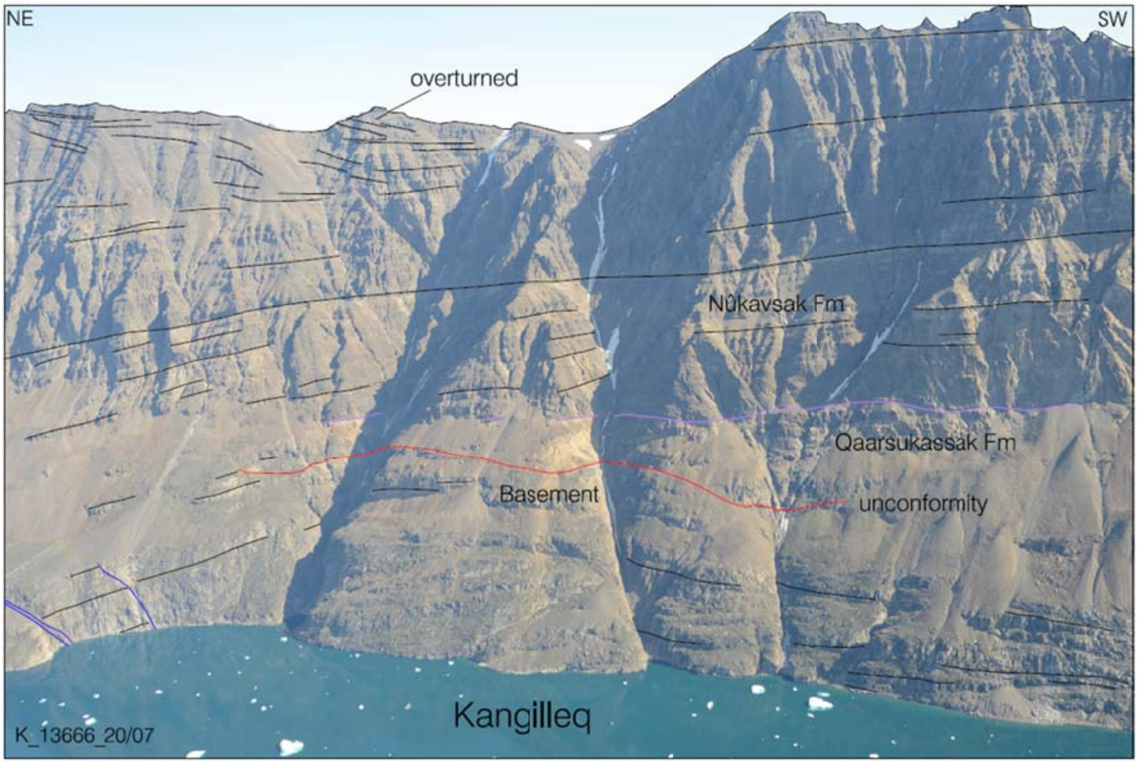


Figure 55. *Oblique photo of the southern side of Kangilleq Fjord showing the Qaarsukassak Formation between "banded gneiss" and the Nûkavsak Formation*

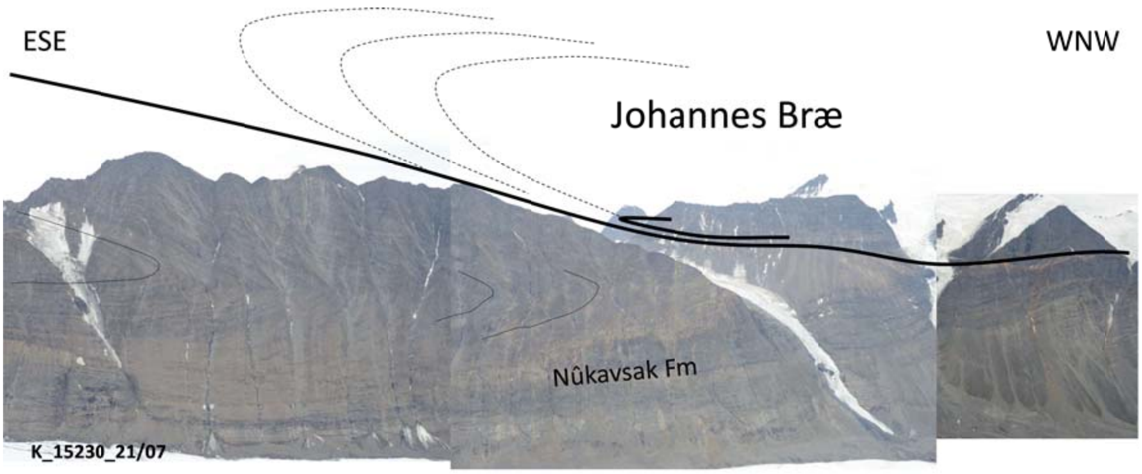


Figure 56. Composite o*blique photos of the southern side of Johannes Bræ showing the deformation in the Nûkavsak Formation in relation to a thrust fault responsible for the repetition of the sequence and folding.*

Along Johannes Bræ, a small glacier in the south east side of Kangilleq, meta-sandstone of the Nûkavsak Formation are deformed and tectonically repeated into two thrust units (Figure 56). The D2-thrust fault belongs to the Kigarsima Nappe described previously.

Along the northern side of Kangilleq, the Umiammakku ridge shows isoclinally folded Umanak Gneiss together with amphibolite, pelites, mica schists, thin marble and quartzites of the Qeqertarssuaq Formation. The main foliation in the Umanak Gneiss dips shallow SW.

Ultramylonite is developed at the contact between the Umanak Gneiss and probably Archean amphibolite, dipping shallow NNE-NNW and indicating NE-vergent transport. The ultramylonite is overlain by calcite marble of the Qeqertarssuaq Formation with fine quartz bands. On the western side of inner Kangilleq Fjord, phyllite and quartz-phyllite of the Nûkavsak Formation occur together with greenschist and weakly metamorphosed and deformed meta-volcanic rocks. The meta-volcanic rocks preserved a number of primary structures that are described in the Volcanic Rocks section. The phyllites have a closely spaced foliation dipping NNE. They form Z-folds with shallow NNE-plunging fold axis. Quartz veins also form Z-folds and are boudinaged parallel to the SE-plunging mineral stretching lineation, suggesting normal sense of shear to the ESE, similar to what is observed at a larger scale in Johannes Bræ (Figure 56). Z-folds in the meta-volcanic rocks fold bedding and the fold axis plunges NW. The main foliation and Z-folds are refolded by M-folds with moderately E-plunging fold axis, suggesting a local evolution from WNW-ESE extension to N-S compression at a later deformation stage.

In the easternmost end of Qeqertarssuaq Island and along the Umiammakku section toward Rinks Isbræ on the northern side of Kangilleq Fjord, it is possible to observe the geometry of the Paleoproterozoic unconformity post-dating D1-folds observed in the Qeqertarssuaq Formation (Figure 57).

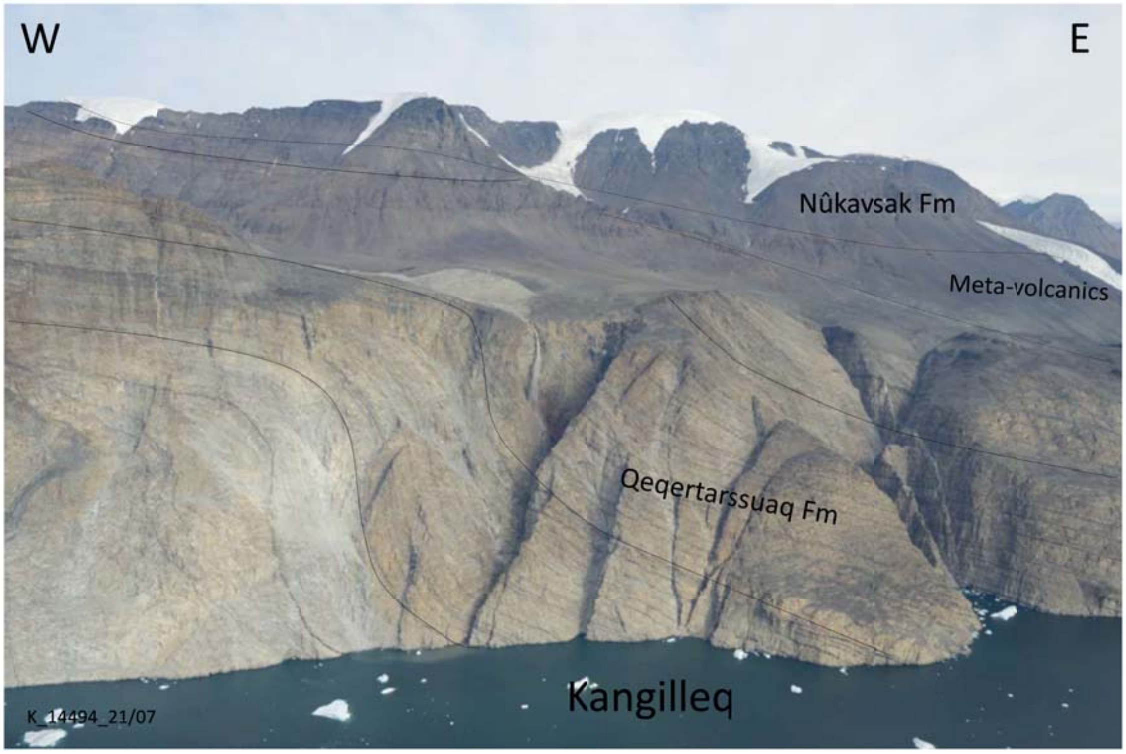


Figure 57. *Oblique photo of the northern side of Kangilleq Fjord showing the angular unconformity between the folded quartzites of the Qeqertarssuaq Formation and the meta-volcanic rocks and the meta-sandstones of the Nûkavsak Formation*

In general, the deformation observed in the Qeqertarssuaq Formation is not seen in the overlying succession and for this reason it is considered that a separated tectonic stage pre-dated the unconformity and the emplacement of the meta-volcanic rocks during the

Paleoproterozoic (Figures 57 and 58). This deformation is considered the oldest one preserved in the Paleoproterozoic Karrat Group and named Qeqertarssuaq Stage (D1).

