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## Chemical and physical transfers in an ultramafic rock weathering profile: Part 1. Supergene dissolution of Pt-bearing chromite

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1 **Revision 1 (including editorial corrections)**

2  
3 **Chemical and physical transfers in an ultramafic rock weathering profile: 1. Supergene**  
4 **dissolution of Pt-bearing chromite**

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25

**ABSTRACT**

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Chemical weathering and supergene dissolution processes of platinum-bearing chromite are studied in a lateritic weathering profile developed at the expense of ultramafic rocks in New Caledonia (Southwest Pacific). The chemical distributions of alkaline earth, transition metals and precious metals, including Pt and Pd are determined in a weathering profile varying from bedrock at the base upward through coarse and fine saprolites, and capped by a mottled zone and a lateritic colluvial nodular horizon. Chemical analyses and mass balance calculations suggest that progressive weathering of the parent rock is characterized by an enrichment of Fe, Co, and Mn, segregation of Ni at the transition between the bedrock and the coarse saprolite and in the lower part of the fine saprolite, and a depletion of Mg, Ca, Si, Al, and Cr. The higher concentrations of transition metals at the interface between the coarse and fine saprolite is due to vertical transfers and precipitation at the base of the weathering profile. In such a lateritic environment, the Pt-bearing chromite grains are progressively dissolved and the platinum group minerals (PGM) are released in the weathering mantle with a preferential depletion of palladium with regard to platinum.

*Keywords:* Lateritic weathering, ultramafic rocks, mass balance calculation, Pt-chromite, New Caledonia

**INTRODUCTION**

43

44 Lateritic weathering of rocks is one of the major processes that modify the earth's surface  
45 and contribute to the geochemical cycle of elements (Marker et al. 1991; Compton et al.  
46 2003). It affects numerous regions of the intertropical zone (Pedro 1968; Nahon 1986; Tardy  
47 and Roquin 1992; Tardy 1997), where long-term chemical weathering has led to the  
48 dissolution of primary minerals including heavy minerals like metal-bearing spinel that results  
49 in supergene formation and accumulation of secondary and residual minerals in profiles of 10  
50 to 100 m in thickness. The mobilization and recycling of chemical elements during supergene  
51 weathering processes is complex, depending on dissolution kinetics of primary minerals,  
52 formation of secondary phases, Eh-pH conditions, mass transfers and co-precipitation and  
53 ionic exchanges between various minerals (Harris and Adams, 1966; Nesbitt 1979; Cramer  
54 and Nesbitt 1983; Nahon 1991; Nesbitt and Wilson 1992; Islam et al. 2002). We study here  
55 the chemical weathering of ultramafic rocks of New Caledonia and particularly the supergene  
56 dissolution of platinum-bearing chromite grains disseminated in the weathering profile to  
57 characterize the weathering processes of the parent rocks and the release mechanism of  
58 platinum group minerals (PGM) in the weathering profile.

59 More than one-third of the area of New Caledonia is covered by ultramafic rocks,  
60 which are remnants of a Late Eocene overthrust belt now dissected by erosion (Paris  
61 1981). These ultramafic rocks are deeply weathered, resulting in progressive leaching of  
62 Mg and Si and relative concentration of Fe and other metals in thick weathering profiles  
63 (Trescases 1975; Latham 1986). Ultramafic rocks are mainly harzburgite or lherzolite,  
64 which can exhibit serpentinization at their base; these rocks are also intercalated with  
65 dunite layers (Trescases 1975). Chromium spinel ( $\text{Mg, Fe}^{2+}$ )(Cr, Al,  $\text{Fe}^{3+}$ )<sub>2</sub>O<sub>4</sub> is present  
66 interstitially up to 3% (Guillon 1975) or in pure chromite deposits of the ophiolitic  
67 harzburgites (Cassard et al. 1981; Augé 1985; Leblanc 1995). This primary chromite is

68 subsequently mobilized in eluvial and alluvial deposits. Significant proportions of this  
69 mineral have been previously reported in New Caledonian ophiolitic complexes, but the  
70 secondary supergene evolution of chromium spinel is poorly understood (Phan and  
71 Routhier 1964). A petrological and geochemical study of lateritic weathering profiles  
72 can contribute to improve this knowledge, and more particularly to address the specific  
73 metallogenic issue of the supergene weathering processes of platinum-bearing chromite.

#### 74 **GEOLOGICAL SETTING**

75 The study area is located in the downslope part of the Pirogues River drainage basin  
76 in Southern New Caledonia (Fig. 1). The lithological units of this area consist of  
77 ultramafic rocks as cumulates of dunite, wehrlite and pyroxenite, and also harzburgites,  
78 which are serpentinized and cross-cut by pyroxenite dikes (Fig. 1). Platiniferous  
79 chromite are primarily concentrated either as stratiform accumulations in dunite and  
80 wehrlite or are disseminated in pyroxenite dikes and wehrlite. Most of the PGM are  
81 included in chromite (Augé and Maurizot 1995). Chromite forms thin schlieren and layers  
82 a few centimeters thick and a meter or so long in dunite and wehrlite cumulates. Irregular  
83 concentrations of massive chromite form ore in the pyroxenite dikes (Augé and Maurizot  
84 1995). Chromite is crystallized in between large grains of pyroxene. Massive chromite was  
85 also observed in the different horizons of the weathering profiles.

86 The ultramafic rocks are deeply weathered under the influence of a warm and humid  
87 climate characterized by a mean annual rainfall of 1700 mm with a wet season occurring  
88 from December to August. The ultramafic bedrock is generally overlain by a thick  
89 lateritic weathering mantle consisting typically from the base to the top (Trescases 1975;  
90 Besset 1980; Latham 1986; Llorca 1986) of: a coarse saprolite comprised of parent rock  
91 blocks, surrounded by weathering cortices; a fine saprolite where the silicates are totally  
92 hydrolyzed but the parent rock structure is preserved; a mottled zone composed of some

93 ferruginous nodules embedded in a goethitic matrix crossed by numerous millimeter-  
94 scale bioturbations; a soft nodular layer consisting mainly of millimeter to centimeter  
95 size nodules and pisoliths, and ferricrete fragments embedded in a red goethitic  
96 ferruginous matrix; a ferricrete exhibiting a massive, alveolar, and/or pisolitic structure,  
97 which is essentially composed of goethite and hematite. The parental structures are  
98 generally blurred in the ferruginous upper horizons.

99 Natural weathering profiles exposed in deep gullies (also locally called “lavakas”)  
100 have been described and sampled *in situ* (Fig. 2) for mineralogical and geochemical  
101 studies.

#### 102 MATERIAL AND METHODS

103 Fourteen samples of parent rock, laterite and soil were collected *in situ* for measuring the  
104 bulk and grain density (Figs. 2 and 3). These samples were analyzed to determine (1) major  
105 element composition by Inductively Coupled Plasma - Atomic Emission Spectroscopy  
106 (ICP-AES) and (2) trace and precious metals by Inductively Coupled Plasma - Mass  
107 Spectrometry (ICP-MS). For ICP-AES analyses, the samples were crushed and finely  
108 ground ( $\leq 75 \mu\text{m}$ ) after oven drying to be decomposed with 10 times their weight of a  
109 composite flux comprising 65% metaborate and 35% tetraborate according to the ME-ICP93  
110 analytical procedure developed by the Australian Laboratory Services (ALS, Chemex). The  
111 resulting melts were dissolved in dilute nitric acid. Repeated fusion of finely ground  
112 powder was necessary to obtain complete decomposition of chromite, particularly for  
113 the samples containing coarser-grained chromite. For ICP-MS analysis of precious  
114 metals (Pt and Pd) each ground sample was fused with a mixture of lead oxide, sodium  
115 carbonate, borax and silica, inquarted with 6 mg of gold-free silver and then cupelled to yield  
116 a precious metal bead according to the PGM-MS23 analytical procedure developed by ALS  
117 Chemex, Australia. After cupellation the bead was dissolved in nitric and hydrochloric

118 acids and the solution diluted to volume. Detection limits for Pd and Pt are 1 and 0.5  
119 ppb, respectively. X-ray diffraction (XRD) determinations were also processed on each  
120 sample. Semi-quantitative proportions of minerals were deduced by the measurements of  
121 the surface of main peaks in XRD spectra.

122 Three samples of 50 kg were also collected in the friable layers of the weathering profile  
123 (fine saprolite, mottled zone and nodular layer). The samples were carefully washed, sifted to  
124 1 mm and panned in order to separate out the heaviest particles. Chromite grains were  
125 separated from the other heavy minerals under a binocular microscope for morphological  
126 examination by scanning electron microscopy (SEM). After the SEM observation, chromite  
127 grains were mounted with resin and polished sections were prepared for electron microprobe  
128 analyses. Microanalyses of chromite grains were obtained using a Cameca SX 100 electron  
129 microprobe with an acceleration potential of 15 keV, a beam current of 50 nA and counting  
130 time of 10 s. The standards used were olivine for Mg, albite for Al, hematite for Fe,  
131 orthoclase for Si, Cr<sub>2</sub>O<sub>3</sub> for Cr, MnTiO<sub>2</sub> for Mn and Ti, NiO-466.6 for Ni, ZnO for Zn and  
132 synthetic Co for Co.

