



The tectono-stratigraphy of the Emmie Bluff/Oak Dam IOCG deposits

Exploring step-change ideas to expedite discovery

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SUMMARY

A tectono-stratigraphic model is proposed for the c.1588Ma Olympic Metallogenic Event (OME) that includes the iconic haematite iron oxide copper gold (HIOCG) deposits. The model has significant ramifications for research and copper exploration.

A review of public data was undertaken for the well-preserved Emmie Bluff and Oak Dam HIOCG systems adjacent either side of a regional fault zone. The deposits formed near the palaeosurface on the shoulder of a mega “Gawler” caldera where structural complexity facilitated pulsed compression and extension that injected hydrothermal metals into collapsed pipes of heterolithic breccia.

A new c.1590Ma Emmie Formation is proposed to encompass a rift arkose and maar package of chlorite-magnetite and haematitic sediments previously considered to be unmetamorphosed c.1730Ma Wallaroo Group. The flat-lying Emmie sequence filled a half graben at the fault margin with the 1850Ma Donington granite. The granite hosts the Oak Dam West HIOCG pipe adjacent to the same fault zone. Rapid deposition of red shale then haematitic siltstone of the upper Emmie Formation preserved the tops of the deposits as a regional regolith and hydrothermal mound remnants above the Oak Dam West pipe, at Oak Dam East and over a potential undrilled pipe at Emmie Bluff.

The Emmie Formation is correlated with the lower Pandurra Formation based on comparison with sedimentological facies, dating, geochemistry and spectral data from the distant type drillhole Vanguard 1.

The tectono-stratigraphic model disrupts current targeting dogma, redefines the exploration space and will expedite further discoveries. In particular, 1) initial rifting and sedimentation of the Cariewerloo Basin was contemporaneous with the caldera collapse, OME and HIOCG formation; and 2) the Emmie Formation provides a regional datum and 4-D framework for advanced target vectoring, both locally at Emmie Bluff and regionally.

Recommendations are made for further research and testing of the new concepts and target vectors.

Key words: Copper, Olympic, IOCG, Wallaroo, Pandurra

INTRODUCTION

Thirty years of minerals exploration and collaborative research on the southern margin of the Gawler Range Volcanics (GRV) (Figure 1) widened the deposit spectrum for the 1588Ma mega Olympic Metallogenic Event (OME). New concepts were developed of: 1) precursor subduction and a subsequent “Gawler” mega caldera infilled by 1586Ma Upper GRV; 2) a stratigraphic marker and palaeosurface; and 3) a simpler geochemical pathfinder to improve target vectoring towards and within OME mineral systems (Anderson, 2017).

The concepts were tested with public data in the haematitic iron oxide copper gold (HIOCG) district under the Stuart Shelf (Anderson, 2020) with advances in recognising 1) the HIOCG deposits are situated on the caldera shoulders, whereas hotter magnetite “skarn” MIOCGs are deeper in the caldera; 2) a tectono-stratigraphic model for the OME; and 3) the Zircon Alteration Index (ZAI = 40 - Zr/Hf - analysed with the right digestions) enables better far-field 4D target vectoring when combined with the new stratigraphic model (Anderson, 2021a, b).

The concept of an OME tectono-stratigraphy is further developed in this study of the well-preserved Emmie Bluff and adjacent Oak Dam (Ehrig & Oliveira, 2022) HIOCG systems. In particular, the outcomes challenge the current dogma of HIOCG gravity targeting exclusively for pre-Kimban hosts in basement highs and under the passive, much younger cover of Pandurra Formation.

Early interest in the district was developed by WMC and MIM drilling initial discovery holes AD1 & 4 (Oak Dam), AD2 & 8 (Emmie North) and SAE 3, 4, 5, 6 & 7 (Emmie Bluff) in the seventies and eighties. Gow et al. (1994) recognised the stratabound nature of the IOCG mineralisation at Emmie Bluff and complex syn-min faulting in the Arcoona Fault Zone. Gunson Resources, Argo Exploration and Glencore drilled the MGD and IHAD holes through to 2011, developing the concept of the “Emmie Iron Oxide Beds” (EIOB).

