Cambrian mineral resources come of age — the Kanmantoo revival

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Introduction

It seems that everything old is new again. This certainly appears to be the case for the Kanmantoo Trough, located within Australia's oldest mining province, and currently experiencing an exploration revival.

The Kanmantoo Trough is an arcuate zone of metamorphosed and deformed Cambrian rocks of the Stansbury Basin that crop out along the eastern Mount Lofty Ranges, through Fleurieu Peninsula, and extending to Kangaroo Island in the south (Fig. 1). Related Cambrian rocks are known to the east beneath the Tertiary Murray Basin, and to the south along the Padthaway Ridge, with correlatives in the Glenelg River region of western Victoria.

Mineralisation is widespread within the trough and, with recent gains in geological and metallogenic understanding, it continues to be highly prospective. The region is host to numerous historical base and precious metal mines that have been mined sporadically since the mid-1800s.

The Kanmantoo copper mine (Hillgrove Resources Ltd) and Angas Zinc Project (Terramin Australia Pty Ltd) are currently the 'hottest' prospects within the Kanmantoo Trough (Fig. 2). With strong metal prices and recent upgrades of resource and grade definition, these once marginal prospects are now considered to be economically viable.

This article summarises the mineral potential of the Kanmantoo area and the recent advances made by these two relatively new mineral exploration companies to South Australia.

Geological setting of the Kanmantoo Trough

Predominantly immature clastic sediments were deposited in the Kanmantoo Trough during the Early Cambrian as a result of the last of several phases of rifting in the Adelaide Geosyncline. Three transgressive–regressive sequences were deposited before the onset of the Delamerian Orogeny in the late-Early Cambrian. Syn- to post-tectonic felsic and mafic bodies intruded the sedimentary sequence and are spatially related to higher grade metamorphic zones in the Fleurieu Arc, Padthaway Ridge and Glenelg River regions. Metamorphic grades range from greenschist to amphibolite facies (Burtt, 2003).

D_1 of the Delamerian Orogeny produced a layer parallel schistocity that is overprinted by D_2 and D_3 deformation. D_2 structures dominate the Kanmantoo Trough and Fleurieu Arc and are expressed as major north–south-trending upright to steeply inclined folds plunging shallowly southwards with an associated axial plane crenulation cleavage. D_2 structures are locally overprinted by late D_3 shear zones and north-northwest-trending D_3 folds (sub- to coaxial to D_2) in the high-grade metamorphic cores (Burtt, 2003).

Mineralisation models

There are two main mineralisation models for the Kanmantoo Trough — syngenetic, hydrothermal 'exhalite' Pb–Zn–Ag mineralisation (i.e. Broken Hill type) and epigenetic, hydrothermal Cu–Au mineralisation (i.e. Kanmantoo Mine type; Burtt, 2003). Both styles of mineralisation occur within a thick sequence of turbidites that contains a distinctive sequence of lithologies resulting from metamorphism of syngenetically or epigenetically altered sediments. Mineralisation is spatially related to and hosted by these lithologies, which consist of garnet quartzite, BIF, quartz–biotite–garnet±gahnite schist and quartz–biotite–andalusite±garnet±chlorite schist.

Mineralisation at the Kanmantoo, Angas and other prospects within the trough is thought to have undergone

Northwesterly aerial view of the Kanmantoo Mine and plant, with the overburden dump and tailings dam behind, 1982. (Photo 036406)

varying degrees of remobilisation as a result of metamorphic and structural modification during the Delamerian Orogeny. Mineralisation is stratigraphically restricted to the Tapanappa Formation of the Kanmantoo Group (Fig. 3).

Past and present mineral explorers target the distinctive lithologies (described above) within the Tapanappa Formation, along with favourable structures that may have thickened and concentrated mineralisation into isoclinal fold hinges, crosscutting shears and possible stratiform, plunging, boudin-like pipes.

Kanmantoo Mine redevelopment — Hillgrove Resources Ltd

Recent strong metal prices, in particular copper, have encouraged Hillgrove Resources to re-evaluate the economic viability of the historic Kanmantoo Mine, 55 km southeast of Adelaide.

In 2004, Hillgrove Resources acquired a 100% interest in Mining Lease 5776 (excluding oxide ore stockpiles and tailings) covering the former workings of the Kanmantoo Mine, which operated from 1971 to 1976, producing 39 000 t of copper concentrate. Previous mining operations ceased due to low copper prices, a high exchange rate and increasing costs.

