THE HILLSIDE Cu-Au DEPOSIT:
Geological Model and Alteration Paragenesis

Geological Survey of South Australia:
Iron Oxide-Copper-Gold Mineral Systems Workshop
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Interpreted Solid Geology of the Southern Gawler Craton, shown over a 1st Vertical Derivative Magnetic Intensity Image
(from Reid and Hand, 2012)

Mine / Mineral Deposit
- OPERATING
- PROSPECT
- HISTORICAL

Mesoproterozoic c.1595 - 1570 Ma
- Gawler Range Volcanics (upper)
- Gawler Range Volcanics (lower)
- Hiltaba Suite

Paleoproterozoic c.1630 - 1608 Ma
- St Peter Suite, Nyuts Volcanics
- Donnington Suite
- Miltalie Suite

Neoarcheon-early Paleoproterozoic, c.2560-2440 Ma
- Mulgathing Complex
- Sleaford Complex

Mesoproterozoic c.3150 Ma
- Cooyerdoo Granite and associated gneisses
Hillside Deposit

- Total Mineral Resource of 337Mt @ 0.6% Cu and 0.14g/t Au
- Fe-Cu-Au-U-LREE-Co (-HREE). Anomalous Sn and Y in some skarn types but no Mo, F
- Uranium phases tend to develop away from the Cu mineralisation. Low U in Cu concentrate (average 30ppm)
- Au, Ag and Co phases occur within the copper sulphides and report to the Cu concentrate (6.1g/t, 56g/t and 832ppm respectively)
- Ag present in telluride (hessite, stuetzite, petzite), Ag-bearing gold and electrum with Ag in solid solution in copper sulphides
- Au present as electrum, high fineness gold (in veins), Ag-bearing (8%-15%) gold and in petzite (Ag-Au-telluride)
- Individual “fault blocks” confuse zoning, however there does appear to be an outer bornite-chalcocite-rich “shell” which can be Ag and Au enriched
- Mineralisation over ~2500m x 600m with mineralisation continuing at depth and N/S (open in all directions)
"Stratigraphic" Subdivision of the Eastern Yorke Peninsula

- Soil, sand, gravel cover.
- Cambrian red shales, grits and sands.
- Western Bounding Fault of the PPSC
- Hillside granite / syenite
- Hillside gabbro
- Eastern granite
- Metacarbonaceous siltstones, scapolitic (not present at Hillside)
- Meta - Impure carbonate unit
- Meta - Calc - pelite / feldspathic sediment unit ("transitional unit", "Parara unit")
- Meta psammopelite / pelite / arenite unit
- Western Meta-Volcanic unit
REX MINERALS LTD.

Hillside Cu-Au Project
Parara Prospect
Schematic Section

G Teale, Aug 2010
Banded meta-psammopelite from Parara Prospect. Also observed in drill-hole PDD03 as well as Hillside, Ranald, T3 and Port Julia Prospects.

K-feldspar-cordierite-sillimanite-biotite-hematite gneiss from the Ranald prospect area (fabric $S_2$)

Deformation on the eastern Yorke Peninsula appears more complex than previously stated. Here, a tightly folded fibrolitic sillimanite band is contained within the strong fabric.

Banded, Fe-rich meta-psammite
Skarned meta-psammite

HDD023 – 317.9m

Intensely red rock altered meta-psammite (minor pyroxene).

Red-rock and epidote altered meta-psammite
**Meta calc-pelite/feldspathic sediment unit**

- Highly variable unit containing abundant K-feldspar-rich meta-sediments, tourmaline-chlorite-K-feldspar-rich meta-sediments, carbonates, scapolitic meta-sediments, albitites and lesser mafics, graphite schist or phyllite, sodic Fe-formation and impure carbonate. Carbonates can be highly tectonised with adjacent quartz-feldspar rock-types crackle brecciated.

- Can be carbonate flooded with remobilised carbonate common.

- Can be infolded with the Impure Carbonate Unit.

- Common in the Parara area. Can be intensely skarned in the PPSC.

- Tourmalinites, meta-evaporites and para amphibolites.
Former scapolitic calc-silicate. This texture is often mimicked in the skarns, especially the red rock and pyroxene skarns.

