On the terminology, geologic setting, morphology, chemistry, mineralogy and the distribution of metals within the global weathering profiles:

Caribbean and Zimbabwean scenarios

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“What I have called clay ... is one of the most valuable construction materials. It is distributed in immense masses, without any appearance of stratification and overlies granites that forms the base of Malayala. It is full of cavities, pores and contains a very large amount of iron in the form of yellow and red ochre. In the mass, deprived of air, it is so soft that any iron instrument may cut it and it is dug out into square masses with a piquet and immediately cut into the desired shape with a large blade or a knife. Immediately after it becomes as hard as brick and resists the air and water than any brick that I have seen in India ... the most appropriate English name would be "laterite," a term derived from the Latin word lateritis, which is a term that can be used in science”
Weathering crusts are commonly found within tropical regions and they host important economic deposits of nickel, cobalt, aluminium and recently there has been an upsurge of research into their potential for Platinum Group and Rare Earth Minerals (Njila & Diaz Martinez, 2016).

Examples: Caribbean oxide-type nickel and ferrosialitic “laterites” (Moa Bay, Cuba), hydrous magnesium silicate type (Santo Domingo, Dominican Republic) and the Zimbabwean nickel-magnesium-silicates in the North Dyke.
The presentation focuses mainly on the similarities, differences in the terminology, geologic setting, morphology, chemistry, mineralogical composition and the distribution of metals within the global weathering crusts.
Terminology
## Terminology applied to weathering profiles in different regions

<table>
<thead>
<tr>
<th>Term</th>
<th>Translation</th>
</tr>
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<tbody>
<tr>
<td>Iron clay (India)</td>
<td>Moco de hierro (Venezuela)</td>
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<tr>
<td>Brickstone (India)</td>
<td>Ironstone (Nigeria)</td>
</tr>
<tr>
<td>Canga (Brazil)</td>
<td>Plinthite (USA)</td>
</tr>
<tr>
<td>Murrum (Uganda)</td>
<td>Laterita (Cuba)</td>
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<tr>
<td>Ouklip (South Africa)</td>
<td>Picarra (Brazil)</td>
</tr>
<tr>
<td>Ferricrete (southern Africa)</td>
<td>Eisenkruste (Germany)</td>
</tr>
<tr>
<td>Laterite (India)</td>
<td>Pisolite (Australia)</td>
</tr>
<tr>
<td>Cuirasse (France)</td>
<td>Mantle rock (rock)</td>
</tr>
<tr>
<td>Carapace (France)</td>
<td>Krusteneisenstein (Germany)</td>
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<tr>
<td>-----------------------------------</td>
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<tr>
<td>Ferruginous Zone [Laterite]</td>
<td>Laterite gravel</td>
</tr>
<tr>
<td>[Lateritic ironstone]</td>
<td>Cuirasse (pisolithic nodular, massive)</td>
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<tr>
<td>[Plinthite]</td>
<td>---</td>
</tr>
<tr>
<td>Mottled zone</td>
<td>Mottled (clay) zone</td>
</tr>
<tr>
<td>Plasmic/arenose horizon</td>
<td></td>
</tr>
<tr>
<td>Saprolite [Pallid zone]</td>
<td>Saprolite</td>
</tr>
<tr>
<td>Plinthite</td>
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<tr>
<td>Bedrock/unweathered rocks</td>
<td>Unweathered/ fresh bedrock</td>
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</tbody>
</table>

Correlation of terms for complete profiles
Depending on the perspective of the researcher…

- The term laterite has been applied to a variety of aspects of tropical weathered rocks.

- Laterite has been known as a variably cemented sesquioxide-rich soil, a surficial or near surface reddish soil, and also by an assortment of mineralogical definitions (Helgren and Butzer, 1977; Schellmann, 1986).

- The term has since evolved: a profile in a tropically weathered regolith in which the most soluble elements are removed and the least soluble elements are progressively redistributed throughout a series of more to less weathered protoliths to form a concentrated deposit (Samama, 1986).
Geologic setting

Falcondo Ni laterites (Santo Domingo, Dominican Republic): developed over Loma Caribe peridotite (a serpentinized belt of ultramafic rocks approximately 4–5 km wide and 95 km long in the NW of Santo Domingo).