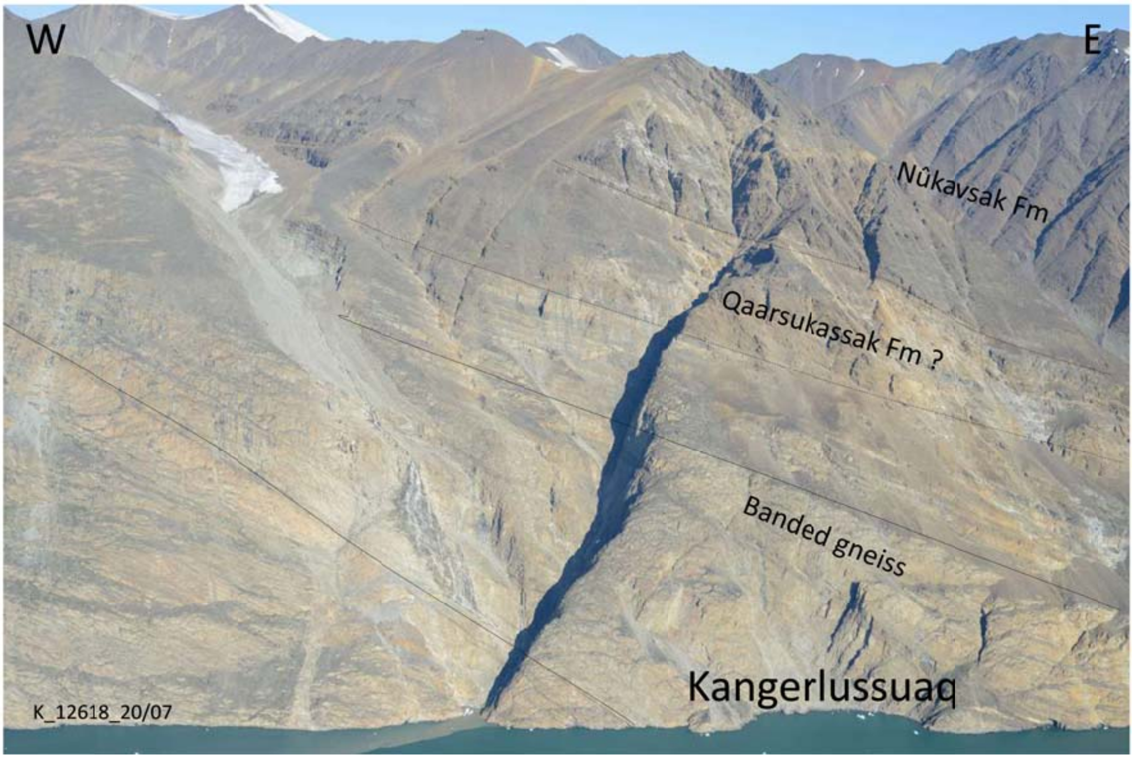


Figure 58. *Oblique photo of the northern side of Kangerlussuaq Fjord. This locality was considered by Henderson and Pulvertaft (1987) as the clear evidence for an unconformity between "banded gneiss" and Nûkavsak Formation. However, we believe that the "banded gneiss" likely correspond to quartzites, similar to those cropping out 20 km to the north and visible in Figure 57. In this case, this locality illustrates the unconformity at the top of the Qeqertarssuaq Formation.*

The northern flank of the Rinks Isbræ was visited to investigate the deformation of the basal contact between the Nûkavsak Formation and the meta-volcanic rocks. The near-vertical reverse faults seem to cut only the basal levels of the Nûkavsak Formation (Figure 59). Quartzite interlayered with mica schist is overlain by graphite phyllite that forms the base of the meta-volcanic rocks further to the northeast. The main foliation dips shallow to the ENE and mylonitic structures indicate normal shear to the E. This foliation is cut by two near-vertical ENE-dipping shear zones with a spacing of 2 km. Mineral stretching is near-horizontal, and dragging of foliation suggests dextral strike-slip shear. Mica schist and quartzite are retrogressed, forming phyllonite structures in the shear zone.

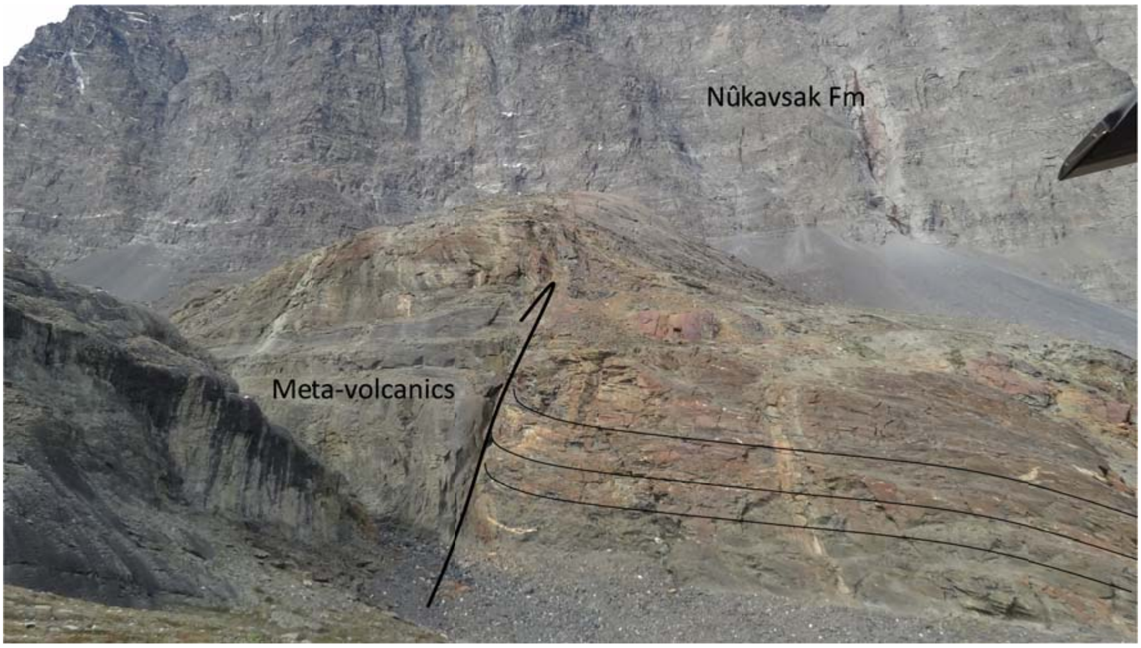


Figure 59. *Near-vertical reverse fault cutting the basal levels of the Nûkavsak Formation*

Along the east side of Kussinersuup Aaffaa, isoclinally folded quartzites and pelites occur together with in-folded Umanak Gneiss belonging to the Qeqertarssuaq stage (Figures 60 and 61).

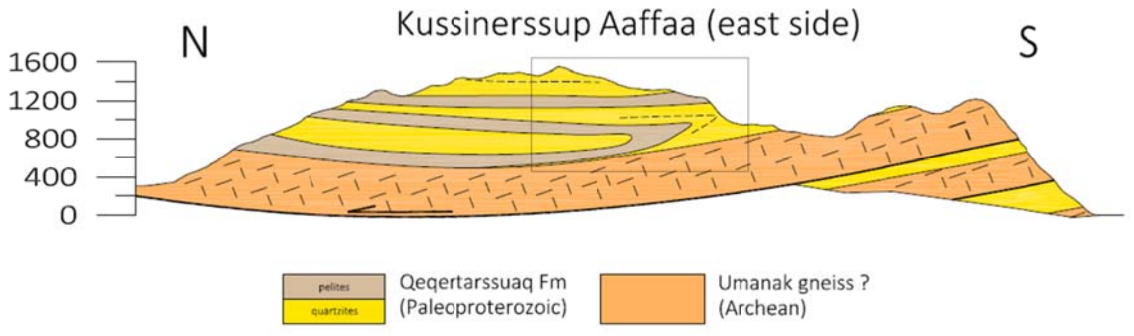


Figure 60. *Geological cross-section of the east side of Kussinersuup Aaffaa ridge showing recumbent D1-isoclinal folds in the Qeqertarssuaq Formation Inset corresponds to Figure 61.*

Figure 61. *Oblique photos of the east side of Kussinersuup Aaffaa showing the recumbent iso-clinal folds in the Qeqertarssuaq Formation. Any estimation of thickness for this formation should have to consider the tectonic repetitions of it.*

Figure 62. *The fold hinge made of light grey quartzites of the Qeqertarssuaq Formation at Kussinersuup Aaffa.*

Kussinersuup Aaffaa was shortly visited to understand the structural setting of this gold showing (see more in the Economic Geology section). In this locality, what apparently looks like a stratigraphic sequence of brown altered quartzites, hornblende schist and light grey quartzites (Figure 62), is actually a deeply deformed core of a parasitic fold anticline as depicted in Figure 63. Quartzite and amphibolite form a close, recumbent, W-vergent syncline with higher-order folds as the anticline in Figure 63. The syncline is crosscut by axial planar reverse shear zones that dip W/WSW with down-dip mineral stretching lineation. The shear zones have a spacing of ~10 m and host locally laminated quartz veins.

Figure 63. *Detail of the hinge showing the intense deformation of the quartzite.*

North of Qeqertarsuaq Island on the opposite side of the fjord, quartzite and kyanite-mica schist are tectonically overlain by orthogneiss, which is in turn overlain by amphibolite, mica schist and hornblende schist. The main foliation dips shallow WSW and mineral stretching lineation plunges W. Ultramylonite is developed in the upper quartzite and D1 shear sense is to the E.

In a section to the north, orthogneiss and amphibolite are folded in recumbent isoclinal folds with shallow NE-plunging fold axis. Banding in fine-grained amphibolite shows interference patterns of an early upright fold structure and the recumbent isoclinal folds. The amphibolite is overlain by mica schist and a darker garnet-biotite schist. This unit is overlain by quartzite with foliation-parallel lenses of amphibolite. In the quartzite, a NW-dipping mylonite developed that is characterized by D1 reverse shear to the E. The shear zone juxtaposed biotite schist, garnet-biotite schist and hornblende-biotite schist with the quartzite. This shear zone is probably the same as described before. The schists are overlain by meta-volcanic rocks that are cut by moderately NW-dipping shear zones. The main D1 foliation dips shallow to the WNW.

The east side of Inngia Fjord was visited and major D1-shear zones dipping toward SW (Figures 64 and 65) were recognized. Few kilometers to the north, two similar shear zones dip toward the NW (Figure 66). These D1-thrust faults seem to be folded into a gentle NW-SE trending open D2-anticline dipping to the NW. At the northwest-kink of Inngia Fjord, the stratigraphy is duplicated by ESE-vergent thrust systems, where orthogneiss is structurally overlain by quartzite, mica schist and amphibolite of the Qeqertarsuaq Formation twice (Figure 66). The ultramylonite is always developed at the orthogneiss-quartzite contact. The rocks of the Qeqertarsuaq Formation are overlain by meta-volcanic rocks. The meta-volcanic rocks preserved primary structures such as vesicular clasts and heterolithic volcanic breccia. They are overlain by metasandstone of the Nûkavsak Formation. Both units are cross cut by localized brittle shear zones with reverse to the S sense of movement.

