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Critical metals (REE, Sc, PGE) in Ni laterites from Cuba and the Dominican Republic

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ABSTRACT

Ni laterites are considered worthy targets for critical metals (CM) exploration as Rare Earth Elements (REE), Sc and platinum group elements (PGE) can be concentrated during weathering as a result of residual and secondary enrichment. In this contribution geochemical and mineralogical data of CM from two different nickel laterite types (i) from the Moa Bay mining area in Cuba (oxide type) and (ii) from the Falcondo mining area in the Dominican Republic (hydrous Mg silicate type) are presented. Emphasis is given on examining their potential to accumulate CM and on processes involved. Results show that CM are concentrated towards the surface in specific zones: (i) REE in clay minerals rich horizons and within zones composed of secondary Mn oxide(s), (ii) Sc within zones rich in secondary Fe and Mn bearing oxide(s) and (iii) PGE in zones with high concentrations of residual chromian spinel and secondary Fe and Mn bearing oxide(s) at upper levels of the Ni laterite profiles. Concentration factors involve (i) residual enrichment by intense weathering, (ii) mobilization of CM during changing Eh and pH conditions with subsequent reprecipitation at favourable geochemical barriers and (iii) interactions between biosphere and limonitic soils at highest levels of the profile (critical zone) with involved neoformation processes. Total contents of CM in both Ni laterite types are low when compared with conventional CM ore deposits but are of economic significance as CM have to be seen as cost inexpensive by-products during the Ni (+Co) production. Innovative extraction methods currently under development are believed to boost the significance of Ni laterites as future unconventional CM ore deposits.

1. Introduction

The Rare Earth Elements (REE), Platinum Group Elements (PGE) and scandium (the so-called "High Tech metals") are elements with special chemical and physical properties needed for sophisticated technical applications associated with renewable energy, reduction of greenhouse gases and energy efficiency (green technologies). The rapidly growing market in this sector (e.g. production of permanent magnets, cell phones, electric cars, wind turbines) led to an increasing demand of these metals over the last few years (e.g. Chakhmouradian and Wall, 2012; Hein et al., 2013). In 2014, the EU Commission assessed 54 materials (metallic ore, biotic material and industrial minerals) on their criticality for Europe's industry on the basis of their high economic importance and their high relative supply risk (EC, 2014). 20 raw materials were identified as critical including REE and PGE.

In 2010, the unexpected drastic reduction of export quotas for REE by the Chinese government revealed the vulnerability of western high tech industries. As a consequence, new exploration projects have been initiated worldwide. However, to be competitive these deposits must be large in scale, easily accessible (open pit mining) with favourable ore mineralogy from a metallurgical point of view and tolerable environmental impact. With respect to PGE, being essential for gasoline-engine catalytic converters in the car industry and in other high tech applications, an estimated 82% of the currently mined PGE come from only two major ore deposits in South Africa (Bushveld complex) and Russia (Norilsk) (USGS, 2013). Supply risks and price instabilities can occur when producers suffer full-scale mine shutdowns as seen during several strikes held by mining workers in South Africa 2013 (USGS, 2013), or when political environments change in times of crisis (e.g. 2015 EU–Russia sanctions during Ukraine crisis).

Ore deposits associated with near-surface modification of ultramafic rocks could help to minimize supply risks of these critical metals (CM) (e.g. Wilde et al., 2003). Ni laterites are considered worthy targets for CM exploration as REE, Sc and PGE can be concentrated during

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weathering as a result of residual and secondary enrichment (e.g. Maksimović and Pantó, 1996; Economou-Eliopoulos et al., 1997; Eliopoulos and Economou-Eliopoulos, 2000; Audet, 2008; Ndjigui and Bilong, 2010; Wang et al., 2011; Eliopoulos et al., 2014). In addition, changing Eh–pH conditions at higher levels of the laterite profile and subsequent interactions within the biosphere can favour mobility, reprecipitation and concentration of these elements (Aiglsperger et al., 2015).

Ni (±Co) laterite deposits account for about 60% of the current world's annual Ni production and host 60 to 70% of the world land-based Ni resources (Butt and Cluzel, 2013). In this context Cuba and the Dominican Republic host some of the world's most important Ni laterite deposits. They formed by weathering of ophiolitic serpentinized peridotites in the Tertiary as a result of tropical climate conditions (e.g. Linchenat and Shirakova, 1964; Haldemann et al., 1979; Lithgow, 1993; Lavaut, 1998; Lewis et al., 2006a). They have been mined since 1943 when the Nicaro processing plant (eastern Cuba) went into production (Nelson et al., 2011). The Ni laterite deposits currently being mined are located in eastern Cuba (Moa Bay mining area) and the central Dominican Republic (Falcondo mining area). According to the mineralogy of principal ore-bearing phases, the Moa Bay ore deposits are classified as oxide type, and Falcondo ore deposits as hydrous Mg silicate type (Brand et al., 1998; Lewis et al., 2006a).

In this work, geochemical and mineralogical data from two different nickel laterite types (i) from the Moa Bay mining area (eastern Cuba) and (ii) from the Falcondo mining area (Dominican Republic) is presented, with emphasis on their potential to accumulate CM and on processes involved. Data and behaviour of the most abundant CM in Ni laterites, cobalt, are discussed in a separate publication currently under development and continues with previous work from the study area (Labrador et al., 2007; Proenza et al., 2010; Roqué-Rosell et al., 2010). The underlying idea of this investigation is that here discussed CM could be produced as by-products additionally to approximately 130,000 t of Ni annually produced in active plants in the Caribbean (Nelson et al., 2011).

