Geological, petrographical and geochemical characteristics of the granitoid hosted Amphibolite Ridge gold occurrence in south Greenland

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Abstract. South Greenland is a recognized gold province that hosts Greenland's first gold mine, Nalunaq. Because Nalunaq consists of an auriferous quartz-vein hosted in altered metavolanic rocks these rocks were traditionally regarded as being most favourable for gold exploration and only limited gold exploration was carried out in other settings. Here we present recent results from exploration work that targeted granitic rocks at Amphibolite Ridge (AR) about 25 km north of Nalunaq. Diamond drilling has intersected large portions of gold mineralized granitic rocks together with auriferous quartz-veins associated with shear zones. The hydrothermal alteration fluids have added gold to the granitoids, and the presence of bismuth-rich tellurides implies that the fluids responsible for the introduction of gold were also enriched in Bi and Te. The granitic rocks were subjected to Kfs (K-feldspar), sericite and carbonate hydrothermal alteration together with silicification. Surface mapping of the AR has revealed that the gold mineralization occurs near the contact of granitoids and quartz-diorites. Because all these are typical features of intrusion-related gold systems (IRGS), we suggest that the granitoid hosted AR gold mineralization is a member of the IRGS class. Future gold exploration in South and in South-east Greenland should target K and Si-altered granitic rocks containing quartz-veins associated with shear zones near contacts of rocks with contrasting competence.

Keywords. Intrusion-related gold systems, granitic rocks, Niaqornaarsuk peninsula, South Greenland

1 Introduction

South Greenland is recognized as a gold province of early Paleoproterozoic age (Steenfelt 2000) and hosts Nalunaq, Greenland's first producing gold mine. Nalunaq is a shear hosted high-grade gold deposit with abundant visible gold (VG) in quartz (Kaltoft et al. 2000, Schlatter and Olsen 2011). The quartz-vein is hosted in hydrothermally altered metavolcanic rocks and is associated with a shear zone. The hydrothermal alteration is characterized by addition of gold together with Si and K (Schlatter and Kolb 2011). Renewed exploration activities in South Greenland have regionally targeted not only metavolcanic rocks but also granitoids that showed similar K and Si hydrothermal alteration than seen from Nalunaq. Here we present the results of the first drill program of six holes totalling 1193 metres together with preliminary geological, geochemical and petrological data. The drill program has targeted for the first time granitic rocks belonging to the Julianehåb Batholite Zone that occur on the AR on the Niaqornaarsuk peninsula (Fig. 1) just 25 km north of the existing Nalunaq mine.

2 Regional geology

The Ketilidian orogen evolved between 1850 Ma and 1725 Ma during northward subduction of an oceanic plate under the southern margin of the Archaean North Atlantic craton. The orogen is divided into four geological domains (Chadwick and Garde 1996): (1) the Ketilidian Border Zone, (2) the Julianehåb Batholith Zone, (3) the Psammite Zone and (4) the Pelite Zone (Fig. 1). AR is located in the Julianehåb Batholith Zone and is made up of granites, granodiorites, diorites and gabbros metamorphosed to greenschist facies.

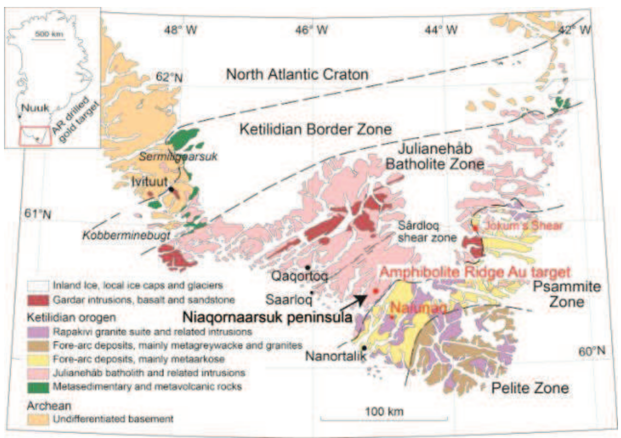

Figure 1. Schematic geological map of the Ketilidian Orogen, South Greenland (modified after Chadwick and Garde 1996) showing the Amphibolite Ridge gold target which is located on the Niaqornaarsuk peninsula about 25 km north of the existing Nalunaq gold mine.

