Host rock composition and hydrothermal alteration as tools for exploration in the Nanortalik gold district

Denis M. Schlatter, Jochen Kolb
Department of Petrology and Economic Geology, Geological Survey of Denmark and Greenland (GEUS), Øster Voldgade 10,1350 Copenhagen K, Denmark

Abstract. Nalunaq, Greenland's first gold mine, was officially opened in August, 2004 and is located on the Nanortalik peninsula in South Greenland. The high-grade gold mineralization is hosted in an up to 2 m wide quartz vein in hydrothermally altered amphibolite of Paleoproterozoic age. The auriferous quartz vein is controlled by a higher-order thrust in the lowermost stratigraphy of the Ketilidian Nanortalik nappe. Immobile-element ratios indicate seven different primary amphibolite rock types and identified one single marker horizon namely basalt X. Three different hydrothermal alteration stages were distinguished but only the latest one is associated with economic gold mineralization. The most proximal part of the gold-stage hydrothermal alteration system is the auriferous quartz vein. The medial alteration zone comprises biotite and the distal alteration zone is made up of diopside and quartz. Lithogeochemical techniques show that the gold-stage is characterized by mass gains of Si and K and that the Au-rich fluids were enriched in Ag, As, Sb, Bi and W which are typical characteristics for hypozonal orogenic gold deposits.

Keywords. orogenic gold, Nalunaq, South Greenland

1 Introduction

Nalunaq is the first and only gold mine in Greenland. To date >300,000 troy ounces of gold have been produced. The Nalunaq ore body yields high gold grades with several hundred g/t of gold and underground samples with visible gold (VG) and gold contents of up to 5200 g/t (Kaltoft et al. 2000). Here we present the geochemical whole rock data of >4,700 rock samples. These were reported by exploration companies in the period 1992 to 2004, however a comprehensive interpretation of this data set was only undertaken by this study. Angel Mining (Gold) A/S has recently built an underground CIP plant, which is expected to produce 35,000 ounces of gold per year (Chadwick 2010). The data and interpretation presented here aim to provide inspiration to define brownfield exploration targets which can be tested and possibly provide ore feed to the CIP plant in the future.

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: the Ketilidian Border Zone, the Julianehåb Batholith Zone, the Psammite Zone and the Pelite Zone (Fig. 1). Nalunaq is located in the Psammite Zone, which comprises mafic meta-volcanic rocks, meta-arkoses as well as post-kinematic rapakivi granites. The Nalunaq gold deposit is hosted in mafic meta-volcanic rocks metamorphosed to upper greenschist to amphibolite facies grades, which are thrust over the meta-arkose. In the following the prefix "meta" is omitted for simplicity.

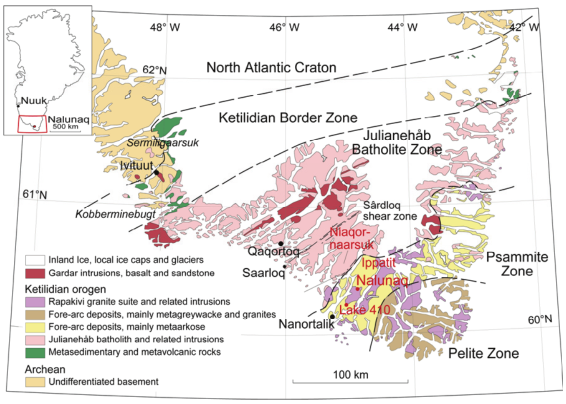

Figure 1. Schematic geological map of the Ketilidian Orogen, South Greenland (modified after Chadwick and Garde 1996). The Nalunaq gold mine is about 35 km NE of Nanortalik. Other gold occurrences near Nalunaq are Lake 410, Ippatit and Niaqornaarsuk.

2.1 Geological setting of the Nalunaq gold deposit

The Nalunaq gold mineralization has an age of approximately 1.80 to 1.77 Ga (Stendal and Frei 2000), is hosted in a thrust sheet of the Nanortalik nappe and formed during the Ketilidian orogeny. The true stratigraphic way up of the host rock unit is unknown because of the lack of primary textures; hence the unit is labelled into structural footwall (FW) and structural hanging wall (HW) with respect to the main auriferous quartz vein (MV-Qtz); (Fig. 2).

