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DISCUSSION

Discussion: The timing of gold mineralization across the eastern Yilgarn Craton using U–Pb geochronology of hydrothermal phosphate minerals

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Abstract The presentation of recent geochronological work on orogenic gold deposits in the Eastern Goldfields of the Yilgarn Craton, Western Australia, claims to prove that there is a single broad event of gold mineralization and that structural work demonstrating that there are a number of discrete gold mineralization events is wrong. This new data demonstrates no such thing, as this data, no doubt the best that can currently be produced, shows a very wide and inconsistent range in ages. Geochronology is not yet able to reliably separate these events, which appear to be spread over an interval of perhaps 30 Ma, up to ~2635 Ma.

Keywords Geochronology · Orogenic gold · Yilgarn · Kalgoorlie · Leonora

Introduction

Vielreicher et al. (2015) have given a comprehensive review of the Archaean geology of the eastern Yilgarn Craton and contributed new U–Pb geochronology on phosphate minerals related to gold mineralization. Amongst a broad-ranging discussion, they reconsider and re-emphasize the applicability of the crustal continuum model of Groves (1993) to Archaean orogenic, lode gold mineralization. In particular, they dispute the conclusions of several workers that gold mineralization in the Eastern Goldfields of Western Australia occurred in distinguishable pulses within a late orogenic event, with each pulse having distinct ore mineralogies (Davis et al. 2000; Witt 2001; Bateman and Hagemann 2004; Bucci et al. 2004; Blewett et al. 2010).

We wish to highlight here some detailed field relationships that need to be considered in any comprehensive study of the relative timing of gold mineralization in the Eastern Goldfields. Isotope geochronology gives absolute ages, structural work gives relative ages and inferior results will arise where one approach ignores and downplays the results from the other.

Kalgoorlie mineralization events

Vielreicher et al. (2015) wrote "Indirect timing constraints from spatially related dykes have also been presented as evidence for multiple events over a protracted period of up to 45 m.y. (Bateman and Hagemann 2004)." This statement is gravely in error: we used overprinting relationships between structures sets, and these are as direct a relative age criterion as it is possible to be (albeit relative ages, not absolute). We made only very passing references to dykes and did not use them to infer multiple gold mineralization events.

Vielreicher et al (2015) stated that "The final phase of gold deposit formation proposed by Blewett and co-workers (Blewett and Czarnota 2007; Blewett et al. 2010; Czarnota et al. 2010) includes the brittle-style lodes characterized by telluride-bearing ore-mineral paragenesis (Mt Charlotte lodes at Golden Mile, Sunrise Dam, St Ives, Mt Morgans, Wiluna, Kundana)." This is factually wrong: at Kalgoorlie, the Mount Charlotte lodes are characterized by the near absence of

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telluride minerals, relative to the telluride-rich Fimiston lodes in the same camp and mine.

Vielreicher et al. (2015) dispute the conclusion (Bateman and Hagemann, 2004) that Kalgoorlie experienced several distinct episodes of gold mineralization but offer absolutely no debate over the structural criteria by which they came to that conclusion. With regard to the time span, regional structural geochronological work completed since the publication of Bateman and Hagemann (2004), all quoted by Vielreicher et al. (2015), obliges us to modify that estimate of the ~45-Ma time span of the Kalgoorlie gold mineralization events. With Kalgoorlie D_1 of Bateman and Hagemann (2004) equated to D_2 of Blewett et al. (2010) (2665 Ma), and Kalgoorlie D_4 with their D_5 (2635–2650 Ma), mineralization likely spanned up to 30 Ma, but this shorter period may still be termed “protracted”.

The best alteration geochronology cannot yet distinguish these events

The ages of Kalgoorlie mineralization quoted from Heath (2003) by Vielreicher et al. (2015) include a Mt Charlotte age as young as 2601 Ma and a Lakeview (a Fimiston lode) age as old as 2656 Ma. These dates allow a difference in age between Fimiston and Mt Charlotte of 55 Ma. This is nearly twice the range previously estimated from regional deformation events.

Vielreicher et al. (2010) produced new ages for monazites and xenotime from Kalgoorlie: Fimiston lodes (possibly as old as 2656 Ma) and Golden Pike (Charlotte-style) veins (possibly as young as 2585 Ma, but also a date possibly as old as 2655 Ma). Using these ages, this gives potential age differences between Fimiston and Mt Charlotte of as little as 1 Ma and as much as 71 Ma.

Indeed, individual dates produced by Vielreicher et al. (2010) permit the interpretation that Mt Charlotte ore is at least 23 Ma *older* than Junction lode (Fimiston style). Comparing data of Rasmussen et al. (2009) and Heath (2003) allows the interpretation that Mt Charlotte is 62 Ma older than Fimiston. These interpretations are completely contrary to the universal and indisputable structural observation that Mt Charlotte-style veins crosscut Fimiston style lodes. The conclusion is inescapable that the best geochronology is still unable to reliably distinguish these events with absolute ages.

