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Yamarna Geology: Foundations for Further Discovery

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SUMMARY

World class gold discoveries are being made in the Yamarna Terrane, one of the least understood terranes of the Yilgarn Craton. Despite many and varied challenges, Gold Road are in the unique position of compiling and constructing the stratigraphic map for this immature exploration terrane allowing continual improvement to ongoing targeting and exploration programmes.

The key to successful exploration is the development of a regional stratigraphic and structural geological model through acquisition of new data, application of modern science, and integration of fundamental geological observation. Lithogeochemical classifications, geochronology, and development of mineralisation models are the three areas of focus Gold Road considers paramount to combine with the fundamental structure of the Yamarna Terrane. New geochronological data has implications for the understanding of the geodynamic evolution of the Yilgarn Craton, identifying some of the oldest rocks so far found in Eastern Goldfields Superterrane.

A case study is presented of the development in the understanding of the tectonostratigraphic evolution of the Yamarna Terrane to target for gold efficiently and effectively.

Key words: Yamarna, Gruyere, geochronology, stratigraphy, lithogeochemistry.

INTRODUCTION

The dearth of recent world class Greenfields discoveries in the global gold sector highlights a significant need for improvement in our industry, stressing the requirement for innovation to be coupled with an ever-important geological grounding. Despite the many challenges of exploring in a remote undercover region of the East Yilgarn of Western Australia, world class gold deposits are being discovered in the Yamarna Terrane. The fundamental geological map is considered the foundation for successful gold exploration. Prior to Gold Road Resources exploration activities at Yamarna the understanding of stratigraphy, structural architecture, and variable mineralisation styles were poorly understood.

Gold exploration in the Yamarna Terrane is challenged by the remoteness of a region over 1,100 kilometres from Perth, complicated by cover conditions of Cenozoic and Permian desert sand, and the relative immaturity of an area which has seen minimal modern exploration. These difficulties are compounded by with the sheer size of the Gold Road tenement holding (6,000 km^2), which is almost the equivalent area of the entire Norseman to Kalgoorlie districts to the west, and access to capital which is a perennial problem for junior explorers world-wide. Despite the challenges, innovative thinking, novel analytical interrogation of an increasingly rich data set, and a willingness to trial new exploration techniques has led to recent Greenfields gold discoveries.

The discovery of the multi-million-ounce Gruyere Gold Deposit in October 2013 incorporated all of these elements (Osborne et al., 2015). Up until the Gruyere discovery Gold Road's exploration programme focussed predominantly on the western Yamarna Greenstone Belt, favouring a model of gold mineralisation strongly associated with mafic-dominant lithologies. A strategy incorporating passionate exploration, smart targeting, "gut-feel", continual focus on geological and geochemical understanding, a touch of serendipity, and ultimately persistence, combined to crack the Gruyere code. Rapid resource development now sees Gold Road on the cusp of becoming Australia's next mid-tier gold producer less than six years after the deposit discovery.

Gold Road has applied lessons learned from the Gruyere discovery, with capital available through an innovative approach to funding of the Gruyere development and construction, to focus on acquiring more data, improving targeting and making further discoveries across the entirety of the vast tenement package.

DEVELOPING THE GEOLOGICAL FOUNDATION

Outcrop is extremely limited in the Yamarna Terrane, with less than 5% of the area exposed. Samples collected though drilling are the only way geologists can directly observe the Archean host rocks. The rocks are often structurally deformed and variably metamorphosed making rock identification difficult to determine with confidence. As is the case with most modern exploration programmes, large quantities of data are now routinely acquired as part of the exploration process. However, data alone rarely identifies gold deposits undercover. The integration of the data with novel intelligent interpretation, scientific analysis, and encouraged creativity is the critical exploration step that is often given scant attention.

Example of Data Analysis: Mafic Stratigraphy

Geochemical discriminatory diagrams for classification of rocks of the Yilgarn have previously been constructed and documented using scatter diagrams of immobile elements (Hallberg, 1983; Halley, 2016; S. Barnes et al., 2014; and Smithies et al., 2018). The foundation` of the stratigraphic map and characterisation of the lithological units at Yamarna utilises lithogeochemical analysis and interpretation of high quality 4-acid digest assay data. While a selection of the published classifications have been used as a basis by Gold Road, a Yamarna-specific classification has been developed relying heavily on integration of geological logging with the fundamental chemistry of the rocks. All classifications diagrams rely on the geologist's interpretation on the extrusive or intrusive provenance of the rocks based on field observation and interpretation, which can be difficult in rocks subjected to intense deformation and alteration.