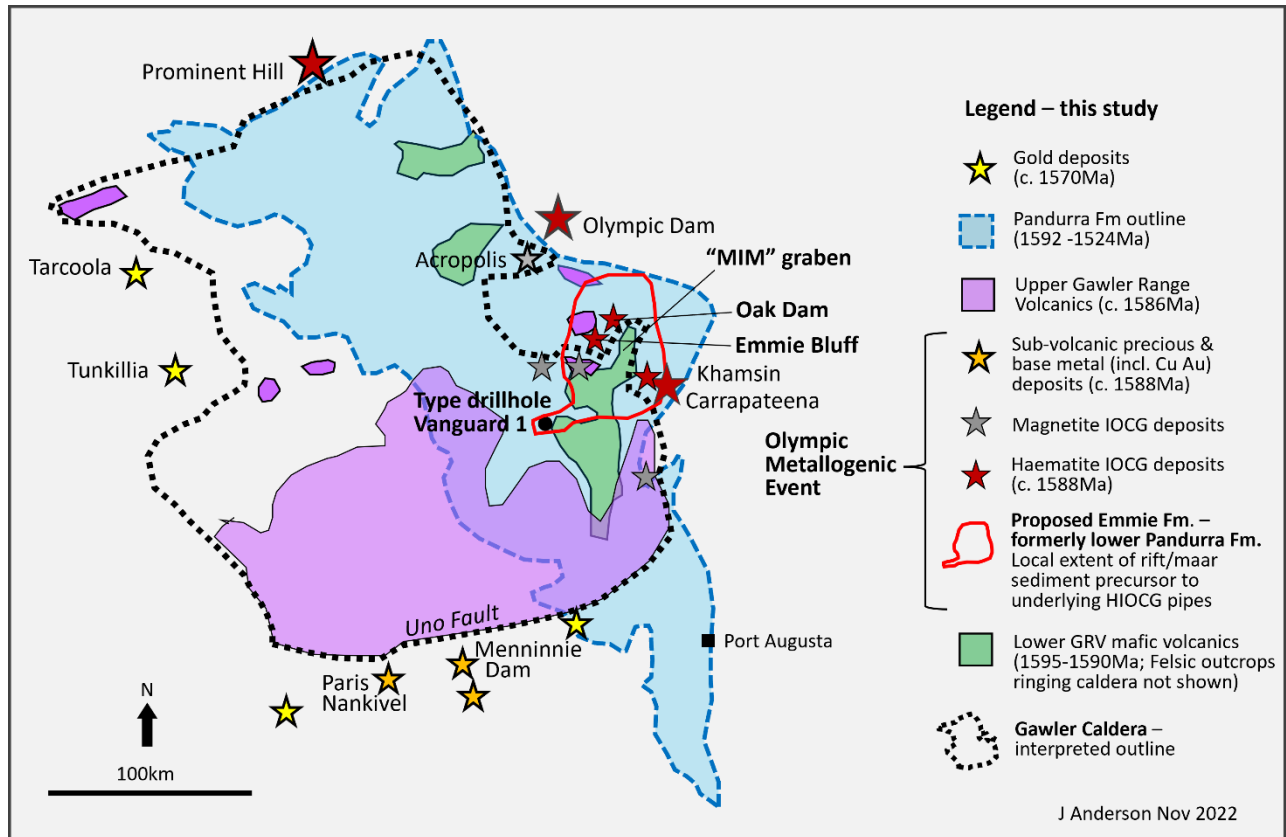


Figure 1. Location plan of the interpreted Gawler Caldera, indicative metal deposits and outline of the Pandurra Formation extent (SARIG). The red outline is the local extent of OME marker units within the proposed Emmie Formation. This shows coincidence with the underlying HIOCG breccia pipes in the Carrapateena - Oak Dam district.

DATA & CORE REVIEW

The following results came from a review of past drill logs, often handwritten with detailed empirical observations (e.g. WMC, 1986 Open File Env 3927, Argo Exploration 2007 Open File Envelope 6735) unbiased by current dogma, plus core tray images from the SARIG website of the Department of Energy and Mining. The advantage of seasoned explorers reviewing historic logs is familiarity with the past process and limitations, including knowledge of what we did not know at the time, and the ability to iterate old but high-quality observations with new concepts and data.