## 133 RESULTS AND DISCUSSION

### 134 Physical and geochemical characterization

135 **Density and porosity change.** The weathering profile is developed from a wehrlite  
136 type ultramafic rock (40-70% olivine, 30-45% antigorite and 10-20% diopside), and its  
137 thickness is up to 4 meters. At the base of the profile (Fig. 2), the greenish-black parent  
138 rock (-470 to -400 cm) changes to a brownish coarse saprolite (-400 to 290 cm) that  
139 preserves parental structure and texture. Above (-290 to -100 cm) a yellow fine saprolite  
140 is overlain by a red mottled zone (-100 to -60 cm) and a colluvial nodular horizon close  
141 to the ground surface (Fig. 2), which is composed of ferruginous nodules, pisolites and  
142 fragments of a previous ferricrete.

143 Rock porosity is an important physical parameter of weathering mantles as it controls soil,  
144 water and air circulation, and thus permeability. Therefore, pores are a first order factor  
145 controlling erosion and mass movement processes. In the profile studied, the bulk density  
146 decreases from an average  $2.37 \text{ g.cm}^{-3}$  in the fresh wehrlite to  $1.32 \text{ g.cm}^{-3}$  in the coarse  
147 saprolite,  $0.93 \text{ g.cm}^{-3}$  and  $1.13 \text{ g.cm}^{-3}$  in the fine saprolite and mottled zone, respectively, and  
148  $1.71 \text{ g.cm}^{-3}$  in the nodular horizon (Fig. 3a and Table 1). The grain density slightly increases  
149 from an average  $3.05 \text{ g.cm}^{-3}$  in the parent rock and the coarse saprolite,  $3.58 \text{ g.cm}^{-3}$  in the fine  
150 saprolite and  $3.64 \text{ g.cm}^{-3}$  in the mottled zone to  $3.67 \text{ g.cm}^{-3}$  in the nodular horizon (Fig. 3b  
151 and Table 1). The porosity change is thus very important, from 22% in the fresh wehrlite to  
152 56%, on average, in the coarse saprolite, 74% in the fine saprolite, 69% in the mottled zone,  
153 and 53% in the upper nodular layer (Fig. 3c and Table 1).

154 **Petrologic and geochemical patterns.** The XRD mineralogical characterization of each  
155 horizon composing the weathering profile indicates the presence of olivine, antigorite,  
156 diopside and goethite with accessory chromite and enstatite. In the saprolites, the  
157 silicates are progressively replaced by goethite, olivine being the first affected by  
158 weathering. The coarse saprolite is composed of 30% olivine (up to 50% in the parent  
159 rock), 40% antigorite (35% in the parent rock), 15% diopside, 15% goethite. The base of  
160 the fine saprolite is composed of 15% olivine, 5% antigorite, 10% diopside (15% in the  
161 parent rock) and 50% goethite. At the top of the fine saprolite olivine, antigorite and  
162 diopside are completely replaced by goethite, which reaches 100%. The mottled zone  
163 and the nodular layer are essentially composed of goethite with accessory hematite and  
164 chromite.

165 The geochemical analyses of the unweathered wehrlite indicate, on average, 39.6  
166 wt.%  $\text{SiO}_2$ , and 34.70 wt.%  $\text{MgO}$ , and 19.3 wt.%  $\text{Fe}_2\text{O}_3$  (Table 1). Silica decreases to  
167 21.2 wt.% at the top of the coarse saprolite and  $\text{MgO}$  to 7.1 wt.%. Iron (III) oxide



168 contents increase, on average, from 19.3 wt.% to 45.2 wt.%. Aluminum and chromium  
169 contents do not significantly change between parent wehrlite and coarse saprolite: on  
170 average, 0.6 – 0.7 wt.%  $\text{Al}_2\text{O}_3$ , 1.5 – 2.3 wt.%  $\text{Cr}_2\text{O}_3$ . The transition metal contents  
171 increase, on average, from 1.97  $\text{g.kg}^{-1}$  to 4.40  $\text{g.kg}^{-1}$  for Mn, 0.23  $\text{g.kg}^{-1}$  to 0.48  $\text{g.kg}^{-1}$  for  
172 Co, and 0.34  $\text{g.kg}^{-1}$  to 0.53  $\text{g.kg}^{-1}$  for Ni (Table 1).

173 The coarse saprolite is progressively transformed into a fine saprolite, in which the  
174 texture and the structure of the parent rock are still preserved. On average, the  
175 geochemical analyses of the fine saprolite indicate 3.4 wt.%  $\text{SiO}_2$ , 0.9 wt.%  $\text{Al}_2\text{O}_3$ , 77  
176 wt.%  $\text{Fe}_2\text{O}_3$ , 3.3 wt.%  $\text{Cr}_2\text{O}_3$ , 0.04 wt.% CaO, 0.85 wt.% MgO, 8.3  $\text{g.kg}^{-1}$  Mn, 2.8  $\text{g.kg}^{-1}$   
177 Co, and 8.2  $\text{g.kg}^{-1}$  Ni (Table 1).

178 Toward the top of the profile, the fine saprolite changes to a bioturbated-mottled  
179 laterite in which the original rock structure is no longer preserved. The chemical  
180 composition is similar to the one analyzed in the upper part of the fine saprolite except  
181 for decreased Co content (Table 1).

## 182 **Mass balance calculations**

183 Mass balance calculations related to weathering processes require the application of  
184 rigorous means to estimate losses or gains based on a thorough petrological study  
185 (Millot and Bonifas 1955; Gresens 1967; Brimhall and Dietrich, 1986; Colin et al. 1992,  
186 1993; Beauvais and Colin 1993). The parental rock structures are well preserved in the  
187 saprolite suggesting that weathering processes have preserved the original volume.

188 Based on the assumption that the volume has not varied between bedrock (-470 cm) and  
189 the top of the fine saprolite (-110 cm), isovolume mass-balance calculations can be  
190 applied to quantify mass transfers induced by the transformation of parent-rock into  
191 saprolite (Millot and Bonifas 1955). Numerous authors have mathematically formalized  
192 mass balance calculations (Gresens 1967; Brimhall and Dietrich 1986) by a functional

193 form of the constitutive relationships between the chemical compositions of parent and  
 194 weathered material, their bulk densities, and volumes. The net gains and losses of  
 195 chemical constituents are calculated from the following equation (Brimhall and Dietrich  
 196 1986):

197

$$198 \quad K_j = \left[ \left( \frac{C_{jw} \times \rho_{jw}}{C_{jp} \times \rho_{jp}} \right) - 1 \right] \times 100, \quad (1)$$

199

200 where  $K_j$  is the gain and/or loss factor of chemical element  $j$ ;  $C_{jw}$  and  $C_{jp}$  are the  
 201 chemical element  $j$  concentrations (expressed in  $\text{g.kg}^{-1}$  for Si, Al, Fe, Ca, Mg and Cr, or  
 202  $\text{mg.kg}^{-1}$  for Mn, Co and Ni) in the weathered layer,  $w$ , and the parent material,  $p$ ,  
 203 respectively; and  $\rho_{jw}$  and  $\rho_{jp}$  are bulk densities of the weathered material,  $w$ , and the  
 204 parent material,  $p$ , respectively (expressed in  $\text{g.cm}^{-3}$ ).

205 The total mass ( $m_{jw}$ ) of each element  $j$  gained or lost during the weathering  
 206 process is calculated from the following equation (Colin et al. 1993):

207

$$208 \quad m_{jw} = C_{jp} \times \rho_{jp} \times V_p \times K_{jw}, \quad (2)$$

209

210 where  $V_p$  is the volume of the parent rock ( $V_p = 1 \text{ m}^3$ ),  $K_{jw}$  is the gain and/or loss factor  
 211 of chemical element  $j$  in the weathered layer,  $w$ , calculated from the equation (1), and  
 212  $C_{jp}$ ,  $\rho_{jp}$  and  $m_{jw}$  are expressed in  $\text{kg.ton}^{-1}$ ,  $\text{ton.m}^{-3}$  and  $\text{kg.m}^{-3}$ , respectively.

