Paper 29

Unravelling Tropicana – Where, What, How and Why?

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ABSTRACT

The Tropicana gold deposit is located east of the Archean Yilgarn Craton within the Albany-Fraser Orogen. It is hosted in Neoarchean rocks, including granitic rocks with subduction-zone affinities that formed between 2722 –2554 Ma during the 'Atlantis Event'. The early history of the Atlantis Event overlaps with komatiite-hosted Ni development within the Eastern Goldfields Superterrane of the Yilgarn Craton. Later metamorphism and magmatism during the Atlantis Event overlaps with orogenic Au development within the Eastern Goldfields Superterrane as part of regional-scale prograde greenschist facies metamorphism. Neoarchean gold mineralization within the Albany-Fraser Orogen is currently only known within the 'Tropicana Zone', and occurred at about 2520 Ma as part of a retrograde greenschist facies event that coincided with the development of a northwesterly-directed fold-and-thrust belt above the flat-lying Plumridge Detachment. The extent of the Plumridge Detachment is investigated in this paper. The detachment is extended northward, toward the Archean Yamarna Greenstone Belt, linking it to the Yamarna Shear Zone which forms the boundary between the Burtville and Yamarna Terranes.

INTRODUCTION

The 7.9 Moz Tropicana gold deposit was discovered in 2005 by AngloGold Ashanti Limited (AGA) and it Joint Venture partner Intependence Group NL (IGO) (Doyle et al., 2013, 2014, 2015). The c. 2520 Ma deposit occurs within Neoarchean rocks of the Tropicana Zone within the Kepa Kurl Booya Province of the Albany-Fraser Orogen.

Tropicana is situated adjacent to the Archean Eastern Goldfields Superterrane of the Yilgarn Craton (Figure 1), which is known for its' world class gold and nickel deposits. However, the Tropicana gold deposit is substantially different to those in the Yilgarn Craton.

Delineation of the Tropicana gold camp was hampered due to limited outcrop, sand cover, and burial beneath the Cenozoic Eucla Basin to the east and northeast, and the Permian Gunbarellel Basin to the west. Although the Tropicana deposit is well understood (Blenkinsop and Doyle, 2014; Doyle et al., 2014, 2015), regional-scale understanding of the gold prospectivity of the region has been reliant on public domain and proprietary magnetic and gravity geophysical data hindering the interpretation of this belt, and exploration targeting.

Current-day understanding of the 4D evolution of the Albany-Fraser Belt has been aided through select geochemical and geochronological work, coupled with potential fields and 2D reflection seismic transects across the region. Seismic reflection surveys indicate that the architecture of the southeastern and northeastern margins of the Yilgarn Craton with the Albany–Fraser Orogen are vastly different, suggesting exploration models in the region must be applied with caution, and cannot be applied across the whole belt.

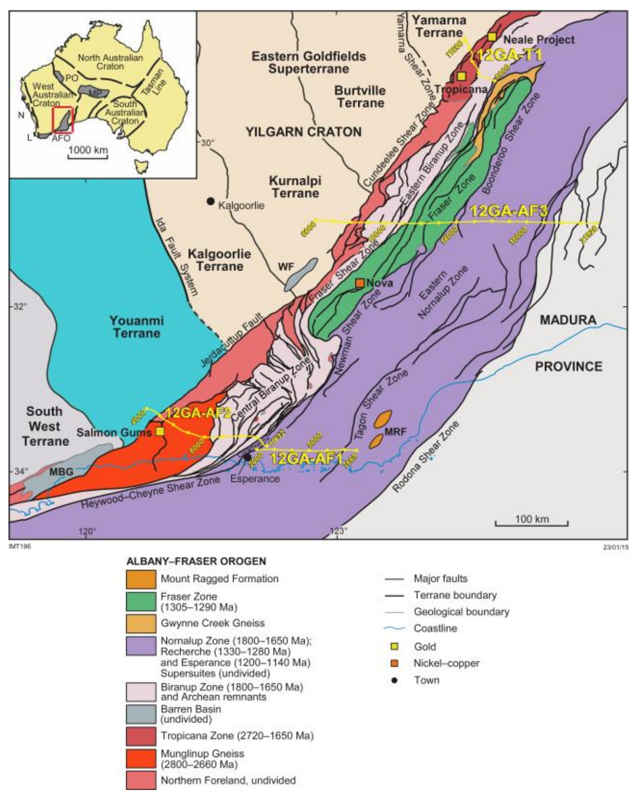

Figure 1: Simplified geological map of the eastern Albany-Fraser Orogeny, from Occhipinti et al., (2017). Shown are the seismic reflection transects 12GA-AF1, 12GA-AF3 and 12GA-T1. Inset map shows location in the southwest of Australia: AFO: Albany-Fraser Orogen; MP: Musgrave Province; PO: Paterson Orogen.

