The Pilbara Mesoarchean conglomerate gold versus Quaternary colluvial gold: are they genetically linked?

Sam Spinks  
CSIRO Mineral Resources  
Kensington, WA 6151  
Sam.spinks@csiro.au

Mark Pearce  
CSIRO Mineral Resources  
Kensington, WA 6151  
mark.pearce@csiro.au

Margaux Le Vaillant  
CSIRO Mineral Resources  
Kensington, WA 6151  
margaux.levaillant@csiro.au

David Fox  
CSIRO Mineral Resources  
Kensington, WA 6151  
David.fox1@csiro.au

SUMMARY
Recently discovered nugget gold (Au) in boulder conglomerate between the Mesoarchean West Pilbara Superterrane basement and the overlying volcano-sedimentary stratigraphy of the Neoarchean Fortescue Group in Western Australia have drawn comparisons with the famous Witwatersrand conglomerate Au deposits. Links have also been made between the Pilbara conglomerate gold and nugget Au occurrences in Quaternary colluvial deposits throughout the region. However, little is known about the origin of these as they are hitherto critically unstudied. Therefore, any genetic link is uncertain. Understanding the source and deposition of these nugget Au deposits is critical to aid further exploration in the region.

Here we present a detailed study on the texture, composition and sedimentology of the nugget Au and their host rocks. The Archean conglomerate Au is comprised of a central nugget that is overgrown by a barren chloritic halo, which is further enveloped by a wider halo of Au-bearing chlorite. The central nuggets show no evidence for sedimentary transport, and have faceted surface textures consistent with chlorite imprinting. We argue these represent a modified placer deposit, with surface evidence for sedimentation removed by partial dissolution post-deposition. The Quaternary colluvial nugget Au is hypogene in origin, with minor flattening and limited silver (Ag) leaching on their surface indicative of limited colluvial-fluvial transport from source. Furthermore, preserved facets on their surface are similar to those in the Archean conglomerate deposits.

We propose the source of the Quaternary colluvial nugget Au was a modified placer deposit within a proximal Archean colluvial-conglomerate that has been eroded in situ.

Key words: conglomerate gold, Pilbara, Archean, West Pilbara Superterrane, Fortescue Group.

INTRODUCTION
The Mesoarchean West Pilbara Terrane of Western Australia (Figure 1) has long been known to host numerous nugget gold (Au) occurrences in Quaternary regolith deposits, and less numerous occurrences in Archean clastic sedimentary units. Recent discoveries of extensive nugget Au in previously unknown Archean boulder conglomerate units (Figure 2, Figure 3) drew comparisons with the famous Witwatersrand conglomerate Au deposits of South Africa, and prompted inferences about a possible genetic link between Archean conglomerate Au and the Quaternary colluvial-fluvial Au. This generated significant interest in exploration for Witwatersrand-style conglomerate Au in the Pilbara. However, the Pilbara conglomerate nugget Au deposits are critically understudied and little is known about their formation or deposition. This is of key importance to aid ongoing exploration in the region.

One such occurrence, the Purdey’s Reward deposit, is hosted in a boulder conglomerate unit at the base of the Neoarchean Mount Roe Basalt on the unconformity with the Mesoarchean basement, ~50 km south of Karratha. Numerous other Quaternary regolith nugget Au occurrences are known in the immediate area around Purdey’s Reward, such as the 47K Patch deposit. The nuggets from both deposits look similar, some with distinctive ‘watermelon seed’ morphology, thus empirical links were made between both deposits as having genetic links. These deposits also were, prior to the time of writing, unstudied, and therefore the exploration strategy for further deposits in the region was unclear. In this study, we aim to address these uncertainties.

Figure 1. Simplified regional geological map of the West Pilbara Superterrane, highlighting the Sholl Terrane (ST) and the Sholl Shear Zone. The localities of the 47K Patch Alluvial Au, Purdey’s Reward Conglomerate Au, projects are also shown. Inset map of Western Australia with box showing area in geological map. Modified after (Van Kranendonk et al., 2002).
Conglomerate vs. colluvial gold: are they genetically linked? Spinks et al.