213 Mass balance calculations show that 96% Si, 99% Mg, 94% Ca have been depleted in the  
 214 fine saprolite (Table 2a and Fig. 4) that corresponds, on average, to mass transfers of -426 kg  
 215 Si, -488 kg Mg and -5.4 kg Ca per cubic meter of weathered parent rock (Table 2b). This is  
 216 accompanied, on average, by 47% loss of Al and 16% loss of Cr, i.e.,  $-4 \text{ kg.m}^{-3}$  Al and -4

217 kg.m<sup>-3</sup> Cr, the highest values being recorded at the base of the fine saprolite (Table 2 and  
218 Figs. 4a and 4c). Iron, Mn, and Co contents are enriched at the top of the coarse saprolite only  
219 by 4.7% (+17.2 kg.m<sup>-3</sup>), 8% (+0.39 kg.m<sup>-3</sup>), and 9% (+0.05 kg.m<sup>-3</sup>), respectively, while Ni is  
220 slightly depleted by -10% (-0.69 kg.m<sup>-3</sup>) (Fig. 4 and Table 2). At the base of the fine  
221 saprolite, the enrichment rates strongly increase by 30% (+110 kg.m<sup>-3</sup>) for Fe, 45% (+3.18  
222 kg.m<sup>-3</sup>) for Ni, 54% (+2.61 kg.m<sup>-3</sup>) for Mn, and 458% (+2.35 kg.m<sup>-3</sup>) for Co. At the top of  
223 the fine saprolite, the enrichment rates are 38% (+142 kg.m<sup>-3</sup>) for Fe, 81% (+3.9 kg.m<sup>-3</sup>)  
224 for Mn and 312% (+1.6 kg.m<sup>-3</sup>) for Co, while Ni is depleted by -20% (-1.38 kg.m<sup>-3</sup>)  
225 (Table 2a and 2b).

226 The sharp decrease of Si, Mg and Ca contents (from parent rock to saprolite) reflects the  
227 congruent weathering of primary silicates (Eggleton et al. 1987; Nesbitt and Wilson 1992;  
228 Islam et al 2002). The weathering creates high porosity and resultant improved drainage  
229 conditions if pore spaces are interconnected (Trescases 1975; Latham 1986; Marker et al.  
230 1991). The Fe-enrichment at the transition between coarse and fine saprolite (Fig. 4a and  
231 Table 2) is due to relatively short vertical migrations of iron in the weathering profile that has  
232 led to goethite formation, which may have trapped transition metals such as Mn, Co and Ni  
233 (Millot and Bonifas 1955; Tardy and Roquin 1992; Beauvais and Colin 1993; Beauvais and  
234 Roquin 1996).

235 The primary host minerals for Ni in the ultramafic rocks are olivine, serpentine and  
236 accessory pyroxene (Zeissink 1969; Trescases 1975; Besset 1980; Colin et al. 1990; Gaudin,  
237 2002). During the weathering of these parent minerals in strong oxidizing conditions, Ni is  
238 mobilized and enriched by co-precipitation with secondary Fe and Mn oxides at the transition  
239 between the coarse and fine saprolite (Fig. 4c and Table 2) as previously shown (Schellmann  
240 1981; Golightly 1981; Elias et al. 1981; Trescases 1975; Reimann and Caritat 1998).

241 Manganese enrichment in the fine saprolite (on average, +60%), as compared to its content  
242 in the parent rock (Table 2a), can be explained by significant vertical and/or lateral transfers  
243 of Mn, which is released as  $Mn^{2+}$  in the saturated zone of the deeper saprolite (Golightly  
244 1979). Vertical transfers may be due to the leaching of Mn from the near-surface part of the  
245 profile under conditions of low pH and high  $CO_2$  activity. These environmental conditions  
246 favor reduction of  $Mn^{4+}$  to  $Mn^{2+}$  (Golightly 1979; Beauvais et al. 1987). Colloidal  $Mn^{2+}$   
247 complexes are highly mobile and can be transported in the soils over long distances  
248 (Krauskopf 1979; Marker et al. 1991). As soon as Mn-bearing solutions reach the lower part  
249 of the weathering profile, rising pH due to silicate hydrolysis and increased concentration of  
250 the solution above the saprolite, are likely to result in the oxidation of  $Mn^{2+}$  and precipitation  
251 of Mn oxides from the colloidal solution (Trescases 1975; Golightly 1979; Llorca 1986;  
252 Marker et al. 1991).

253 The behavior of Co is also controlled by physical-chemical properties of the downward-  
254 migrating solutions (Marker et al. 1991). Cobalt is adsorbed by negatively charged  $Mn^{4+}$   
255 colloids and/or incorporated into Mn oxides (Burns 1976; Manceau et al. 1987; Llorca and  
256 Monchoux 1991; Llorca 1993). Precipitation of Co at the base of the profile, where pH is  
257 higher, is more effective, because the solubility product of Co hydroxide is lower than that of  
258 Mn hydroxide (Trescases 1975; Schellmann 1978; Golightly 1981). This property can explain  
259 the higher enrichment factor of Co (+450%) compared to Mn (+54%) or Ni (+45%) in the  
260 lower cementation zone (Figs. 4c and d, Table 2) (Marker et al. 1991).

261 The Cr-bearing minerals in the ultramafic rocks are mainly chromite and accessory silicate  
262 minerals. Chromium-bearing silicate minerals are, however, depleted in the upper saprolite.  
263 Some Cr may be leached downward in the form of  $Cr(OH)_3$  in alkaline environments (Marker  
264 et al. 1991). Chromium within chromite is generally considered immobile in supergene  
265 environments (Trescases 1975; Schellmann 1978; Becquer et al. 2003). However, recent

266 thermodynamic and field studies have shown that chromite is soluble in lateritic environments  
267 (Fendorf 1995), suggesting that Cr in laterites derived from the weathering of ultramafic rocks  
268 may be depleted from the profile. As chromite is the main host mineral of aluminum in the  
269 wehrlite, its solubility also explains the depletion of Al in the profile.

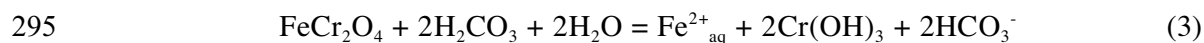
#### 270 **Supergene dissolution of chromite**

271 The chemical compositions of chromite from different samples of Pt-rich chromitite of the  
272 Pirogues site are plotted in Figure 5, together with disseminated chromite from the cumulate  
273 series, and chromitite from previously studied mantle deposits (Augé and Maurizot 1995), as,  
274 for example, those from the Tiebaghi massif in northwestern New Caledonia, in which the  
275 chromite has a very constant composition (high  $\text{Cr}^{3+}$  (55.5-63.5 wt.%  $\text{Cr}_2\text{O}_3$ ) and low  $\text{Fe}^{3+}$   
276 (1.5-4.3 wt.%  $\text{Fe}_2\text{O}_3$ )). Chromite disseminated in mineralized cumulates is slightly  
277 impoverished in Cr (Fig. 5). Platinum-bearing chromite concentrations in the cumulate series  
278 of the Pirogues area differ significantly from those of mantle chromitite in having relatively  
279 low  $\text{Cr}^{3+}$  (40-46 wt.%  $\text{Cr}_2\text{O}_3$ ) and high  $\text{Fe}^{3+}$  (10-17 wt.%  $\text{Fe}_2\text{O}_3$ ) (Fig. 5). No significant  
280 difference was observed between chromitite of pyroxenite dikes and chromitite of cumulates.

281 The platinum-bearing chromite in the parent rock and coarse saprolite is euhedral (Fig. 6a),  
282 with surfaces that may represent small primary dissolution cracks (Fig. 6b). The progressive  
283 weathering of chromite is illustrated in Figure 6. In the fine saprolite, where the lowest bulk  
284 densities and the highest porosities were measured (Fig. 3 and Table 1), the dissolution of  
285 chromite starts along the primary cracks and increases until forming a network of etching pits  
286 of sub-micrometric size (Fig. 6c and 6d). This effectively corresponds to the highest losses of  
287 Cr (Fig. 4c and Table 2). In the mottled zone, residual chromite grains with smooth edges are  
288 embedded in ferruginous aggregates and/or pisolites (Fig. 6e), which are essentially  
289 composed of goethite. The dissolution front increases in the chromite by widening of  
290 microcracks and fissures hosting weathering solutions (Fig. 6f). The supergene dissolution

291 process leads to the dislocation of chromite crystals in the superficial layers (Fig. 6g and 6h).  
 292 Chromite grain dissolution in supergene environments is driven by an hydrolysis process that  
 293 produces  $\text{Cr(OH)}_3$  (Cooper 2002) via:

294

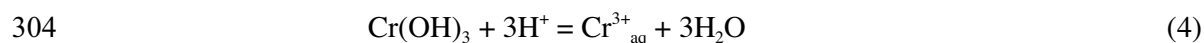


296

297 The production of  $\text{Cr(OH)}_3$  requires moist, slightly reduced conditions to keep Fe(II) ions in  
 298 solution, such as those prevailing in the fine saprolite, which is characterized by an  
 299 unconnected fine porosity and poor drainage. The  $\text{Cr(OH)}_3$  produced can be adsorbed to the  
 300 surface of the crystal structure of iron and/or manganese oxyhydroxides (McKenzie 1977;  
 301 Manceau and Charlet 1992; Fendorf 1995).

302 The dissolution reaction of  $\text{Cr(OH)}_3$  to produce soluble Cr(III) ions is represented by :

303



305

306 This reaction is possible only under strongly acidic conditions with pH values lower than 4  
 307 (Fendorf 1995; Cooper 2002). Such conditions prevail at the top of lateritic profiles, which is  
 308 often rich in organic matter.