Equis Prospect, north of Hillside. Scapolite-hornblende schist (meta-evaporite)

Parara prospect. Contact between amphibole-scapolite (LHS) rock and a scapolite-anhydrite-tourmaline-biotite meta-evaporite

Sodic meta-iron formation (41% Fe₂O₃) intercalated with meta-impure carbonates
Meta Impure Carbonate Unit

- Dominated by carbonate (calcitic or dolomitic) with milled to angular clasts and porphyroblasts. Porphyroblasts include diopside, phlogopite, scapolite, tourmaline, grossularite, allanite and actinolite.

- K-feldspar ± quartz ± tourmaline ± chlorite ± biotite clasts are derived via the transposition and boudinaging of silicate-rich layers (beds). These can then be milled.

- The impure carbonate can be highly tectonised but is not often brecciated. Skarns develop in this unit and in the meta calc-pelite-feldspathic sediment unit.
Scapolitic meta-carbonate, intercalated with fine grained biotite-chlorite-quartz-tourmaline meta-calc pelite (Parara prospect)

Highly tectonised, impure carbonate. Darker material is variably altered, transposed and boudinaged, tourmaline-bearing K-feldspar rock.

Impure carbonate (carbonate-K-feldspar with minor bornite-chalcocite-hematite)

Non skarned, meta impure carbonate with abundant tremolite
**General Sequence & Timing of Events on Yorke Peninsula**

- Older deformational events ........................................... ~1700Ma-1840Ma
- Wallaroo Group ........................................................... ~1750Ma-1760Ma
- Detrital zircons, tuffaceous metasediment ...................... ~1760Ma; ~1860Ma (Reid et al)
  Hillside West
- Felsic volcanics .......................................................... 1763 ± 14Ma
- Curramulka Gabbro ....................................................... 1589 ± 5Ma
- Arthurton Granite ......................................................... 1582 ± 7Ma
- Hillside Gabbro ............................................................ 1579 ± 5Ma (Teale & Fanning)
- Hillside Syenite ............................................................ 1583.1 ± 7.9Ma (Teale & Fanning)
  1602 ± 13Ma (Reid et al)
  1588 ± 10Ma (Reid et al)
- Hillside mineralisation (allanite) .............................. 1585 ± 7Ma (Reid et al)
  (titanite) ....................................................... 1601 ± 16Ma (Reid et al)
  (titanite) ....................................................... 1586 ± 11Ma (Reid et al)
  (titanite) ....................................................... 1571 ± 12Ma (Teale & Fanning)
- Moonta-Wallaroo mineralisation .................................. 1585Ma
**Hillside syenite**
- Generally 58%-64% SiO$_2$, ~0.8% TiO$_2$, 9%-12% Na$_2$O + K$_2$O, ~1000ppm Zr.
- Can be carbonated or silica-flooded. Fractionated from gabbro. Different from other granitoids in the district. Can be albitised or K-feldspar altered as well as skarned.

**Eastern granite**
- Crackle fractured, pegmatitic in part, silica-flooded, zircon-poor.
- May equate with the Arthurton Granite

**Hillside gabbro**
- Average SiO$_2$ 49.1%, Fe as Fe$_2$O$_3$ 13.83%, MgO 6.4%, Ni 63ppm, Cr 227ppm, V 409ppm
- Intensely altered. Magmatic pyroxenes and amphibole altered to new amphibole and subsequently most amphibole is altered to chlorite
- Plagioclase replaced by early albite and by late “red” K-feldspar ± albite
- High T early alteration
These three slab photographs show the changing nature of the Hillside syenite as the skarn mineralisation is approached.

There is a reddening of the syenite as mineralisation is approached and altered sphene becomes more easily observed. Note the intense fracturing of the syenite.

