The Bald Hill gold deposits in the Paleoproterozoic Tanami Group, Western Australia

by L. Bagas and D. Huston[1]

Abstract

The Bald Hill Member of the Killi Killi Formation in the western part of the Granites–Tanami Complex of Western Australia (Tanami region in the Northern Territory) contains significant gold deposits over a 15-km strike length. Preliminary geological, geochemical, and structural data from the area suggest that gold was localized early in the tectonic history, during the c. 1835–1815 Ma Tanami Orogeny. This early timing of mineralization is atypical for other parts of the Tanami region, where mineralization is associated with c. 1790 Ma granitic intrusions. Gold localization was controlled by a number of factors. These include structures that focused fluids into depositional sites, where fluid–rock interaction in chemically receptive rocks and structural opening caused fluctuations in fluid pressure, which enhanced gold deposition.

KEYWORDS: Paleoproterozoic, Granites–Tanami Complex, Killi Killi Formation, Tanami Orogeny, gold deposits.

Introduction and regional setting

The Granites–Tanami Complex (Tanami region of Crispe et al., in prep.) of Western Australia and the Northern Territory (Fig. 1) contains mostly Proterozoic rocks (Table 1), which are largely covered by Cenozoic regolith. Over the last two decades more than 280 t of gold has been mined, making this region one of the pre-eminent Paleoproterozoic gold provinces in the world. The locations of significant gold deposits in the western part of the Granites–Tanami Complex are shown in Figure 2.

This paper documents a study of oriented diamond drillcore from the Sandpiper and Kookaburra gold deposits in the Bald Hill area of Western Australia carried out by the Geological Survey of Western Australia (GSWA) and Geoscience Australia. Characteristics of the deposits and JORC-compliant resource estimates are presented in Table 2.

Deposits of the Bald Hill area

The Bald Hill area includes prospects over a 15-km strike length in the c. 1835 Ma Killi Killi Formation of the Tanami Group (Fig. 3). Many of these prospects are hosted by the 200 m-thick Bald Hill Member of the turbiditic Killi Killi Formation.

The Bald Hill Member contains a succession of tightly folded and faulted iron-rich siltstone, graphitic and carbonaceous shale, banded and nodular chert, siltstone, turbiditic sandstone, basalt, and dolerite sills (Bagas et al., in prep.).

The eastern contact of the Bald Hill Member with the interbedded turbiditic sandstone, siltstone, and shale of the Killi Killi Formation (Fig. 3) is a layer-parallel fault, which may represent an early structure (D_{B1}*; Table 1). In outcrop, folds formed during D_{B1} are tight to isoclinal with an S_{B1} cleavage, and have been refolded by F_{B2} and later folds (Fig. 4). F_{B2} folds are typically asymmetrical, angular, tight, and have a wavelength of less than a kilometre (Fig. 3). The folds are locally overturned, inclined, verge south, plunge moderately towards the east, and trend around 120°, consistent with north-northeast–south-southwest compression. The folds also have an S_{B2} axial-planar spaced cleavage that dips steeply to the north-northeast. Both the S_{B1} and S_{B2} surfaces are defined by flattened quartz, and aligned sericite and chlorite, indicative of greenschist-facies metamorphism. D_{B2} faults may develop on overturned F_{B2} fold limbs. Mineral occurrences in the area are in D_{B2} faults, in axial-planar zones of F_{B2} folds where they intersect southeast-trending faults or fractures, and along lithological boundaries.

Subsequent deformation resulted in open folding with a moderate plunge to the north-northeast (around 60°),

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* 'B' refers to deformation events in the Bald Hill area

