

Supergene gold transformation:  
Secondary and nano-particulate gold  
from northern Finland

Thesis submitted in accordance with the requirements of the University of  
Adelaide for an Honours Degree in Geology

Paige Sawley  
November 2014



THE UNIVERSITY  
*of* ADELAIDE

## **SUPERGENE GOLD TRANSFORMATION: SECONDARY AND NANO-PARTICULATE GOLD FROM NORTHERN FINLAND**

### **SUPERGENE GOLD TRANSFORMATION**

#### **ABSTRACT**

The transformation of gold (Au) in many supergene environments is driven by (bio)geochemical processes. This study assesses the link between surface morphologies of Au grains and supergene transformation processes in arctic settings. Gold grains were collected from nine sites across two localities in northern Finland, *i.e.*, Ivalojoiki and Lemmenjoki. Sites were chosen based on contrasting elevations and settings, from glacial till to alluvial. Gold grains were studied using field emission scanning electron microscopy (FEG-SEM), focused ion beam-scanning electron microscopy (FIB-SEM) coupled with Energy Dispersive X-ray Spectroscopy (EDXS), and electron microprobe analyses (EPMA). Gold grains from all sites displayed supergene transformation features, *i.e.*, morphotypes indicative of Au and Ag dissolution, as well as Au aggregation. The latter included a variety of secondary Au morphotypes, such as nano-particles and  $\mu$ -crystals, sheet-like Au and branched Au networks. Dissolution features on grains from high organic matter environments suggest fulvic and humic acids are important contributors in the transformation of Au. Secondary Au occurs as part of the polymorphic layer. In addition to the secondary Au, the polymorphic layer consists of active microbial biofilms, organic matter and biominerals suggestive of remnant biofilms, as well as aluminosilicates, iron-sulfides and oxides. Bacterial cells and putative fungal hyphae were closely associated with Au nano-particles, suggesting that Au biomineralisation is an important factor in the transformation of Au. In conclusion, surface morphologies of Au grains from Finland are the result of supergene (bio)geochemical transformations occurring in the arctic environment.

#### **KEYWORDS**

Gold, supergene, Finland, arctic, nano-particles, biofilm

## TABLE OF CONTENTS

Supergene gold transformation: Secondary and nano-particulate gold from northern Finland .....	i
Supergene gold transformation .....	i
Abstract .....	i
Keywords .....	i
1. List of Figures .....	2
2. List of Tables .....	3
3. Introduction .....	4
4. Geological Setting .....	6
5. Methods .....	8
6. Observations and Results .....	10
5.1 Gold grains from Ivalojoiki, Finland .....	10
5.1.1 Ivalojoiki 1 .....	10
5.1.2 Aila's claim .....	13
5.1.3 Risto's Claim .....	15
5.2 Gold grains for Lemmenjoki, Finland .....	17
5.2.1 Jäkäläpää claim .....	17
5.2.2 (Miessi) Turkka's Claim .....	20
5.2.3 (Miessi) Pekka's Claim .....	22
5.2.4 (Miessi) Raimo's Claim .....	24
5.2.5 Kaarreoja Claim .....	25
5.2.6 (Miessi) Ami's Claim .....	27
7. Discussion .....	29
8. Conclusions .....	34
9. Acknowledgments .....	35
10. References .....	35
Appendix A: Methods .....	39
Appendix B: Supplementary Figures .....	45

