

Mineralized Terranes

Targeting criteria for the Mt. Isa Inlier

Overview

The lecture summary is largely taken from a report of the same name prepared by Murphy et al (2008) and describes the explorationist's role when targeting new ore deposits. Criteria on which area selections are made are scale dependant, determined by conceptual models that are applied and limited by the availability of appropriate data sets. The variety of deposits at the Mt Isa Inlier can be regarded as belonging to two general types, traditionally related to separate mineral systems:

1. the generally older (1660-1595 Ma) Pb-Zn-Ag sediment hosted massive sulphides (e.g. Mt Isa, Century, McArthur River). These deposits are characterised by stratiform massive sulphide lenses in carbonaceous shales and siltstones at varying stratigraphic levels within the Isa Superbasin. There is a strong fault control on the localisation of deposits. The age and timing of mineralisation remains a source of considerable debate, from early, shallow burial sub-seafloor replacement (e.g. McArthur River) to later, deeper burial, syn-inversion replacement (e.g. Century). However, there is increasing consensus that ore deposition at the sediment-water interface is a less important process than sub-seafloor replacement (Huston *et al.* 2006). However, Feltrin *et al.* (2007) used geometric and numerical models in their model of primary syngenetic mineralization for Century with a protracted history of reworking
2. the generally younger (1600-1500 Ma) Cu +/-Au (+/- U) deposits which encompass Isa Cu and Mammoth Cu deposits in the Western Succession and the IOCG Cu-Au deposits in the Eastern Succession (e.g. Earnest Henry, Osborne). These deposits are characterised by a distinctive epigenetic association, very strong structural controls (breccias, fault bends and intersections, rock competence contrasts), and modest to high copper grades

with highly variable gold. The spectrum of deposits ranges from almost pure copper-rich and Au-absent (e.g. Mt Isa and Gordon in the Western Succession) to Cu-Au deposits of the iron-oxide-Cu-Au (IOCG) association which carry a diverse and complex additional element enrichment (U, REE, Co, Ba being the most common). The deposits are mostly of the low sulphidation variety being dominated by chalcopyrite and iron oxides. The timing of these deposits is dominated by geochronology centred on 1530 Ma, the same timing as emplacement of many intrusions of the Williams Batholith, and several lines of evidence point to a magmatic origin for some of the fluids at least in the Eastern Succession. In the Western Succession, where granitoids of this age are unknown, and for older IOCGs in the Eastern Succession, basinal fluid sources are likely. Much of the ~1530 Ma mineralisation appears to have formed by the initiation of strike-slip faulting and granite emplacement during the final stages of cratonisation.

Pb-Zn-Ag SHMS	Key Criteria (inc ranking)	Necessary Data	Min Data Density
Regional Analysis (Province)	Precambrian Rift-fill sediments Regional scale faults	Terrain Chron Gravity Aeromagnetics Regional geology	100km ² catchments 10km stations 5km flight line 1:500k, 1:250k maps
District Analysis (60x60km)	Major (basin margin) Faults Supersequence boundaries Late Basin Seds (Isa SG) Extension and Compression. ! Geological Complexity	Gravity Aeromagnetics Geology maps Seismic AEM 3D Map	3km stations 1km flight line 1:250k, 1:100k maps Reflection/Refraction
Prospect Analysis (5x5km)	Carbonaceous shale Fault intersections, Cross Faults Growth Faulting/Depocenter? Alteration halo	Detailed geophysics AEM Petrophysics Remote sensing WR geochem 3D Map	500 m stations 200m flight line Magnetotellurics Aster, Hymap, Hyperion, PIMA
Ore System Definition	Fluid focussing Multiple fluids/mixing Alteration halo	Drill core Field/Lab integration WR geochem	500m stations 50m flight line or ground based
Ore Deposit Identification	Alteration gradients	Drill core Microscopy	

Figure 1: Table summarizing the targeting criteria for Pb-Zn-Ag deposits at the different scales.