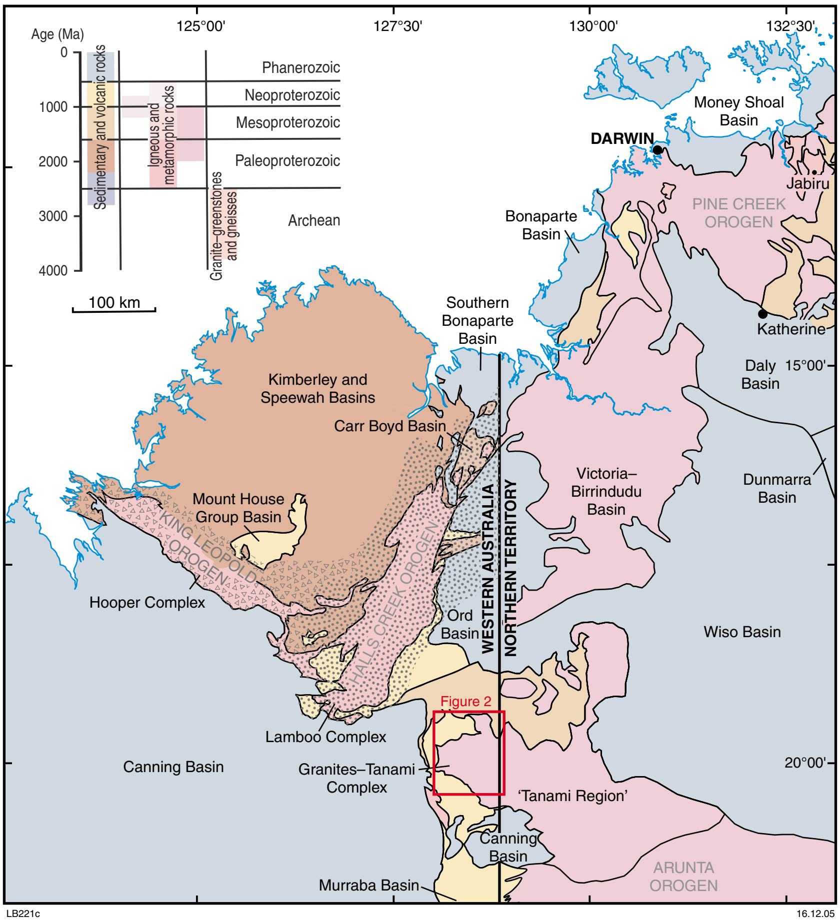

Figure 1. Regional tectonic sketch showing the locality of the Granites–Tanami Complex

Table 1. Early geological events in the Granites–Tanami Complex (modified after Huston et al., in prep.)

Rock types	*Deformation and metamorphic events*
Frederick Suite (c. 1815–1790 Ma): magnetic peraluminous biotite monzogranite to syenogranite **Grimwade Suite** (c. 1820–1790 Ma): nonmagnetic, peraluminous biotite monzogranite to syenogranite	D_3 and ?D_{B3}^{*}: northeast- to east-trending angular folds with 100 m wavelength (?c. 1810–1800 Ma) D_2: Open, angular, north-northwest- to northeast-trending folds (?c. 1815–1800 Ma, may be correlated with the Stafford Event in the Arunta Orogen)
	Tanami Orogeny (1835–1815 Ma): D_{B1}^{*}: low-angle faulting and isoclinal folding D_1–M_1 and D_{B2}: asymmetric, disharmonic folds with wavelengths up to 1 km; greenschist- to middle amphibolite-facies metamorphism with highest grades to the southeast. Prolonged period of deformation that affects the Tanami Group
Tanami Group (c. 1840): Killi Killi Formation (c. 1835 Ma): interbedded metawacke and pelite Dead Bullock Soak Formation: interbedded pelite and sandstone (Ferdie Member, c. 1840 Ma) fining up into graphitic pelite and banded iron-formation (Callie Member) Dolerite sills intrude the Tanami Group	