AEGC 2019: From Data to Discovery – Perth, Australia

Figure 2. Trench section of the unconformable contact between the Purdey’s Reward conglomerate and the Whundo Group basalts. The pencil marks the point of the contact, which in this field of view formed in a localised channel.

Figure 3. Simplified lithological log of drill hole 17PDD-058 that intersects the Purdey’s Reward project conglomerate and underlying basement. The interpreted stratigraphic units to which each lithology belongs is shown on the right. Scale in metres.

METHODS

Geochemical maps were collected using the Maia Mapper, a new laboratory XRF mapping system for efficient elemental imaging of drill core sections. Data was collected using a 20 µm source size, filtered using a 1.0 mm aluminium window, and (iii) an efficient XOS polycapillary lens with a flux gain 15,900 at 21 keV into a ~32 µm focus, all integrated with stage raster scanning (Ryan et al., 2018). Maps were processed using GeoPIXE, which uses the Dynamic Analysis method for image projection (Ryan et al., 2000).

The exteriors of gold nuggets were imaged using a Tescan Mira3 field emission gun scanning electron microscope (FEG-SEM). Operating conditions were in secondary electron imaging mode in variable pressures on nugget surface that were uncoated. Interior chemistry of gold nuggets was measured in backscatter electron mode an accelerating voltage of 15 kV, a beam current of 2.0 nA and a live count time of 100 s. Elemental calibrations were made against a range of natural mineral standards, an XPP matrix correction procedure was used, and count rate was calibrated using a pure cobalt metal standard. Data were collected and processed using the Oxford Instruments AZtec software package.

RESULTS

Archean Conglomerate Gold

Maia Mapper analyses of the nugget-bearing samples cut along the plane of the in situ nuggets shows the nuggets are hosted in the matrix between mafic clasts, usually in contact with clasts Figure 4). The nuggets occur surrounded by a thin halo of barren chlorite, with a wider halo of chloritic intergrown with finely disseminated gold (Figure 4). The mineralized chlorite halo may have a thin outer halo of barren clays, as demonstrated by the rubidium (Rb) distribution (Figure 5). The nuggets are Ag-bearing in composition, and there is no evidence for Ag depletion around the rims.

Closer SEM analysis of the outer edges of the nuggets show that the barren chlorite halo is approximately 100 µm thick and is intergrown with a zone of fine-grained Au and REE-bearing monazite (Figure 6). The contact between the barren chlorite and surrounding halo of secondary Au-bearing chlorite is sharp and nowhere appears to be gradational.

Maia Mapper data shows that minor Au also occurs in conglomerate samples that are devoid of macro-scale nuggets. Micro-nuggets <100 µm in diameter occur in the matrix, again, close to the edge of larger clasts. These micro-nuggets are too small to be detected by metal detector methods or by the CT scanner, but demonstrate that Au is dispersed throughout the conglomerate, at least in the sampled basal horizon

Figure 4. Maia Map of nugget-bearing conglomerate sample from Purdey’s Reward project. (A) photomicrograph of sample showing location of nugget. (B) RGB map of field of view highlighted by box in (A), showing distribution of Fe (red), Au (green), Rb (blue). Nuggets occur in the matrix between large clasts. White box in (B) indicates detailed area shown in Figure 5.
Conglomerate vs. colluvial gold: are they genetically linked?

Spinks et al.

AEGC 2019: From Data to Discovery – Perth, Australia

Figure 5. Detailed Maia Map of area shown in Figure 4B showing distribution of Fe (red), Au (green), Rb (blue). Barren chlorite (Chl) around the nugget is indicated by rim enriched in Fe (red). Halo of fine Au and Chl is surrounded by a halo enriched in Rb possibly indicating barren clays.