IOCG Cu	Key Criteria (inc ranking)	Necessary Data	Min Data Density
Regional Analysis (Province)	Carbonate Sequences/Evaporites Granites (esp A-types) Mafic rocks Basin Inversion (compression) Regional scale faults Metamorphic gradients...?? Precambrian	Terrain Chron Regional geophysics Regional geology	10km gravity 5km aeromag 1:500k, 1:250k geol maps
District Analysis (60x60km)	Geological Complexity Major Structures – through- going Stress partitioning and dilation Strike slip/transpression Corella/SCG boundary Regional alteration patterns	- as above, more detailed - fault architectural map Remote sensing - ASTER, HyMap	1:250k, 1:100k geol maps 5km gravity ASTER and HyMap mineral maps from www.em.csiro.au/NGMM webpage
Prospect Analysis (5x5km)	Magnetic highs/Gravity highs Fluid focussing and dilation Host rock rheology/permeability Fault intersections, jogs, bends Stress anomalies Magnetite depletion Alteration footprints Lithogeochemical haloes	Detailed geophysics Petrophysics Analysis of fault fills Remote sensing - Aster, Hymap, Hyperion, PIMA 1:100k, 1:50k geol maps AEM	2km gravity 200m aeromag

Figure 2: Table summarizing the targeting criteria for Cu(-Au) IOCG deposits at the different scales.

Pb-Zn-Ag deposits

SCALE 1: REGIONAL ANALYSIS–How to recognise a metal bearing province (1000 km x1000 km area selection)

If the explorationist were to undertake project generation at a terrane scale in other parts of the world for regions with similar characteristics as the Mount Isa terrane, some distinguishing features are, in approximate order of importance:

- Plumbing system that taps deep into the crust (maybe even mantle?), as evidenced by:
 - Linear, strike extensive gravity anomalies with strong gradients within an overall high gravity response. The sources of the high gravity responses are varied (Wellman, 1987) but an association with abundant mafic rocks at depth

is implied. Sampling on at least 5 km station spacing is needed to determine this and, typically, such data is available from Government organisations.

- Aeromagnetic response, though more influenced shallower level responses, with evidence of long wavelength gradients. These typically have a similar fault-related nature as the gravity responses, and an integration of these two data sets provides essential information relating to the terrane scale architecture.
- Complex pattern of faulting and major, laterally continuous, large dimension faults. This is not unique to the Isa region, as other terranes with similar features are far less mineralised. In outcropping terranes, mapped geology and TM, in the first instance, would determine this, otherwise, in under cover regions, determined from available regional geophysics. Sources of such data generally reside with Geological Survey organisations.
- Mesoproterozoic age – metal abundance varies in a non-systematic pattern over Earth history with the Mesoproterozoic being a particularly fertile period and a major contribution to this global abundance is from the Mt Isa and Broken Hill regions of Australia (Huston et al., 2006). Stream sediment sampling of detrital zircons to determine age spectra maybe an appropriate technology (e.g. Terranechron) to gain a rapid, first pass assessment of this history, in catchments of ~ 100 km² and is a cost effective strategy.
- Intracratonic rift or distal back arc environment, abundant mafic and felsic rocks, and a thick sediment pile. A history of repeated extension and inversion, perhaps observable from geological maps (at a minimum, 1:250 000 scale) and regional signatures, particularly the magnetic expression of rift-related mafic sequences.
- High geothermal gradient and regional high temperature/low pressure metamorphism. Nor is this unique to the region, as there other less mineralised terranes with similar features. Such information, however, requires detailed analysis and is generally not determinable from remote data sets.
- Existing deposits and occurrences (“smoke”) are a clear signal of fertility.

