Twenty years of pre-competitive geoscience data in the Capricorn Orogen: the link between mineral systems and crustal evolution

Simon P. Johnson
Geological Survey of Western Australia
Mineral House, 100 Plain Street, East Perth, WA
simonpaul.johnson@dmirs.wa.gov.au

SUMMARY

State- and federal-generated pre-competitive geoscience data is critical for exploration success. These relatively low-cost but high-quality regional-scale datasets ultimately reduce the financial risk to explorers by reducing the search space and allowing a more targeted use of exploration expenditure.

In Western Australia, over 20 years of geological mapping and associated research in the Capricorn Orogen has led to a robust understanding of the orogen architecture and its temporal and thermal evolution. Recent in situ geochronology work in the northern part of the orogen, has bridged the gap between prospect-scale 'exploration' geoscience data with regional- and province-scale data, ultimately leading to a better understanding of the regional-scale drivers and pathways for gold mineralization in this part of the orogen. This information is critical for exploration models as it opens up older parts of the northern Capricorn basins that were traditionally considered unprospective, and refines and focusses exploration strategies to target the major crustal structures and their ancillary structures.

Key words: Capricorn Orogen, crustal architecture, geoscience data, mineralization, mineral system

INTRODUCTION

State- and federal-generated pre-competitive geoscience data is critical for exploration success. These relatively low-cost but high-quality regional-scale datasets ultimately reduce the financial risk to explorers by reducing the search space and allowing a more targeted use of exploration expenditure. Traditional geological survey generated datasets include regional-scale geophysics (e.g. aeromagnetic, gravity, and radiometric), whole rock and soil geochemistry, high-precision geochronology as well as detailed bedrock and regolith–landform mapping. Over the past decade, however, a wealth of new, government-generated datasets, including for example, mineral chemistry and isotope data or regional passive and active seismic data, have transformed the number and complexity of available datasets. Together these provide a more holistic understanding of the 4D geological evolution of a region at the province scale. Furthermore, by applying the mineral system concept (Wyborn et al., 1994; McCuaig and Hronsky, 2014), geological surveys can play a critical role in integrating regional-scale crustal evolution models with those of ore formation. This bridges a critical gap between traditional government geoscience and exploration geoscience (Figure 1), thus providing industry with a more complete data set that can open up previously unrecognised exploration targets and greatly refine and focus exploration strategies.

In Western Australia, over 20 years of geological mapping and associated research in the Capricorn Orogen has led to a robust understanding of the orogen architecture and its temporal and thermal evolution (e.g. Sheppard et al., 2004, 2005, 2007, 2010; Occhipinti et al., 2004; Korhonen and Johnson, 2015; Korhonen et al., 2017; Johnson et al., 2011, 2013, 2017). Recent in situ geochronology work in the northern part of the orogen (Fielding et al., 2017, 2018, 2019; Fielding and Johnson, 2019), has managed to bridge the gap between prospect-scale 'exploration' geoscience data and regional- and province-scale data, by integrating the timing of ore formation with the crustal evolution. This has led to a better understanding of the regional-scale drivers and pathways for gold mineralization in this part of the orogen (e.g. Fielding and Johnson, 2019).

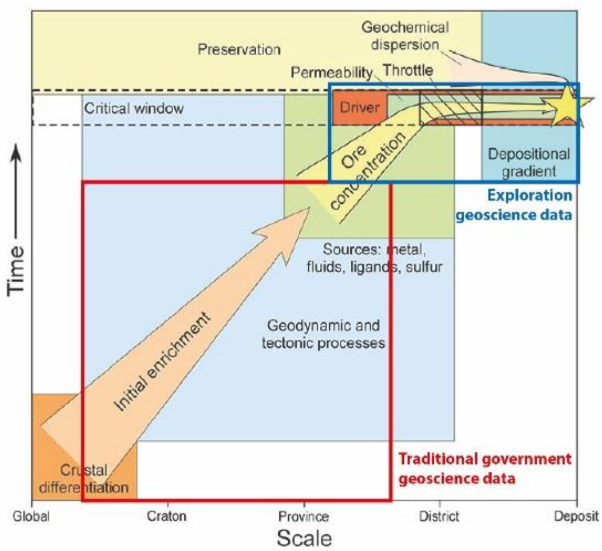

Figure 1. Conceptual mineral systems diagram showing the traditional space of government and exploration geoscience (after Wyborn et al., 1994).

