

Technical Report

Laterization Process of Ultramafic Rocks in Siruka, Solomon Islands

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The lateritic weathering crusts exposed in Siruka, Choiseul Islands, Solomon Islands, were developed on the expense of serpentinized peridotite underlain by Choiseul Schists and Voza Lavas with a subhorizontal contact. The lateritic profile consists of four zones: bedrock, weathered zone, decomposed (or saprolitic) zone and limonitic zones upwards. The profiles demonstrate variations in depths and continuity but illustrate mineralogy and geochemical characteristics affinity down profile. They are broadly analogous to saprolite - oxide nickel laterite deposits. Silica and magnesia in the bed rock and the saprolitic zones have been removed and only the residual elements (iron, chromium, aluminium, manganese, cobalt and nickel) remain in the limonitic zone. These elements are relatively concentrated by the removal of the soluble elements. However, nickel becomes unstable and is leached towards the lower part of the profile and concentrated at the saprolitic zone. Nickel is combined with silica and magnesia, as lizardite or mixed gels (garnierite nickel ore) at the weathering front. Significant supergene nickel enrichment occurring in the decomposed zone, indicating that water had percolated downward to a very low water table at depth during the weathering process. Cobalt and manganese are concentrated in the limonitic part of the profiles (~3-6 m depth) of which are poorly protected against erosion and mechanical transportation. The behavior of nickel is contradictory to that of cobalt and manganese and its relative mobility is a little higher than them. It is leached out of the limonitic concretions, where it is first concentrated with Co and Mn, and largely migrates to the bottom part of the profiles. The structure and mineralogy of the weathering profile indicate environmental conditions likely to have been dominated by alternating wet and dry periods.

1. Introduction

Nickel laterites are an important resource of Ni and ferronickel and account for approximately 40% of world annual Ni production¹⁾. Of the 130 million tonnes (Mt) of Ni in land-based resources containing over 1% nickel, approximately 60% is in laterite deposits (USGS Mineral Commodity Summary, 2002). These deposits are produced by the prolonged and deep weathering of Ni silicate-bearing ultramafic rocks, generally in humid tropical to subtropical climates. As a consequence, many recently formed and actively forming deposits are situated in equatorial latitudes, where major-producing countries of Ni laterite ores are located (e.g. New Caledonia, Cuba, Philippines, Indonesia, Colombia, and increasingly Australia). Lateritic deposits usually consist of three layers, namely the limonite, the saprolite and the garnierite layer²⁾. Nickel laterites are generally formed by the weathering of ultramafic rocks, such as peridotite or serpentinite. Studies on nickel deposits coupled with simultaneous chemical analysis have been widely documented³⁻⁵⁾. During weathering, some elements become leached (e.g. Mg, Ca and Si) and others either are secondarily enriched (e.g. Ni, Mn, Co, Zn and Y) or residually concentrated (e.g. Fe, Cr, Al, Ti and Zr) within laterite profiles⁶⁾. As the rocks are weathered, nickel, iron, and sometimes cobalt are taken into solution by descending meteoric water and re-deposited at greater depth, creating a zone of enrichment. Because laterites are formed by surface water percolating downward through ultramafic rock, most laterite deposits are either in the tropic or in subtropical to temperate coastal regions that posses long geologic history of heavy rainfall. Enrichment and distribution of minor and trace elements

in the laterites are often controlled by weathering processes and morphology of the peridotite massifs⁷⁾. The Ni content of ultramafic rocks, although relatively high compared with that of other rocks, rarely exceeds 0.3% by weight on the earth surface⁸⁾. The formation of lateritic deposits is controlled by four major factors: parent-rock characteristics which include chemical and mineralogical compositions; geomorphological conditions (location in the landscape, drainage conditions, and local erosion rate); paleoclimatic history, and the age of lateritic weathering⁹⁾. Laterites above Siruka ultramafic rocks in Choiseul, the Solomon Islands (Fig. 1) consist of in-situ (autochthonous) with possibly semi-autochthonous upper most organic horizons. Petrography, mineralogy and geochemistry of lateritic weathering crusts developed at the expense of Siruka ultramafic rocks is the focus of attention in this paper. The study considers the chemical behavior of several specific elements (e.g. Al, Fe, Ni, Mn, Co, Mg, Cr and Si) and constituent minerals according to their depth in the weathering profile which in return should contributes in understanding lateritization processes in the Solomon Islands. The annual climatic conditions in the Solomon Islands are tropical and Siruka in Choiseul province is characterized by average precipitation of 3200 mm/year. The tropical climate is very aggressive and the peridotites are quickly weathered. The result of these two combined factors is that the Siruka ultramafic rocks tend to behave as soluble rocks. Moreover, these rocks are very easily faulted. The stressed serpentines promotes sliding of blocks against one another, and at every scale of observation the peridotitic bodies show a dense network of joints and minor faults.