Figure 6. X-ray SEM images of the edges of in-situ nuggets. (A) Outer section of nugget shown in box highlighted in Figure 5. The contact between the outer halo of Au and chlorite (Chl) and inner halo of barren Chl is shown to be sharp in nature. (B) Higher magnification of area highlighted by box in (A) showing barren Chl and veinlet of AU and REE-bearing monazite (Mon).

Figure 7. (A) Secondary SEM image of exhumed nugget from Purdey’s Reward project, showing intensely faceted surface texture. (B) Higher magnification image of area highlighted by box in (A), showing morphology and scale of facets and embayments.

Quaternary Colluvial Gold

The nuggets sampled from the 47 K Patch alluvial project range in size from < 500 µm to several cm in diameter and are predominantly flattened with rounded-blunt edges and protruding peninsular elongate branches. Some appear smooth and have the distinctive infamous appearance of ‘watermelon seeds’.

Examination of the exteriors of these nuggets at the micron (µm) scale using the SEM shows that the while the nuggets are rounded and broadly flat at the macro-scale, many retain well-developed facets on the surface whilst some have developed smoother semi-faceted surfaces with (Figure 8). Closer inspection of the textures within the facetted depressions show they are comprised of numerous smaller, sometimes overlapping, embayments a few hundred µm wide. Within these embayments the surface texture is often irregular and nodular. X-ray analysis of the interior of the 47K Patch nuggets shows they have are composed of coarse annealed Au crystals that are generally up to ~1 mm in diameter, with variable Au-Ag ratios (Figure 9A). The nuggets have between 4 and 13 wt% Ag with most approximately 8 wt% Ag.

However, there are distinctive thin outer rims of pure Au up to a few tens of µm wide developed on all nuggets that are devoid (less than ~0.5 wt%) of detectable Ag (Figure 9B). The Ag depletion zones are well-developed and have sharp boundaries with the nugget interiors. Silver depletion appears to be particularly well-developed in zones where the nugget exteriors are folded. Some nuggets have sub-mm scale embayments that are filled with clays, REE phosphate (florencite) and fine-grained dusty particulate Au. This fine-grained secondary Au contains little Ag.
DISCUSSION

Clues in Gold Nuggets’ Textures and Geochemistry

The origin of the Archean conglomerate gold is subject of intense debate, and three models have been proposed, particularly to the economically-important and well-studied Witwatersrand Basin conglomerate Au: 1) placer Au, 2) modified placer Au, 3) hydrothermal (see Robb and Hayward, (2013) and references therein). The Placer Au model implies primary hypogene Au is weathered from basement rock and is transported in fluvial systems and ultimately deposited in sediment traps, retaining the evidence of transportation such as nugget rounding, flattening and Ag depletion. The modified placer model suggests similar erosion, transport and sedimentary processes as placer model, but with later remobilization of Au and other metals by intensely-reducing basinal fluids during diagenesis-metamorphism. The hydrothermal model implies Au and other metals and metalloids are derived from structurally-controlled hydrothermal basinal fluid movement, allowing authigenic Au and pyrite to form in porous conglomerate facies. The main source of controversy over the placer versus modified placer/hydrothermal origin for the Witwatersrand deposits is the apparent control on Au deposition in sedimentary traps and the co-occurrence of other heavy detrital minerals such as pyrite and uraninite. This is then countered by the presence of primary authigenic-hypogene textures, consistent with a hydrothermal or alteration formation model. The same controversy is ongoing with regard to occurrences of Archean conglomerate gold in the Pilbara terrane. These occurrences are hitherto poorly understood as they are critically understudied, but general convention assumes they are placer in origin.

Understanding the ore formation model in the West Pilbara is of critical to the ongoing exploration effort as it may imply the sedimentary environment had a primary control on the occurrence and distribution of primary placer Au, or post-deposition events have altered the distribution, morphology, grade, and composition of Au. Therefore, it is critical to understand the origin of the Purdey’s Reward conglomerate nugget Au in order to understand the wider mineral system. Likewise, the presence of nugget Au in Quaternary colluvial deposits in the West Pilbara Supergrenera must be better understood before the question of a genetic link with the Archean conglomerate Au can be addressed.

