Broken Hill Exploration
Sydney Mineral Exploration Discussion Group
February 2014

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Where does one look for ..... + 1 Billion ounces Silver

Broken Hill

ref: Large et al 2002

Stratiform Sediment Hosted Zn-Pb-Ag Deposits
Broken Hill Mine

- Continuously mined for over 125 years to present day
- Largest and richest lead-zinc-silver deposit of its kind in the world
- 300 million tonnes averaging >15% combined lead and zinc and 100-300g/t silver, over 150MT at +20%.
- Recorded 28Mt of lead, 24Mt of zinc, 1 billion ounces of silver
- Historical importance for Australia

Giant Orebody

- **GLOBAL COMPANY MAKER**
How many people in this room have at some stage in their career worked at Broken Hill?

Is the geology well understood?

How well explored is the district? Has it been done to death?

Is the next Broken Hill-type (BHT) deposit going to be different?
The under-explored-ness of Broken Hill; how data rich is the district?

Geological setting

Mineral system and likely genetic model for BHTs

Character of the model and identifiable geological parameters that are practical to exploration.

Talks about a subjective ranking methodology

Looks at the datasets available for explorers and what seems to be useful

Talks about high ranking targets for future exploration
ACKNOWLEDGEMENTS

Barney Stevens, Wolf Leyh, Ian Plimer, Gordon McLean, John Greenfield, Rob Barnes, Gary Burton, Peter Gunn, Rob Gordon, Steve Collins, Mike Raetz, Tony Webster, Iain Groves, Terry Barkley, Bill Laing

.....................

.....................And about 5000 other geologists who have worked at Broken Hill before us.
Genetic Models
- CBH (2008-09)

Geology/Stratigraphy
- Stevens (Proterozoic to 2015)….. and unpublished work on magnetic rocks

District Exploration
- Perilya (MEGWA talk). XRF, RAB, Drill hole analysis
- CBH XRF geochemistry
Allendale Mine

Drilling reported to date. Multiple high grade intersections.

- 10m at 4.1% Pb, 12% Zn, 29g/t Ag
- 2m at 8.4% Pb, 11.5% Zn, 39.2g/t Ag
- 2m at 5.0% Pb, 6.8% Zn, 44.3g/t Ag
- 3m at 4.0% Pb, 9.2% Zn, 31g/t Ag
- 7m at 2.5% Pb, 2.3% Zn, 21g/t Ag
- 9m at 2.5% Pb 3.1% Zn, 19.7g/t Ag
- 5m at 3.5% Pb, 5.8% Zn, 37 g/t Ag
- 10m at 3.4% Pb, 6.2% Zn, 26 g/t
Allendale Mine

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- 10m at 4.1% Pb, 12% Zn, 29g/t Ag
- 2m at 8.4% Pb, 11.5% Zn, 39.2g/t Ag
- 2m at 5.0% Pb, 6.8% Zn, 44.3g/t Ag
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- 9m at 2.5% Pb 3.1% Zn, 19.7g/t Ag
- 5m at 3.5% Pb, 5.8% Zn, 37 g/t Ag
- 10m at 3.4% Pb, 6.2% Zn, 26 g/t
- 6m at 10.4% Zn...Off-hole conductor

Now looking deeper and along strike: FOUR VTEM LINES FLOWN
The big miners controlled the mine and the district

Increased understanding of regional geology

More Juniors

Conventional drilling

Wireline

RC

Hole Depth (m)
1. Outcropping Geology and magnetics
2. Broken Hill Group Interpreted
3. Gravity and IP
4. Drilling and RAB Anomaly
Why is Silver City interested?

- Strategic tenure position
- Under-explored tenure position
EXPLORATION AT BROKEN HILL

What have we tested?

APPROX 130 holes TOTAL at 13 Prospects

- Allendale, 45 drill holes
- Razorback West, 18 drill holes
- Champion, 3 drill holes
- Stephens Trig, 6 drill holes
- Umberumberka (Ag,Pb), 6 drill holes
- Yellowstone (Au), 6 holes
- Golden King (Au), 9 holes
- Wolseley, 6 holes
- Maybell, 12 holes
- Ziggys, 4 drill holes
- Mt Brown, 6 holes
- Native Dog, 4 holes
- Parnell, 4 holes
- Widespread RAB, ground magnetics, IP (Yellowstone, Razorback), VTEM also completed
Approx 1200 square kilometres

15 granted EIs

Joint Ventures with CBH, GCR over 60% of tenure

CBH locally contributing (25%)

Covers key stratigraphic horizons with remainder held by Perilya

Well established mining centre

Two mills operating in town

Great infrastructure

Main projects within 25 km of town
GEOLOGY

- Rift sedimentation and volcanism Proterozoic age 1850 to 1670Ma. Narrow Rift.
- Mineralisation 1685-1670Ma