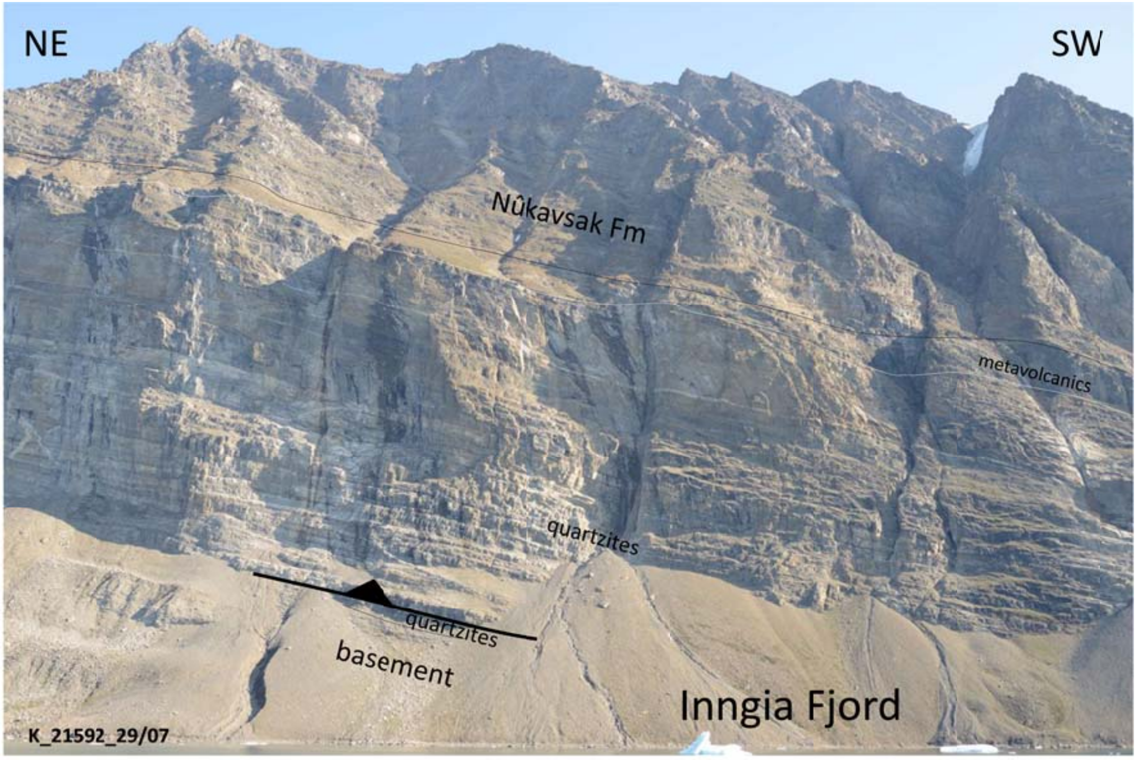


Figure 64. *Oblique photos of the east side of Inngia Fjord showing a D1 SW-dipping shear zone (thrust fault).*

Figure 65. *Thrust in quartzites of the Qeqertarssuaq Formation The shear zone is marked by the white line below the mafic layer.*

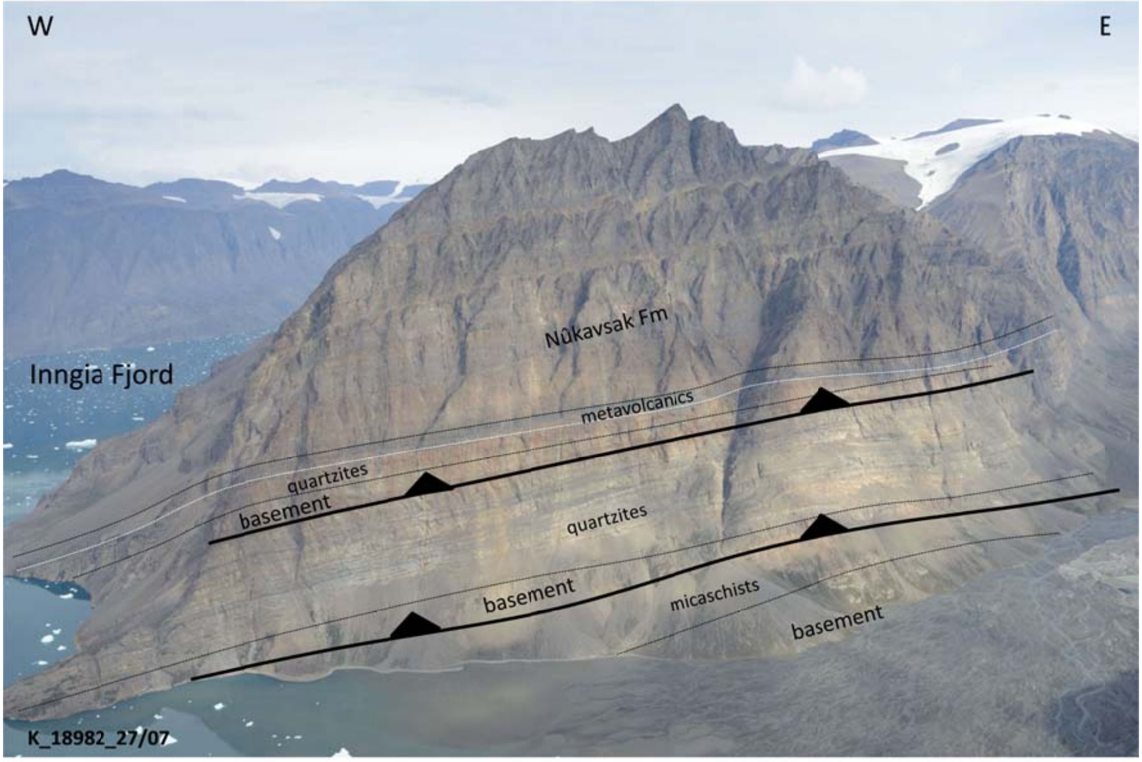


Figure 66. *Oblique photos of the east side of Inngia Fjord showing D1 NNW-dipping shear zones (thrust faults).*

In this section, the Qeqertarssuaq-Basement sequence is repeated three times.

At least five major deformation stages were recognized in this domain:

- E-W compression, representing the main deformation involving basement and Qeqertarssuaq Formation characterized by N-S to NNW-SSE oriented isoclinal folds, broadly W-dipping foliation and shallow W-plunging foliation (D1a);
- N-S compression, represented by isoclinal folds with W-plunging fold axis (D1b);
- SW-NE compression (D2) documented by the deformation visible in the Nûkavsak Formation and the re-folding of D1 thrust faults;
- NW-SE compression (D3), forming local fold structures with NE-plunging axes;
- E-W compression (D4), forming N-NNW-plunging fold axes and E-vergent shear zones mainly in the Nûkavsak Formation.

In summary, this domain appears to be the most complicated structural domain with several deformation stages overprinting each other. Supporting the stratigraphical considerations from above, the structural data is significantly different between the stratigraphic units, supporting a break between Umanak Gneiss and Qeqertarsuaq Formation, and meta-volcanic rocks and Nûkavsak Formation. The foliation, mineral stretching lineation and fold data from Umanak Gneiss and Qeqertarsuaq Formation are indistinguishable, being affected by D1, D2, D3 and D4 (not shown) structures (Figure 67). The meta-volcanic rocks show very similar structures compared to rocks of the Nûkavsak formation. In these two units, however, D1 structures are not recognized (Figure 67).

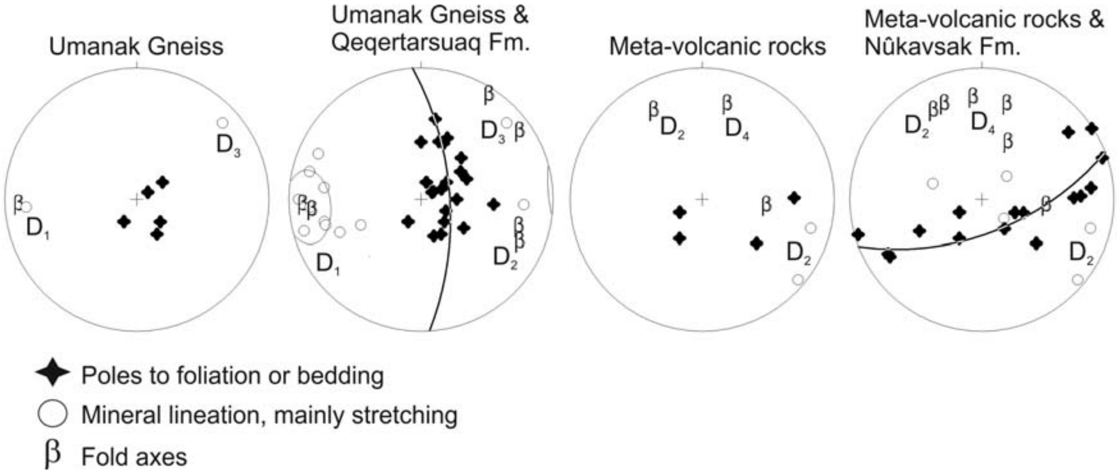


Figure 67. *Stereoplots of various structural data from the Umiammakku-Inngia Fjord Domain and the different stratigraphic units, showing that D1 structures are missing from meta-volcanic rocks and the Nûkavsak Formation (lower hemisphere, equal area).*

Kangiusap Kuua-Ukkusissat Fjord Domain

This structural domain is characterized by the presence of the intrusive Paleoproterozoic Prøven Igneous Complex, dominated by charnockites (Escher & Stecher 1978; Thrane et al. 2005). The meta-sedimentary cover is mainly represented by the deformed Nûkavsak Formation and minor outcrops represented by meta-volcanic rocks and the Qeqertarssuaq Formation.

