Comparative Camp-scale studies in the Eastern Yilgarn Craton

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Introduction

The emphasis within the AGCRC and more recently within the pmd*CRC on “where is the deposit” led inevitably to a restating of the “source”, “transport” and “trap” paradigm of mineral systems. The “5 Question” description of the mineral system explicitly highlights the problem of understanding the system in time and space.

The “where” question is inherently a scale independent question. It may be asked at an ore shoot-scale or at a terrane scale. Hence there is a need to build models that are scale integrated, that is, models that are consistent with the data sets at all scales.

As part of the scientific drive to build scale-integrated models, we are developing camp-scale comparative studies. The work is focused on properties of Placer Dome Asia Pacific in the Kalgoorlie and Laverton districts and the St Ives property of GoldFields of South Africa and supported by MERIWA within the framework of the pmd*CRC Yilgarn terranes (Y) project. Future work is planned for the Agnew property of Goldfields of South Africa.

The comparative study of camps is designed in part to understand the influence of district-scale factors, such as bulk composition of host sequences, regional metamorphic grade, proximity to granites and porphyries, on the types of alteration assemblages and the compositions of the fluids that produced those alteration assemblages. Another goal is to establish the diversity of processes leading to the formation of high grade gold deposits. Inter-camp comparisons may help to elucidate lithological and structural controls on seals, aquicludes and aquifers in the system and the size and geometry of large-scale hydrothermal cells.

Here we comment on learnings that are emerging from inter-camp comparison of lithostratigraphic settings of the deposits, styles of alteration associated with gold and on some future research directions.

Comparative Lithostratigraphic Setting and Regional-scale Seals

In the eastern Yilgarn, gold deposits occur in all the major rock units of the Kalgoorlie Group and correlates as well as in the conglomerates of the late basins. Relative and increasing absolute age constraints overlap the timing of gold deposition with emplacement of the mafic to syenitic granites that peaked circa 2665 to 2650 Ma and with Black Flag and late-basin sedimentation.
In the St Ives camp, deposits are hosted in predominantly mafic-ultramafic lavas and dolerite intrusions. In the Central Corridor, of the camp, deposits are hosted by units stratigraphically below the Blag Flag Beds (Kambalda Komatiite, Kapai Slate, Paringa Basalt, Defiance Dolerite) and along porphyry-ultramafic rock contacts. Deposits on the southwestern side of the camp (Argo and Junction) are hosted by the Junction and Condenser Dolerites that intruded the Black Flag Beds. Theses dolerites are correlates of the Golden Mile Dolerite and the overall lithostratigraphic setting is similar to that of the Golden Mile.

In the Kanowna district, northeast of Kalgoorlie the upper sequence of the Kalgoorlie Group (Paringa Basalt, Blag Flag Beds) is absent and the lower sequence of mafic, ultramafic and intermediate volcanic rocks is unconformably overlain by coarse, clast-supported polymict conglomerate and felsic, crystal-rich volcaniclastic units (re-sedimented pyroclastic mass flow deposits) that are correlated with the late basin stratigraphy. Mineralization in the Kanowna Belle deposit straddles this boundary, defined locally by the Fitzroy Fault. The major portion of the deposit is hosted by the Kanowna Porphyry, which is part of the mafic granite suite. By contrast, the Wallaby gold deposit, located 25km southwest of Laverton, occurs within late-basin conglomerates. The deposit is hosted by a >1500m thick, polymict, matrix-supported conglomerate that has been intruded by a differentiated alkali syenite suite of dykes. The dykes range in composition from relatively early monzonite and carbonatite through younger syenite and porphyritic syenite. Both pre-ore and post-ore lamprophyre dykes are also present.

Again in the Agnew Camp the equivalent of the upper sequence of the Kalgoorlie Group is absent and the lower sequence correlates (Lawlers Basalt, Agnew Ultramafic) are overlain by conglomerates rich in mafic and ultramafic clasts and sandstones. Deposits occur in all rock types but within 100s of metres stratigraphically of the mafic or ultamafic conglomerates.

The proximity of deposits to either the footwall of the Black Flag Group or the late basins hint that these units of the lithological architecture may have acted as regional aquicludes at the time of gold mineralization, such that fluid pressures were sustained in compartments beneath these units. The formation of deposits above these seals reflected localized rupturing of the seal. It may be that the ultramafic units also acted as aquicludes within camps hosted in the lower sequence of the Kalgoorlie Group and correlates. The occurrence of ultramafic units subjacent to deposits, at Kanowna Belle and in the St Ives camp hints that more competent rocks such as the porphyries were the aquifers and the ultramafic rocks were aquicludes.

