Archean controls on basin development and mineralisation in the Southern Capricorn Orogen

Sandra Occhipinti
CET/SES/UWA
Crawley, WA
Sandra.occhipinti@uwa.edu.au

Alan Aitken
CET/SES/UWA
Crawley, WA
alan.aitken@uwa.edu.au

Mark Lindsay
CET/SES/UWA
Crawley, WA
mark.lindsay@uwa.edu.au

Lara Ramos
CET/SES/UWA
Crawley, WA
lara.ramos@uwa.edu.au

**presenting author asterisked*

SUMMARY

Basins along the northern margin of the Yilgarn Craton developed in response to extensional and compressional processes during the Paleoproterozoic. Early extension resulted in the formation of the Yerrida Basin as a large single basin over the northern Yilgarn Craton. Subsequent rifting led to voluminous volcanism in the northern part of the basin, within two depositional centres – the c. 2.03 to 1.96 Ga Bryah and Mooloogool Sub-basins. Cu-Au VMS deposits formed in the Bryah Sub-basin. Yilgarn Craton crust can be mapped using gravity and magnetic data beneath the Yerrida Basin, and Mooloogool Sub-basin. However, the Yerrida Basin can't be mapped below much of the Bryah Basin, implying the formation of an ocean in this region. The degree of rifting of the Yilgarn Craton, and resulting architecture influenced subsequent basin development, and deformation in the region. For example, in areas where Yilgarn Craton crust can't be mapped beneath basin sediments deformation is pronounced with the formation of disharmonic folds, refolded folds, and anastomosing shear zones. The southern part of the Yerrida Basin and the Earaheedy Basin formed shallow depositional centres over the Yilgarn Craton, and subsequent deformation in these regions is less intense. Base metal mineralisation in the region can, in part be related to the presence of deep crustal scale structures that initially developed in the Archean, and were re-activated during the Proterozoic. However, the location of c. 1800 Ma orogenic Au mineralization in the Bryah Sub-basin may not have been influenced by localisation of fluid flow around deep crustal-scale faults that formed as 200 Ma earlier, or even as early as the Archean.

Key words: Volcano-sedimentary basins, Paleoproterozoic, Tectonics, Mineralisation, Structure.

INTRODUCTION

Volcano-sedimentary basins record the subtle record of tectonic events and geologic environment, specifically periods of extension and compression related to plate tectonic movement, orogenic collapse or variations in gravitational potential energy and mantle convection (Sengör, 1978; Houseman and England, 1986; Rosenbaum et al., 2008). Basins develop within plates or along their margins, however, Proterozoic basin interpretation is often difficult because of the lack of stratigraphic constraints such as fossils or precise depositional ages needed to identify unconformities or time breaks in deposition.

The understanding of tectonism that led to the formation of basins between the Yilgarn and Pilbara Cratons in the Capricorn Orogen, particularly those on the northern margin of the Yilgarn Craton, has been held back by sparse geochronological control (Fig. 1). However, these basins can inform models of the tectonic amalgamation of the West Australian Craton (part of the Columbia supercontinent). The Capricorn Orogen developed between the Archean Pilbara and Yilgarn Cratons during periods of rifting and convergence in the Paleoproterozoic and Neoproterozoic (Occhipinti et al., 1998; Occhipinti et al., 2004; Sheppard et al., 2004; Sheppard et al., 2005; Sheppard et al., 2007; Sheppard et al., 2010; Johnson, 2013; Sheppard et al., 2016). Cratonic blocks beneath the Capricorn Orogen include the Pilbara and Yilgarn Cratons and Glenburgh Terrane (Hackney, 2004; Fishwick and Reading, 2008). The Glenburgh and Pilbara Cratons were amalgamated during the Ophthalmian Orogeny at c. 2215–2145 Ma (Occhipinti, 2004; Occhipinti et al., 2004; Johnson et al., 2013), and then accreted to the Yilgarn Craton during the 2005–1950 Ma Glenburgh Orogeny (Occhipinti et al., 2004; Johnson et al., 2013), to form the West Australian Craton. Subsequent reworking events that variably resulted in deformation, magmatism, metamorphism and magmatism, and basin development include, but are not restrictred to the 1830–1770 Ma Capricorn Orogeny. Within the southern part of the Capricorn Orogen, sedimentary and volcanosedimentary basins formed between 2200 Ma and 1820 Ma responding to tectonothermal events in the region.

