

Implications of the Capricorn deep seismic survey for mineral systems

by

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Introduction

The acquisition of the Capricorn deep seismic survey in 2010 was carried out as a collaborative project between the Geological Survey of Western Australia (GSWA), AuScope, and Geoscience Australia, with GSWA's funding provided by the Western Australian Government's Exploration Incentive Scheme (EIS) (Kennett et al., 2011). The survey has provided new insights into the architecture of the Capricorn Orogen, and into its geodynamic setting and tectonic history (Plate 2; Thorne et al., 2011; Johnson et al., 2011a; Korsch et al., 2011). This improved understanding of Capricorn Orogen development can be used to re-evaluate the mineral systems within the orogen, and the resultant implications for regional-scale mineral prospectivity.

One of the aims of the survey was to identify structures that cut through the crust to the mantle and form pathways for fluid flow to mineral systems (Kennett et al., 2011). Known significant mineralization in the Capricorn Orogen is restricted to the reworked orogenic forelands formed along the Pilbara and Yilgarn Craton margins. The hinterland of the Capricorn Orogen has not had a prominent history of major mineral deposit discovery, and currently lacks major resource projects or operating mines (Frontispiece 1; Fig. 1). Central to a reassessment of the orogen's prospectivity is the growing understanding that most giant orebodies are generated by lithosphere-scale deep plumbing systems that concentrate fluids, energy, and metals into specific sites in the crust. These are often related to sites of fossil subduction zones or to old cratonic margins; both settings have been interpreted from the new Capricorn deep seismic survey data (Thorne et al., 2011; Johnson et al., 2011a; Korsch et al., 2011).

Mineral systems in the Capricorn Orogen

Several mineral systems have been recognized in the Capricorn Orogen (Frontispiece 1; Plate 1). These include the world-class hematite iron-ore deposits of the

Hamersley Basin, which occur within structural settings in the Ophthalmia Fold Belt; volcanic-hosted metal sulfide (VHMS) copper–gold deposits in the Bryah Basin on the Yilgarn Craton margin; orogenic lode-gold mineralization, such as that at Peak Hill in the southern Capricorn Orogen margin, Glenburgh and the Star of Mangaroon in the Gascoyne Province, and at Paulsens and Mount Olympus in the northern Capricorn Orogen margin; various intrusion- and shear zone related base metal, tungsten, rare earth element (REE), uranium, and rare-metal deposits in the Gascoyne Province; and lead–copper–zinc sediment-hosted mineralization at Abra within the Edmund Basin (Frontispiece 1; Plate 1).

Ophthalmia Fold Belt

The world-class iron deposits of Western Australia's Pilbara region are currently a major driver of Australia's economy. The enriched iron-ore deposits of the Hamersley Basin currently have an estimated resource of over 40 billion tonnes, mainly consisting of banded iron-formation (BIF) hosted bedded iron deposits and channel iron deposits.

The genesis of the Hamersley Basin BIF-hosted iron ores has recently been the subject of a major review by Morris and Kneeshaw (2011). Two major ore types are recognized: the dominant martite–goethite ores, which developed in the Mesozoic to Paleocene, and the premium Paleoproterozoic martite – microplaty hematite ores.

Models for the development of the martite – microplaty hematite ores have been controversial. Initial models, developed in the 1980s (e.g. Morris, 1985), envisaged Paleoproterozoic supergene martite–goethite ores that were upgraded to martite – microplaty hematite ores by regional metamorphism or diagenesis and hydrothermal activity at 80–100°C, during burial by the Proterozoic lower Wyloo Group (c. 2200 Ma). An alternative hypogene–supergene model for the martite – microplaty hematite ores has been proposed following the identification of hydrothermal fluid-flow related to the c. 2200 Ma Ophthalmian Orogeny (e.g. Powell et al.,

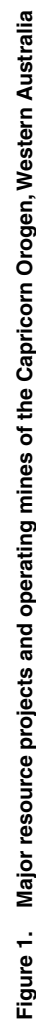


Figure 1. Major resource projects and operating mines of the Capricorn Orogen, Western Australia

1999; Taylor et al., 2001; Brown et al., 2004). The timing of the martite – microplaty hematite ore formation, relative to the history of deposition, deformation, and metamorphism in the Hamersley Basin, and adjacent Turee Creek and Ashburton Basins, is critical to the assessment of these competing models (see Martin and Morris, 2010).