There is an increase in K as mineralisation is approached.
Brecciated syenite

HDD555 – 169.8m

Contact between syenite and impure carbonates

Intensely red rock altered syenite
Gabbros

- Two gabbro types are present
  - an equigranular, fine to medium grained variant
  - a porphyritic variant

- The gabbros have been altered and can be brecciated and skarned

- Early alteration involves development of magnetite + biotite ± K-feldspar ± bornite. Late alteration involves replacement of (albitised) plagioclase by K-feldspar, chloritisation of magmatic amphibole and alteration biotite

- Gabbros can be flanked by skarn (exoskarn) or have skarn developed within the intrusive (endoskarn). This also occurs with the granitic intrusives

- The gabbros are fractionated, having high V (+ 400ppm) and abundant Ti and P
Contact between gabbro and syenite

Co-mingled gabbro and syenite

HDD023 - 595.3m

Gabbro textures

HDD016 - 458.9m

K-feldspar stained off-cut of altered gabbro (from dated gabbro sample). Plagioclase has been totally pseudomorphed by K-feldspar.
HILLSIDE PROJECT

0.2% Cu cut off
Global 330 Mt @ 0.6%Cu
-200 mRL Slice

Date: Aug 2012
• Initial 400m magnetic data
  - too coarse, difficult to correlate to drilling

• Helimag completed @ 25m spaced EW lines, 25m sensor height (400 line km)

• Combined strike potential of magnetic structures of over 6km

**Residual Magnetics – 400m lines**

**Residual Magnetics – 25m lines**
Hillside Geology -100mRL

Feb 2013

Legend:
- Cambrian red shales, grits and sands.
- Western Bounding Fault of the PPSC
- Hillside syenite / syenogranite
- Hillside gabbro
- Eastern granite
- Skarns Mineralised
- Skarns
- Remobilised chalcopyrite mineralisation
- Massive, high grade remobilised chalcopyrite (breccia) and mineralised skarn
- Western Meta-Volcanic Unit
- Meta - psammopelite/pelite unit; includes cordierite-K-feldspar-sillimanite gneiss
- Meta - psammite / psammopelite unit
- Meta - Calc - pelite / feldspathic sediment unit
- Meta - Impure carbonate unit
- Western Mylonite
- Fault
Evolution of the Hillside IOCG Skarn Deposit c.1570Ma - 1585Ma

Stage 1: Isochemical Skarn (Contact Metamorphism)

- Meta - volcanics (upper)
- Meta - psammites to psammopelites
- Meta - volcanics (lower)
- Carbonates, impure carbonates, calc - silicates
- Mafic hornfels
- Marble, calc - silicate schist, calc sils.
- Feldspathic hornfels
- Granite
- Gabbro
- Transfer of heat
- Major structure
Skarn Types Present at Hillside

- Highest T skarns are composed of magnetite, garnet, pyroxene, magnetite + garnet and magnetite + pyrite ± garnet ± allanite

- These are invariably replaced and flanked by lower T mineralogies involving clinopyroxene (more ferroan), more andradite-rich garnet, K-feldspar, hematite, amphibole (wide compositional range), epidote, carbonate, Cu-sulphides, bladed hematite, biotite, chlorite, albite, sphene and rare vesuvianite and wollastonite

- Temperatures of formation range from ~200ºC to ~550ºC with increasing oxygen fugacities associated with increase in copper deposition

- Clinopyroxene ranges in colour from colourless (diopside) to deep emerald green (ferroan diopside to hedenbergite). There is a strong compositional zoning from area to area with the Fe-rich clinopyroxene being more distal. The amount of Mn contained is negligible
Replacement textures are complex and often telescoped with some skarn types almost totally pseudomorphed over distances as small as 10cm.

Brown and dark brown garnet is often developed immediately adjacent to intrusives (proximal) with more yellow-green (Ti-rich) garnet developed in more distal areas. Zoning in garnet is common.

The most significant reaction occurring in the skarns is the replacement of magnetite by hematite + chalcopyrite or hematite + bornite + chalcocite. The hematite + chalcopyrite association is also present with retrograde skarn phases in garnet and/or clinopyroxene skarns.
Evolution of the Hillside IOCG Skarn Deposit c.1570Ma - 1585Ma

Stage 2: Metasomatic Skarn (Magmatic Fluid Exsolution)

- Meta - volcanics (upper)
- Meta - psammites to psammopelites
- Meta - volcanics (lower)
- Carbonates, impure carbonates, calc - silicates
- Mafic hornfels
- Marble, calc - silicate schist, calc sils.
- Feldspathic hornfels
- Metasomatic skarn - prograde
- Granite
- Gabbro

Exsolution of magmatic fluid
Major structure
HDD346 - 381.5m
Allanite and magnetite associated with chalcopyrite which cuts both phases.
The chalcopyrite develops with hypogene hematite.

