



Geochemical signatures and critical metal contents of key deposit types in the Mount Isa Province, Queensland, Australia

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SUMMARY

Geological Survey of Queensland undertook a program of geochemical and mineralogical characterisation of key deposit types in the Mount Isa Province in Queensland, Australia. The main objectives of the study included: (1) identification of complete multi-element geochemical signatures of mineralisation for main types of Cu, Zn-Pb-Ag and P deposits in the region, (2) creation of an extensive internally consistent baseline geochemical database, (3) assessing concentrations of critical minerals contained in 'traditional' deposit types in the region as potential by-products.

Iron Oxide Copper-Gold (IOCG) deposits in the eastern Mount Isa Province are characterised by common significant enrichment in Te, Se and Ag (generally co-varying with Cu and Au) but otherwise highly variable geochemical and mineralogical signatures of mineralisation and alteration, with several distinct variants.

Sediment-hosted copper deposits in the western Mount Isa Province are generally significantly enriched in Co; IOCG deposits are variably enriched in Co (and only some of them – in light REEs, Re and In). Siliciclastic-carbonate (SEDEX) Zn-Pb deposits are significantly enriched in Ge (In) and phosphorites – in REEs.

Key words: geochemistry, IOCG, SEDEX critical minerals.

INTRODUCTION

Geological Survey of Queensland (GSQ) has undertaken a large-scale program of systematic geochemical and mineralogical characterisation of key deposit types and mineral systems in the Mount Isa Province, with a particular focus on their critical metal contents. This work contributed to and expanded multi-year collaborative projects between GSQ and CSIRO. The program encompassed: targeted systematic acquisition of representative drill core and ore samples from multiple deposits of different geological types; continuous hyperspectral and XRF scanning of drill core; multi-element geochemistry on multiple samples from each deposit (from ore to distal alteration footprints and background). Target deposit types (and deposits) included (Figures 1, 3): Iron-oxide copper-gold (IOCG – Ernest Henry, E1, Mount Elliott - SWAN, Eloise, Little Eva, Kalman, Osborne and Starra), siliciclastic-carbonate (SEDEX) Zn-Pb-Ag (Mt Isa Zn-Pb, Hilton-George Fisher),

siliciclastic-mafic (Broken Hill-type) Pb-Ag-Zn (Cannington), sediment-hosted Cu (*sensu lato*) (Mt Isa Copper, Capricorn Copper, Lady Annie) and phosphorite (Phosphate Hill, Ardmore).

The program is currently progressing to North-east Queensland, expanding the largest internally consistent public database of Queensland's mineral deposit geochemistry.

METHOD

Samples from each deposit (20 – 200 – depending on the spatial extent and variability of mineralisation) were generally collected from multiple boreholes, at a downhole spacing ranging from continuous (phosphorite) to 10-50 m (Cu and Zn-Pb-Ag deposits). Sampling intended to characterise deposit geochemistry and its variability over the entire range from high-grade mineralisation in central parts of main orebodies to distal alteration footprints and (where possible) regional background. Major and trace element geochemistry (for up to 67 elements) was consistently characterised using a combination of exploration industry-standard digestion methods and analytical techniques: four-acid digestion and ICP-MS / OES (48 elements), lithium metaborate fusion and ICP-MS / OES (31 elements), fire assay and ICP-MS (Au, Pt, Pd), Leco furnace (C, S), KOH fusion - ion chromatography (F), Aqua regia - ICP-MS (Hg, Se, Te) and specialised HNO₃ - HF digestion with orthophosphoric acid leach and ICP-MS finish (Ge).

QA / QC procedures included routine use of matrix-matched Certified Reference Materials (1 per 20 samples) and field duplicates.

GEOCHEMISTRY AND CRITICAL MINERALS IN CU AND ZN-PB-AG DEPOSITS

Major base metal deposits in the region include: sediment-hosted copper and Zn-Pb-Ag deposits in the western Mount Isa Province and diverse IOCG and siliciclastic-mafic (Broken Hill-type) Zn-Pb-Ag deposits in the eastern Mount Isa Province (Figure 1).

