OROGENIC GOLD DEPOSITS IN FINLAND

by

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Introduction: general characteristics of orogenic gold deposits

Orogenic gold deposits are typical metallogenic features in moderate to high temperature - low to moderate pressure metamorphic belts of convergent plate margins (GROVES et al., 2003). They formed in large scale metamorphic fluid dominated fluid flow systems at 3-20 km depths, along compressional-transpressional shear zones in accreted terrains during the late stages of orogenies. Their host rocks most typically consist of mafic metavolcanic and metasedimentary sequences which also often host felsic (porphyry) and lamprophyre dikes and granitoid intrusions and thus magmatic input into the fluid flow system cannot be ruled out in some deposits. Location of ore is controlled by brittle-ductile shear zones and it is also influenced by competency contrasts among host rock lithologies as well as by superimpo-sition of shear zones on each other or on fold structures. The mineralization forms dissemina-tions, stockworks and veins. Gold enrichments are usually associated with elevated concen-trations of Ag, Bi, Sb, As, Te, W. The base metal content of the ore is usually low; exceptions are the orogenic gold deposits with atypical metal associations. Epizonal (3-6 km depth) deposits may be enriched in Sb and Hg whereas concentration of As and Te is more typical to meso- and hypozonal (6-10 and >10 km depths, respectively) deposits. Native gold most commonly associates with pyrite and/or pyrrhotite, arsenopyrite and telluride minerals in car-bonate-quartz veins. Hydrothermally altered host rocks are characterised by enrichments of K, Na, Ca, Fe, Mg, CO_2, B and S. Thus albite, K-feldspar, K-micas, biotite, phlogopite, amphibole, tourmaline, carbonates and Fe-sulphides are the typical alteration minerals. Parent fluids of mineralisation are dilute (<6-8 NaCl equiv wt%) H_2O-NaCl-CO_2 (± CH4 ± N_2) type fluids. These reduced, near-neutral fluids transport gold in sulphur complexes and preci-pitation of gold is triggered by phase separation as a consequence ofpressure fluctuation, removal of sulphur by sulphurisation of Fe-rich silicate/oxide minerals in the wall rocks and changes in the oxidation state by mixing with more reductive/oxidative fluids or carbonatisation of wall rocks. Most of the giant (>250t Au) and world class (>100t Au) deposits were formed in relation to Archean and Paleoproterozoic supercontinent cycles at around 2.6-2.7 and 1.8-1.9 Ga, as well as during the Phanerozoic, modern-style orogenic cycles between 600 and 50 Ma (GOLDFARB et al., 2001). Therefore it is especially interesting to study this kind of deposits on the Fennoscandian shield where the Archean cratonic nuclei are surrounded by Proterozoic and Phanerozoic orogenic belts (Fig.1).

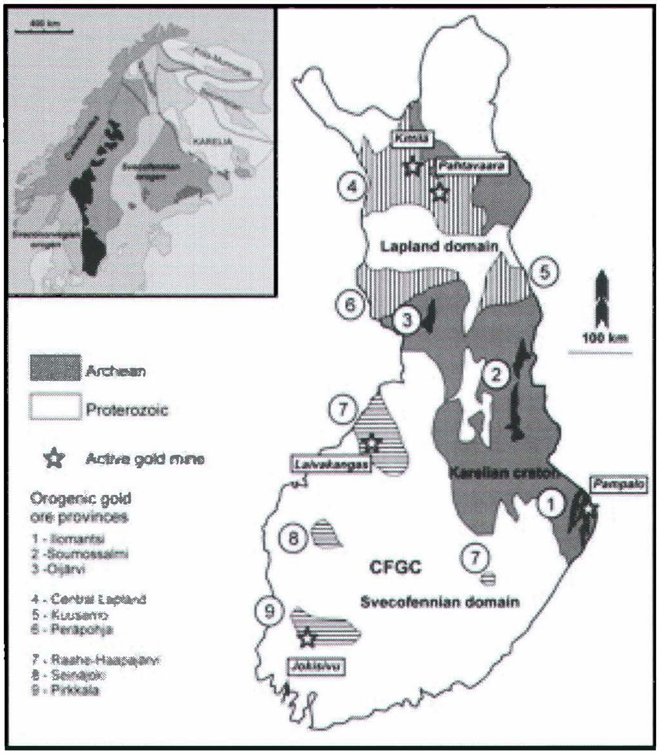

Figure 1: orogenic gold provinces in Finland.