The stratigraphic re-appraisal for Emmie Bluff and Oak Dam was integrated and reinterpreted with modern geochemistry (Fabris et al., 2013), Hylogger™ spectral analyses and precise regional dating also provided by SARIG. These excellent data expedited the review with core only directly examined for holes IHAD 5 and MGD 55 to date in this personal unfunded study.

The data and facies interpretations in a sedimentological study of the Pandurra Formation in type drillhole Vanguard 1 by Rollison (2016) were also used in this study.

RE-INTERPRETED STRATIGRAPHY

The new model proposes an informally named Emmie Formation up to 600m thick and contemporaneous with and hosting the tops of the HIOCG breccia pipes (Figure 2). The basal rift unit is an arkosic grit/conglomerate (“Emmie Arkose”) that is unmetamorphosed, flat-lying and consistently fining upwards. The arkose occupies a half graben about 4 x 5km in drilled area and is bounded on the east by the complex Arcoona fault system. The arkose onlaps a deformed meta-siltstone basement (Figure 3 – IHAD 3) to the west and coarsens and thickens to over 250m adjacent to the eastern fault margin. On the east side of the north-south Arcoona fault zone, the Donington Granite is the local source of the consistently 1850Ma aged detrital zircons (Jagodzinski, 2005) in the re-assigned Emmie Arkose. The deformed granite basement also hosts much of the HIOCG pipe at Oak Dam West adjacent to the Arcoona fault zone 16km to the northeast of Emmie Bluff.

The arkose transitions into the overlying EIOB, a tabular horizontal body up to 150m thick with a basal magnetite Mg chlorite siltstone that transitions to a haematitic, brecciated and IOCG mineralised ironstone in the upper half of the EIOB. The horizon is interpreted in this study as the surface expression of the OME in stratiform aprons to the HIOCG breccia pipes, rather than prior interpretations of a basement host to later HIOCG replacement. At Oak Dam East, remnants of the haematite unit are underlain by magnetite chlorite altered Donington granite (Davidson et al., 2007). The arkose and EIOB were previously interpreted as Wallaroo Group by Gow et al, 1994 and Jagodzinski, 2005.

The EIOB is overlain by a Red Shale then a haematitic siltstone of the lower Pandurra Formation. In hole SAE 3, the EIOB is interpreted to transition conformably into the overlying Red Shale that has rare multielement geochemical analysis. Anderson, (2020) noted the Red Shale and enclosed mafic unit above the EIOB in SAE 3 continued to be significantly anomalous in metals and ZAI. This supports a conformable pre- or syn-OME transition between the EIOB and Red Shale. Detrital zircon dates for coarser units in the Red Shale (Cherry, 2018) show a statistical peak around 1580Ma.

In other holes, multiple loggers describe a widespread regolith surface between the EIOB and haematitic siltstone. This is consistent with a short time break across a regional disconformity. The Red Shale drapes off the breccia pipes with rubble of haematite boulders. In the above context, these are interpreted as coeval downslope rubble around hydrothermal mounds at the OME palaeosurface, rather than erosional reworking on a younger unconformity surface.

Therefore, the Red Shale and haematitic siltstone are re-assigned to the upper Emmie Formation. Supported by spectral mineralogy, the haematitic siltstone continues up holes for up to 350m to an unconformity with a characteristic quartz cobble conglomerate, including GRV clasts. This unconformity uncovers the Oak Dam East mineralisation creating the oxidised metal-depleted cap described by Davidson et al. (2007) that is more consistent with a major unconformity.