IOCG deposits are characterised by a particular complexity and variability of their geochemical signatures (Figures 2-3). The entire group has a common signature of significantly enriched (more than 10 times the average crustal abundance) and generally co-varying Cu-Au-Ag-S-Te-(Se-In-Co-Bi), while some deposits are also variably enriched in U, W, Mo, light rare earth elements (Ce, La), As, Ba, F, Sb and several other elements. Only a few deposits in the region have a dominant complex polymetallic signature (significantly enriched Te-Cu-Re-As-Au-Mo-Se-Bi-Co-W-Sb-Ag-Ba) and proximal K-feldspar-magnetite alteration (Ernest Henry, E1). Most IOCG

deposits in the region have much simpler geochemical signatures and low-to moderate-K proximal alteration footprints, indicative of predominantly Na-Ca-Fe to Fe-Ca-(K) metasomatism.

Most IOCG deposits are significantly enriched in one or more critical minerals. Cobalt is relatively enriched in most deposits, with common average concentrations in the range of 300 – 800 ppm and occasional higher grades (0.1 – 0.2% Co) in individual samples and mineralised zones. Rhenium is strongly enriched only in some Mo-rich IOCG and affiliated deposits (such as Merlin and Kalman, with average grades exceeding 3 ppm Re and locally >30 ppm). REEs (mostly light – La, Ce) are significantly enriched in parts of only several deposits and rarely exceed 1,000 ppm TREE (SWAN).

Cobalt is also locally significantly enriched in parts of sediment-hosted ‘orogenic’ copper deposits in the western Mount Isa Province (Mount Isa Copper, Capricorn Copper, Mount Oxide, Lady Annie), where its concentrations in copper mineralisation commonly varies in the range of 100 – 1,000 ppm Co, with individual samples and cobalt-rich zones of some deposits reaching 0,15% - 0,2% Co.

Major siliciclastic-carbonate (SEDEX) Zn-Pb-Ag deposits in the western Mount Isa Province (Mount Isa Zn-Pb, Hilton) are significantly enriched in Pb-Ag-Cd-Zn-Tl-Sb-As and contain elevated Ge, with concentrations in Zn mineralisation commonly exceeding 10-20 ppm Ge and locally - 40 ppm in individual samples. In comparison, Ge concentrations in siliciclastic-mafic (Broken Hill-type) Pb-Ag-Zn deposits in the eastern Mount Isa Province rarely exceed 5 ppm Ge. Accurate assessment of germanium concentrations requires specialised geochemical analyses preventing losses of volatile phases or specifically tailored for germanium, as standard 4-acid digestion with ICP-MS finish can significantly under-report Ge grades – by as much as >90%.

GEOCHEMISTRY OF REE IN PHOSPHORITES

Systematic collection of geochemical data of known deposits has allowed REE concentrations of Cambrian-aged marine phosphorites from the Georgina Basin to be compared for the first time. Whole-rock geochemical analyses of drill core and hand samples identified phosphorite intervals in the south east of the basin with average REE concentrations exceeding 3000 ppm (Figure 4), favouring the mid-to-heavy REE. Meanwhile, deposits further north in the basin contain an order of magnitude lower REE concentrations at comparable phosphate content. The highest REE concentrations reported here compare favourably to other known REE deposit types. Variation of REE in these temporally associated deposits approach the known range for phosphorites, globally. We propose that weathering input from granitic rocks in the Cambrian enabled

selective enrichment of REE in Georgina Basin phosphorites. Proximity of the southern deposits to Proterozoic A-type granites containing elevated U-Th-REE is contrasted by the Neoproterozoic sediments adjacent to phosphorites further north. The association of A-type granite weathering and phosphogenesis offers a model for improved targeting of phosphorites as potential REE resources. Another interesting aspect to this work is that many phosphorite intervals display geochemical and mineralogical evidence of weathering, where the primary phosphate mineral, carbonate fluorapatite, breaks down to form crandalite. Highly weathered samples are recognisable by lower P, higher Al and REE. A trend of decreasing REE concentrations across phosphorite intervals is often observed where maximum REE grades are associated with enrichment in crandalite (Figure 5) and are offset above the highest P₂O₅. We interpret this trend as a result of supergene enrichment of REE via secondary mineralisation of crandalite and other phosphate minerals where total REE can exceed 1.5%.