Origin of the Purdey’s Reward Conglomerate Nugget Au

The nugget Au in the Purdey’s Reward Conglomerate, though hosted in intraclast sandy matrix, shows no direct evidence of a purely placer origin. The high Ag concentrations in the massive polycrystalline nuggets is consistent with formation in hypogene settings (Robb and Hayward, 2013; Hough et al., 2007). However, there is no evidence for Ag depletion around the rim of the main nuggets (Figure 6), which implies there was no transport in a near surface fluvial system (Hough et al., 2007) as Ag leaches from Au-Ag alloys more readily than Au, at least in modern surface environments, e.g. Knight et al., (1999a), Robb and Hayward, (2013) (and references therein). The faceted surface textures on ex situ nugget samples, that are otherwise rounded and oval-discoid in shape, show no evidence of flattening by sedimentary processes (Figure 7). This, again, is inconsistent with a purely placer origin. The phyllosilicate imprints in the faceted surfaces (Figure 7) are consistent with the presence of barren Fe-rich chlorite that is observed to rim all analysed in situ nuggets. This may suggest either concurrent precipitation of an authigenic-hydrothermal nugget immediately followed by chlorite, or partial dissolution/replacement of the outer rim of a placer nugget by chlorite. The sharp boundary between barren chlorite haloes and the Au-chlorite haloes (Figure 6), co-precipitation of rutile with minor Au in pore spaces proximal to the nuggets, and the occurrence of minor Au in Mn oxide-filled microfractures indicate that Au was mobilized and recrystallized well after the deposition of the conglomerate.

Thus, we argue that the Purdey’s Reward Au is not purely placer in origin. The Au-Ag alloy chemistry and coarse polycrystalline crystallography of the main nuggets demonstrate that they have a clear hypogene origin. However, given the elongate-discoid morphology to the nuggets, a potential paleopplacer origin from a hypogene source prior to partial dissolution cannot be discounted. In this scenario, it is possible that paleopplacer nugget Au in the conglomerate that possessed textural and morphological evidence for sedimentary processes was subject to later dissolution by basinal or metamorphic fluids that destroyed surficial evidence of sedimentary transport. Subsequent envelopment of barren chlorite haloes around remnant nugget, followed by paragenetically-later secondary Au-Ag may represent local recrystallization of the dissolved Au. This would be consistent with a modified placer model e.g. Robb and Hayward (2013).

Alternatively, the main hypogene nugget may have formed in situ as primary hydrothermal Au, paragenetically followed by chlorite precipitation. The conglomerate unit does not show any obvious broad-scale alteration signatures, but some clasts do show distinctive concentric alteration haloes. However, the elongate morphology of the main nugget, and fact nugget Au is limited to the basal section of the conglomerate is difficult to account for, in this scenario.

Therefore, we favour a modified placer model for the Purdey’s Reward conglomerate nugget Au. To fully understand this mineral system, however, further work is needed including geochronology of the Au-phosphates, and fluid chemistry modelling.

Origin of the 47K Patch Colluvial Nugget Au

Figure 9. X-ray SEM images of from 47 K Patch nugget interiors. (A) High contrast mode shows the nugget is composed of course (~1 mm diameter) annealed crystals with variable Au-Ag ratios. (B) Localized Ag depletion (bright) occurs in the interiors of some nuggets, as well as on the exterior.

Figure 9: X-ray SEM images of from 47 K Patch nugget interiors. (A) High contrast mode shows the nugget is composed of coarse (~1 mm diameter) annealed crystals with variable Au-Ag ratios. (B) Localized Ag depletion (bright) occurs in the interiors of some nuggets, as well as on the exterior.
Au-Ag alloy chemistry and coarse polycrystalline crystallography of the 47K Patch nugget Au demonstrate that they have a clear hypogene origin (Hough et al., 2007), similar to the Archean Purdey’s Reward nuggets. This precludes a supergene origin for the nuggets, though minor secondary ‘pure’ gold was observed on the surface of some nuggets, which is likely indicative of low-temperature origin (Robb and Hayward, 2013).