Originally the sedimentary successions in the southern Capricorn Orogen were assigned to large basins —Nabberu, later Glengarry and Earaheedy (Occhipinti et al., 2017 and references therein) — interpreted as geosynclines between the Pilbara and Yilgarn Cratons of Western Australia (Gee, 1979). The geosyncline concept predated plate tectonics, and related to basins formed by regular subsidence of the ocean floor where sediments accumulated to great thicknesses, or as deep axially elongate sedimentary troughs with mountain chains on their sides (Aubouin, 1965).

Sedimentary and volcanic rocks along the northern Yilgarn Craton were then assigned to the Yerrida, Bryah, Padbury and Earaheedy Basins (Occhipinti et al., 1997; Pirajno and Adamides, 2000; Pirajno and Occhipinti, 2000a; Pirajno and Adamides, 2000; Pirajno and Occhipinti, 2000b; Pirajno et al., 2000b; Pirajno et al., 2004; Pirajno et al., 2009b), but recently it was recognised that the Bryah Basin, is simply a sub-basin of the Yerrida Basin, and parts of the Padbury and Earaheedy Basins formed during the same tectonic events (Fig. 1).

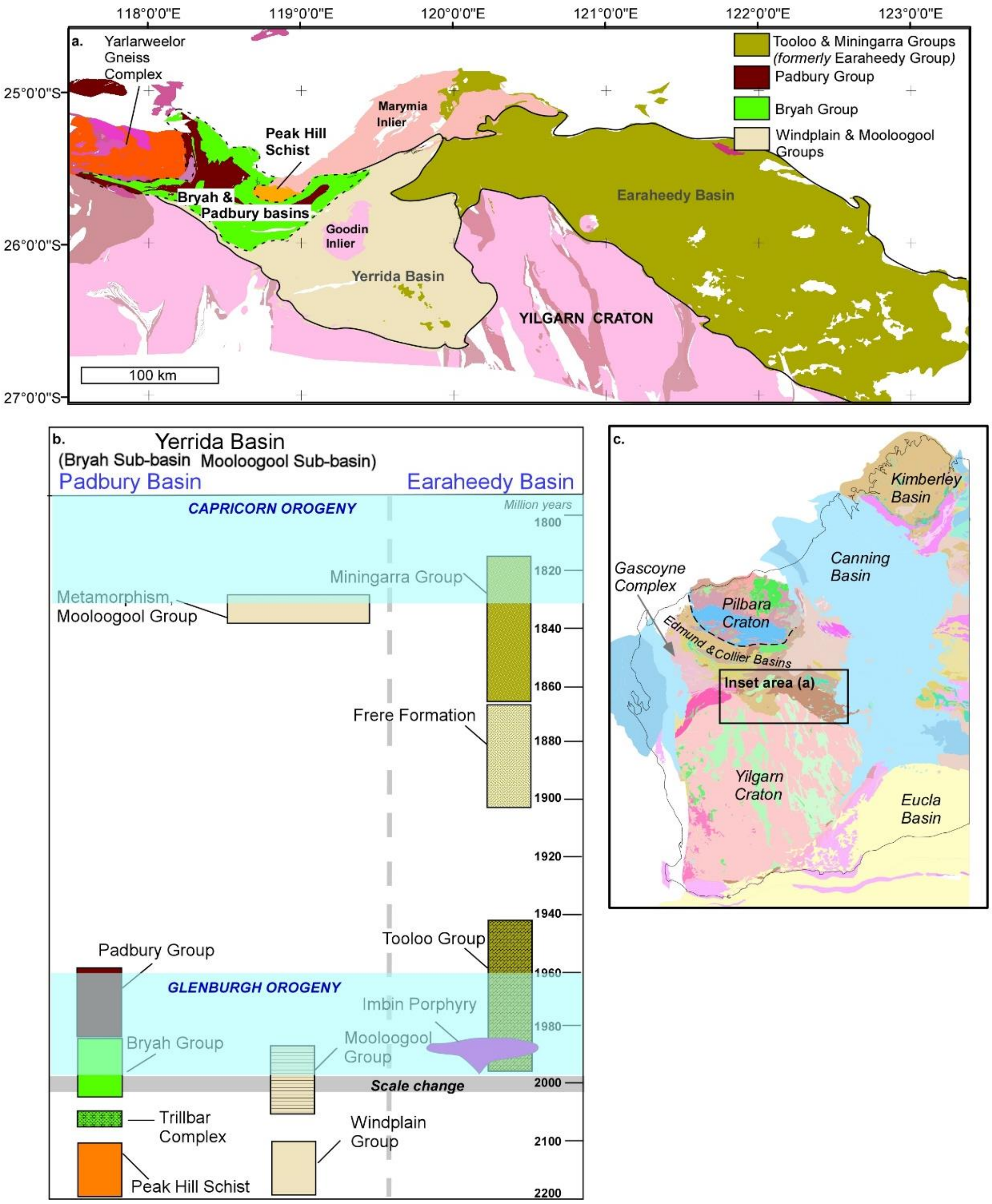

Figure 1: Simplified geological map for the Yerrida, Earaheedy and Padbury Basins, modified from (Occhipinti et al., 2017).

METHOD AND RESULTS

A major part of the tectonic history of the southern Capricorn Orogen comprised lithospheric extension along the northern Yilgarn Craton that is manifested through the formation of the Yerrida and Earaheedy Basins. The development of basins over Archean crust is influenced by the chemistry of the lithosphere (reflected by its density or buoyancy) and the thickness and degree to which it is modified through rifting or magmatism, or both (Poudjom Djomani et al., 2001). Archean lithosphere (including the subcontinental lithospheric mantle (SCLM) that continues to the asthenospheric boundary) contains more magnesium and less iron than Proterozoic and Phanerozoic lithosphere. This, and other chemical variations renders Archean lithosphere relatively buoyant. Archean lithosphere is usually between 180 and 240 km thick, in contrast to Proterozoic lithosphere at 150–180 km thick and Phanerozoic lithosphere, commonly less than 100 km thick (Poudjom Djomani et al., 2001). The lithosphere of the Yilgarn Craton is considered to be at least 250 km thick (Fishwick et al., 2005), whereas the thickness of the lithosphere beneath the Capricorn Orogen is closer to 150 km (Fishwick et al., 2005). In the southern part of the Capricorn Orogen where sedimentary or volcanic rocks overlie the Yilgarn Craton, rifted Archean inliers are mapped (e.g. Goodin Inlier and Malmac Inlier) or reworked fragments of Yilgarn Craton are known (Marymia Inlier, Yarlarweelor Gneiss Complex). This, and the decrease in lithospheric thickness from the Yilgarn Craton to the Capricorn Orogen suggests, unsurprisingly that the Archean lithosphere has been modified and/or thinned in this region.

