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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Francis Buchanan, 1807

“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”

Introduction

- 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

Iron clay (India)	**Moco de hierro (Venezuela)**
Brickstone (India)	Ironstone (Nigeria)
Canga (Brazil)	Plinthite(USA)
Murrum (Uganda)	Laterita (Cuba)
Ouklip (South Africa)	Picarra (Brazil)
Ferricrete (southern Africa)	Eisenkruste (Germany)
Laterite (India)	Pisolite (Australia)
Cuirasse (France)	Mantle rock (rock)
Carapace(France)	Krusteneisenstein (Germany)

Correlation of terms for complete profiles

GENERAL TERMS	BUTT & ZEEGERS (1992)	NAHON & TARDY (1992)	LEPRUN (1979)	LAVAUT (2003)	ANAND et at (1989)
Ferruginous Zone [Laterite]	Lateritic gravel	Pebbly Ferruginous layer	Cuirasse [Ferricrete]	OICP	Lateritic gravel
[Lateritic ironstone]	Cuirasse (pisolitic nodular, massive)	Pisolitic iron crust Indurated conglomeratic iron			Lateritic gravel (pisolitic massive, etc)
[Plinthite]	---	Soft nodular crust	Carapace nodulaire		
Mottled zone	Mottled (clay) zone Plasmic/arenose horizon	Mottled (clay) zone	Argiles tachetees	OI	Mottled zone
Saprolite [Pallid zone]	Saprolite	Fine Saprolite	Lithomarge argiles bariolees	OEF	Saprolite
---	Saprock	Coarse Saprolite	Alteration pistaches [arene/grus]	OEI RML	Saprock
Bedrock/ unweathered rocks	Unweathered/ fresh bedrock	Bedrock	Roche mere	RMA	Fresh rocks

Depending on the perspective of the researcher…

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

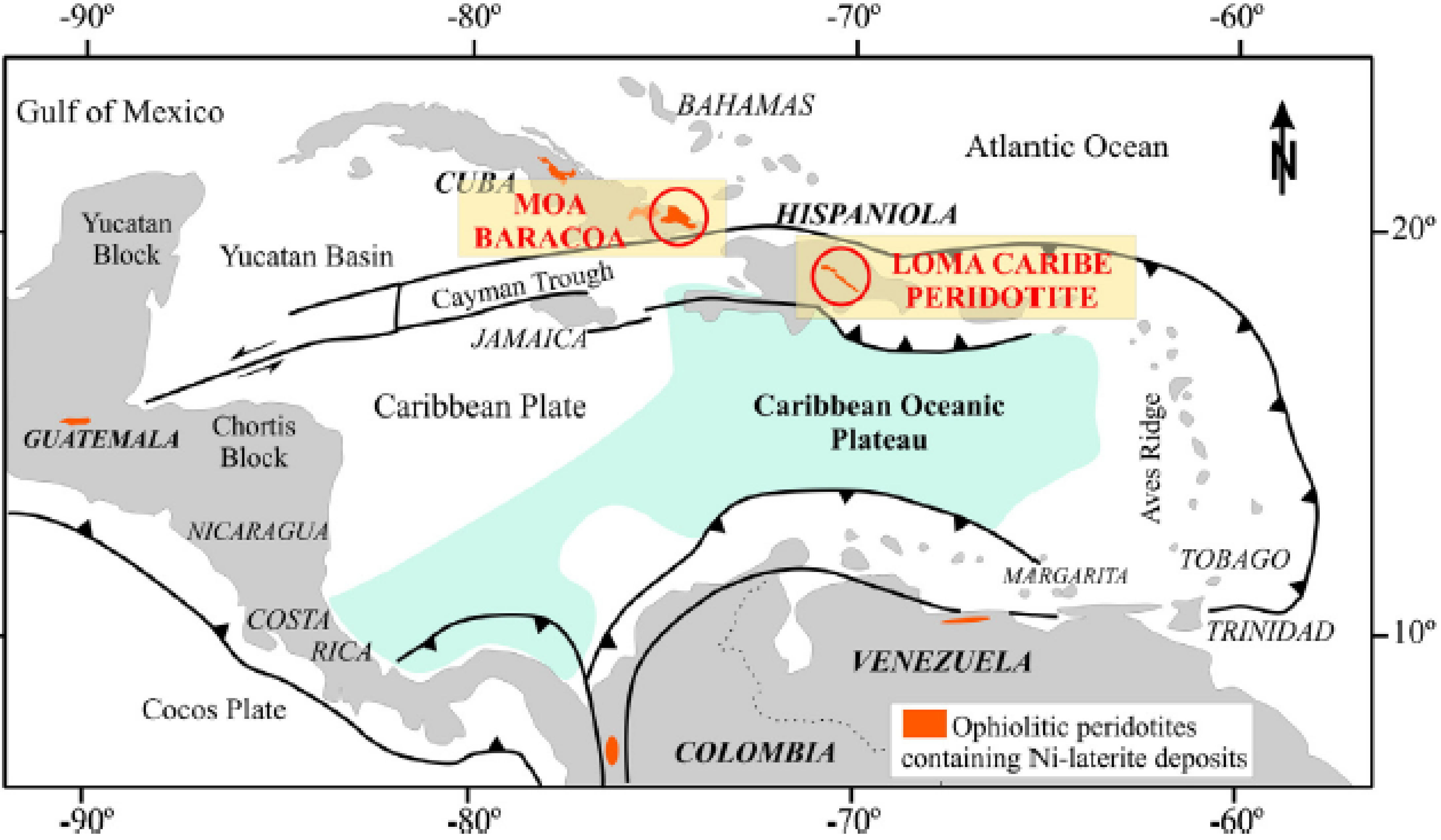
- Laterite has been known as a variably cemented sesquioxide-rich soil, a surficial or near surface reddish soil, and also by an assortment of mineralogical definitions (Helgren and Butzer, 1977; Schellmann, 1986).