Archean greenstone belts of the Karelian craton

The northerly trending, up to 200 km long, narrow greenstone belts with gree amphibolite facies metasedimentary and metavolcanic units are surrounded b granite-gneiss complexes on the Karelian craton (Fig.1). The most important deposits are located in the Hattu schist belt (HSB) in the eastern part of the Ilo similar deposits are also known in the Soumussalmi belt and in the Oijärvi bel latter belts have comparable geology to the Ilomantsi greenstone belt. However, rocks and related cumulates are more widespread in relation to sedimentary currently known cumulative ore resource of gold deposits in the HSB is 4.8208 M Pampalo mine has 1.6488 Mt resources with 4.3 g/t Au grade. In the HSB, the deposits are located along the major N-S trending shear zones which cut folded, sedimentary and volcanic units. Pre- and syn-deformation emplacement of tonali granite plutons and felsic porphyry dikes took place between 2.75 and 2.72 amphibolite facies peak metamorphic conditions were established at aroun (VAASJOKI et al, 1993). According to SORJONEN-WARD (1993), formation o took place before the peak of metamorphism, but STEIN et al. (1998) reported 2 Re-Os isochron age for pyrite associated to gold and suggested syn- to post pea timing of gold ore deposition.

Results of Pb-isotope studies on galena, altaite and hydrothermal K-feldspar, sulphur isotope data for sulphides from the Pampalo mine and regional boron-isotope studies on tourmaline in the HSB suggest that an early stage ore formation was synchronous with emplacement of granitoids and the hydrothermal circulation included magmatic fluids. Occurrences of high salinity (30-40 NaCl equiv wt.%) high temperature (min. 300-350°C) carbonic-aqueous fluid inclusions in addition to the dilute CO_2-CH_4-NaCl-H_2O type ones in some deposits of the HSB (and in the Suomussalmi belt; POUTIAINEN & PARTAMIES (2003) probably also indicate this input of magmatic fluids. The gold mineralisation consists of disseminated-stockwork, locally vein type ore which is enveloped by sericite-chlorite alteration zones with tourmaline in the host metasedimentary units and felsic dikes. Gold is associated with pyrrhotite, pyrite, arsenopyrite and various telluride minerals. The ore of the Pampalo mine is slightly different due to the presence of more widespread K-feldspar alteration zones and almost total absence of pyrrhotite and arsenopyrite. At ca. 1.85-1.7 Ga, tectonothermal processes affected the western parts of the Karelian craton due to overthrust of the up to 5-6 km thick east-verging Svecofennian nappe complex. (KONTINEN et al., 1992; O`BRIEN et al., 1993). Pb-isotope and fluid inclusion data from the Pampalo mine indicate local re-mobilisation of ore and overprinting wall rock alteration during interaction of carbonic-aqueous dilute (5-12 NaCl equiv. wt.%, 350-400°C temperature) fluids with the Archean mineralisation. Pb-isotope and fluid inclusions data also record an even more younger and lower temperature (200-250°C) saline (up to around 20 NaCl equiv. wt.%) fluid flow and ore remobilisation event.

Orogenic gold provinces of the Lapland domain

The Lapland domain (Fig.1) contains three orogenic gold provinces: the Central Lapland greenstone belt (CLGB), the Kuusamo belt (KS) and the Peräpohja belt (PB). One of the largest gold producer of Europe, the Kittilä mine (Suurikusikko deposit, 59 Mt total resources + reserves with 4.18 g/t average gold grade) is located in the CLGB. Pahtavaara (5.5 Mt total resources and reserves with 2.65 g/t average grade) is another active mine in this belt. In addition to these active mines, several other orogenic gold deposits and occurrences are known in the CLGB and KS. The PB is underexplored but the current discovery of extremely high grade (over 1000 g/t Au) showings in the northern part of this province highlights further exploration potential. The host rocks of gold deposits in these belts deposited during the elon-gated (2.45-2.0 Ga) intracontinental rifting of the Karelian craton. The early stage rifting pro-duced bimodal komatiitic and felsic volcanic accumulations which are covered by quartzite, carbonate, BIF, turbidite, and graphitic schist bearing metasedimentary sequences with inter-calations of tholeiitic basalts and repeated emplacement of mafic dikes and sills (LAHTINEN et al., 2005). The KS and PB represent failed rift zones but a narrow oceanic basin was developed in the zone of CLGB at around 1.97-1.95 Ga. SW oriented subduction and final collision took place between 1.93-1.91 Ga. Metamorphism and synorogenic plutonism between 1.96-1.88 Ga and repeated deformation events with development of ore controlling shear zones between 1.92 and 1.77 Ga established the final geological architecture of the Lapland domain. The common feature of the CLGB and KS is that the zones of ore deposits along the major shear zones and connected second to fourth order structures show low grade (greenschist facies) metamorphism whereas the metamorphic grade is increasing apart from these zones (HÖLTTÄ et al., 2007).