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Geological Setting

The Albany–Fraser Orogen has been divided into the Kepa Kurl Booya Province and Northern Foreland (Figure 1; Spaggiari et al., 2009, 2014a), which were affected by tectonic events between the Neoarchean to Mesoproterozoic. The Northern Foreland consists of greenschist, amphibolite to granulite facies Archean rocks and gneisses that include remnant greenstones that were reworked during the Proterozoic. In places, these rocks have been thrust back over the non-reworked Archean Yilgarn Craton (Spaggiari et al., 2009, 2014b)

The Kepa Kurl Booya Province forms the bulk of the Albany–Fraser Orogen and includes four, fault-bounded domains: Tropicana, Biranup, Fraser and Nornalup (Figure 1; Occhipinti et al., 2017). These domains are distinguished by their different rock protoliths each reflecting distinct geological histories (Spaggiari, 2009, 2014a, b).

Paleoproterozoic events in the Albany–Fraser Orogen include those driven by extensional and compressional tectonics. Between 1815 to 1760 Ma, extensional tectonism resulted in basin formation, and bi-model magmatism during the Salmons Gum's and Ngadju event's (Spaggiari et al., 2014a). Rifting of the Yilgarn margin led to the development of the extensive Barren Basin, forming an ocean-continent transition. This eventually resulted in the formation of the 1600 to 1305 Ma Arid Basin in a passive margin setting. The Zanthus Event, which occurred at c. 1680 Ma included contractional tectonism (Kirkland et al., 2011).

Subsequent tectonism led to the onset of 1330–1260 Ma Stage I of the Albany–Fraser Orogeny, producing voluminous bi-modal magmatism (exposed as intrusive rocks) that were deformed and metamorphosed at high-temperatures and moderate to high pressures (Clark et al., 2014; Smithies et al., 2015). This was followed by orogen-scale thrusting during Stage II of the Albany–Fraser Orogeny (1225–1140Ma), also accompanied by high-temperature, moderate-pressure metamorphism (Dawson et al., 2003; Spaggiari et al., 2014b). Stage II of the Albany–Fraser Orogeny produced voluminous A-type magmatism (Esperence Supersuite granites) in the southern and eastern parts of the Albany–Fraser Orogen (Smithies et al., 2015).

Tropicana Zone

The Tropicana Zone mainly consists of amphibolite to granulite facies Neoarchean rocks of the Tropicana and Hercules Gneiss (Occhipinti et al., 2017). These rocks are overlain by greenschist to lower amphibolite facies rocks of the Lindsay Hill Formation (Barren Basin), and intruded by Paleoproterozoic granitic and mafic rocks that developed during the 1780–1760 Ma Ngadju Event.

Neoarchean rocks in the Tropicana Zone have been described by various authors including Doyle et al. (2015), Crawford and Doyle (2016), and Kirkland et al. (2015). In summary, these rocks include amphibolite to granulite facies and intermediate to felsic orthogneiss (including garnet gneiss) with meta-greenstone successions, the protoliths of which were deposited in a possible continental margin arc in a submarine setting (Crawford and Doyle, 2016). The orthogneiss has a range of possible granitic protolith compositions including monzonitic, tonalitic, and quartz-syenogranitic that are implied to represent calc-alkaline magmas that include adakites (Crawford and Doyle, 2016) and sanuikitoids (Kirkland et al., 2015). Possible metamorphosed greenstone rocks include mafic to ultramafic gneiss, metachert and meta-iron formation (Doyle et al., 2014, 2015).

The magmatic age of the granitic protolith to the gneiss in the Tropicana Zone is taken as c. 2722 Ma and is based on the age of magmatic zircon sampled from foliated granite close to the Tropicana gold deposit. A younger age of c. 2640 Ma is taken as the age of high-grade metamorphism of these rocks in that the age is from zircons that appear to have crystallized during granulite facies metamorphism as part of the Atlantis Event (Kirkland et al., 2015; Occhipinti et al., 2017). The Atlantis Event appears to represent a protracted high grade metamorphic event that spanned between c. 2718 Ma and 2554 Ma (Kirkland et al., 2015).