Through extensive mine and near-mine exploration and resource definition drilling, Hillgrove Resources is focusing on bringing the Kanmantoo Mine back into production, supported by satellite prospects such as Emily Star and the O'Neil Zone.

Mineralisation

The Kanmantoo Cu–Au mine is the largest known orebody in the Kanmantoo Trough and lies within the Tapanappa Formation of the Cambrian Kanmantoo Group. Mineralisation in the vicinity of the mine occurs in a discordant Cu–Au stockwork within a quartz–biotite–andalusite±garnet±chlorite schist host.

The orebody at the mine forms a pipe-like body with podiform lenses and veinlets of chalcopyrite, pyrrhotite, pyrite, magnetite, chalcocite and covellite in garnet–andalusite–biotite±chlorite schist. Minor pentlandite, marcasite, sphalerite, galena, gold, silver, molybdenite, wolframite and bismuth also occur.

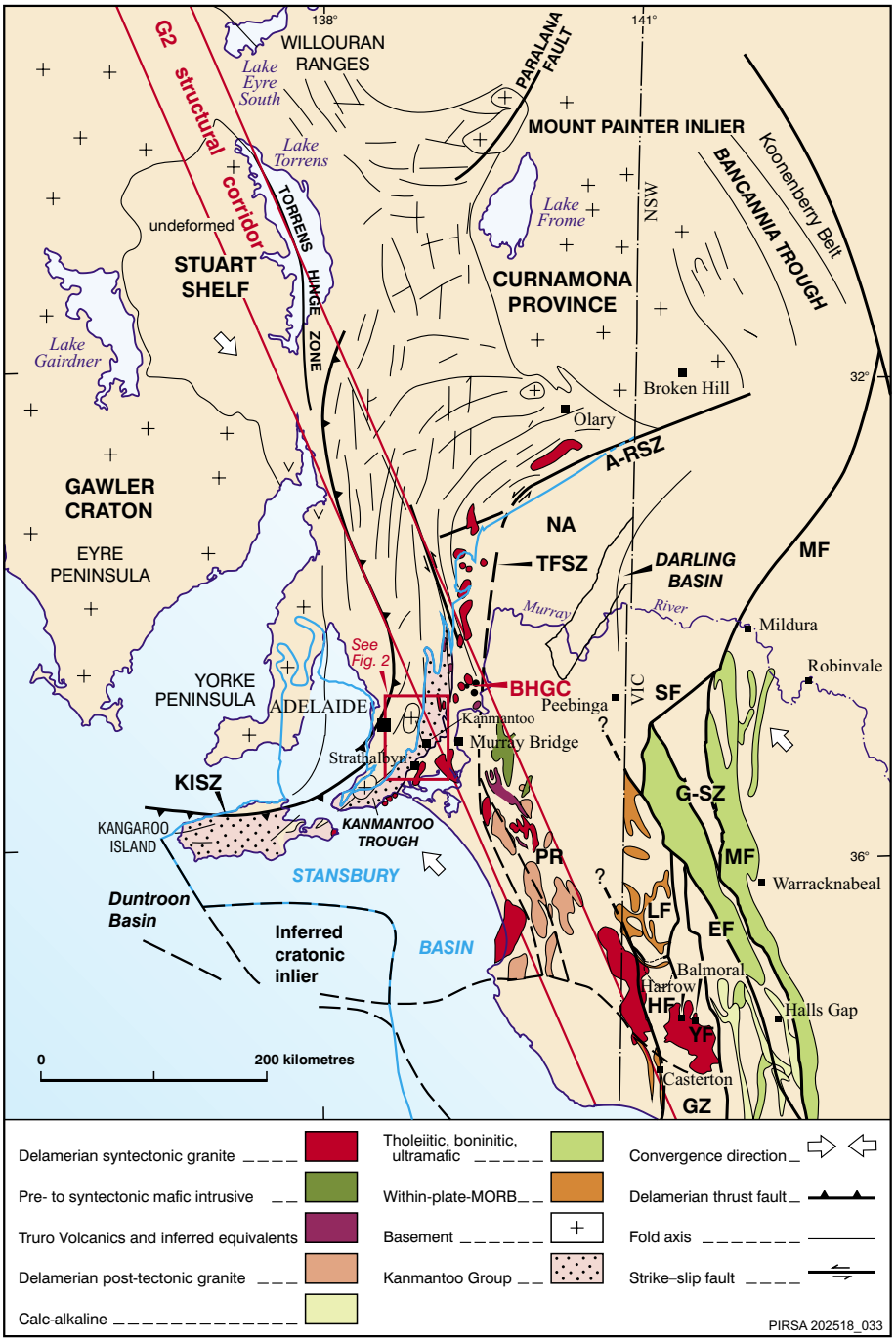

***Fig. 1** Extent of the Kanmantoo Trough and Kanmantoo Group equivalents (after Preiss, 1999). **A-RSZ:** Anabama–Redan Shear Zone; **BHGC:** Black Hill Gabbroic Complex; **C:** Coonalpyn (Truro Volcanics equivalents); **EF:** Escondida Fault; **FA:** Fleurieu Arc; **G–SZ:** Grampian–Stavely Zone; **GZ:** Glenelg Zone; **HF:** Hummocks Fault; **KISZ:** Kangaroo Island Shear Zone; **MF:** Moyston Fault; **NA:** Nackara Arc; **PR:** Padthaway Ridge; **SF:** Skreity Fault; **TFSZ:** Teal Flat Shear Zone; **YF:** Yarramyljup Fault.*

Mineralisation, locally thickened by folding, is grossly discordant to relict bedding and lodes occur parallel to the local and regional axial plane schistosity (S_2). There are also some discordant 020–045°-striking mineralised shears and faults, with shearing and remobilisation of mineralisation into shears interpreted to have occurred post-D_2 to syn-D_3.

The origin of the Kanmantoo Mine mineralisation has not been resolved as two of the main authors that have studied this region have opposing views (Toteff, 1999; Schiller, 2000). Toteff favoured structurally modified syngenetic hydrothermal Cu–Au mineralisation that was part of a feeder

