Geochemical Exploration in Lateritic Terrains

Paul Agnew
Chief Geochemist
Rio Tinto Exploration Pty. Ltd.
Presentation outline

- The Lateritic Weathering Profile
- Geochemical Exploration in Lateritic Environments
- Analytical Techniques
- The Microscopic Future
Global Lateritic Weathering

Global Distribution of “Lateritic Soils”
Deep Lateritic Weathering

- A process of “Landscape Reduction” in tropical environments
- Multiple periods of extended weathering caused by fluctuating water table
- Leads to the development of a “weathering profile”
Lateritic Landscapes - Australia

Australian “Dry” Lateritic Terrain - A challenge to early explorers
Lateritic Landscapes - Australia

Australian “Dry” Lateritic Terrain - A challenge to early explorers
Lateritic Landscapes - Australia

Australian “Dry” Lateritic Terrain - A challenge to early explorers
Regolith: Everything between Fresh Rock and Fresh Air!

The Lateritic Profile

Terminology of weathering profile:
- Lag
- Soil
  - Lateritic residuum
  - Lateritic gravel
  - Lateritic duricrust
- Mottled zone
- Clay zone
  - Cementation front
  - Pedoplasmaion front
- Saprolite
  - Weathering front
  - Pedolith
  - Regolith
  - Saproolith
  - Bedrock

Lateritic residuum
Mottled saprolite
Fe-saprolite

Slide: R. Anand
**Regolith:**
Everything between Fresh Rock and Fresh Air!

**The Lateritic Profile**

[Diagram of the Lateritic Profile]

1. **Regolith**
2. **Saprolith**
3. **Saprock**
4. **Bedrock**

**Terminology of weathering profile**

- Lag
- Soil
- Lateritic residuum
  - Lateritic gravel
  - Lateritic duricrust
- Mottled zone
  - Cementation front
- Clay zone
  - Pedoplasmatation front
- Saprolite
  - Weathering front
- Lateritic residuum
- Mottled saprolite
- Fe-saprolite

*Slide: R. Anand*
The Lateritic Profile

Leached Saprolite

Ferruginous Saprolite
Regolith: Everything between Fresh Rock and Fresh Air!

The Lateritic Profile

Terminology of weathering profile:
- Lag
- Soil
- Lateritic residuum
- Lateritic gravel
- Lateritic duricrust
- Mottled zone
- Clay zone
- Saprolite
- Saprock
- Bedrock

Lateritic residuum
Mottled saprolite
Fe-
saprolite

Pedoplasmation front
Weathering front
Cementation front

24th May 2010
P. Agnew - Geocemical Exploration in Latteritic Terrains
Regolith:
Everything between Fresh Rock and Fresh Air!

The Lateritic Profile

Terminology of weathering profile

- Lag
- Soil
- Lateritic residuum
- Lateritic gravel
- Lateritic duricrust
- Mottled zone
  - Cementation front
- Clay zone
  - Pedoplasmatization front
- Saprolite
- Saprock
  - Weathering front
- Bedrock

Lateritic residuum
Mottled saprolite
Fe-saprolite
Mottled Saprolite

Ferruginous Saprolite

Mottled Saprolite

Mega Mottled Saprolite
Regolith: Everything between Fresh Rock and Fresh Air!

The Lateritic Profile

Terminology of weathering profile

- Lag
- Soil
- Lateritic residuum
- Lateritic gravel
- Lateritic duricrust

Pedolith

Regolith

Saprolith

Clay zone

Mottled zone

Cementation front

Pedoplasmanation front

Saprolite

Saprock

Weathering front

Bedrock

Lateritic residuum

Mottled saprolite

Fe-saprolite

Slide: R. Anand

CSIRO
Regolith: Everything between Fresh Rock and Fresh Air!

The Lateritic Profile

Terminology of weathering profile

- Lag
- Soil
- Lateritic residuum
- Lateritic gravel
- Lateritic duricrust

Mottled zone
- Cementation front

Clay zone

- Pedoplasmation front

Saprolite

- Weathering front

Saprock

Bedrock

Lateritic residuum

Mottled saprolite

Fesaprolite

CSIRO
Pisolitic Lag

Lateritic Soil
Protolith controls on the regolith profile...