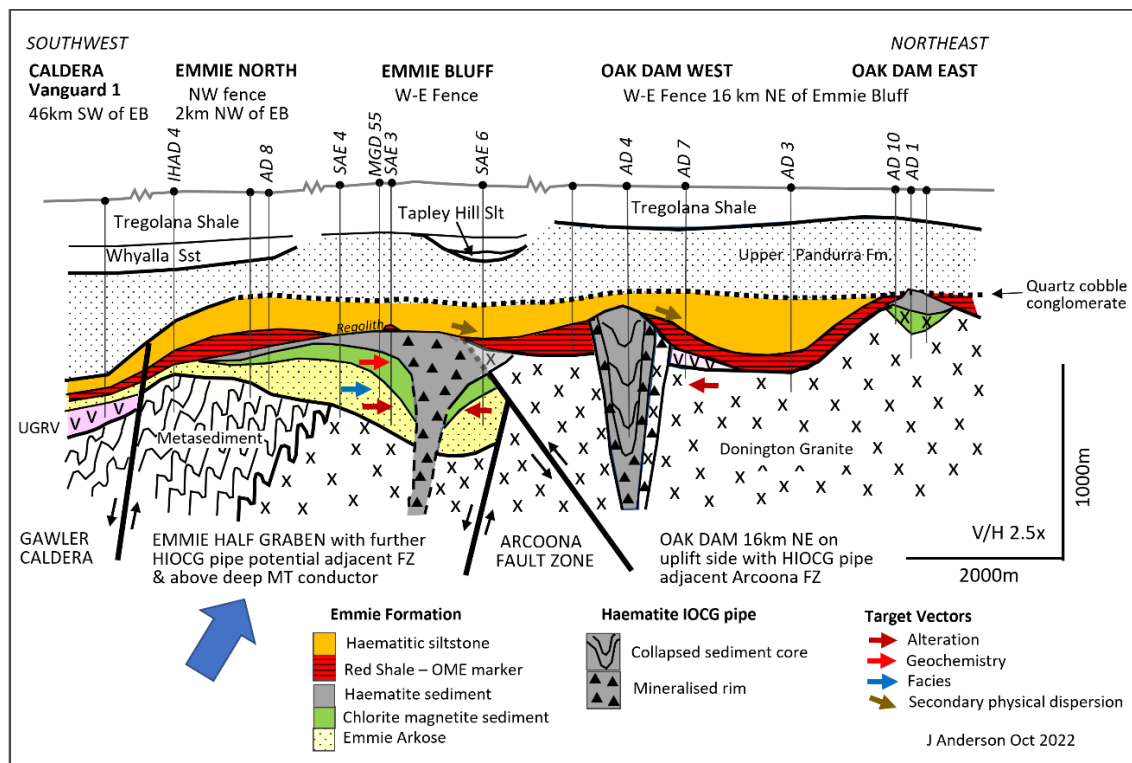
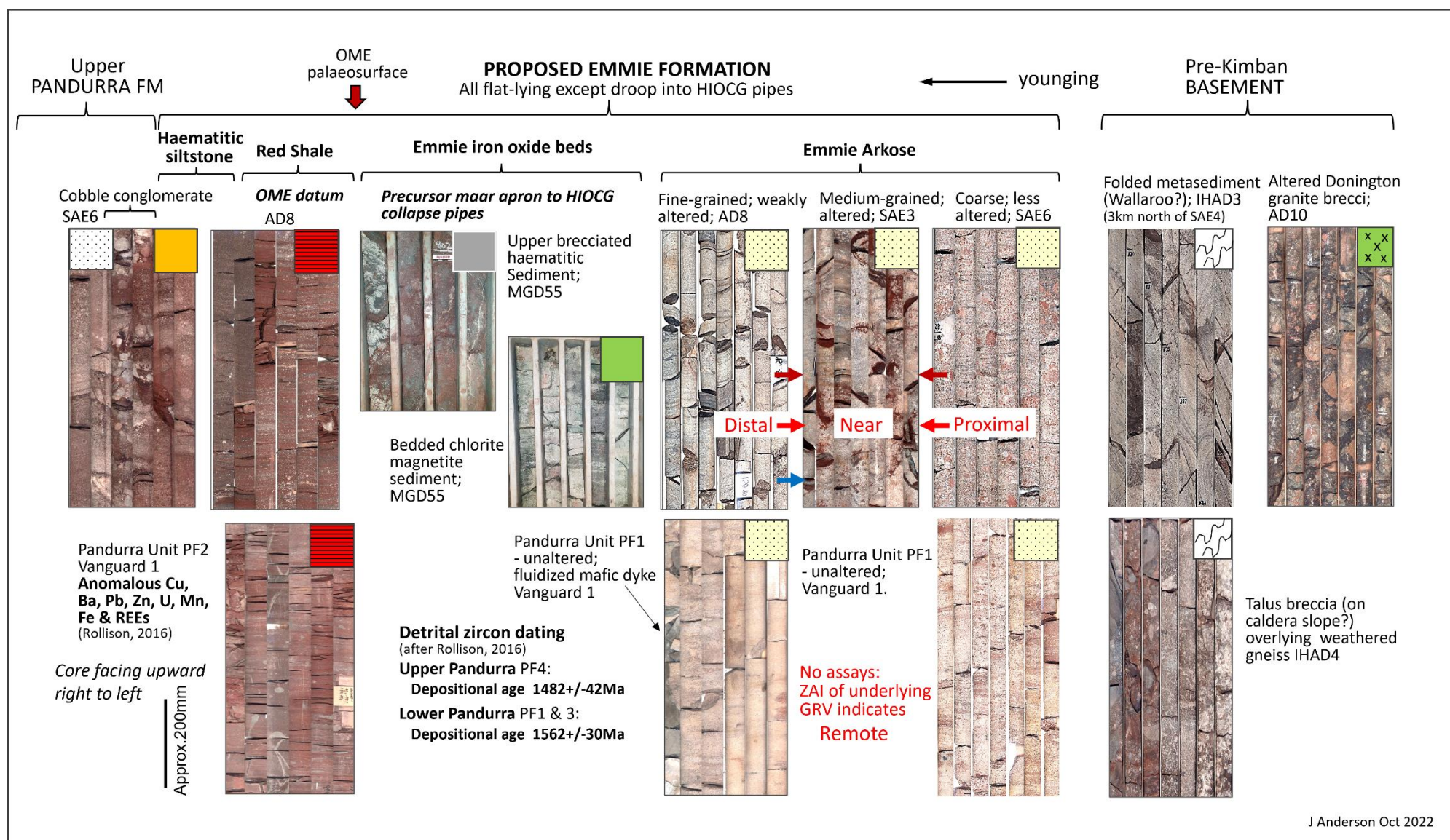