NOTE: * 'B refers to deformation events in the Bald Hill area

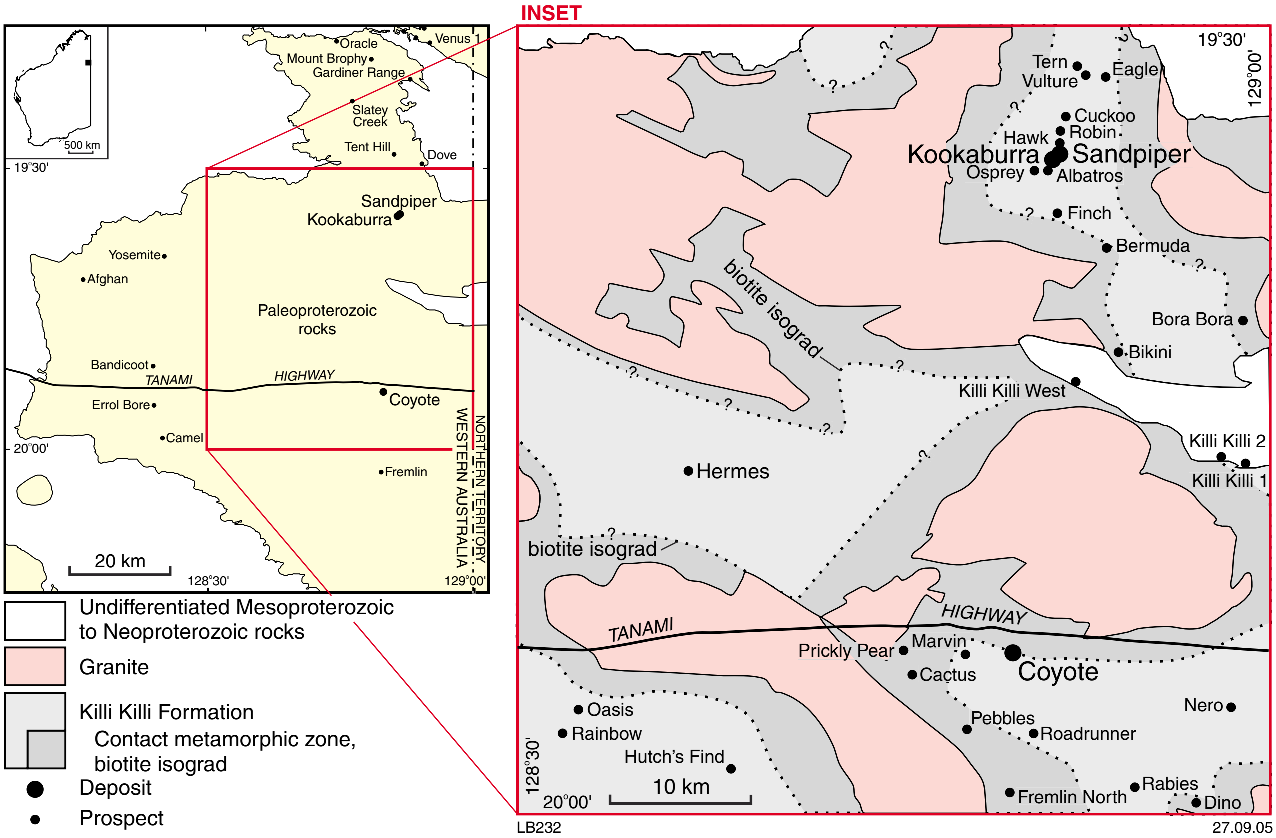

Figure 2. Mineral deposits and prospects in the western Tanami region

and was accompanied by development of a vertical cleavage (Fig. 5). These folds and the cleavage are interpreted as post-D_{B2}, and are referred to as F_{B3} and S_{B3} respectively. The orientation of later F_{B3} folds indicates compression in a northerly to northwesterly direction. A late spaced cleavage (S_{B4}) that dips about 60° towards 220–230° is also recognized in the area.

The Kookaburra and Sandpiper gold deposits

The Kookaburra and Sandpiper gold deposits (Figs 2 and 3, Table 2) were discovered in the Bald Hill Member in the mid-1990s during a geochemical survey by Glengarry Resources NL and Tanami Gold NL. The Kookaburra deposit is in the hinge of an overturned F_{B2} syncline and the Sandpiper deposit is on the southwest limb of an overturned F_{B2} anticline. Both folds trend southeast and plunge about 50° towards the east. A southeast-trending D_{B2} fault at Kookaburra separates the eastern side of the syncline from the Sandpiper deposit to the northeast (Fig. 3). The Sandpiper deposit is largely unexposed, except for auriferous quartz veins, and was discovered following investigation of geochemical anomalies in the area (English, L., 2005, written comm.). At the prospect RAB drillhole cuttings include sericitic, graphitic, and silicified pelite, metachert, and metawacke, and probably also represent the Bald Hill Member of the Killi Killi Formation.