This presentation outlines the wide variety of pre-competitive geoscience data collected and disseminated by the Geological Survey of Western Australia, and how data for the Capricorn Orogen were integrated to better understand the tectonic and metallogenic framework of the orogen.

THE CAPRICORN OROGEN

The Capricorn Orogen of Western Australia is a ~1000 km long, 500 km wide region of variably deformed and metamorphosed igneous and sedimentary rocks located between the Pilbara and Yilgarn Cratons (Figure 2). The orogen records the punctuated Paleoproterozoic assembly of these two cratons, and an exotic Archean to Paleoproterozoic continental fragment, the Glenburgh Terrane of the Gascoyne Province, to form the West Australian Craton (Sheppard et al., 2004; Occhipinti et al., 2004; Johnson et al., 2011, 2013, 2017), as well as over one billion years of subsequent intracratonic reworking (Sheppard et al., 2005, 2007, 2010; Korhonen and Johnson, 2015; Korhonen et al., 2017; Johnson et al., 2017). The orogen includes the deformed margins of the Pilbara and Yilgarn Cratons and associated continental margin rocks deposited in the Fortescue, Hamersley and Turee Creek Basins in the north; medium to high-grade metamorphic rocks of the Gascoyne Province; and various low-grade metasedimentary rocks deposited in the Ashburton, Blair, Padbury, Bryah, Yerrida, Earaheedy, Edmund and Collier Basins, that overlie these tectonic units. Despite the widespread abundance of gold, base metal and rare earth element occurrences throughout the orogen (Figure 2), the region has few working mines, although, over the past decade there have been some significant discoveries such as the world-class Cu–Au–Ag DeGrussa deposit in the east (Figure 2).

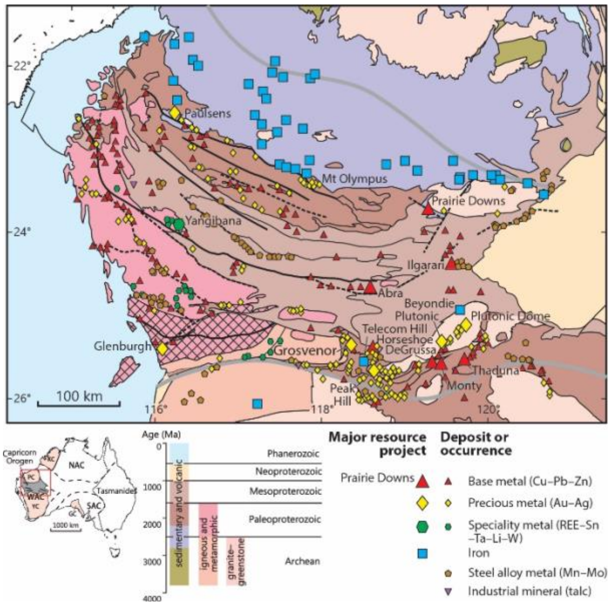

Figure 2. Simplified geological map of the Capricorn Orogen showing the location of mineral deposits and occurrences. The thick grey lines define the boundaries of the Capricorn Orogen. Abbreviations: GC – Gawler Craton; KC – Kimberley Craton; MI – Marymia inlier; NAC – North Australian Craton; PC – Pilbara Craton; SAC – South Australian Craton; WAC – West Australian Craton; YC – Yilgarn Craton; YGC – Yarlarweelor Gneiss Complex.