Figure 2. Emmie Formation: Schematic Oak Dam-Emmie Bluff-Caldera section

Figure 3. Lithological examples of the proposed Emmie Formation and correlates in the Pandurra Formation. Except for MGD 55, all the core photos are from SARIG. Lithological legend as for Figures 2 & 4. For contrast to the flat-lying Emmie Formation, an example of a pre-Kimban basement is shown by the folded metasediment in IHAD 3. Indicative target vector arrows as for Figure 2. Proximity estimates as per Anderson (2020, 2021b) are shown in red.



In this study, the Emmie Formation is correlated firstly on lithological grounds with the lower Pandurra Formation. A comparison is shown in Figures 2 & 3 with the Pandurra type hole Vanguard 1 about 50km south of Emmie Bluff (Figure 1). The Emmie Arkose correlates visually with Pandurra unit PF1 of Tonkin (1980), whereas Pandurra unit PF2 closely compares with the Red Shale at Emmie Bluff. The arkose hosts rare fluidised mafic dykes at both locations.

The correlation is further supported by the sedimentological data of Rollison (2016). Detrital zircons in PF1 and PF2 have ages limited within an error range of 1592 – 1532Ma in comparison with a range of younger ages down to 1459+/-26Ma in PF4 of the upper Pandurra Formation. Cherry (2018) obtained a similar discrete peak around 1580Ma for zircon in coarser interbeds within the Red Shale over Oak Dam. The lower Pandurra (Emmie Formation) shows upward fining and white mica illite phengite spectral mineralogy whereas Rollison describes the upper Pandurra as upward coarsening with a dickite kaolinite mineralogy.

The lower Pandurra in Vanguard 1, particularly the PF2 Red Shale, has distinctly elevated metals and rare earths compared with the upper Pandurra Formation. This implies a primary connection of the shales to the OME rather than secondary dispersion over such a large distance. The Red Shale also has elevated K₂O and MgO and unweathered hornblende and augite grains. The geochemistry and association with fluidised mafic dykes around the contact indicate a mafic association for the Red Shale consistent with the strong association of mafic dykes with HIOCG deposits.

