Distal Footprints: UNCOVER Australia
SIEF & MRIWA supported project– Capricorn case study

Rob Hough, Tim Munday, David Gray - CSIRO
Cam McCuaig, John Miller, Mike Dentith, Marco Fiorentini - UWA
Steve Reddy, Chris Clark - Curtin U
Ian Tyler, Simon Johnson - GSWA
The Exploration Challenge

Deep Exploration Targeting

A New Search Space
Theme 1: A Mineral System Approach to the Capricorn Orogen

- Understand the Capricorn mineral system in the context of the 4D evolution of the Orogen
- Important tectonic processes that have affected it throughout its evolution
- Different geodynamic settings that have affected the region of its geological history.
- Basis for understanding known ore deposits, and their likely expression as distal footprints
- Framework for regolith development and context for future exploration.
Theme 1.1: Architecture of the Capricorn Orogen

- Translate known western crustal structures into the eastern part of the Orogen, where the rocks are poorly exposed.
- Variety of deep geophysical techniques
- 3D geologically attributed map of the distribution of magnetization and density.
- Magnetic modelling and inversion will incorporate estimates of resultant magnetization direction for all prominent anomalies
- Long period MT surveys across the study area. Geochemistry etc also acquired as part of other Themes
- Regional characterisation of geology, geochemistry and geophysics from the top few metres to more than 100 km depth
- Seismic recordings will complement the MT data
SIEF Project
Geophysical Transects
Theme 1.2: Tectonic & Geodynamic Evolution

• Reconstruct the earlier history of the crustal blocks caught up in the Orogen and establish the role of continental margin formation in the potential enrichment of ore deposit precursors within the orogeny.

• Immobile trace elements geochemistry.

• U-Pb, O and Hf isotopes in key phases (e.g. zircon) within granitic rocks and gneisses will provide constraints on the location and timing of melting and by inference the tectonic environment.
Time-Space Plot
Existing U-Pb data

Data in preparation and in press:
- GSWA, new in 2013 (n = 85)
- GSWA, 2010–2012 (n = 177)

Published data
- GSWA, published in 2012–13 (n = 60)
- GSWA, published 1995–2012 (n = 1083)
- Geoscience Australia data from OZCHRON

Capricorn ~ 100 analyses
Zircon Geochemistry

Existing Capricorn data
• U-Pb (geochronology)

Planned Capricorn zircon data
• U-Pb (geochronology)
• Trace elements geochemistry (e.g. Ti for Temperature)
• REE (LREE vs HREE)
• Hf isotope data (crustal residence time)
• O data (crust vs mantle sources)
Theme 1.3: Fluid Sources, Transport & Deposition

• Precisely date mineralization, subject to access to paragenetically well-constrained samples, using in-situ ion microprobe geochronology (zircon and phosphate dating)
• Link surface fluid flow to potential sources at depth.
• Focus on radiogenic (Lu–Hf) and stable isotopes (O & H) of minerals (such as zircon, monazite and xenotime) and whole rocks, as well as trace element analyses,
• Analysis of microstructurally characterized fluid inclusions will be used to establish fluid chemistry and PT conditions of entrapment
Theme 2: Characterisation of Cover in the Capricorn Orogen

- Combine regional geophysical and geochemical datasets
- Effectively explore in remote and complex environments
- Define the nature of the cover.
- New datasets for exploring the Capricorn Orogen
- New protocols for data integration and interpretation
- Input from geophysics, remote sensing, geology, regolith science and exploration geochemistry etc.
- Depth to basement and 3D regolith framework will support other exploration methods e.g. geochemistry.
- Critical importance of sediment filled palaeovalleys. Sometimes >150m deep and several km wide. Prospective for both U and CIDs
- Geometry and internal variability mapped by a regional AEM survey
Theme 2.1: Regional Cover Characterisation using Airborne Electromagnetic Data

- 21 500 line km of AEM data at a 5 km line spacing
- Determine regional variations in regolith thickness
- Understand regional variations in regolith stratigraphy
- Finer scale infill surveys - potential to explore for conductive regions related to alteration effects and sulphide enrichment
Gaining knowledge of Depth through the AEM