Vein paragenesis and alteration assemblages

The Kookaburra and Sandpiper gold deposits have different structural settings, but are characterized by similar vein parageneses and alteration assemblages. The earliest veins within the Kookaburra and Sandpiper ore zones contain quartz(–pyrite–arsenopyrite) or quartz–carbonate (Table 3). These vein types are commonly anastomosing, form saddle reefs, are locally folded by F_{B2}, and are sheared by the dominant fabric (S_{B2}) within altered wallrock, suggesting that they developed pre- to syn-kinematically with respect to D_{B2}. The veins are typically 3–10 mm thick, and are cut by thick (up to 500 mm), planar, massive quartz veins. Assay results suggest that only the earlier veins carry ore-grade gold mineralization.

The Sandpiper deposit also contains minor carbonate–galena(–sphalerite) veins. Although quartz is absent, the veins have a similar structural timing to veins containing gold mineralization, suggesting contemporaneity.

Quartz(–pyrite–arsenopyrite) veins in the ore zones at both deposits are associated with quartz–mica(–sulfide) schist, with the schistosity defined by sericite and biotite. This fabric is

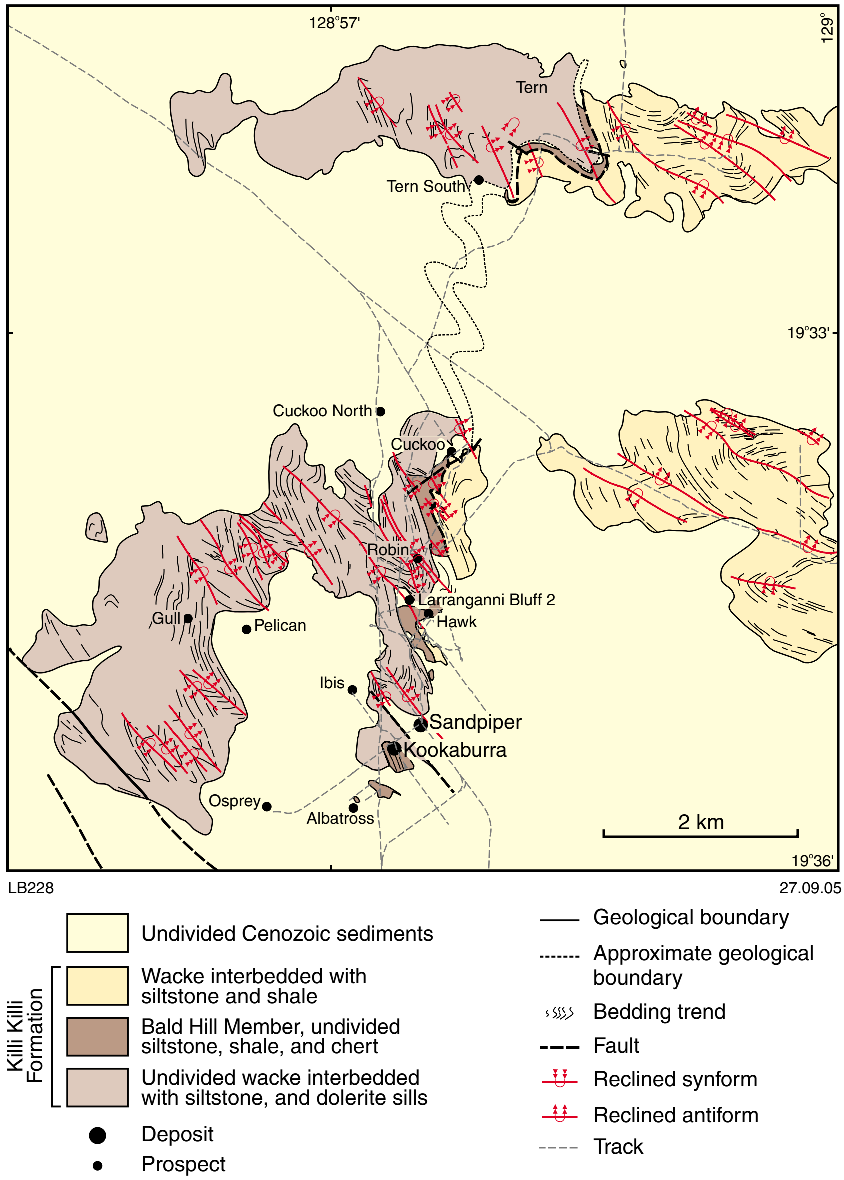

Figure 3. Geological map of the Bald Hill area (modified after T. Beardsmore, 2005, written comm.)

Table 2. Characteristics and resource estimates of the Kookaburra and Sandpiper gold deposits