Crustal Architecture

A recent deep crustal seismic reflection survey across the Capricorn Orogen has defined the crustal architecture of the West Australian Craton (Johnson, et al., 2013). The survey identified several discrete crustal blocks that are exposed at the surface, including the Pilbara and Yilgarn Cratons, and the Glenburgh Terrane, as well as several unexposed deep crustal terranes (Johnson, et al., 2013). These discrete tectonic blocks are sutured along three major crustal structures, the Cardilya, Lyons River and Baring Downs Faults, which most likely represent collisional suture zones associated with the assembly of the West Australian Craton. The location and orientation of these major structures appear to have fundamentally controlled all subsequent intraplate reworking events, including the style and orientation of deformation, as well as the location of magmatism, sedimentation and mineralization (Johnson et al., 2013, 2017).

Linking Mineral Systems and Tectonic Evolution

The absolute age of mineralization and its timing relative to regional-scale tectonothermal events, is often poorly known but is critical for understanding the causes of ore formation (Hronsky et al., 2012). Without this information the key factors in ore generation may not be correctly identified, particularly in areas that have been subject to multiple hydrothermal or crustal reworking events (e.g. Rasmussen et al., 2006; Fielding et al., 2018). Dating hydrothermal activity and associated gold mineralization is inherently difficult as many chronometers are either scarce or susceptible to isotopic resetting during subsequent tectonothermal events (Chesley, 1999; Kerrich and Cassidy, 1994). However, the rare earth element-rich phosphate minerals monazite and xenotime are ideal chronometers for dating such events as they do not undergo lead loss at low temperature and they readily grow from hydrothermal fluids (Rasmussen et al., 2001, 2006; Vielreicher et al., 2003). In the northern Capricorn Orogen numerous gold-bearing systems including the >1 Moz gold deposits at Paulsens and Mount Olympus, as well as numerous other gold deposits and occurrences, were targeted for phosphate geochronology (Fielding et al., 2017, 2018, 2019). Furthermore, in this part of the orogen, there is a strong spatial relationship between the gold occurrences and their proximity to steeply-dipping, crustal-scale faults, or their ancillary structures, which juxtapose different stratigraphic packages or tectonic blocks (Johnson et al., 2013). The geochronology results demonstrate that the faults have a long lived history of (re)activation accompanied by hydrothermal fluid flow and gold mineralization with at least three episodes of hydrothermal gold mineralization, at c. 2400, 1770 and 1680 Ma (Fielding et al., 2017, 2018, 2019; Fielding and Johnson, 2019) that can be directly linked to discrete, regional-scale tectonothermal events recorded elsewhere in the orogen (e.g. Johnson et al., 2017).

These data demonstrate an intrinsic link between fault (re)activation, hydrothermal fluid flow and gold mineralization and indicate that the major crustal faults and their splays provide a critical pathway for mineralizing hydrothermal fluids (e.g. Fielding and Johnson, 2019). This information is critical for exploration models as it opens up older parts of the northern Capricorn basins that were traditionally considered unprospective, and refines and focusses exploration strategies to target the major crustal structures and their ancillary structures.

ACKNOWLEDGEMENTS

SPJ publishes with the permission of the Executive Director of the Geological Survey of Western Australia.

REFERENCES

Chesley, J. T., 1999, Integrative geochronology of ore deposits: new insights into the duration and timing of hydrothermal circulation, *in* Lambert, D. D., and Brown, P. E., *eds*., Reviews in economic geology, 12, 115-142.

Fielding, I.O.H., and Johnson, S.P., 2019, Gold metallogeny of the northern Capricorn Orogen, AEGC 2019 Extended Abstracts, this volume, 6p.

Fielding, I.O.H., Johnson, S.P., Meffre, S., Zi, J-W., Sheppard, S., Large, R.R., and Rasmussen, B., 2019, Linking gold mineralization to regional-scale drivers of mineral systems using in situ U–Pb geochronology and pyrite LA-ICP-MS element mapping: Geoscience Frontiers, 10, 89–105.