The FW is made up of biotite granite belonging to the Julianehåb Batholith and underlying the volcanic rocks. The biotite granite is intruded by a porphyritic granite that contains up to 200 ppb gold. The FW also comprises basaltic volcaniclastic rocks, fine-grained amphibolite and several metres thick coarse-grained dolerite sills. Although the sequence of volcaniclastic rocks are sulfide-enriched, they never contain economic gold mineralization.

The Nalunaq ore horizon comprises the 0.5 m to 2 m thick auriferous MV-Qtz and the proximal about 1 m to 1.5 m wide hydrothermal alteration halo, which occurs on both sides of the vein. The MV-Qtz can be traced at surface for about one km on the east and north facing slopes of the Nalunaq mountain and crosscuts the foliation at a low angle, whereas the foliation is parallel to the bedding. The Nalunaq hanging wall vein (HWV), although thinner, less continuous and containing less gold than the MV-Qtz, comprises a few tens of centimetre thick Qtz vein sometimes with VG. The HW consists of a sequence of fine-grained amphibolite, medium-grained and coarse-grained dolerite. Several generations of pegmatite and aplite crosscut the tectonostratigraphic sequence.

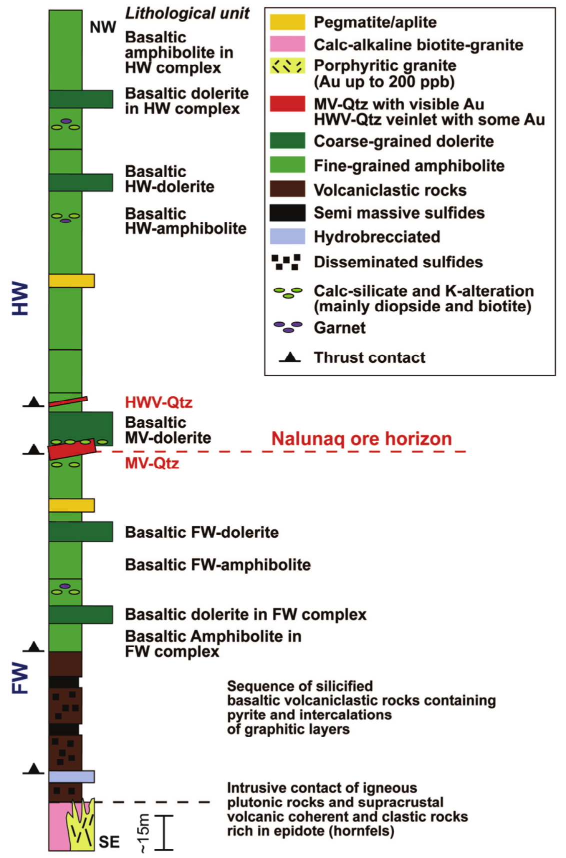

Figure 2. Simplified tectonostratigraphic sequence of Nalunaq. The stratigraphy is relatively simple and consists mainly of fine-grained amphibolite and coarse-grained dolerite sills. Host rocks are amphibolite or dolerite because of the cross cutting nature of the MV-Qtz.

2.1 Hydrothermal alteration and gold mineralization

The most abundant hydrothermal alteration minerals are quartz, biotite, diopside, Ca-rich amphibole, Ca-rich plagioclase, carbonates, muscovite, epidote, chlorite, tourmaline and sphene and the ore minerals are gold, arsenopyrite, pyrrhotite, pyrite, chalcopyrite, scheelite, maldonite, löllingite and Bi-sulfosalts (Kaltoft et al. 2000). Three hydrothermal alteration stages are distinguished: early alteration is characterized by garnet, epidote, diopside and plagioclase; a second alteration stage is caused by contact metamorphism between granite and volcaniclastic rocks of the FW and epidote occurs in the contact aureole (Fig. 2); and a third alteration stage is associated with economic gold mineralization. The most proximal part is the auriferous quartz vein (Fig. 3). The intermediate hydrothermal alteration zone comprises biotite-altered bands of about 15 cm thickness containing sulfides. The distal hydrothermal alteration zone is about 1.5 m thick and is made up of diopside and silica-altered amphibolite and dolerite rocks. The thickness of the hydrothermal alteration zones varies between several tens of centimetres to up to a few meters.

