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MINERALOGY AND GEOCHEMISTRY OF THE WHALE TAIL ZONE, AMARUQ GOLD PROJECT, NUNAVUT

M-C. Lauzon[1], P. Mercier-Langevin[2], G. Beaudoin[1], O. Côté-Mantha[3], M. Simard[3], M. Valette[4], and S. De Souza[4]

1. Introduction

The 4.2 Moz Amaruq gold project, fully owned by Agnico Eagle Mines Ltd, is located in the Kivalliq region, 50 km north of the Meadowbank gold mine in Nunavut. The mineralized zones at Amaruq are hosted in an E-W-trending, strongly deformed, steeply N- to S-dipping, volcanosedimentary succession that belongs to the Archean Woodburn Lake group, Churchill Province. Since its discovery in 2013, an intensive exploration campaign is being carried out in the area to define and expand the main mineralized zones (i.e. Whale Tail and IVR) and their extensions. The Whale Tail zone is the most extensively drilled to date and the best understood in terms of geometry (Côté-Mantha et al., 2015). Although each auriferous zone shows distinct geological features at Amaruq, this study focus on the Whale Tail zone. Preliminary investigations and current exploration and research at Whale Tail suggest that this zone is a stratiform- and vein-type iron-formation-hosted gold deposit as described by Kerswill(1996).

Sampling of representative altered and mineralized core intervals (e.g., 9.97 g/t Au over 6.4 m) was completed along a representative drill hole (IVR14-158) that crosscuts a succession of chert intercalated with argillite and greywacke, the chert being the principal host rock to mineralization.

2. Geological setting

2.1 Regional

The Amaruq gold project is hosted in a volcanosedimentary succession that belongs to the Archean Woodburn Lake group, located in the Rae domain of the Western Churchill Province of the Canadian Shield. The Rae domain is characterized by granodioritic to tonalitic rocks, orthogneiss and supracrustal rocks (figure 1). The Woodburn Lake group consists of a strongly deformed succession of Archean metavolcanic and metasedimentary (Zaleski et al., 1997).

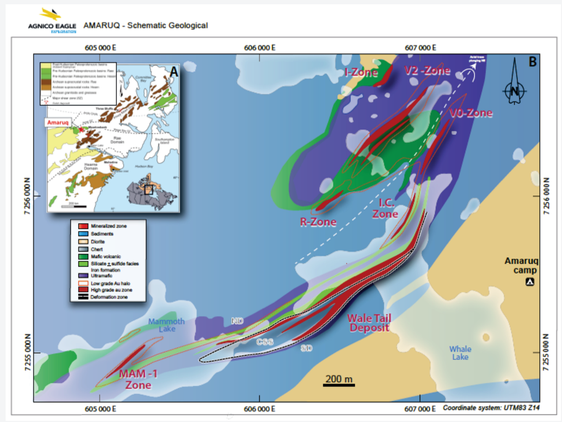


Figure 1 : (a) Simplified geology of the Western Churchill Province showing the Rae and Hearne domains and the Snowbird Tectonic Zone. The Amaruq and Meliadine gold projects, and the Meadowbank mine are shown. (b) geological map of the Amaruq gold project with location of the main mineralized zones I, V and R, Whale Tail and Mammoth (Agnico Eagle Mines website, 2016).

2.2 Whale Tail zone

The Whale Tail gold zone varies in dip but globally dips abruptly to the south-east. It extends down to at least 430 meters (Agnico Eagle Mines, 2016).From south towards north, the main geological units in the study area are, as shown on Figure 2:

1- dorite;
2- volcanosedimentary succession (greywackes intercalated with mafic volcanic rocks);
3- sedimentary succession composed of chert, silicified and graphitic chert and greywackes that host most of the mineralization;
4- silicate-sulphide facies iron formation;
5- two geochemically distinct ultramafic units;
6- the Whale Tail north domain composed of clastic sedimentary rocks(greywacke and mudstone) overlain to the south by ultramafics.