- 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

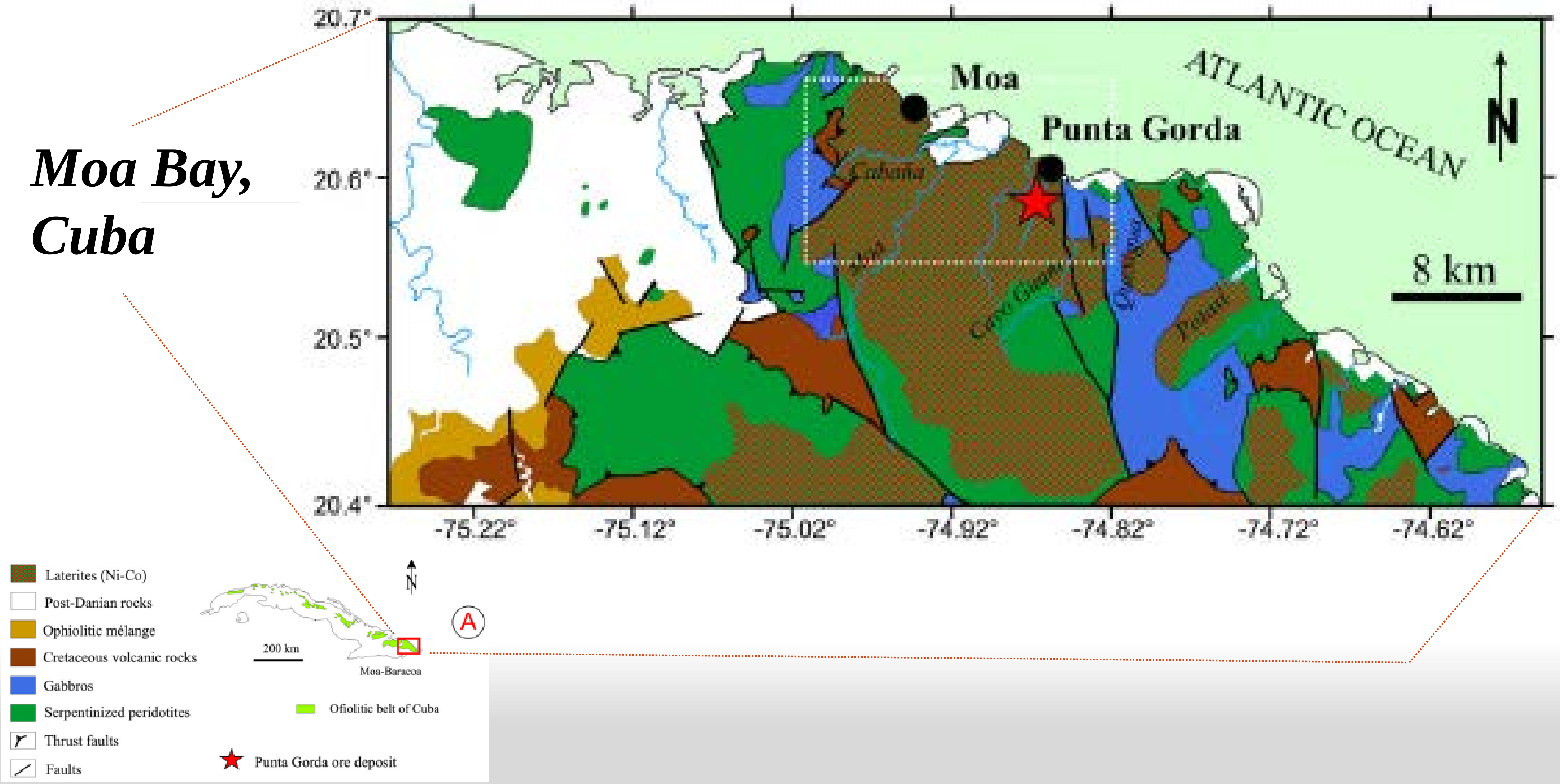
- Falcondo Ni laterites (Santo Domingo, Dominican Republic): developed over Loma Caribe peridotite (a serpentinized belt of ultramafic rocks approximately 4–5 km wide and 95km long in the NW of Santo Domingo).

- 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).