- At least four deformations, two thermal events; rocks reach upper amphibolite-granulite metamorphic grade locally. Need to filter out the effects of the Olarian Orogeny

Key units
1. Thackaringa Group: potential source for metals and saline fluids. Itself a host to ore.
2. Broken Hill Group: host to ore especially in upper parts.
3. Silver City Suite: granitic intrusions. Silver King and Parnell metadolerites introduced as sills or volcanic rocks penecontemporaneous with ore. Important source of sulphur.
GEOCHRONOLOGY

Silts, black shales: deep marine, turbiditic: cap rocks, deep burial

RAPID SUBSIDENCE

quartzofeldspathic: shallow marine-shelf (maybe lacustrine)

Albitic, quartzofeldspathic: fluvial to estuarine

Stevens (2006)
- Broken Hill orebodies emplace over 6 million years and are younger than host rocks
- Pinnacles orebody formed 6 million years after its host rocks and 10 million years before Broken Hill ores

Stevens (2010)
MODEL FOR THE BROKEN HILL OREBODY FLUID SYSTEM
(Attempted unfolding of geology to scale, but corrections for attenuation are very uncertain. Faults are diagrammatic, added because they are a factor in fluid flow.)

From Stevens B.P.J. (2003)
Broken Hill Schematic ‘unfolded’ Cross section

Metals located close to feeder structure over a 6 Ma period (eg C-lode feeder)

BIF as connected Outflow zones

Fig. 2. Schematic reconstructed section across the Broken Hill lodes in the southern operations. Schematic section based on numerous cross sections, such as that of section 58 in Figure 1, with allowance for structural modification of the ore lenses, including inversion of the lithostratigraphic package.

Groves et al. (2008)
Looks like this now
Long-section
PURPOSE

“To focus exploration for discovery of high quality BHT lead-zinc-silver ore (+20Mt at plus 20% Pb+Zn, with high grade Ag).”

EVALUATION

1. Mineral System Approach to district. Recognises quantifiable proxies (geological indicators) to best ore setting.
2. Systematic data collation, collection and interpretation.

THREE TARGET TYPES

1. Known and previously evaluated prospect “hot-spots”. Often heavily drilled.
2. Hot-spots with data gaps…. Largely untested, sparse drilling.
3. Hot-spots defined by new geological interpretation….data poor, no drilling.
Mineral Systems Approach

Process Driven Assessment
Looks at:
- Fluid and metal source
- Transport of ore-bearing fluids
- Fluid traps and depositional sites

Geological Indicators (proxies) reflect past processes and can be defined
- Mineral system proxies are the essential ‘ingredients’ of a model
- Proxies are independent, quantifiable attributes
- Used for target ranking/probability analysis

Data Evaluation and Assessment
- Continued compilation, collation and analysis of historic and modern exploration data
## KEY EXPLORATION CRITERIA BHT’s

### Mineral System Proxy

- Within influence of Upper Thackaringa Group
- Bimodal volcanic rocks in the footwall stratigraphy
- Strong folding and complexity, structural re-activation
- Rapid/complex host facies variations (and lateral ‘potosi gneiss’)
- IP response (sulphide detection)
- Zoned or stacked Pb and Zn geochemistry
- Envelope of fine-grained Fe-Mn garnet-quartzite, element enrichment/depletion trends (enriched in K, Fe, Si, Mn, Rb and depleted in Na, Ca, Sr)
- Silver bearing galena-sphalerite dominant with subordinate poddy pyrrhotite and minor pyrite.
- Lateral/overlying stratigraphic marker units - quartz-gahnite and/or overlying BIF units

### System Variable

<table>
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<th>Mineral System Proxy</th>
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• Pole-dipole IP may detect some halos (including false positives), ground EM not reliable.

• Zones of strong folding and complex structural reactivation. (early high temperature) high strain zones and drag folds.

• zoned or stacked Pb and Zn geochemistry

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• Silver bearing galena-sphalerite with subordinate poddy po and minor pyrite.

• Envelope of fine-grained Fe-Mn garnet-quartzite, Si-Fe-K/Rb-eincr.; and Na-Ca/Sr decr., including ‘Skarn-like’ mineralogy.

• bimodal volcanics in the footwall stratigraphy.

• Rapid/complex host facies variations (and lateral ‘potossi gneiss’?)