2.3 Gold mineralization

Detailed petrography and electron probe micro-analyses (EPMA) indicate two major gold-bearing mineralization styles at Whale Tail:

1- "silica flooding" with significant pyrrhotite, arsenopyrite in and around veinlets and/or as disseminated grains preferentially developed in chert bands. This type of mineralization is mainly developed within the central sedimentary succession, between the two ultramafic rock units.

2- quartz-pyrite-pyrrhotite±chalcopyrite ±gold extension veins at high angle with the main foliation.

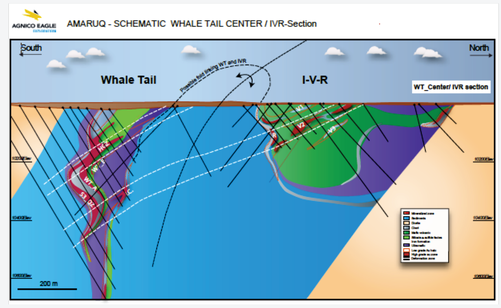
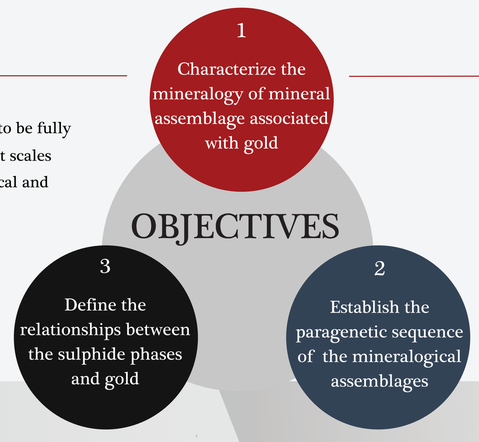


Figure 2 : Cross-section (looking west) of the Whale Tail and IVR zones (Agnico Eagle Mines website, 2016).

3. Problematic

The Whale Tail zone differs in style from other well-known ore deposit in the Kivalliq area, in Nunavut (e.g.,: Vault, Portage and Goose zones at the Meadowbank mine), both in terms of ore zone geometry and in terms of host rock composition.The discovery of mineralized zone with distinct characteristics at Amaruq in 2013 by Agnico Eagle Mines highlighted the presence of gold zones in the region that have different controls than other know systems in the area.

Therefore, distribution and genesis of the gold zones remain to be fully understood to better constrain exploration models at different scales in the sector and in similar contexts elsewhere. A mineralogical and geochemical study of the auriferous mineralization of the Whale Tail zone is being carried out as part of an honours thesis research project to characterize its proximal footprint and better understand the relative timing of events relative to gold mineralization.



4. Methods

- Microscopic and macroscopic study on 19 polished thin sections taken along ddh IVR14-158 that was studied and sampled in detail
- Electron probe micro-analyses on sulphide
- Scanning electron microscope used to obtain the quantitative analysis of major silicates and sulphides.

5. Summary of results and discussion

The sulphide phases associated with gold are arsenopyrite and loellingite. Sulphides are mainly within a gangue of Fe-, Mn-, K-, and Al-rich amphiboles (grunerite, cummingtonite ferro-hornblende and ferro-anthophyllite), chlorite (ripidolite and brunsvigite), biotite (siderophyllite) and carbonates (ankerite and calcite). The fine-grained (1–25 µm) gold, which exhibits a variety of shape (from rounded to angular), is closely associated with the arsenopyrite-loellingite. Scanning electron microscope shows that gold occurs as electrum (Au=63.56–86.73 wt.%). Loellingite (172–196 ppm Au) and arsenopyrite (<DL–257 ppm Au) contain the highest concentrations of gold, which is substantially less concentrated in pyrite (<DL – 54 ppm) and pyrrhotite (<DL– 17 ppm).

Table 1: average trace element abundances (ppm) in different type of pyrrhotite, arsenopyrite and loellingite.

