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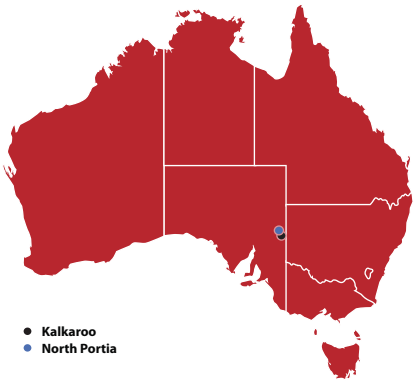

Copper-gold deposits of the Benagerie Ridge, Curnamona Province

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INTRODUCTION

The Kalkaroo (-31.74°, 140.52°) and North Portia (-31.43°, 140.45°) copper-gold deposits and several similar prospects lie beneath the Lake Frome plains, approximately 400–450 km north-east of Adelaide (Figure 1). These deposits are located on the Benagerie Ridge, which is a tectonic horst of greenschist facies, Paleoproterozoic metasedimentary rocks of the Willyama Supergroup (1720–1640 Ma), unconformably overlain by Mesoproterozoic felsic volcanics and associated intrusives (1595–1580 Ma) located within the Curnamona Province (Conor and Priess, 2008).

This portion of the Curnamona Province is almost entirely covered by younger sedimentary rocks, including thick Neoproterozoic to Early Cambrian sequences flanking the Benagerie Ridge to a ubiquitous 20 to 75 m thick cover of Cenozoic clays and sands. As a consequence, the Benagerie Ridge was never accessible to the early prospectors and there is no history of hard rock mining. All modern exploration has therefore relied extensively on geophysical methods and various drilling techniques.

Copper-gold mineralisation was discovered at both locations in the 1990s by drilling magnetic and bedrock geochemical anomalies. Havilah Resources' subsequent exploration was guided by 3D geological models that it generated from the more than 50 000 m of previous drilling data. At Kalkaroo it was observed that the mineralisation was distributed along a boomerang shape corresponding to a particular stratigraphic and magnetic horizon. Subsequently, JORC Resources totalling more than 1.4 Mt of copper and 3.6 Moz of gold were drilled out in the region by specifically targeting this structurally controlled, stratabound replacement-style mineralisation (Table 1).

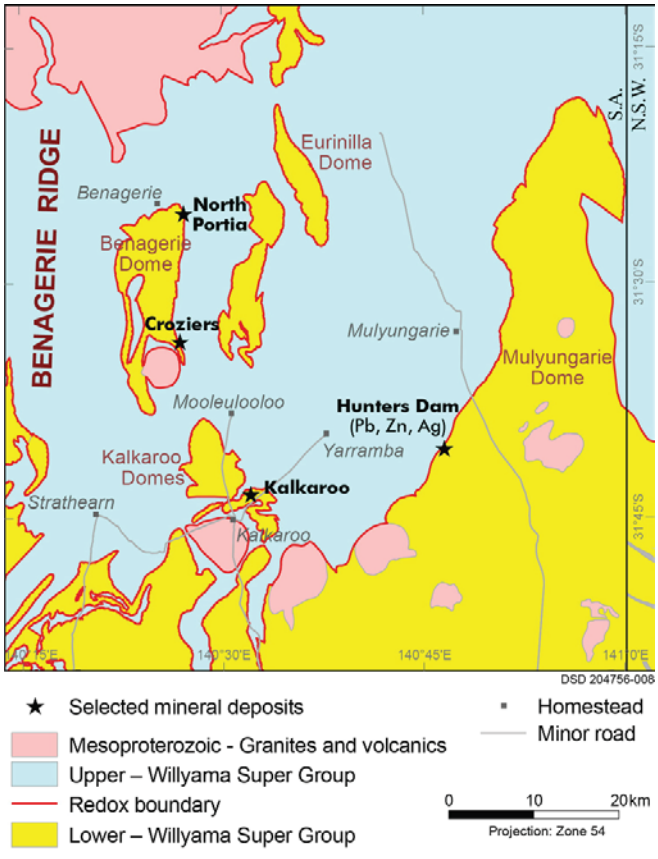

FIG 1 – Regional geology and location.