Sheared basalt
- Lateritic residuum
- Mottled saprolite
- Ferruginous saprolite
- Saprolite
- Saprock

Felsic Porphyry
- Mottled zone
- Clay zone
- Saprolite
- Sprock

Ultramafic (dunite)
- Silcrete

Depth below surface (m)

Slide: R. Anand

CSIRO
Regolith Controls on Geochemical Dispersion

No geochemical Response

Strong anomaly
Wide dispersion

Moderate anomaly
Wide dispersion

Weak / absent anomaly
Narrow dispersion
Residual – Erosional – Depositional

Relict regime (R)
- Lateritic residuum

Erosional regime (E)
- Residual soil and ferruginous lag
- Ferruginous saprolite
- Saprolite

Depositional regime (D)
- Exposed and buried ferricrete (Fe-cemented sediments)
- Colluvium and alluvium
Geochemical Exploration in Lateritic Terrains

Regolith, landforms and sample media

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. A. Where transported overburden is <5 m thick: - Soil sampling
   B. Where transported overburden is >5 m thick: - Pisoliths and mottles developed in sediments
      - Interface (unconformity)
      - Buried saprolite

Recent alluvium
Colluvium, alluvium
Ferruginous duricrust and loose nodules and pisoliths
Fe saprolite, collapsed Fe saprolite
Saprolite
Bedrock
Public Domain Geochemical Sampling

Western Australia: n = >194,000

- Ni Deposits and Occurrences
- Geochemical Sample Location (soil, pisolitic lag, laterite, ferruginous saprolite, sediment, rock)
Public Domain Geochemical Sampling

Western Australia: n = > 194,000

Percentile Sliced Ni (All Media – Raw)

Ni Deposits and Occurrences
SW Western Australia Regolith Map
1:500,000

- Residual; Ferruginous, Siliceous, Calcareous Duricrust
- Erosional Saprock Saprolite Fe-Saprolite
- Depositional Aeolian Colluvium Sheetwash
- Depositional Alluvial-Lacustrine Deposits
Public Domain Regolith Sampling
SW Western Australia: n = 30,488

Percentile Sliced Ni
(All Media – Raw)

Ni Deposits and Occurrences

Percentile Slice Legend

- > 99th %
- 98th - 99th %
- 95th - 98th %
- 90th - 95th %
- 80th - 90th %
- 60th - 80th %
- 30th - 60th %
- < 30th %
Analysis of Lateritic Sample Media

- Lateritic weathering leads to intense leaching and concentration through residual accumulation.

- Lateritic materials therefore need both low detection and strong digestion to reveal the complete geochemical patterns.

- They also require matrix matched standards (leached and ferruginous matrices).
Basic Exploration Suite

- Strong Total Acid Digest (4 acid)
- XRF is a option but may lack low detection limits required for some ore and pathfinder elements

- Inductively Coupled Plasma
  Optical Emission Spectroscopy
  ICP-OES
  Al, Ba, Ca, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Sr, Th, Ti, V, Zn, Zr

- Inductively Coupled Plasma
  Mass Spectroscopy
  ICP-MS
  Ag, As, Bi, Cd, Mo, Nb, Pb, Sb, U, W

Fire Assay (Pb collection, ICP-MS finish)
Au, Pt, Pd

Ore and path-finder elements

Lithochemistry + Transported Overburden ID
Basic Exploration Suite - Mineralogy

- Portable Spectroscopy (PIMA, Terraspec)

- Particularly applied to identification of transported overburden on leached saprolite which can be visually very similar. Illite crystalinity

- Potential identification of alteration minerals preserved in saprolite / saprock
Our Microscopic Future.....

**Mineral Liberation Analyser (MLA)**

**Large Chambered FEI Quanta 600 SEM**
Equipped with:
- EDAX – EDS analytical system
- MLA image analysis system
- Quantitative analytical software

[Image: Mineral Liberation Analyser (MLA) with labels for EDAX - EDS detector, Electron gun and column, Large sample chamber]
Mineral Liberation Analyser (MLA)

Approx 30,000 Grains per block (75-250um)

16 blocks per automated run

- Modal Mineralogy
- Mineral Chemistry
  - High quality data
  - >1% detection limit
- Mineral associations
- Chemical mapping
Mineral Liberation Analyser (MLA)

- Minerals identified by comparison of ED spectra with standards

Rapid (200ms) spectrum
Produced by high Mg ilmenite grain

Reference high quality high Mg ilmenite spectrum
Mineral Liberation Analyser (MLA)

- Mineral classification map

<table>
<thead>
<tr>
<th>Reference Mineral</th>
<th>Area_%</th>
</tr>
</thead>
<tbody>
<tr>
<td>11 Chromite6</td>
<td>67.44</td>
</tr>
<tr>
<td>5 Ilmenite5</td>
<td>5.53</td>
</tr>
<tr>
<td>9 Chromite4</td>
<td>4.43</td>
</tr>
<tr>
<td>20 FeOxide1</td>
<td>3.31</td>
</tr>
<tr>
<td>2 Ilmenite2</td>
<td>2.84</td>
</tr>
<tr>
<td>17 TiMagnetite1</td>
<td>2.49</td>
</tr>
<tr>
<td>12 Chromite7</td>
<td>2.19</td>
</tr>
<tr>
<td>24 Tourmaline1</td>
<td>1.92</td>
</tr>
<tr>
<td>10 Chromite5</td>
<td>1.85</td>
</tr>
<tr>
<td>26 Unknown</td>
<td>1.39</td>
</tr>
<tr>
<td>6 Chromite1</td>
<td>1.18</td>
</tr>
<tr>
<td>1 Ilmenite1</td>
<td>1.05</td>
</tr>
<tr>
<td>8 Chromite3</td>
<td>0.79</td>
</tr>
<tr>
<td>7 Chromite2</td>
<td>0.78</td>
</tr>
<tr>
<td>18 Rutile1</td>
<td>0.75</td>
</tr>
<tr>
<td>14 Corundum2</td>
<td>0.64</td>
</tr>
<tr>
<td>4 Ilmenite4</td>
<td>0.27</td>
</tr>
<tr>
<td>19 Rutile2</td>
<td>0.22</td>
</tr>
<tr>
<td>23 MnOxide1</td>
<td>0.19</td>
</tr>
<tr>
<td>3 Ilmenite3</td>
<td>0.19</td>
</tr>
</tbody>
</table>
Mineral Liberation Analyser (MLA)