309 The poorly-aerated chromite-rich ferruginous aggregates can also undergo oxidation-  
 310 reduction conditions that favor the hydrolysis of Cr(III) into  $\text{Cr(OH)}_3$  (Cooper 2002). The  
 311 dissolution of chromite ultimately leads to the release of PGM initially included in chromite  
 312 crystals.

### 313 **Residual origin of platinum**

314 Decoupling of platinum group elements, Pt and Pd, and variation of the ratio Pt/Pd, are  
 315 characteristic of the behavior of the PGE in supergene environments (Prichard and Lord 1994;

316 Evans et al. 1994; Oberthür et al. 2003). Between the bedrock and the upper part of the fine  
317 saprolite, the Pt/Pd ratio is as high as the chromium is depleted (Fig. 7 and Tables 1 and 2).  
318 The increase of Pt/Pd in the weathering profile reflects the preferential release of palladium  
319 with regard to platinum (Varajao et al. 2000). Figure 7 also suggests that PGM could be  
320 released concomitant with chromite dissolution and also, that the supergene dissolution of Pt-  
321 bearing chromite and/or newly released PGM lead to a preferential depletion of Pd with  
322 regard to Pt. The specific behavior of PGM in the lateritic weathering profile is addressed  
323 separately (Traore et al. 2007).

### 324 CONCLUSION

325 Supergene dissolution of platinum-bearing chromite has been characterized in a lateritic  
326 weathering profile from New Caledonia. Based on mass balance calculations, the results  
327 document the spatial redistribution of chemical elements during chemical weathering  
328 processes. Silicon, Mg and Ca are depleted entirely from the weathering profile resulting from  
329 the chemical weathering of olivine, pyroxene and serpentine. The residual Fe forms iron  
330 hydroxides, often crystallized into goethite, which can eventually trap other transition metals.  
331 Manganese, Co and Ni form poorly crystallized secondary minerals such as Mn-asbolanes  
332 and/or co-precipitate with iron hydroxides. The Cr-bearing silicates are dissolved and Cr is  
333 leached out of the profile. Chromite dissolution induces Cr depletion and Al removal. This  
334 investigation illustrates the decoupling of PGE and Cr content during the lateritic weathering  
335 of Pt-bearing chromite and suggests that the platinum mineralization is globally residual. The  
336 chromite dissolution may effectively contribute to the release of PGM in the profile with a  
337 preferential depletion of palladium with regard to platinum.

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346



## REFERENCES CITED

- 346  
347 Augé, T. (1985) Chromite et minéraux du groupe du platine dans les complexes ophiolitiques.  
348 Caractérisation des séries hôtes. Thesis, 270 p., Université Orléans, orléans, France.
- 349 Augé, T., and Maurizot, P. (1995) Stratiform and alluvial platinum mineralization in the New  
350 Caledonia ophiolite complex. *Canadian Mineralogist*, 33, 1023-1045.
- 351 Beauvais, A. and Colin, F. (1993) Formation and transformation processes of iron duricrust  
352 systems in tropical humid environment. *Chemical Geology*, 106, 77-101.
- 353 Beauvais, A., Melfi, A.J., Nahon, D., and Trescases, J-J. (1987) Pétrologie du gisement  
354 latéritique manganésifère d'Azul (Brésil). *Mineralium Deposita*, 22, 124-134.
- 355 Beauvais, A. and Roquin, C. (1996) Petrological differentiation patterns and geomorphic  
356 distribution of ferricretes in Central Africa. *Geoderma*, 73, 63-82.
- 357 Becquer, T., Quantin, C., Sicot, M., and Boudot, J.P. (2003) Chromium availability in  
358 ultramafic soils from New Caledonia. *Science of Total Environment*, 301, 251-261.
- 359 Besset, F. (1980) Localisation et répartitions successives du nickel au cours de l'altération  
360 latéritique des péridotites de Nouvelle-Calédonie. Mémoire du Centre d'Etudes et de  
361 Recherches Géologiques et Hydrologiques, 129 p., Tome XV, CERGA Ed., Montpellier,  
362 France.
- 363 Brimhall, G.H., and Dietrich, W.E. (1986) Constitutive mass-balance relations between  
364 chemical composition, volume, density, porosity and strain in metasomatic hydrochemical  
365 systems: results on weathering and pedogenesis. *Geochimica et Cosmochimica Acta*, 51,  
366 567-587.
- 367 Burns, R.G. (1976) The uptake of cobalt into ferromanganese nodules, soils and synthetic  
368 manganese (IV) oxides. *Geochimica et Cosmochimica Acta*, 40, 95-102.

- 369 Cassard, D., Nicolas, A., Rabinovitch, M., Moutte, J., Leblanc, M., and Prinzhofer, A. (1981)  
370 Structural classification of chromite pods in southern New Caledonia. *Economic Geology*,  
371 76, 805-831.
- 372 Colin, F., Brimhall, G.H., Nahon, D., Lewis, C.J., Baronnet, A., and Danti, K. (1992)  
373 Equatorial rain forest lateritic mantles: A geomembrane filter. *Geology*, 20, 523-526.
- 374 Colin, F., Nahon, D., Trescases, J.J, and Melfi, A.J. (1990) Lateritic weathering of  
375 pyroxenites at Niquelandia, Goias, Brazil: The supergène behavior of nickel. *Economic*  
376 *Geology* 85, 1010-1023.
- 377 Colin, F., Veillard, P., and Ambrosi, J.P. (1993) Quantitative approach to physical and  
378 chemical gold mobility in equatorial rainforest lateritic environment. *Earth and Planetary*  
379 *Science Letters*, 114, 269-285.
- 380 Compton, J.S., White, R.A., and Smith, M. (2003) Rare earth element behavior in soils and  
381 salt pan sediments of a semi-arid granitic terrain in the Western Cape, South Africa.  
382 *Chemical Geology*, 201, 239-255.
- 383 Cooper, G.R.C. (2002) Oxidation and toxicity of chromium in ultramafic soils in Zimbabwe.  
384 *Applied Geochemistry*, 17, 981-986.
- 385 Cramer, J.J, and Nesbitt, H.W. (1983) Mass-balance relations and trace element mobility  
386 during continental weathering of various igneous rocks. In S.G. Memory, Ed., p. 63-73.,  
387 *Symposium on Petrology of Weathering and Soils*.
- 388 Eggleton, RA., Foudoulis, C., and Varkevisser, D. (1987) Weathering of basalt: changes in  
389 rock chemistry and mineralogy. *Clays and Clay Minerals*, 35, 161-169.
- 390 Elias, M., Donaldson, M.J., and Giorgetta, N. (1981) Geology, mineralogy, and chemistry of  
391 lateritic nickel-cobalt deposits near Kalgoorlie, Western Australia. *Economic Geology*, 76,  
392 1775-1783.

- 393 Evans, D.M., Buchanan, D.L., and Hall, G.E.M. (1994) Dispersion of platinum, palladium  
394 and gold from the main sulphide zone, Great Dike, Zimbabwe. Transactions of the  
395 Institution of Mining and Metallurgy, 103, (Section B: Applied earth science), B57-B67.
- 396 Fendorf, S.E. (1995) Surface reactions of chromium in soils and waters. *Geoderma* 67, 55-71.
- 397 Gaudin, A. (2002) Cristalochimie des smectites du gisement latéritique nickélique de Murrin  
398 Murrin (Ouest Australie). Ph D, 236 p. Université Aix-Marseille III, Marseille, France.
- 399 Golightly, J.P. (1979) Geology of Soroako nickeliferous laterite deposits. AIME International  
400 Laterite Symposium, p. 38-55., New Orleans, USA.
- 401 Golightly, J.P. (1981) Nickeliferous laterite deposits. *Economic Geology*, 75th Anniversary  
402 vol., 710-735.
- 403 Gresens, R.L. (1967) Composition-volume relations of metasomatism. *Chemical Geology*, 2,  
404 47-65.
- 405 Guillon, J.H. (1975) Les Massifs péridotitiques de Nouvelle-Calédonie: type d'appareil  
406 ultrabasique stratiforme de chaîne récente. Mémoire ORSTOM 76 Paris, 113 p.
- 407 Harris, R.C., and Adams, J.A.S. (1966) Geochemical and mineralogical studies on the  
408 weathering of granitic rocks. *American Journal of Science*, 264, 146-173.
- 409 Islam, M.R., Peuraniemi, V., Aario, R., and Rojstaczer, S. (2002) Geochemistry and  
410 mineralogy of saprolite in Finish Lapland. *Applied Geochemistry*, 17, 885-902.
- 411 Krauskopf, K.B. (1979) Introduction to Geochemistry, 617 p. McGraw-Hill Tokyo.
- 412 Latham, M. (1986) Altération et pédogenèse sur roches ultrabasiques en Nouvelle-  
413 Calédonie: genèse et évolution des accumulations de fer et de silice en relation avec la  
414 formation du modelé. Etudes et Thèses, 331 p., ORSTOM, Paris, France.
- 415 Leblanc, M. (1995) Chromitite and ultramafic rock compositional zoning through a  
416 paleotransform fault, Poum, New Caledonia. *Economic Geology*, 90, 2028-2039.