The Moa Bay Ni laterites: developed over hydrated ultramafic (mantle tectonites, mainly harzburgites, dunites) rocks of the Moa–Baracoa Ophiolitic Massif (eastern part, Mayarí–Baracoa Ophiolitic Belt, NE Cuba) (Proenza et al., 1999a,b); mafics of bark arc basin affinity. (Iturralde-Vinent et al., 2006; Marchesi et al., 2006; Proenza et al., 2006).
Moa Bay,
Cuba
Santo Domingo,
Dominican Republic
“North Dyke,” Zimbabwe

• Emplaced at ~2.58 Ga (Oberthür et al., 2002) mainly into Archaean granites and minor greenstones of the Zimbabwe craton.

• 2 principal chambers (North and South) sub-divided into 5 contiguous, narrow intrusions (subchambers), transverse synclinal layered structure (Wilson & Prendergast, 1989; Wilson, 1996).
Morphology

Mineworkers and Cuban geologists: (e.g. Lavaut, 1998; Proenza et al., 2007a; Golightly, 2010). Bottom to top

(i) parent rock peridotite, (ii) saprolite, (iii) lower limonite, (iv) upper limonite, and (v) duricrust (Fig. 4a). *Pale bauxitic zones of weathered gabbro* (< 5 m thick) are abundant.

(ii) Typical: dominant limonite horizons (>50m) above the Mg discontinuity (Butt and Cluzel, 2013)

(iii) devoid of hydrous Mg silicate rich saprolite horizons below Mg discontinuity

Mine geologists: profile several zones (A–F) based on Ni, Mg & Fe contents, textures and mineralogy (Lithgow, 1993; Lewis et al., 2006a; Villanova-de-Benavent et al., 2014; Aiglsperger et al., 2015).

Simplified for comparison, bottom to top:

(i) parent rock peridotite, (ii) hard saprolite, (iii) soft saprolite, (iv) lower limonite, and (v) upper limonite and duricrust (Fig. 4b).
mesas with a complex, layered profile. Typically, mesa have a cliff-like upper slope and a concave lower slope.

The concave lower slopes: massive serpentine and horizontally-fractured serpentine.

Above serpentine, flat tops of a silica cap of variably-silicified serpentine in two parts: a lower zone of sheeted silica veins within horizontally-fractured serpentine, its base roughly coincident with the cliff-tops, and an upper (red-brown) ferruginous silicified zone.

Characteristic drusy vugs, ferruginous silicified zone made of a crude siliceous stockwork of closely spaced, horizontal sheeted veins and cross-veins plus local enclaves of massive silicification.

The preserved thicknesses are ca. 5 m each, although the full thickness of the horizontally-fractured serpentine, may be significantly greater.
Santo Domingo,
Dominican Republic

Modified from Aiglsperger et al., 2016
Moa Bay, Cuba

Modified from Aiglsperger et al., 2016
The geomorphological and geological features of Great Dyke nickel laterites are closely analogous to those of classic, saprolite type nickel laterite deposits in Brazil (Prendergast, 2013).
Loma Caribe ore deposit (hydrous Mg silicate type)

(Falcondo)

Chemistry

Aiglsperger et al., 2016
Mineralogy
**Santo Domingo, Dominican Republic**

Ore minerals

- Mainly Ni-lizardite and poorly defined varieties of Ni containing serpentine,

- Talc, chlorite and sepiolite, commonly termed as “garnierites” (up to 49 wt.% NiO).