MINERALIZATION

Gold mineralization at Tropicana formed on a retrograde path, after the amphibolite- to granulite-grade Atlantis Event. Orogenic gold mineralization is associated with potassium metasomatism and growth of biotite and pyrite under greenschist facies conditions (Doyle et al., 2014, 2015). Timing of gold mineralization is dated at c. 2520 Ma, constrained by a range of geochronometers including Ar-Ar in biotite (2515 ± 14 Ma), Re-Os on pyrite (2505 ± 50 Ma), and U-Pb on rutile (c. 2520 Ma) (Doyle et al., 2015). These are consistent with uplift along a retrograde (cooling) path through amphibolite facies (500 – 550^{o} C) at c. 2520 Ma through greenschist facies (c. 350 ^{o} C) at c. 2515 Ma.

Gold mineralization occurred over 100 million years after typical Yilgarn Craton orogenic gold systems. The mineralization is structurally controlled within a framework of moderately east to southeasterly dipping, biotite-pyrite shear zones consistent with forming part of a northeast directed thrust system with lateral ramps occurring orthogonal to the transport direction (Tyler et al., 2014).

Doyle et al. (2009, 2015) describe gold as precipitating in K-feldspar-rich pegmatitic rocks, consistent with potassium metasomatism accompanying gold mineralization at Tropicana. Boundaries between these rocks and quartzo-feldspathic orthogneisses around them are often gradational. These boundaries may have originated from local partial melting of the total rock package which suggests that the pegmatites formed as a diatexite migmatite. Paucity of quartz veining at the deposit and dominance of biotite over sericite supports that gold mineralization occurred at higher temperatures and pressures than many of gold deposits in the adjacent Yilgarn Craton and either in an environment undersaturated in silica, or one where silica could not precipitate (e.g. Solomon and Groves, 1994). In some parts of the deposit biotite, sericite and minor chlorite crystallized in shear zones and exsolution fabrics in 'crackle-brecciated' K-feldspar pegmatitic rocks.

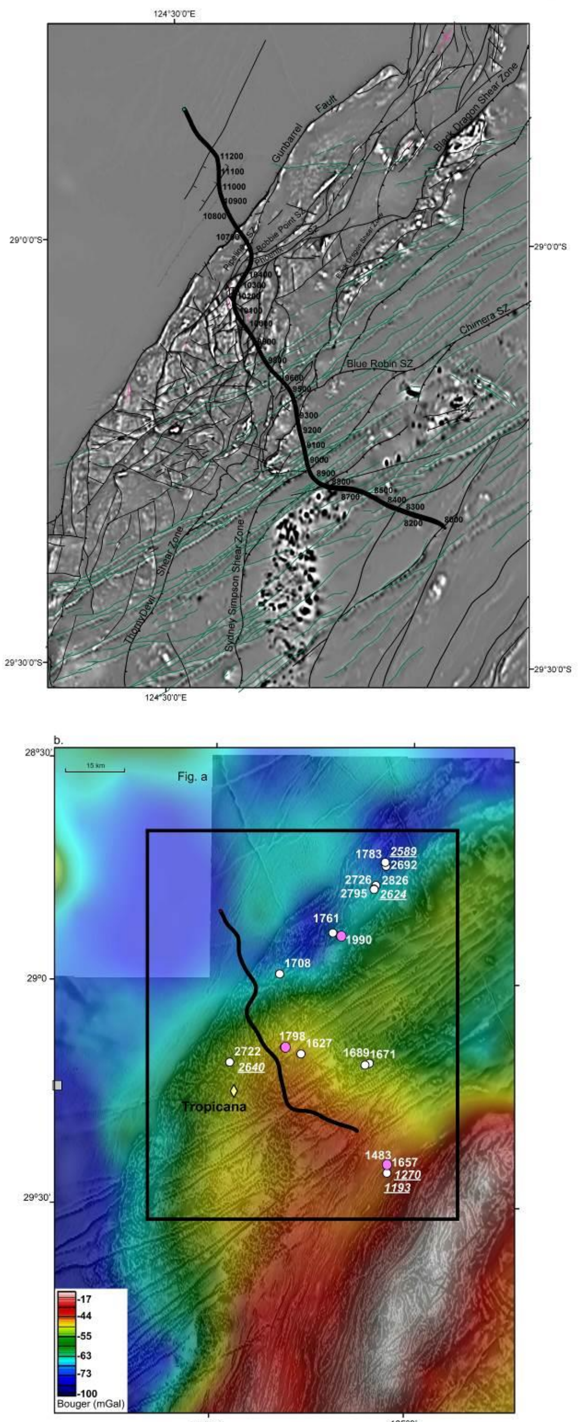

Figure 2: a) Grey-scale image of 1VD, low-pass filtered TMI overlain with map of regional-scale faults and shear zones, with the location of seismic line 12GA-T1, across the Tropicana Zone, Kepa Kurl Boya Province modified from Occhipinti et al., (2017); b) Bouguer gravity (colour) in transparency over 1VD magnetic image in greyscale, illustrating coincidence of relatively high amplitude gravity and magnetic anomalies.