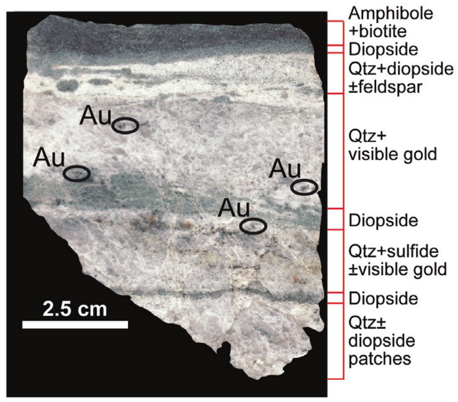

Figure 3. Photograph of a sample from the MV-Qtz at the 450 m drift. Zones of lighter parts are quartz and the green parts represent diopside slivers. Gold grains are indicated.

3 Lithogeochemistry

In order to establish the geochemical classification, we used immobile element ratios involving Zr/TiO_2, Zr/Al_2O_3 and Al_2O_3/TiO_2. 447 amphibolites are classified into basalt 1, basalt 2, basalt 3, basalt 4, basalt X, basaltic andesite 1 and basaltic andesite 2 (Table 1).

Table 1. Average immobile-element ratios of the amphibolites (division from Barrett and MacLean 1994).

Chemical group (amphibolites)		Immobile element ratios			
		Zr/TiO_2	Zr/Al_2O_3	Al_2O_3/TiO_2	Zr/Y
Basalt 1	mean	65.7	4.3	15.4	3.2
n=116	average deviation	7.6	0.6	1.2	0.7
Basalt 2	mean	53.0	3.5	15.2	2.7
n=87	average deviation	1.3	0.3	1.2	0.4
Basalt 3	mean	45.5	3.0	15.1	2.8
n=208	average deviation	2.6	0.3	1.0	0.5
Basalt 4	mean	45.8	4.8	9.6	2.6
n=20	average deviation	3.8	0.4	0.3	0.3
Basalt X	mean	27.4	1.7	16.4	1.4
n=6	average deviation	4.1	0.3	1.1	0.2
Basaltic andesite 1	mean	106.8	6.7	16.1	4.1
n=4	average deviation	3.7	0.7	1.8	0.2
Basaltic andesite 2	mean	161.8	9.9	16.3	5.5
n=6	average deviation	12.1	0.5	1.1	1.9

In detail basalt 2, basalt 3 and basalt 4 have similar geochemical characteristics, are tholeiitic as shown by their Zr/Y ratios (Table 1) and are possibly co-magmatic although time relations are unknown. Basalt X has different immobile element ratios (Table 1) and represents one single geochemical marker horizon, which is only found in the FW.

3.1 Pathfinder elements for gold and mass change calculations

The elements Ag, As, Sb, Bi and W correlate with gold and display Spearman rank correlation coefficients >0.45 (Schlatter and Olsen, 2011). The hydrothermal alteration as defined by mass change calculations using single-precursor treatments (Barrett and MacLean 1994) is characterized by the addition of SiO_2 (up to 35 g/100g of rock), K_2O (up to 1.2 g/100g), CaO (up to 20 g/100g) and gold. Enrichment of As is seen not only from the MV-Qtz level, but also in the FW and HW. This is in agreement with the observations from rocks, which are characterized by strong As enrichment accompanied by silicification but without gold enrichment (Fig. 4). E.g., several silicified rocks from the HW-dolerite located about 25 m above the MV-Qtz level are strongly enriched in As, but not Au-enriched. It is suggested that this alteration belongs to the latest stage occurred distal to the MV-Qtz and involved lower fluid/rock ratios and, thus, less gold. Therefore As enrichment cannot be used solely as a vector to the ore.

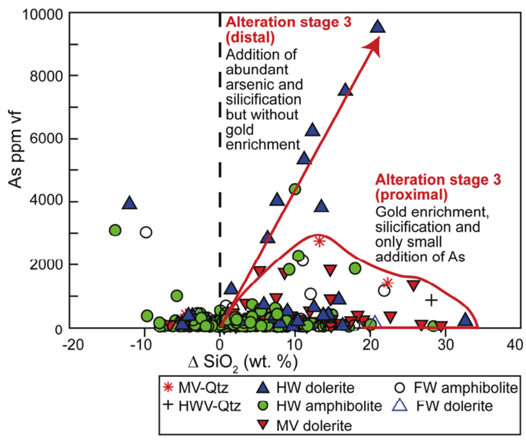

Figure 4. As versus ΔSiO_2 for samples of the footwall, the hanging wall and the ore horizon.