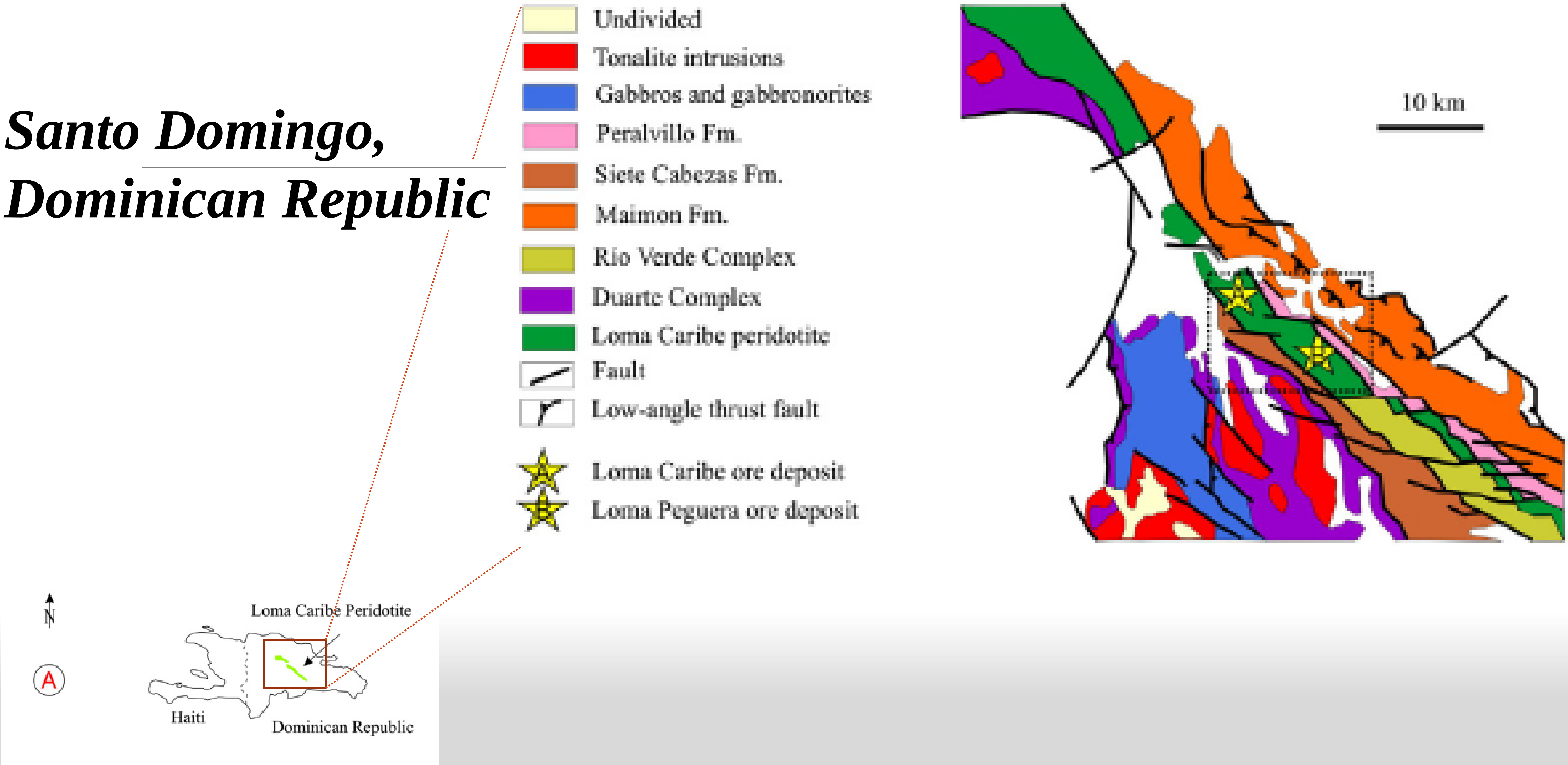
-90°
-80°
-70°
-60°
Gulf of Mexico
BAHAMAS
Atlantic Ocean
N
CUBA
MOA
BARACOA
HISPANIOLA
Yucatan Block
Yucatan Basin
20°
20°
LOMA CARIBE
PERIDOTITE
Cayman Trough
JAMAICA
Caribbean Plate
Caribbean Oceanic Plateau
Aves Ridge
GUATEMALA
Chortis Block
NICARAGUA
TOBAGO
MARGARITA
COSTA RICA
10°
10°
TRINIDAD
VENEZUELA
Cocos Plate
Ophiolitic peridotites containing Ni-laterite deposits
COLOMBIA
-90°
-80°
-70°
-60°

Moa Bay, Cuba

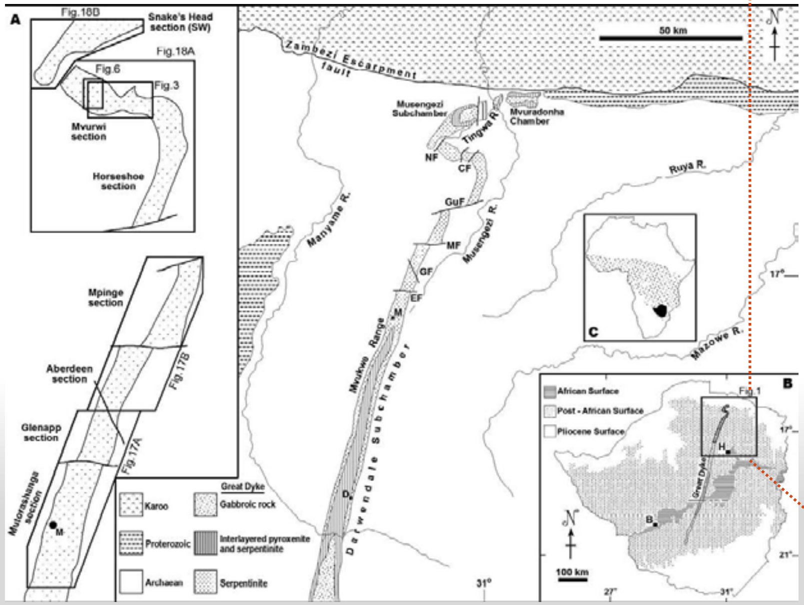


20.7°
20.6°
20.5°
20.4°
-75.22°
-75.12°
-75.02°
-74.92°
-74.82°
-74.72°
-74.62°
Moa
Punta Gorda
ATLANTIC OCEAN
N
8 km
Cabana
Laterites (Ni-Co)
Post-Danian rocks
Ophiolitic mélange
Cretaceous volcanic rocks
Gabbros
Serpentinized peridotites
Thrust faults
Faults
200 km
Moa-Baracoa
A
Ofiolitic belt of Cuba
Punta Gorda ore deposit