An example of the application of a published geochemical discriminatory diagram to categorise lithologies and develop an understanding of the tectonic evolution of a terrane is Barnes' classification of the basalts of the Eastern Goldfields Superterrane (Barnes et al., 2012). Three distinct basaltic groups were defined at Yamarna, based on geochemical characteristics, documented stratigraphy, and comparison to modern day tectonic settings (Barnes et al., 2012): low-Th basalts, high-Th siliceous basalts, and an intermediate-Th basalt.

Classification of the basalts in the Yamarna Terrane shows a distinct spatial distribution of similar basaltic types: Low-Th pillow basalts occur in the oldest stratigraphic succession at Dorothy Hills and in the Southern Yamarna area; High-Th siliceous variolitic basalts are situated in the most northern and central parts of the Yamarna belt, and in the western part of the Dorothy Hills Belt; and Intermediate-Th basalts generally proximal to the Low-Th basalts. A tectonostratigraphic history of the Yamarna terrane can be interpreted from the distribution of the basalts: tectonic activity initiated as plume-related low-Th tholeiitic basalts at Dorothy Hills and southern Yamarna Belt followed by extensive crustal contamination and input of komatiite melt forming the high-Th siliceous basalts according to the Barnes model (Barnes et al., 2012; Barnes et al., 2014).

Understanding the spatial distribution of the mafic stratigraphic sequences is extremely important for gold targeting in the Yilgarn. Differentiated dolerites of the Golden Mile and St Ives districts (Golden Mile Dolerite, Defiance Dolerite, Condenser Dolerite), and the various Paringa Basalt equivalents, are demonstrated excellent host rocks for multiple world class gold deposits. Construction of a map documenting the distribution of these equivalent mafic units at Yamarna is imperative for effective targeting to guide efficient exploration programmes. Two significant zoned doleritic units have been identified in the Yamarna Terrane: the Smokebush and Toppin Hill dolerites. The most favourable fractionated host rocks of the dolerite and high-Th type basalts are discernible using lithogeochemical analysis (Halley, 2016). While focus on identification of such units can readily identify prospective host rocks for gold, it does not ignore the importance of other prospective host rocks in the district which may have other pathfinder signatures.

New Geochronology of the Yamarna Terrane

The acquisition of research quality geochronological information across an entire greenstone terrane such as Yamarna is an exercise not often associated with Junior exploration companies. Going against the norm, Gold Road initiated a comprehensive age-dating programme across the Yamarna and Dorothy Hills Belts in 2015. Work is ongoing to refine the understanding of the stratigraphic column and structural architecture to better understand the controls to gold mineralisation and identify the presence of prospective geology for gold exploration targeting. Compilation of a detailed paper is in progress pending completion of the current dating programme.

It was relatively recently that the Yamarna Terrane was recognised as a major terrane of the Eastern Goldfields Superterrane, located close to the margin of the eastern Yilgarn craton (Pawley et al., 2012). The crustal scale Yamarna Shear marks the boundary between the Yamarna Terrane to the east and Burtville Terrane to the west (Pawley et al., 2009). Interpretation of seismic imagery suggests the Yamarna structure is a broad, crustal-scale, east dipping listric feature extending to a depth of more than 35 kilometres, being equivalent to other terrane bounding faults of the East Yilgarn (Goleby et al., 2004; Korsch et al., 2013). The Yamarna Terrane itself has been subdivided into two greenstone belts: the eastern Dorothy Hills Belt and the western Yamarna Belt (Romano et al., 2008) (Figure 1).

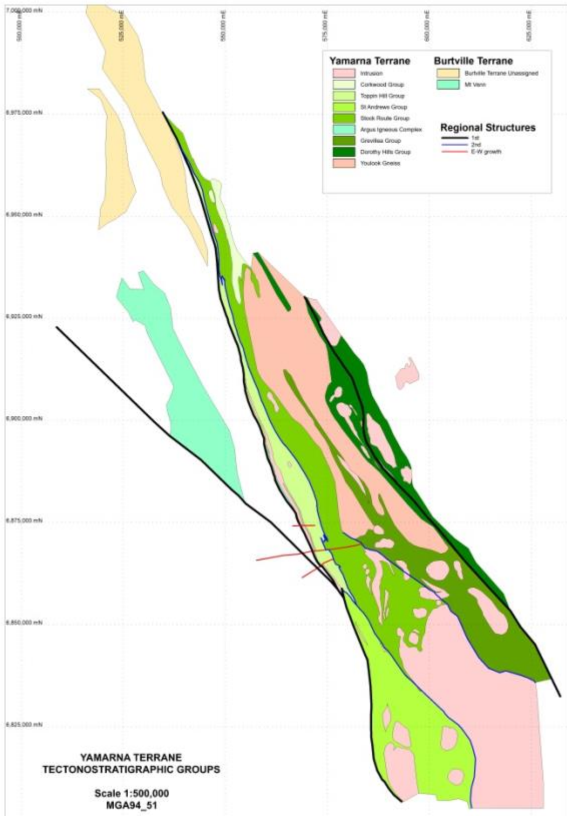

Figure 1. Stratigraphic map for the Yamarna Terrane.

