Mineral Hosts for Gold and Trace Metals in Regolith

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Introduction

- The geochemical dispersion of gold and base metals and their pathfinders is strongly dependent on the retention of these trace elements in the regolith.

- Which residual and newly formed regolith minerals contain Au, base metals and pathfinders?

- How much?

- Implications for exploration
A CRC LEME-Normandy Mining Limited (now Newmont Australia) project has investigated the element-mineral associations in the regolith of three deposits in Western Australia:

- Boddington Au deposit in the southwest of the Yilgarn craton;
- Mt Percy Au deposit in the Kalgoorlie goldfield;
- Scuddles Cu-Zn deposit in the Golden Grove district.
Methods

- A combination of mineralogical and chemical analyses
- Emphasis on *in situ* micro-analyses of clays and Fe oxides/hydroxides:
  - Bulk and clay fraction XRD
  - SEM-EDS
  - *In situ* LA-ICP-MS (Laser ablation inductively coupled mass spectrometry)
in situ LA-ICP-MS

- Samples: very little preparation
  - Thin sections > 30 µm
  - Cut blocs and polished blocs
  - Grains mounted in a binder

- Detection of element concentrations of down to 1 ppm and lower.

- About 5 minutes per analysis.

- Spatial resolution: 20 to 50 µm and down to <0.5 µm in depth.
In situ LA-ICP-MS analysis of regolith material

Element concentration

Homogeneous material
- one or several types of minerals

- Internal standard concentration: microprobe value of the concentration of a chosen element

![Element concentration graph](image)

**Element concentration graph**

- Al27
- Mn55
- Fe57
- Ni60
- Cu65
- Zn66
- Ba137
- Ce140
- Pb208
Heterogeneous material

- Internal standard concentration

  - Microprobe value cannot be used

  - The material can be “sliced”: microprobe values for each slide or elemental stoichiometry

  - Otherwise the results are normalised to 100% oxide.
Boddington Au deposit

After Anand, 1994
Geochemical composition of the regolith
Saprolite mineralogy

- Abundant kaolinite and quartz;
- Partially weathered mica;
- Goethite + hematite replace Fe-sulphides.
  - Vermiculite, interstratified minerals chlorite/vermiculite (corrensite), and biotite/vermiculite. Vermiculite is partially weathered into kaolinite and goethite.
- Anatase grains

Chlorite  Corrensite
Clays

- Vermiculite: Zn (980 ppm), Mn (1.5%) and Cu (1.5%)

- Goethite + kaolinite: Cu, Zn, Mn
  - Cu, Zn and Mn % increase with goethite content
  - Goethite hosts the traces

- Kaolinite does not contain Zn, Mn, Cu
Iron oxides

- **Microcrystalline goethite**
  - Cu: up to 4% Cu in goethite-kaolinite
  - Zn (180 ppm) and Mn (350 ppm)
  - Au (>270 ppb), sub-micrometer particle
  - As (0.5 %)
  - Bi (>330 ppm), Mo (>210 ppm)
  - W (>100 ppm) and Pb (>190 ppm)

- **Massive goethite and hematite in iron sulfides relicts**
  - Lower contents than in microcrystalline goethite
Boddington (Au-Cu): pisolithic duricrust

- Au (up to 1 ppm)
- Individual particles disseminated in the pisolith core and cortex and internodular matrix

- Cu (130 ppm), As (88 ppm), P and Mo (100 ppm) are concentrated in goethite in the cortex and matrix of the pisoliths
- About 110 ppm W in the core and cortex
- Gibbsite does not trap any of these elements
Ti-rich phases

- Anatase (titanite weathering product)
- High levels of W (>235 ppm), Ta (>271 ppm), Bi (>56 ppm) and V (885 ppm)
Mt Percy (Au)

Soil + Pedogenic carbonate

lateritic duricrust
mottled and plasmic clay
clay saprolite
saprolite
porphyry

(After Butt, 1991)
Mottled and plasmic clay zone

- **Goethite-rich cutans (Fe >40 %)**
  - high levels of Cu (up to 740 ppm), As (up to 0.1%), Mo (up to 430 ppm) and Sb (up to 900 ppm).
  - W is hosted in Ti-rich grains

- **Goethite-hematite in ferruginised rock**
  - Comparatively depleted: Cu (140 ppm), As (370 ppm), Mo (8 ppm) and Sb (50 ppm)
Au

- Cutans
  - up to 400 ppm
  - Au occurs as crypto-crystalline particles

- Ferruginised material
  - Au has not been detected
Scuddles (Cu-Zn)

- Cu, Pb, Zn
- Sb, In, Bi, Mo
- Cu, Pb, Zn, Mn, Co

Host horizon, Epiclastic sandstones, Volcaniclastic sediments, Dolerite

Silicified hardpan, laterite and mottled zone
Upper saprolite
Lower Saprolite
**Hanging wall**

**Lower saprolite**
- Quartz, muscovite, kaolinite
- Up to 7% corrensite
- Chlorite/smectite and Chlorite/vermiculite
- Mn oxides: coronadite + lithiophorite
- Ilmenite

**Upper saprolite**
- Corrensite (2 %)
- Fe-smectites are present (up to 7%).
**Lower saprolite**

- **Vermiculite layers of high-charge corrensite**
  - About 0.30% Cu and Zn and Zn,
  - Ni (up to 340 ppm) and Co (up to 80 ppm)
- **Smectite layers of low-charge corrensite**
  - Lowers amounts of these elements
- **Kaolinite**
  - Cu, Zn, Ni, and Co are not present
Upper saprolite

- **Smectites**
  - >0.25% Cu, Zn (>0.12%), Ni (>150 ppm) and Co (>50 ppm).

- **Kaolinite**
  - does not trap trace elements
  - does not inherit cations released by the weathering of muscovite
Over mineralisation

Lower saprolite
- Quartz, muscovite, kaolinite
- Abundant chlorite
- Corrensite (1%)
- Mn oxides: coronadite + lithiophorite
- Hematite-goethite

Upper saprolite
- Intensively silicified
- Fe-rich banded concretions
Lower saprolite

- Hematite-goethite assemblages
  - Cu (2%), up to 0.4 % Zn and Pb, and 0.15% As
  - V (220 ppm), Mn (740 ppm), Ni (130 ppm) and Co (70 ppm)
  - About 40 ppm Sb

Upper saprolite

- Fe oxides
  - Depleted in Cu (0.4%), Zn (250 ppm) and As (370 ppm)
  - High contents of Sb (up to 400 ppm) and Mo (up to 220 ppm)
loose pisoliths

Goethite: Cu, Zn, As, Mo

Goethite: Au

Anatase: W, Ta, Bi, V

Au: micro-particles

Vermiculite: Cu, Zn, Mn
Microcrystalline goethite
Massive Gt-Ht
Anatase: W, Bi, Mo

Cu, Zn, Mn, Au, As, Bi, Mo, W, Pb

CRCLEME
Conclusions

- Base metals and pathfinders are concentrated in:
  - Clay fraction: vermiculite, smectite and interstratified minerals
  - Microcrystalline goethite
  - Massive goethite, hematite
  - Cutans in voids and around pisoliths and nodules
  - Kaolinite is barren
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