Table 1 Geochemical composition variation occur with depth at CD0040 drill hole (*representative profile in Siruka)

CD0040 Major Element anomalies											
Hole No.	From (m)	To (m)	Ni (%)	Co (%)	Mg (%)	Cr (%)	Fe (%)	Mn (%)	Al (%)	Si (%)	Al/Fe
CD0040	0.00	0.50	0.22	0.02	0.25	1.65	36.23	0.06	11.32	0.88	0.31
CD0040	0.50	1.00	0.45	0.04	0.25	2.24	43.27	0.13	8.89	0.44	0.21
CD0040	1.00	1.50	0.36	0.02	0.23	1.82	36.34	0.07	11.20	2.48	0.31
CD0040	1.50	2.00	0.14	0.00	0.19	0.55	23.13	0.03	13.93	10.17	0.60
CD0040	2.00	2.50	0.34	0.01	0.30	1.20	33.64	0.11	8.65	5.22	0.26
CD0040	2.50	3.00	0.84	0.13	0.38	1.82	45.13	1.45	5.90	1.07	0.13
CD0040	3.00	3.50	0.74	0.13	0.39	1.78	46.49	1.14	6.58	0.92	0.14
CD0040	3.50	4.00	0.68	0.11	0.45	2.17	46.54	0.90	7.56	0.89	0.16
CD0040	4.00	4.50	0.88	0.09	0.46	1.91	45.99	0.72	5.95	1.20	0.13
CD0040	4.50	5.00	0.80	0.13	0.52	1.99	44.21	1.14	6.51	1.07	0.15
CD0040	5.00	5.50	0.93	0.15	1.09	2.16	46.02	1.12	5.97	1.98	0.13
CD0040	5.50	6.00	1.05	0.15	0.53	2.08	47.90	1.40	4.55	1.69	0.10
CD0040	6.00	6.50	0.72	0.12	0.62	1.71	40.62	0.94	7.37	3.18	0.18
CD0040	6.50	7.00	0.88	0.10	1.46	1.62	35.48	0.96	7.21	6.23	0.20
CD0040	7.00	7.50	1.31	0.08	2.17	1.88	34.73	0.92	3.25	11.89	0.09
CD0040	7.50	8.00	1.50	0.07	2.27	1.91	32.87	1.01	2.88	12.31	0.09
CD0040	8.00	8.50	2.80	0.05	7.87	1.25	21.32	0.94	1.39	20.09	0.07
CD0040	8.50	9.00	2.44	0.02	15.56	0.53	10.03	0.25	0.64	20.24	0.06
CD0040	9.00	9.50	2.42	0.04	13.12	0.83	14.58	0.50	1.62	19.29	0.11
CD0040	9.50	10.00	2.35	0.04	12.94	0.92	15.44	0.33	1.10	20.09	0.07
CD0040	10.00	10.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CD0040	10.75	11.00	1.98	0.07	6.05	1.38	31.07	0.58	1.70	16.23	0.05
CD0040	11.00	11.50	2.07	0.06	6.52	1.04	28.31	0.49	0.78	18.68	0.03
CD0040	11.50	12.00	1.67	0.04	11.42	0.94	19.06	0.50	1.36	20.99	0.07
CD0040	12.00	12.50	1.39	0.02	16.74	0.45	9.46	0.16	0.45	19.66	0.05
CD0040	12.50	13.00	1.02	0.02	15.83	0.46	8.98	0.19	0.69	19.51	0.08
CD0040	13.00	13.50	0.21	0.01	20.51	0.24	5.41	0.08	0.34	18.85	0.06
CD0040	13.50	14.00	0.26	0.01	20.41	0.23	5.25	0.07	0.30	19.13	0.06
CD0040	14.00	14.50	0.70	0.01	18.42	0.32	6.72	0.09	0.42	19.32	0.06
CD0040	14.50	15.00	0.96	0.03	11.93	0.99	17.53	0.66	0.87	19.06	0.05
CD0040	15.00	15.50	0.43	0.01	18.48	0.35	7.06	0.17	0.39	19.39	0.06
CD0040	15.50	16.00	0.34	0.01	18.95	0.36	7.34	0.16	0.36	19.23	0.05
CD0040	16.00	16.50	0.28	0.01	20.41	0.32	6.54	0.13	0.29	19.28	0.04
CD0040	16.50	17.00	0.22	0.01	21.11	0.23	5.45	0.07	0.23	19.29	0.04
CD0040	17.00	17.50	0.25	0.01	21.39	0.14	4.34	0.04	0.15	20.01	0.03
CD0040	17.50	18.00	0.30	0.01	22.36	0.08	4.30	0.04	0.14	19.34	0.03
CD0040	18.00	18.50	0.24	0.01	22.49	0.21	4.92	0.06	0.20	17.87	0.04
CD0040	18.50	19.00	0.19	0.01	21.69	0.24	5.31	0.08	0.39	16.86	0.07
CD0040	19.00	19.50	0.19	0.01	21.88	0.26	5.39	0.08	0.46	17.43	0.09
CD0040	19.50	19.80	0.19	0.01	22.14	0.26	5.75	0.06	0.41	18.10	0.07

2. Analytical Methods

Sampling of lateritic profiles was carried out on drill cores drilled by Sumitomo Metal Mining Solomon Islands, at the Siruka ultramafic rocks. Bulk chemical analyses of samples were obtained by combined X-ray fluorescence (XRF) and atomic absorption spectroscopy (AAS) techniques. X-ray diffraction (XRD) analyses of clay minerals were done on oriented mounds. Scanning Electron Microscope/Energy Dispersive Using X-Ray (SEM-EDX) was used for quantitative mineralogy.