REGIONAL GEOLOGY

An important geological feature of the Benagerie Ridge is a regionally persistent redox boundary that coincides with the transition from (footwall) magnetite-bearing psammitic metasedimentary rocks of the Curnamona Group to (hanging wall) carbonaceous pelites of the Strathearn or Saltbush Group (Leyh and Conor, 2000; Conor, 2006). This change is clearly visible as a regionally prominent magnetic gradient

TABLE 1 – Mineral Resources at 31 May 2017.

Mineral Resources[a]	Tonnage (Mt)	Cu grade (%)	Au grade (g/t)
Kalkaroo			
Indicated and Inferred Resource (gold cap)	21 700 000	-	0.74
Measured Resource (copper-gold)	74 500 000	0.56	0.42
Indicated Resource (copper-gold)	46 200 000	0.50	0.34
Inferred Resource (copper-gold)	111 800 000	0.44	0.35
Total Kalkaroo Resource (excluding gold cap)	232 500 000	0.49	0.37
North Portia			
Indicated Resource (supergene, oxidised)	2 750 000	1.0	0.65
Inferred Resource (sulfide)	8 610 000	0.85	0.64
Total North Portia Resource	11 360 000	0.89	0.64

a. Mineral Resources are reporting inclusive of Ore Reserves. Source: based on JORC resources released to the Australian Securities Exchange on 29 March 2017 (for Kalkaroo) and 23 October 2010 (for North Portia).

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on aeromagnetic images and is marked by a 120–170 m thick package of variably albite-altered, pyritic and scapolitic pelites and calc-pelites, with distinctive carbonate beds, ellipsoids and rare thin quartz-hematite banded iron formation beds that are considered to be at least partly of evaporitic origin (Teale and Fanning, 2000). This formation is informally referred to as the mine sequence or prospective sequence because it is host to virtually all known copper-gold mineralisation drilled in the area, including the Kalkaroo and North Portia deposits. Formally, it is termed the Portia Formation, and has been dated at 1705 Ma (Conor and Preiss, 2008). The sequence has been subdivided into ten distinctive subunits that are remarkably consistent over the entire area (Teale and Fanning, 2000). Carbonaceous pelites that are ~200 m stratigraphically above the Portia Formation contain widespread low-grade Pb and Zn mineralisation. Much of the sequence was affected by a pervasive albite alteration event that occurred around 1630 Ma (Teale and Fanning, 2000), which at an orebody scale is frequently overprinted with pinkish-red iron and potassic alteration, and greenish calc-silicate alteration.

The metasedimentary rocks are of lower greenschist facies metamorphic grade and there is no D1 layer parallel schistosity, pointing to a much shallower depth of burial than elsewhere in the Curnamona Province. As a consequence there is frequent preservation of delicate sedimentary features in the Portia Formation, including ellipsoids of presumed diagenetic origin and various drape and loading structures.

The chief structural features are large domes and basins caused by the interference of two orthogonal sets of open folds (for example, Benagerie and Kalkaroo domes, Figure 1) and cross-cutting brittle fracture faults. Axial planar schistosity associated with this folding is pervasive. A string of high-level granite intrusions belonging to the 1595–1580 Ma Ninnerie Supersuite (Wade, 2011) intrude the metasedimentary sequence at least 1 km stratigraphically below the Portia Formation. They do not crop out, but are clearly identified by distinctive circular gravity and magnetic lows, and are most likely cogenetic with the Benagerie Volcanic Suite.

Mineralisation is considered to have formed late in the Olarian Orogeny event between 1620 and 1590 Ma (Teale and Fanning, 2000) at about the time of intrusion of the Ninnerie Supersuite.

ORE DEPOSIT FEATURES

The following descriptions are drawn directly from the authors' own experience and observations, supported by the high-quality unpublished work of numerous earlier company and consultant geologists.

At Kalkaroo, the bulk of the copper-gold mineralisation is stratabound, being hosted by the Portia Formation. Extensive resource drilling shows continuous mineralisation for more than 3 km of strike that curves around the 35° north-dipping northern nose of the Kalkaroo south dome (Figure 2). The best primary mineralisation is found in the two middle units of the Portia Formation, where it typically occurs as fine-grained chalcopyrite-pyrite replacing carbonate-rich laminae (Figure 4). Cross-cutting sulfide-carbonate veinlets are also common, and bleeding from these into the laminated mineralisation provides clear evidence of highly selective replacement-style mineralisation (Figure 5). Primary sulfide mineralisation is comparatively simple, comprising almost exclusively chalcopyrite-pyrite with entrained free gold grains. Molybdenite is a widespread but minor component and is not intimately associated with the chalcopyrite-pyrite, and usually occurs in later brittle fractures.