2.1 Geological setting of the AR gold occurrence and drill results

The gold mineralized zone of the AR gold target is at least 79 m wide and comprises two narrow shear zones associated with auriferous quartz-veins containing VG (Fig. 2). Both vein systems are hosted in hydrothermally altered and gold mineralized Kfs-rich granitoid rocks The gold mineralized zone also comprises enclaves of mafic rocks at the contact of the auriferous quartz-veins. These mafic rocks crop out on the eastern flank of the AR and are best described as Kfs and pyroxene-rich alkali lamproites. Drill hole VAG-12-02 intersected a wide gold mineralized zone (Fig. 2, table 1) and the end of the drill hole is still mineralised.

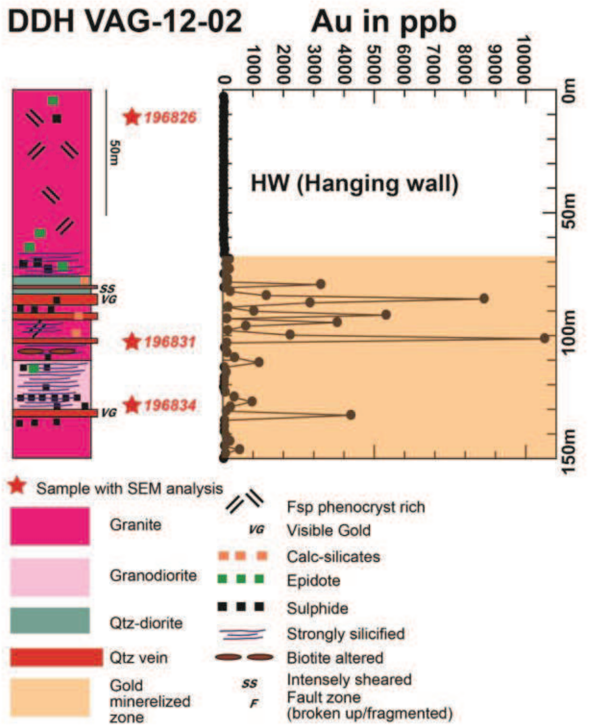

Figure 2. Simplified geological log of the diamond drill hole VAG-12-02 that intersected at the AR gold mineralized granitoid rocks and two narrow quartz-veins with VG.

Drill core samples, based on an average two-metre intersections, were analysed for gold using fire assay methods at Actlabs in Nuuk. A selection of these samples were check assayed at a second, independent laboratory (SGS Toronto). The results of these check assays showed an acceptable level of repeatability.

Hole ID	From (m)	To (m)	Interval (m)	Gold (g/t)
VAG-12-01	70.00	78.00	8.00	0.76
including	72.30	74.00	1.70	2.74
VAG-12-02	68.00	147.00	79.00	0.96
including	78.70	133.40	54.70	1.33
including	78.70	102.00	23.30	2.47
VAG-12-03	62.00	76.00	14.00	0.57
including	62.00	64.00	2.00	2.74
VAG-12-04	294.55	304.00	9.45	0.40
including	295.20	298.50	3.30	0.94
VAG-12-06	28.00	66.00	38.00	0.18
including	54.00	56.00	2.00	0.99

Table 1. Summary of the drill program 2012 at AR.

Other drill holes of the AR together with excellent surface exposure reveals that the footwall (FW) and the hanging wall (HW) are made up of granitic rocks. A few hundred metres south of drill hole VAG-12-02 a rigid 200 m wide diorite body occurs and it is interpreted that the granitoids have intruded into the diorite.