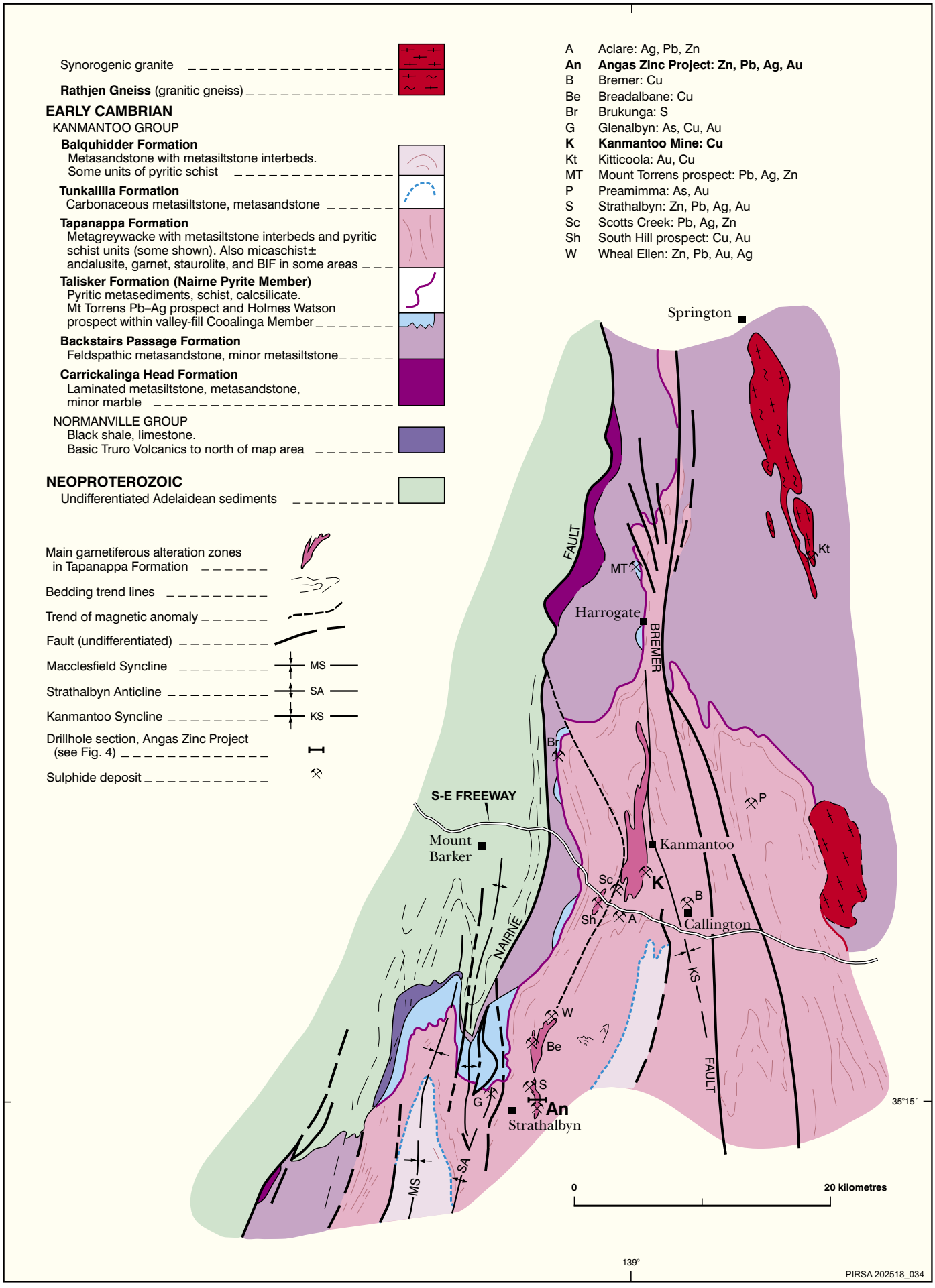
Synorogenic granite
Rathjen Gneiss (granitic gneiss)
EARLY CAMBRIAN
KANMANTOO GROUP
Balquhidder Formation
Metasandstone with metasiltstone interbeds.
Some units of pyritic schist
Tunkalilla Formation
Carbonaceous metasiltstone, metasandstone
Tapanappa Formation
Metagreywacke with metasiltstone interbeds and pyritic schist units (some shown). Also micaschist± andalusite, garnet, staurolite, and BIF in some areas
Talisker Formation (Nairne Pyrite Member)
Pyritic metasediments, schist, calcsilicate.
Mt Torrens Pb–Ag prospect and Holmes Watson prospect within valley-fill Cooalinga Member
Backstairs Passage Formation
Feldspathic metasandstone, minor metasiltstone
Carrickalinga Head Formation
Laminated metasiltstone, metasandstone, minor marble
NORMANVILLE GROUP
Black shale, limestone.
Basic Truro Volcanics to north of map area
NEOPROTEROZOIC
Undifferentiated Adelaidean sediments
Main garnetiferous alteration zones in Tapanappa Formation
Bedding trend lines
Trend of magnetic anomaly
Fault (undifferentiated)
Macclesfield Syncline
Strathalbyn Anticline
Kanmantoo Syncline
Drillhole section, Angas Zinc Project (see Fig. 4)
Sulphide deposit
MS
SA
KS
A Aclare: Ag, Pb, Zn
An Angas Zinc Project: Zn, Pb, Ag, Au
B Bremer: Cu
Be Breadalbane: Cu
Br Brukunga: S
G Glenalbyn: As, Cu, Au
K Kanmantoo Mine: Cu
Kt Kitticoola: Au, Cu
MT Mount Torrens prospect: Pb, Ag, Zn
P Preamimma: As, Au
S Strathalbyn: Zn, Pb, Ag, Au
Sc Scotts Creek: Pb, Ag, Zn
Sh South Hill prospect: Cu, Au