CONCLUSIONS

Internally consistent extensive multi-element geochemical data acquired by this study allows identification of geochemical signatures of mineralisation and alteration for multiple deposit types, representing genetically diverse mineral systems in the Mount Isa Province. This dataset can provide a baseline of mineral deposit geochemistry for future research and interpretation of exploration results.

The data indicates that deposits of major ‘traditional’ commodities in North-west Queensland are often significantly enriched in one or more critical minerals – sometimes approaching potentially economic grades which could allow their profitable extraction as by-products - or even as main commodities in their own right.

ACKNOWLEDGMENTS

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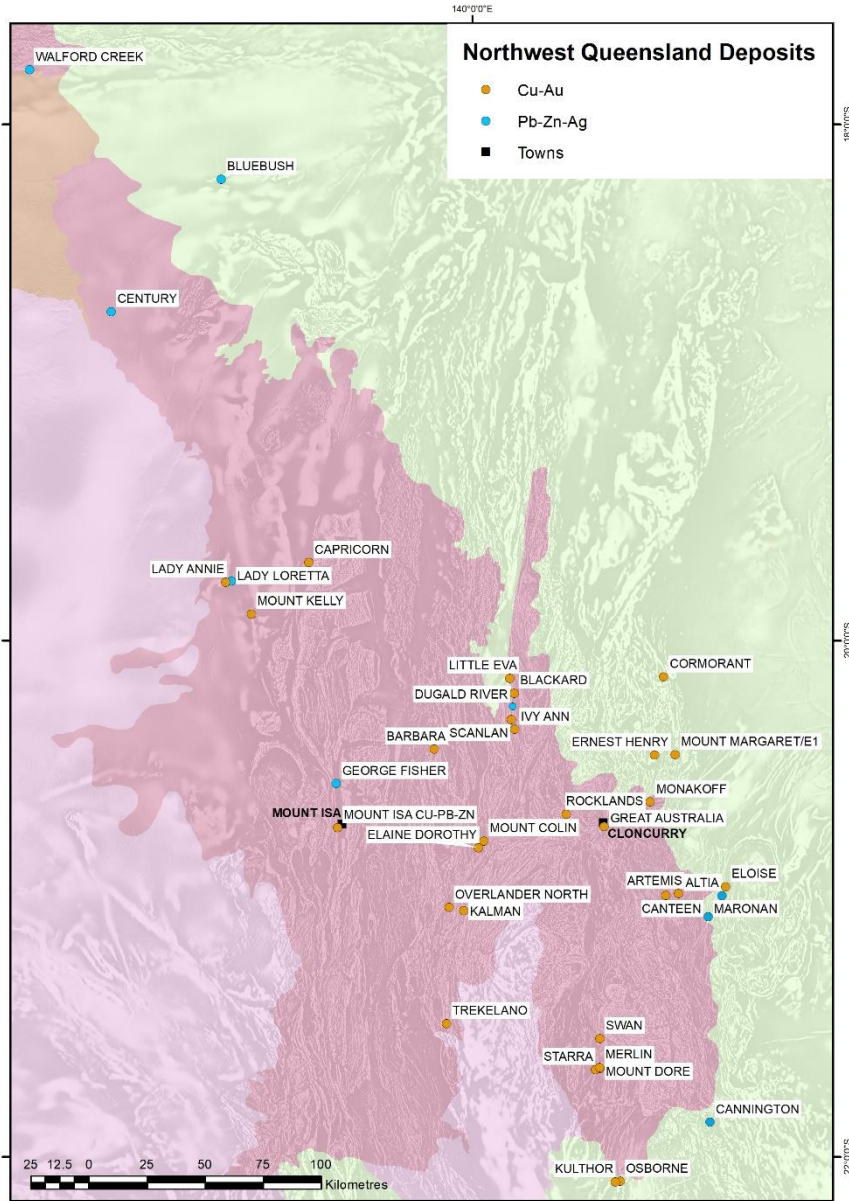


Figure 1. Copper and Zn-Pb-Ag deposits investigated in this study.