Deep weathering during the Cenozoic and the resulting vertical redistribution of metals has produced a stratified supergene mineralisation profile, consisting of a gold cap, successively underlain by a native copper zone and a chalcocite zone, immediately above the primary sulfides (Figure 2). This profile is relatively simple around the main dome but is distorted at Kalkaroo West, where the base of weathering plunges to a depth of over 250 m due to extensive fracturing associated with faulting (Figure 3).

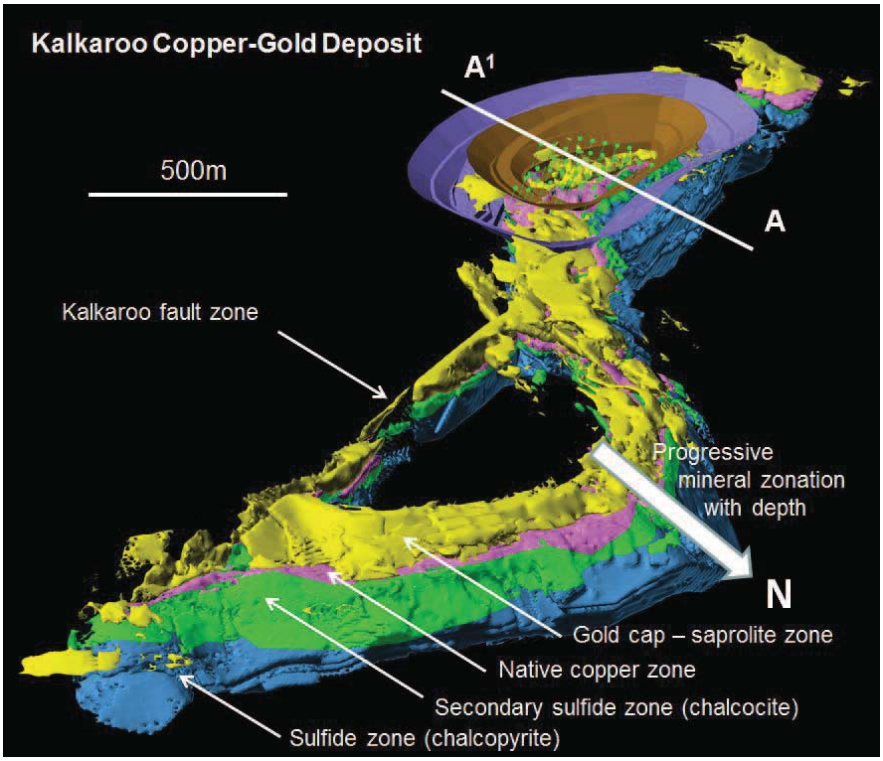

FIG 2 – Kalkaroo resource envelope from block model shell showing weathering mineralisation zonation.