Deposits	*Combined indicated and inferred resource estimates*	*Host rock and structures*	*Vein paragenesis and alteration*
Kookaburra	1.44 Mt at 2.02 g/t Au	Bald Hill Member. Auriferous veins in a synclinal hinge zone	Gold associated with silica–carbonate–sericite–chlorite alteration. Bleached and decarbonized host rocks
Sandpiper	1.21 Mt at 2.92 g/t Au	Bald Hill Member. Auriferous veins in east- to southeast-trending faults	Gold associated with silica–carbonate–sericite–chlorite alteration. Bleached and decarbonized host rocks

SOURCE: Resource estimates after Tanami Gold NL (2005)
Geology after Bagas et al. (in prep.)

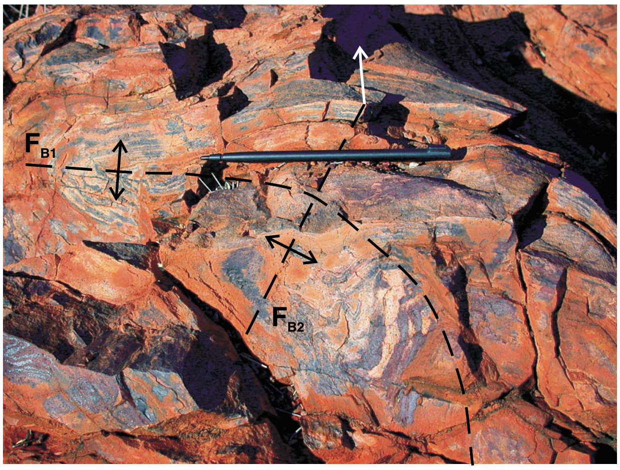

Figure 4. Photograph showing the relationship between a tight to isoclinal F_{B1} fold and angular F_{B2} fold plunging 25° towards the east (105°). The rocks are laminated, ferruginized pelite interbedded with metachert in the Killi Kill Formation (MGA 499998E 7835559N)

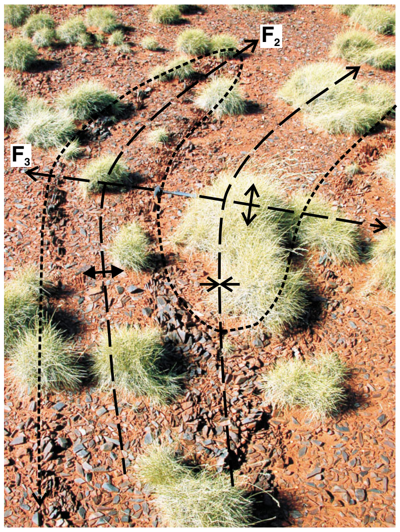

Figure 5. Refolded early (F_{B2}) fold hinges in the Bald Hill area (MGA 487124E 7840210N). The F_{B2} folds are upright and plunge moderately to the southeast. The F_{B3} fold hinge plunges steeply to the east-northeast. The hammer is parallel to the F_{B3} fold axis. The photograph was taken facing south, and the area was first reported by T. Beardsmore (2005, written comm.)