W Wheal Ellen: Zn, Pb, Au, Ag
Springton
Harrogate
Mount Barker
Kanmantoo
Callington
Strathalbyn
S-E FREEWAY
FAULT
BREMER
NAIRNE
FAULT
35°15´
0
20 kilometres
139°
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Fig. 2 Geology of the Kanmantoo–Strathalbyn region, with the garnetiferous alteration zone related to mineralisation within the Tapanappa Formation highlighted. See Fig. 1 for location.

system to stratigraphically overlying meta-exhalites, whereas Schiller proposed an epigenetic origin with ore fluids being derived from several phases of hydrothermal activity during metamorphism, with metals sourced from metamorphic or magmatic fluids.

As mineralisation occurs along discrete structures, is grossly discordance to bedding, and is associated with amphibolite-grade metamorphic assemblages, an epigenetic–hydrothermal origin is favoured. Further work is currently underway to better understand the origin of the mineralisation.

Recent exploration

In addition to Hillgrove Resource's ML 5776 and EL 3298, the company also has an interest in nearby EL 3277 covering a region around the former Kanmantoo Mine. With little contemporary exploration conducted in the project area, field exploration activities commenced in December 2003. Drill targets were defined, with RC and diamond drilling commencing in February 2004. During 2004, 9000 m of RC and 1200 m of diamond drilling were completed (Fig. 3), allowing Hillgrove Resources to recently announce a significant upgrade of the current mine resource.