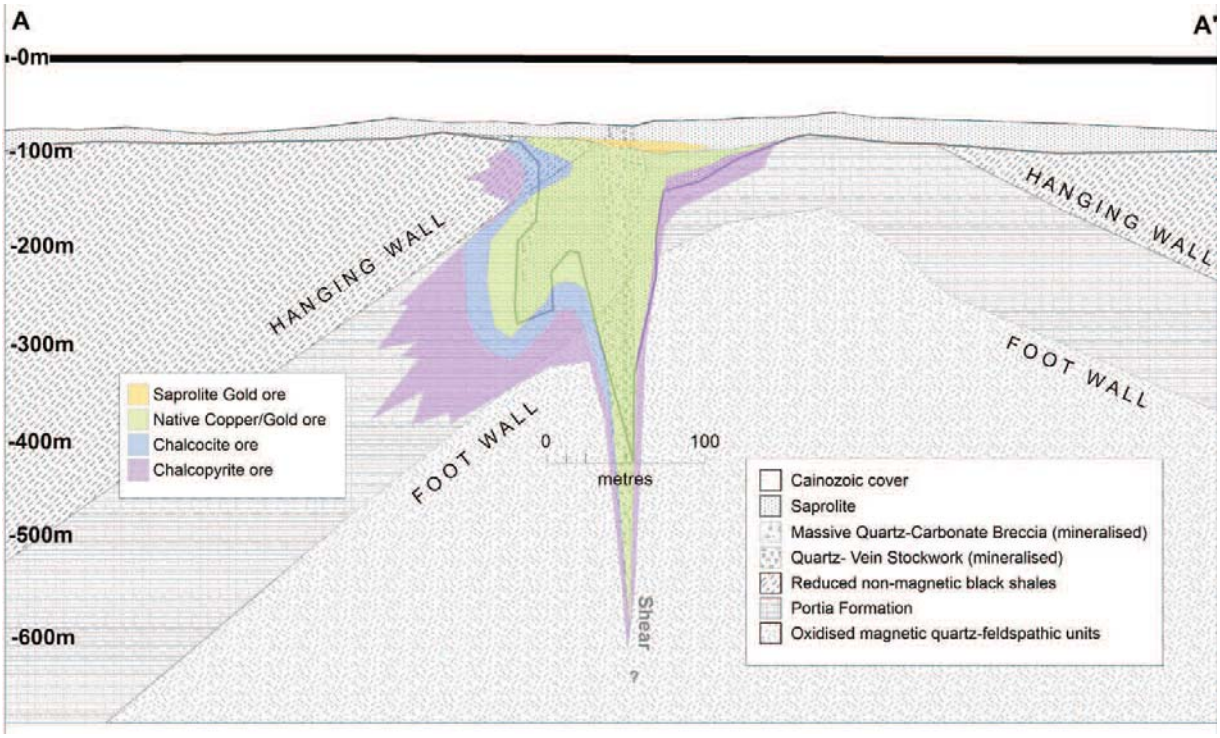

FIG 3 – West Kalkaroo cross-section.

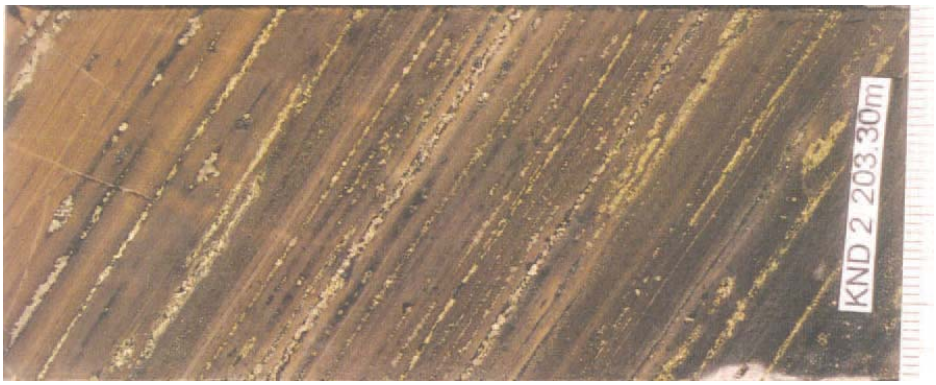

FIG 4 – Beige albitite rock with chalcopyrite replacing original carbonate or pyrite laminae (after Teale, 2000).

FIG 5 – Vein and associated bedding plane replacement-style chalcopyrite mineralisation emanating from a biotite ± carbonate vein in hard grey albitite from Havilah drill hole KKDD0286, 212.8 m.

At the western and eastern ends of the Kalkaroo deposit, the Portia Formation is cut by the major regional Kalkaroo fault, a near-vertical ENE-trending mineralised quartz-carbonate (±magnetite-biotite) vein breccia system that is up to 50 m wide (Figure 2). The Kalkaroo fault itself is often well mineralised and produces noticeable upgrading of the copper and gold grades where it transects the Portia Formation at West Kalkaroo (Figure 3). A halo of mineralised quartz-carbonate and biotite veins surround the main structure. The mineralising events were associated with early sodium-rich alteration, which is manifest as widespread pervasive and intense albitisation throughout the sequence. Potassium-iron alteration is more intimately associated with the mineralising events in the form of an intense halo of very fine-grained pink K-feldspar-magnetite alteration around the Kalkaroo fault, which in addition to the primary magnetite in the footwall gives rise to a strong magnetic anomaly. Narrow biotite and K-feldspar selvedges to veins and replacement along bedding planes is ubiquitous. Biotite spotting and clots are also common, often as the replacement of scapolite or carbonate

rhombs (product of albite alteration) and are frequently accompanied by chalcopyrite.