3. Result

A lateritic Ni ore deposit was discovered in Siruka during mineral exploration and was investigated with the help of numerous drill holes. Detailed analyses give a general idea of the composition and genesis of this deposit. The weathering mantle which covers the Siruka serpentinite massif consists generally of three layers. Above the serpentized harzburgite follows the ore zone, consisting of Ni-rich saprolite, which is of variable thickness. Detail geochemical description of the profile is as tabulated (Table 1) and on the field observation column below.

3.1 Geology

The Solomon Islands form an archipelago situated between longitudes 156° to 170°E, and latitudes 5° to 12°S (Fig. 1). This paper concentrates on the larger

islands which form the characteristic NW-SE-trending double chain of islands comprising Choiseul, the New Georgia Group, Santa Isabel, Guadalcanal, Malaita and Makira (or San Cristobal), but with special emphasis on Choiseul and Santa Isabel. It was conventionally acknowledged that the Solomon block is bounded by two trench systems; the Vitiaz trench to the Northeast and the Britain-San Cristobal trench to the Southwest, later termed as South Solomon Trench System (SSTS)¹⁰. The focused island in this study, Choiseul province, forms part of the Northwest-Southeast trending Solomon arc and illustrate pronounced elongation along the trend (Fig. 1B). Convergent plate margin tectonics has much control over the structural development of the island which subsequently gives rise to two distinct structural units; (i) the Pre-Miocene igneous and metamorphic basement complex and (ii) the Miocene-Holocene volcanic and sedimentary cover. The distribution of rock types in the Choiseul Pre-Miocene basement is as shown on the geological map of SE Choiseul (Fig. 1). The basement includes the Voza Lavas, Choiseul Schists (termed as Siruka Schist in here), Oaka Metamicrogabbro and Siruka Ultramafic rock¹¹. The Voza Lavas are the predominant formation of the Choiseul basement together with the Choiseul Schists. This basement sequence of Choiseul is thought to represent an ophiolite complex with MORB characteristics, developed close to a subduction zone^{11,12}. The Voza Lavas occur as pillowved, massive and brecciated basalts^{11,12} and can be further divided into