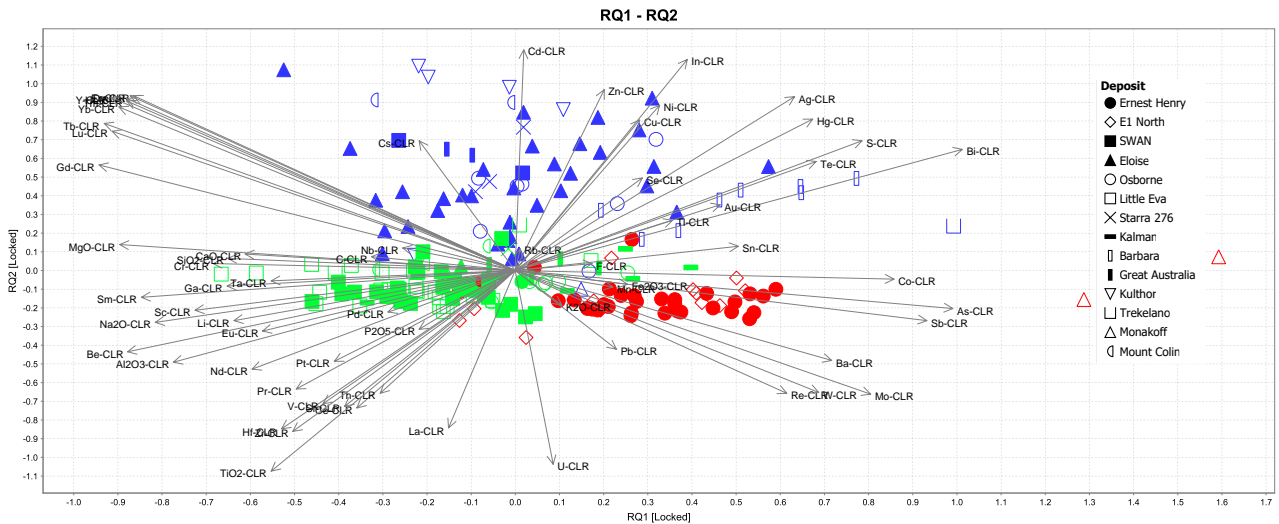


Figure 2. Illustration of results of the Principal Component Analysis of the combined geochemical data for ~200 mineralised samples (>0.2% Cu) from 14 IOCG deposits in the eastern Mount Isa Province (Robust PCA (Fast MCD), after Centred Log Ratio Transformation, ioGAS 7.3), plotting individual samples against principal component vectors for each element. Colours represent distinct geochemical variants of copper mineralisation.