The orthogneiss mapped in the southern part at the contact with Tertiary and Cretaceous units is reinterpreted as a monzogranite intrusion. The monzogranite consists of porphyritic Kfs in Pl, Qtz, Bt, Hbl, Mag matrix. Several magmatic stages with generally increased grain size with relative younging can be distinguished. The final magmatic-hydrothermal stages are characterized by cross cutting pegmatite dikes and quartz veins. The intrusion has abundant angular xenoliths of amphibolite, meta-hornblendite, mica schist and metasandstone, suggesting that the monzogranite intruded both the Qeqertarsuaq and Nûkavsak formations. The NE contact is marked by a mylonite in the monzogranite with brittle deformation of feldspar resulting in a granular fabric. The shear zone dips ENE and has a normal sense of movement to the NE as indicated by mineral stretching and S-C fabrics. Medium-grained amphibolite forms a competent lens in the shear zone. The shear zone juxtaposed light grey Pl-Bt-Hbl-Qtz gneiss, quartzite and mica schist against the monzogranite (Figures 68 and 69). The direct contact to these lithologies was inaccessible, but ESE-dipping metasandstone and biotite schist occur in close distance. These rocks locally contain abundant centimeter- to decimeter-scale andalusite and sillimanite porphyroblast pseudomorphs formed by retrograde muscovite. In an ~3 km wide zone to the east, near-vertical shear zones are interrupted by zones of shallow-dipping foliation with Z-shape and to the northeast by upright closed folds (Figures 70-72). In the fold cores, meta-volcanic rocks, meta-chert and massive to semi-massive sulfide mineralisation of pyrrhotite and pyrite are preserved. The near-vertical shear zones form strongly foliated zones in the metasandstone transferring the rock to phyllite. They have a down-dip lineation with W-up sense of movement. The structural grain of this area is defined by the monzogranite intrusion in the west that is surrounded by extensional detachments at the contact to wall rocks, suggesting diapiric monzogranite emplacement. The extensional ENE-vergent deformation grades into WSW-ENE compressional structures with upright moderately NW-plunging fold axis and NW-trending, near vertical shear zones (Figure 72).

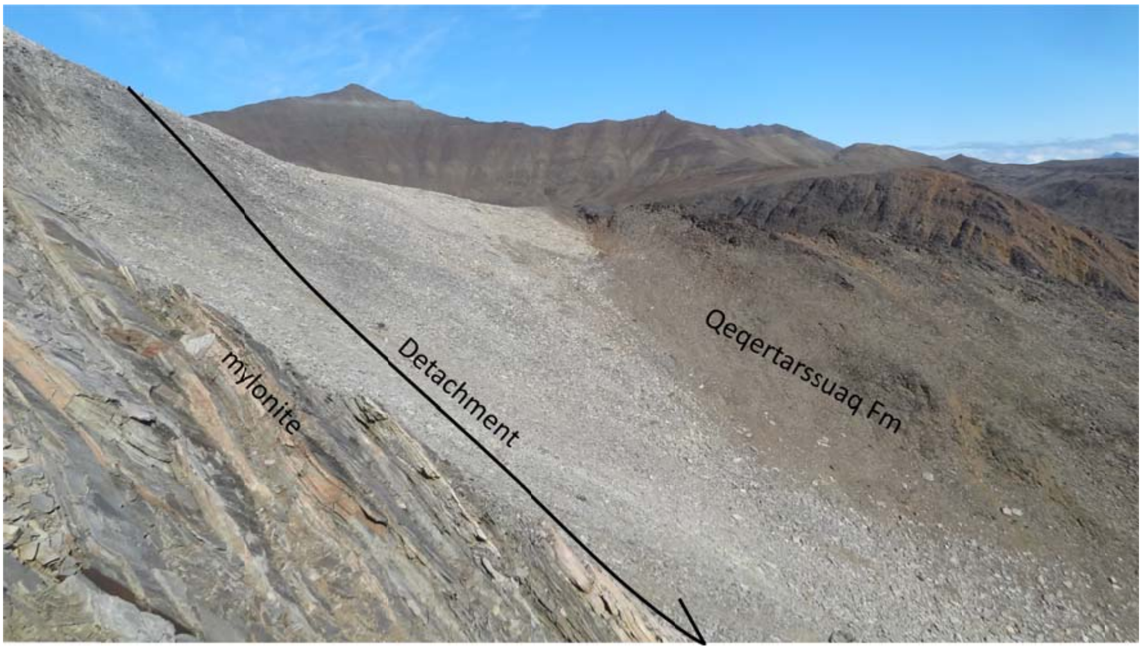


Figure 68. *The top-down to the east shear zone between the monzogranite intrusion (to the left) and the Qeqertarssuaq Formation (to the right).*

Figure 69. *Detail of the mylonite along the shear zone at Southern Kangiusap Kuua.*

The main foliation is parallel bedding and moderately dipping WSW. The sense of shear in higher strain zones is reverse to the ENE. The main fabrics in this area are S-C’ and asymmetric quartz veins cross cut by a weak second foliation dipping moderately NW.

Figure 70. *West-dipping thrust fault (D3?) in the Nûkavsak Formation at Inngia Fjord.*

Figure 71. *West-dipping thrust (D3) in the Nûkavsak Formation at Ukkusissat Fjord.*

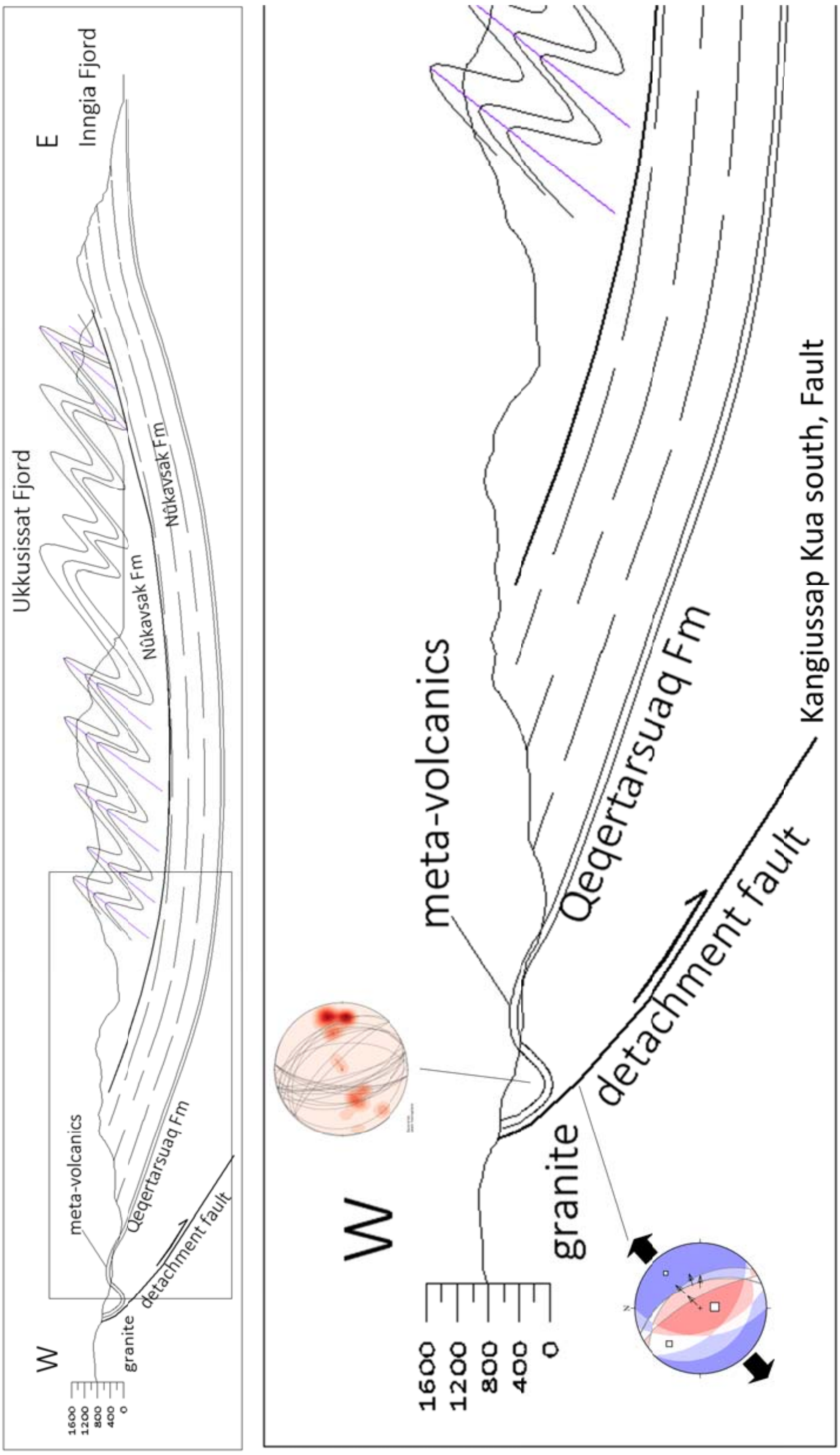


Figure 72. Geological cross-section showing the deformation in the Nûkavsak Formation between Ukkusissat Fjord and Inngia Fjord with upright kink folds above a basal detachment. To the west, the Uparuarqussuitsut shear zone and the folds associated to it shown in the detailed section together with structural data in the fold hinge and along the shear zone.

To the north, the contact between the Prøven Igneous Complex and Paleoproterozoic meta-sedimentary rocks at the end of Ukkusissat Fjord is along a NW-dipping thrust as shown in Figure 73 and, in detail, in Figure 74. The Paleoproterozoic paleostress reconstructed with the inversion of fault-slip data show a NW-SE compression (Figure 75).