2.2 Hydrothermal alteration and introduction of gold

The granitic rocks are variable altered and alteration as identified from hand lens inspection of drill cores and surface rock outcrops includes silicification, quartz veining and hydrobrecciation as well as precipitation of Kfs, pyrite and pyrrhotite (occurring in both patches and stockwork like fine stringers), calc-silicate, biotite and epidote. The alteration pattern is complex with narrow zones of strongly altered rocks and wider zones of less altered rocks.

3 Lithogeochemistry and pathfinder elements for gold

The lithogeochemical study is based on 42 surface samples and 39 drill core samples that were analysed for major and trace elements at Actlabs in Ancaster. The classification of the rocks as identified in the field are largely confirmed by geochemical assessments (Fig. 3). The rocks from AR plot into the fields of granodiorite, granite, adamellite, tonalite, quartz-diorite, monzo-gabbro and monzonite (Fig. 3). The rock classification based on major elements (Fig. 3) confirmed most of the rock names given in the field, and lithogeochemistry also helped to verify and to refine the rock classification.

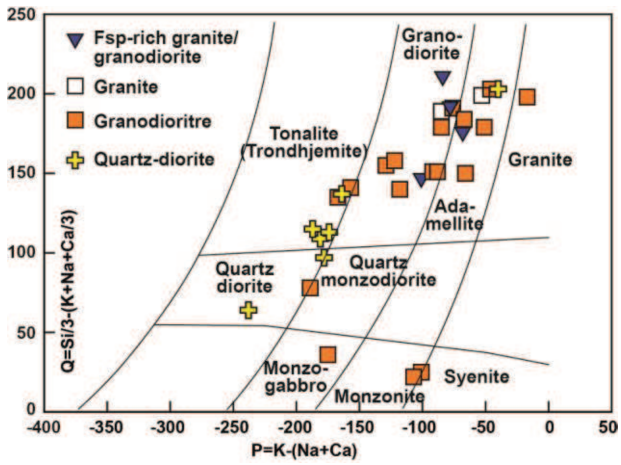

Figure 3. Least to weakly hydrothermally altered felsic igneous plutonic rocks from AR classified by applying the diagram of Debon and LeFort (1982). In the diagram 32 least to weakly altered samples from drill core and 27 samples from surface rocks are plotted.

Preliminary geochemical results based on 594 drill core and 275 surface samples show that the hydrothermally altered granitoids are elevated in gold and in bismuth with a weak correlation between these elements for drill core samples (Fig. 4). Correlation between Bi and Au has been reported from orogenic gold deposits (e.g. Eilu and Groves 2001) and from IRGS (Hart 2007). Other elements that are elevated in the gold zone at AR are silver (up to 6 ppm), gallium (up to 20 ppm), tungsten (up to 22 ppm) and barium (up to 2000 ppm) whereas the base metals copper, zinc and lead are only slightly elevated. Arsenic contents of the samples from the AR gold mineralized zone are low (less than 25 ppm for all samples) which is in strong contrast to the nearby Nalunaq gold mine where the FW and HW are strongly arsenic enriched (Schlatter and Kolb 2011).

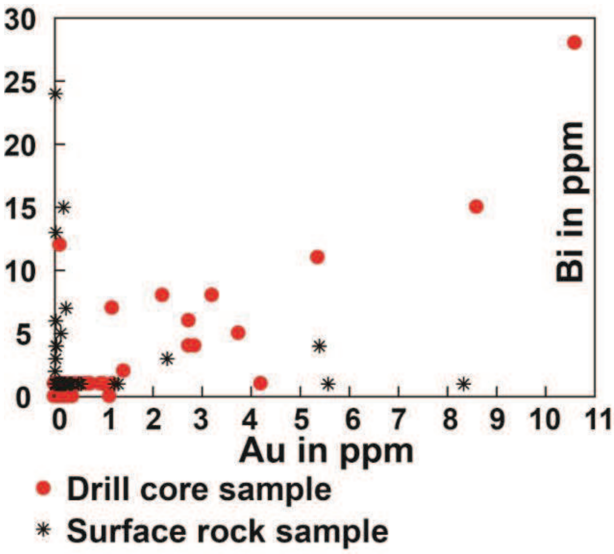

Figure 4. Drill core samples from the AR region show a weak correlation between Au and Bi (Spearman rank coefficient of correlation r' = 0.56) whereas surface samples show no correlation between Au and Bi.