2. Geological setting

The Ni laterites from the Moa Bay and Falcondo mining areas are located in the northern Caribbean (Fig. 1). They are developed on ophiolite complexes with serpentinized peridotite that crop out as tectonic belts along the margins of the Caribbean plate (Lewis et al., 2006a). However, eastern Cuba and the central Dominican Republic contain the largest ore deposits.

2.1. The Moa Bay mining area

Ni laterites of the Moa Bay mining area form part of an ~100 km^2 large Ni laterite province in the northeast of Cuba (Pinares de Mayarí, Nicaro and Moa Bay mining areas), making it one of the largest reserves of nickel and cobalt in the world (Linchenat and Shirakova, 1964; Lavaut, 1998; Lewis et al., 2006a; Fig. 2a, b). According to Beaton et al. (2011) measured and indicated metal resources were 66.60 Mt at 1.26% Ni and 0.13% Co in 2010. Proven and probable reserves of 47.77 Mt with a grade of 1.19% Ni and 0.13% Co were reported by the same authors. The Moa Bay Ni laterites have developed from weathering of hydrated ultramafic rocks of the Moa–Baracoa ophiolitic massif. This massif form the eastern part of the Mayarí–Baracoa ophiolitic belt in northeastern Cuba (Proenza et al., 1999a,b; Marchesi et al., 2006) and consists of mantle tectonites (>2.2 km) followed by a thin (~300 m) crustal section of lower gabbros and discordant basaltic rocks with back arc basin affinity (Iturralde-Vinent et al., 2006; Marchesi et al., 2006; Proenza et al., 2006). The ultramafic rocks are mainly harzburgites (more than 70%) and lesser amounts of dunites. Concordant and subconcordant bodies of dunite, sills of gabbro and chromitite bodies within a dunite envelope are also present. The degree of serpentinization is most in shear or fracture zones, where it reaches a maximum value of 95% relative to the whole rock (typical serpentinite). The peridotites are cut by dikes of gabbro, pegmatite gabbro, olivine norite and minor pyroxenite (Proenza et al., 1999a,b; Marchesi et al., 2006). The emplacement of the ophiolite took place in the Maastrichtian to early Danian with weathering, lateritization and subsequent ore deposit formation commencing during the Miocene (Iturralde-Vinent et al., 2006; Lewis et al., 2006a).

The Moa Bay Ni laterite mining area is classified as oxide type (Brand et al., 1998; Gleeson et al., 2003) and is divided into 9 ore deposits: Moa Occidental, Moa Oriental, Punta Gorda, Yagrumaje, Camarioca Norte, Camarioca Sur, La Delta, Cantarrana, and Santa Teresita (e.g. Lavaut, 1998) producing at least 34.263 t of Ni and 3.792 t of Co in 2012 (Sherritt, 2012).

The laterite profile at Moa Bay has been divided into various zones and subzones by mine workers and Cuban geologists but the nomenclature of these zones does not follow the recommended classification for

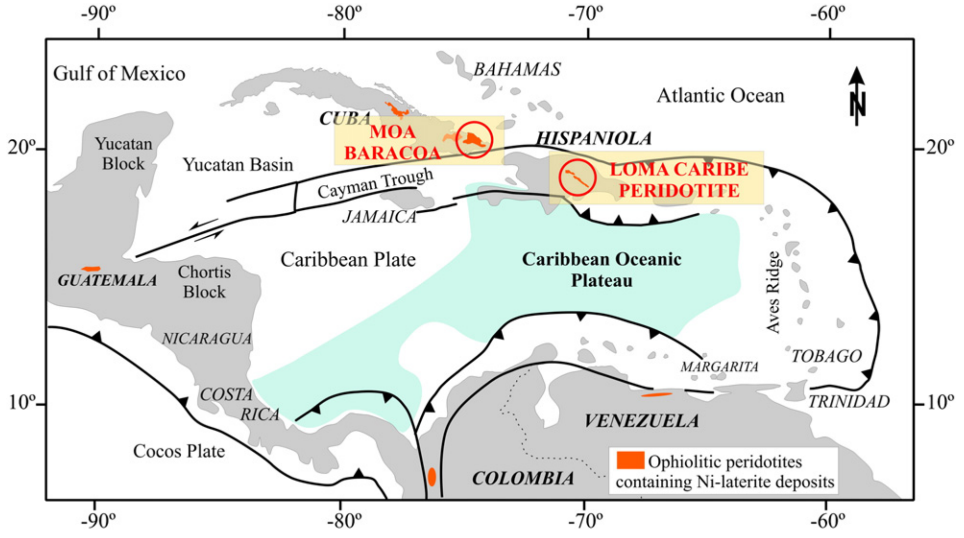

Fig. 1. Distribution of ophiolitic peridotites containing Ni laterite deposits around the margins of the Caribbean Plate; Ni laterite deposits from Moa Baracoa (Cuba) and from the Loma Caribe peridotite (Dominican Republic) are highlighted.
Modified from Lewis et al. (2006a).