STRUCTURAL INTERPRETATION

Interpreted structural domains, based on field observations and magnetic field characteristics, delineated zones that are dominantly Archean or Paleoproterozoic in the region (Figures 2 and 3). Although the Tropicana Zone must have been relatively in-situ by the Ngadju Event because granitic rocks that formed at this time intrude the Tropicana Zone, the gravity and magnetic data used for the interpretation did not offer a 3D view which was required to ascertain how the region developed (Figure 2). However, valuable insight was gained from regional-scale seismic reflection data which offered a cross-section view of the region (Figure 3). Used together, the gravity, magnetics and seismic data allowed a regional structural interpretation of the development of the Tropicana Zone to be made. A detailed interpretation 12GA-T1 is outlined in Occhipinti et al., (2017), though the following description offers a summary of regional tectonic development and is accompanied by Figures 2, 3, and 4.

Seismic line 12GA-T1, and seismic reflection lines to the south (12GA-AF1 to AF3), all show the Yilgarn Craton can be tracked from its margin under the Albany–Fraser Orogen to extend as far as the Nornalup zone (line 12GA-AF1; Figure 1). Along 12GA-T1, it is apparent that the Yilgarn Craton crust is overlain by a distinct reflector that dips shallowly from west to east. The seismic character of crust under this reflector is distinguished by a fairly bland non-reflective zone, underlain by a zone of reflective crust that extends to the MOHO. This is consistent with the seismic character of crust in the Yamarna Terrane, which lies just northeast of the Tropicana Zone (Goleby et al., 2003).

The reflector, or Plumridge Detachment, is taken as representing a thrust surface that carried the Neoarchean Tropicana Zone over the Yamarna Terrane, and its' development is coincident with gold mineralization at Tropicana. Prior to the development of the Plumridge Detachment the Yilgarn Craton margin underwent west to east extension. Extensional structures can be seen in the seismic data and shown to be cut by the Plumridge Detachment. Although, such structures can be inferred from the geological interpretations of the region this area is one of the rare places where one can be verified (Occhipinti et al., 2017).

Structures identifiable above the Plumridge Detachment in regional magnetic data can be correlated with those interpreted from offsets observed in the seismic reflection data and strong reflective zones. Above the Plumridge Detachment, Neoarchean rocks were metamorphosed at amphibolite to granulite facies, well above the greenschist facies that is observed in the Yamarna Terrane to the east which is presumably underlying the detachment. The crooked nature of the 2D line allowed the orientation of structures to be measured in 3D. It is apparent from the 3D visualization that the structures generally dip moderately to shallowly to the east or southeast. Those structures that developed during the Neoarchean are taken as representing thrusts that sole out on the Plumridge Detachment, transporting high-grade metamorphic rocks over low grade rocks of the Yamarna Terrane. Other structures that must have formed during the Paleoproterozoic (as many of them also cut Paleoproterozoic rocks) are subparallel to the thrusts, suggesting that faults and shear zones that formed during the

Paleoproterozoic may have, at least in-part, been co-planar to those that developed during the Archean.