4 Petrography

The petrographic study is based on 18 polished thin sections from drill core samples and 11 polished thin sections from surface rocks. Here we present preliminary petrographic results from the scanning electron microscope (SEM) and observations from the optical microscope for samples 196826, 196831 and 196834. Drill core sample 196826 is from the weakly to moderately altered HW of the AR gold mineralization and the two other drill core samples are taken from the gold mineralized zone intersected by drill hole VAG-12-02 (Fig. 2). The granite from the HW (sample 196826) comprises Kfs, plagioclase, quartz, biotite, sericite and chlorite. The back-scattered electron (BSE) image reveals that feldspars are moderately sericite and chlorite altered which we regard as distal alteration (Fig. 5). The sericite-rich patches (Fig. 5) also contain in some places calcite. The strongly altered granite (sample 196831) that occurs in the gold mineralized zone comprises quartz, plagioclase, relict amphibole and chalcopyrite. Optical microscope observations (Fig. 6) reveals that the rock is strongly sericite altered and SEM work shows that the rock contain fluorite and bismuth-rich tellurides. In sample 196834, albite is strongly sericite and chlorite altered (Fig. 2) and quartz is delicately rimmed by Kfs which appear to be an important characteristic of the proximal hydrothermal alteration at the AR. In the same sample Au and Ag-rich sulphosalts hosted in quartz were identified together with monazite, allanite and barium-rich Kfs (Fig. 7). This mineral assemblage is characteristic of proximal alteration at the AR gold mineralization.

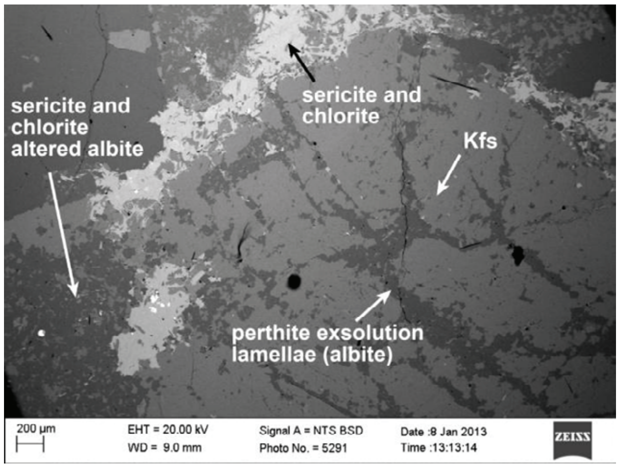

Figure 5. Sample 196826 is weakly to moderately altered granite from DDH VAG-12-02. The BSE image shows that the feldspars are hydrothermally altered. The large Kfs contains perthite exsolution lamellae that can also be identified from the optical microscope.

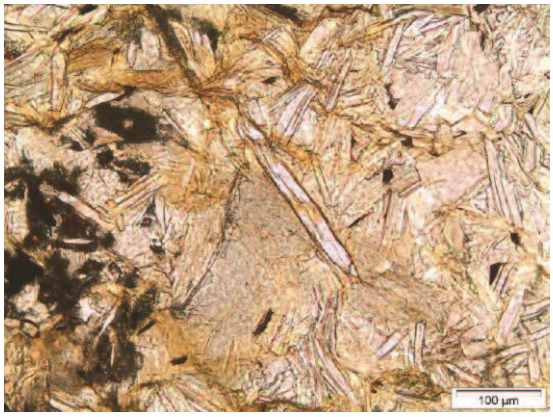

Figure 6. Sample 196831 is strongly altered granite from DDH VAG-12-02. The photomicrograph taken under plane-polarized light shows abundant fine grained muscovite (sericite).

