Orogenic gold deposits: part of a global dynamic conjunction between subduction and gold

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SUMMARY

Orogenic gold deposits represent a coherent deposit class that were deposited from low-salinity CO_2-rich fluids over a range of crustal depths from 3 to 20 km. They are widely considered to have formed from crustal metamorphic fluids generated at the amphibolite-greenschist-facies transition. However, recent research, particularly in China, shows that only a sub-crustal source of fluid is viable and that devolatilization of subduction slabs and overlying sediment wedges is the most plausible source of the auriferous fluids. An alternative source is devolatilization of fertilized mantle lithosphere that was earlier metasomatized by subduction-related fluids. This recognition of a subduction-related origin allows the orogenic gold deposits to be placed into a coherent, subduction-related dynamic model in which all epigenetic gold deposits formed during evolution of a convergent margin. The earliest deposits that formed from subduction-related magmatic-hydrothermal fluids during mild compression are inter-related porphyry Cu-Au, high-sulfidation epithermal Ag-Au and skarn deposits in volcanic and continental arcs. Subsequent mild extension resulted in formation of low-sulfidation epithermal Ag-Au in volcanic and continental back-arcs and gold-rich VMS systems in volcanic back-arcs. Orogenic gold deposits then developed under transpression during late orogenesis in the convergent margin. The initiation of orogenic collapse saw the formation of IRGDs and Carlin-type gold deposits related to hybrid magmas, formed by melting of subduction-related metasomatized lithosphere, in far back-arc environments. Finally, following supercontinent assembly, IOCG deposits formed on the margins of continental blocks during extension, mantle up-welling and melting of subduction-related fertilized lithosphere that released highly volatile magmatic-hydrothermal fluid systems into the crust.

Key words: orogenic gold, gold metallogeny, metamorphic fluids, subduction zones, convergent margins

INTRODUCTION

The term orogenic gold deposit was defined by Groves et al. (1998) as a coherent group to replace a wide variety of terms that referred to gold-only deposits. Orogenic gold deposits are commonly vertically-extensive, gold-only deposits that formed in broad thermal equilibrium with their wall-rocks from low-salinity H_2O-CO_2 ore fluids at crustal depths from 2 to 15, and arguably up to 20 kilometres, as summarized by Goldfarb and Groves (2015). Although this term has been widely accepted, the genesis of orogenic gold deposits has been widely debated.

Goldfarb and Groves (2015) provide an exhaustive review of these genetic models and the various geological, geochemical, isotopic and fluid-inclusion constraints on the component ore fluids and gold-related metals. Their review is used to develop a holistic, coherent and unified subduction-related model for orogenic gold deposits in various continents and of all ages, in a similar way to development of coherent minerals-system models for other mineral deposit groups (McCuaig and Hronsky, 2014). Once a subduction-related model is accepted, orogenic gold deposits can be placed into a coherent tectonic model involving the progressive development of all epigenetic gold deposits in a subduction-dominated convergent margin setting.