Figure 73. *The NW-dipping thrust contact between the Prøven Igneous Complex and meta-sedimentary rocks.*

Figure 74. *Detail of the thrust, top to the SE.*

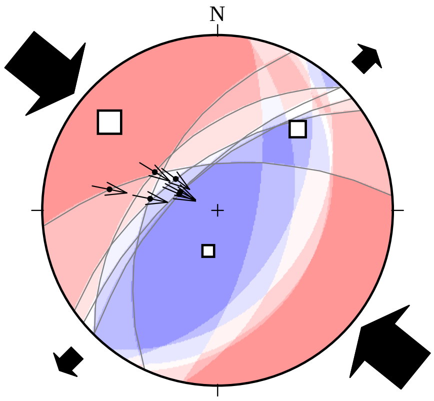


Figure 75. *Paleostress reconstructed from inversion of fault-slip data showing the maximum horizontal stress of the thrust between the Prøven Igneous Complex and meta-sedimentary rocks.*

At least three major deformation stages were recognized in this domain:

- N-S trending upright folds and thrusts (D2?);
- NW-SE compression (D3) post-dating the emplacement of the Prøven Igneous Complex
- SW-NE extension and associated folds, probably associate to D3;

Summary

At this stage of the study, without constraints placed by geochronology and metamorphic petrology, and taking into account the regional approach of the field work, it is possible to conclude the following:

- A Paleoproterozoic unconformity separates the Karrat Group into a lower and upper Karrat Group. The Lower Karrat Group composed of quartzites, amphibolites, and pelites of the Qeqertarsuaq Formation, while the Upper Karrat Group is composed of meta-volcanic rocks of the Kangigleq Formation, the now defined Qaarsukassak Formation, and the Nûkavsak Formation. The position of the Mârmorilik Formation with respect to the unconformity is not clear yet, even though we believe it belongs to the Upper Karrat Group.
- In the central part of the study area, the intra-Karrat Group unconformity is marked by paleovalleys filled by the Qaarsukassak Formation and the Nûkavsak Formation;
- Early deformation structures observed in the Qeqertarsuaq Formation and also the Umanak Gneiss pre-date the development of the unconformity and are here summarized under the name Qeqertarssuaq Stage (D1). This stage represents the first recognized Paleoproterozoic deformation, which is not recorded in the Upper Karrat Group;
- The Qaarsukassak Formation, the meta-volcanic rocks of the Kangilleq Formation, and possibly the Mârmorilik Formation, represent the first sedimentary sequences of the Upper Karrat Group, above the unconformity, and for this reason, these could be lateral equivalents;
- The deformation that post-dates the unconformity and the Upper Karrat Group can be separated into three distinct stages, named the Kigarsima Stage (D2) related to a WSW-ENE to SW-NE oriented compression, the Maarmorilik Stage (D3) related to NW-SE compression and the Svartenhuk Stage (D4) with extension around intrusions and distal E-W compression;
- Paleoproterozoic normal faults, probably representing remnants of the original rift basin architecture, are still preserved and recognized in the area. Most of them are inverted as thrust fault during the D3 event.

The overall structural grain of the study area is characterized by complex interference of the structures related to the different stages (Figure 76). The area between to the south of Nuugaatsiaq is characterized by fold structures with NW-trending axial traces that formed during the Kigarsima Stage (D2). The main regional overprint is by D4 folds with N-trending axials traces (Figure 76). The area between Inngia Fjord and Rinks Isbræ is very complex with also mainly D2 and D4 interference patterns. D1, restricted to the Umanak Gneiss and the Lower Karrat Group, and D3 appear not to have a major influence on the regional-scale structural grain (Figure 76). The area between Svartenhuk and Inngia Fjord is defined by N-trending structures related to extension proximal to intrusions in the west and E-vergent distal deformation.

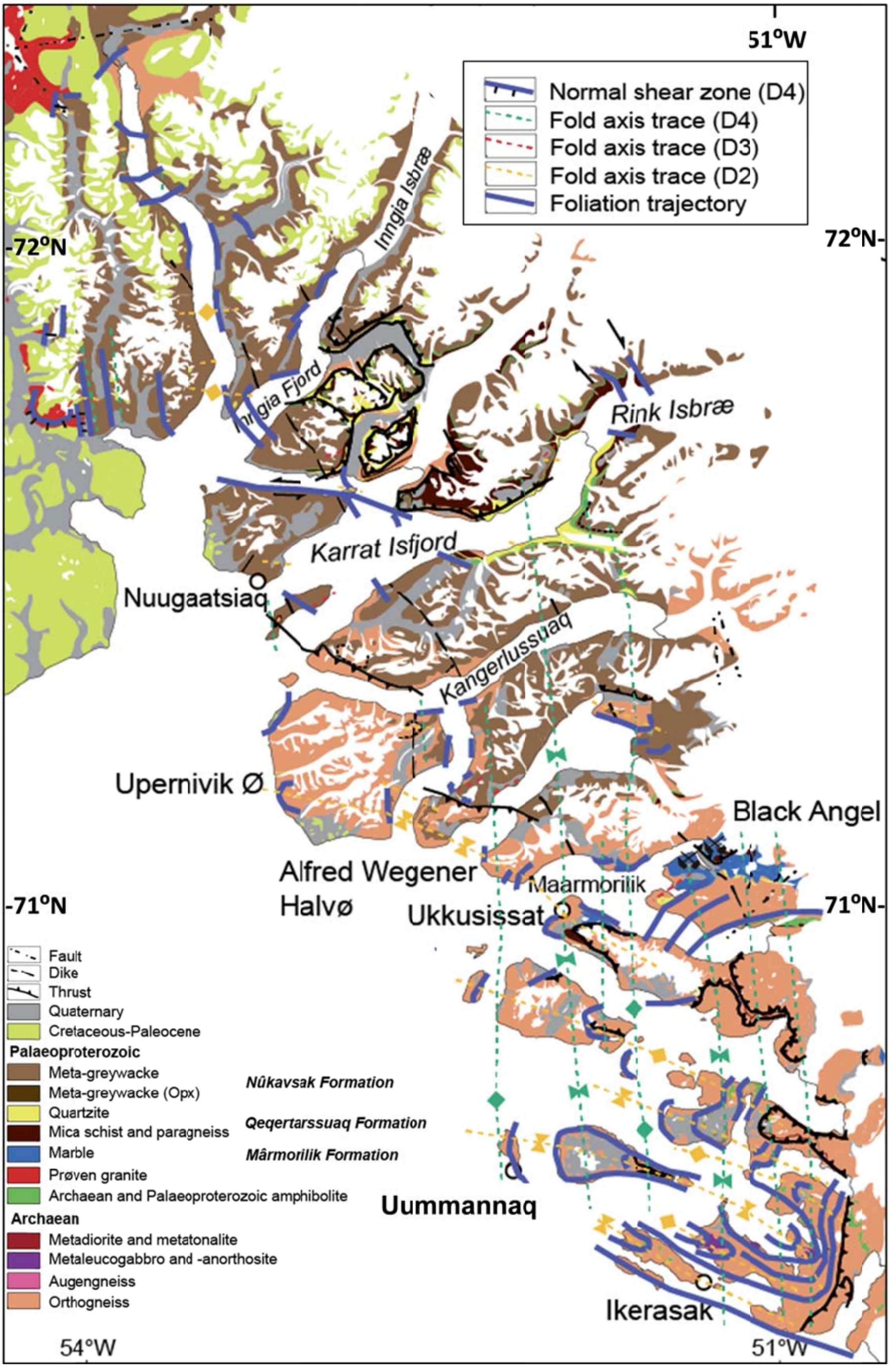


Figure 76. *Regional geological map with foliation trajectories and traces of various generations of fold axes, showing the general structural grain characterized by large-scale interference patterns.*

Economic Geology

Gold

The study area is anomalous in As, Au and W, as evidenced by drainage geochemistry and mineralised floats. It has been suggested that the Au stems from semi-massive pyrrhotite-pyrite, sulfidic cherts or siliceous shales and gossanous horizons, or from auriferous quartz veins (orogenic gold) (Thomassen 1992, Steenfelt et al. 1998).

During the 2015 season, a gold-anomalous outcrop of Qeqertarssuaq Formation quartzite at Kussinersuup Aaffaa was re-investigated. Rock samples collected at this exposure had previously returned up to 304 ppb Au (Thomassen, 1993). The lowermost ~200 m of the ~800 m wide exposure was grab sampled in its western, central and eastern parts, as defined by two main streams (Table 2). To the west, three samples yielded 25–58 ppb Au, thirteen samples from the central part yielded 8–328 ppb Au, average 86 ppb, median 40 ppb, and seven samples from the eastern part gave only max. 9 ppb Au in quartz veins. A float yielded 618 ppb Au. Several of the collected samples are high in Zr (max of 736 ppm), Nb (max of 50 ppm), Y (max of 122 ppm), Th (max of 173 ppm), U (max of 77 ppm) and lanthanides (max of 1077 ppm), while no correlation with Au is apparent. The mineralised rock is a light grey, medium-grained quartzite composed of quartz, muscovite and kyanite. Pyrite and locally pyrrhotite form 0.5-1 mm large grains, are disseminated in the quartzite and occur in abundant mm- to few cm -thick quartz veins (Figure 77). Surrounding the quartz veins, a hydrothermal muscovite, K-feldspar, tourmaline, rutile and pyrite alteration zone developed. The quartzite contains bands of amphibolite, which form a close, recumbent, W-vergent syncline with higher-order folds. The syncline is crosscut by axial planar reverse shear zones that dip W/WSW with down-dip mineral stretching lineation. The shear zones have a spacing of ~10 m and host locally laminated quartz veins. Extension veins are developed in the hanging wall of the shear zones.

Table 2. *Summary of analytical results, obtained through fire assay or INAA:*

			Au	Zr	Nb	Y	Th	U	Lanthanides
Sample #	Location	Rock type	ppb	ppm	ppm	ppm	ppm	ppm	ppm
568701	Kussinersuup Aaffaa	quartzite	<2	736	49.8	95.8	164	57.9	1077
568704	Kussinersuup Aaffaa	quartzite	<2	442	25.9	40.6	121	32.9	639
568702	Kussinersuup Aaffaa	quartz vein	9						
568703	Kussinersuup Aaffaa	quartz vein	7						
568705	Kussinersuup Aaffaa	quartz vein	<1						
571614	Kussinersuup Aaffaa	quartz vein	58	72	9.2	29.6	40	17.8	271
571615	Kussinersuup Aaffaa	quartzite with vein quartz	42	194	13.2	46	43	26.2	455
571616	Kussinersuup Aaffaa	quartzite	25	87	5.6	14	16	8.88	192
571617	Kussinersuup Aaffaa	quartzite float	618	94	10.1	15.8	17	7.15	164
571618	Kussinersuup Aaffaa	quartz vein	158	87	4.5	38.8	24	36.3	174
571619	Kussinersuup Aaffaa	quartzite	9	302	39.7	45.1	141	61	764
571620	Kussinersuup Aaffaa	quartz vein	26	456	28.5	83.9	173	63.6	1005
571621	Kussinersuup Aaffaa	quartzite with vein quartz	328	316	3.4	122	16	9.45	237
571622	Kussinersuup Aaffaa	quartzite	67	160	7	19	16	23.7	152
571623	Kussinersuup Aaffaa	quartz vein	48	222	11.9	6.8	28	35	214
571624	Kussinersuup Aaffaa	quartz vein	129	354	23.8	33.9	34	12.6	210
571625	Kussinersuup Aaffaa	quartz vein	40	173	18.9	26.2	63	41.6	351
571626	Kussinersuup Aaffaa	quartz vein	<1	196	2.3	14.4	18	6.67	181
571627	Kussinersuup Aaffaa	quartzite	8	56	7	20.1	22	22.9	182
571628	Kussinersuup Aaffaa	quartz vein	242	71	2.1	10.1	4.9	6.5	112
571629	Kussinersuup Aaffaa	quartz vein	36	221	2.3	8.4	7.3	4.92	96
571630	Kussinersuup Aaffaa	quartzite with vein quartz	19	122	24.9	28	97	77	556
569934	Kussinersuup Aaffaa	quartzite	13	57	8.4	16.2	21	14.7	189
568706	Inngia Fjord	quartz vein	22						
568726	Southern Kangiusap Kuua	quartz vein	6						
568727	Southern Kangiusap Kuua	alteration zone	<2						
568728	Southern Kangiusap Kuua	quartz vein	11						
568729	Southern Kangiusap Kuua	alteration zone	<2						
568730	Southern Kangiusap Kuua	quartz vein	24						
568731	Southern Kangiusap Kuua	quartz vein	<1						
568732	Southern Kangiusap Kuua	quartz vein	16						
568733	Southern Kangiusap Kuua	quartz vein	14						
568734	Southern Kangiusap Kuua	quartz vein	<1						
568735	Southern Kangiusap Kuua	quartz vein	<2						
568743	Southern Kangiusap Kuua	quartz vein	<1						
568745	Southern Kangiusap Kuua	quartz vein	<1						
568747	Southern Kangiusap Kuua	quartz vein	<1						