**Comparative Camp-scale Alteration Studies**

The study of the St Ives Camp has shown that high-grade gold mineralization is localized in zones where reduced, pyrrhotite-bearing assemblages overlap with oxidized, magnetite-bearing assemblages (Neumayr et al., this volume) which indicates that large differences in the redox state of hydrothermal fluids facilitated gold deposition. Do such spatial as well as temporal zonations in oxidized and reduced assemblages occur in all camps proximal to mineralization or are there gradients in other parameters such as pH or H₂S activity? Is the mineralogical and/or geochemical expression of such gradients always the same?

The Kanowna Belle deposit and environs is dominated by pyrite, with little known magnetite or pyrrhotite. However, sulfur isotopes variations in pyrite at the deposit- to district-scale at Kanowna Belle are similar to those documented in the St Ives camp and may be related to changes in redox state. Variations in the abundance of phengite relative to muscovite and the trace metal contents of the alteration zones across the Kanowna Belle deposit demonstrate that it is possible to finger print the redox gradient in different environments using different mineralogical indicators and by correlating trace element suites with mineralogical assemblages. It remains to be determined if all the observed variations reflect changes in the redox state of the fluids or sympathetic changes in other chemical parameters such as pH, etc.
A feature of the Agnew Camp is the S to N zoning over about 8 km from Au-pyrite mineralization (Sonvang deposit) with marginal magnetite and distal pyrrhotite, features typical of deposits in the Central Corridor of the St Ives camp, to Au-magnetite mineralization (Crusader deposit) to Au-biotite-amphibole mineralization (Redeemer deposit), the latter two lacking in sulfide or magnetite. These last styles of mineralization occur in an equivalent stratigraphic setting to deposits in the Central Corridor, St Ives and in the Kanowna district. So, clearly the mineralogical differences do not reflect a host-rock control. The mineralogy of the Crusader and Redeemer deposits is consistent with higher temperature fluids, and/or more reduced fluids and/or sulfur poor fluids compared to inferred temperatures and fluid compositions from other camps. However mineralogical zoning equivalent to Agnew camp-scale pattern is observed at the drill-core and hand-specimen scale in the Revenge and Wallaby deposits. It may be that study of the Agnew camp will provide insights into a significant fluid end-member not easily deciphered in the other camps.

Summary Comments on Future Directions: Architecture, Chemical Gradients and Targeting

The work on both the St Ives camp and the Kanowna area has elucidated mineralogical zoning patterns that may be mapped at the camp scale that reflect chemical gradients at the time of gold mineralization. High grade gold zones occur on these gradients. The task is to identify the optimum places for finding high grade-large tonnage deposits on these gradients. Paragenetic and sulfur isotope studies in the Revenge and Kanowna Belle deposits indicate that these will be places of maximum oxidation: hematite stable, negative sulfur isotope signal in pyrite. They may well be places of minimum oxidation also and combined C and S isotope studies are being directed to resolve this question.

In the St Ives camp, the spatial association of oxidized assemblages with porphyry intrusions at the drill core to camp scale strongly suggests that magmatic volatiles drove the oxidation. Recent detailed mapping of the Wallaby deposit has identified both close spatial and paragenetic links between gold mineralization and syenite magmatism (Drieberg et al., this volume). In the Kanowna Belle District, a series of transitional TTG and mafic-granite porphyry intrusions have intruded the Kanowna stratigraphy before, during and after deposition of the sedimentary and felsic volcanic facies into the late basins. A better understanding of the geodynamic setting and the prediction of the location of these magmatic suites emerges clearly as a critical goal in the quest of predictive mineral discovery.

One task is to geochemically finger print the porphyries to identify the precise chemical characteristics that correlate with the occurrence of highly oxidized fluids in each of the camps. Another task is to establish the whole-rock geochemical characteristics of the most reduced and oxidized fluids in the system, correlating these characteristics with fluid inclusion and stable isotope data and identify the pathways of these fluids. These characteristics may well change with depth in the system. Successfully correlating these constraints across camps should provide some powerful insights into the structures that controlled flux of the most chemically contrasting fluids in the system at various scales, aiding the effort to build robust, scale-integrated models and the targeting process. The integration of the architecture of these critical faults with the chemical composition of the hydrothermal fluids in 3D-4D at and beyond camp scale will be critical to improve our predictive capability in the targeting process in brown fields to greenfields exploration.