Lithospheric extension along the mapped extent of the northern Yilgarn margin (Martin et al., 2016) has been viewed in the context of a passive margin that was established at 2200 Ma, initially forming the Yerrida Basin and continuing until c. 1860 Ma with the development of the Earaheedy Basin (Pirajno and Adamides, 2000; Pirajno et al., 2009b; Akin, 2014). However, this is unlikely as basal units in the Padbury Basin are interpreted to have formed as a result of convergence (Martin, 1998) during the Glenburgh Orogeny (Occhipinti et al., 2004) as a pro-foreland basin (Sheppard et al., 2016). Therefore basin development across the southern Capricorn region was not straightforward. For example, at the same time the Padbury pro-foreland basin formed along a plate collision zone, the extensional Earaheedy Basin initiated in the eastern Capricorn Orogen (Occhipinti et al., 2017).

The following discussion presents a re-interpretation of basin development along the northern Yilgarn Craton based on the compilation of age data for the region and the re-interpretation of the lithostratigraphy through a combination of geophysical–geological mapping and interpretation. Based on this work five phases of basin development along the northern Yilgarn Craton margin have been defined (Occhipinti et al., 2017).

Basins that developed along the northern Yilgarn Craton during lithospheric extension appear to be large shallow basins, except for the Bryah and Mooloogool Sub-Basins. This is probably a function of the buoyant and thick Archean lithosphere (Poudjom Djomani et al., 2001) that underlies the Earaheedy Basin and the southern part of the Yerrida Basin. In these scenarios, Occhipinti et al., (2017) suggested that deep Paleoproterozoic basins over Archean lithosphere may only form through replacement of the lithosphere by the confluence of rifting and intrusion of hot asthenospheric material. Evidence for rifting is present in the Yerrida and Earaheedy Basins; but, the thin nature of basin fills, and shallow water environments recorded in lithofacies of the Windplain and Mooloogoo Groups and units in the Earaheedy Basin suggests limited subsidence in most of the region. The deepest basin succession is recorded in the Bryah Sub-basin, corresponding with the largest volume of mafic rock accumulation in the region, suggesting rift development (Occhipinti et al., 2017).