The same quartzite unit from the Qeqertarssuaq Formation was visited along the south-eastern shore of Inngia Fjord, between Akuliarusinnguaq and Puallarsiivik. Disseminated chalcopyrite and pyrrhotite associated with quartz veins from this locality have previously yielded up to 2.3 wt.% Cu and 323 ppb Au in grab samples (Thomassen 1990). Quartzite, mica schist and hornblende-biotite schist are intercalated in a WSW-dipping reverse shear zone on top of tonalitic orthogneiss composed of plagioclase, quartz, hornblende, biotite and local leucosomes. The orthogneiss is greenish, showing retrogression of mafic minerals to epidote. The schists consist of variable amounts of muscovite, biotite, hornblende, quartz, plagioclase, cordierite and garnet. The 3-5 m wide shear zone hosts locally laminated quartz veins in quartzite and hornblende-biotite schist (Figure 78). The hydrothermal alteration assemblage consists of quartz, actinolite, muscovite, pyrrhotite, chalcopyrite and arsenopyrite, which is typical of mesozonal orogenic gold mineral systems. Only one quartz vein was sampled, this returned only 22 ppb Au (Table 2). Numerous parallel reverse ESE-vergent shear zones occur in the near-vertical cliff along the fjord in mica schist, hornblende-biotite schist and quartzite. At Puallarsiivik, the stratigraphy is duplicated by ESE-vergent thrust systems, where orthogneiss is structurally overlain by quartzite, mica schist and amphibolite of the Qeqertarssuaq Formation twice. An ultramylonite is always devel-

oped at the orthogneiss-quartzite contact. The rocks of the Qeqertarssuaq Formation are overlain by meta-volcanic rocks consisting of variable amounts of hornblende, biotite, plagioclase, quartz and magnetite. The meta-volcanic rocks preserved primary structures such as vesicular clasts and heterolithic volcanic breccia. They are overlain by metasandstone of the Nûkavsak Formation. Both units are cross cut by localized brittle shear zones with reverse to the S sense of movement.
The hydrothermal alteration assemblage and the shear zone-hosted quartz veins, both at Kussinersuup Aaffaa and at Inngia Fjord, are typical of a mesozonal orogenic gold mineral system. Gold assays from the quartz veins are, however, low. However, the fact that quartzite, from Kussinersuup Aaffaa, is often also often enriched in Zr, Nb, Y, U, Th, and lanthanides, hints at a possible association of gold with heavy minerals like zircon, monazite, etc. It is therefore possible that gold mineralisation in the quartzite of the Qeqertarssuaq Formation formed by sedimentary processes (paleoplacer) and was partly remobilized locally into quartz veins during deformation and metamorphism. Both models, paleoplacer gold and orogenic gold mineralisation, should therefore be tested further by detailed petrography and geochronology of pyrite and associated heavy minerals.

Figure 77. *Hydrothermal quartz vein with black tourmaline in sheared quartzite (Kussinersuup Aaffaa).*

On eastern Svartenhuk, a number of arsenopyrite-bearing floats of vein quartz with up to 1.4 ppm Au have been reported by Thomassen & Lind (1998). It was the aim to trace these to outcrop in 2015. In Southern Kangiusap Kuua, within an ~3 km wide zone, near-vertical shear zones are interrupted by zones of shallow-dipping foliation with Z-shape and to the northeast by upright closed folds. In the fold cores, meta-volcanic rocks, meta-chert and massive to semi-massive sulfide mineralisation are preserved. The near-vertical shear zones form strongly foliated zones in the metasandstone transferring the rock to phyllite. They have a down-dip lineation with W-up sense of movement. Several parallel shear zones in the ~3 km wide zone host locally laminated quartz veins, extension veins and extensional shear veins. Lithons in the shear zone form hydraulic breccia with stockwork quartz veins (Figure 79). The veins are composed of quartz, calcite, arsenopyrite and pyrite. The host rock consists of hornblende, plagioclase, quartz and minor biotite with a fine-grained distal alteration zone of quartz, arsenopyrite and pyrite. The proximal alteration bleached the rock and consists of quartz, calcite, muscovite, chlorite, pyrite and arsenopyrite. Further to the north, an anticline-syncline pair is cross cut by a reverse shear zone that hosts laminated quartz veins in direct contact to meta-chert and meta-volcanic rocks preserved in the core of the anticline. The mesozonal hydrothermal alteration assemblage is quartz, epidote, chlorite, pyrite and arsenopyrite. Such hydrothermal alteration systems around shear zone-hosted quartz veins are typical of mesozonal orogenic gold systems. The maximum Au values, however, returned from quartz veins and hydrothermal alteration zones are 24 ppb Au (Table 2). Although very similar in situ quartz vein mineralisation was discovered during this field season, the promising result from the float sample could still not be confirmed.

Figure 78. *Shear zone-hosted hydrothermal quartz vein at the contact of amphibolite and quartzite (eastern shore of Inngia Fjord).*

Figure 79. *Stockwork quartz vein geometry developed in lithons in the shear zone system between high strain zones (Southern Kangiusap Kuua)*

Base metals

Zn-Pb mineralisation is common in marbles of the Mârmorilik Formation, and was the subject of mining at the Black Angel mine, between 1973 and 1990 (Thomassen, 1991). Additionally, Coppard et al. (1992) identified the intermittent stratabound Zn-Pb mineralisation of the Discovery and Kangerluarsuup Sermia occurrences, hosted within a metamorphosed carbonate and clastic sequence. This sequence is considered to be the basal sequence of the Mârmorilik Formation by Coppard et al. (1992), but is herein called the Qaarsukassak Formation, stratigraphically below the Nûkavsak Formation (see Stratigraphy section), and laterally discontinuous as it appears to have been deposited on an irregular paleosurface (see Structural Geology section). Despite the many known occurrences, the exact timing, fluid and metal sources and pathways, as well as the nature of the traps and mechanisms for metal precipitation are poorly constrained. The deformation and metamorphism that affected these occurrences has led to difficulties interpreting their genesis, and Mississippi Valley-Type (MVT) and Sedimentary Exhalative (SEDEX) models can be advocated.
To understand the context for these marble-hosted occurrences and contribute towards understanding their potential and assist in their exploration, these occurrences were visited and sampled. Half-day helicopter drop-off visits were made to the South Lakes Glacier occurrence in Maarmorilik (Figure 80) and to the Kangerluarsuup Sermia occurrence (Figure 81). A fly camp was established near the Discovery occurrences (Figure 82), allowing for three full days of work in that area. The stratigraphic setting of the sequence hosting the mineralisation in this area (Qaarsukassak Formation) was documented (see Stratigraphy

section). In the visited occurrences as well as, according to their description, in other Maarmorilik occurrences, the proximity to the gneiss basement contact (Figure 82) suggests that these are epigenetic (MVT), rather than syngenetic (SEDEX). However, this should be verified through geochronology work, namely through attempting Re/Os dating of pyrite. This brittle mineral appears to be fractured and rotated, rather than recrystallized during deformation as galena and sphalerite, and therefore it might provide a meaningful formation age. The massive to porphyroclastic ores seen at the South Lakes Glacier occurrence, also have ellipsoidal quartz inclusions, which are tentatively interpreted as implying significant cooling of the mineralising fluid, suggesting the possibility of high temperature transport of both base metals and of reduced sulfur in one fluid. Alternatively, base metals would have to be transported by fluids without any sulfur or by oxidizing fluids together with sulfate, with metal precipitation caused by mixing with sulfide-rich fluids or by reduction of the sulfate. In the latter case, the ellipsoidal quartz inclusions should be interpreted as resulting from the silicification of evaporite nodules.