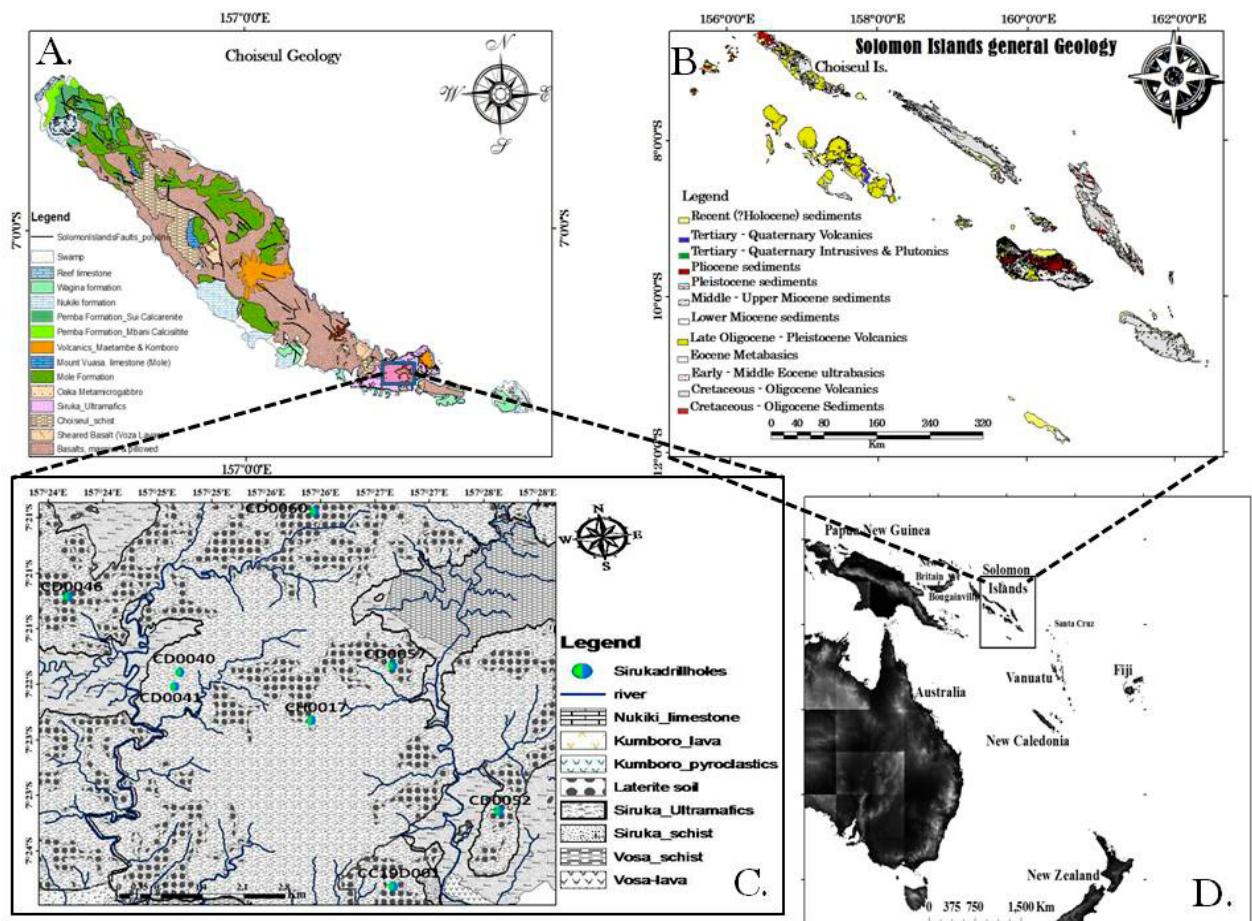


Fig. 1 General Geology of Choiseul (A), Geology of Solomon Islands (B), various drilled locations (C) identifying CD0040 and Solomon Islands in the Pacific region.

Drill Hole No.: CD0040		Elevation: 288m	WGS84 UTM: Easting: 324690 Northing: 9185608
Depth (m)	Laterite profile	Description	Formation
0		> 0.00 – 0.01m Organic soil predominated with roots	
1		> 0.01 – 2.00m Reddish brown heterogeneous clay soil	*Red Limonite Zone (Limonite 1)
2	2.00	> 2.00 – 4.50m Yellowish brown layer, increasingly heterogeneous with increasing depth, silty sized laterite soil	
3	4.50	> 4.50 – 5.00m Brown silty soil	*Limonite 2
4	5.00		
5	5.00	> 5.00 – 8.00m Yellowish - Brown heterogeneous silty Laterite soil layer with observable soil (yellow/brown/dark) bandings	
6	7.00		*Limonite 3
7	7.00	> 8.00 – 9.50m Yellowish brown partially homogeneous laterite soil	
8	8.00	> 9.50 – 10.40m Yellowish brown heterogeneous soil with intense garnierite stains	*Decomposed Serpentine
9	9.50	> 10.40 – 11.20m Fragmented harzburgite plus short columnar shaped cores	
10	10.40	> 11.20 – 12.25m Intensive decomposed serpentine	
11	12.25	> 12.25 – 14.00m Strongly weathered harzburgite with intense columnar shaped core	
12	14.00	> 14.00 – 16.00m Moderately weathered transitional layer with cross cut veining and garnierite filled voids	*Weathered base rock
13	14.50		
14	14.50		
15	16.00		
16	16.00		
17	x x		
18	x x x		
19	x x x	> 16.00 – 19.50m Fresh serpentine basement with apparent parent rock (harzburgite) characteristics	*Base rock
20	19.50		

Fig. 2 Schematic section through the lateritic profiles in Siruka, Choiseul Province, in the Solomon Islands.

two groups; (i) unmetamorphosed and low grade rocks and (ii) more highly metamorphosed varieties such as amphibolite facies. The Choiseul Schists are considered to be dynamothermally altered Voza Lavas, and are distinct from Voza Lavas by their possession of tectonic fabrics within their textures.

Ridgway and Coulson (1987)¹¹ suggested that the Siruka Schists were formed by deformation and metamorphism of parts of the original Voza Lava sequence. No radiometric age has yet available for the Choiseul basement sequence but stratigraphic and structural evidence suggest a probable Cretaceous age^{10,11}. The Siruka Ultramafic rocks are predominantly harzburgites and dunite though patches of lherzolites were also reported present and have undergone varying degree of serpentinization. The Siruka Ultramafic rocks form a large sheet lying on Choiseul Schists and Voza Lavas with a general subhorizontal contact^{13,14}, hence, are perhaps emplaced as coherent thrust sheet on a subhorizontal plane in Late Miocene to Pleistocene¹⁴. Field observation showed that the mentioned relationships have been modified by post-emplacement faulting and high angle fault contacts are common. Estimates of the thickness of the emplaced sheet based on valley bottom to hill crest measurement; show an increasing thickness towards the south¹¹.

A maximum of 560m of the emplaced was reported present on the south, thinning to 300m on the northwest¹¹. The sedimentary and volcanic cover ranges in age from Miocene to Recent and are arranged in order of decreasing age¹¹ which includes Mole Formation - Kumboro and Maetambe Volcanics (Early – Middle Miocene); Vaghena Formation (Early Pliocene); Pemba Formation (Early to Late Pliocene); Nukiki Limestone Formation - backreef and lagoonal deposits (Pliocene); Holocene deposits including alluvium, mangrove and freshwater swamp; backreef and lagoonal facies sediments and coralline reef limestones (Holocene). Petterson et al. (1997)¹⁵ suggested that stage 1 arc development is represented by crystal and lithic-rich turbidites from the Mole Formation whereas the Kumboro and Maetambe Volcanics constitute the stage 2 arc sequence of the Solomon Islands tectonism.

