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Hypozonal lode gold deposits: A genetic concept based on a review of the New Consort, Renco, Hutti, Hira Buddini, Navachab, Nevoria and The Granites deposits

Jochen Kolb[a,*], Annika Dziggel[b], Leon Bagas[c]

[a] Department of Petrology and Economic Geology, Geological Survey of Denmark and Greenland, Øster Voldgade 10, 1350 Copenhagen K, Denmark
[b] Institute of Mineralogy and Economic Geology, RWTH Aachen University, Wüllnerstr. 2, 52056 Aachen, Germany
[c] Centre for Exploration Targeting, The University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia

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ABSTRACT

The mineral system of hypozonal lode gold deposits has been a matter of scientific discussion in recent years, mainly centring around two models: (1) syn- to post-peak metamorphic hydrothermal mineralization (hypozonal orogenic gold) and (2) pre-peak metamorphic mesothermal mineralization and subsequent metamorphic overprint.

Here we review the evidence for and against the existence of hydrothermal gold mineralization in high-temperature metamorphic terranes. The New Consort, Renco, Hutti, Hira Buddini, Navachab, Nevoria and The Granite deposits are considered to represent hypozonal orogenic gold deposits based on petrographic and field observations. Gold mineralization is hosted in syn- to post-peak metamorphic shear zones. Ore and hydrothermal alteration assemblages replace the metamorphic mineral assemblages of the host rocks and follow the same retrograde PT path. This indicates that the mineralization forms an integral part of the terrane evolution from syn- to post-peak metamorphism to final exhumation.

Comparison with other hypozonal deposits indicates that the hypozonal orogenic gold system is active at ca. 500–700 °C and 2–7 kbar, and forms a Ca–Se–Cu–Ni–Co–S-dominated enrichment compared to the mesozonal counterparts. The hypozonal deposits appear to be restricted to Precambrian terranes in variable host rocks ranging from amphibolite and banded-iron formation to marble and granite. The fluid source for hypozonal gold is metamorphic, magmatic or a combination of both. A complex tectonometamorphic evolution of the high-grade metamorphic host terranes is regarded critical for forming the deposits by: (1) generating permeability in shear zones; (2) creating PT gradients that promote fluid migration; (3) inverting the metamorphic gradient by thrusting or extensional shearing; and (4) initiating crustal anatexis and granite emplacement as source of heat and ore fluid. Hypozonal orogenic gold deposits form in syn- to post-peak metamorphic shear zones of high-grade terranes in the centre or foreland of Precambrian accretionary and collisional orogens during the evolved collision stage, when active subduction ceased or moved outboard and the terranes are uplifted.

1. Introduction

Lode- and quartz vein-hosted, gold-only, or orogenic gold mineralization in metamorphic terranes is generally accepted as hydrothermal deposits formed during focused fluid flow in an orogenic setting during metamorphism and deformation (Bierlein and Crowe, 2000; Colvine et al., 1988; Goldfarb et al., 2005; Groves et al., 2003; Hagemann and Cassidy, 2000; Kerrich and Cassidy, 1994; McCuaig and Kerrich, 1998; Witt and Vanderhor, 1998). Regional reviews of orogenic gold deposits have shown that the majority formed at 1–3 kbar and 250–400 °C in greenschist to lower amphibolite facies terranes, but lower and especially higher temperature counterparts have also been recognized (Anhaeusser and Maske, 1986; Bagas et al., 2008; Colvine et al., 1988; Foster, 1989; Goldfarb et al., 2005, 1998; Goldfarb and Santosh, 2014; Groves et al., 1992; Ridley et al., 2000; Robert and Poulsen, 1997; Witt and Vanderhor, 1998). Notwithstanding their formation temperature and metamorphism of the host terrane, these gold deposits are characterized by their common structural control, and similar hydrothermal alteration (Si, K, Rb, Ba, Li, Cs, Tl, S, H_2O, CO_2 enrichment) and metal (Au–Ag ± As, Sb, Te, W, Mo, Bi) association (Goldfarb et al., 2005; Groves et al., 1992, 2003; Hagemann and Cassidy, 2000; McCuaig

* Corresponding author. Tel.: +45 91333863; fax: +45 38142050.
E-mail address: jkol@geus.dk (J. Kolb).