Brecciated magnetite skarn with ochreous red hematite developing interstitial to the magnetite clasts

Massive magnetite skarn

Unusual textured magnetite + clinopyroxene + epidote skarn
Brecciated garnet skarn containing andradite with lesser hematite, clinopyroxene and network of carbonate veining

HDD033 - 287.5m
Extremely coarse grained garnet crystals make up this garnet skarn. Crystallographically oriented alteration (K-feldspar + quartz + chalcopyrite) is easily observed.

HDD033 – 335.8m
Coarse grained garnet skarn with the individual garnets extremely altered
HDD (Hillside) Drill-holes: Garnet Skarns
This calcite-K-feldspar-magnetite-chalcopyrite skarn ("salt and pepper" style) develops on the flank of a garnet skarn.

A "salt and pepper" skarn. This lithotype consists of quartz, K-feldspar, magnetite, carbonate and sulphides in varying proportions.

This rock-type is considered to be a "precursor" to the "salt and pepper" skarn. Red-rock altered granitoid is brecciated and inundated with magnetite.

Red-rock magnetite skarn from the Omero Domain. Red-rock altered granitic material is crackle brecciated.
HDD (Hillside) Drill-holes: Salt & Pepper Skarns

Diagram showing elemental compositions and abundances relative to Chondrite standards.
A brecciated clinopyroxene skarn with clasts sitting within blood red hematite.

Non-skarned calc-silicate from the Omero Domain. These textures are mimicked during skarn development.

Magnetite-clinopyroxene skarn with coarse pyroxene developing within magnetite.

Diopside idioblasts developed within intense skarn domain, Omero area.
Clinopyroxene skarn contains large crystals of diopside which sit within a recrystallised and more Fe-rich clinopyroxene groundmass.

Large diopsidic clinopyroxene has been recrystallised and replaced by more Fe-rich clinopyroxene.

A relatively large, zoned and euhedral zircon sits within skarn. It suggests that the skarn observed here is derived from an altered syenite.
Evolution of the Hillside IOCG Skarn Deposit
c.1570Ma - 1585Ma

Stage 3: Retrograde skarn development and introduction of mineralisation

- Meta-volcanics (upper)
- Meta-psammites to psammopelites
- Meta-volcanics (lower)
- Carbonates, impure carbonates, calc-silicates
- Mafic hornfels
- Marble, calc-silicate schist, calc silts
- Feldspathic hornfels
- Metasomatic skarn - prograde
- Retrograde skarn
- Granite
- Gabbro

- Upwelling magmatic mineralised fluids
- Exsolution of magmatic fluids
- Re-activation, brecciation and mineralising of structures
- Meteoric and late magmatic fluids
- Major structure
- Accumulation of massive sulphide in dilational positions
### Hillside Project Area – Mineral Paragenesis (Preliminary)
## Hillside Project Area – Mineral Paragenesis (Part 1)

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Hillside Project Area – Mineral Paragenesis (Part 2)
Corroded remnants of garnet skarn sit within clinopyroxene skarn

HDD044 - 220.4m area
Garnet skarn being pseudomorphed by a clinopyroxene-rich skarn phase

- clinopyroxene
- garnet + magnetite

HDD047 - 222.0m
K-feldspar (red-rock) skarn is replacing clinopyroxene-bearing skarn. Rare garnet can still be observed within the clinopyroxene remnants.
Chalcopyrite mineralisation is associated with hematite-altered magnetite and tabular to lath-like actinolite. With increasing Cu grades the amphibole is usually replaced by carbonate.

(1m @ 0.99% Cu and 0.23g/t Au)

Chalcopyrite-rich magnetite-hematite skarn with all amphibole replaced by carbonate. Note that the lath-like carbonate pseudomorphs appear well aligned.

The sample interval contains 2.31% Cu and is a retrograde skarn. Bladed amphibole (replacing clinopyroxene) is replaced by carbonate and lesser chalcopyrite which sit in hematite altered magnetite.
A retrogressed clinopyroxene grain, now composed of carbonate, chlorite and quartz, contains abundant chalcopyrite.

The BSE image shows clinopyroxene being replaced by talc + carbonate + chlorite + chalcopyrite.

A tremolite grain which has replaced former clinopyroxene is now being totally consumed by fine grained talc.