It is clear from Plates 1 and 2 that the major deposits at Tom Price in the Turner Syncline, above the Moona Fault and Paraburdoo on the Nanjilgardy Fault, are spatially associated with large crustal-scale faults, interpreted as being active during the Ophthalmian Orogeny (Martin and Morris, 2010; Thorne et al., 2011; Johnson et al., 2011a; Korsch et al., 2011). This appears to provide support for the hypogene–supergene model, in that there is an expectation of large-scale fluid flow through the faults at the time of orebody formation. It is also unclear how the hydrothermal upgrading of supergene ores could operate as a closed system in such a setting. This may have implications for the exploration for blind premium martite – microplaty hematite orebodies, particularly beneath the Turee Creek and Wyloo Groups south of the Nanjilgardy Fault and along the Soda Fault (Frontispiece 1–3; Plate 1).

Northern Capricorn Orogen: orogenic gold

Evidence of vein-related, orogenic gold mineralization is widespread in the northern Capricorn Orogen (Plate 1; Frontispiece 1); however, most of the historical workings are small and relatively shallow. The largest gold deposits occur within Fortescue Group rocks at Paulsens in the Wyloo Dome, and in Ashburton Basin rocks at Mount Olympus southeast of Paraburdoo. Although host-rock geology is different for each of these deposits, both occur in close proximity to a major mantle-tapping structure, the Nanjilgardy Fault (Thorne et al., 2011).

Paulsens Mine commenced production in 2005, and since that time has consistently produced 70 000 to 80 000 ounces of gold per annum (Northern Star Resources Limited, 2011). It currently has an Indicated and Inferred Mineral Resource estimate of 1 268 000 t @ 5.3g/t for 226 000 oz of gold. Mineralization occurs within a structurally controlled quartz vein, hosted by a folded metasedimentary sequence within the Fortescue Group. Gold is associated with quartz, carbonate, and pyrite, and the high-grade gold is commonly associated with zones of massive sulfides (Northern Star Resources Limited, 2011).

The Mount Olympus mine is not currently operating, but produced about 350 000 oz of gold between 1999 and 2004 (Sipa Resources Limited, 2011). The deposit is hosted by low-grade metasedimentary rocks of the Mount McGrath Formation (upper Wyloo Group), and mineralization consists of submicrometre-sized or solid solution gold in disseminated arsenian pyrite (Young et al., 2003). Mineralization has been dated at c. 1738 Ma, and is associated with quartz–sericite alteration that post-dates the regional metamorphism (Young et al., 2003; Sener et

al., 2005).

Southern Capricorn Orogen

In the southern Capricorn Orogen, the Errabiddy Shear Zone has been recognized as a suture between the Narryer Terrane (of the Yilgarn Craton) and the Glenburgh Terrane (Johnson et al., 2011a); however, it shows little evidence of major mineralization, despite being the target of diamond exploration (e.g. Flint et al., 2000). Based on the interpretation of 10GA–CP3, the shear is north-dipping, and is cut off at about 10 km depth by the south-dipping Cardilya Fault, giving it no direct link to the underlying lithospheric mantle (Johnson et al., 2011a).

The Cardilya Fault is recognized as a major crustal-scale fault that offsets the Mohorovičić discontinuity ('the Moho') and separates the Archean Yilgarn Craton from the Paleoproterozoic Gascoyne Province at depth (Johnson et al., 2011a), but as yet shows little evidence of mineralization at the surface.

To the east of the seismic survey, the Bryah Basin, which overlies Yilgarn Craton basement, has recently seen the discovery of the high-grade DeGrussa copper–gold deposit within Sandfire Resources NL Doolgunna tenement package. The deposit has been interpreted as a VHMS, and has Indicated and Inferred Resource of 10.67 Mt @ 5.6% copper, 1.9g/t gold, and 15g/t silver, containing 600 000 t of copper, 660 000 oz of gold, and 5.1 Moz of silver (Sandfire Resources NL, 2011).