3.2 Field observation and mineralogy

Lateritic profiles in Siruka show large variations in thickness and continuity of individual layers. Differences are also observed in the mineralogy and chemistry of the zones over short distances. Intense post-erosion processes are unlikely after laterization in Siruka, though possibilities of erosion cannot be absolutely ruled off considering the incline geomorphology of the study area. Due to lack of intense erosion, observation of well developed ferruginous zones, referred to us limonite 1, limonite 2 and limonite 3 hereafter is enabled. Though slightly varied (in depths, and serpentinization level) most other drilled hole cores considered were analogous to CD0040, hence the usage of CD0040 as the representative drilled hole for discussion and been characterized as; (a) Bedrock (protolith), (b) Weathering

zone, (c) Decomposed zone (Saprolite) and (d) Limonitic zone. The bedrock is mostly serpentinized harzburgite which grades into the weathered and decomposed zone. Consistent to descriptions suggested by previous authors where the protolith is the original ultramafic rock, most commonly harzburgite, other types of peridotite or dunite³. The bedrock comprised predominantly of olivine, pyroxene, serpentine (Fig. 3) and grades into weathered irregular boundary on the weathered zone. Weathered serpentinite clasts are apparent and are interpreted as relicts. Hard and relatively substantial fragmented rock boulders were observed at the lower saprolite zone which gradually grades upward into soft and argillized matrixated saprolite. The weathering zone is occasionally transected by loosely printed stockwork talc, garnierite and carbonate veins.

The fragmented boulders in the weathering zone still retain the mineral textures of the original rock however with slight variable appearances. Locally, within the saprolite, areas of intense secondary veining and boxworks are commonly observed. These can naturally go after relic structures, fractures, and grain boundaries and can contain neo-formed quartz and Ni-rich minerals such as the distinguishing green mineral garnierite¹. The saprolite zone is generally yellowish brown with numerous rock fragments. Filling of voids and cracks by garnierite is commonly observed in the saprolitic zone yielding higher nickel concentration (~avg. 1.5 g/t) at ~7-14 m depth. The transition to the limonitic zone is marked by gradual disappearance of yellowish dark-green serpentine into smectite unit at ~8 m depth. The limonitic zone is categorized into brown homogeneous argillic soil (L3), banded yellowish orange argillic (L2) to goethite and hematite enriched brown homogeneous silty soil (L1) with random occurrences of darkish manganese oxide blebs within the oxide matrix and finally, the surface organic zone which randomly host visible iron crusts. Locally the limonitic zone extends downward to the decomposed serpentinite. The primary mineralogy and texture of the host rock is totally destroyed in this encrusted zone. The limonitic zone is soft and friable consisting of goethite, gibbsite, minor hematite, traces of magnetite-maghemic and kaolinite. At 5 m depths, relicts of serpentine and talc were detected by XRD which are still part of the friable layer. The contact between the limonitic zones with the decomposed zone is intertonguing and not as clearly demarcated as in Fig. 2. The modal proportion of goethite and hematite increases toward the surface with ambiguous transition between the two along the profile, meaning they both occur coherently with each other on the schematic profile. Geochemical analysis of the various drilled holes analyzed to understand the chemical behavior of certain elements on the profiles during laterization process at Siruka show geochemical affinities to that of CD0040. Analogous to other nickel enriched profiles studied in this local; Fe, Cr and Al show enriching behavior with increasing weathering intensity. Contrary, Si and Mg got depleted as weathering increases. Ni, Co and Mn seem to positively correlate with each other at depth but varied on the upper portion of the profiles.