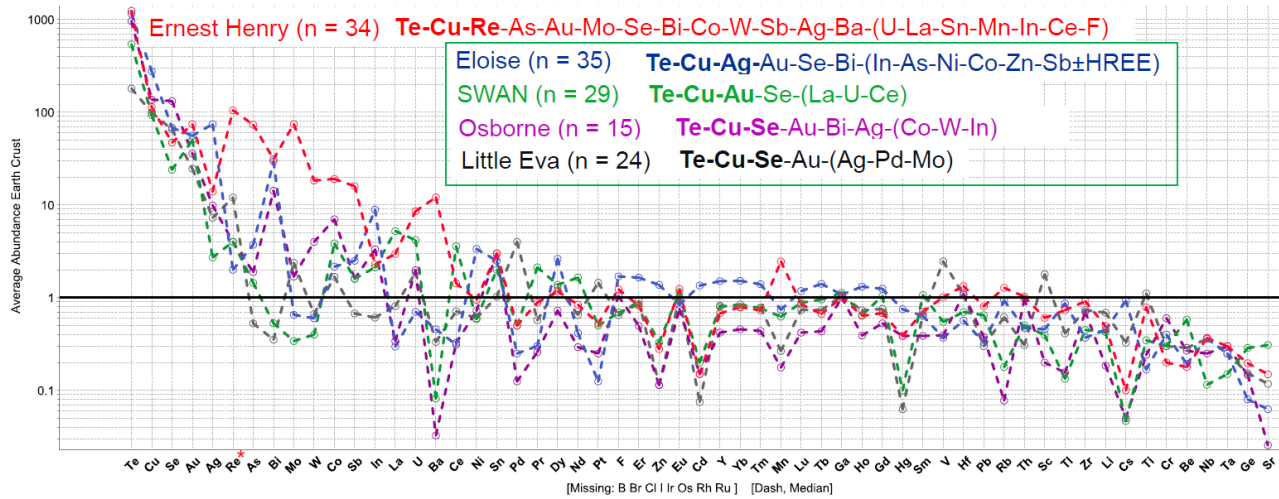


Figure 3. Relative trace element enrichment (compared to average crustal abundance) of copper mineralisation (>0.2% Cu) in selected IOCG deposits – median values for Ernest Henry, Eloise, SWAN, Osborne and Little Eva. Multi-element deposit signatures include elements in the descending order of relative enrichment; values in brackets denote elements enriched by less than an order of magnitude but considered ‘symptomatic’ for a given deposit.