- 417 Llorca, S. (1986) Les concentrations cobaltifères supergènes en Nouvelle-Calédonie:  
418 géologie, minéralogie. Thesis 90 p., Université Paul Sabatier, Toulouse, France.
- 419 Llorca, S. (1993) Metallogeny of supergene cobalt mineralization, New Caledonia. Australian  
420 Journal of Earth Science, 40, 377-385.
- 421 Llorca, S., and Monchoux, P. (1991) Supergene cobalt minerals from New Caledonia.  
422 Canadian Mineralogist, 29, 149-161.
- 423 Manceau, A., and Charlet, L. (1992) X-ray absorption spectroscopic study of the sorption of  
424 Cr(III) at the oxide-water interface: I. Molecular mechanism of Cr(III) oxidation on Mn  
425 oxides. Journal of Colloidal Interface Science, 148, 425-442.
- 426 Manceau, A., Llorca, S., and Calas, G. (1987) Crystal chemistry of cobalt and nickel in  
427 lithiophorite and asbolane from New Caledonia. Geochimica et Cosmochimica Acta, 51,  
428 105-113.
- 429 Marker, A., Friedrich, G., Carvalho, A., and Melfi, A. (1991) Control of the distribution of  
430 Mn, Co, Zn, Zr, Ti, and REEs during the evolution of lateritic covers above ultramafic  
431 complexes. Journal of Geochemical Exploration, 40, 361-383.
- 432 McKenzie, R.M. (1977) Manganese oxides and hydroxides. In J.B. Dixon, and S.B. Weed,  
433 Eds., Minerals in Soil Environments, Soil Science Society of America, 181-193.
- 434 Millot, G., and Bonifas, M. (1955) Transformations isovolumiques dans les phénomènes de  
435 latéritisation et de bauxitisation. Bulletin du Service de la Carte Géologique d'Alsace-  
436 Lorraine, Strasbourg, 8, 8-10.
- 437 Nahon, D. (1991) Introduction to the Petrology of Soils and Chemical Weathering, 313 p.  
438 Wiley Interscience, New York.
- 439 Nahon, D.B. (1986) Evolution of iron crusts in tropical landscapes. In S.H. Coleman, and  
440 D.P. Dethier, Eds., Rates of Chemical Weathering of Rocks and Minerals, p. 169-187.  
441 Academic Press Incorporation, San Diego.

- 442 Nesbitt, H.W. (1979) Mobility and fractionation of rare earth elements during weathering of  
443 granodiorite. *Nature*, 279, 206-210.
- 444 Nesbitt, H.W., and Wilson, R.E. (1992) Recent chemical weathering of basalts. *American*  
445 *Journal of Science*, 292, 740-777.
- 446 Oberthür, T., Weiser, T.W., and Gast, L. (2003) Geochemistry and mineralogy of platinum-  
447 group elements at Hartley Platinum Mine, Zimbabwe. *Mineralium Deposita*, 38, 344-355.
- 448 Paris, J.P. (1981) Géologie de la Nouvelle-Calédonie: un essai de synthèse. *Mémoire BRGM*  
449 113, Orléans, 278 p.
- 450 Pedro, G. (1968) Distribution des principaux type d'altération chimique à la surface du globe.  
451 Présentation d'une esquisse géographique. *Revue de Géographie Physique et Géologie*  
452 *Dynamique*, 10, 457-470.
- 453 Phan, K.D., and Routhier, P. (1964) Altération météorique de chromite de Nouvelle-  
454 Calédonie: Etude à la microsonde électronique. Contribution à la géochimie supergène du  
455 chrome en milieu latéritique. Conséquences pratiques pour la concentration des chromite  
456 détritiques. *Bulletin BRGM*, 4, 111-133.
- 457 Prichard, M.H., and Lord, R.A. (1994) Evidence for differential mobility of platinum-group  
458 elements in the secondary environnement in Shetland ophiolite complex. *Transactions of*  
459 *the Institution of Mining and Metallurgy*, 103, (Section B; Applied earth science), B79-  
460 B86.
- 461 Reimann, C., and de Caritat, P.D. (1998) Chemical elements in the environment. Factsheets  
462 for the geochemist and environmental scientist, Springer Verlag Publication, Berlin.
- 463 Schellmann, W. (1978) Behavior of nickel, cobalt, and chromium in ferruginous lateritic  
464 nickel ores. *Bulletin BRGM*, 2, 275-282.
- 465 Schellmann, W. (1981) Formation of nickel silicate ores by weathering of ultramafic rocks.  
466 *Development in Sedimentology*, 35, 623-634.

- 467 Tardy, Y. (1997) Petrology of laterites and tropical soils, 459 p. Balkema, Amsterdam.
- 468 Tardy, Y., and Roquin, C. (1992) Geochemistry and evolution of lateritic landscapes. In I.P.  
469 Martini, and W. Chesworth, Eds., *Weathering, Soils & Paleosols*, p 407-443. Elsevier  
470 Publication, Amsterdam.
- 471 Traoré, D., Augé, T., Beauvais, A., Parisot, J.C., Colin, F., and Cathelineau, M. (2007)  
472 Chemical and physical transfers in an ultramafic rock weathering profile: 2. Dissolution vs.  
473 accumulation of platinum group minerals. *American Mineralogist*, submitted.
- 474 Trescases, J.J. (1975) L'évolution géochimique supergène des roches ultrabasiqes en zone  
475 tropicale: formation des gisements nickélicifères de Nouvelle- Calédonie. Mémoire  
476 ORSTOM 78, Paris, 280 p.
- 477 Varajao, C.A.C., Colin, F., Vieillard, P., Melfi, A.J., and Nahon, D. (2000) Early Weathering  
478 of palladium gold under lateritic conditions, Maquine Mine, Minas Gerais: Brazil. *Applied*  
479 *Geochemistry*, 15, 245-263.
- 480 Zeissink, H.E. (1969) The mineralogy and geochemistry of a nickeliferous laterite profile  
481 (Greenvale, Queensland, Australia). *Mineralium Deposita*, 4, 132-152.
- 482

482 **Figure and Table Captions**

483

484 Figure 1. (a) Geological map and location of studied area (after Augé and Maurizot, 1995).

485 The black star shows the location of the studied weathering profile (Fig. 2). (b) Inset of the

486 main Island of New Caledonia with its ultramafic massifs and location of (a) by the black

487 rectangle.

488

489 Figure 2. Weathering profile log from a crosscut into a natural gully (“lavaka”) and the

490 location of analyzed samples (white squares), the numbers of which being in italics.

491

492 Figure 3. (a) Bulk density, (b) Grain density and (c) Porosity variation along the profile.

493

494 Figure 4. Results of the geochemical mass balance calculation along the profile.

495

496 Figure 5. Chemical compositions of chromite from PGE-rich chromitite of the Pirogues River

497 mineralization (black circles) and disseminated chromite in cumulate hosting the

498 mineralization (grey circles). Light gray circles correspond to mantle chromitite from

499 Tiébaghi (after Augé, 1985).

500

501 Figure 6. S.E.M. photomicrographs of the progressive weathering of chromite (a) euhedral

502 grain of primary chromite in the coarse saprolite, (b) detail of a primary chromite grain

503 surface showing dissolution cracks, (c) euhedral grain of chromite affected by a microdrain

504 network in the red laterite, (d) etching dissolution pits of a chromite grain, (e) residual

505 chromite grain in a ferruginous cortex, (f) detail of dissolution features of a chromite, (g)

506 small size chromite grain disseminated in a pisolite, (h) detail of (g).

507

508 Figure 7. Comparison between the total mass transfer of Cr and Pt/Pd variation in the

509 weathering profile.

510 TABLE 1. Physical and chemical characteristics of the parent rock, and the different  
511 layers of the weathering profile ( $\rho_w$  = bulk density;  $\rho_g$  = grain density).  
512  
513 TABLE 2. Results of (a) the mass balance factor (K) and (b) the total mass transfer (m) of  
514 chemical elements calculated from equation (1) and (2), respectively.