- These are found mainly within the lower part of the saprolite horizon

(Villanova-de-Benavent et al., 2014)
Mainly goethite (~1.4 wt.% Ni), minor maghemite (up to ~8 wt.% Ni), lithiophorite (~8.1 wt.% Ni, ~4.5 wt.% Co), “lithiophorite–asbolane intermediate” (up to 22 wt.% Ni)

All occur in the limonite horizon of the profile

(Proenza et al., 2007a; Roqué-Rosell et al., 2010).
Mineralogy

North Dyke, Zimbabwe

Three principal mineralogical associations are postulated for the contained nickel:

(1) discrete, fracture-related, ‘garnieritic’ minerals (in both regolith and protolith),
(2) nickeloan serpentine within drusy vugs associated with silica veins, and, probably,
(3) pervasive enrichments associated with goethite and/or chrysotile. Cobalt, concentrated towards the top of the preserved regolith profile, is most likely linked to goethite via a primary association with Mn.

(Prendergast, 2013)
Distribution of Metals
Santo Domingo, Dominican Republic

- PGM grains were found in the 40, 63 and 80 μm fractions HS concentrates of the analyzed saprolite sample.
- PGM assemblage comprises Ru, Os, and Ir-rich phases, including laurite [(Ru,Os,Ir)S2] and undetermined Ru-Fe, Ru-Fe-Ir-Os, and Ru-Pt-Fe-Os-Ir alloys/oxides, and Rh-Ir sulfide.
- The heavy concentrate: chromite, magnetite, goethite and awaruite grains, as well as metals: Fe, (Fe,Cr), Ni, Cu, Sn and Pb.
- The silicate minerals consist predominantly of serpentine, and minor olivine and quartz.
The PGM can be divided into two categories:

1. **PGM included in fresh chromite grains.** They were found in 63 and 80 μm fractions, and form single-phase euhedral grains. They consist of laurite and an undetermined Rh-Ir-S phase, corresponding to the formula (Rh,Ir)$_3$S$_4$. The shape and composition of PGM enclosed in fresh chromite grains suggest a primary origin.

2. **Free PGM grains (only found in 40 μm fraction),** that mainly consist Ru-Os-Ir-Fe oxides, undetermined Pt-Ir-Fe-Ni and Ru-Os-Ir-Rh alloys (fig. 2). These PGM are characterized by an irregular shape, rugged surface and high porosity. In some case, the PGM grains consist of two phases intimately intergrown, one containing an oxide and the other composed of PGE alloy.
Moa Bay, Cuba

- CMs enriched in the limonite, especially within zones with elevated Mn oxide(s) concentrations & towards the surface.
- Total REE concentrations are low in the unweathered harzburgite (~0.1 ppm) and vary from 1 to 3 ppm in the saprolite and from 15 to 68 ppm in the limonite.
- The parent rock (harzburgite) shows a pronounced positive slope from Tb–Lu. Cerium anomalies are observed in the saprolite (negative) and in the limonite (positive and negative).
- Sc contents range from 8 to 17 ppm in the saprolite and from 70 to 98 ppm in the limonite whereas PGE concentrations vary from 27 to 61 ppb in the saprolite and from 109 to 239 ppb in the limonite. In general saprolite and limonite samples have similar flat PGE chondrite normalized patterns with slight peaks of Ru and Pd as previously observed in Ni laterites from Santo Domingo (Aiglsperger et al., 2015).
North Dyke, Zimbabwe

Not much is known yet, but the potential lies in the:

- discrete, fracture-related, ‘garnieritic’ minerals (in both regolith and protolith),

- nickel oxide serpentine within drusy vugs associated with silica veins, and, probably,
Discussion
There are marked similarities in the terminology used to refer to weathering profiles formed over different types of lithologies in different geological settings, with a similar but different morphology, chemistry, mineralogical composition and the distribution of metals within the global weathering crusts
Their morphology is large determined by the geologic setting in which they occur; the chemistry and mineralogy are a function of the bedrock, climate and other physical conditions of the geologic setting.

Their potential to concentrate economic metal deposits is controlled by their mineralogy. The Caribbean laterites have been found to host Platinum Group Minerals (PGM), the Cuban laterites are known to host nickel and cobalt whereas the Zimbabwean laterites have been evaluated for nickel-magnesium silicates and iron oxyhydroxides which may host Platinum Group Minerals.

Critical Metals may be concentrated by Hydroseparation (HS) and Electric Pulse Disaggregation (EPD), and more studies are being carried out on the extractability of these minerals.
Thank you