Dorothy Hills Belt Geochronology

Previous literature describing the stratigraphy of the Dorothy Hills Belt is scarce: the Geological Survey of Western

Australia (GSWA) documented the belt to be dominated by basaltic and meta-sedimentary rocks intruded by widespread felsic activity, including the Ziggy Monzogranite where zircon grains yielded a crystallisation age of 2832 +/- 4 Ma via SHRIMP dating (Wingate et al., 2010f; Romano et al., 2008; Pawley et al., 2012).

Recent geochronological results acquired by Gold Road across the Dorothy Hills Belt indicate all rocks formed or were deposited in the Mesoarchean between 2840 to 2810 Ma. This includes the Gruyere Porphyry (host to the Gruyere Deposit), crystal rich tuffs found in the footwall of the Gruyere Porphyry, siltstones located in the western part of the belt, in addition to the previously documented Ziggy Monzogranite (Wingate et al., 2010f). Surprisingly the crystallisation age of the Gruyere Porphyry (which hosts the 6 Moz gold deposit) is only slightly younger than the volcanoclastic sediments in which it is intruded. The recently initiated MRIWA Project M530 – Yilgarn 2020 will aim to date the mineralisation at Gruyere to determine whether gold mineralisation is part of the 2800 Ma orogenic deformation event, or a younger gold mineralising event closer to the more common 2640-2625 Ma age observed in the majority of the Yilgarn gold districts to the west.

The Dorothy Hills Shear Zone marks a clear boundary between older mafic and felsic volcanism deposited around 2840-2827 Ma to the east and younger siliciclastic, mafic and intermediate volcanic sediments deposited around 2810 Ma in the west of the belt. The shear zone itself has a significant control on gold mineralisation hosting the Gruyere Deposit and other prospects to the south.

In comparison to the Yilgarn Craton, the Dorothy Hills belt appears to be equivalent in age and character to widespread volcanism and sedimentation of the Burtville and Youanmi Terranes, being significantly older than the East Yilgarn Craton (Pawley et al., 2012; Van Krandendonk et al., 2012). The origin of the belt may be as a relic fragment of the Burtville Terrane or part of a well-preserved older rift basin forming the east margin of the Yilgarn Craton. Seismic data reveals the Yamarna Terrane extends beneath the Proterozoic sedimentary stratigraphy to the east (Korsch et al., 2013).

Yamarna Belt Geochronology and Stratigraphy

Regional mapping by the GSWA identified the Yamarna greenstone belt to be comprised of three main formations: the Argus Igneous complex, and the Toppin Hill and Tobin Formations (Romano et al., 2010).

The oldest basal unit of the Argus Igneous complex is a layered gabbro-anorthosite, with minor massive low-grade chromite layers, intruding the western margin of the Yamarna greenstone sequence (Pawley et al., 2010; Romano et al., 2010). SHRIMP dating of anorthosite grains revealed an age of 2738 26 Ma, similar in age to the Mt Venn Igneous Complex (Wingate et al., 2011g, Pawley et al., 2012). Pawley suggests the age and textural similarities indicate the Mt Venn and Argus complex may have been the same sill subsequently detached and sheared into the Yamarna Shear zone, and possibly represents a piece of older basement crust to the Yamarna Terrane caught up in the Yamarna Shear (Pawley et al., 2012, Pawley et al., 2010).

The Toppin Hill Formation consists of metamorphosed felsic volcanoclastic rocks, varying in composition from dacitic to rhyolitic, interbedded with siliciclastic conglomerates, sandstones, siltstones and minor shales (Romano et al., 2010a, Pawley et al., 2010). Petrography reveals the crystal and lapilli tuffs have undergone extensive reworking. Zircons recovered from a metadacite indicate a crystallisation age of 2683 +/- 5 Ma; 2677 +/-7 Ma SHRIMP age (Wingate et al., 2011l). The formation has also been assigned to rocks in the southern Yamarna Region which yielded dates from sandstones of 2699 +/- 5Ma and 2682 +/- 5 Ma (Sircombe et al., 2007).

The Tobin Formation located on the eastern margin of the belt is interpreted to overly the Toppin Hill Formation conformably. The formation largely comprises wacke and lithic sandstones, siltstone, abundant chert and banded iron-formation with minor felsic volcanic rocks (Romano et al., 2010a, b). Dating of a psammitic schist sample derived an age of maximum deposition for the basin between 2682-2640 Ma or 2686 +/- 4 Ma SHRIMP age (GSWA, 2015).