SUBDUCTION-RELATED MODEL FOR OROGENIC GOLD DEPOSITS

The term orogenic gold deposit (Groves et al., 1998) has been widely accepted for the majority of epigenetic gold-only deposits, but there is continuing debate on their genesis, as summarized by Goldfarb and Groves (2005). Early syn-sedimentary or syn-volcanic models and hydrothermal meteoric-fluid models are now invalid. Magmatic-hydrothermal models, except for rare examples of intrusion-related gold deposits (IRGDs), fail because of the lack of consistent spatially-associated granitic intrusions and inconsistent temporal relationships. The most plausible, and widely-accepted models involve metamorphic fluids, but the source of these fluids continues to be hotly debated. Deep continental intra-basin sources, underlying continental crust, subducted oceanic lithosphere with its overlying sediment wedge, and metasomatized lithosphere are all potential sources. Several features of Precambrian orogenic gold deposits are inconsistent with derivation from a continental metamorphic fluid source. These include: 1) the presence of hypozonal deposits in amphibolite-facies domains; 2) the proposed source region of the metamorphic fluids; 3) their anomalous multiple sulfur isotopic compositions; and 4) problems of derivation of gold-related elements from devolatilization of dominant basalts in the sequences (summarized with references by Groves et al. in press). The Phanerozoic deposits are largely described as hosted in greenschist facies domains, consistent with supracrustal devolatilization models (Goldfarb and Groves, 2015). However, notable exceptions are the deposits of the giant Jiaodong gold province of China, where ca 120 Ma gold deposits are hosted in Precambrian crust that was metamorphosed over 2000 million years prior to gold mineralization (Goldfarb and Santosh, 2014). Other deposits in China are comparable to some of those in the Massif Central of France and Meguma terrane in Canada, in that they are hosted in amphibolite-facies domains or clearly post-date regional metamorphic events imposed on hosting supracrustal sequences (Zhao et al., 2019). If all orogenic gold deposits have a common genesis, as argued by Wyman et al. (2016), the only realistic source of fluid and gold is from devolatilization of a subducted oceanic slab with its overlying gold-bearing sulfide-rich sedimentary package, with CO_2 released during decarbonation and S and ore-related elements released from transformation of gold-rich pyrite (Large et al., 2014) to pyrrhotite at about 500°C (Figure 1). The only alternative is derivation of auriferous fluid via devolatilization of mantle lithosphere that was earlier metasomatized and fertilized by subduction-related fluids: that is, an indirect relationship to subduction. Although this model satisfies all geological, geochronological, isotopic and geochemical constraints, and is consistent with limited computer-based modelling of fluid release from subduction zones, the precise mechanisms of fluid flux are model-driven and remain uncertain. However, the model re-emphasises the ubiquitous occurrence of orogenic gold deposits in subduction-related orogenic belts and importance of continental-scale lithosphere-tapping fault and shear zones to focus large volumes of auriferous fluid. It also confirms the importance of the consistent spacing between world-class deposits, broadly equivalent to the depth to the Moho, as derived from empirical observations.

SUBDUCTION-RELATED MODEL FOR ALL EPIGENETIC GOLD DEPOSITS

Traditionally, epigenetic gold deposits that formed through transport and deposition from auriferous ore-fluids are grouped into specific deposit types, such as porphyry, skarn, high and low sulfidation-type epithermal, gold-rich volcanogenic massive sulfide (VMS) Carlin-type, orogenic, intrusion-related (IRGD) and iron-oxide copper-gold (IOCG). These deposit classes are reviewed in several papers in Hedenquist et al. (2005). District-scale mineral system approaches propose inter-related groups such as porphyry Cu-Au, skarn Cu-Au-Ag and high sulfidation Au-Ag (Sillitoe, 2010), but other deposit types are not grouped at this scale.

The recognition that the orogenic gold deposits have a direct genetic connection to subduction allows all of these deposits to be considered at greater than deposit and district scales (Hronsky et al., 2012), the classic scales normally considered in ore deposit research. At the tectonic scale of mineral systems, all hydrothermal gold deposits are shown to be inter-related in that they formed progressively during the evolution of subduction-related processes along convergent margins. Porphyry-related systems formed initially from magmatic-hydrothermal fluids related to melting of fertile mantle to initiate calc-alkaline to high-K felsic magmatism in volcanic arcs directly related to subduction. Many of these deposits were rapidly exhumed and eroded during continued convergence and major orogenesis, explaining their general absence from pre-Mesozoic orogenic belts. However, submarine gold-rich VMS systems that formed in volcanic back-arcs (Dubé et al., 2014) and epithermal Ag-Au deposits that formed in continental back-arcs, during mild extensional episodes in the same environments that porphyry systems were earlier formed, more commonly survived this orogenic phase. Orogenic gold deposits formed largely through fluids derived from the down-going subduction slab and overlying sediment wedge, as described above, during late transpression in the orogenic cycle. Carlin-type gold deposits, IRGDs and some continental-arc porphyry Cu-Au systems formed during the early stages of orogenic collapse via fluids directly or indirectly related to hybrid magmatism from melting of lithosphere that was metasomatized and gold-fertilized near margins of continental blocks Mair et al., 2011; Muntean et al., 2011). The IOCGs were formed during post-orogenic asthenosphere upwelling beneath such metasomatized and fertilized lithospheric blocks via fluid release and explosive emplacement of volatile-rich melts (Groves et al., 2010) at continental margins, normally in Precambrian supercontinents.