The preservation of faceting on many of the nuggets’ surfaces, limited flattening and the preservation of elongated protrusions on the nuggets suggest that they have been subject to limited transportation and sedimentary processes. The classification by (Knight et al., 1999a, Knight et al., 1999b) suggests that (in the Klondike, Yukon) nugget morphology can be used to estimate transportation distances, with rapid flattening within ~5 km of the Au source. Whilst the sedimentary environment at 47K Patch is not comparable with the Klondike, this simple classification can be applied, and the morphological evidence would suggest the nuggets have not undergone significant sedimentary transport. Furthermore, the presence of Ag-depleted rims is evidence for, albeit limited, fluvial transport. The sharp boundaries of the Ag-depleted rims would suggest their distribution is controlled by grain boundaries within the polycrystalline structure, rather than diffusion processes through the nugget. Silver depletion is strongly controlled by the crystal structure and proceeds along crystallographic grain boundaries by a selective solution process (Hough et al., 2007). This limited extent of the Ag-depleted rims (~10s µm; Figure 9) on the nuggets thus may suggest that they have been subject to minimal exposure to leaching in a fluvial environment. However, the arid environment and ephemeral fluvial environment must be considered here, thus the limited development of Ag-depleted rims may be controlled by the limited availability of water in the channel systems.

Collectively, the evidence suggests that the hypogene nuggets at 47K Patch are locally derived. The general preserved texture and morphology of the 47K patch nuggets is strikingly similar to the Purdey’s Reward Archean nuggets. This may imply that they either: 1) share a primary hypogene lithological source in the hinterland, or 2) they are derived from the weathering of a Au-bearing conglomerate unit similar to that at Purdey’s Reward. If the nuggets were sourced locally as part of the quaternary colluvial erosion and sedimentary processes, they are likely to be derived from the proximal Whundo Group lithologies, that are mapped as Bradley Basalt. This is problematic, as there has been no evidence for nugget Au found in these basalts either locally or regionally. The potential of the presence of a colluvial-type paleo-conglomerate at 47K Patch, which has since been weathered to mimic the Quaternary colluvial deposits allows the possibility that there may have also been Archean conglomerate Au in the 47K Patch area. Given the similarities in chemistry, crystallography and texture between the two occurrences, any Archean conglomerate Au at 47K Patch would likely have a similar origin, i.e. that of a modified placer or hydrothermal origin. In the case of a modified placer Au system, given the similar monomictic basaltic lithology of the clastic detritus at 47K Patch, any source of Au is likely to be derived ultimately from the Whundo Group hinterland, via a Mesoarchean conglomerate.

CONCLUSIONS

The Purdey’s Reward Archean conglomerate was likely deposited in a high-energy mass-flow environment with fluvial influence. There are several possibilities for the provenance for the Purdey’s Reward conglomerate, including: 1) the detritus is locally sourced from within the Whundo Group volcano-sedimentary facies from the SW or NE, 2) locally-sourced from the Whundo Group to the SW possible additional input of detritus from the Sisters’ Supersuite felsic-ultramafic intrusives, 3) distal input from the Mesoarchean Cleaverville Formation and/or Whim Creek-Bookingarra groups of the De Grey Superbasin.

Conglomerate nugget Au at Purdey’s Reward is likely a modified placer deposit, but a hydrothermal origin cannot be discounted.

Quaternary colluvial nugget Au at 47K Patch is locally sourced, either from primary Whundo Group lithologies, or a local eroded Au-bearing paleo-conglomerate. However, given the preserved surface textures, the latter is more likely. Therefore the question of are they the Mesoarchean and Quaternary gold linked? In this case, probably.

ACKNOWLEDGEMENTS

We thank Artemis Resources for funding this study. Thanks go to Novo Resources Corp. for access to the Purdey’s Reward site and access to drill core. Thanks also go to Mark Creasy for access to additional samples.

REFERENCES