The different facies, diagenetic mineralogy, geochemistry and age gap between the lower and upper Pandurra sequences, plus the complete sequence at Emmie Bluff, warrants the separation of the lower Pandurra into the Emmie Formation.

STRATO-TECTONIC MODEL

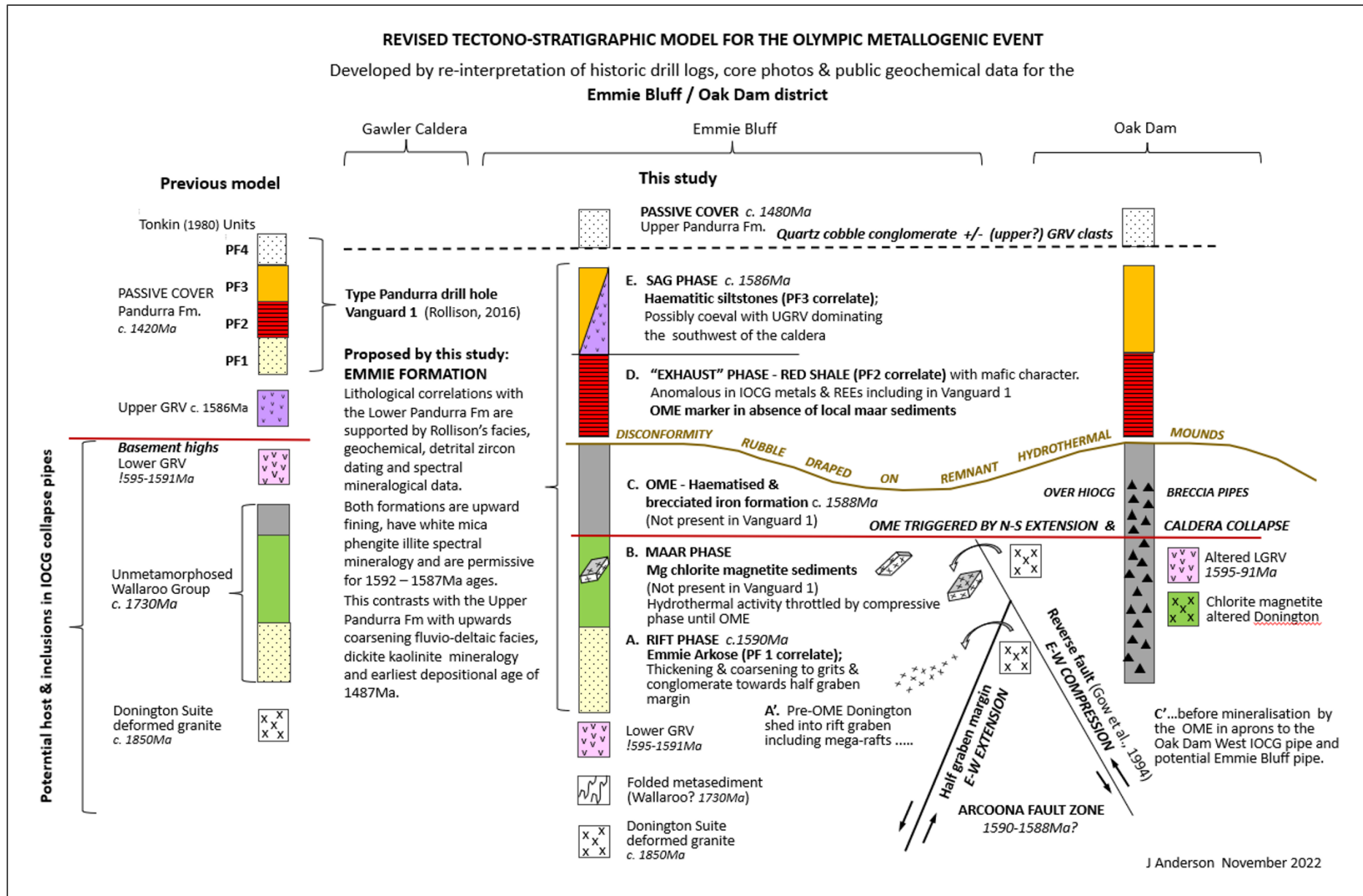
The tectonic setting at Emmie Bluff and Oak Dam is developed from the new stratigraphic interpretations. The prospects' locations along an embayment ("MIM" graben) in the caldera margin (Figure 1) are proposed to have been conducive for alternating east-west compressive and north-south extensional conditions. This resulted in the formation of grabens, maars and collapse breccias as exemplified at Emmie Bluff or Oak Dam West.

