Mineralogy of oxide and hydrous silicate Ni laterite profiles in Moa Bay area, northeast Cuba

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ABSTRACT: The nickel laterite deposits of Moa Bay area are part of a large province of nickel laterites in eastern Cuba. The mineralogy of principal ore-bearing phases indicates that both oxide- and hydrous silicate-type profiles are present. The former weathering profile (e.g., the Yagrumajé deposit) comprises a thick limonite horizon that overlies a thin saprolite, and the Ni and Co occur mainly in the limonite zone associated with goethite (≈ 1.4 wt.% Ni), maghemite (up to 8 wt.% Ni), lithiophorite (≈ 6.1 wt.% Ni, ≈ 4.5 wt.% Co). The later Ni laterite profile (e.g., the Yamanagüey deposit) comprises a zone of saprolite and saprolitized harzburgite, capped by a thin limonite horizon, and the ore minerals are Ni-rich lizardite (up to 3.7 wt.% Ni) and hydrous Mg-Ni silicates (“garnierites”, up to 32 wt.% Ni) occurring deeper in the profile.

KEYWORDS: Nickel, Oxide, Hydrous silicates, Ni-Laterite, Moa, Cuba

1 INTRODUCTION

Nickel laterite profiles have been classified into three types on the basis of the dominant mineralogy developed in the profile (Brand et al. 1998). In general, based on mineralogy of principal ore-bearing phases (silicified or oxidized), northeastern Cuba Ni-laterite deposits are classified as oxide-type. In this case, the upper part (limonite zone) is the main ore horizon. According to Gleeson et al. (2003) the best known example of Ni-laterite deposits of oxide-type, in commercial production, are those of Moa Bay area in northeastern Cuba. However, these deposits contain oxide and hydrous silicate ores in varied proportion. In some cases, silicate ore dominates the laterite profiles forming typical hydrous silicate-type deposits. Despite their economic importance, relatively little has been published on the Cuban laterite deposits.

Here, we report new data on the mineralogical composition and mineral chemistry of two Ni-laterite profiles in northeastern Cuba (Fig. 1). These profiles come from Yagrumajé Norte and Yamanagüey economic deposits, located in the Moa mining district (Moa Bay in the English literature). Laterite mineralogy was investigated using X-ray diffraction, optical microscopy, scanning electron microscopy and electron probe microanalysis. The primary aim of this study is to identify the major Ni-bearing phases.

2 GEOLOGICAL SETTING

The largest area of exposed serpentinitized peridotites in the whole Caribbean occurs in northeastern Cuba in the Mayari-Baracoa Ophiolite Belt. The eastern part of this belt is constituted by the Moa-Baracoa massif (Fig. 1, Proenza et al. 1999, Lewis et al. 2006). The Moa-Baracoa massif is comprised of mantle tectonites (> 2.2 km thick) topped by a thin crustal section made up of lower gabbros (ca. 300 meter thick) and discordant basaltic rocks with back arc basin affinity (Marchesi et al. 2005). The ultramafic rocks correspond mainly to harzburgites (more than 70%) and to a lesser extent to dunites and impregnated peridotites with clinopyroxene and plagioclase. They have a variable degree of serpentinization that in shear or fracture zones can reach up to 95% of the whole rock (typical serpentinite). The peri-
dotites are cut by dikes of gabbro and pegmatite gabbro (Pronzini et al. 1999, Marchesi et al. 2006). The emplacement of the ophiolite took place in the Maastrichtian to early Danian.

The Moa laterite deposits are part of a larger province of nickel laterites in northeast Cuba. The deposits were developed over serpentined harzburgite with weathering and laterization commencing during the Miocene (Lewis et al. 2006). The elevation above sea level of the peneplain surface of the deposits varies from 60 to 350 m, and the weathered mantle attained a considerable thickness (10-50 m, Linchenat & Shraivakova, 1964).

3 THE LATERITE PROFILES AND MINERALOGY

The Ni laterite profile of the eastern Cuban deposits has been divided into various zones and sub-zones by mine personnel and Cuban geologists. The nomenclature of these zones does not follow the recommended classification of Ni laterite deposits (e.g. Lavaut 1998). However, in general terms one can recognize, in eastern Cuba, the same horizons that have been described in other Ni laterite deposits of the world (e.g. Brand et al. 1981, Gireson et al., 2003), the laterite profile is composed of four principal horizons (Lewis et al. 2006), from bottom to top these are: (i) serpentined peridotite, (ii) saprolite, (iii) limonite, (iv) ferricrete. The studied laterite profiles from Yagrumaje and Yamanigüey deposits exhibit variation in total thickness and the thickness of individual horizons (Fig. 1).

3.1 The lateritic profile at Yagrumaje

The lowest part of the profile is represented by non-weathered serpentined harzburgite. This horizon is overlain by a saprolite zone (4 m thick), which is characterized by the preservation of the primary fabric. This horizon is fine grained, and contains remnants of the protolith. The mineralogical composition is dominated by lizardite, which replaces original serpentined olivine grains. Small amounts of goethite and chromite are also present. The saprolitic zone passes upwards in the section to a limonite zone (19 m thick), which is the horizon of economic interest. This zone consists mainly of goethite (> 50 wt.%), and minor maghemite, haematite and gibbsite (Fig. 2). Goethite grains are locally replaced by haematite. The ground mass is very fine grained, and evidence of the original texture of the protolith has been destroyed. Maghemite is more abundant towards the lowest part of the limonite horizon (11 wt.% at 18 m deep; 1 wt.% at 8 m deep), while haematite is dominant in its upper part. Finally, a concentration of Mn-Co-Ni oxide minerals (cryptomelane and lithiophorite) occurs at the limonite horizon, particularly at the lowest part. These Mn oxides occur as veins and coatings or concretions along fractures.