Rifting along the northern Yilgarn margin, likely resulted in mafic to ultramafic magmatism comprising the c. 2.07 Ga Trillbar Complex (Oilerook et al., submitted) and mafic volcanic rocks within the northeastern part of the Juderina Formation (Occhipinti et al., 2017), and eventual differentiation of the Yerrida Basin into the Bryah and Mooloogool Sub-basins on the northern and souther sides of the active Goodin Fault, respectively. Basin-wide sulphidic black-shale sedimentation followed and culminated in mafic and intermediate magmatism in the Karalundi Formation. This was interspersed with volcaniclastic and siliciclastic sedimentation that became the host rocks for volcanic mafic- and siliciclastic-hosted massive sulphides (Cu, Zn, Au, Ag, Pb), such as the 2.03–2.02 Ga DeGrussa deposit (Hawke et al., 2014; Pirajno et al., 2015). With time, mafic volcanism also migrated to the south with the development of the Mooloogool Sub-basin. However, no known mineralisation is associated with the Mooloogool Sub-basin. Northwest–directed subduction of the extended Yilgarn Craton margin beneath the combined Glenburgh–Pilbara craton began by c. 2005 Ma (Sheppard et al., 2004), causing the coincident cessation of mafic volcanism (Narracoota and Karalundi Formations) in the Bryah and Mooloogool Sub-basins (Occhipinti et al., 2017). In addition, c. 2000 Ma E–NE-trending dolerite dykes cross-cutting the Narracoota Formation (Hawke et al., 2015), overlap temporally with the Glenburgh Orogeny (Hawke et al., 2015) and early development of the Earaheedy Basin. This suggests approximate W–NW extension at c. 2 Ga (Fig. 2).

Deposition of chemical and siliciclastic sedimentary rocks in the Bryah and Mooloogool Sub-basins (Bryah and Mooloogool Groups) took place after mafic volcanism had ceased in the region, perhaps during a transition period between local extension and collisional processes. Concurrently at c. 2 Ga, there was felsic volcanism in the northeastern Bryah Sub-basin, contrasting with the voluminous mafic volcanism earlier in the basin’s history. Eventual collision and accretion of the combined Pilbara–Glenburgh craton with the Yilgarn Craton marks both the end of deposition in the Yerrida Basin, and the initiation of the Padbury and Earaheedy Basins. The lowermost units of these basins were deposited as a result of the 2005–1950 Ma Glenburgh Orogeny. However, overlying iron formations were deposited sometime after the Glenburgh Orogeny, as suggested by the c. 1890 Ma age of the Frere Formation (Rasmussen et al., 2012), during a global phase of iron-formation deposition spurred by a change in global ocean chemistry.