Chlorite + chalcopyrite are replacing an amphibole. The former grain shape and cleavage of the amphibole can still be observed.
On the RHS of the photomicrograph is a magnetite inclusion in pyrite which has not been oxidised. Note the oxidised magnetite on the LHS of the photomicrograph.

The photomicrograph shows the relationship between magnetite and replacive hematite + chalcopyrite + bladed hematite.

This BSE image shows a highly corroded and embayed carrollite grain which is being replaced by chalcopyrite.
Dart-style mineralisation is here associated with weak skarn development. Amphiboles are associated with the chalcopyrite.

HDD381 - 293.4m

High grade remobilised chalcopyrite in the Zanoni system (zone is 6m @ 8.1% Cu and 1.5g/t Au - 416-422m)

HDD037 - 256.1m

This clast of mylonitic quartz exhibits typical ribbon textures. It has been cut by late veining which contains abundant chalcopyrite.
Location of gold and silver within the Hillside Orebody

- Initial studies show that gold grains are intimately associated with chalcopyrite, both in massive and remobilised variants.
- Grains range in size from \(~0.1\mu\) to \(~50\mu\). Grains associated with remobilised chalcopyrite are probably Ag-poor and grains associated with massive chalcopyrite are close to electrum in composition. Rare grains found in carbonate veins contain negligible Ag.
- Gold found in micro-fractures within annealed fractured pyrite is associated with (along with chalcopyrite) tennantite, hematite, tellurides and other sulphosalts. Gold or electrum found within massive chalcopyrite is usually associated with hematite and tellurides.
- Gold (and silver) report to the copper concentrate.
- Ag ± Au tellurides are common and tend to be fine grained (<2\(\mu\)) and included in chalcopyrite.
HDD026 - 394.4m
A small gold grain is present as an inclusion within chalcopyrite which is contained within fractured pyrite.

HDD396 - 664.9m
The photomicrograph shows carrollite replacing pyrite within chalcopyrite. A small electrum grain is attached to the carrollite grain margin.

HDD406 - 391.5m
This BSE image shows a small gold grain containing ~8% Ag sits within bornite and abuts a petzite grain (Ag-Au-telluride).
HDD190 - 338.1m

This BSE image shows an electrum grain (~71% Au and ~29% Ag) sitting within chalcopyrite which is annealing intensely fractured pyrite.

HDD190 - 338.1m

A minute hessite grain sits within chalcopyrite attached to pyrite. The chalcopyrite is annealing fractured pyrite.

HDD239 - 271.5m

Hessite inclusions are located along bornite-chalcocite grain boundaries. Most of the hessite is actually included within the bornite. It is suggested that, as with gold and electrum, the telluride phases will report to the copper concentrate.
Primary Bornite and Chalcocite

- Bornite is observed as an early alteration phase (with magnetite-biotite-K-feldspar) in gabbro. It occurs as fine grains (<10μ) throughout the groundmass.

- Bornite and chalcocite have been recognised in strongly hematite-altered magnetite skarn, in uraninite-pitchblende-bearing carbonate vein systems, in carbonate altered skarn and also in carbonate “flooded” domains. There is growing evidence of an outer shell of primary bornite + chalcocite enclosing the chalcopyrite-rich “core”. Increases in Cu:S ratios have been noted at the margins of the orebody.

- Invariably, bornite contains exsolution lamellae or “worm-like” intergrowths of primary chalcocite. Chalcopyrite can also be present as exsolution from bornite and can occasionally rim bornite. Digenite appears to be intergrown with chalcocite and rare hypogene covellite can be observed.
HDD062 - 353.4m
This sample is dominated by pink carbonate which contains clasts of red-rock skarn. Primary bornite and chalcocite dominate and the carbonate flooded domain contains a high uranium concentration.

HDD062 - 430.8m
Abundant primary bornite containing intergrowths of chalcocite have developed in this red-rock skarn. There is extreme carbonate flooding and silicification and the domain (429m-433m) contains 0.25% U3O8

HDD62 - 430.8m
Intergrown primary chalcocite and bornite. Note the “eutectoid-like” texture.
Bladed hematite sits within primary chalcocite. Bornite develops along fractures as flame-like exsolution. Gold is present along the fracture.