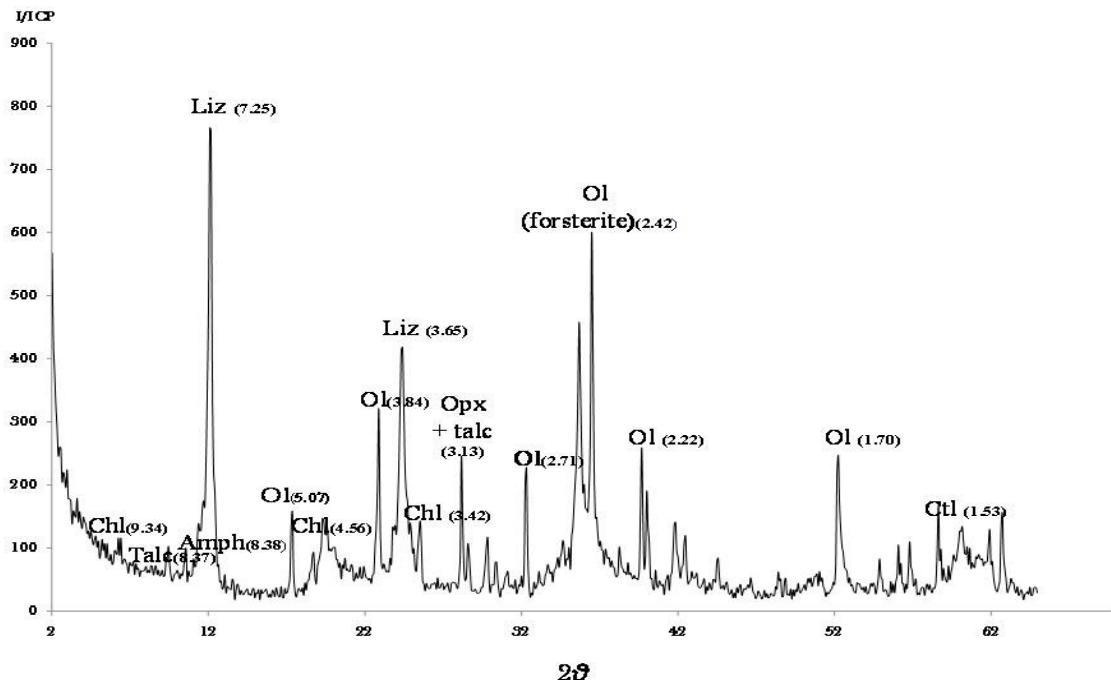


Fig. 3 XRD patterns of serpentized peridotite (specifically CD0040 protolith unit) from Siruka. The spectrum was obtained using an X-ray diffractometer ‘Rigaku’ at room temperature, using a rotating ‘Cu K α ’ target with a voltage of 40 kV and a current of 20 mA. The scan range (2θ) was 2–65° with a step size of 0.02°. Olivine = Ol, Chlorite = Chl; Amphibole = Amph, Chrysotile = Ctl, Lizardite = Liz, Orthopyroxene = Opx, Clinopyroxene = Cpx and talc.

4. Discussion

Chemical analyses were performed on the samples taken for each half a meter thickness from seven drill holes at Siruka for this study. Distribution model of elements on the diagnosed weathering profiles are identical to patterns of nickel laterites elsewhere in the world (e.g. New Caledonia and Cuba)¹¹. The mineralogical and geochemical process which affected the ultramafic bedrock and gave rise to the weathering crust in Siruka is distinguished as follows. The incipient stage encompasses; Amphibolitization, serpentization, chloritization, introduction of talc and carbonate during dissolution of bedrock. The Mg replacement process could be attributed to an ionic exchange reaction such as: Mg-serpentine + Ni²⁺ = Ni-rich serpentine + Mg²⁺. Complete destruction of primary silicates took place and higher in the profiles, collapse and loss of primary fabric is apparent. Coherently, leaching process of Mg is attributed to the formation of nontronite depicted by XRD on the profiles. The incipient dissolution process explains the apparent depletion of Mg and Si in the upper portion of the profiles illustrated in Fig. 4. We further suggest that reactions involving substitution of Mg with Ni in Siruka may have occurred as a result of Ni bearing solutions from more alkaline zone (e.g. limonitic zone) moving to more basic environment (e.g. saprolitic zone, Fig. 2). The suggestion brewed following previous work on mineralogy and geochemistry of iron-rich laterites, where it has been articulated that reactions involving

substitution of Ni with Mg require a course where by Ni bearing solutions do move from a low pH to a high pH environment¹⁶. Following the dissolution process is limonitization or laterization where crystallization of Fe oxyhydroxides (goethite in particular) dominates the upper saprolite and the overlying limonite horizon of the Siruka profiles. This oxide rich portion of the profile is referred to informally as limonite and the volume of the upper collapsed portion may become as little as ~15% of the original rock⁴. XRF results (Table 1) from the Siruka profiles illustrate Mn oxides to be concentrated at the interface between the organic zone and the saprolite. High EH condition may prevail at such boundary mentioned above, where the Mn oxides can coprecipitate with Ni, Co and other elements¹⁷. This could explain the coexisting may prevail at such boundary and the Mn oxides coprecipitate with Ni, Co and other elements¹⁷. This could explain the coexisting relations between Mn and Co on the profiles. According to Llorca (1993)¹⁸ manganese do leached from concretions of olivine, pyroxene coupled with their metamorphic products’ concretions and precipitates as Mn oxides however, was limited to certain horizons or depths. Elevated concentration of Mn oxides in Siruka was proposed to have precipitated and form significant Mn-Co-Ni enrichment, coherent to those in Ora Banda-Siberia area of Western Australia¹⁹ and equivalently alluded to by Kuck (1992)⁸ in New Caledonia. Considering the significant correlation between MnO and CoO, as suggested by previous workers²⁰, Mn oxyhydroxides would be the