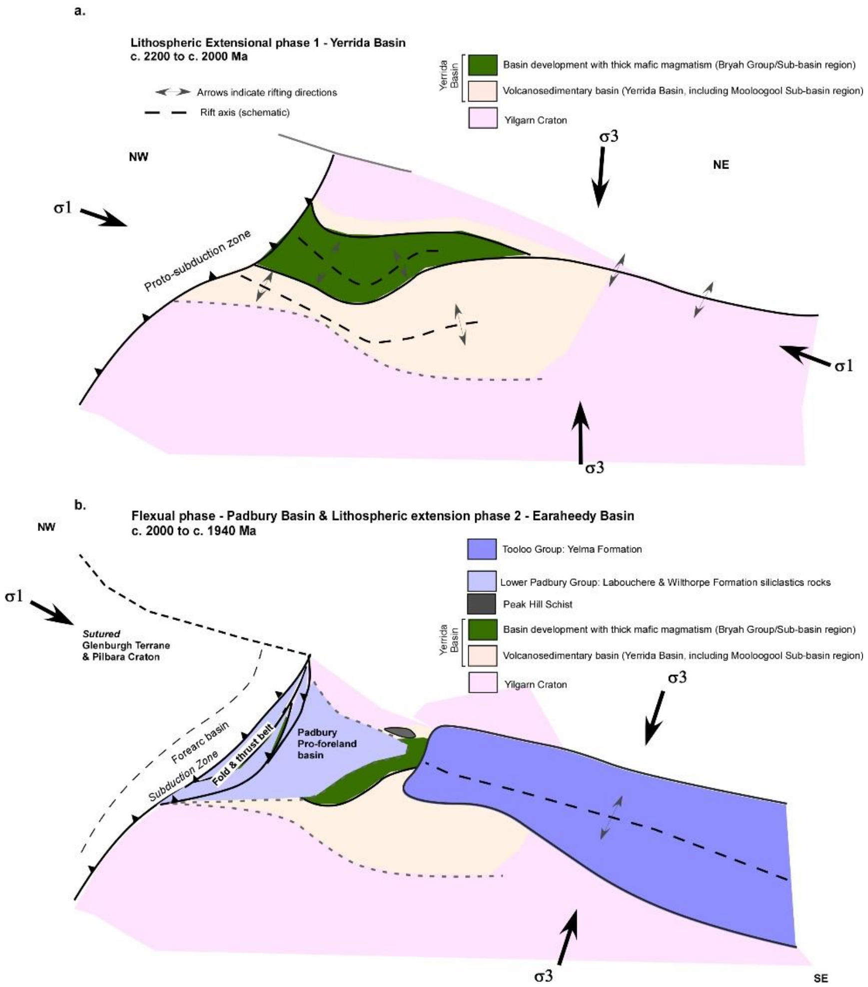

Figure 2: Simplified geological model for the development of basins over the northern Yilgarn Craton, modified from (Occhipinti et al., 2017).

Iron-formations in the upper part of the Padbury and Earaheedy Basins (Occhipinti et al., 2017) are separated from each other by a north-trending zone marked by the Marymia and Goodin Inliers, which may have been topographic highs during deposition. The source of iron is uncertain but Rasmussen et al. (2012) and Sheppard et al. (2016) suggest it may have originated from a coeval large igneous province, although more recently (Stark, in review) suggested evidence for a Large Igneous Province in the southwestern Yilgarn Craton, which may have been connected to another continent at that time.

The presence of banded iron-formations in the west and granular iron-formations in the east of the Bryah Sub-basin and in the Earaheedy Basin suggests that the Earaheedy Basin may have developed into a large depositional basin deepening from east to west, extending across the present day outcrop of the Yerrida Basin. Thus the upper parts of the Padbury Group (eg. The Robinson Range and Millidie Creek Formations) may have formed in a much larger, than is now known, Earaheedy Basin (Fig. 2). Basin development along the northern Yilgarn margin probably ceased with onset of the intracratonic Capricorn Orogeny at c. 1820 Ma, which involved approximately north to south compression within the West Australian Craton. Units such as the Millidie Creek Formation (upper Padbury Group), Kulele Limestone and Mulgarra Sandstone (Miningarra Group) were deposited just prior to this.

Mineralisation in the Yerrida, Padbury and Earaheedy basins includes base metals in carbonates, Cu-Au in volcanosedimentary rocks, and Au in mafic and siliciclastic rocks. Within the Bryah Sub-basin the DeGrussa Cu-Au deposit is a volcanic hosted massive sulphide deposit that appears to have developed proximal to the axial rift zone of the basin. This deposit developed in the lowermost unit formed in the Bryah Sub-basin, the Karalundi Formation. Other VMS deposits of approximately the same age in the region include some exposed around the ‘edges’ of the rift in the southwestern part of the basin. The recognition that the Mooloogool and Bryah Sub-basins formed at approximately the same time suggests the possibility of similar types of deposits forming in units deposited in the Mooloogool Sub-basin.