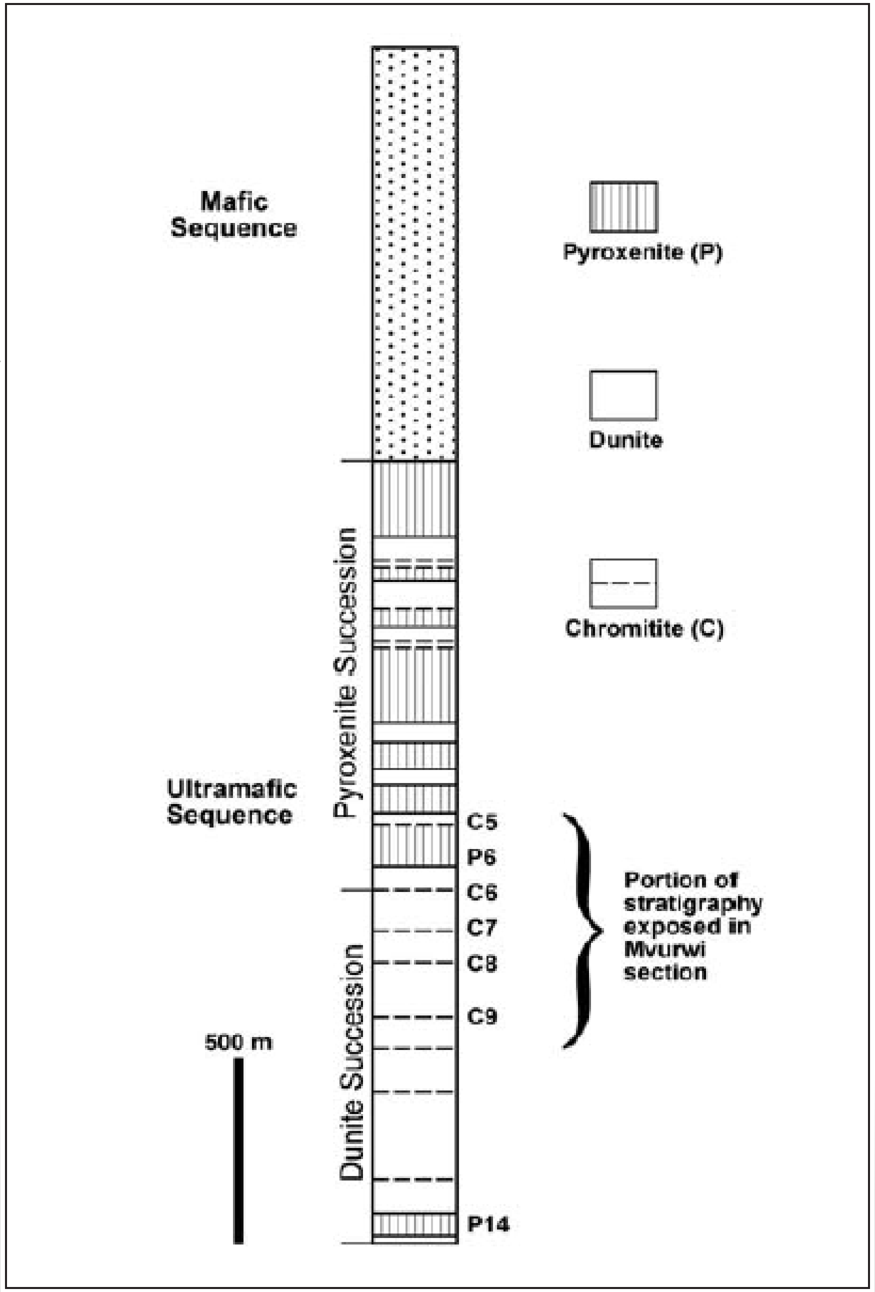
Santo Domingo, Dominican Republic



“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

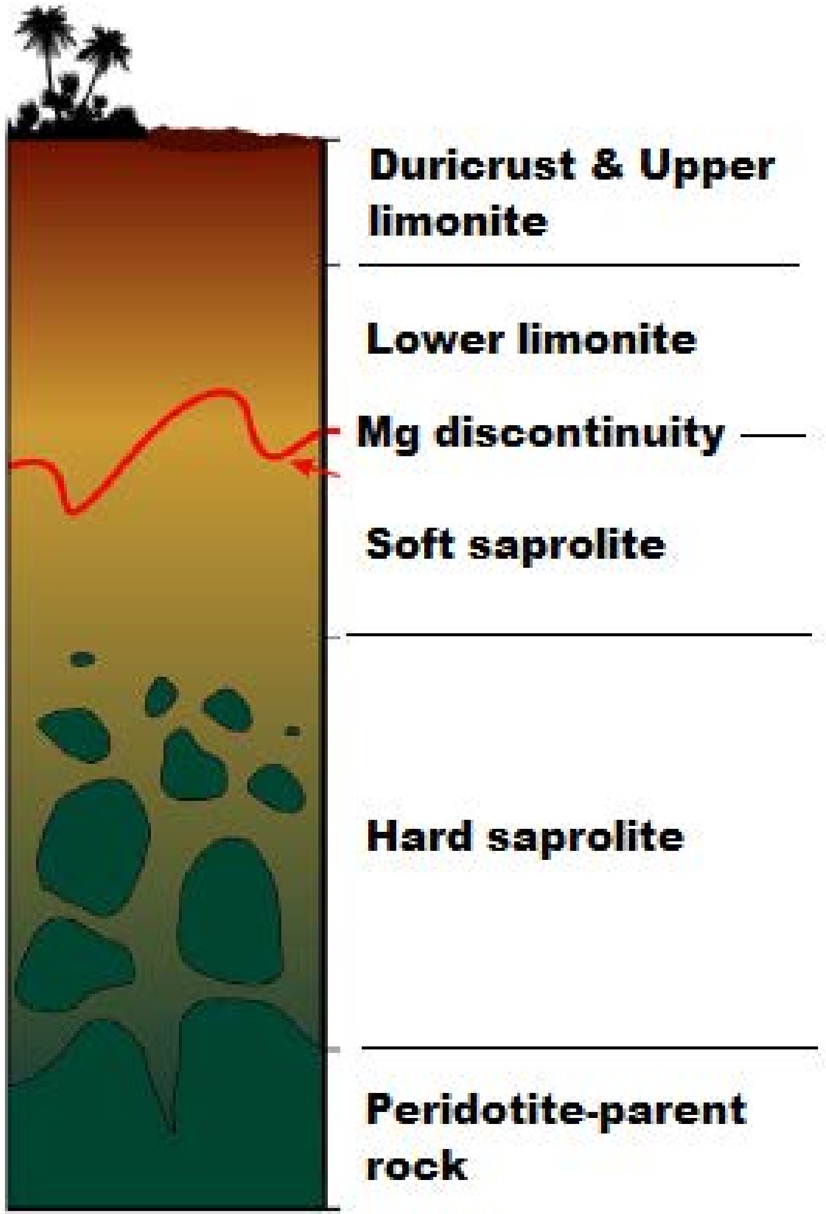
Mine geologists: profile several zones (A–F) based on Ni, Mg & Fe contents, textures and mineralogy (Lithgow, 1993; Lewis et al., 2006a; Villanova-de-Benavent et al., 2014; Aiglsperger et al., 2015).