A single age date for gold mineralisation in the Yamarna belt is 2820 Ma obtained from molybdenite in a quartz vein within a granitic gneiss in the eastern part of the Yamarna Terrane (Fuller et al., 2014).

With new data made available through extensive regional exploration, specific stratigraphic drilling across the belt, and recent geochronological data compiled by Gold Road, the stratigraphy of the belt has been refined considerably. The most significant change has been the identification of multiple and variable basaltic units, ultramafic lenses, and dolerites. Geochronological dating of samples from detrital zircons, volcanoclastic tuffs, and predominantly felsic intrusions, reveals the Yamarna greenstone belt developed over the period from 2737 Ma to 2673 Ma, supporting the findings of the GSWA (Pawley et al., 2012). Overall the Yamarna volcano-sedimentary package is similar in age and stratigraphic character to the Kalgoorlie Terrane in the western part of the Eastern Goldfields Superterrane (Kositcin et al., 2008; Wyche et al., 2012).

The Yamarna succession was originally interpreted to have formed as a single evolutionary cycle of ultramafic-mafic-felsic volcanic and siliciclastic rocks (Sircombe et al., 2007). However the evolutionary history now appears to be far more complex with bimodal volcanism identified, and coeval tuff deposition with reworked clastic sedimentation. As with the Laverton Belt to the west, the best interpretation for formation of the Yamarna belt is as a series of sedimentary basins, and fragments of structurally emplaced older stratigraphy, amalgamated to form a composite terrane (Standing, 2005). A single 2830-2840Ma inheritance grain was also found at Toppin Hill, suggesting the source of sedimentation was in part derived from the Dorothy Hills belt, implying the two belts had already amalgamated prior to basin formation.

The Yamarna Terrane is a long-lived orogenic belt active over 185 million years. The older Dorothy Hills Belt is interpreted to have a similar greenstone history to the Youanmi and Burtville Terranes, whilst the Yamarna Belt contiguous with the Kalgoorlie Terrane (Pawley et al., 2012). As explorers this insight enables us to target Youanmi Terrane type gold deposits in the Dorothy Hills belt and classic Kalgoorlie Terrane type gold deposits in the Yamarna Belt.

Gold Mineralisation Controls

The Yamarna Terrane has undergone a complex and prolonged history of structural deformation and folding adding to the difficulty of interpreting the stratigraphic package. As gold explorers it is imperative to identify structural and/or stratigraphic horizons that might serve as conduits for gold bearing fluids. In the Yamarna Greenstone Belt multiple parallel splays to the Yamarna Shear have been identified, such as the Golden Highway Shear which hosts more than 600,000 ounces of gold in several gold deposits, and appears to juxtapose older mafic-andesitic volcanoclastic rocks against siliciclastic sandstones and an important tectonic marker conglomerate horizon. Gold Roads' latest discovery of the Gilmour deposit is situated along the Golden Highway Shear trend with mineralisation localised at or near important stratigraphic contacts.

With a greater understanding of stratigraphic and structural controls to mineralisation the importance of host rock and competency-contrast models are being recognised and developed. Discrete stratigraphic horizons, and the juxtaposition of different geological units, are a critical criterion for gold deposition at Yamarna. Narrow high-grade laminated veins deposits such as Gilmour are situated in a highly strained brittle conglomerate unit where ductile/brittle behaviour of the rocks appears to play a role as a structural trap for gold mineralisation. In contrast, the massive low-grade Gruyere Deposit is a large competent mineralised intrusive body, sheared and hosted in ductile volcanoclastic sediments. Many deposits form a continuum between these two extreme model types. Rheological contrast and geochemical gradients are interpreted as significant controls to gold mineralisation in these deposits along with the traditional structural controls so important in Archean gold mineralisation.

CONCLUSIONS

Newly acquired geochemical and geochronological data highlight the complex structural and stratigraphic evolution of the Yamarna Terrane. Previously the tectonostratigraphic evolution of the Dorothy Hills belt was poorly understood. A stratigraphic column has been constructed using new data which identifies the belt to be similar in age and type to the Youanmi and Burtville terranes. In contrast the younger Yamarna belt appears to be similar in age and character to the greenstones belts of Eastern Goldfields Superterrane. The identification of numerous basaltic and doleritic units adds refinement to the existing stratigraphic section of the Yamarna belt, which appears to have formed as an amalgamation of multiple structurally emplaced sedimentary basins. Our new understanding of the tectonostratigraphic evolution of the terrane has led to a greater knowledge of mineralisation styles for the belt and results in continually improved targeting for gold exploration.

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