SCALE 2: DISTRICT ANALYSIS—How to identify the location of major mineral camps (60 km x 60 km area selection)

Having determined the terrain of interest, the following criteria can be indicative of mineral camps, in approximate order of importance:

- Evidence of potential source rocks (rift-related volcanics) and diagenetic aquifers in lower parts of stratigraphic pile, comprising thick proximal clastic sequences with potential to be buried to 5-10 km depth at times of mineralisation, e.g. Leichhardt Superbasin sediments and volcanics (e.g. Polito et al. 2006a, b, c).
- Evidence of carbonaceous, argillaceous host rocks in upper levels of youngest (pre-orogenic) basin, e.g. Isa Superbasin sediments.
- Faulting – evidence for long strike length faults (Figure 2), commonly associated with significant gradients in potential field data, indicative of penetrative, crustal scale faulting. In addition to mapped geology, critical data sets are:
 - Seismic data is an important contribution to this, and is generally acquired by State organizations in collaboration with exploration companies.
 - Gravity – minimum 3km spacing, typically acquired by Geological Surveys.
 - Aeromagnetics – minimum 400m line spacing, 100m height, acquired by Geological Surveys and/or exploration companies.
 - Geostatistical approaches to the clustering of vein-style Pb-Zn deposits which should show strong correlations between faults and mineral occurrences
- Evidence of extension and growth faulting – potential driver of fluids by underpressure, dilation and downward excavating convective flow.
- Evidence of inversion, compressional folding and faulting - potential driver of fluids by upward expulsion from breached reservoirs.
- Evidence of saline brines, evaporates or remnants thereof in deeper parts of sediment pile.
- Alteration – possibly seen from geophysical (magnetite depletion?) or remote sensed data (TM, ASTER). This would particularly include the common occurrence of primary and diagenetic carbonates such as siderite or dolomite

that should be distinctive from regional stratigraphic signals irrespective of the specific genetic model.

- Clustering of existing deposits and occurrences (“smoke”)
- Stream sediment sampling – in catchments of 10 km². Geological Surveys and/or exploration companies

SCALE 3: PROSPECT ANALYSIS–How to identify the location of a specific ore deposit (5 km x 5 km area selection)

Within a mineral camp, key features to evaluate are:

- Host rock – presence of carbonaceous argillite
- Fault architecture – fault intersections, dilational jogs; complexity. Existence of penetrative faults, supported by potential field data: detailed gravity, minimum 500m station spacing, and aeromagnetics, minimum 200m flight line spacing.
- Local depocentres – growth faulting, hanging wall positions? May be determined from mapping, and/or magnetotelluric and seismic data.
- Alteration footprints
 - lithogeochemical haloes up to 15 km from McArthur River deposit (Large et al. 2000; enriched Zn, Pb, Cu, Ag, Tl, Hg and Mn)
 - Illite xtalinity halo at Century – (Wilde 2006 – G14 project)
 - carbonate (siderite), pyrite.
- Stream sediment and rock chip sampling
- Airborne electromagnetic
- Drilling

SCALE 4: ORE SYSTEM DEFINITION

At this scale, an advanced mineralised prospect has been outlined and further work in delineating its potential lies in:

- Drilling
- Determining the size and tenor of the alteration footprint – within halos:

- Hylogger characteristics ??
- PIMA at Mt Isa does not show diagnostic signals
- Mn halo, C-O isotope halo as per Large *et al* (ref), Zn to Pb to Mn zonation and vectors related to that
- Constraining fault architecture, through mapping and 3D modelling
- Constraining stratigraphy to look for parts of the package with alternating shale/siltstone and stratigraphic variations that could be interpreted as growth faulting
- Constraining fluid compositions and isotopes. See above, these have pretty good isotope haloes. Fluid inclusions next to useless due to fine grain size and questionable relationship of veins to mineralization (except for Silver King style)
- Ground based EM
- DHEM

Cu (-Au) Deposits

SCALE 1: REGIONAL ANALYSIS—How to recognise a metal bearing province (1000 km x1000 km area selection)

- Thick volcano-sedimentary packages lying on rifted continental margin, actual arc rocks obscure or absent
- Widespread intrusions of likely same age as mineralization
- Paleo- to Mesoproterozoic
- Continent-scale anomalous magnetism and gravity (big gradients, worms)