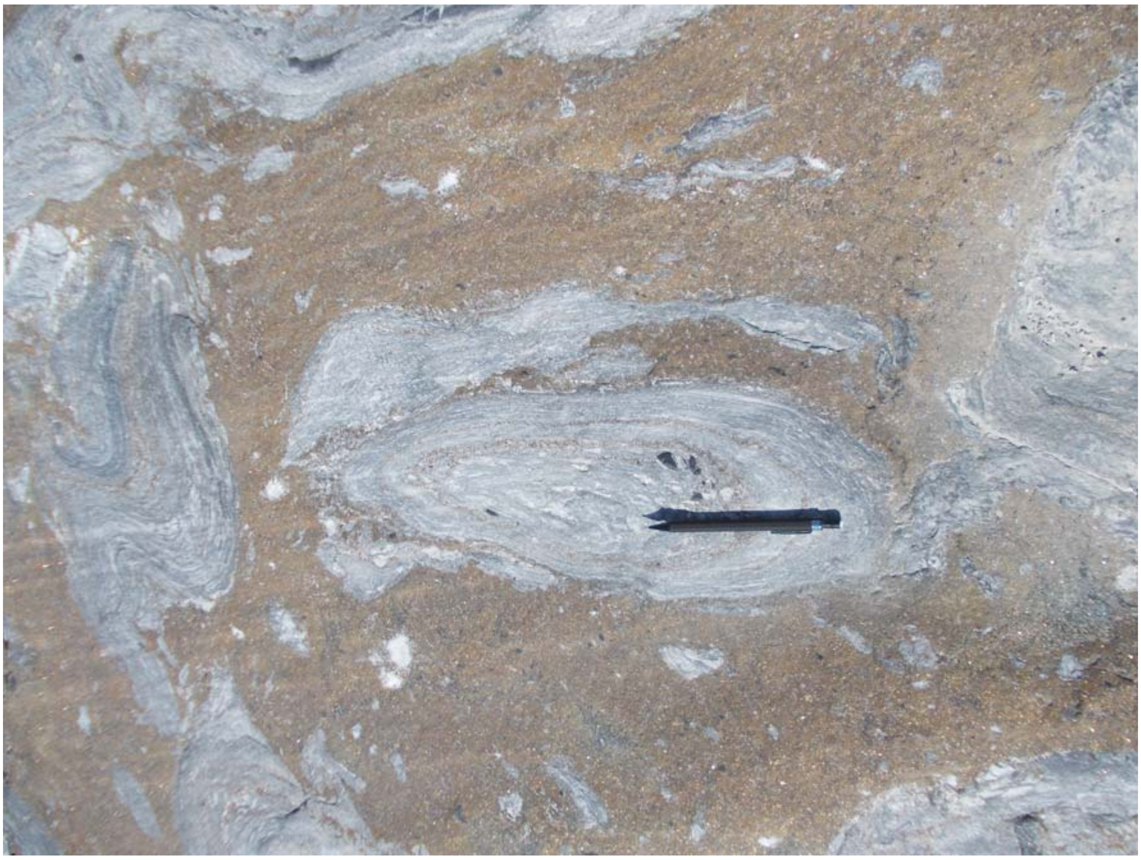


Figure 80. *Sphalerite-galena-pyrite mineralisation, with marble rafts, at the South Lakes occurrence (Maarmorilik).*

Figure 81. *Sphalerite-galena-pyrrhotite bearing chert, Kangerluarsuup Sermia East occurrence.*

Figure 82. *Discovery showing, looking N, highlighting proximity of the mineralised horizon (rusty horizon to the right) to basement (grey outcrops to the left).*

Mineralised quartz-tourmaline breccia in pelite float, found in northern Alfred Wegener Halvø, was interpreted by Coppard et al. (1992) as part of a feeder to an exhalative system. Because of this, the Nûkavsak Formation was considered prospective for SEDEX targets by Coppard et al. (1992). Should this be confirmed, it would be quite significant, considering the areal extent of this formation. During fieldwork, a search for the source for the mineralised quartz-tourmaline breccia float was attempted, but without any success, in part due to the steepness of the terrain. Use of zinc zap in the search of pelite-hosted zinc mineralisation in the Nûkavsak Formation was hampered by the masking interference blue color caused by reaction with iron sulfides often present in these rocks. In any case, use of zinc zap failed to document the presence of significant zinc mineralisation when following up on stream sediment or float anomalies. Instead, it appears that these anomalies can be accounted by several of the abundant rusty-weathering horizons. These rusty-weathering zones occur within the Nûkavsak Formation and where described by Allen & Harris (1980). They result from the weathering of semi-massive pyrrhotite-pyrite, sulfidic cherts or siliceous shales and gossanous metasandstone horizons. Many of these horizons were previously sampled and yielded only low base metal contents (Allan & Harris, 1980),possibly as the result of relatively low temperature and diffuse subsea discharge. However, alternatively they can be distal expressions of exhalative systems, and thicker and more base metal-rich vent proximal areas can be found.

The thicker and more continuous semi-massive sulfide horizons, which are heavily boudinaged, appear to occur on top or laterally to mafic volcanic rocks (the “Kangigdleq basic volcanics”, of Allen & Harris, 1980). This suggests that they are related to submarine volcanic activity and could correspond to volcanogenic massive sulfide systems (VMS), rather than SEDEX systems. Footwall rocks to the sulfide horizons were therefore often checked, and whenever possible briefly described and also sampled (namely in Kussinersuup Aaffaa and Central Kangiusap Kuua). At the latter location, this work allowed to establish that, what is mapped (sheet 71 V1, Henderson and Pulvertaft, 1987) as quartzite and pelite with gossans, are actually sulfidic cherts which lie on top of metamorphosed mafic volcanic rocks. These volcanic rocks are hydrothermally altered, and in some places sulfide and calcite stockworks were recognized (Figure 83), which represent feeders to the exhalative system above. Higher up in the stratigraphy, fresher volcanic rocks, retaining primary features (hyaloclastic textures), are present. While visits to Northern and Southern Kangiusap Kuua were shorter, it appears their setting is similar, ie. what has been mapped as quartzite, actually corresponds to recrystallized chert horizons.

As stated above, these VMS systems appear to be low, yet anomalous, in base metals and gold, and generally constitute small volumes, possibly due to dilution caused by relatively large clastic inputs and/or due to dismemberment during subsequent deformation. Nevertheless, systematic sampling and analysis was carried out and should continue, in order to test the former and establish possible vectors to possible base metal-rich areas. Furthermore, the dating of these exhalative systems (ores, black shales and related volcanic rocks) should be attempted, to constrain the depositional age of the Nûkavsak Formation.

Figure 83. H*ydrothermally altered volcanic rocks, cut by sulfide and calcite stockwork at the footwall of a sulfidic chert horizon, in Central Kangiusap Kuua*

Assay results for stratabound mineralised samples hosted by the Mârmorilik, Qaarsukassak and Nuûkavsak formations are shown in Table 3. A look at this data will allow to quickly identify two base metal-rich samples from the Discovery and South Lakes Glacier occurrences (569807 and 13, respectively). However, such a glance will overlook samples that might not have high base metal contents, but have elevated base metal contents relative to their sulfur content (akin to the tenor concept, in nickel exploration). For this, it is best to use the Fe-S-10x(Zn+Pb) ternary diagram in Figure 84. This diagram attempts to discriminate the different metal signatures of the base-metal mineralisation hosted by calcite marbles of the Mârmorilik Formation or of the Qaarsukassak Formation, and of the rusty-weathering zones hosted by the Nûkavsak Formation above. It shows that the latter are dominated by pyrite and/or pyrrhotite and lack significant amounts of base metals. Due to the effects of weathering, resulting in gossan horizons, compositions can depart from pyrite and become enriched in Fe and depleted in S. The former have variable amounts of iron sulfide, but can also have significant sphalerite and/or galena contents. The two samples closest to the base metal corner were collected at the previously known Discovery and South Lakes occurrences (569807 and 13, respectively). However, a third sample (569816) was collected approx. 10 km to the WNW, near Kangerlussuakassak, were the presence of mineralisation was not previously acknowledged. This supports the continuation of the Qaarsukassak Formation hosting base metal mineralisation to the NW, as illustrated by Figure 47 (Structural Geology section).

Table 3. *Summary of analytical results obtained through sodium peroxide fusion ICP-OES:*

		Cu	Fe	Pb	P	S	Zn
Sample #	Stratigraphic unit - Location	%	%	%	%	%	%
568713	Nukavsak Fm - Rinks Isbræ	0.007	4.32	<0.01	0.025	0.90	0.01
568714	Nukavsak Fm - Rinks Isbræ	0.010	9.78	<0.01	0.067	3.28	<0.01
568715	Nukavsak Fm - Rinks Isbræ	0.010	6.35	<0.01	0.095	1.55	<0.01
568716	Nukavsak Fm - Rinks Isbræ	0.023	35.90	0.01	0.011	25.90	0.18
568725	Nukavsak Fm - Central Kangiussap kua	0.011	32.20	<0.01	0.034	20.90	<0.01
569806	Qaarsukassak Fm - Discovery	0.047	44.20	<0.01	< 0.005	21.30	0.47
569807	Qaarsukassak Fm - Discovery	0.028	31.10	<0.01	< 0.005	33.70	20.10
569813	Marmorilik Fm - South Lakes	0.075	8.07	10.20	0.011	26.40	32.30
569816	Qaarsukassak Fm - Kangerdlugssuakavsak	0.016	4.05	0.05	0.042	0.96	0.22
569817	Nukavsak Fm - Kangerlussuakassak	0.025	19.70	<0.01	0.156	9.38	0.03
569819	Nukavsak Fm - Qingarssuaq	0.081	12.40	<0.01	0.060	9.99	0.09
569820	Nukavsak Fm - Qingarssuaq	< 0.005	15.50	<0.01	0.005	18.00	<0.01
569821	Nukavsak Fm - Qingarssuaq	0.019	9.35	<0.01	0.213	8.11	0.02
569822	Nukavsak Fm - Qingarssuaq	0.026	9.53	<0.01	0.052	10.10	0.05
569824	Nukavsak Fm - NW Alfred Wegener halvø	0.020	5.84	<0.01	0.086	4.05	<0.01
569827	Nukavsak Fm - Anchorage #2	< 0.005	1.18	<0.01	< 0.005	1.47	<0.01
569829	Nukavsak Fm - Qeqertarssuaq Ø	0.018	1.27	<0.01	< 0.005	0.73	<0.01
569830	Nukavsak Fm - Qeqertarssuaq Ø	0.007	1.87	<0.01	0.045	0.65	<0.01
569848	Nukavsak Fm - Kugssinersup auvfa	0.076	37.80	<0.01	0.019	26.00	0.07
569849	Nukavsak Fm - Kugssinersup auvfa	0.010	9.45	<0.01	0.178	2.35	<0.01
569853	Nukavsak Fm - Kugssinersup auvfa	0.063	45.50	0.01	0.013	29.40	0.10
569857	Nukavsak Fm - Kugssinersup auvfa	0.016	12.50	<0.01	0.165	1.95	0.04
569858	Nukavsak Fm - Kugssinersup auvfa	0.016	3.70	<0.01	0.045	0.86	0.01
569866	Nukavsak Fm - Rinks Isbræ	< 0.005	1.56	<0.01	0.007	0.36	<0.01
569869	Nukavsak Fm - Rinks Isbræ	0.018	10.70	<0.01	0.049	5.42	0.04
569876	Nukavsak Fm - Central Kangiussap kua	< 0.005	1.63	<0.01	< 0.005	0.30	<0.01
569879	Nukavsak Fm - Southern Kangiussap kua	0.035	25.50	<0.01	0.023	19.00	0.42
569882	Nukavsak Fm - Central Kangiussap kua	0.016	37.70	<0.01	0.008	17.20	0.01
569884	Nukavsak Fm - Central Kangiussap kua	0.034	43.80	<0.01	< 0.005	27.10	<0.01
569885	Nukavsak Fm - Central Kangiussap kua	0.010	30.70	<0.01	< 0.005	2.02	<0.01

