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Article

Ni-Co Bearing Laterites from Halmahera Island (Indonesia) †

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† In memory of Gustaw Konopka who died in 2020 at the age of 34 in the full creative force.

Abstract: Eastern Indonesia, including the island of Halmahera, is a region with a high mineral potential, particularly Ni-Co, Au-Cu, and Ag ores, which are a globally important and critical source of raw materials (CRMs). The research was conducted within the framework of scientific cooperation between the Faculty of Geology, University of Warsaw (Poland), and PT Halmahera Resources Percasa Ltd. (Jakarta, Indonesia) Between the years of 2009 and 2011, 42 boreholes were drilled using an impact system (up to 15 m below surface) and 3 test pits (up to 8 m below surface). The presence of a laterite deposit containing Ni-Co mineralization was identified on the license area. The resources estimated in accordance with JORC Code, with a cut-off grade Ni $\geq$ 0.5%, equaling 185,510 t Ni and 17,747 t Co, with the stock of raw material amounting to 14.8 million t and with an average content of 1.00% Ni and 0.13% Co. The ore in the deposit has mixed character. To date, studies have shown the dominance of oxide ore, but saprolite composed of magnesium silicates was also identified in significant amount. The Ni mineralization in oxide ore (limonite) is bound to goethite and manganese minerals, while in the case of silicate (saprolite) ore, it occurs locally in the form of veins as well as zonally in the weathered serpentinites. Cobalt mineralization is almost entirely related to the Mn minerals that occur in the lower oxide zone. It has been found that both serpentinites and harzburgites (and possibly locally lherzolite) are the parent rocks for laterite deposit.

Keywords: Halmahera Island; Co-Ni bearing laterites; saprolite; resources; JORC Code

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1. Introduction

The global increase in world demand for metals in the short term (to 2030) must be covered by the development of new mining projects. Of particular importance for new energy transition are nickel (Ni) and cobalt (Co), which are used in the production of steel alloys and rechargeable battery technologies, e.g., lithium ion (NMC)—($LiNiMnCoO_2$); lithium ion (NCA)—($LiNiCoAlO_2$). The global demand for nickel is forecast to achieve around 4200 kt by 2030 and for cobalt around 340 kt [1]. The COVID-19 pandemic and the conflict in Eastern Europe (Russia–Ukraine) contributed to the breaking of raw material supply chains and price speculation on financial markets (on the London Metal Exchange the price of nickel passed $100,000 a tonne—14 March 2022). Increased costs of mining, processing, and smelting of sulphide deposits and the embargo on Russian raw materials will further affect the development of new mining projects.

Laterite deposits are a major source of Ni (±Co) and a potential source of Sc, rare earth elements (REE) and platinum group elements (PGEs) [2–4]. The origin of the deposits is related to intensive processes of chemical and mechanical weathering of ultramafic rocks exposed to the surface, under specific climatic and topographic conditions [5–7].

Current identified land-based nickel resources are estimated to be at least 300 million tonnes [8], of which about 60% in laterites (The Caribbean region, Indonesia, Philippines, and other areas) and 40% in sulphide deposits (Russia—Norilsk; Canada—Sudbury; and

South Africa—Bushveld). In the case of Co, the world land-based resources are about 25 million tonnes [8] and occur mainly in sediment-hosted stratiform copper deposits in Congo and Ni-bearing laterite deposits.

The largest resources in laterite deposits have been found in New Caledonia (23%; 37.0 × 10^6 t), Philippines (17%; 27.4 × 10^6 t), and Indonesia (16%; 25.8 × 10^6 t) [9,10]. In 2020, Ni production from laterites deposits achieved 69% [9]. Indonesia is one of the world's major suppliers of nickel from laterite deposits, and most of the resources are located in the Molucca and Sulawesi regions. Despite numerous discoveries of laterite deposits in Indonesia, few investigations have been made into the geochemical characteristics of these deposits [11–14]. New research of Indonesian laterites has focused on the remobilization/recrystallization and enrichment of critical raw materials (i.e., Co, REE, Pt, and Pd) in the laterite profile based on mass-balance [15]. Understanding the geochemical processes leading to metal enrichment in different zones of the profile may contribute to more effective exploration of deposit and subsequent metallurgical processes.