60–100m

first vertical derivative magnetics conductivity from the AEM from ~15 to 20 m

Multi-resolution Valley Bottom Flatness (MrVBF) (Gallant and Dowling, 2003). Flatness index using DEM
Mapping and Working with Regolith Complexity

Interpreted Regolith Section

AEM Section

Geochemical sampling domains

A

B
Outputs - Regolith Thickness (from AEM) – link to Geochemistry – eg Cu
Theme 2.2: Regional Geochemistry and mineralogy

• multi-element regolith geochemistry data for the region, comprising approximately 6000 individual samples
• U/Th/K radiometrics
• ASTER mineral maps
• Value add to databases, improve lithological discrimination, map hydrothermal alteration, prospectivity analysis
• Relationship of proximal transported units to bedrock and regional coverage applications for mineralization haloes.
Large scale lithological and weathering effects
Alteration assemblages
Theme 2.3: Regional Geochemistry Protocols

- Individual site will be selected to address specific problems
- Possibly Ashburton, Bryah-Padbury and Sylvania regions
- Establish optimal sample media in the different regolith-landform settings
- Information on geochemical thresholds
How will this assist geochemical sampling?

1. Ferruginous duricrust, nodules, and pisoliths (establish origin)
2. Fe saprolite; lag
3. Lag, soil, saprolite (identification of aeolian material critical)
4. Soil, fresh rock (identification of aeolian material critical)
5. Buried ferruginous duricrust and loose nodules and pisoliths (establish origin), Fe saprolite
6. Where transported overburden is <10 m thick: - Soil sampling
   A. Where transported overburden is <3 m thick: - Soil sampling (Northern region)
   B. Where transported overburden is >3 m thick: - Pisoliths and mottles developed in sediments
      - Interface (unconformity)
      - Buried saprolite
      - Vegetation sampling

Recent alluvium
Colluvium, alluvium
Ferruginous duricrust and loose nodules and pisoliths
Fe saprolite, collapsed Fe saprolite
Saprolite
Bedrock

SCIENCE INDUSTRY ENDOWMENT FUND

Geological Survey of Western Australia
Curtin University
Centre for Exploration Targeting
mriwa
CSIRO
Theme 3: Mineral hosts as Distal Footprints

• What are the distal footprints associated with mineral deposits?
• A ‘distal footprints toolbox’, applied to exploration in the Capricorn Orogen. E.g.,
  • rutile is a useful mineral indicator that can survive prolonged weathering,
  • goethite and hematite clasts can replace sulfides and retain primary metal anomalism
  • alluvial gold grains are proving valuable in provenance studies.
  • Weathering sulfides can be reprecipitated into the cover sediments as secondary minerals such as alunite → useful anomalism indicator?
• interface sampling at the base of unconformities in covered terrains, or specific mineral species within the cover sediments
• Develop understanding of key indicator elements and their mineral associations at different distances from different ore deposit types
Theme 3.1: Characterization of distal footprints

- Hydrothermal rutile and magnetite as pathfinder minerals for mineral exploration through sampling of top of fresh rock, and base of transported overburden.
- Elements in these minerals can display characteristic signatures used to fingerprint hydrothermal ore deposits.
- Apatite can be a useful mineral host for a magmatic signature with anomalous iron. Halogen signatures of mineralizing fluids in a system might be preserved in the apatite.
- Targeting secondary minerals such as alunite, and iron oxides.
- Distal Footprint indicators.
Theme 3.2: The Distal Footprint Toolbox

• Outline an approach for early exploration in a covered terrain, e.g.:
  • Major discontinuities in the upper and lower crust and mantle 
lithosphere in a 3D volume of the crust as a vector to mineral 
systems
  • How thick is cover in a given region? How do you use the 
geophysical data, the nature of the cover, the palaeosurface and the 
3D regolith framework to prospect this ancient landscape.
  • Using fresh rock analysis for a background v anomalism picture for 
alteration, lithogeochemistry, & indications of a potential mineralized 
system.
  • Analysing faults for signatures of spent as well as pregnant fluid flux
  • Understanding the pre collisional structure as an indication of 
potential fertility
  • Detecting the mineral system footprint through analysis.
Theme 4: Hydrogeochemistry of the Capricorn