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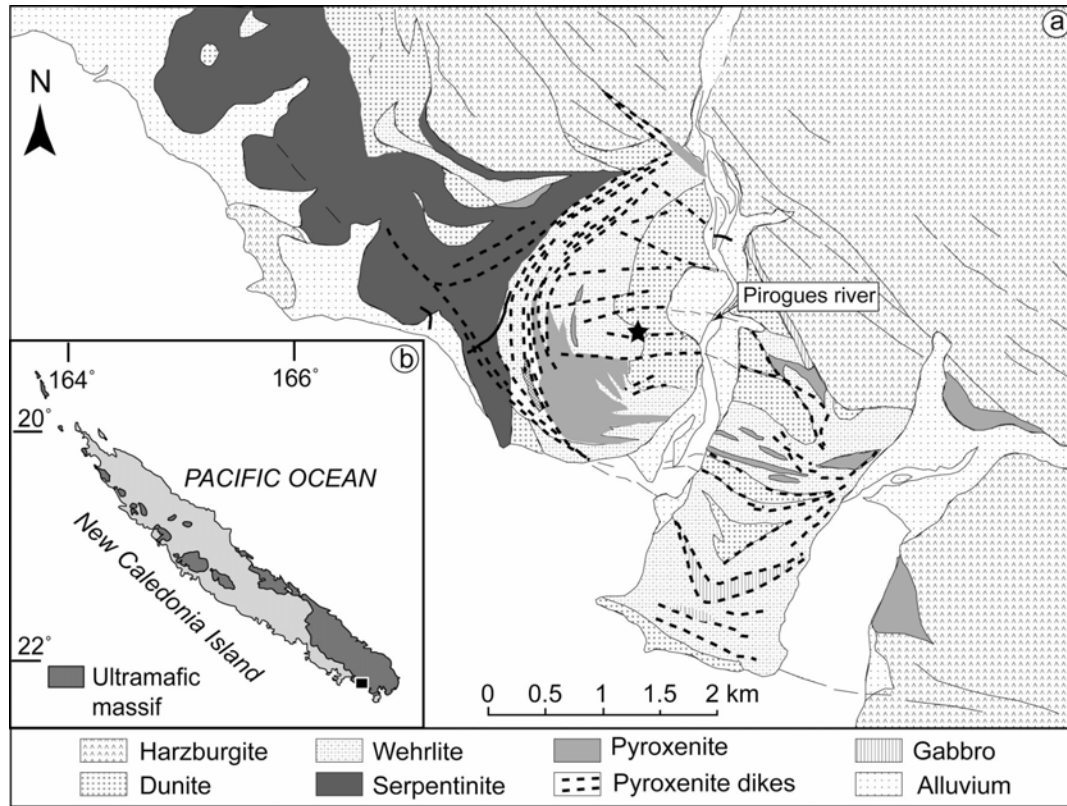


FIG. 1

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*Traore et al., 2007*

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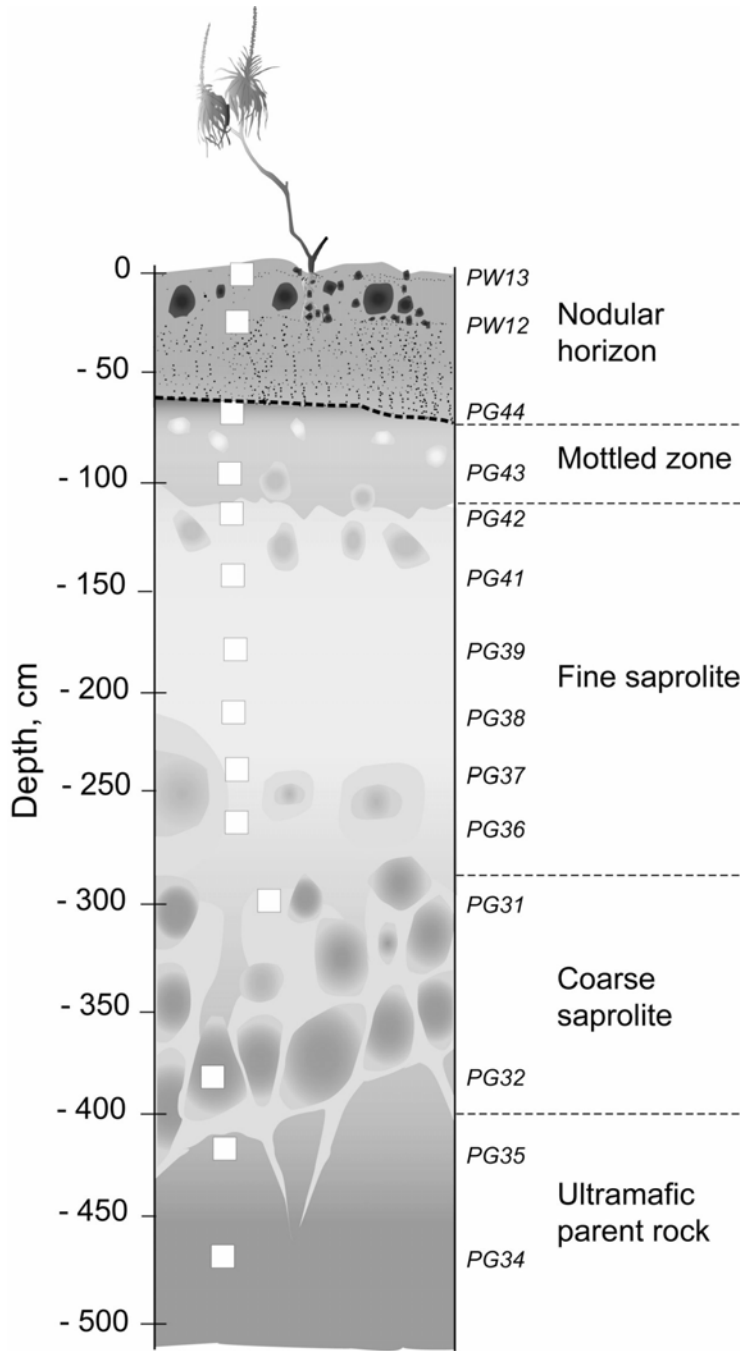


FIG. 2

*Traore et al., 2007*

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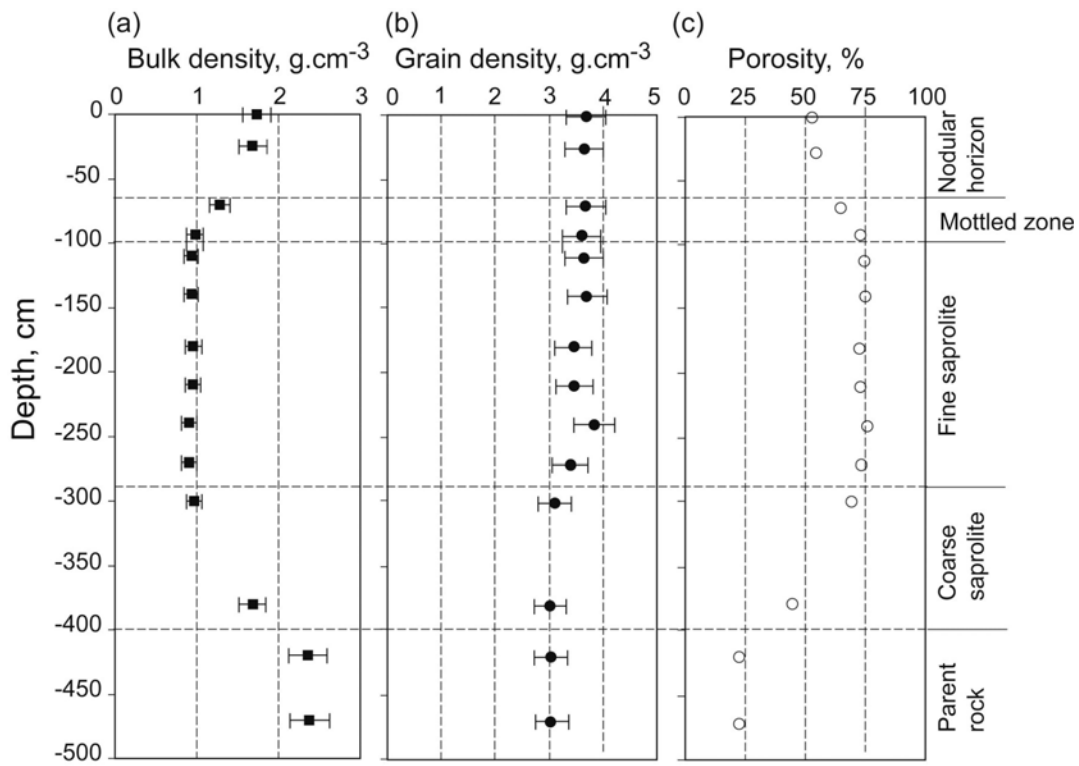