Table 3. Characteristics of veins sets in the Bald Hill area

Vein set and host rocks	*Characteristics*	*Structures*	*Comments and interpretations*
Early veins			
Chloritized mafic igneous rocks	Abundant 1–3 mm, irregular to folded carbonate veins	Veins are folded and crenulated (F_{B2}), and also form disrupted fragments within D_{B2} shears	Carbonate also fills amygdales in basalt, suggesting that the veins and chloritic alteration may be the result of spilitic alteration
Metasedimentary rocks	Carbonate veins associated with a purplish carbonate–(?)hematite wallrock assemblage		
Syn-ore veins			
Dolerite, metawacke, and pelite	Layer-parallel quartz veins, up to tens of metres thick	Saddle reefs, steeply inclined veins in F_{B2} fold axial planes, or subhorizontal veins perpendicular to the direction of maximum D_{B2} extension (σ_3; Fig. 6)	Formed during various stages of D_{B2}
Post-ore veins			
Dolerite, metawacke, and pelite	Planar, 1–10 mm quartz–carbonate–pyrite–chalcopyrite veins	Located along or cut the D_{B4} spaced cleavage; associated with sericitic alteration selvedges that commonly pick out the S_{B4} fabric	This assemblage is similar to late (regional D_{6+}) quartz–carbonate – base metal sulfide veins that cut auriferous veins at the Callie deposit (Wygralak et al., 2005)

parallel to the axial-planar S_{B2} cleavage and D_{B2} faults. Disseminated sulfides within quartz–mica(–sulfide)-bearing rocks commonly form lenticular aggregates parallel to this schistosity. Sulfides include pyrite, marcasite after pyrrhotite, galena associated with native bismuth, chalcopyrite, and sphalerite. Arsenopyrite typically forms euhedral porphyroblasts with common quartz and muscovite pressure shadows. The pressure shadows contain pyrite and, in some cases, marcasite. The fabric commonly wraps around arsenopyrite porphyroblasts, suggesting an early kinematic timing for arsenopyrite introduction. The sulfide and phyllosilicate assemblage in the vein wallrocks appears to have formed syn-kinematically, and is contemporaneous with vein formation.

Massive quartz veins cut the fabric in the quartz–mica(–sulfide) schist, suggesting a post-D_{B2} timing. These veins have a simple mineralogy, with only minor carbonate and pyrite, and very rare arsenopyrite and pyrrhotite.

Conclusion: towards a genetic model for the Bald Hill deposits

Data collected in this study place some constraints on models for the genesis of gold in deposits in the Bald Hill area. Gold deposition occurred early in the tectonic history of the area (i.e. during the c. 1835–1815 Ma Tanami Orogeny), contemporaneous with regional greenschist-facies metamorphism. This timing is atypical for the majority of gold deposits in the Tanami region, which are considered to have formed at c. 1790 Ma (Huston et al., in prep.), broadly coeval with the emplacement of granites (Table 1). Gold deposition in the Bald Hill area was localized along structures that focused fluids into depositional sites, and by fluid–rock interaction in chemically receptive rock types, such as at or near the contacts between mafic igneous rocks, graphitic shale, and sandstone.

Figure 6 summarizes the types of mineralized quartz veins observed in the area. These veins are likely to have been related to the $D_{B1–B2}$ events. The saddle reefs formed in extensional zones at the hinges of folds and continue along bedding contacts where bedding slip was common. These reefs are also generally parallel to the plunge of folds. Other structural controls on veins are fractures parallel to the fold axial plane, and along extensional fractures at right angles to the fold axial surface. Quartz veins in these fractures commonly form en echelon sheets.

The early timing for gold mineralization in the Bald Hill area implies that no single model should be used in exploring for gold in a region, and that gold mineralization can be temporally linked to a number of factors such as tectonism, regional metamorphism, and granite emplacement.

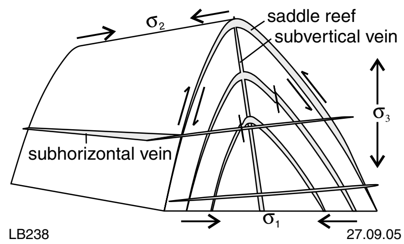

Figure 6. ***Schematic diagram of quartz veins formed in the Bald Hill area during D_{B2}, showing principal stress directions (σ_1, σ_2, σ_3)***

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