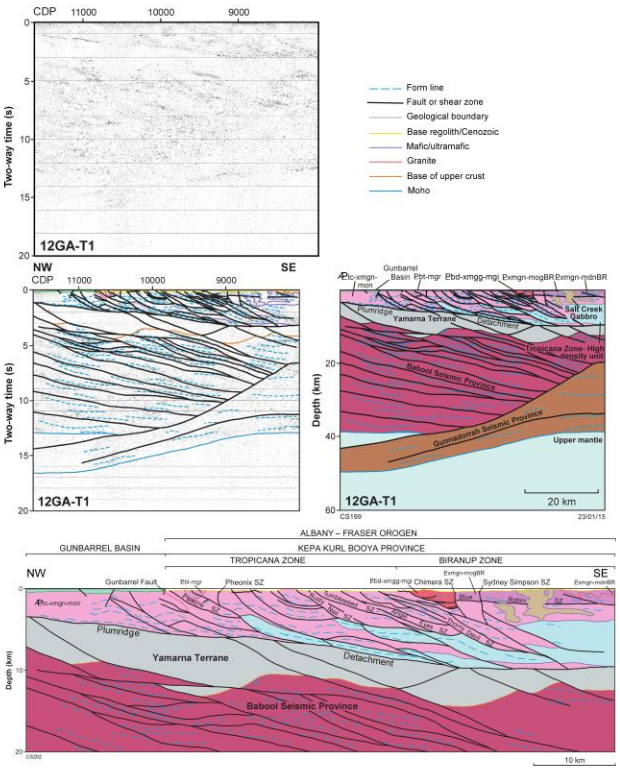

Figure 3: Interpretation of seismic line 12GA-T1 across the Tropicana Zone, Kepa Kurl Boya Province from Occhipinti et al., (2017).

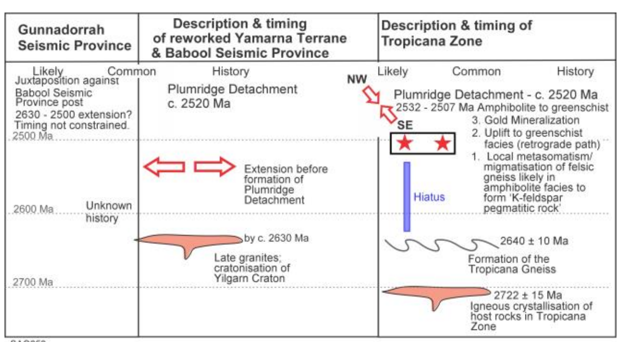

Figure 4: Paragenesis of the Tropicana Zone during the Archean modified from Occhipinti et al., (2017).

NEOARCHEAN TECTONIC SETTING

Within the Tropicana Zone, the Hercules Gneiss is dominated by sanuikitoids dated at c. 2722 to 2692 Ma (Kirkland et al., 2013, 2015) and the Tropicana Gneiss contains a suite of medium to high-K calc-alkaline and adakitic magmatic rocks (Crawford and Doyle, 2016). The presence of sanuikitoids and calc-alkaline magmatic rocks imply that the Tropicana Zone may have developed in a subduction zone setting. This is very different from the interpreted tectonic setting of the Yilgarn Craton at this time that gave rise to the formation of komatiite-related Ni-sulfide mineralization at the base of greenstones in the Eastern Goldfields Superterrane.

Prolonged granulite facies metamorphism of the Tropicana Terrane between 2722 Ma and 2554 Ma (Kirkland et al., 2015) spanned the entire evolution of the Eastern Goldfields Superterrane, including orogenic gold development in the greenschist facies. At this time, the Tropicana Zone was at deep crustal levels, prior to being thrust onto the Eastern Goldfields Superterrane at c. 2520 Ma to 2505 Ma, accompanied by orogenic gold mineralization (Doyle et al., 2015). Although the initial extent of this thrust sheet is unknown, it is now understood that it did not extend far enough to the south to be imaged in seismic line GA-AFO3 and thus probably dies out about 50km south of Tropicana. This is supported by gravity and magnetic interpretation (Figure 2).

IMPLICATIONS FOR MINERAL EXPLORATION

Neoarchean gold mineralization in the Albany-Fraser Orogen developed during a retrograde metamorphic event within the Tropicana Zone during exhumation of that zone onto the Eastern Goldfields Superterrane. There is no known substantial Paleoproterozoic gold mineralization within the Tropicana Zone, or in fact within the Albany Fraser Orogen to the south, or north of Tropicana. We suggest that rocks that are host to the Tropicana gold deposit were fertile for gold mineralization, perhaps due to being formed in a fossil subduction zone. Therefore the Tropicana Zone is still highly prospective for Archean gold mineralization. Exploration targeting in this zone should avoid younger Proterozoic igneous rocks, especially those that developed during the extensional events that seem prevalent along the margin. However, that is not to say that other types of mineral occurrences could be found in those regions, for example base metals.

What drove the exhumation of the Tropicana Zone is unknown. There are other c. 2500 Ma events recorded around the Yilgarn Craton, for example intermediate magmatism recorded in augen gneiss in the Glenburgh Terrane to the northwest of the craton, leucocratic REE-rich pegmatites that intruded the southwest of the craton; however the drivers to their development are unknown. The improved understanding of the fertility of rocks that formed during the Neoarchean and tectonism around Archean cratonic margins suggests that atypical gold deposits can form if hydrothermal conditions, fertility, and preservation features are favorable. In some regions these might be delineated under sand cover, whereas in others they could be present under Proterozoic basins.

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