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and Kerrich, 1998). These similarities form the basis for a unified genetic model: the crustal continuum model (Colvine, 1989; Groves, 1993). This model was designed to describe orogenic gold deposits, which formed at different PT conditions equivalent to lower greenschist to lower granulite facies levels over an interval of 20–25 km in the middle to upper crust (Gebre-Mariam et al., 1995; Groves, 1993). It proposes the syn-metamorphic upward migration of auriferous fluids from deep-seated sources along structural conduits such as shear and fault zones (Colvine, 1989; Groves, 1993). The critical and important factors of the active pathway, the fluid throttle and the deposition in the orogenic gold mineral system are well-defined as: (1) long-lived, polyphase damage zones at cratonic margins that transect the lithosphere; (2) complex, smaller scale deformation zones that are spatially associated with permeability barriers and rocks of contrasting competency; and (3) heterogeneous host rocks with a large chemical gradient or chemically reactive rocks that would be in disequilibrium with the mineralizing fluid (Groves et al., 2003; Hagemann and Cassidy, 2000; McCuaig et al., 2010). Differences in PT conditions and host rock composition are reflected by distinct hydrothermal alteration and ore assemblages, which are used to subdivide the deposits into epizonal (low temperature), mesozonal (medium temperature) and hypozonal (high temperature) groups (Gebre-Mariam et al., 1995). A clear definition of the hypozonal group is, however, lacking and different PT-depth parameters are discussed, with a lower limit at 475–550 °C at 3 kbar and depth of >10–12 km, and an upper limit at <700–740 °C and 5–6 kbar (Gebre-Mariam et al., 1995; McCuaig and Kerrich, 1998; Phillips and Powell, 2009; Ridley et al., 2000).

In contrast to the crustal continuum model, where hypozonal gold deposits are understood as syn- to post-peak-metamorphic hydrothermal alteration products, newer studies consider gold-only deposits in amphibolite to granulite facies terranes as overprinted mesothermal deposits (Phillips and Powell, 2009, 2010; Tomkins and Grundy, 2009). Assuming a metamorphic fluid source, these authors argue that the main fluid producing reactions within the crust take place at the greenschist-amphibolite facies transition (Elmer et al., 2006), making formation of gold-only deposits at high metamorphic grades unlikely. In addition, the deposit-scale characteristics of many overprinted mesothermal gold-only deposits such as: (1) alteration and ore assemblages in textural equilibrium with regional metamorphic assemblages; (2) granoblastic fabrics in quartz veins; (3) evidence for desulfidation and decarbonation in ore horizons and alteration zones; (4) the presence of deformed quartz veins and orebodies; and (5) leucosomes associated with the ores are consistent with a later metamorphic overprint (Phillips and Powell, 2009). Examples of such overprinted deposits include Kolar (India), Big Bell (Australia), Hemlo (Canada), and Osikonmäki (Finland) (Hamilton and Hodgson, 1986; Kontoniemi and Nurmi, 1998; Phillips, 1985). Recently, Griffins Find and Challenger in Australia and Renco in Zimbabwe have been reinterpreted as metamorphosed mesothermal gold-only deposits (Phillips and Powell, 2009; Tomkins and Grundy, 2009; Tomkins and Mavrogenes, 2002; Tomkins et al., 2004), whereas Kolar (India) has been reinterpreted as a hypozonal orogenic gold deposit that formed at peak metamorphic conditions (Goldfarb et al., 2005; Hagemann and Cassidy, 2000).