Drilling targeted both the down dip and strike extent of two broad zones of Cu–Au mineralisation identified in recent rock chip and channel sampling. Mineralisation was intersected in all holes, with widths up to 40 m. The mineralisation intersected was generally a combination of chalcopyrite, malachite, azurite and lesser pyrite, varying in concentrations from 1 to 2%, with some zones up to 60%.

Some of the more significant drilling results from recent work at the Kanmantoo Mine are:

KTRC127 — 39 m at 1.38% Cu, 0.21 g/t Au (O'Neil Zone)

KTDD006 — 26 m at 2.04% Cu, 0.22 g/t Au (Main Zone)

KTRC109 — 41 m at 1.28% Cu, 0.33 g/t Au (South East Zone)

KTRC138 — 18 m at 2.02% Cu, 0.59 g/t Au (Eastern Zone).

The Emily Star prospect, 300 m southwest of the Kanmantoo Mine, was also targeted in recent exploration, with excellent drilling results indicating potential to develop this prospect as a satellite open cut. Some of the more significant results are:

KTRC008 — 27 m at 3.94% Cu (inc. 14 m at 6.77% Cu)

KTRC023 — 14 m at 4.46% Cu, 10.96 g/t Ag, 0.14 g/t Au

KTRC022 — 10 m at 2.16% Cu, 3.15 g/t Ag, 0.10 g/t Au

KTRC024 — 14 m at 1.08% Cu, 3.00 g/t Ag, 0.13 g/t Au

KTRC002 — 16 m at 1.12% Cu

KTRC006 — 15 m at 1.15% Cu.

Cu–Au resource

Hillgrove Resources recently upgraded its total JORC-compliant indicated and inferred resource to 18 371 000 t at 1.1% Cu and 0.2 g/t Au, equating to 196 700 t of contained copper and 104 400 oz of gold. This resource definition more than doubles the previous estimate of 8.45 Mt and represents a discovery cost of $1.2 million (or 0.5 c/lb Cu) using the current copper price of US$1.36/lb. The current resource area extends over 1320 m and significant potential exists to further expand this at Emily Star, and the O'Neil, South East and North East Zones as all remain open along strike and down dip.

Current focus

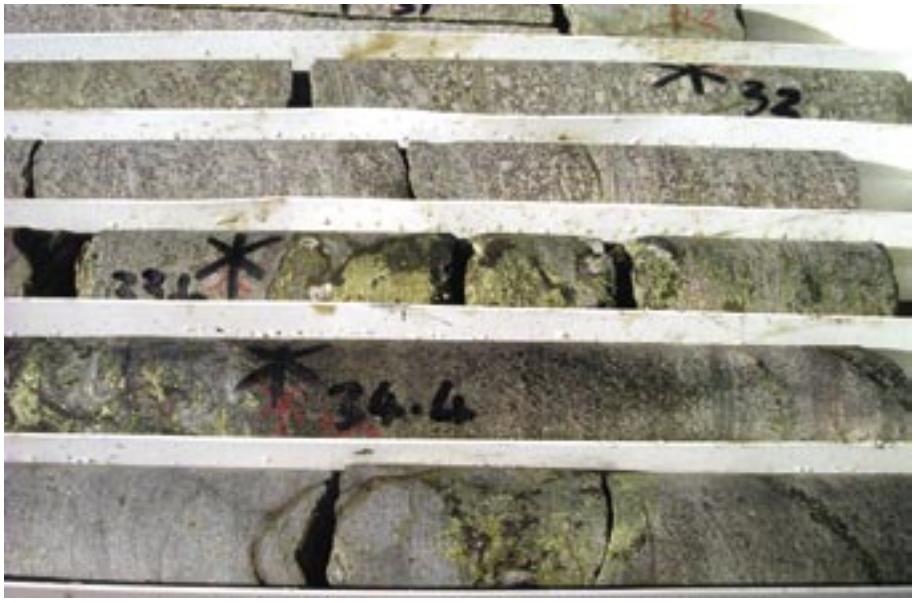
Preliminary metallurgical test work is being undertaken on recent drill samples to determine the viability of metal extraction from sulphide ore. The original operators of the Kanmantoo Mine rarely analysed for gold, and until recent drilling, assaying and resource delineation, the gold content of the orebody had been poorly constrained. Further drilling and assaying is anticipated to substantially upgrade the gold content of the deposit.

Regional exploration is continuing on a number of highly prospective greenfields areas, and an additional 6–8000 m of RC and 1–2000 m of diamond resource definition and near-mine exploration drilling is expected to begin in early 2005.