	Nickel (ppm)	Cobalt (ppm)	Gold (ppm)	Number of samples
Po 1	**303.9**	**15.0**	**0.0**	**7**
Po 2	1099.8	50.0	4.5	12
Po 3	68.0	0.0	0.0	4
Aspy 1	206.0	989.9	101.1	7
Aspy 2	492.0	30.0	257.0	1
Aspy 3	135.3	11.9	33.7	7
Lo	5396.7	76.8	185.1	9

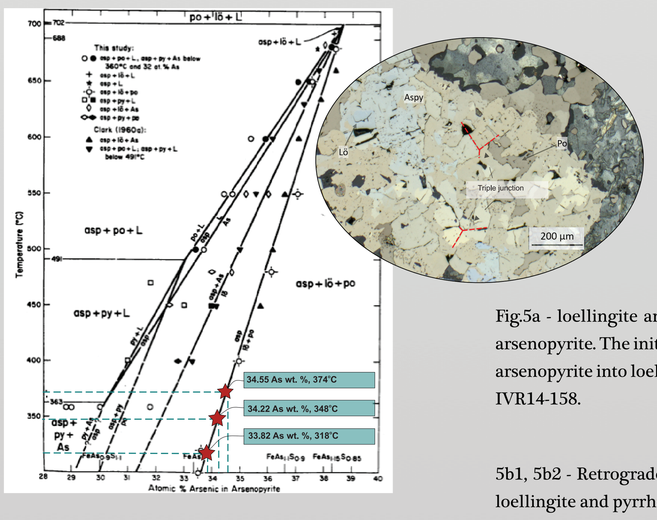


Figure 6: Pseudobinary temperature – composition plot showing arsenopyrite as a function of temperature and equilibrium mineral assemblage (Kretschmar and Scott, 1976) and microphotography of a sample that has been taken to define the range of equilibrium

In recrystallized coarse grain arsenopyrite, visible equilibrium textures between arsenopyrite, pyrrhotite and loellingite (mainly triple junction) are present (figure 6). Microprobe analysis on those minerals allowed to estimate the temperature of retrograde metamorphism, which ranges between 318°C and 374°C. This interval is coherent with the greenschist facies and thus, is in agreement with the regional metamorphism conditions currently interpreted at Amaruq (Thompson, 2015).

Although the relative timing of events in the study area has yet to be fully resolved, observations from this study indicate that gold was present before prograde metamorphism of arsenopyrite at Whale Tail. The loellingite-pyrrhotite-arsenopyrite assemblage shows different stages of retrogressive metamorphism that helps understanding the evolution of gold concentration in the studied rocks.

Fig.5a - loellingite and pyrrhotite forms during prograde metamorphism from arsenopyrite. The initial retrogressive phase will make invisible gold diffuse from arsenopyrite into loellingite. This stage isn't visible in any of the thin section from IVR14-158.

5b1, 5b2 - Retrograde metamorphism will gradually consume the gold-bearing loellingite and pyrrhotite to form arsenopyrite. Native gold will start to appear at the loellingite-arsenopyrite interface and will also keep diffusing in the remaining loellingite crystal.

5c1, 5c2 -As the rate of loellingite destruction overtakes the rate of gold diffusion during retrograde metamorphism, the gold exsolves.

5d - When all the retrogressive process is completed, all the loellingite is consumed and only a native gold-rich core arsenoyrite remains with a gold-barren rim.

Gold, liberated from loellingite is not readily incorporated into arsenopyrite, even down to 300°C (Tomkins and Mavrogenes, 2001).

The analysis of three types of arsenopyrite supports these observations. It shows that the one that forms from retrograde metamorphism of loellingite contains less gold then the two other types (i.e. 34 ppm Au, n=7 vs 120.58 ppm Au, n=8).