• Upper Thakaringa Gp or younger and within stratigraphic 2km of Thakaringa Gp

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**Raw data totals**

**By proxy**
PROSPECTIVITY RANKING

Highest Rank

Broken Hill Line-of-Lode *
Potosi *

Stephens Trig
Pinnacles *
Razorback West
Native Dog
Balaclava

Group 1

Peppertree
Mt Brown
Speedwell

Group 2

Allendale
Parnell
Southern Cross South
Yalcowinna West

Group 3

* Not SCI Prospect

Lowest Rank
Tier One Targets (large systems)

- Razorback West Corridor
- Stephens Trig Corridor
- Balaclava
- Native Dog

Tier Two Targets (constrained or poorly defined systems)

- Speedwell
- Selected VTEM targets
- Southern Cross South
- Further work required(Coombarra, Riddock, Rildar, Yalcowinna, Mt Brown, Parnell)
Thackaringa Group source rocks…thickest beneath the Broken Hill Group
THACKARINGA GROUP

- Albite (Na) rich
- Depleted in metals
Broken Hill type (BHT) mineralisation has strong correlation to Broken Hill Group stratigraphy.

- BHT’s associated with “lode rocks” quartz-gahnite, blue quartz, garnet-quartzites, BIFs.

- Important proximity of mineralisation to Silver City Suite Granite Gneisses.
SILVER CITY SUITE

Interpretation based on outcrops
Interpretation based geophysics
- Mafic Volcanic and Intrusive rocks:
  - MORB-like melts: Fe-Ti enriched.
- Restricted magma chamber in rift setting derived from partial melt of asthenosphere
- BIFs in close proximity to ore; exhalative
- Curvilinear magnetic ridges represent disseminated magnetite formed also in exhalative setting.
Psammite, pelite, Potosi Gneiss

Magnetic linears transgress rock units, but generally conform with stratigraphy

NO OUTCROP
Distribution of gahnite, garnets, BIF and qtz-mt
Distribution of gahnite, garnets, BIF and qtz-mt

And BHts
Garnet quartzite, blue quartz-gahnite-garnet rocks, plumbian orthoclase
GEOLOGY

- Rift sedimentation and volcanism
  Proterozoic age 1850 to 1670Ma.
  Narrow Rift.
- Mineralisation 1685-1670Ma
- At least four deformations, two thermal events; rocks reach upper amphibolite-granulite metamorphic grade locally.
  Need to filter out the effects of the Olarian Orogeny

Key units
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3. Silver City Suite: granitic intrusions. Silver King and Parnell metadolerites introduced as sills or volcanic rocks penecontemporaneous with ore.
   Important source of sulphur.
Important feature of Broken Hill between 50 to 60% of SCI tenure lies beneath a veneer of regolith (alluvium/soil).

To date Stephens Trig mineralisation is only significant zone discovered under cover.

Zones of strong interest for SCI include Razorback West and Trig East.
Spatial relationship between BHts and gravity ridges

To date no clear relationship between ore and gravity.

Ribbon-like plunging nature of ore difficult to resolve with gravity.

“Theoretical studies of Falcon gravity gradiometry acknowledge that the survey would have seen a positive anomaly over the intact Broken Hill orebody but that it would have been indistinguishable from other anomalies cause by other geological features”

Amphibolites
FALCON GRAVITY GRADIOMETRY

- Relationship between gravity gradiometry and amphibolites
Observed Gdd

Restored to pre-mining state

Equivalent source Gdd, 2.75 g/cc terrain density, ~600m minimum wavelength

Lane 2003
Review suggests IP is a good technique for mapping out prospective packages, but not a targeting tool. (Allendale, Native Dog, Razorback West)

EM largely thought to be ineffective:
1. Occurrences of stratabound py-po.
2. Graphitic and pyritic shears
3. Saline water in streambeds and shear zones
4. Local supergene pyrite
5. Non conductive sphalerite-rich ores
6. Ribbon-shaped, pencil-like orebodies
7. Old EM technology and inadequate line spacings.

However:
1. Flying Doctor BHt highly conductive
2. Potosi applied potential techniques effective, Mise-a-la-masse
3. DHMMR a possibility
4. Perilya VTEM targets hit sulphides

So we have not written-off EM as a tool; currently reviewing historic interpretations
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RAB Zinc

RAB Lead
- Combination of geology and geochemistry; RAB, soil, drilling
- Focus on specific zones
- And specific prospects

**Prospectivity Ranking**

- Highest Rank
  - Broken Hill Line-of-Lode *
  - Potosi *
- Group 1
  - Stephens Trig
  - Pinnacles *
  - Razorback West
  - Native Dog
  - Balaclava
- Group 2
  - Peppertree
  - Mt Brown
  - Speedwell
- Group 3
  - Allendale
  - Parnell
  - Southern Cross South
  - Yalcowinna West

* Not SCI Prospect
“BUT THE DEVIL IS IN THE DETAIL”
Broken Hill Cross section

Figure 1: Cross-section of the southwestern part of the Broken Hill orebody, through the Zinc Corporation main shaft. Based on interpretations by Haydon & McConachy (1987), W.R. Leyh (unpublished diagram), and G. Reed (unpublished data).
Area Interpreted by Laing (1996) to be overturned in nappe structures

SCHEMATIC CROSS SECTIONS – Laing, (1996) nappe model

Thick skinned layer folds

(pastry making)
What do we actually know?