A scoping study to determine a base-case preliminary economic model, including open-pit optimisations, preliminary capital and operating costs is about to commence and will be available in early 2005.

Angas Zinc Project

Terramin Australia's Angas Zinc Project is located within an industrial zone and quarry ~60 km southeast of Adelaide and 2 km east of Strathalbyn (Fig. 1). Aberfoyle Resources discovered the



Core from Kanmantoo drillhole KTDD 003, showing sulphide mineralisation, dominantly chalcopyrite, with minor pyrite. Host rock (seen best at rear of core tray) is garnet–andalusite–biotite schist (courtesy Hillgrove Resources). (Photo 400950)

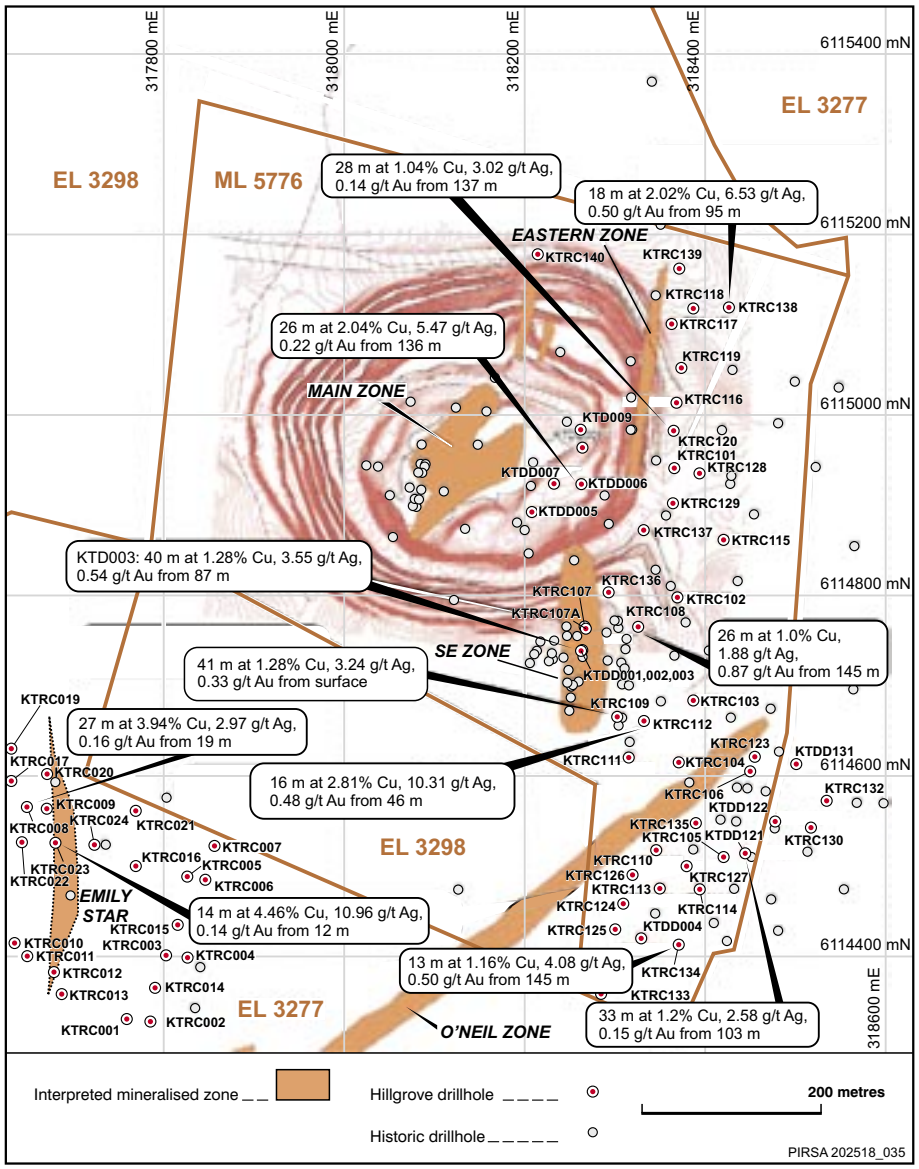


Fig. 3 *Kanmantoo Mine plan and drillhole locations (courtesy Hillgrove Resources).*

Angas mineralisation in 1991 through mapping and soil geochemistry. Initial drilling in 1992 intersected significant Zn–Pb–Ag mineralisation, including 8 m at 15.5% Pb+Zn in AN13. Subsequent exploration and resource definition drilling defined a resource of 930 000 t grading 20% Zn equivalent, comprising a main south-plunging body known as the Rankine Deposit and several smaller shoots. The total resource for the Angas Zinc Project has recently been upgraded to 2.8 Mt.