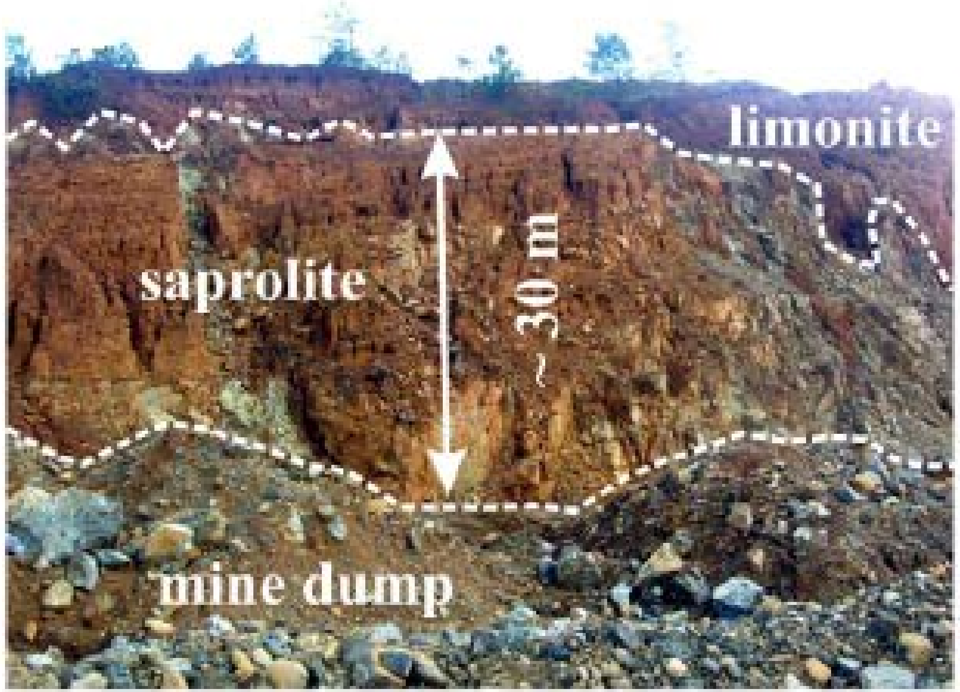
Simplified for comparison, bottom to top:

(i) **parent rock peridotite, (ii) hard saprolite, (iii) soft saprolite, (iv) lower limonite,** and **(v) upper limonite and duricrust** (Fig. 4b).

North Dyke

- mesas with a complex, layered profile. Typically, mesa have a cliff-like upper slope and a concave lower slope.
- The concave lower slopes: massive serpentinite and horizontally-fractured serpentinite.
- Above serpentinite, flat tops of a silica cap of variably-silicified serpentinite in two parts: a lower zone of sheeted silica veins within horizontally-fractured serpentinite, 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 closelys paced, 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 serpentinite, may be significantly greater.