The peculiar feature of the mineralised zones is the presence of pre-ore albite-carbonate (±scapolite) alteration which resulted in formation of competent massive albitites. This alteration most likely indicates mobilisation of formational brines during the early stages of the development of crustal scale fault structures (VANHANNEN, 2001). The same structures were reactivated during the development of major ore controlling shears and competency differences between albitites and the metasedimentary-metavolcanic units supported development of favourable conditions for ore deposition. The Fe-rich composition of mafic metavolcanic host rocks also supported precipitation of gold by extraction of sulphur from hydrothermal fluids. The most common Fe-minerals in association to gold are pyrite, pyrrhotite, arsenopyrite and löllingite.
In the Suurikusikko deposit, most of the gold is refractory and is hosted by arsenopyrite and pyrite. Typical wall rock alteration assemblages around ore veins and stockwork zones contain quartz, carbonate, sericite/fuchsite, biotite, chlorite and feldspars. Another interesting feature of the CLGB and KS is that about half of the orogenic gold deposits have atypical metal associations with possible economic concentrations of cobalt (gersdorffite) and enrichments of Cu, Ni, Mo, U, Se, Ba and LREE (EILU et al., 2003). This specific geochemistry of ore may be connected to remobilisation of these metals by saline fluids from the Paleoproterozoic basin sequences. Age of formation of orogenic gold deposits in the Lapland domain is not well established; Pb-isotopic data from galena suggest 1.84-1.80 Ga ages (MÄNTTÄRI, 1995). Lead isotopes data also indicate Caledonian reactivation of ore controlling structures and local redistribution of metals.

Orogenic gold provinces in the Svecofennian domain

Orogenic gold provinces in the Svecofennian domain are located in collision zones surrounding the Central Finland granitoid complex (CFGC; Fig. 1). Gold is currently mined at Laivakangas (22Mt@ 2.03 g/t Au) in the southern Ostrobothnia part of the Raahe-Haapajärvi province and at Jokisivu (1.9 Mt@ 5.8 g/t Au) in the Pirkkala province. The basement of the CFGC, the Keitele microcontinent with a ca. 2.0 Ga old continental crust (LAHTINEN et al., 2005) formed the upper plate in those subduction zones which were developed along its eastern, western and southern boundaries between 1.92-1.89 Ga. Subduction related volca-nism and plutonism, then metamorphism and deformation of accreted domains took place between 1.9 and 1.87 Ga. Formation of orogenic gold deposits post dated the mid to upper amphibolite facies metamorphism: results of studies by SAALMAN et al. (2010) support 1.83-1.80 Ga age for ore deposition in the Jokisivu deposit. The mineralized shear zones have NW-SE most typical orientation in the Svecofennian domain. They are mostly located in intrusive-volcanic complexes in Ostrobothnia: these host rocks also contain earlier formed porphyry-Cu type ore at some places. In the Seinäjoki and Pikkala province, turbiditic rocks are also common hosts of orogenic gold deposits. In the Seinäjoki province, and subordinately in the Pirkkala province (Jokisivu deposit) composition of ore is characterised by enrichments of antimony (aurostibnite, native antimony). The deposits usually contain free gold in association to pyrite, pyrrhotite, löllingite, arsenopyrite and Bi-Te minerals.

Conclusions

Orogenic gold deposits in Finland were formed at around 2.7 Ga and 1.8 Ga in correlation with the Archean and Paleoproterozoic global crustal growth cycles. This feature and their comparable mineralogical, petrological, geochemical and structural peculiarities with orogenic gold deposits on other shield areas highlight the exploration and mining potential in the metallogenic provinces introduced in this brief summary.

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