1. Laing: Ore body and large areas of district overturned.
2. Webster: strong arguments to contrary
3. SCI Interp on basis if Geological Survey mapping suggests some is and some isn’t
Domains that show overturned fold structures vs Laing overturned nappes

Less extensive,
But detected only if refolded

Razorback area seems UPRIGHT
SIGNIFICANCE OF FACING DOMAINS FOR EXPLORATION?

- High strain zones and complex folding near the transition from downward to upward facing sequences may be inherited from growth faults that originally controlled mineralisation and as such should be the focus of exploration.

- Problematic because many of these boundaries are now younger focussed Delamerian shears.

• What do these boundaries look like? - 2 cross sections
Razorback cross
Section
Line shown

‘upright domain’
Interpretive cross section Maybelle-Yellowstone Shear

Assumes NSWGS structure (upright)

(buckled up carpet)
Rupee cross Section Line shown
‘overturned domain’
Interpretive Cross section - Rupee

Clevedale fold as synform?
Mt Darling fold as F1?
Himalaya Ftm not recognised near B Hill
Thorndale Gneiss closed fold (sheath?)
(can’t do this to carpet!)
Sheath Folds

Not Pastry but Dali?

Spider of the Evening... Hope!, 1940 - Dali
Figure 2: a) Photo of a F2 sheath fold plunging shallowly to moderately (out of the page) in a thin psammitic gneiss unit. Photo looking north. This fold structure is interpreted to be representative of the overall structure of the Maybell East Fold.
Two Important Targets

Razorback West and Stephens Trig Prospects

Two large (related?) systems of:

- Proven geochemical anomalism
- High mineral system ranking
- Uncertain architecture (structure)
Stephens Trig
Razorback West
Native Dog
Balaclava

STEPSHENS TRIG/RAZORBACK WEST
North Broken Hill Targets
RAB geochemistry (zinc) shows strong anomalism in the Stephens Trig trend and at Razorback West, including a new area to NE of current Razorback survey area
Line of Lode extensions

LONGITUDINAL SECTION

Line-of-lode Plunge reversals
Interpretive cross section Maybelle-Yellowstone Shear

The Razorback West link to Stephens Trig Prospect
Razorback West

- Potential northern extension of Broken Hill Line of Lode
- Large coincident gravity, induced polarisation and weak RAB geochemical anomalies 5 kilometres long
- 90% of anomaly under thin cover
- Structural facing conflicts across Stephens Creek Shear Zone
RAZORBACK WEST

Work Program

- Target massive sulphides under cover
- Ground electro-magnetic surveys
- Gravity profiles
- Extend IP to northeast
- Follow-up drilling.
North Broken Hill TARGET ZONES

- RAB Anomaly (Pb-Zn)
  - Drill Hole

- Stephens Trig West Target Zone
- Stephens Trig South Target Zone
- Pepper Tree
- Maybell
- Silver City Suite Granite Gneiss
- Stephens Ck Shear Zone
- Broken Hill Mining Leases
- Thackaringa Group
- Thordale Composite Gneiss

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Stephens Trig – Peppertree Corridor

Maybell East Fold suggests-
extra folds or rapid sequence thickening
Required to explain geology
Alternative Stephens Trig geological interpretations

Current-Simple synform – thickening limbs

Gordon McLean interpretation
Added fold pair-equal limbs

MESD1 - Maybell

Stephens Trig

TARGET

(Stevens et al 2004)
Stephens Trig South alternatives

Published (implied)

Gordon McLean alternative – added fold pair
Trig South

Alteration minerals in RAB
New target zone “Trig East”

- Alteration and geochemical signature in high strain zone
- South plunge 40 degrees
NEXT TARGETS FOR SILVER CITY

- Upper parts of BH Group
- High strain zones
- Right geochem
- Right alteration
- Close relationship to coeval volcanic rock and intrusions (heat engines)
- Gravity Ridges

......but largely under cover with geology poorly understood.
Diverse alteration studies on BHt have an overall consistent conclusion:

On approaching the ore position the alteration halo displays-

- enrichment in K, Fe, Si, Mn, Rb
- depletion in Na, Ca, and Sr
- Metasomatic complications

“Hyperspectral imagery can be successfully employed to recognise minerals and lithologies ….”

AND

“The spectrally-derived maps are dependent on scene statistics generated for whole image swaths. Should an explorer wish to generate lithology and mineral abundance maps for a small exploration target, the scene statistics can be optimised for that target, and a better resolution of small outcrops can be achieved than has been illustrated here”. Geoff Taylor 2005