4 Discussion and conclusions

Rocks of low-K tholeiitic basaltic composition are known from island arc and sea floor settings. Therefore it is conceivable that the volcanic rocks at Nalunaq represent oceanic basalts. This is in agreement with low-K tholeiitic amphibolites exposing relict pillow structures in fine-grained amphibolite (Petersen et al. 1997). Although the gold mineralization is not hosted in a distinctive chemical rock type, Basalt X is only seen in the FW and allows the establishment of the chemostratigraphy. The location of the economic gold mineralization is likely not controlled by the wall rock geochemistry, but is rather controlled by the rheology contrast between dolerite and amphibolite. Based on the alteration mineral assemblage and lithogeochemistry three hydrothermal alteration stages were distinguished. Nevertheless only the latest stage characterized by quartz, biotite and diopside is associated with economic gold mineralization. Diopside and garnet occur also in the first alteration stage, which is barren and possible related to sea-floor hydrothermal alteration. The latest hydrothermal alteration stage involving Au, Si and K might then have overprinted pre-existent metamorphosed alteration assemblages.

The gold mineralisation at Nalunaq is located in volcanic rocks at the contact of dolerite and amphibolite units where a maximal rheological contrast occurs. At this contact the MV-Qtz developed from Au, As, Ag, Sb, Bi and W-enriched fluids. Although the Nalunaq deposit is orogenic, the close spatial association with calc-alkaline and porphyritic granites is intriguing. Elements such as Sb, Bi and W are often associated with felsic igneous rocks and also indicate a possible intrusion related gold system (Groves et al. 2003). It is, therefore recommended, to target volcanic rocks associated with calc-alkaline and porphyritic granites for gold exploration. Within these volcanic rocks, or even possibly within granitic rocks, a shear zone associated with Si-and K-enriched rocks with anomalous levels of Au, As, Ag, Sb, Bi and W represent a particular good target in the Nanortalik gold district or elsewhere in South Greenland.

Acknowledgements

This study has been funded by GEUS, Copenhagen and the Bureau of Minerals and Petroleum, Nuuk Greenland.

References

Barrett TJ, MacLean WH (1994) Chemostratigraphy and hydrothermal alteration in exploration for VHMS deposits in greenstones and younger volcanic rocks. In: Lentz DR (ed) Alteration and alteration processes associated with ore-forming systems. GAC Short Course Notes 11:433-467

Chadwick J (2010) Innovative Angel. International Mining, November 2010, 6 (11):10-14

Chadwick B, Garde AA (1996) Palaeoproterozoic oblique plate convergence in South Greenland: a reappraisal of the Ketilidian Orogen. In: Brewer TS (ed) Precambrian crustal evolution in the North Atlantic region. Geol Soc Spec Publ 112:179-196

Groves DI, Goldfarb RJ, Robert F, Hart CJR (2003) Gold deposits in metamorphic belts: Overview of current understanding, outstanding problems, future research, and exploration significance. Econ Geol 98:1-29

Kaltoft K, Schlatter DM, Kludt L (2000) Geology and genesis of Nalunaq Palaeoproterozoic shear zone-hosted gold deposit, South Greenland. Appl Earth Sci 109:B23–B33

Petersen JS, Kaltoft K, Schlatter D (1997) The Nanortalik gold district in South Greenland. In: Papunen, H. (ed) Mineral deposits: research and exploration. Where do they meet? Proceedings 4th SGA Biennal Meeting, Turku, Balkema, Rotterdam: pp 285-288

Schlatter DM, Olsen SD (2011) The Nalunaq gold mine: a reference sample collection and compilation and interpretation of geochemical data. GEUS Rapport 2011/31, 77 p

Stendal H, Frei R (2000) Gold occurrences and lead isotopes in Ketilidian Mobile Belt, South Greenland. Appli Earth Sci 109 (Section B):B6–B13