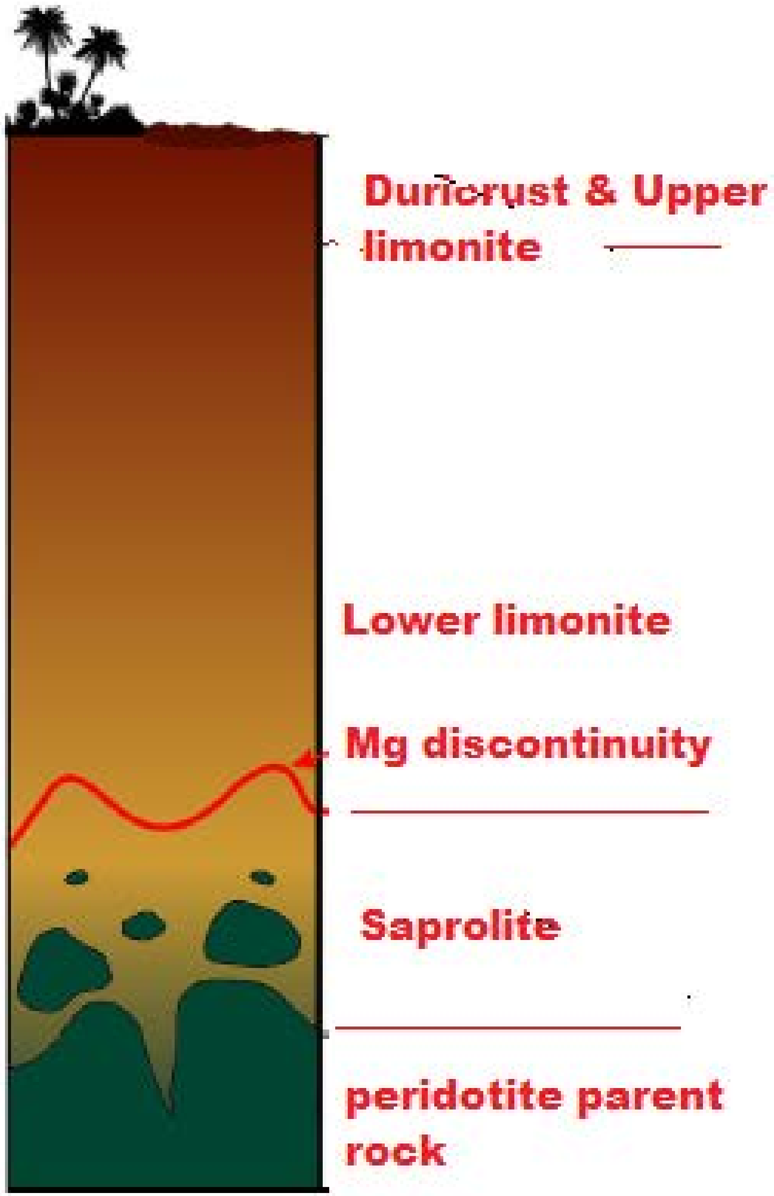




Santo Domingo,

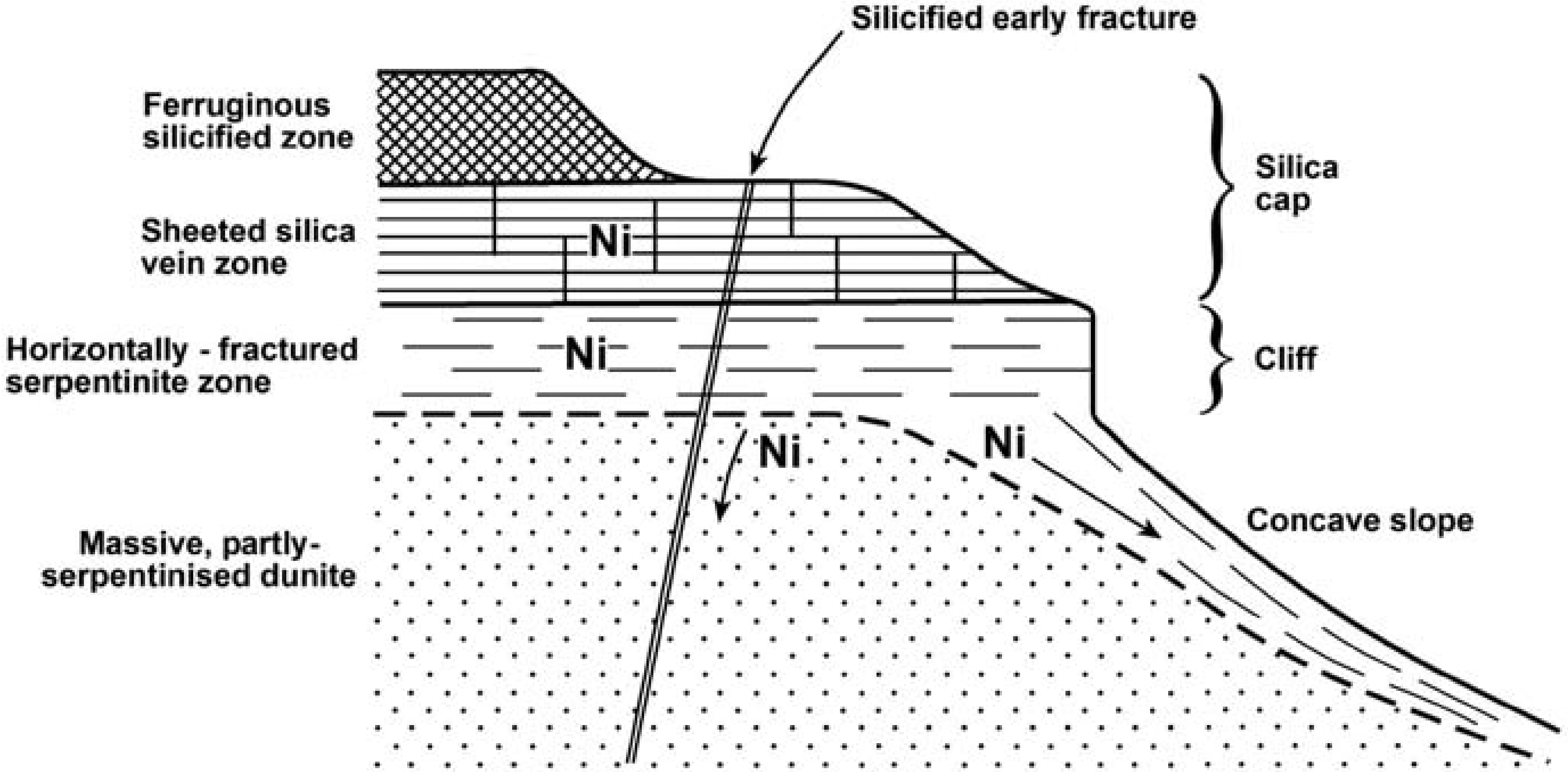
Dominican Republic

Modified from Aiglsperger et al., 2016



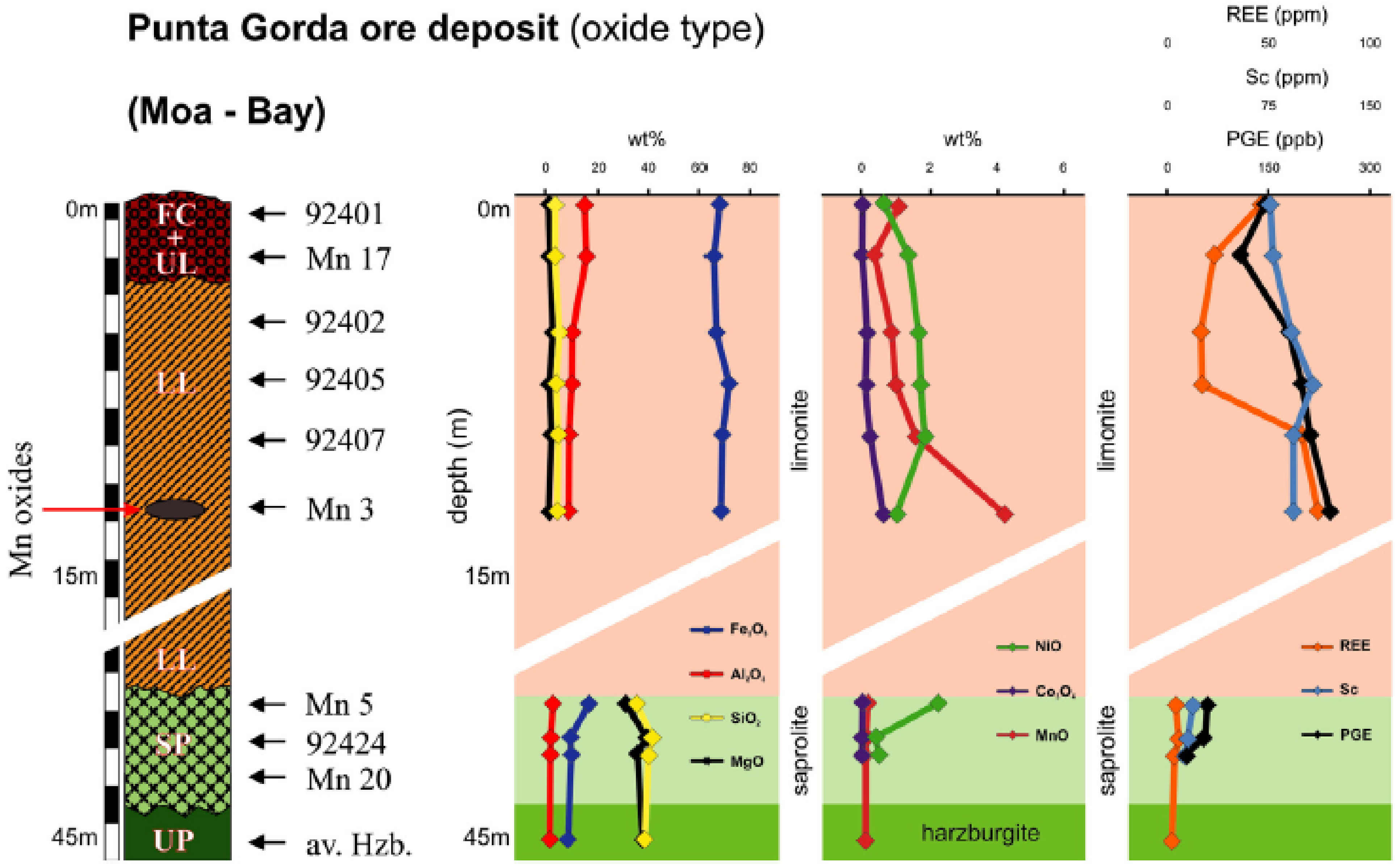
Moa Bay, Cuba

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)**

Chemistry

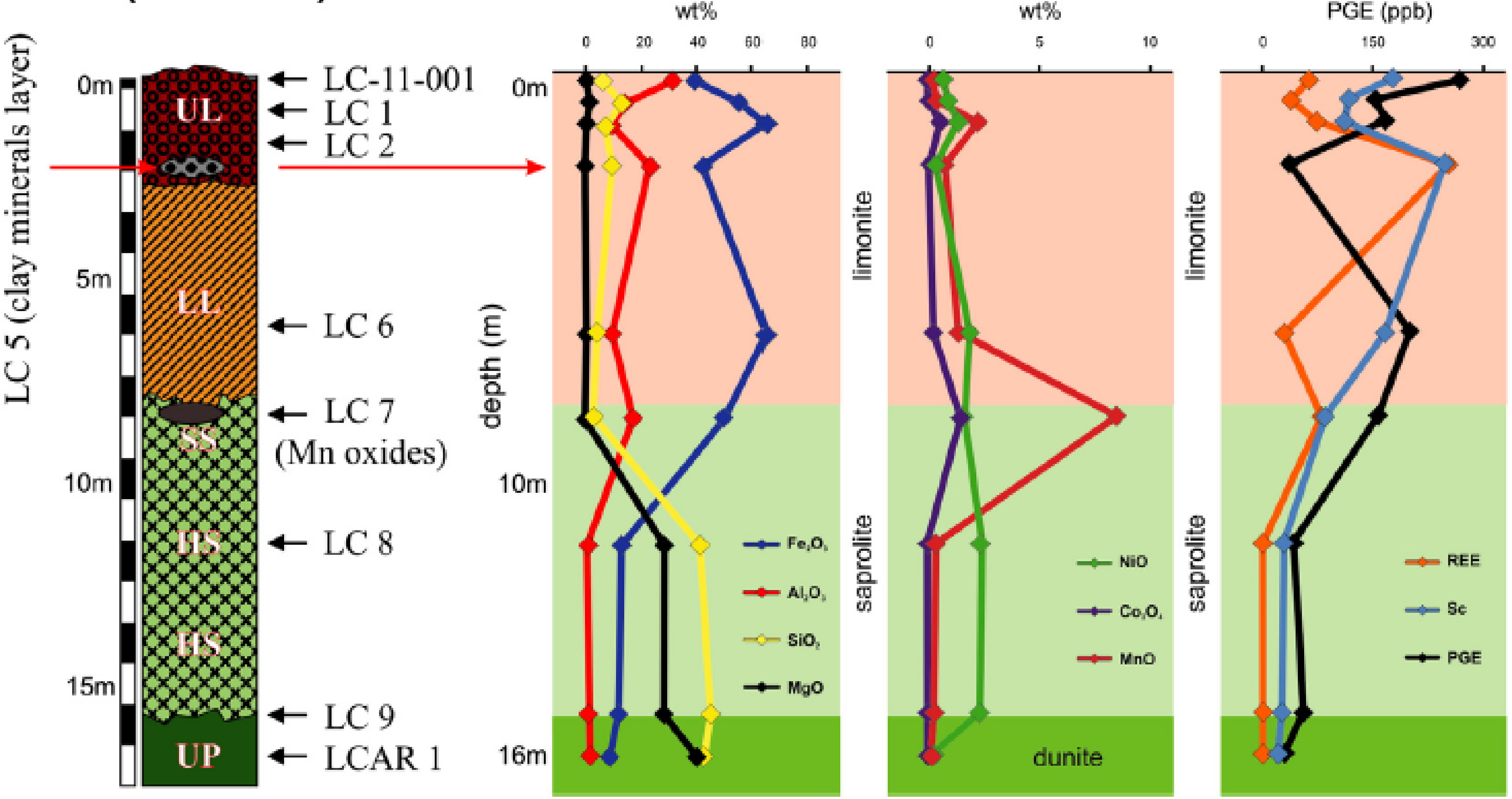


Aiglsperger et al., 2016

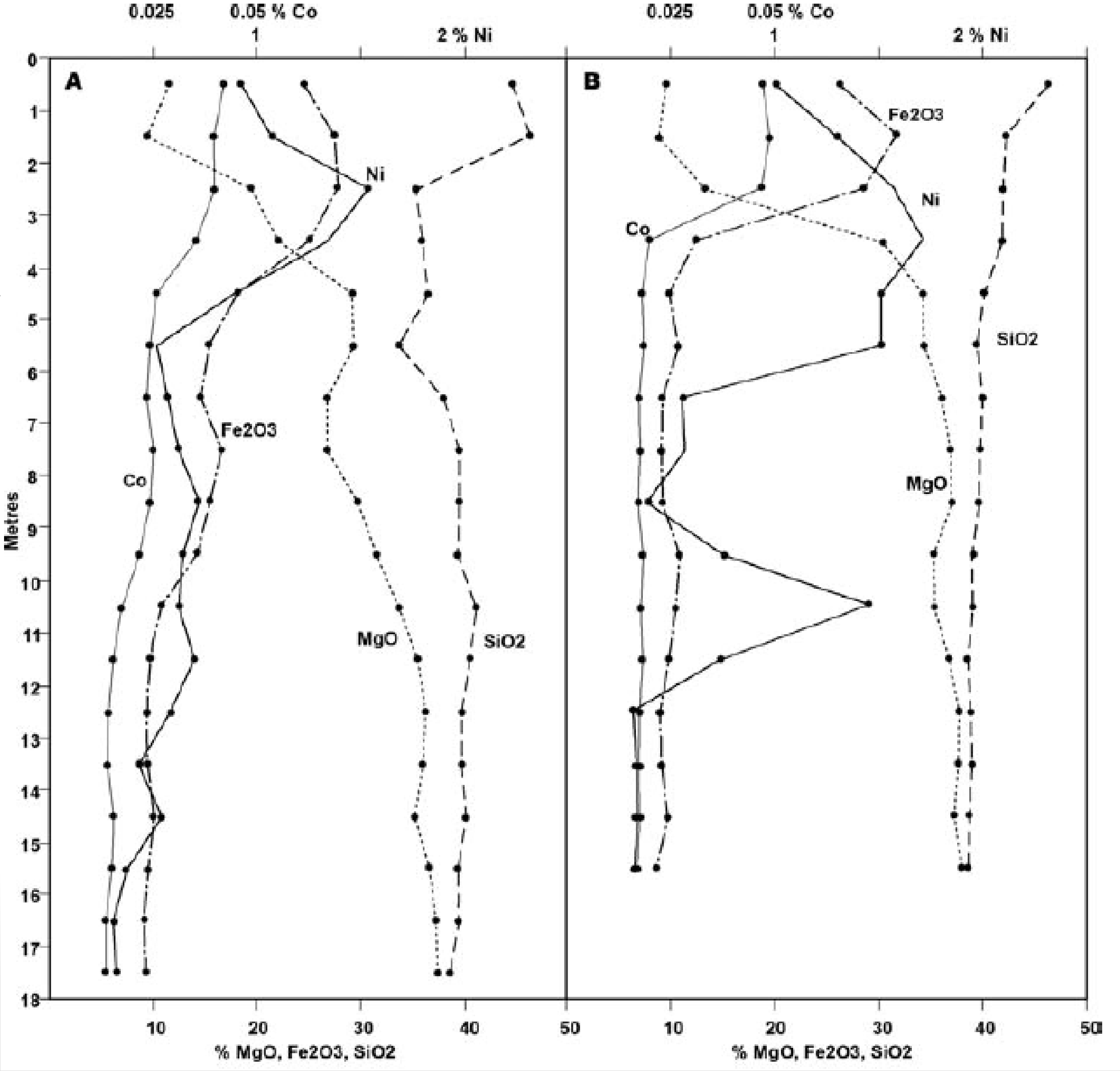
Loma Caribe ore deposit (hydrous Mg silicate type)

(Falcondo)

Chemistry



Aiglsperger et al., 2016



Chemistry

North Dyke

Prendergast, 2013

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)

Moa Bay, Cuba

Ore minerals

- 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 Irrich 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 sufide.
- 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 mµ fractions, and form single-phase euhedral grains. They consist of laurite and an undetermined Rh-Ir-S phase, corresponding to the formula $(Rh,Ir)_3S_4$. 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 from15 to 68 ppmin 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 from70 to 98 ppm in the limonite whereas PGE concentrations vary from27 to 61 ppb in the saprolite and from109 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),
- nickeloan 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