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Focus Paper

Structural geometry of orogenic gold deposits: Implications for exploration of world-class and giant deposits

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A B S T R A C T

With very few exceptions, orogenic gold deposits formed in subduction-related tectonic settings in accretionary to collisional orogenic belts from Archean to Tertiary times. Their genesis, including metal and fluid source, fluid pathways, depositional mechanisms, and timing relative to regional structural and metamorphic events, continues to be controversial. However, there is now general agreement that these deposits formed from metamorphic fluids, either from metamorphism of intra-basinal rock sequences or de-volatilization of a subducted sediment wedge, during a change from a compressional to transpressional, less commonly transtensional, stress regime, prior to orogenic collapse. In the case of Archean and Paleoproterozoic deposits, the formation of orogenic gold deposits was one of the last events prior to cratonization. The late timing of orogenic gold deposits within the structural evolution of the host orogen implies that any earlier structures may be mineralized and that the current structural geometry of the gold deposits is equivalent to that at the time of their formation provided that there has been no significant post-gold orogenic overprint. Within the host volcano-sedimentary sequences at the province scale, world-class orogenic gold deposits are most commonly located in second-order structures adjacent to crustal scale faults and shear zones, representing the first-order ore-forming fluid pathways, and whose deep lithospheric connection is marked by lamprophyre intrusions which, however, have no direct genetic association with gold deposition. More specifically, the gold deposits are located adjacent to $\sim 10^{\circ}-25^{\circ}$ district-scale jogs in these crustal-scale faults. These jogs are commonly the site of arrays of $\sim 70^{\circ}$ cross faults that accommodate the bending of the more rigid components, for example volcanic rocks and intrusive sills, of the host belts. Rotation of blocks between these accommodation faults causes failure of more competent units and/or reactivation and dilation of pre-existing structures, leading to deposit-scale focussing of ore-fluid and gold deposition. Anticlinal or antiformal fold hinges, particularly those of ‘locked-up’ folds with $\sim 30^{\circ}$ apical angles and overturned back limbs, represent sites of brittle-ductile rock failure and provide one of the more robust parameters for location of orogenic gold deposits.

In orogenic belts with abundant pre-gold granitic intrusions, particularly Precambrian granite-greenstone terranes, the boundaries between the rigid granitic bodies and more ductile greenstone sequences are commonly sites of heterogeneous stress and inhomogeneous strain. Thus, contacts between granitic intrusions and volcano-sedimentary sequences are common sites of ore-fluid infiltration and gold deposition. For orogenic gold deposits at deeper crustal levels, ore-forming fluids are commonly focused along strain gradients between more compressional zones where volcano-sedimentary sequences are thinned and relatively more extensional zones where they are thickened. World-class orogenic gold deposits are commonly located in the deformed volcano-sedimentary sequences in such strain gradients adjacent to triple-point junctions defined by the granitic intrusions, or along the zones of assembly of micro-blocks on a regional scale. These repetitive province to district-scale geometrical

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patterns of structures within the orogenic belts are clearly critical parameters in geology-based exploration targeting for orogenic gold deposits.

1. Introduction

The genesis of vein-type to disseminated gold deposits, broadly classified as orogenic gold deposits (Groves et al., 1998; Goldfarb et al., 2005) has remained controversial. The genetic models for these deposits were evaluated in a recent review by Goldfarb and Groves (2015). Much attention has been focused on the source of auriferous fluids. The majority of evidence favours a metamorphic source, either from fluids released during metamorphism of sequences deeper in the gold-hosting basins and oceanic rock sequences (see review in Goldfarb and Groves, 2015) or from de-volatilization of the sediment wedge above a downgoing subduction slab (Groves and Santosh, 2015). From an exploration viewpoint, the source of the auriferous fluids is largely irrelevant because, with either of the more accepted models, the fluid is deeply sourced and widespread over the entire orogenic belt. This is demonstrated empirically by the widespread distribution of gold deposits, gold prospects and/or gold-related geochemical anomalies in many subduction-related tectonic environments with a moderate to steep geothermal gradient. Moderate to high pressure/low temperature blueschist belts represent the only parts of orogens without such gold favourability. The issue in terms of exploration is not where the gold came from but to where it was focussed to form mineable gold deposits (e.g., Hronsky and Groves, 2008). The most important aspects are crustal environments leading to enhanced fluid migration and focussing into sites favourable for gold deposition, both of which are intimately related to the structural evolution and structural geometry of gold-prospective orogens (e.g., Ridley, 1993; Cox et al., 2001; Sibson, 2004; Deng et al., 2015).