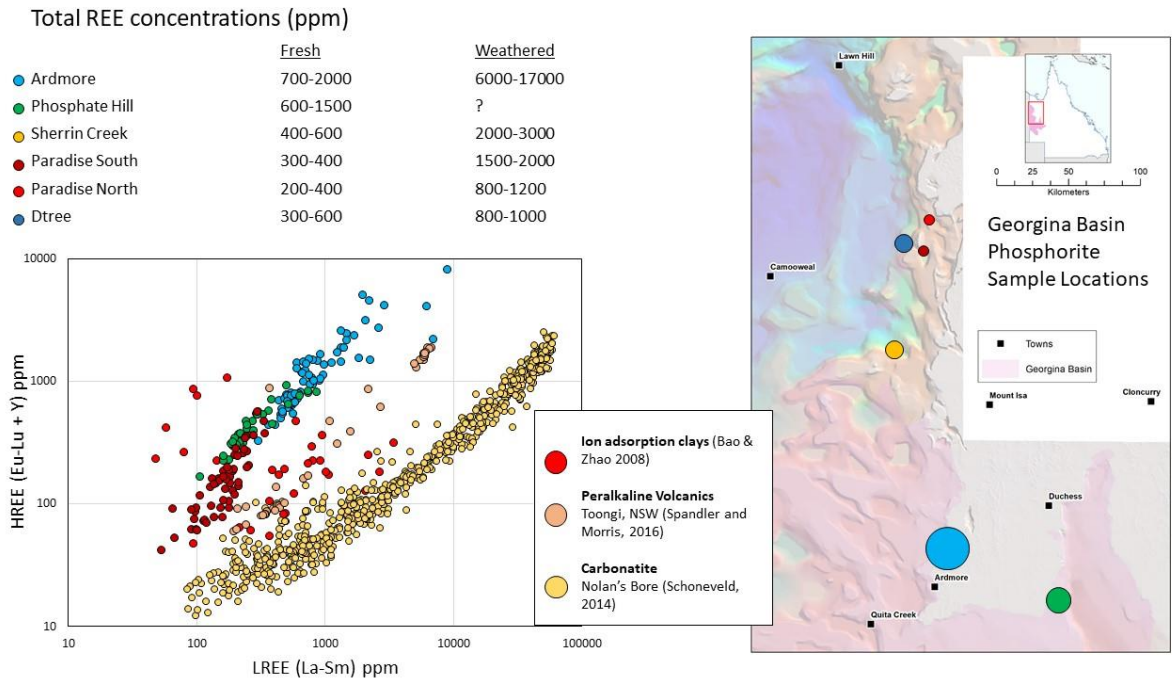


Figure 4. (Top left) REE (Lanthanides + Yttrium) concentrations in fresh and weathered phosphorites from the eastern margin of the Georgina Basin, Queensland. (Bottom left) Light REE versus Heavy REE of selected Georgina Basin phosphorites, compared to several known REE sources. (Right) Phosphorite occurrences of the eastern margin of the Georgina Basin sampled by GSQ. Location symbols vary in size, proportional to REE concentrations measured in the phosphorites at those locations.

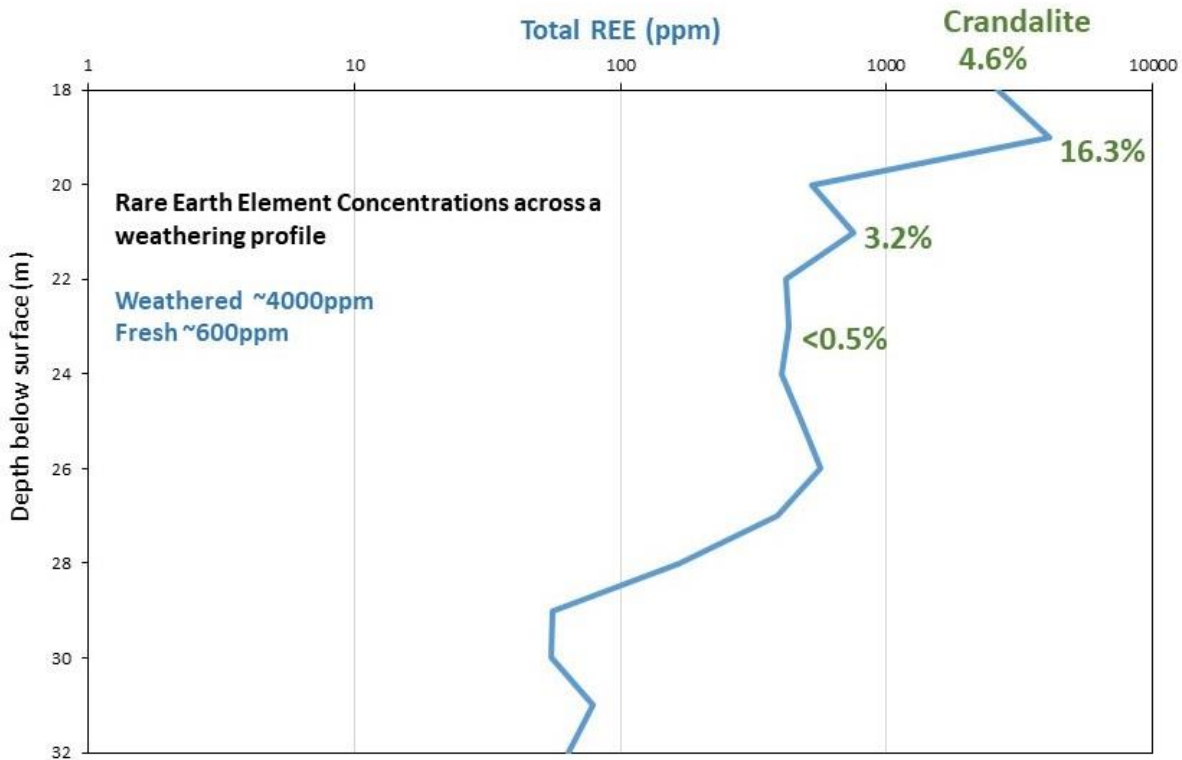


Figure 5. Total REE versus depth below the surface, displaying a weathered phosphorite interval where elevated REE concentrations are reflected by an increased modal abundance of crandallite.