5.1 Paragenetic sequence

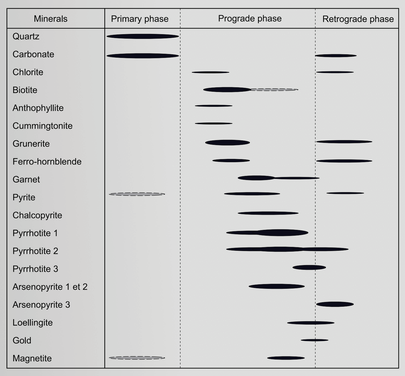


Figure 3: Paragenetic sequence of the IVR14-158 drill hole minerals.

4a - Stratiform pyrite (diagenetic?) that occurs within a gangue of silicate (mainly quartz) in a barren chert.
4b - Prograde pyrrhotite formed at the expense of pyrite, and metamorphic grunetrite-biotite overgrowth over pyrrhotite. Late arsenopyrite overprints the pyrrhotite-pyrite-silicate assemblage.
4c - Different types of amphiboles overprinting quartz bands in a chert. Again, the arsenopyrite is late in the sequence.
4d - Primary idiomorphic magnetite in iron formation. Some grains are stretched/flattened into the main foliation.
4e - Subidioblastic zoned garnet (almandine core and spessartite rim) showing a synkinematic structure. The core is rich in inclusions relative to the rim. This texture indicates initially rapid grain growth followed by slower growth resulting in complete expulsion of inclusions (Geusebroek, 2004).
4f - Evidence of retrograde metamorphism; biotite is selectively to pervasively retrograded to chlorite.
4g - Retrograde, gold-bearing loellingite over prograde pyrrhotite and arsenopyrite.
4h - Late calcite veins.

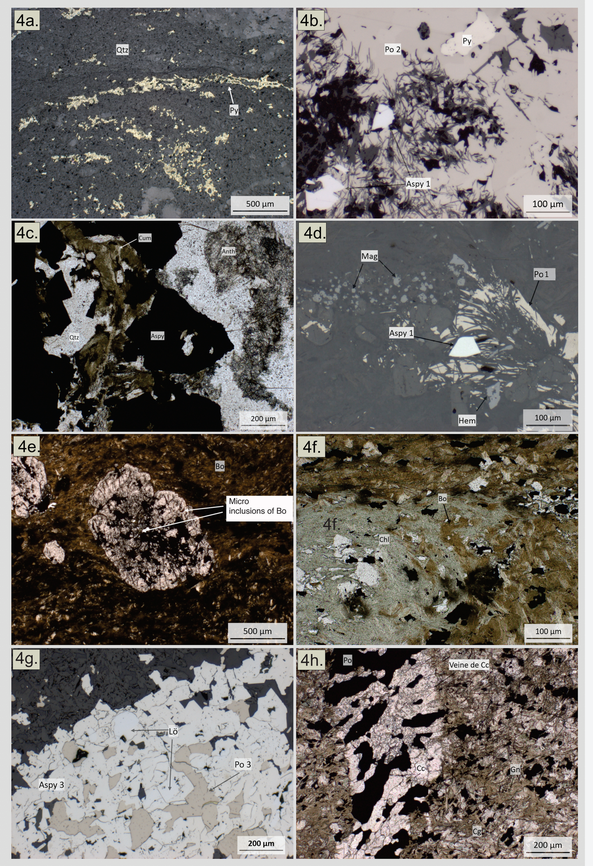


Figure 5: Photomicrographs showing different textures typical of the mineralized intervals in ddh IVR14-158 at Whale Tail. Py=pyrite, Qtz=quartz, Po=pyrrhotite, Aspy=arsenopyrite, Cum=cummingtonite, Anth=anthophillite, Mag=magnetite, Hem=hematite, Bo=biotite, Chl=chlorite, Lo=loellingite, Cc=calcite