In order to use structural geology as an integral tool in gold exploration, the timing of gold mineralization within the structural history of the orogenic belt is a crucial constraint. As demonstrated in the seminal paper by Goldfarb et al. (1988) on the gold districts of the Juneau Gold Belt in south-eastern Alaska, studies on the timing of formation of gold deposits are most robust if they involve an understanding of tectonic and structural evolution within a geochronological framework which involves robust isotopic ages of the gold mineralization itself. Goldfarb et al. (1988) demonstrated that gold mineralization was essentially a single widespread event late in tectonic evolution, related to a shift in tectonic regime from compression to transpression during Pacific plate re-orientation (Goldfarb et al., 2005, fig. 9). Such late structural timing involving re-activation of pre-existing structures developed during previous deformation events has been verified in numerous studies worldwide that integrate structural analysis with textural information on the timing of gold within the deposits, within a robust geochronological framework (e.g., Goldfarb et al., 1991; Knight et al., 1993; Bloem et al., 1994; De Ronde and de Witt, 1994; Groves et al., 1995; Leader et al., 2010, 2013; Yang et al., 2016).

Despite these studies, there are still erroneous models that imply multiple gold mineralization events, commonly argued to have been separated by tens of millions of years, within individual gold provinces or districts. Although some of these reflect problematic issues with selected dating techniques or dating materials, most of these involve a scale problem where studies of the structural history of the individual deposits produce resultant deformation episodes that are then poorly correlated with those of the host terrane. This is perhaps best illustrated by a specific example, the Archean Eastern Goldfields of the Yilgarn Block of Western

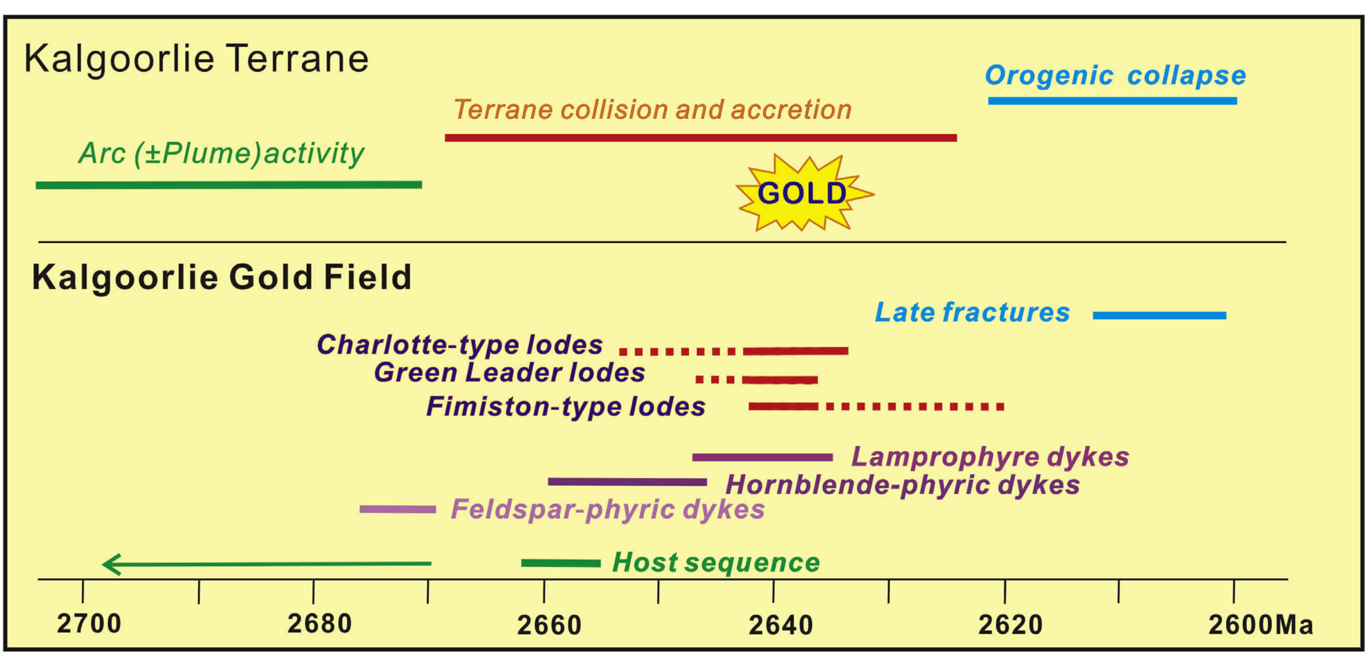

Figure 1. Figure demonstrating characteristic late kinematic timing of orogenic gold deposits. Timing of gold mineralization in the Kalgoorlie Gold Field and its host Kalgoorlie Terrane, Yilgarn Block, Western Australia (after Vielreicher et al., 2016).

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