A specific type of orogenic gold deposits is represented by mesozonal mineralization in high-grade metamorphic Precambrian terranes that formed ca. 2 billion years after metamorphism of the host rocks as in the Jiaodong district of eastern China (Chen et al., 2005; Goldfarb and Santosh, 2014). These Mesozoic deposits differ from their Phanerozoic equivalents, which formed in a single metamorphic cycle in one orogeny (Goldfarb et al., 2005, 1998; Goldfarb and Santosh, 2014). Although the Jiaodong gold deposits are hosted by high-grade metamorphic rocks including high-pressure rocks, they notably formed under mesozonal conditions and postdate the peak of metamorphism (Qiu et al., 2002). Their formation is controlled by Mesozoic tectonics, reactivation of Precambrian structures and a fluid source either in the subducted slab or the subcontinental lithospheric mantle (Chen et al., 2005; Goldfarb and Santosh, 2014).

Irrespective of the conditions of gold deposition, the source of gold and hydrothermal fluids is not resolved and different scenarios are discussed (Fyfe and Kerrich, 1985; Goldfarb et al., 1998; Groves et al., 2003; Hagemann et al., 1994; Manikyamba et al., 2004; Nesbitt and Muehlenbachs, 1989). For most of the mesozonal group, a metamorphic source in the host terrane or a magmatic source deeper in the crust is favoured (Burrows and Spooner, 1987; Goldfarb et al., 1991; Ho et al., 1992; Kerrich and Fyfe, 1981; Krienitz et al., 2008; Ridley and Diamond, 2000). Many authors based their mineral system models around a metamorphic source (Kolb et al., 2000; Phillips and Powell, 2010; Powell et al., 1991; Stüwe, 1998; Stüwe et al., 1993; Wulff et al., 2010; Yardley, 1997), supported by the syn-metamorphic depletion of gold in potential source rocks on the south island of New Zealand (Pitcairn et al., 2006). Metamorphic devolatilization reactions in mafic rocks are most efficient at temperatures between 440 and 520 °C, producing up to 5 wt.% aqueous-carbonic fluid (Elmer et al., 2006; Fyfe et al., 1978; Phillips and Powell, 2010). Large-scale fluid flow will generally be buoyancy-driven and, thus, upward directed at crustal levels of the greenschist to amphibolite facies transition or deeper (Cox et al., 2001; Manning and Ingebritsen, 1999; Oliver et al., 2001). The production of major quantities of metamorphic fluid at the greenschist to amphibolite facies transition in combination with the generally upward-directed fluid migration make it difficult to explain hydrothermal mineralization at crustal levels of higher grade metamorphism. In addition, an upper temperature limit for hydrothermal mineralization was postulated at 600–650 °C based on the assumption that partial melting would result at these conditions in a water-saturated crust and would inhibit large-scale fluid migration at amphibolite facies conditions or higher (Phillips and Powell, 2009, 2010; Tomkins and Grundy, 2009). The metamorphic devolatilization model, thus, eliminates the formation of hydrothermal gold-only deposits at metamorphic conditions of the host terrane above ~520–600 °C, below the greenschist to amphibolite facies transition (Elmer et al., 2006; Phillips and Powell, 2009, 2010; Tomkins and Grundy, 2009).

In this paper, we review the petrological and structural evidence for hypozonal hydrothermal alteration at the peak or post-dating peak-metamorphic conditions. Data from gold deposits studied by the authors provide constraints on the PT limit of hypozonal gold mineralization to be host rock dependent. Genetic models for these deposits together with established models for well-known orogenic gold districts are used to discuss the tectonometamorphic terrane evolution and to identify various settings for hypozonal gold mineralization in an evolving Precambrian orogen.

2. Hypozonal orogenic gold deposits

2.1. New Consort gold mine in the Palaeo- to Mesoarchaean Barberton greenstone belt, South Africa

The first example of hydrothermal gold mineralization at temperatures above ~520 °C is the New Consort gold mine in the Palaeo- to Mesoarchaean Barberton greenstone belt, South Africa. Mining started in 1886, with a total production of ~2.4 million ounces of gold by 2009 (Dirks et al., 2009).

2.1.1. Geological setting

The Barberton greenstone belt is one of the best preserved mid-Archaean volcano-sedimentary sequences on Earth. The