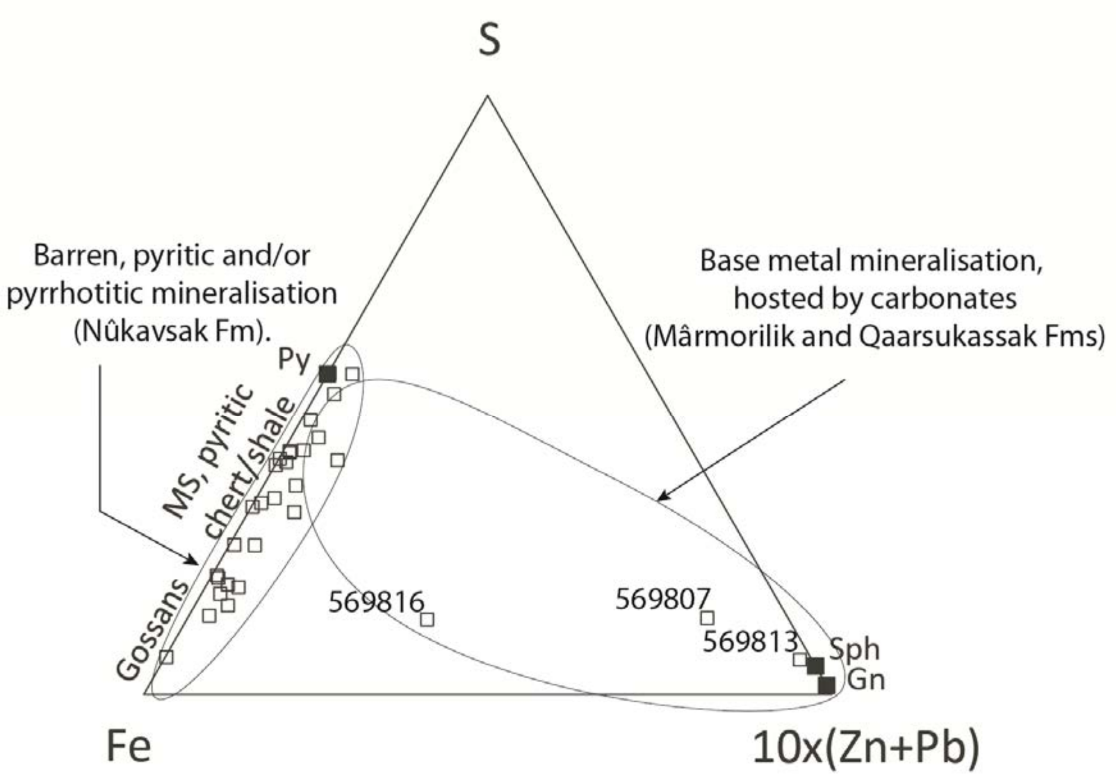


Figure 84. *Fe-S-10x(Zn+Pb) ternary diagram, with discrimination of signatures of base-metal mineralisation hosted by marbles of the Mârmorilik Formation or of the Qaarsukassak Formation, and of the rusty-weathering zones hosted by the Nûkavsak Formation.*

Preliminary conclusions and recommendations

Stratigraphic investigations during the 2015 field season revealed important new information on the nature and relationships between units of the metamorphosed sedimentary-volcanic Karrat Group. A new stratigraphic unit, the Qaarsukassak Formation, was established as a result of the field season's mapping in Kangerluarsuk Fjord. The thin (<20m thick) Qaarsukassak Formation occurs locally in depositional contact with Archean basement and stratigraphically below the Nûkavsak Formation. Though the contact with Nûkavsak Formation is not well-exposed, it is likely unconformable based on variable thickness across the area (result of erosion) as well as integration of clasts recognized as Qaarsukassak Formation in the base of the Nûkavsak Formation.

In Kangilleq Fjord, a package of meta-volcanic rocks occurs stratigraphically below the Nûkavsak Formation. Contact relationships between the Nûkavsak Formation and these meta-volcanic rocks were observed to be transitional over several tens of metres, suggesting that there was no hiatus between the deposition of these two units. From these new observations, stratigraphic revisions are suggested, which would either elevate the meta-volcanic rocks to a standalone formation (the Kangigdleq Formation) separate from the Qeqertarssuaq Formation or would include the meta-volcanic rocks as a member of the Nûkavsak Formation, since these units show conformable relationships in the field.

The Nûkavsak Formation contains primary sedimentary structures (including flute casts, scour structures, flame structures, and cross-bedding) and also contains abundant clasts of reworked, older Karrat Group rocks, including meta-volcanic pebbles and cobbles. This was not previously reported, but provides important stratigraphic and basin tectonic constraints.

An unconformity is inferred from field relationships between the Lower (Qeqertarssuaq Formation) and Upper (Kangigdleq-Nûkavsak formations) Karrat Group (Figure 3). The Qeqertarssuaq Formation shows at least one more phase of deformation and is transposed, i.e. it is not present in a consistent stratigraphic order and is sometimes infolded with Archean basement. A post-Qeqertarssuaq Formation unconformity is also supported by: 1. Meta-volcanic rocks of the Kangigdleq Formation rest on different units of the Qeqertarssuaq Formation, and 2. clasts of Qeqertarssuaq Formation occurring in the Nûkavsak Formation. New field observations suggest that rock units currently mapped as amphibolite with map code 'A' are not equated across the 71 V.2 South and 71 V.2 North map sheets (Henderson and Pulvertaft, 1987). Usually it represents meta-volcanic rocks of the Kangigdleq Formation, which are stratigraphically above the Qeqertarssuaq Formation and are mostly in the greenschist facies, but sometimes this unit is an amphibolite of uncertain protolith clearly within the Qeqertarssuaq Formation.

Geochronological studies are needed to better constrain the depositional age of the Karrat Group overall, test hypotheses regarding possible unconformities within the Karrat Group, and elucidate sedimentary provenance. Building a large dataset of U-Pb detrital zircon analyses will also allow for meaningful comparison with other Paleoproterozoic units, especially the Piling and Penrhyn groups in eastern Arctic Canada, with which the Karrat Group might correlate (e.g., Jackson and Taylor, 1972; Johns et al., 2006; St-Onge et al., 2009; Partin et al., 2014). Improving the age constraints of Karrat Group rocks that host Zn-Pb mineralisation is important for comparison to Re-Os ages of sulfides that can provide constraints on the timing of mineralisation. A good age control on the host rocks is critical for understanding whether mineralisation was dominantly syngenetic or epigenetic in origin, which can guide more effective exploration. More work is needed to fully understand the depositional environment and tectonic setting of the Karrat Group, but preliminary observations suggest a dynamic and possibly multi-stage basin that records a major Paleoproterozoic orogenic event.

Anomalous but low gold values were confirmed at Kussinersuup Aaffaa, Inngia Fjord and Southern Kangiusap Kuua, in quartz veins and alteration zones. At Kussinersuup Aaffaa, Qeqertarssuaq quartzite is also anomalous in U, Th, Zr, and lanthanides, based on which we suggest the possible presence of paleoplacer mineralisation, from where gold could have been subsequently remobilized into quartz veins. In this case, follow-up prospecting using a scintillometer is recommended, in order to identify detrital horizons enriched in heavy minerals.

Whether of syngenetic (SEDEX) or epigenetic (MVT) nature, the mineral potential of the Mârmorilik Formation has remained limited by the limited extent of marble outcrops (approximately 100 km^2). Therefore it is recommended that the presence of relatively shallow and eventually thick Mârmorilik Formation marbles, which might be buried under gneiss thrust sheets, is evaluated through interpretation of the stereo images acquired during the expedition, 3D mapping and interpretation.

The structural studies, supported by the photogeology, show that the Qaarsukassak Formation lies on an unconformity cutting across Archean gneisses. Since this formation has been deposited in the deeper parts of and profoundly dissected paleo-topographic relief, it appears to be laterally discontinuous. However, considering that marble horizons of this formation appear to control the mineralisation at the Discovery and at the Kangerluarsuup Sermia occurrences, the study of the distribution of the Qaarsukassak Formation, through 3D mapping using the stereo images, is recommended to direct subsequent mineral exploration. In addition to the stratigraphic and structural information, regional variation in base metal “tenors”, rather than merely contents, should also merit attention.

The spatial association between semi-massive sulfide horizons within the Nûkavsak Formation and the mafic volcanic rocks (the “Kangigdleq basic volcanics” of Allen & Harris (1980), suggests that the former are related to submarine volcanic activity and could correspond to VMS, rather than SEDEX systems. In VMS systems, the relatively high temperature allows metals to be effectively transported under reduced conditions. This is in contrast to SEDEX systems in which metals are transported under lower temperature, but oxidized conditions. Furthermore, in the former both sulfur and metals can be derived from leaching of rocks, while in the latter metals only react with sulfide derived from seawater upon subsea discharge. As seawater sulfide only became available after ocean oxidation and stratification, and after oceans were no longer dominated by iron, this implies that SEDEX systems, can only form after oxygenation of oceans at approximately 2 Ga (Leach et al, 2010), in contrast to VMS systems which have formed throughout geological history. It is therefore possible that the Nûkavsak Formation is too old to host SEDEX deposits, but could host significant VMS deposits. To verify the SEDEX exploration potential of the Nûkavsak Formation, it is recommended that its depositional age should be established or further constrained (<1946+13 Ma; Kalsbeek et al. 1998). However, even if the Nûkavsak Formation was deposited at a favorable time for SEDEX mineralisation, the redox state, thickness and permeability of the underlying Qeqertarssuaq Formation, which would have had to be the possible source for base metals, could have been constraints. Even if the Qeqertarssuaq Formation could have been a suitable source for base metals, by being oxidized (allowing metal extraction and mobility) and thick enough (to source large quantities of base metals), the work carried out to date indicates this formation would have been buried and metamorphosed, thereby losing its permeability, prior to sedimentation of the rocks of the Nûkavsak Formation, significantly compromising the possibility of SEDEX deposit formation.

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Author Contributions

CP wrote the Stratigraphy section, EVS+LT+JP+JH wrote the Volcanic Rocks section, PG+JK wrote the Structural Geology and JK+DR+BT wrote the Economic Geology sections.

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