Recent exploration has indicated potential for down-plunge extensions of known mineralisation and a large conductive anomaly offset from the line of lode. All have the potential to significantly upgrade the resource of the prospect.

Terramin Australia is currently in the process of defining and upgrading the resource with a view to developing the deposit as an open-cut and/or underground operation in the near future. A scoping study to determine its economic viability has been undertaken and was encouraging enough for a pre-feasibility study to be commissioned. If this study indicates viability, then a feasibility and bankable feasibility study will be commissioned in 2005 with a view to begin mining in mid-2006 (Moriarty, 2004).

Mineralisation

The Angas mineralisation is considered to be a Broken Hill style, coarse-grained, Zn–Pb–Ag±Au orebody that extends over 500 m, plunging 45°S from the surface to a depth of 450 m (Fig. 4). Mineralisation is open at depth, and several drillholes beyond the defined resource contain high-grade zinc intersections, indicating potential to add to the known resource. The mineralisation and host lithologies occur within fine-grained, laminated to massive, poorly developed turbidites of the Tapanappa Formation of the Kanmantoo Group. Pyrrhotite within the mineralised horizon produces a magnetic anomaly, which contrasts to the weakly magnetic Tapanappa Formation turbidites.

The Angas mineralisation occurs on the eastern limb of the shallowly south-plunging, regional-scale D_2–F_2 Strathalbyn–Macclesfield anticline–syncline pair. From the Angas Zinc Project to the Kanmantoo Mine area, small-scale, sub- to coaxial, N–S to NNW-trending D_3–F_3 folds and shears overprint the east-dipping limb of the Strathalbyn–Macclesfield D_2 fold. Metamorphic remobilisation and overprinting D_3 folds and shears are interpreted to have affected the orientation and distribution of the original syngenetic Angas mineralisation.

High-grade, massive, coarse-grained, granoblastic sphalerite–galena–pyrite mineralisation at the deposit is concentrated in south-plunging, linear, banded sulphide zones (BSZ) that are contained within a strongly silicified gahnite±garnet quartzite and garnetiferous host that is closely related to a garnet–andalusite–sillimanite–gahnite schist envelope. In addition to the Rankine Deposit mineralisation, two potential BSZ have been identified in the footwall and hanging wall using downhole electromagnetic techniques. High-grade, remobilised vein mineralisation also extends from margins of the BSZ.

Recent extensive drilling has been integrated into a new structural and stratigraphic model for the mineralisation, and is being used to update the current resource and provide targets for further drilling.

Exploration history

Aberfoyle Resources Ltd identified the Angas Zinc Prospect in 1991; an inferred resource of 1 Mt at 10% Zn, 4% Pb, 60 g/t Ag and 1 g/t Au was outlined by 1993 (Anderson, 1993). In July 1997, Terramin Australia Ltd (as Playford

Resources NL) joined Aberfoyle Resources as operator of EL 2839 and the Angas Zinc Project in a 60:40 joint venture. In December 2004, Terramin became 100% owners of the Angas Zinc Project.

Terramin has carried out considerable work since 1997, including soil geochemistry, micro-gravity, magnetics, downhole geophysics and drilling. The micro-gravity has been useful in delineating garnet-rich zones, and electrical geophysics in delineating mineralisation.

During 2004, Terramin completed 32 diamond-drillholes at Angas, totalling 7028 m, resulting in the successful delineation of the Rankine Deposit and a revised resource estimate. Some of the more significant results are as follows:

AN013 — 8.0 m at 4.6% Pb, 61 g/t Ag, 10.9% Zn, 0.64 g/t Au

AN029 — 27.7 m at 2.8% Pb, 19 g/t Ag, 12.0% Zn, 0.31 g/t Au

AN037 — 11.9 m at 3.0% Pb, 27 g/t Ag, 13.3% Zn, 0.44 g/t Au

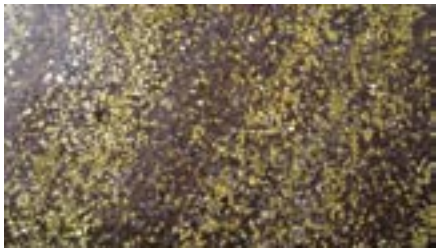
AN048 — 6.3 m at 6.3% Pb, 54 g/t Ag, 15.6% Zn, 0.61 g/t Au.