FIG. 3

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Traore et al., 2007

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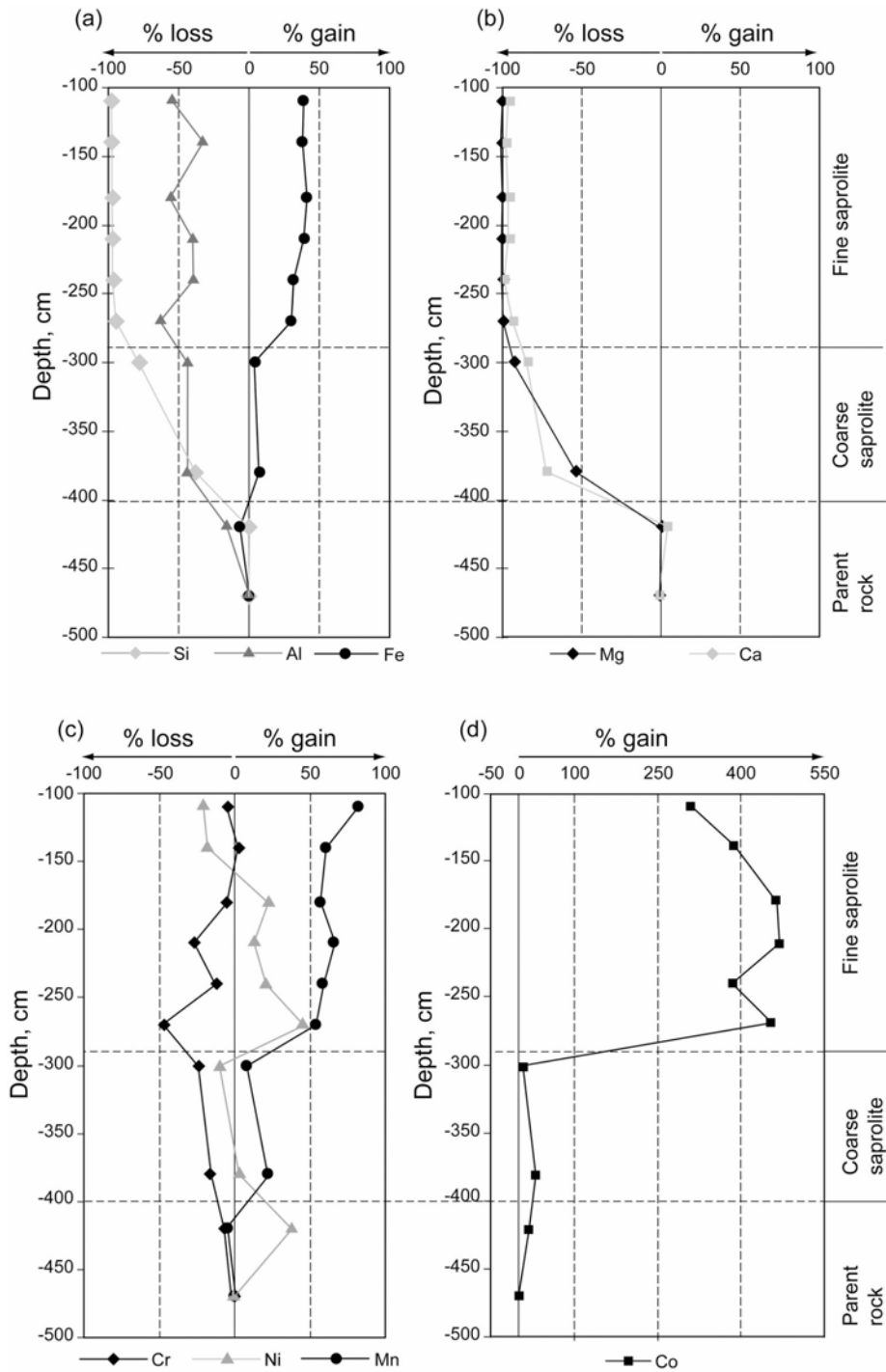


FIG. 4

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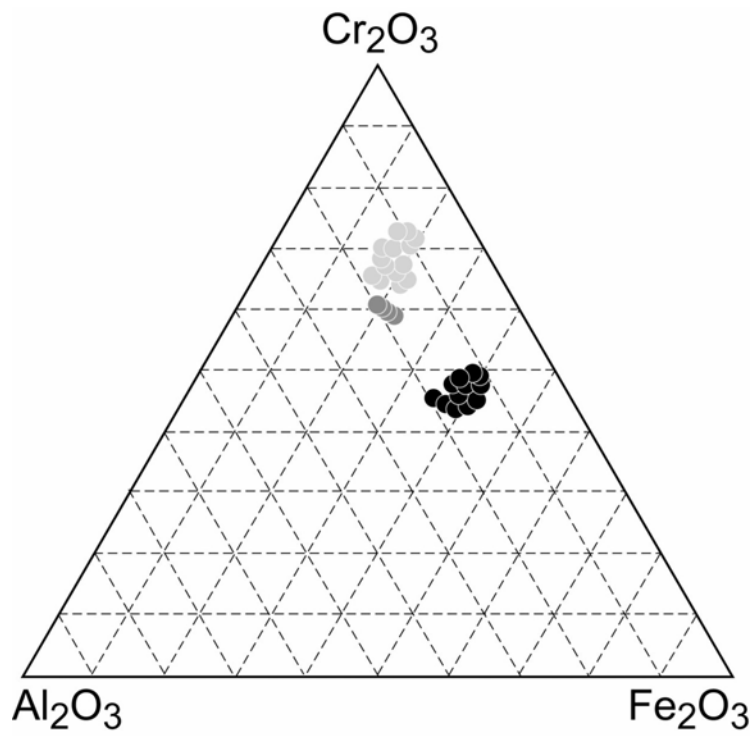


FIG. 5

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*Traore et al., 2007*

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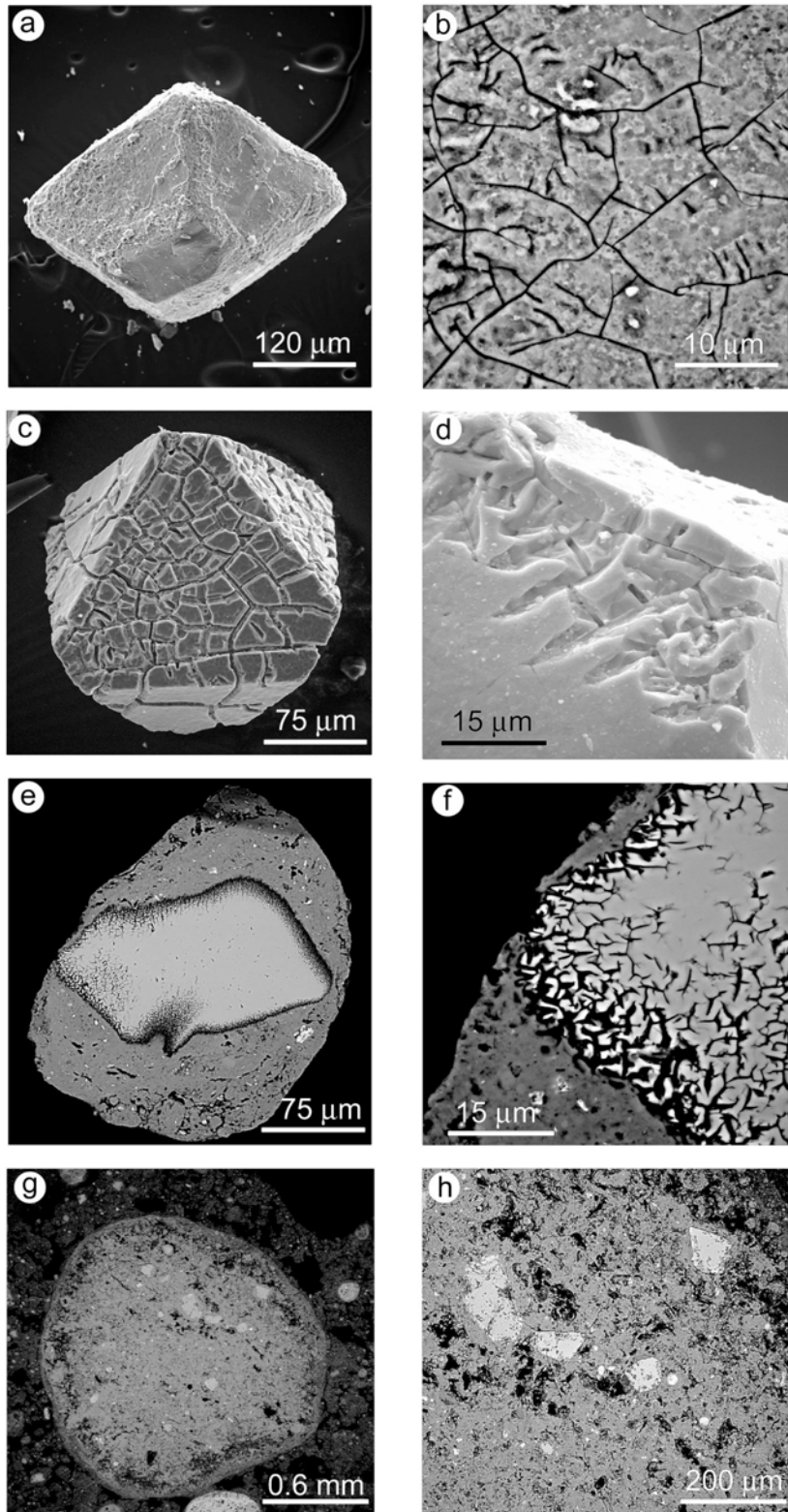