The sequence for the tectono-stratigraphic model (Figure 4) is:

- A) The Emmie Arkose is interpreted to be initial rift sedimentation in a half graben against the Arcoona Fault Zone after the 1595-1590Ma Lower GRV. Rare fluidised mafic dykes at the Red Shale transition (e.g. Vanguard 1 - Figure 3) are consistent with this setting and the strong association of mafics with HIOCG breccias.
- B) Deposition of the Mg-chlorite magnetite sediments with early copper mineralisation in a likely maar environment is consistent with the model of Davidson et al. (2007) for Oak Dam East and the lake setting interpreted by Rollison (2016) for Pandurra units PF2 and lower PF3. Reverse faulting (Gow et al., 1994) dispersed rafts of Donington granite into the maar during this phase.
- C) Collapse of the Gawler caldera resulted in rapid release and pulsing of the HIOCG hydrothermal overprint, producing brecciation and an alteration halo of haematite, Fe-chlorite and phengite in the stratigraphic aprons to the central HIOCG pipes. The model permits the incorporation of arkose, as well as reworked haematite sediment breccias, basement and GRV inclusions in the breccia pipes and would explain the enigma of Pandurra-like inclusions deep in Olympic Dam (Ehrig, 2018). This is a viable alternative to the proposal by Cherry, 2018 of deep fault incorporation of 1440Ma Pandurra into the Olympic Dam breccia. The mass addition of the HIOCG phase produced 200m high hydrothermal mounds adjacent to and above the haematite collapse pipes with late sericite fluorite copper gold mineralisation of the pipe margins.
- D) After faulting and hydrothermal activity ceased, the Red Shale with a possible hydrothermal mafic association preserved the HIOCG deposits under a regional regolith and remnant haematite mounds. The role of the Red Shale appears important as a regional marker in what is labelled as the "Exhaust" phase for further research.
- E) A sag phase of haematitic siltstones formed the final member of the Emmie Formation with a minimum detrital zircon age around 1620Ma (Rollison, 2016) thusfar, indicating a St Peters Suite provenance. The upper GRV separately dominates the southwestern half of the caldera (Figure 1), so the lack of 1586Ma upper GRV zircon in the northeastern haematitic siltstones may be a clue for why the southwestern sector has a different metallogenic assemblage with epithermal-porphyry style deposits of OME age (Anderson, 2017) and later gold deposits such as Tarcoola.

Therefore, the Cariewerloo Basin, as presently defined, started forming around 1590Ma with the initial OME rifting. The rifting provided the sedimentary pile of lower Emmie Formation for redistribution into the HIOCG breccia pipes that closely followed with the collapse of the Gawler caldera. The caldera was infilled with the 1586Ma Upper GRV and upper Emmie Formation. This was followed by the much later deposition of the c. 1450Ma upper Pandurra Formation in an elongate belt approximating the centre of the original caldera.

Figure 4. A tectono-stratigraphic model for haematite IOCG deposits in the Emmie Bluff / Oak Dam district & by corollary, for the OME.



The 1450Ma Coorabie Orogeny initiated the upper Pandurra deltaic sequence of fluvio-deltaic sediments described by Rollison (2016). The orogeny reset the Rb-Sr and Ar-Ar isotope systems used to make previous early age estimates for the lower Pandurra Formation.

Re-activation of the same structures at the former caldera and graben margins created new sub-basins and remobilised copper and other metals into stratabound deposits in upper Pandurra and Adelaidean traps (Figure 2).

A STEP-CHANGE FOR EXPLORATION

The new OME tectono-stratigraphic model significantly disrupts the current geological framework and targeting tactics for HIOCG deposits such as:

- 1) Exclusive targeting of gravity anomalies for eroded haematitic basement highs.
- 2) The role of un-metamorphosed Wallaroo Group as the preferred basement host (Reid & Fabris, 2015).
- 3) An inferior class of two-stage IOCG deposits (Bastrakov et al., 2007).