- Map the hydrogeochemistry of specified areas within or adjacent to the Capricorn Orogen, to an approximate 5km spacing
- Determine background concentrations of elements with exploration importance for different rock types
- Modify and improve exploration parameters developed in previous project
- Develop utility of isotopes in groundwater for structural and prospectivity analysis
- Improve information on the prospectivity of the underexplored Capricorn Orogen
- Integrate with AEM, radiometrics and mapped soil geochemistry
- Disseminate the results and exploration implications of the research to the Industry sponsors
Tungsten Distribution – Thomson Belt

Highly anomalous for Cuttaburra, consistent with drilling results running 0.41% W

Seeing through 100’s m of exotic cover
North Yilgarn Groundwater – Ca rel. Sr

Ca rel. Sr
- v. high Ca
- high Ca
- mod. Ca
- mod Sr
- high Sr
- v. high Sr

SCIENCE AND INDUSTRY ENDOWMENT FUND
Geological Survey of Western Australia
Curtin University
Centre for EXPLORATION TARGETING
MRIWA
CSIRO
Various Indices → targeting at Regional & Prospect Scale

- NiS Index
- Major Ni deposits clearly observed
- Harmony deposit strongly anomalous
- + additional anomalies along strike
- Works very well at 10m – km scale
Carnotite Saturation + U:Th Radiometrics
Capricorn (& north Yilgarn) Groundwater Sampling
Theme 5: Geochemical Mapping for Lithospheric Evolution, Metal Reservoirs & Predictive Targeting
Alternative plot – Napier Complex Zircon

Napier Complex data collected in 1.5 hrs by Chris Clark
Detailed LASS mapping of single grains

Image courtesy of LASS Facility UCSB, USA
Multiple S isotopic Architecture of the Capricorn Orogen

In most mineralised systems, sulfides play a fundamental role in transporting and concentrating a wide range of metals.

Minerals such as pyrite (FeS$_2$), chalcopyrite (CuFeS$_2$), galena (PbS) are common in both hydrothermal and magmatic ore systems.

However, it is generally difficult to determine *origin and timing* of sulfides in ore systems.
Sources and Sinks

Most sulfur isotope studies in ore systems focussed on $\delta^{34}\text{S}$ (not as insightful as easily reset and modified)

This study will utilise multiple S isotopes ($\delta^{34}\text{S}$, $\delta^{33}\text{S}$ and $\delta^{36}\text{S}$) to accurately fingerprint sulfur source and map fluid pathways in magmatic and hydrothermal ore systems

Trace element (Se, Te, Co, Ni, As, Sb, Au, Ag) compositions of pyrite can also be used to correlate sources and sinks of ore forming fluids

Re-Os dating of sulphides to provide a time constraint

Multiple sulfur isotopic map of the orogen is the final goal: will superimpose and integrate with other datasets

Spatial and temporal representation of data is a critical part (=4D), and never done before at this scale
Method

Representation of the predicted $\delta^{33}S/\delta^{34}S$ fractionation trend in young S-bearing compounds (<2.0 Ga) = terrestrial fractionation line

Real world $\delta^{33}S/\delta^{34}S$ Fractionation trend in S-bearing compounds (<2.0 Ga)

Deviation = chemical tracer

Re-Os of sulphides to provide a time constraint
The multiple sulfur isotope record

Mass-independent fractionation is a chemically-conservative tracer. For the Proterozoic Capricorn Orogen we will be able to detect if, and where, there is an Archean link to system – will tie with existing and new geophysical data generated by SIEF (MT, passive seismic)
Theme 6: Digital Model using virtual environments for data integration and visualization
Data Portal

Virtual Geophysics Laboratory

Featured Layers

Geoscience Australia Coverages (4 Items)
- Onshore Only Bouguer Geodetic
- Onshore and Offshore Gravity Anomaly Geodetic
- RadMap Totaldose
- MagMap V5 2010

Add Layer to Map

Active Layers

Layer Name | Visible
---|---
Onshore Only Bouguer Geodetic | ✔

Onshore Only Bouguer Geodetic
1. Mineral Systems
2. Cover
3. Mineral Footprints
4. Deep Geological sensing – Hydrogeochemistry
5. Metal Reservoirs
6. Data Management and digital models