The simplest explanation for these observations is that the Kalkaroo fault (and possibly related vertical structures) formed the conduit or channel ways for the rising mineralising fluids, which reacted with the pyritic and carbonate-rich Portia Formation to precipitate copper sulfide and gold. The dome structure may have acted as a structural trap for the rising mineralising fluids carried by these vertical structures, with the reduced hanging wall pelites representing both a physical and chemical barrier.

North Portia copper-gold mineralisation has very similar features to Kalkaroo and is mostly confined to the lower carbonate and overlying albitite unit of the Portia Formation, located on the 55° east-dipping eastern limb of the Benagerie dome (Figure 1). As at Kalkaroo, predominantly chalcopyrite-pyrite-carbonate mineralisation has mostly formed in regularly spaced bedding parallel laminations, preferentially replacing carbonate beds and pyritic laminations, with frequent cross-cutting veinlets and sulfide blebs. Molybdenum forms a geochemical halo surrounding the copper-gold mineralisation. Similarly to Kalkaroo, locally high-grade molybdenum concentrations are found in the latest-stage fractures and joints, and are associated with potassic (biotite and K-feldspar) veining and alteration.

North Portia mineralisation may be controlled by an ENE-trending fault (similar to the Kalkaroo fault orientation) that is very evident on both gravity and aeromagnetic data, although there is abundant evidence for strike and in part bedding parallel faulting that disrupts and truncates the orebody.

The unusual Portia gold deposit, lying 500 m south of the North Portia copper-gold deposit, contains an Inferred Resource of 67 000 oz of mostly coarse eluvial gold at the base of the Cenozoic cover. The gold occurs in a horizontal, distinctive silty clay unit averaging about 2 m thick, and also in the underlying Portia Formation saprolite bedrock, where it is hosted by cross-cutting and layer parallel base metal-carbonate veins and albite alteration selvedges. The gold is typically angular and of very local derivation, probably with some supergene enrichment component. The source could have been North Portia, but an atypical metal association of Bi, Te and Sb plus abundant accessory tourmaline and barite may indicate another (as yet unrecognised) possibly lower temperature source for the primary gold.

Widespread subeconomic copper-gold mineralisation hosted by the Portia Formation also covers thousands of hectares on the eastern and western limbs of the Eurinilla dome, and extends for tens of kilometres of strike at Croziers in the southern Benagerie dome (Figure 1).

ORIGIN AND EXPLORATION IMPLICATIONS

The geological evidence indicates that the stratabound copper-gold mineralisation of the Benagerie Ridge formed as the result of a favourable combination of stratigraphic (reactive sedimentary beds) and structural controls (domes cut by late brittle fracture faults). The mineralising fluids were generated during the waning stages of the 1620–1590 Ma Olarian Orogeny, at the same time as extensive felsic magmas of the Ninnerie Supersuite were being mobilised and emplaced at depth. The mineralisation formed in the youngest brittle fracture cross-cutting structures after extensive waves of pervasive albite alteration permeated the sequence.

The general characteristics of this mineralisation, particularly its stratabound nature and location at a regional redox boundary, are more akin to the Central African copper belt style. The geochemical signatures of iron oxide copper-gold deposits – namely enriched uranium, light rare earths and an iron-rich host – are absent.

It is noted that the copper-gold-molybdenum association, with peripheral lead-zinc mineralisation, is very reminiscent of a zoned magmatic association (compare porphyry system). A curious regional link is provided by the ubiquitous cobalt-rich pyrite that is found in all copper-gold deposits in the region, irrespective of age or origin, and also in aplitic intrusions near Broken Hill. This is unlikely to be coincidental, and points to a widespread regional mineralising event with potential to generate large mineral deposits in favourable stratigraphic and structural settings.

Given that the depth of cover is generally prohibitive for surface geochemical sampling methods, aeromagnetics and low-cost aircore drilling remain the first-pass exploration tools of choice. Considering there is more than 300 km of prospective unexplored strike of the Portia Formation, the exploration potential of the Benagerie Ridge is largely untested, and it is likely that the application of proven exploration methods will yield many more discoveries in the future and confirm the Benagerie Ridge as a major, hitherto unrecognised, Australian copper province.

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