SCALE 2: DISTRICT ANALYSIS—How to identify the location of major mineral camps (60 km x 60 km area selection)

- Intense strike-slip fault networks in which it can be demonstrated that some were active during mineralization

- Intensity of sodic-calcic alteration (for IOCGs) or chlorite-hematite+/- carbonate +/-talc alteration (for Isa-Mt Gordon-style Cu). HyMap and ASTER data can be used to detect regional metasomatic alteration systems (e.g. sodic-calcic alteration in the Snake Creek Anticline: "white mica composition", "white mica abundance") or hydrothermal alteration along major fault zones (e.g. Mt Dore fault zone in the Selwyn Corridor: "white mica abundance", "white mica composition", "white mica relative water").
- Strong rock property contrasts in association with fault offsets
- For IOCG style – abundant granite intrusion into sediments or metasediments containing diverse rock suites (carbonates, pelites, mafic volcanics)
- For Mt Isa copper style - large contrasts in gravity, magnetics, rock property contrasts at this scale (e.g. Sybella Block vs Mt Isa valley)
- Multi-layer prospectivity analysis. Blenkinsop et al's (2005) work in the I2 project appears particularly effective both at this scale and at Prospect Scale
- Broad-scale geomechanical analysis of fault arrays

SCALE 3: PROSPECT ANALYSIS – How to identify the location of a specific ore deposit (5 km x 5 km area selection)

- Geostatistical and/or numerical analysis of parts of the fault arrays most favourable for failure in tension or extensional shear failure (weights of evidence, UDEC, FLAC), using 2D and 3D prospect data from 1:100 000 to 1:10 000 scales.
- Trace element analysis of iron oxides for which transition elements should reveal distinctive signals in haloes, at least in the Eastern Succession
- Core or edges of aeromagnetic anomalies in conjunction with gradients in radiometrics and/or gravity, particularly in the context of a prospectivity analysis and geomechanical models
- Abundance of veins and potassic alteration overprinting earlier sodic-calcic alteration (for IOCGs) or dolomite-silica+/- hematite-chlorite (for Isa – Mt Gordon style Cu).

- Hyperspectral mineral maps, alone or in combination with other geophysical data (e.g. magnetics, radiometric) can be used to detect not only possible host rocks, but also alteration assemblages and their spatial distribution. A good knowledge of the mineralisation-related alteration assemblage and its spatial distribution in combination with a good knowledge of the geology (calibration) of the investigated area is required.
 - Amphibolites are host rocks for some of the IOCGs in the EFB (e.g. Mount Elliott, Selwyn Corridor) and can be separated from other mafic units (e.g. gabbros, dolerites) using mineral maps derived from hyperspectral data ("MgOH content", "MgOH composition", "amphibole/chlorite" and "Fe²⁺ ass. with MgOH")
 - Spatial relationships of sodic-calcic and potassic alteration are important for the recognition of IOCGs in the EFB and can be detected with mineral maps derived from hyperspectral data (Na(-Ca)-alteration: e.g. "white mica composition", "white mica abundance"; Kalteration in mafics: "MgOH content", "MgOH composition", "amphibole/chlorite" and "Fe²⁺ ass. with MgOH" combined with "white mica composition" and "white mica abundance")
 - The combination of magnetic, radiometric and hyperspectral data can be used to detect sodic-calcic alteration (integration of ASTER band 8 data with magnetic and K-radiometric data)

SCALE 4: ORE SYSTEM DEFINITION

- Detailed aeromag with backup groundmag
- IP and/or other electrical, I think hi-res/shallow magneto-tellurics have even been employed at Isa, or was it IP?
- Geochemical zonation studies from drill chips or core (EH shows good 'radial' zonation) focussing on Cu, Fe, As, Mn, Co, As, K, Na, Ca
- Stress inversion studies on veins, faults etc to determine likely stress field during mienralisation

- Detailed structural mapping and/or interp of dilatant fault, fault-bend, fault/rock properties
- Numerical modelling using stress inversion results to impose far-field stresses on known fault or shear arrays

References

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