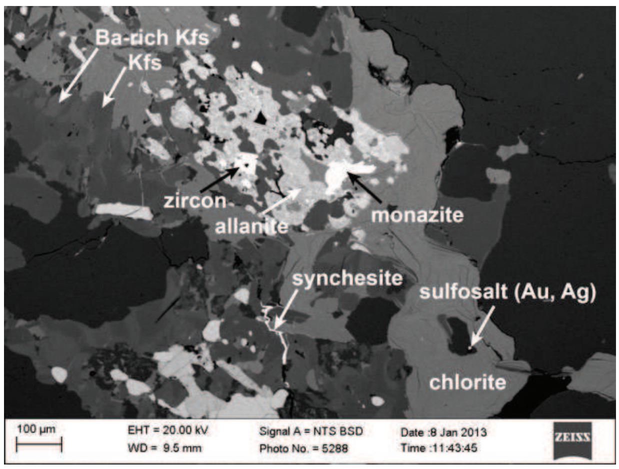

Figure 7. Sample 196834 from DDH VAG-12-02 is strongly altered granodiorite containing Au and Ag rich sulphosalt. The BSE image reveals that the alteration minerals are Kfs, chlorite, monazite and allanite.

5 Discussion and conclusions

The characteristics of the AR mineralization are elevated W, Bi and Te in the alteration zones, sericite, chlorite, biotite, epidote, sulphide and carbonate altered rocks, presence of shear zones with Qtz and VG, and the typical granite-granodiorite host rock. At the AR a large quartz-diorite body that was likely intruded by granitic rocks at relatively shallow crustal level possibly represents a favourable contact trap for the gold. The gold zone intersected at the AR (table 1) shows that large portions of the granitic rocks are mineralized in strong contrast to Nalunaq where the gold is hosted by a narrow, gold-rich quartz-vein (Schlatter and Kolb 2011). In South and South-east Greenland, several gold occurrences and showings are located near the southern margin of the Julianehåb Batholith Zone within the granites and metavolcanic rocks (Stendal and Frei 2000). Recent exploration by NunaMinerals A/S in a locality known as Jokum's Shear in South-east Greenland (Fig. 1) yielded several samples of strongly silicified and sulphidized intrusive plutonic rocks with more than 1 g/t gold including one rock chip sample yielding 9.3 g/t gold over a width of 3.1 metres as well as one composite sample with 3.7 g/t gold over a width of two metres. Several characteristics are recognized at the AR gold occurrence that are typical for IRGS such as widespread gold mineralization of granitoid rocks, granitoid rocks in FW and HW, elevated Bi in the gold zone as well as proximal sericite, Kfs and carbonate alteration. The setting of quartz-diorite intruded by granitic rocks at the AR possibly represents a roof zone as defined by Hart (2007) from work that he carried out in the Tintina Gold Province in Yukon and Alaska. The presence of different deposit styles in South Greenland (narrow gold-rich quartz-vein at Nalunaq, wide gold mineralized granitic rocks at AR) within the same district is as well a typical characteristic of IRGS (Hart 2007)

The results of this preliminary investigation suggest that additional gold resources are to be found in South and South-east Greenland in altered granitic rocks of the southern margin of the Julianehåb Batholite (Fig. 1). Future mineral exploration should drill-delineate the newly discovered AR mineralization and regional exploration should target silicified and Kfs- altered granitic rocks that are elevated in gold and bismuth. Contacts between hydrothermally altered granitic rocks and quartz-diorites or any other contact between altered granite and rocks with a competence and/or a chemical contrast seems to be a favourable locus of gold mineralizations in South and South-east Greenland.

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