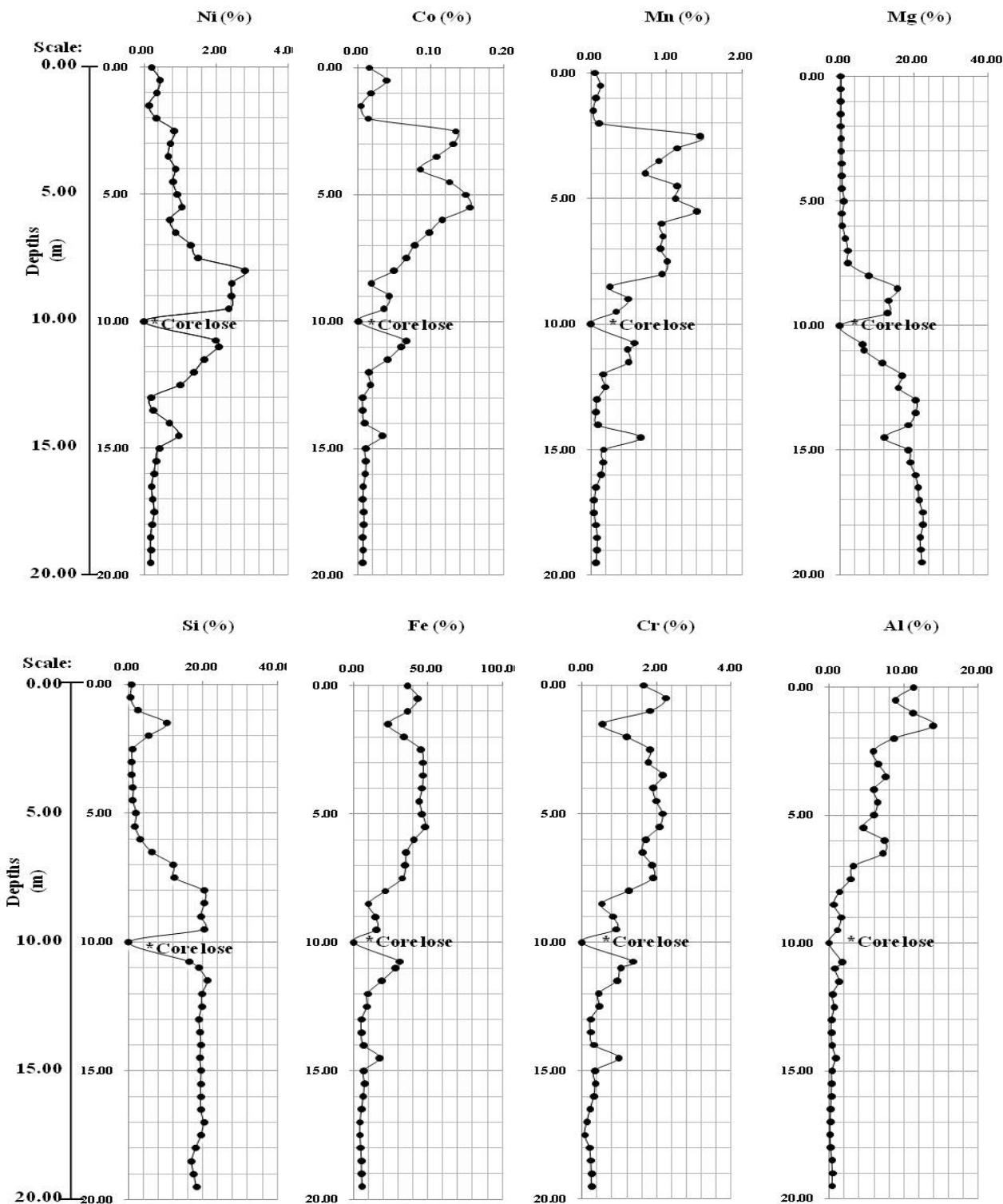


Fig. 4 Vertical distribution of elements major elements in CD0040 drill core obtained from XRF. Concentrations are in wt %. AAS results are not included in the figure though the experiment was carried out to evaluate major elements.

main carriers of cobalt and in some cases nickel. In silicate laterites in New Caledonia²¹⁾ and even in clayey laterites in Western Australia²²⁾, cobalt mineralization is principally associated with Mn-oxyhydroxides (asbolane-lithophorite group). Based on these known deposit characteristics, Mn enrichment in Siruka is

attributed to occurrence of asbolane group manganese on the limonite zone shown by XRD. Contrary, previous authors also suggest that nickel is present in an adsorbed or lattice bound state substituting Fe in less crystalline goethite²³⁾. Nonetheless, following previous intensive Mn oxides deliberations²⁰⁾ we suggest that nickel, cobalt,