- Cu Anomalous -80# Stream Sediment Sample – 120ppm Cu (Heavy Mineral Concentrate)

### Mineral Distribution

<table>
<thead>
<tr>
<th>Mineral Type</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bornite</td>
<td>Purple</td>
</tr>
<tr>
<td>Chalcopyrite</td>
<td>Yellow</td>
</tr>
<tr>
<td>Pyrite</td>
<td>Red</td>
</tr>
<tr>
<td>Aluminosilicates</td>
<td>Light Blue</td>
</tr>
<tr>
<td>Amphibole</td>
<td>Blue</td>
</tr>
<tr>
<td>Apatite</td>
<td>Light Green</td>
</tr>
<tr>
<td>Augite</td>
<td>Purple</td>
</tr>
<tr>
<td>Augite</td>
<td>Purple</td>
</tr>
<tr>
<td>Pyroxene</td>
<td>Blue</td>
</tr>
<tr>
<td>Clinozoisite</td>
<td>Light Blue</td>
</tr>
<tr>
<td>Chlorite</td>
<td>Green</td>
</tr>
<tr>
<td>FeOxide</td>
<td>Brown</td>
</tr>
<tr>
<td>FeOxide_Ti</td>
<td>Brown</td>
</tr>
<tr>
<td>FeOxide_Altered</td>
<td>Brown</td>
</tr>
<tr>
<td>FeOxide_Other</td>
<td>Brown</td>
</tr>
<tr>
<td>Ilmenite</td>
<td>Dark Magenta</td>
</tr>
<tr>
<td>IronOxide</td>
<td>Gray</td>
</tr>
<tr>
<td>Rutile</td>
<td>Dark Brown</td>
</tr>
<tr>
<td>Quartz</td>
<td>Light Blue</td>
</tr>
<tr>
<td>Other</td>
<td>Gray</td>
</tr>
</tbody>
</table>

100um
Mineral Liberation Analyser (MLA)

- “Stream sediment” sample from a deep lateritic weathering terrain in NW Queensland, Australia.

![Map of Australia with Weipa marked and mineral liberation analysis diagram]
Mineral Liberation Analyser (MLA)

- Some of the resistate Fe-oxides associated with known bauxite occurrences have distinctive chemical compositions.
Mineral Liberation Analyser (MLA)

- Direct detection of bauxite profiles - Curua Bauxite Discovery, Brasil

![Image of geological survey with labeled holes indicating mineralization and barren areas.](image-url)
Mineral Liberation Analyser (MLA)

- Direct detection of bauxite profiles - Curua Bauxite Discovery, Brasil

BR50012968 - Mineralised

BR50012416 - Barren

- Aluminous Fe Oxides
- Gibsite
- Gibsite_FeTi
- Fe Oxides
- Clay
- Other
Conclusions 1

➢ Lateritic weathering impacts exploration globally

➢ Lateritic weathering processes lead to the progressive volumetric reduction of the regolith profile, the total destruction of rock fabric, and dramatic modification of geochemical composition, presenting a significant challenge to mineral explorers

➢ Pioneering work by CSIRO in the early 90’s demonstrated that geochemical exploration techniques can be effectively applied in lateritic terrains
Conclusions 2

- Basic regolith mapping (Residual-Erosional-Depositional) provides essential context for geochemical exploration surveys

- The more ferruginous Residual (relict) materials are excellent sample media which generate a broad, multi-element geochemical halo

- Ferruginous components of the Erosional zones are also viable sample media but most saprolite is intensely leached and anomalism may be completely absent, low level or in highly immobile elements

- There are no reliable surface geochemical techniques to “see through” Depositional cover
Conclusions 3

- A strong digest and a low detection limit multi-element analytical suite is required

- PIMA or Terraspec mineralogy is very useful in lateritic terrains, particularly for identifying depositional materials

- The MLA offers exciting new analytical capacity to identify minerals in geochemical samples very rapidly and investigate the chemistry of selected phases if required.
Obrigado!