3.2 The lateritic profile at Yamanigüey

Unweathered serpentined harzburgite (parent rock) in this section is similar to that in the Yagrumaje profile. The profile is characterized by a thick saprolite horizon (9 m), followed by a thin limonite horizon (3 m thick). The horizon of economic interest is the lower saprolite. This zone consists of variably altered serpentined harzburgite in which most of the original structure and textures in the peridotite are preserved.
The saprolitized harzburgite is usually pale green, and in the upper part the material is more soft and has a wide colour range from yellow to reddish-brown. Lizardite and second generation of Ni-rich lizardite are the major crystalline phases occurring with minor magnetite, chromite and goethite. Ni-rich lizardite replaces and pseudomorph former serpentinized olivine and orthopyroxene, and is locally transformed into goethite. In addition, the saprolite zone contains hydrous Mg-silicate veins, follow fractures and grain boundaries (Fig. 3A).

4 MINERAL CHEMISTRY OF THE NICKEL-BEARING PHASES

The average Ni content of olivine in basal harzburgites of both studied profiles is 0.4 wt.%, whereas the Ni content of orthopyroxene is very low (Ni < 0.1 wt.%).

4.1 Yagrmuaje deposit: oxidized lateritic ore

The principal minerals that contain Ni in the limonite horizon of the studied profile are goethite, maghemite and lithiophorite (Fig. 2). In contrast, taenite, chromite and gabbro have low Ni contents.

The nickel content in goethite varies from 0.3 to 4.5 wt.% (average value = 1.4 wt.%), whilst cobalt content ranges between 0.1 and 1.7 wt.% (average value = 0.27 wt.%). Goethite exhibits variable proportions of Al (substitution of Al$^{3+}$ for Fe$^{3+}$). Al/Fe ratios increase towards the top of the profiles (up to 8.2 wt.% Al$_2$O$_3$). Major amounts of Cr$_2$O$_3$ (< 2.5 wt.%) and MnO (< 1.9 wt.) also were detected.

Maghemite shows Ni contents range from 0.5 to 8 wt.%, and up to 1.1 wt.% of Co$_2$O$_3$ (Fig. 2B).

The analyzed lithiophorite grains may contain up to 6.0 wt.% Co and up to 12 wt.% Ni. These Mn phases are the main hosts to Co mineralization.

4.2 Yamanigutay deposit: hydrous silicate ore

The second generation of lizardite and the hydrous Mg-Ni silicates are the major Ni-bearing silicate phases. Nickel content in Ni-rich lizardite ranges from 1.7 to 3.7 wt.%, in contrast with primary lizardite, which is no more enriched in Ni than the olivine (~0.4 wt.%).

Hydrous Mg-Ni silicates ("garnierites") in veins have Ni contents varying from 20 to 32 wt.% (Fig. 3B). The "garnierite"-like minerals have composition ranging from Ni-bearing talc to serpentine-structured minerals (Gleeson, 2003).

5 DISCUSSION AND CONCLUSION

In the Yagrmuaje Ni-laterite profile, a significant fraction of nickel is associated with goethite and maghemite in the limonite zone, and can be classified as an oxide-type profile.

The analyzed goethite contains up to 4.5 wt. % of Ni, but it is not clear if all Ni occur in solid solution, or as a separated phase. However, isomorphous substitution for Fe$^{3+}$ by Ni within natural goethite has been confirmed with EXAFS data (Carvalho-e-Silva et al. 2003). The charge balance from Ni$^{2+}$ for Fe$^{3+}$ substitution in goethite structure are likely to be locally charge-balanced by the substitution of OH for O$_2$ (Singh et al. 2002). On the other hand, Ni-rich maghemite may have been produced by oxidation of magnetite, but this mineral has not been found. Other mechanism suggested is maghemite formation by dehydroxylation of Fe oxyhydroxides (Anand & Gilkes 1987).

Figure 2. Back scattered electron images showing Ni-rich maghemite in Yagrmuaje deposit (oxide type Ni laterite profile).

Figure 3. Back scattered electron images showing hydrous Mg-Ni silicate in Yamanigutay deposit (hydrous silicate type Ni laterite profile).
In contrast, in the Yanaimarquez Ni-laterite profile most of the nickel occurs in the saprolite zone and can be classified as a silicate-type profile (highest-grade Ni laterites). In this case, Ni is leached from the limonite horizon and moves downwards through the profile, forming concentration, with Si and Mg, within the saprolite horizon. Nickel is mainly derived by the recrystallization of goethite to haematite, which cannot incorporate the Ni formerly contained in the goethite.

Mineralogical composition suggests that the two laterite profiles studied had different weathering histories. This difference may be the result of different serpentization of the protolith, drainage and position of the water table.

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