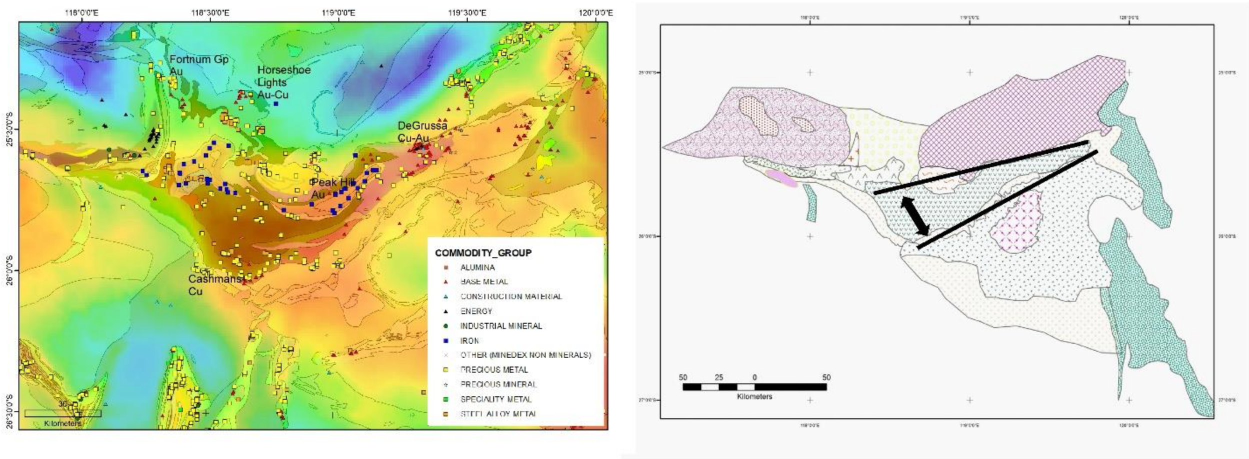

Figure 3: Left, Bouger anomaly map overlain in transparency by geological units and mines. Red = high density, Blue = Low density; Right, Schematic interpretation of the gravity anomalies in the region. Dark Green = Deep Archean Greenstones, Pinks = Archean Inliers, Yellow = Siliciclastic and carbonate sedimentary dominant, Light green and white = Mafic rocks.

Gold mineralisation in the region is most prominent in the northern Bryah Sub-basin and within the Archean Marymia Inlier. The gold appears to have been deposited during the Paleoproterozoic, and more specifically the Capricorn Orogeny (Hawke et al., 2015). The location of the largest deposits in the northern part of the region is not directly associated with the interpreted 'axial rift zone' that led to the development of the Bryah Sub-basin. However, it is associated with interpreted deep crustal scale structures within the region that formed during the Capricorn Orogeny, or earlier. In the southern part of the Yerrida and Earaheedy Basins carbonate hosted base metal deposits appear to be, in part, related to the location of Archean structures. The Pb-Zn prospects in the Earaheedy Basin are present in regions of structurally brecciated stromatolitic carbonate (Yelma Formation), whereas an outlier of Yelma Formation unconformably overlying rocks in the Yerrida Basin may have been mineralised through a complex process involving ancient weathering or metasomatism (Fig. 4). This suggests that Archean structures accommodated fluid flow which led to mineralisation after the formation of the Paleoproterozoic basins in the region.

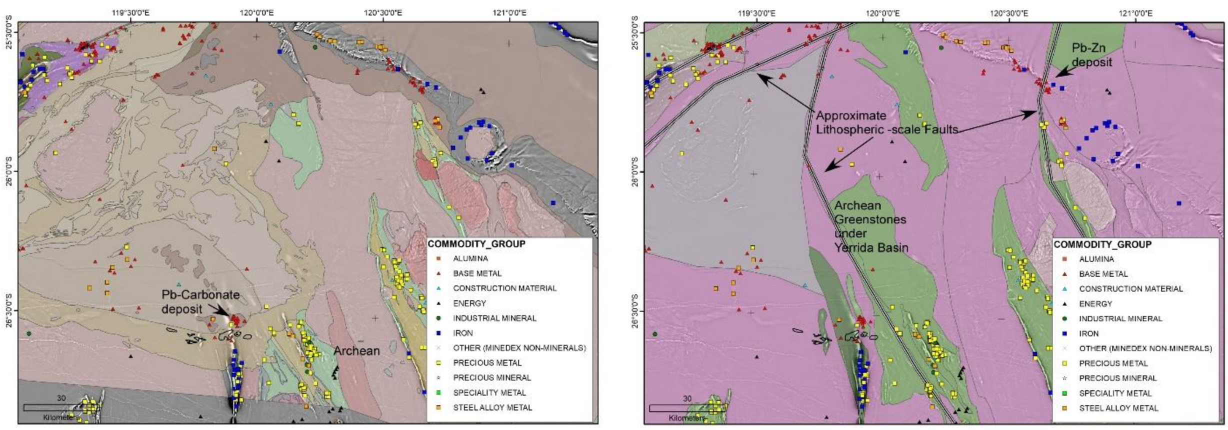

Figure 4: Left, Geology overlain in transparency over 1vd TMI image; Right, 'Archean' geology interpreted under Paleoproterozoic basins for the Yerrida and Earaheedy Basins illustrating the possible coincidence of Archean lithospheric structures with Pb-Zn deposits in the Earaheedy Basin (top right), and the location of Pb-carbonate in an outlier of the Yelma Formation in the Yerrida Basin (see left figure for label 'Pb-carbonate deposit').