FIG. 6

*Traore et al., 2007*

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*Traore et al., 2007*

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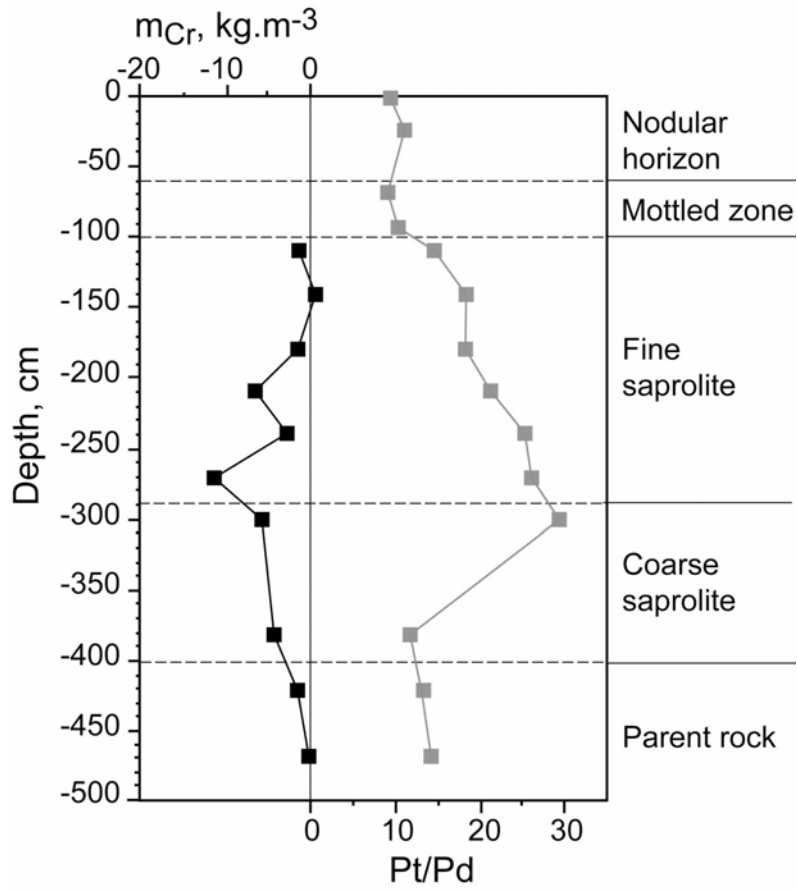


FIG. 7

534

*Traore et al., 2007*

	Uncertainty	Bedrock		Coarse saprolite			Fine saprolite				Mottled zone		Nodular horizon		
Sample n°		PG34	PG35	PG32	PG31	PG36	PG37	PG38	PG39	PG41	PG42	PG43	PG44	PW12	PW13
Depth (cm)		-470	-420	-380	-300	-270	-240	-210	-180	-140	-110	-95	-70	-25	0
$\rho_w$ (g.cm <sup>-3</sup> )	± 0.1	2.38	2.36	1.68	0.97	0.91	0.91	0.95	0.96	0.93	0.93	0.98	1.28	1.69	1.73
$\rho_g$ (g.cm <sup>-3</sup> )	± 0.1	3.06	3.04	3.02	3.11	3.39	3.84	3.47	3.45	3.70	3.65	3.60	3.68	3.65	3.69
Porosity (%)		22.22	22.37	44.37	68.81	73.16	76.30	72.62	72.17	74.86	74.52	72.78	65.22	53.70	53.12
SiO <sub>2</sub> (wt%)	± 0.01	39.48	39.81	34.65	21.27	6.00	4.08	3.32	2.99	2.20	2.07	2.09	1.88	2.10	1.90
Al <sub>2</sub> O <sub>3</sub> (wt%)	± 0.01	0.68	0.58	0.56	0.97	0.67	1.09	1.02	0.75	1.17	0.80	2.43	0.95	4.30	4.20
Fe <sub>2</sub> O <sub>3</sub> (wt%)	± 0.01	19.89	18.86	33.78	56.79	75.11	76.14	77.46	77.33	78.36	78.49	75.82	78.01	76.59	76.59
CaO (wt%)	± 0.01	0.34	0.36	0.14	0.14	0.07	0.02	0.05	0.05	0.03	0.05	0.02	0.03	0.01	0.02
MgO (wt%)	± 0.01	34.36	35.19	22.97	7.17	1.47	1.26	0.67	0.60	0.65	0.49	0.42	0.38	0.27	0.21
Cr <sub>2</sub> O <sub>3</sub> (wt%)	± 0.01	1.54	1.45	1.82	2.88	2.14	3.56	2.84	3.62	4.06	3.76	4.85	4.42	2.05	2.01
LOI (wt%)	± 0.01	3.02	3.91	5.97	8.99	11.41	10.86	11.48	11.66	10.95	11.68	11.84	11.86	12.35	12.45
Total		99.31	100.16	99.89	98.21	96.87	97.01	96.84	97.00	97.42	97.34	97.47	97.53	97.67	97.38
Mn (mg/kg)	± 100	2012	1935	3483	5340	8127	8359	8359	7817	8282	9365	8514	9365	9690	9790
Co (mg/kg)	± 0.5	215	253	399	577	3140	2730	3080	3010	2670	2270	1950	1140	933	901
Ni (mg/kg)	± 5	2910	4040	4230	6430	11100	9190	8250	8820	6140	5960	6760	5530	5598	4802
Pd (µg/kg)	± 1	16	15	17	22	20	17	23	28	25	48	48	25	20	20
Pt (µg/kg)	± 0.5	227	206	204	647	527	440	483	497	442	683	497	241	225	196
Pt/Pd		14.18	13.75	12.00	29.43	26.37	25.90	21.00	17.74	17.68	14.23	10.35	9.68	11.25	9.80

TABLE 1

*Traore et al., 2007*



	Bedrock		Coarse saprolite				Fine saprolite			
Sample	PG34	PG35	PG32	PG31	PG36	PG37	PG38	PG39	PG41	PG42
Depth (cm)	-470	-420	-380	-300	-270	-240	-210	-180	-140	-110
<b>(a)</b>										
K <sub>Si</sub> (%)	0.00	-0.01	-38.05	-78.04	-94.19	-96.05	-96.64	-96.95	-97.82	-97.95
K <sub>Al</sub> (%)	0.00	-15.42	-41.87	-41.86	-62.33	-38.71	-40.13	-55.51	-32.77	-54.03
K <sub>Fe</sub> (%)	0.00	-5.98	7.85	4.69	29.89	31.67	39.84	41.08	38.49	38.72
K <sub>Ca</sub> (%)	0.00	4.99	-70.93	-83.22	-92.13	-97.75	-94.13	-94.07	-96.55	-94.25
K <sub>Mg</sub> (%)	0.00	1.55	-52.81	-91.50	-98.36	-98.60	-99.22	-99.30	-99.26	-99.44
K <sub>Mn</sub> (%)	0.00	-4.65	22.17	8.16	54.41	58.82	65.80	56.69	60.81	81.85
K <sub>Cr</sub> (%)	0.00	-6.64	-16.58	-23.78	-46.87	-11.61	-26.39	-5.18	3.02	-4.59
K <sub>Ni</sub> (%)	0.00	37.66	2.61	-9.94	45.85	20.75	13.16	22.26	-17.55	-19.97
K <sub>Co</sub> (%)	0.00	16.69	31.00	9.38	458.41	385.50	471.82	464.71	385.26	312.57
<b>(b)</b>										
m <sub>Si</sub> (kg.m <sup>-3</sup> )	0.00	-0.05	-166.95	-342.45	-413.31	-421.47	-424.08	-425.40	-429.25	-429.81
m <sub>Al</sub> (kg.m <sup>-3</sup> )	0.00	-1.32	-3.58	-3.58	-5.34	-3.31	-3.44	-4.75	-2.81	-4.63
m <sub>Fe</sub> (kg.m <sup>-3</sup> )	0.00	-21.98	28.87	17.24	109.95	116.50	146.56	151.10	141.58	142.42
m <sub>Ca</sub> (kg.m <sup>-3</sup> )	0.00	0.29	-4.10	-4.81	-5.32	-5.65	-5.44	-5.43	-5.58	-5.45
m <sub>Mg</sub> (kg.m <sup>-3</sup> )	0.00	7.67	-260.42	-451.18	-485.05	-486.20	-489.28	-489.64	-489.47	-490.37
m <sub>Mn</sub> (kg.m <sup>-3</sup> )	0.00	-0.22	1.06	0.39	2.61	2.82	3.15	2.72	2.91	3.92
m <sub>Cr</sub> (kg.m <sup>-3</sup> )	0.00	-1.66	-4.16	-5.96	-11.75	-2.91	-6.62	-1.30	0.76	-1.15
m <sub>Ni</sub> (kg.m <sup>-3</sup> )	0.00	2.61	0.18	-0.69	3.18	1.44	0.91	1.54	-1.22	-1.38
m <sub>Co</sub> (kg.m <sup>-3</sup> )	0.00	0.09	0.16	0.05	2.35	1.97	2.41	2.38	1.97	1.60

TABLE 2

*Traore et al., 2007*