The new model revitalises the regional discovery space:

- 1) Exploration for HIOCG pipes can be more confidently focused around the margins of the Gawler caldera. HIOCG potential is still likely within the caldera where the precursor Emmie Formation (lower Pandurra) is present; i.e. the northeastern half of the caldera, and the right structural conditions exist for pipe formation and pumping of hydrothermal fluids.
- 2) The Emmie Arkose and Red Shale (PF Units 1 and 2) provide a stratigraphic datum and 4-D framework for far-field facies and geochemical mapping towards growth faults, maars and hydrothermal centres prospective for HIOCG breccia deposits. Modification of Rollison's distribution of PF1 and 2 to the new Emmie Bluff interpretation shows the most obvious development of arkose and shale encompasses the Carrapateena - Oak Dam – Emmie Bluff group of HIOCG deposits (Figure 1). There is no coincidence that the one of the thickest developments of Red Shale is in SASC4 situated between Khamsin and Carrapateena, although the Emmie Formation is eroded off Carrapateena by Adelaidean sedimentation.
- 3) Lateral and downhole alteration mineralogy and geochemical profiles through the Emmie Formation / basement profile can provide both vectors and proximity indicators to hydrothermal centres as indicated for Emmie Bluff in Figures 2, 3 and 4. The inherited Donington zircon population in the Emmie Arkose provides a consistent platform for measuring the hydrothermal overprint under the ZAI concept (Anderson, 2020, 2021b).

The Emmie Arkose / Red Shale contact offers a marker for the OME where prospective EIOB-style maar lithologies are absent. Several regional drillholes have lower Pandurra and particularly PF2 (Red Shale) recorded. These warrant priority for re-assessment of vectors to maar environments and structurally favourable settings for HIOCG pipes to prioritise abundant gravity anomalies or give better resolution for broad MT target areas.

At Emmie Bluff, the combination of thickening, coarsening and increasingly altered arkose along with consistently high downhole ZAIs approaching the Arcoona fault zone indicates the “Proximal” to “Near” HIOCG pipe (Figures 2 & 3). In more distal holes, the downhole ZAI profile provides proximity estimates and vectors between holes despite subtle visual indicators.

Conversely, weaker ZAI signatures limited to the EIOB or Red Shale indicate a more “Distal” hole positioning nominally greater than 3 kilometres. The GRV intersected beneath the interpreted Emmie Formation in Vanguard 1 has a low ZAI signature indicating the hole location is “Remote” from hydrothermal activity. This is consistent with the absence of the B Maar facies (Figure 4). However, further multi-element assaying of the Emmie Formation would provide better downhole data on that hole's proximity to HIOCG systems.

The new universal target vectors have potential to identify new generations of deposits without the standard geophysical signatures including the potential for stratiform hydrothermal deposits near the OME palaeosurface. Facies logging and coarse geochemical sampling of additional existing or new strategically placed holes is required throughout the Emmie Formation to determine alteration vectors and proximity measures.

RESEARCH RECOMMENDATIONS

A collaborative program is recommended for the Emmie Bluff / Oak Dam IOCG systems and Vanguard 1 to further research and test the new concepts and targeting advances arising from the proposed tectono-stratigraphic model for the Olympic Metallogenic Event. Precise CA-TIMs dating of detrital zircons in the clastic units and pipe inclusions, as well as dating of geologically constrained felsic and mafic volcanics, intrusives and GRV clasts, such as those at the upper Pandurra unconformity, will assist with the stratigraphic refinement and investigation of the roles of the Red Shale and mafic intrusives.

One question is whether the Red Shale is providing primary alteration or secondary dispersion vectors. Either are valuable but require different exploration applications. Oak Dam is relevant to resolving the relationship. Logging

of the palaeosurface/unconformity and precise dating of detrital zircon cores in clasts progressively down the collapsed sediment pile in the Oak Dam West pipe may further constrain the prospective stratigraphic marker for regional exploration.

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The author looks forward to the debate.

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