CONCLUSIONS

Basins that formed along the northern Yilgarn Craton margin between 2200 and 1820 Ma record prolonged periods of extension and compression that also affected the craton margin. These complex Paleoproterozoic processes resulted in the amalgamation of the West Australian Craton, and eventual assembly of the supercontinent Columbia. Initially, these basins formed as a response to extensional processes, resulting in the deposition of locally derived siliciclastic detritus. Continued subsidence and limited siliciclastic influx from a low-relief Yilgarn Craton led to shallow-marine environments and deposition of carbonates, including stromatolitic dolostone and evaporite. The development of the Bryah Sub-basin led to deepening of the basin to at least 7 km thick, perhaps the thickest Paleoproterozoic sediment and volcanic accumulation in the Yerrida and Earaheedy basins (Fig. 3). Voluminous mafic volcanism in the Bryah Sub-basin coincides with the most mechanically and chemically modified part of the northern Yilgarn Craton SCLM.

Although mineralisation occurs throughout the region it is most prevalent in the Bryah Sub-basin, which is coincident with the most rifted and chemically modified parts of the Yilgarn Craton (Occhipinti et al., 2017). In addition the northern part of the Yerrida Basin was more intensely deformed during subsequent deformation events in the region (during the 2005-1960 Ma Glenburgh Orogeny and 1830-1780 Capricorn Orogeny), not only with the development of disharmonic folds and refolds in the greenschist facies, but also with the formation of the upper greenschist to amphibolite facies Peak Hill Schist, which may be a deformed and metamorphosed equivalent of the largely unmetamorphosed Juderina Formation (which forms the basal unit of the Yerrida Basin). In other parts of the Yerrida and Earaheedy Basins empirical observations suggest that mineralisation is spatially associated with Archean structures which must have been reactivated during the Proterozoic, or later.

ACKNOWLEDGMENTS

We acknowledge the Geological Survey of Western Australia for funding much of this work under the Exploration Incentive Scheme (EIS2). This work was completed as part of the Capricorn Distal Footprints study project, which was funded by the Science and Industry Endowment Fund (SIEF), company sponsorship, Curtin University and the University of Western Australia.

REFERENCES

Aubouin, J., 1965, Geosynclines, in: Company, E.P. (Ed.): Developments in Geotectonics 1, Amsterdam, London, New York, 1-40.

Fishwick, S., Kennett, B.N.L., Reading, A.M., 2005, Contrasts in lithospheric structure within the Australian Craton - insights from surface wave tomography: Earth and Planetary Science Letters 231, 163-176.

Fishwick, S., Reading, A.M., 2008, Anomalous lithosphere beneath the Proterozoic of western and central Australia: A record of continental collision and intraplate deformation?: Precambrian Research 166, 111-121.

Gee, R.D., 1979, The geology of the Peak Hill area, in: Australia, West Australia Geological Survey, Annual Report 1978: Geological Survey of Western Australia, Perth, pp. 90-106.

Hackney, R., 2004, Gravity anomalies, crustal structure and isostasy associated with the Proterozoic Capricorn Orogen, Western Australia: Precambrian Research 128, 219-236.

Hawke, M.L., Meffre, S., Stein, H., Hilliard, P., Large, R., Gemmell, J.B., 2015, Geochronology of the DeGrussa volcanic-hosted massive sulphide deposit and associated mineralisation of the Yerrida, Bryah and Padbury Basins, Western Australia: Precambrian Research 267, 250-284.

Houseman, G., England, P., 1986, A dynamical model of lithosphere extension and sedimentary basin formation: Journal of Geophysical Research: Solid Earth 91, 719-729.