Zn–Pb–Ag resource

The Angas Zinc Project, including the main Rankine Deposit, contains an inferred and indicated resource of 2.8 Mt grading 14% Zn equivalent, including a high-grade indicated resource of 1.1 Mt grading 19.5% Zn equivalent (13% Zn, 5% Pb and 50 g/t Ag at a 10% Pb+Zn cutoff). The total contained metal is 390 000 t of zinc equivalent. The bulk of the resource is in the Rankine Deposit.

Current focus

A new electromagnetic target, the 'Jettner Deeps', has been identified to the west of the Rankine Deposit, indicating a possible fault or stratigraphic repeat. 'Jettner Deeps' is expected to be investigated in February 2005 by extending existing Rankine Deposit drillholes (Fig. 4).



Core from Angas Zinc Project drillhole AN29; this section assayed 27.7 m at 2.8% Pb, 12% Zn and 19 g/t Ag; width of view is ~90 mm (courtesy Terramin Resources). (Photo 400951)

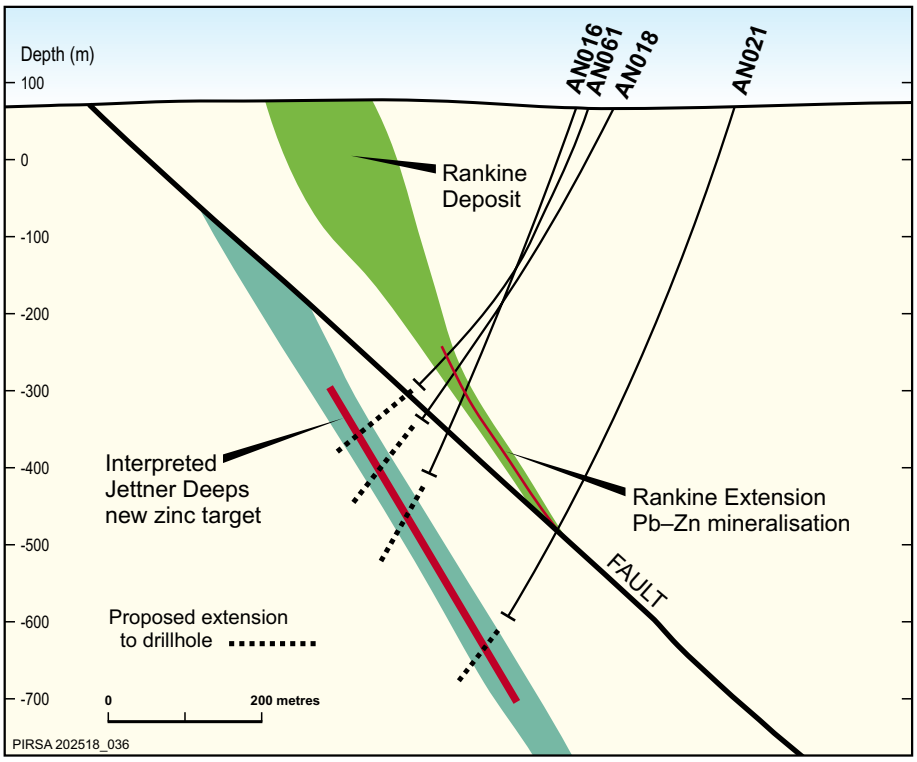


***Fig. 4** Cross-section of the Angas Zinc Project showing Rankine Deposit and the new 'Jettner Deeps' target (lode extension); previous drillholes that are to be deepened are indicated (courtesy Terramin Australia).*

Summary

The Kanmantoo Trough already hosts a copper mine that is on the brink of redevelopment as a Cu–Au mine. The Kanmantoo Group Tapanappa Formation hosts both the Kanmantoo Mine and Angas Zinc Project, and presents an excellent target for mineral explorers in search of copper, gold, lead, zinc and silver. Although it is not known if mineralisation in the Kanmantoo Trough is of syngenetic exhalite or epigenetic metamorphic origin, it is always remobilised and structurally enhanced. With a proven exploration model now in place, and two prospects looking so promising, it is hoped that current explorers have as much success as those who brought the initial discoveries to fruition over 150 years ago.

Further information

The content of this article is from two major sources:

- *South Australian Mineral Explorers Guide (available on CD;* contact PIRSA Customer Services, 101 Grenfell Street, Adelaide, ph. 08 8463 3001*)*
- various reports available on the following websites — Hillgrove Resources (www.hillgroveresources.com.au) and Terramin Australia (www.terramin.com.au).

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