CONCLUSIONS

Recent research, particularly on Chinese examples, invalidates popular continental metamorphic models for the genesis of orogenic gold deposits. Instead it supports a subduction-related model in which auriferous fluids are released during devolatilization of the down-going slab and sediment wedge or from lithospheric mantle metasomatized and fertilized by that fluid. This allows erection of a subduction-related model for all epigenetic gold deposits within an evolving convergent margin setting. Early porphyry Cu-Au-Ag-Mo related systems formed during compressional phases of early convergence, with epithermal Ag-Au and submarine Cu-Au VMS systems forming during superimposed mild extensional phases. Orogenic gold deposits formed during late-orogenic transpression, commonly during accretion, with IRGDs and Carlin-type deposits formed on continental margins during subsequent orogenic collapse. IOCG deposits formed via mantle upwelling related to extension on continental margins after supercontinent assembly. The genesis of all deposits was related to subduction through processes such as exsolution of magmatic-hydrothermal fluids directly from subduction-related magmas, or indirectly from metasomatized mantle lithosphere fertilized by subduction-related fluids, or from direct or indirect auriferous fluid generation from devolatilized subduction slabs. Thus, subduction is the key unifying dynamic factor in epigenetic gold metallogenesis.

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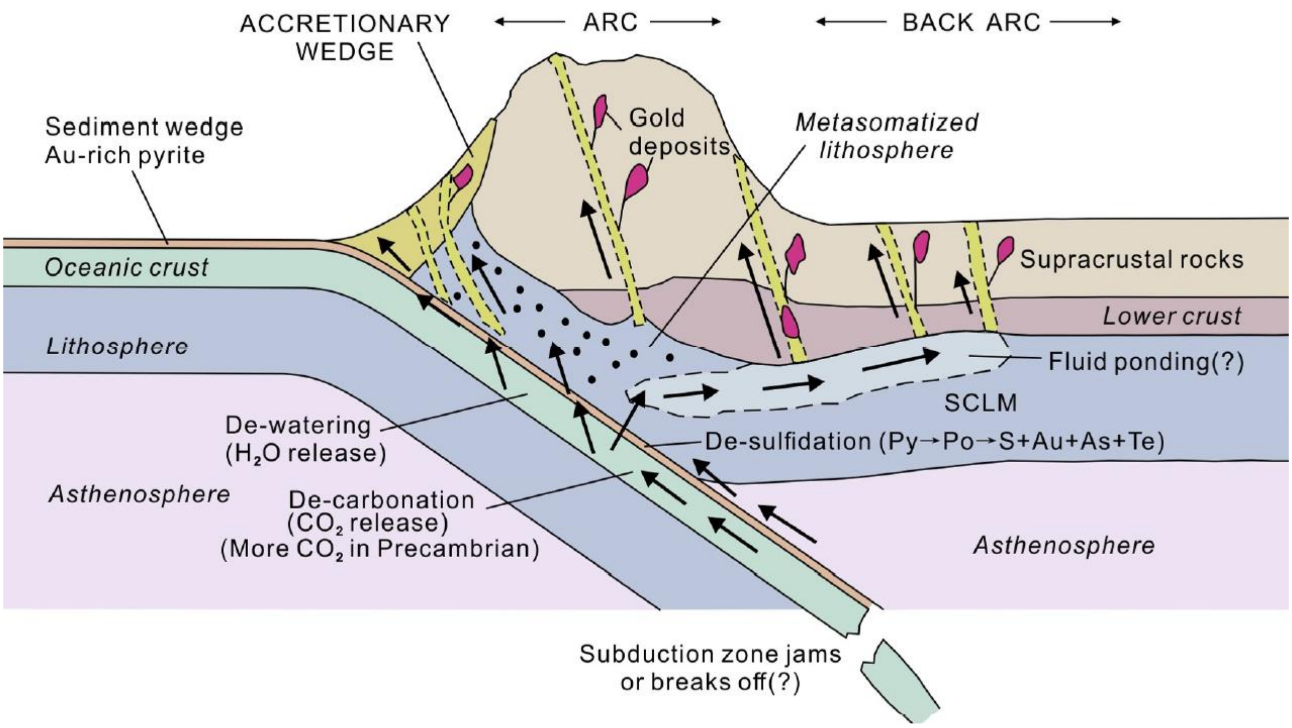

Figure 1. Subduction-related model for formation of orogenic gold deposits via devolatilization of down-going slab and overlying pyrite-bearing sediment wedge. Note also potential fluid source from metasomatized and fertilized mantle lithosphere: from Groves et al. (in press).