Fielding, I.O.H., Johnson, S.P., Zi, J-W., Rasmussen, B., Muhling, J.R., Dunkley, D.J., Sheppard, S., Wingate, M.T.D., and Rogers, J.R., 2017, Using in situ SHRIMP U-Pb monazite and xenotime geochronology to determine the age of orogenic gold mineralization: An example from the Paulsens Mine, southern Pilbara Craton: Economic Geology, 112, 1205–1230.

Fielding, I.O.H., Johnson, S.P., Zi, J-W., Sheppard, S., and Rasmussen, B., 2018, Neighbouring orogenic gold deposits may be the products of unrelated mineralizing events: Ore Geology Reviews, 95, 593–603.

Hronsky, J. M., Groves, D. I., Loucks, R. R., and Begg, G. C., 2012, A unified model for gold mineralisation in accretionary orogens and implications for regional scale exploration targeting methods: Mineralium Deposita, 47, 339-358.

Johnson, S.P., Korhonen, F.J., Kirkland, C.L., Cliff, J.B., Belousova, E.A., and Sheppard, S., 2017, An isotopic perspective on growth and differentiation of Proterozoic orogenic crust: From subduction magmatism to cratonization: Lithos, 268-271, 76–86.

Johnson, S.P., Sheppard, S., Rasmussen, B., Wingate, M.T.D., Kirkland, C.L., Muhling, J.R., Fletcher, I.R., and Belousova, E.A., 2011, Two collisions, two sutures: Punctuated pre-1950 Ma assembly of the West Australian Craton during the Ophthalmian and Glenburgh Orogenies: Precambrian Research, 189, 239–262.

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

Kerrich, R., and Cassidy, K. F., 1994, Temporal relationships of lode gold mineralization to accretion, magmatism, metamorphism and deformation — Archean to present: A review: Ore Geology Reviews, 9, 263-310.

Korhonen, F.J., and Johnson, S.P., 2015, The role of radiogenic heat in prolonged intraplate reworking: The Capricorn Orogen explained? Earth and Planetary Science Letters, 428, 22–32.

Korhonen, F.J., Johnson, S.P., Wingate, M.T.D., Kirkland, C.L., Fletcher, I.R., Dunkley, D.J., Roberts, M.P., Sheppard, S., Muhling, J.R., and Rasmussen, B., 2017, Radiogenic heating and craton-margin plate stresses as drivers for intraplate orogeny: Journal of Metamorphic Geology, 35, 631–661.

McCuaig, T.C., and Hronsky, J.M.A., 2014, The mineral system concept: The key to exploration targeting, in Building exploration capability for the 21st century edited by KD Kelley and HC Golden: Society of Economic Geologists, Inc, Special Publication 8, 153–175.

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

Rasmussen, B., Fletcher, I. R., and McNaughton, N. J., 2001, Dating low-grade metamorphic events by SHRIMP U-Pb analysis of monazite in shales: Geology, 29, 963-966.

Rasmussen, B., and Muhling, J. R., 2007, Monazite begets monazite: evidence for dissolution of detrital monazite and reprecipitation of syntectonic monazite during low-grade regional metamorphism: Contributions to Mineralogy and Petrology, 154, 675-689.

Sheppard, S., Bodorkos, S., Johnson, S.P., Wingate, M.T.D., and Kirkland, C.L., 2010, The Paleoproterozoic Capricorn Orogeny: Intracontinental reworking not continent-continent collision: Geological Survey of Western Australia, Report 108, 33p.

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

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

Vielreicher, N., Groves, D., Fletcher, I., McNaughton, N., and Rasmussen, B., 2003, Hydrothermal monazite and xenotime geochronology: a new direction for precise dating of orogenic gold mineralization: Society of Economic Geologists Newsletter, 53, 10-16.

Wyborn, L.A.I., Heinrich, C.A., and Jaques, A.L., 1994, Australian Proterozoic mineral systems: Essential ingredients and mappable criteria edited by PC Hallenstein: 1994 AusIMM Annual Conference, Darwin, Northern Territory, 1994/08/05: Australian Institute of Mining and Metallurgy, Australian mining looks north - the challenges and choices, 109–115.