Leonora mineralization events

Baggott (2006) and Baggott et al. (2014) suggest that there is only one gold deposition event in the Leonora Domain that occurred between 2655 and 2640 Ma, during D_3 east–west compression. The age range is based on U–Pb ages for gold-related hydrothermal xenotime and monazite for the Gwalia, Tower Hill and Harbour Lights deposits and is similar to ages suggested by Duuring et al. (2004) for mineralization for the Tarmoola/King of the Hills deposit (c. 2655–2645 Ma).

However, recent studies in the Leonora Domain show that the gold deposits display markedly different structural styles that make it difficult to attribute their formation to a single compressive event (Jones 2014). Deposits such as Gwalia (formerly Sons of Gwalia), Tower Hill and Harbour Lights are characterised by strongly folded, boudinaged and recrystallized veins. In stark contrast, the Tarmoola/King of the Hills deposit is not affected by later deformation. Instead, the lodes formed during D_3 east–west compression in the strain shadow of a large granitic pluton. This deposit is more typical of the majority of gold deposits in the Eastern Goldfields.

The dominant fabric in the Leonora Domain is the early S_{1b} foliation that wraps around the Raeside Batholith that formed during extension and exhumation of the granite body. The extensional S_{1b} fabric provides a useful indicator for the relative ages of gold mineralization in the Leonora Domain as this intense fabric is axial planar to the tightly folded lodes at the Gwalia, Harbour Lights and Tower Hills deposits. In contrast, the lodes at the Tarmoola/King of the Hills deposit crosscut the S_{1b} foliation (Jones 2014).

Throughout the Eastern Goldfields the age of this early extensional fabric is thought to be between 2670 and 2655 Ma (Cassidy 2006; Czarnota et al. 2010; Blewett et al. 2010; Jones 2006). In the Leonora Domain, the S_{1b} foliation overprints c. 2760–2740 Ma monzogranite (Fletcher et al. 2001, Baggott 2006, Black et al. 2002) and is crosscut by c. 2667 to 2670 Ma felsic dykes (Fletcher et al. 2001; Dunphy et al. 2003; Baggott 2006). Baggott (2006) reports Ar–Ar ages of 2667±6 Ma for magnesio-hornblende in the schistose hanging wall of the Gwalia main lode and composite amphibole grains (actinolite cores, magnesio-hornblende rims) with cores having Ar–Ar ages of c. 2731 Ma and rims of c. 2665 Ma. These ages are consistent with syn-kinematic mineral growth during the major D_{1b} extensional event. The younger age range (2655 to 2640 Ma; Baggott, 2006) reported for gold deposition at the Gwalia, Harbour Lights and Tower Hills deposits likely reflects recrystallization during subsequent tectono-thermal events ($D_{2–4}$ events of Swager (1997)).

Discussion

Vielreicher et al. (2015) conclude with an endorsement of the crustal continuum model of Groves (1993), with the significant recognition that it “must be modified to account for diachroneity of orogenic events and gold mineralization across the Eastern Goldfields.” This diachroneity refers to the westward migration of tectonism and gold mineralization over 5–20 Ma (Krapež et al. 2000; Fletcher et al. 2001; Sircombe et al. 2007; Kositcin et al. 2008). Thus, there is a crustal continuum in time as well as space, and this was very much a point of Bateman and Hagemann (2004) and of Jones (2014): gold deposits such as those at Kalgoorlie and Leonora vary in character in space as well as in time through this continuum.

Molybdenite Re-Os ages—2620 Ma—from Central Bore in the western Yamarna Terrane (Fuller et al. 2014) compare closely with the maximum age of 2621 Ma (Vielreicher et al. 2010), from the Mt Charlotte-style Golden Pike mineralization at Kalgoorlie. On the basis of these data, one could reject the notion of diachroneity of gold deposition across the eastern Yilgarn Craton. New ages of Vielreicher et al. (2015) vary from ~2655 Ma (Bronzewing and Kanowna Belle), through ~2630 Ma (Redeemer), to younger than 2600 Ma (Kundana). This age range is not incompatible with the range of ages published by Vielreicher et al. (2010) for the Golden Mile alone. Thus, their two publications firmly establish via absolute geochronology the wide range in mineralization ages in the eastern Yilgarn, in broad agreement with the wide range implied by the many structural studies they quote. There is no point in dispute: the ages vary widely.

Vielreicher et al. (2015) say that "However, there is some evidence that there may have been late, localized hydrothermal activity that led to some gold mineralization or remobilization during brittle deformation at 2.61–2.60 Ga. This is evident in new phosphate mineral growth and resetting of zircons in dykes". Despite their declared uncertainties, they insist that their data is adequate to refute relative structural timings via overprinting relationships.

We reaffirm the conclusions that gold deposition at Kalgoorlie and elsewhere in the Eastern Goldfields (e.g. Leonora) occurred over a protracted period, through distinct tectonic episodes, and with distinct ore and alteration mineralogy. The data produced and quoted by Vielreicher et al. (2010; 2015) allow for a much longer period of time: up to 71 Ma, and do not "refute previous suggestions that significant gold mineralization events extended from D_E to D_4 in the evolution of the orogen and that the Kalgoorlie gold deposits formed over a period of 45 m.y." We now estimate this span of time to be perhaps 30 Ma.

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