5.2 Gold concentration versus sulphide assemblages and textures

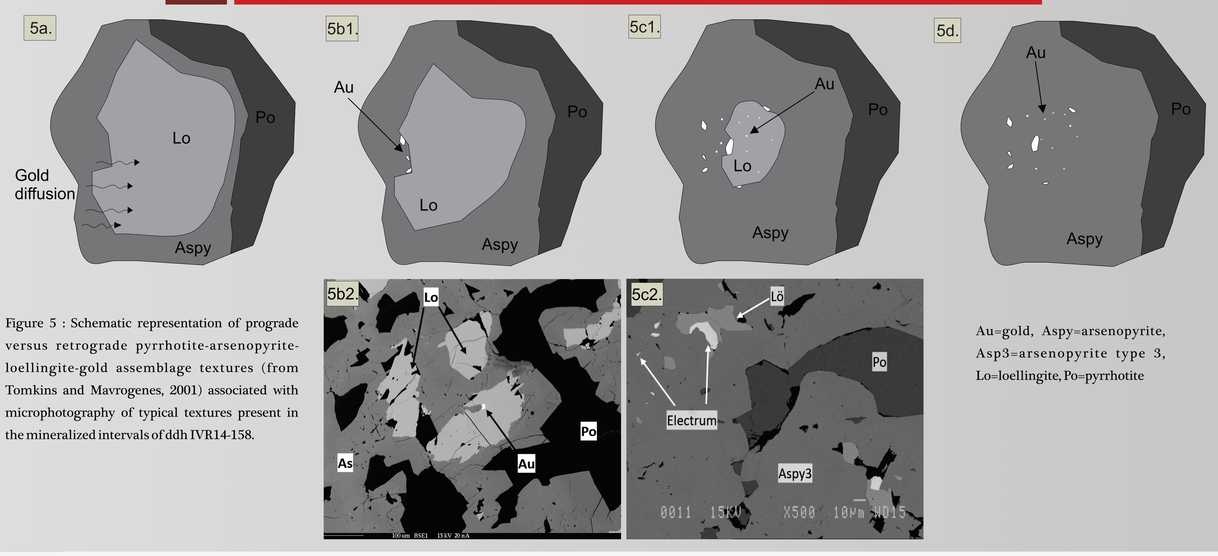


Figure 5 : Schematic representation of prograde versus retrograde pyrrhotite-arsenopyrite-loellingite-gold assemblage textures (from Tomkins and Mavrogenes, 2001) associated with microphotography of typical textures present in the mineralized intervals of ddh IVR14-158.

Au=gold, Aspy=arsenopyrite, Asp3=arsenopyrite type 3, Lo=loellingite, Po=pyrrhotite

6. Conclusion

This work is part of the course Geological Design at Université Laval. Textural studies, mineral chemical analyses and traces element data, obtained by using reflected light microscopy, EPMA and scanning electron microscope of sulphides and silicates associated with gold have been put together to defined the evolution of gold concentration within the Whale Tail zone and establish a paragenetic sequence of the mineralization and metamorphism. Prograde metamorphism of arsenopyrite to loellingite led to the enrichment of gold within the structure of loellingite. During retrograde metamorphism, gold was exsolved from the structure of loellingite. The granoblastic sulphide texture and the equilibrium temperature of loellingite-arsenopyrite-pyrrhotite suggest that gold-sulphide mineralization was early- to syn-main deformation and and pre- to early-peak metamorphism.

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[1] Département de géologie et de génie géologique, Université Laval, 2325 Rue de l'Université, Québec, Quebec
[2] Geological Survey of Canada, 490, rue de la Couronne, Québec, Quebec
[3] Exploration division, Agnico Eagle Mines Ltd., 765 chemin de la mine Goldex, Val-d'Or, Quebec
[4] Département des sciences de la Terre et de l'atmosphère, Université du Québec à Montréal, 201 avenue du Président Kennedy, Montréal, Quebec

For more information, please contact P. Mercier-Langevin (patrick.mercier-langevin@canada.ca).

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