**HDD058 - 366.7m**
Bladed hematite sits within primary chalcocite. Bornite develops along fractures as flame-like exsolution. Gold is present along the fracture.

**HDD212 - 287.8m**
Bornite and bladed hematite are replacing a former magnetite grain. The aggregate is surrounded by hypogene hematite with some of these grains containing inclusions of bornite.

**HDD238 - 238.4m**
The BSE image shows linear aggregates of clausthalite and Se-rich galena developing within bornite. Note that no clausthalite is present within the associated chalcocite. The seleniferous galena contains ~2.4% Se.
Uranium Mineralisation

- Uranium (>100ppm to ~8000ppm) can occur with or without elevated LREEs

- Observed occurrences of uraninite ± pitchblende ± coffinite ± brannerite are contained within late and distinctive carbonate veins and carbonate flooded domains. These veins also contain aikinite, a Pb-Cu-Bi sulphosalt, cobaltite, Se-bearing galena, clausthalite and bornite ± chalcopyrite

- Elsewhere uraniferous phases develop within highly oxidised, often pyritic domains. These domains often appear ochreous and secondary
HDD037 - 270.7m
Unusual pink carbonate which contains abundant uraninite-pitchblende. Chalcopyrite is present and bornite often occurs in the carbonate veining. Aikinite and bismuthinite are intimately associated with the uraninite.

HDD076 - 188.4m
Unusual atoll textured pitchblende-uraninite grains within the vein carbonate

HDD137 - 278.5m
The BSE image shows a small inclusion of uraninite within bornite.

HDD037 - 270.7m
Typical square cross-section array of pitchblende which develops around chalcopyrite, bismuthinite and a Bi-Cu-Pb-sulphosalt.
Eastern Gawler Craton Skarned Sequences

- Prograde skarns dominated by magnetite, andradite garnet, diopside, clinopyroxene and pyrite. Skarns developed at Hillside, Punt Hill, Alford, Pernatty and Lake Torrens. High temperature skarns also developed in the Mt. Woods-Coober Pedy region (see also Curnamona Craton - Koolka, Gunsight, deeper levels at Kalkaroo).

- The skarn assemblages develop in meta-impure carbonates (calcitic and dolomitic), evaporites (often scapolitic), scapolitic calc-pelites and Fe-rich calc-pelites.

- Mineralisation is associated with retrogression of the prograde skarn with the development of amphiboles (often tremolite-actinolite), feldspars, chlorite, talc, hematite, carbonate, quartz, sericite, clay minerals and rutile.

- Main sulphide minerals associated with retrograde skarns are dominant chalcopyrite and minor to rare bornite, chalcocite, carrollite, molybdenite, cobaltite, tellurides, electrum and gold.

- Contact or regional metamorphic assemblages in the impure carbonates contain grossular garnet and extremely high Mg diopsidic clinopyroxene.

- Skarns are geochemically distinct from district to district. This distinction could be used to target areas that hold higher grade/larger tonnage undiscovered resources.
Characterisation of the Hillside Deposit

- Large, low grade orebody with a total mineral resource of 337Mt @ 0.6% Cu and 0.14g/t Au

- Association with intensely altered gabbroic and syenitic intrusives dated at ~1585Ma and emplaced within a major craton bounding structure (PPSC). Mineralisation is also ~1585Ma

- Limited Pb-isotopic data indicate ages similar to the U-Pb age dating with minor Cambro-Ordovician carbonate-galena veins

- Association with long lived, major regional structures (PPSC)

- Association with pre-existing meta felsic-mafic volcanics, calc-pelite, evaporites, carbonate and impure carbonate-bearing sequence
- Major gravity and magnetic anomalies present
- IOCG skarn association with an age of ~1585Ma for mineralisation and intrusives. The intrusive rock-types have been intensely altered and, in part, mineralised
- Association of Fe-Cu-Au-LREE-U; little or no Mo and F but significant Ag
- Dominant chalcopyrite with lesser primary bornite and chalcocite; gold, electrum and minor tellurides usually associated with Cu-sulphides but not with pyrite. The deposit probably hosts an outer “shell” of hypogene bornite-chalcocite enriched in Ag and Au
- Prograde (non mineralised) and retrograde skarns present with copper + gold associated with more oxidised (hematite) retrograde skarns