## 1. LIST OF FIGURES

Figure 1: Finland sample site locations; insert Lemmenjoki, (1) (Miessi) Turkka's Claim, (2) Jäkäläpää Claim, (3) (Miessi) Pekka's Claim, (4) (Miessi) Raimo's Claim, (5) Kaarreoja Claim, (6) (Miessi) Ami's Claim. Insert Ivalojoiki. (1) Ivalojoiki 1, (2) Aila's Claim, (3) Risto's Claim. Modified after Google Earth. ....	7
Figure 2: Backscatter electron (BSE, a, b) and scanning electron (SE, c, d) micrographs and EDXS maps (e–h) of Au grains from Ivalojoiki 1, Ivalojoiki, Finland. (a) Micrograph showing a typical irregular Au grain with rounded and partially folded edges; (b) conglomerate of Au $\mu$ -crystals surrounded by Au nano-particles in the polymorphic layer; (c) micrograph showing the polymorphic layer described in (b); (d) a sheet-like, secondary Au plate; (e–h) EDXS maps of Au, Ag, Fe and Si concentrations (wt. %)...	11
Figure 3: Electron microprobe maps of Au, Ag and Fe concentrations in a polished section of two Au grains from Ivalojoiki 1, Ivalojoiki, Finland. (a) Maximum concentrations of Au 100 wt.%; (b) maximum concentration of Ag 13.37 wt.%; (c) maximum concentrations of Fe 35.50 wt.%. ....	12
Figure 4: Electron micrographs of Au grains from Ivalojoiki 1, Ivalojoiki, Finland, showing (a) typical features of the polymorphic layer, with bacterial cell (arrow); (b) conglomerate of Au $\mu$ -crystals, surrounded by Au nano-particles and bacterial cell (arrow) dispersed through the polymorphic layer; (c) a bacterial, rod-shaped cell attached by pili; (d) a bacterial rod-shaped cell surrounded by Au nano-particles (arrows). ....	13
Figure 5: BSE (a, c–e) and SE (b) micrographs of Au grains from Aila's Claim, Ivalojoiki, Finland, showing (a) a typical Au grain with rounded and partially folded edges; (b) the physically damaged grain surfaces; (c) dissolution pits on the grain surface and budding Au forming bridging structures; (d) Au $\mu$ -crystals and nano-particles dispersed through the polymorphic layer; (e) triangular-shaped, flat Au crystal. ....	14
Figure 6: SE (a) and BSE (b–d) micrographs of Au grains from Risto's Claim, Ivalojoiki, Finland, showing (a) a typical flattened grain with rounded edges; (b) the physically damaged grain surfaces; (c) Au dissolving into the polymorphic layer, (d) the highly transformed grain surfaces with few Au nano-particles and budding structures.	16
Figure 7: SE (a, d) and BSE (b, c) micrographs of Au grains from Jäkäläpää Claim, Lemmenjoki, Finland, showing (a) a branching Au grain with sub-rounded edges; (b) budding Au and extensive Au nano-particles dispersed through the polymorphic layer; (c) Au $\mu$ -crystals and Au nano-particles accumulating in a Ti rich part of the matrix; (d) a pyrite particle (red arrow) and a biomineral (orange arrow). ....	17
Figure 8: Electron micrographs (a, b) and EDSX maps (c–h) of an Au grain from Jäkäläpää Claim, Lemmenjoki, Finland, showing (a) typical surface features of the grains; (b) FIB-SEM micrograph showing a milled section through a layer of material similar to that shown in (a); (c–d) EDXS maps of Au, Ag, Fe, C, O and Ti concentrations (wt.%) of the milled sections shown in (b). ....	18
Figure 9: Electron microprobe maps of Au, Ag and Fe concentrations in a polished section of two Au grains from Jäkäläpää Claim, Lemmenjoki, Finland. (a) Maximum	

concentrations of Au 100 wt.%; (b) maximum concentration of Ag 46.07 wt.%; (c) maximum concentrations of Fe 32.07 wt.%. .....	20
Figure 10: BSE (a, b, d) and SE (c) micrographs and an electron microprobe map of Au grains from (Miessi) Turkka's Claim, Lemmenjoki, Finland showing (a) a wire Au grain with rounded edges; (b) the typical textured grain surface; (c) a network of biological nano-wires (arrows) running through the polymorphic layer; (d) triangular and spherical shaped Au nano-particles; (e) minimum concentrations of Au 60 wt.%, maximum concentrations of Au 100 wt.%. .....	21
Figure 11: BSE (a, d) and SE (b, c) micrographs of Au grains from (Miessi) Pekka's Claim, Lemmenjoki, Finland, showing (a) an elongate grain with sub-rounded edges; (b) the typical features of the polymorphic layer; (c) bacterial, rod-shaped cells (arrows) on the grain surface; (d) Au nano-particles dispersed through the polymorphic layer. . .	23
Figure 12: SE (a–c) and BSE (d, e) micrographs of Au grains from (Miessi) Raimo's Claim, Lemmenjoki, Finland, showing (a) a flattened, branched grain; (b) biological material on the physically damaged surfaces; (c) a cluster of rod-shaped bacterial cells on the surface of the polymorphic layer; (d) the bacterial cells shown in (c) surrounded by Au nano-particles; (e) budding Au forming bridging structures. ....	25
Figure 13: BSE micrographs (a, b) and electron microprobe maps (c–h) of Au grains from Kaarreoja Claim, Lemmenjoki, Finland showing (a) a wire Au grain with rounded edges; (b) Au nano-particles dispersed through the polymorphic layer; electron microprobe maps of Au (c, e, g; maximum concentration 100 wt.%) and Ag (d, f, h; maximum concentration 23.88 wt.%). Note the lack of Ag at enriched Au rims. ....	26
Figure 14: BSE (a–c) micrographs and electron microprobe maps (d, e) of Au grains from (Miessi) Ami's Claim, Lemmenjoki, Finland showing (a) an irregular Au grain with sub-rounded edges; (b) typical surface features of the grains; (c) increased magnification of Au nano-particles, area highlighted in (b); (d, e) electron microprobe maps of Au (d; maximum concentrations 100 wt.%) and Ag (e; maximum concentrations 11.66 wt.%). ....	28

## 2. LIST OF TABLES

Table 1: Summary of the environmental properties at the sampling sites. ....	8
--	---