and manganese at Siruka may have been precipitated together as oxidized concretions during laterization stages. Subsequent to the co-precipitation event Ni then leached out of the limonitic concretions, where it was first concentrated with Co and Mn during the laterization and weathering earlier stages, and chiefly migrates to the saprolitic portion of the profiles at a later weathering stage. The concept is analogous to the previous concepts where Ni has been leached from the limonite Fe oxyhydroxide phases and moves down the profile before redepositing either as hydrous silicate minerals or substituting for Mg in altered serpentine⁵⁾. Major nickel enrichments in the saprolitic zone (average 1.33 g/t) occurred on fractures and voids commonly observed on the weathered and saprolitic columns (Fig. 2). The association of cobalt in Siruka is such that it occurs with manganese mineral phases particularly on the upper part of the profiles, where liberated elements (e.g. nickel, silicon and magnesium) got depleted. Discrete concentration of cobalt is apparent on the profiles. According to Youngue-Fouateu et al., (2006)²⁴⁾, cobalt can significantly become enriched within the less crystalline manganese mineral hosts higher up in the profiles where remobilization and re-precipitations have led to the development of enriched zones and nodules associated with well-crystalline Mn mineral of the asbolane-lithiophorite group are observed. The asbolane of course was detected on XRD peak plots ($d=4.75\text{\AA}$) in the upper portion of the profile at Siruka, specifically on horizons where random dark manganese nodules are common. Though not substantiated with raw data on this paper, SEM-EDX analysis confirmed that nickel is associated with silica and magnesia, as lizardite and mixed gels (garnierite nickel ore) at the weathering front along fractures and joints. Depletion of magnesium in the representative profile (Drill Hole CD0040) (Fig. 4) reflects the leaching process during lateritization and subsequent exclusion of other elements by draining waters, which resulted in large concentrations of Fe, Al and Cr in the upper portion of the laterite profile relative to the bedrock. This explains the magnesium depletion evident bottom to top of the profiles with lowest values in the limonitic zone (Fig. 2). Due to depletion of alkaline metals and silica, the weathering-resistant chromium becomes residually enriched in the mid-limonitic zone (Fig. 2). Gibbsite and manganese oxyhydroxide mineral enrichment in the limonitic layer is attributed to repeat remobilizations of the residual material in which besides goethite, magnetite-maghemite is well represented, this magnetite more or less weathered to maghemite, explain the high chromium content observed in the residue²⁴⁾. Aluminium is residually enriched in the granular limonitic zone as demonstrated in Fig. 4. This explains the presence of gibbsite in the limonitic zone. Parallel resemblance of Al_2O_3 and Fe_2O_3 , as apparently denoted in extracted XRF results possibly attributes to the relative association and the occurrence of goethite, hematite and gibbsite in the upper portion of the profile. Extensive XRD analysis on the granular limonitic portion of the lateritic profile confirmed that goethite, hematite and kaolinite are the dominant minerals while gibbsite, asbolane and smectite (nontronite) are sparsely distributed. On the other hand,

our data (Table 1), illustrate Al/Fe ratio increase from wet to dry areas in the profile, i.e. from the bottom to the top (limonite zone) of profiles, signifying significant underground water involvement during the laterization process. The maximum substitution ratio is attributed to very close association between goethite and gibbsite.

5. Conclusion

The lateritic weathering crusts which developed at the expense of ultramafic rocks exposed at Siruka, the southeastern part of Choiseul are broadly similar to saprolite nickel laterite deposit around the world (e.g. New Caledonia and Cuba¹⁾). The mineralogical and geochemical processes which affected the ultramafic bedrock and gave rise to the weathering crust in Siruka are classified into two stages: Dissolution of bed rock, where nickeliferous serpentine, tremolite, chlorite and talc and carbonate were inferred to form by dissolution of bedrock. During the dissolution process, magnesium and silicon were discharged in solution and Mg was later replaced with Fe and Ni within the rock forming minerals. According to Kelepertsis (2002)¹⁶⁾, reactions involving substitution of Ni for Mg require a course where by Ni bearing solutions migrates from a low pH to a high pH environment. The Ni enrichment in Siruka is inferred to have attributed to percolation of surface solutions and could be the result of an ionic exchange reaction such as: $\text{Mg-serpentine} + \text{Ni}^{2+} = \text{Ni-rich serpentine} + \text{Mg}^{2+}$. Significant supergene nickel enrichments on the saprolite zone indicate water movement through those zones downward to a very low water table. Nickel was removed by percolating waters and reprecipitated in the saprolite zones. With pronounced weathering, all relicts of bedrock and saprolite were obliterated and the limonite zone was formed. Following the dissolution process is limonitization or lateritization where crystallization of Fe oxides (goethite in particular) dominates the upper saprolite and the overlying limonite horizon of the Siruka profiles. In the upper part of the profile, above the water table, smectite was broken down as been indicated by related loose of silica in solution. Leaching of Mg favored formation of nontronite as depicted by XRD analysis. In the present study nickel is a marker in the various horizons and appears in various mineral associations; generally with iron oxides (mainly as goethite but also with magnetite-maghemite relicts) defining the limonitic zone, unclear association with smectite (nontronite) and with serpentine in the saprolitic horizons. It appeared that with respect to nickel content, silicate horizons are richer than oxidized ones as illustrated in Fig. 3, consistent with²⁵⁾. Nickel enrichment decreases upward the weathering profile as it is removed during the recrystallization of goethite and the leaching of manganese oxide phases⁴⁾. Crystallization of iron oxide in the form of goethite has a low capacity for nickel fixation²⁴⁾ which explains the depleting behavior of nickel in the limonitic horizon at Siruka. Following the earlier deliberations it's apparently evident that Ni has been substituting Mg in altered serpentine during the earlier phases of the weathering, leached from the limonite Fe

oxyhydroxide phases, moves down the profile under the influence of gravitated percolating water before redepositing in the saprolite zone, hosted by hydrous silicates, at the later intensive weathering stages.

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