There is also renewed interest in gold exploration in the Peak Hill Schist, which forms the contact between the Bryah Basin and the underlying Marymia Inlier, and contains vein-related, orogenic gold mineralization both at the historic Peak Hill Gold Mine and at a recent discovery by Alchemy Resources at Central Bore (Flint et al., 2000; Pirajno et al., 2000; Alchemy Resources Limited, 2011).

Gascoyne Province

The Gascoyne Province is a major Proterozoic tectonic zone that separates the Yilgarn and Pilbara Cratons (Johnson et al., 2011a,b). The oldest part of the province, the Neoarchean to Paleoproterozoic Glenburgh Terrane, has been interpreted as exotic to both the bounding cratons, and is thus separated from the Yilgarn and Pilbara Cratons by two suture zones (Johnson et al., 2011a–c). The province hosts a variety of mineralization styles (Frontispiece 1; Plate 1), including intrusion and shear zone hosted deposits such as:

- molybdenum–copper–tungsten–lead within the Minnie Creek batholith
- carbonatite-related REE, including uranium, within the Gifford Creek Carbonatite Complex
- scheelite skarns within the Chalba Shear Zone and at Nardoo Well
- rare metal (tantalum, bismuth, beryllium) pegmatites at Morrissey Hill

- copper–lead–zinc(–gold) base metal deposits at Mount James, Glenburgh, and the Star of Mangaroon.

Two of the more significant deposits, the carbonatite-related REE mineralization at Gifford Creek and the base metal – gold deposits at Glenburgh, appear to be associated with major crustal sutures along the former margins of the Glenburgh Terrane.

The Gifford Creek Carbonatite Complex comprises sills, dykes, and veins of ferroan carbonatite, ironstone, and hydrothermally altered rocks (fenites), which intrude porphyritic granites (the Pimbyana Granite and Yangibana Granite) of the 1680–1620 Ma Durlacher Supersuite in the central part of the Mangaroon Zone (Frontispiece 1; Plate 1). These rocks, especially the ironstones, contain significant REE and uranium mineralization, with an estimated total resource of ~2.7 Mt, averaging 1.52% REE oxides (Flint and Abeyasinghe, 2000). The ferroan carbonatite sills and dykes have been emplaced along a northwest-trending belt, close to and parallel to the Lyons River Fault, whereas the veins of iron-oxide minerals and quartz are mostly perpendicular to that of the carbonatite sills (Frontispiece 1; Plate 1; Pearson et al., 1996). The complex shares the characteristics of igneous systems related to alkaline magmatism in extensional settings, and may be the upper crustal response to a presently unexposed alkaline intrusion (Pirajno et al., 2008). The age of the carbonatite complex is not precisely known, but is younger than c. 1660 Ma — the age of the granites that it intrudes — and older than c. 955 Ma, as some of the ironstones have been folded and deformed during the 1030–955 Ma Edmundian Orogeny. Emplacement of the sills appears to have been controlled by the Lyons River Fault, a major crustal suture that separates the Glenburgh Terrane from the Bandee Seismic Province of the Pilbara Craton (Johnson et al., 2011a). Although this structure is primarily related to the 2215–2145 Ma Ophthalmian Orogeny collision, it has been reactivated numerous times throughout the Proterozoic (Johnson et al., 2011b).

At Glenburgh, in the southern part of the province (Frontispiece 1; Plate 1), base metal and gold mineralization is hosted within high-grade pelitic gneisses that form decametre-scale rafts within granitic gneisses of the 2005–1970 Ma Dalgaringa Supersuite. These granitic rocks formed in a continental-margin arc on the southern margin of the Glenburgh Terrane, prior to the collision of the combined Pilbara Craton – Glenburgh Terrane with the Yilgarn Craton during the 2005–1950 Ma Glenburgh Orogeny (Sheppard et al., 2004; Occhipinti et al., 2004; Johnson et al., 2011d). Subsequent greenschist-facies alteration has upgraded the primary deposit into higher-grade shear zones. Currently, the deposit has an estimated total resource of ~7.2 Mt @ 1.6 g/t gold for 360 000 oz of contained gold, at a 0.8 g/t gold cutoff (Gascoyne Resources Limited, 2011). The age of the secondary upgrading is not known.