Johnson, S.P., Thorne, A.M., Tyler, I.M., Korsch, R.J., Kennett, B.L.N., Cutten, H.N., Goodwin, J., Blay, O., Blewett, R.S., Joly, S., Dentith, M.C., Aitken, A.R.A., Holzschuh, J., Salmon, M., Reading, A., Heinson, G., Borden, G., Ross, J., Costellow, R.D., Fomin, T., 2013, Crustal architecture of the Capricorn Orogen, Western Australia and associated metallogeny: Australian Journal of Earth Sceinces 60, 681-705.

Occhipinti, S.A., Sheppard, S., Nelson, D.R., Myers, J.S., Tyler, I.M., 1998, Syntectonic granite in the southern margin of the Palaeoproterozoic Capricorn Orogen, Western Australia: Australian Journal of Earth Sceinces 45, 509-512.

Occhipinti, S.A., 2004, Tectonic evolution of the southern Capricorn Orogen, Western Australia, Applied Geology. Curtin University, p. 220p.

Occhipinti, S.A., Sheppard, S., Passchier, C., Tyler, I.M., Nelson, D.R., 2004, Palaeoproterozoic crustal accretion and collision in the southern Capricorn Orogen: the Glenburgh Orogeny: Precambrian Research 128, 237-255.

Occhipinti, S.A., Hockey, R., Lindsay, M., Aitken, A., Copp, I., Jones, J.A., Sheppard, S., Pirajno, F., and Metelka, V., 2017, Paleoproterozoic basin development on the northern Yilgarn Craton, Western Australia: Precambrian Research 300, 121-140.

Poudjom Djomani, Y.H., O'Reilly, S.Y., Griffin, W.L., Morgon, P., 2001, The density structure of subcontinental lithosphere through time: Earth and Planetary Science Letters 184, 605-621.

Rasmussen, B., Fletcher, I.R., 2002, Indirect dating of mafic intrusions by SHRIMP U–Pb analysis of monazite in contact metamorphosed shale: an example from the Palaeoproterozoic Capricorn Orogen, Western Australia: Earth and Planetary Science Letters 197, 287-299.

Rasmussen, B., Fletcher, I.R., Bekker, A., Muhling, J.R., Gregory, C.J., Thorne, A.M., 2012, Deposition of 1.88-billion-year-old iron formations as a consequence of rapid crustal growth: Nature 484, 498-501.

Rosenbaum, G., Weinberg, R.F., Regenauer-Lieb, K., 2008, The geodynamics of lithospheric extension: Tectonophysics 458, 1-8.

Sengör, A.M., Burke, K., 1978, Relative timing of rifting and volcanism on Earth and its tectonic implications. Geophysical Research Letters 5, 419 - 421.

Sheppard, S., Occhipinti, S.A., Tyler, I.M., 2004, A 2005–1970 Ma Andean-type batholith in the southern Gascoyne Complex, Western Australia. Precambrian Research 128, 257-277.

Sheppard, S., Occhipinti, S.A., Nelson, D.R., 2005, Intracontinental reworking in the Capricorn Orogen, Western Australia: the 1680-1620 Ma Mangaroon Orogeny: Australian Journal of Earth Sceinces 52, 443-460.

Sheppard, S., Bodorkos, S., Johnson, S.P., Wingate, M.T.D., Kirkland, C.L., 2010, The Paleoproterozoic Capricorn Orogeny: intracontinental reworking not continent-continent collision. Geological Survey of Western Australia Report.

Sheppard, S., Rasmussen, B., Muhling, J.R., Farrell, T.R., Fletcher, I.R., 2007, Grenvillian-aged orogenesis in the Palaeoproterozoic Gascoyne Complex, Western Australia: 1030-950 Ma reworking of the Capricorn Orogen: Journal of Metamorphic Geology 25, 477-494.

Sheppard, S., Fletcher, I.R., Rasmussen, B., Zi, J.-W., Muhling, J.R., Occhipinti, S.A., Wingate, M.T.D., Johnson, S.P., 2016, A new Paleoproterozoic tectonic history of the eastern Capricorn Orogen, Western Australia from in situ dating of micro-tuffs: Precambrian Research 286, 1-19.

Stark, J.C., Wange, X.-C., Denyszyn, S.W., Li, Z.-X., Rasmussen, B., Zi, J.-W., Sheppard, S., in review, Newly identified 1.89 Ga 1 mafic dyke swarm in the Archean Yilgarn Craton, Western Australia suggests a connection with India: Precambrian Research xx, xx.