Edmund Basin

The Edmund and Collier Basins have a history of minor gold, base metal, and phosphate production; however, only one major orebody, the Abra polymetallic deposit, has

been discovered in these rocks to date. This deposit occurs within the eastern part of the Edmund Basin, in a fault-bounded structural corridor that links up with the Lyons River Fault system (Frontispiece 1–3; Plate 1), a major mantle-tapping structure interpreted to be the principal crustal suture between the Bandee Seismic Province of the Pilbara Craton and the Glenburgh Terrane (Johnson et al., 2011a, Korsch et al., 2011).

The Abra deposit has a total Indicated and Inferred resource estimate of 93 Mt at 4% lead and 10 g/t silver, and 14 Mt at 0.6% copper and 0.5 g/t gold (Rasmussen et al., 2010). There is only a weak surface expression of the mineral system, most of which has been delineated using geophysical techniques and drilling. The Abra deposit remains open in most directions, supporting its status as the most significant mineral discovery in the central Capricorn Orogen at the present time.

The Abra mineralization occurs in the upper part of the Irregully Formation and the lower part of the overlying Kiangi Creek Formation. Mineralization is centred on a funnel-shaped brecciated zone, interpreted as a breccia feeder pipe, overlain by stratabound mineralization (Vogt, 1995; Pirajno et al., 2009; Rasmussen et al., 2010) divided into a lower Black Zone and upper Red Zone. The Black Zone comprises veins and rhythmically banded galena, sphalerite, and pyrite, with minor tetrahedrite, chalcopyrite, and scheelite. These ore minerals are associated with laminated and/or brecciated hematite, magnetite, iron-rich carbonate, barite, and scheelite. The Red Zone is dominated by barite, banded jaspilite, hematite, galena, pyrite, quartz, abundant barite, and siderite (Pirajno et al., 2009; Rasmussen et al., 2010). Abra mineralization is considered the product of a dynamic, multiphase hydrothermal system (Pirajno et al., 2009).

The age of mineralization is currently poorly constrained. Direct dating of pyrite from the Black Zone using the Re–Os technique has provided a date of c. 1280 Ma (GSWA, unpublished data). Hydrothermal monazite extracted from sedimentary rocks of the Irregully and lower Kiangi Creek Formations yield a range of ages, with the youngest population at 1385 ± 20 Ma (Rasmussen et al., 2010). However, these dates are at odds with the stratigraphic relationships, which suggest that mineralization is a syndepositional feature (Collins and McDonald, 1994; Thorne et al., 2009). Primary mineralization may have occurred during the deposition of the Irregully and lower Kiangi Creek Formations, with secondary upgrading by intense hydrothermal alteration during the 1385–1200 Ma Mutherbukin Tectonic Event. These hydrothermal fluids may be linked to similar-aged magmatic and hydrothermal activity along the Lyons River Fault system that produced the Gifford Creek Carbonatite Complex.

Future work

The Capricorn seismic survey has identified a series of structures cutting through the crust to the mantle, representing either the ancient margins of the Archean Yilgarn and Pilbara Cratons, or the sites of Paleoproterozoic collision zones reactivated periodically

throughout the Proterozoic. Economic mineralization has yet to be discovered along several of these structures, including the Cardilya and Lyons River Faults; however, the survey has highlighted a spatial relationship between crustal-scale faults and premium martite – microplaty hematite ores in the northern Capricorn Orogen margin.

Future work by GSWA, using EIS funding and conducted in partnership with the Centre for Exploration Targeting at The University of Western Australia, will include an integrated geological and geophysical study of the Capricorn Orogen and its mineral prospectivity. The aim of this study will be to obtain a '4D' understanding of the whole orogen that incorporates both the results presented here, and the other new geophysical, geochronological, and isotopic data that is currently being generated, including a recently acquired magnetotelluric traverse that crossed the orogen from the Marymia Inlier to the Sylvania Inlier. A challenge is to project the structures observed in the seismic survey to the east, where the Gascoyne Province may wedge out, and where the Yilgarn and Pilbara Cratons may be in direct contact (e.g. Cawood and Tyler, 2004, fig. 3).

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