The Northern Moluccas, including Halmahera, is the least geologically studied part of Indonesia. So far, exploration has been conducted here for lateritic nickel deposits, epithermal vein gold deposits, and porphyry copper-gold deposits. Only exploration of the first two types of deposits has been successful. Recognition of lateritic Ni and Co deposits was initiated in 1969 by the Japanese INDECO consortium in the Halmahera–Waigeo ophiolite terrane area. Geological works have discovered the Gebe deposit, estimated at 20 Mt of silicate ore and containing an average of 2.61 wt% Ni and 66 Mt of oxide ore averaging 1.25 wt% Ni. A laterite deposit was also found on Obi Island, estimated at 88 Mt with an average content of 1.20 wt% Ni. The Gebe Island deposit was later developed by Indonesian state-owned company PT Antam. PT Anam has also been exploring the Tanjung Buli deposit located in East Halmahera since 1981 [16]. Resources at the Gee silicate ore deposit are estimated at 31.4 Mt with an average content of 2.4 wt% Ni, and at the Tanjung Buli deposit at 25 Mt with an average content of 2.4 wt% Ni. Resources have also been documented at the Sangaji deposit of 33 Mt at an average of 1.40 wt% Ni and 0.19 wt% Co [17]. However, the largest known nickel-bearing laterite deposit is located in the central part of Halmahera. In this area, a project of the Weda Bay Nickel Project is being implemented covering about 55,000 ha, owned by the company Eramet and Mitsubishi Corporation and PT Antam with estimated at 139 Mt resources with an average content of 1.59 wt% Ni. It was discovered in 1995 and the first boreholes in the deposit were drilled by Strand Minerals Pte. Ltd. in 1996 [18]. The exploration history of Ni deposits on Halmahera to date is very promising and it is highly probable that, in the interior of the island in areas of favorable morphology, lateritic caps have formed on ultramafic rocks that may be economically viable to exploit [19].

In this study, the Ni-rich laterite deposits in Halmahera, Indonesia were investigated to: (1) determine the mineral and chemical composition of the ore horizons, (2) mineral resource estimate, and (3) distribution and characteristic of critical raw materials (CRMs). Identification of mineral ore, quality, and resources will enable forecasting of mining and processing efficiency.

2. Geology Settings

The island of Halmahera is located in the center of geotectonically active zone at the junction of three lithospheric plates: the Indo-Australian, the Pacific (and related smaller plates, especially the Philippines plate), and the Eurasian plate [20]. Geologically (Figure 1), the island is divided into an eastern part composed of a dismembered ophiolitic complex with Mesozoic–Paleogene sedimentary and volcanic rocks, and a western part with volcanic rocks associated with the Cenozoic island arc [20]. Ophiolite represents a fragment of the lithosphere formed in the Supra-Subduction Zone at the front of the island arc [21]. Ophiolite contains all rock sequences typical of an ophiolite complex, with the exception of sheeted dikes. The Sm-Nd and K-Ar dating of ophiolite sequence rocks indicate their formation in the Early or Middle Jurassic [22]. The rocks of the mantle sequence are represented by lerzholites and harzburgites, strongly depleted by melting processes of the MORB-type basalts. Mafic series consist of dunites, olivine clinopyroxenites, wehrlites, olivine gabronorites and troctolite. Disconformably overlying the rocks of the Halmahera ophiolite are sedimentary and volcanic rocks of Late Cretaceous to Eocene age [23]. Their genesis is related to volcanism and sedimentary processes on the island arc. As a result of the progressive geotectonic transformation of the region in the middle and late Eocene, the Halmahera area was uplifted, with the exposure ophiolite complex. The weathering processes of ophiolite sequence in the Cenozoic led to the formation of a thick (about 10 m) Weda Bay laterite profile. Laterite is similar to other laterites in Indonesia formed under tropical conditions [12,24].

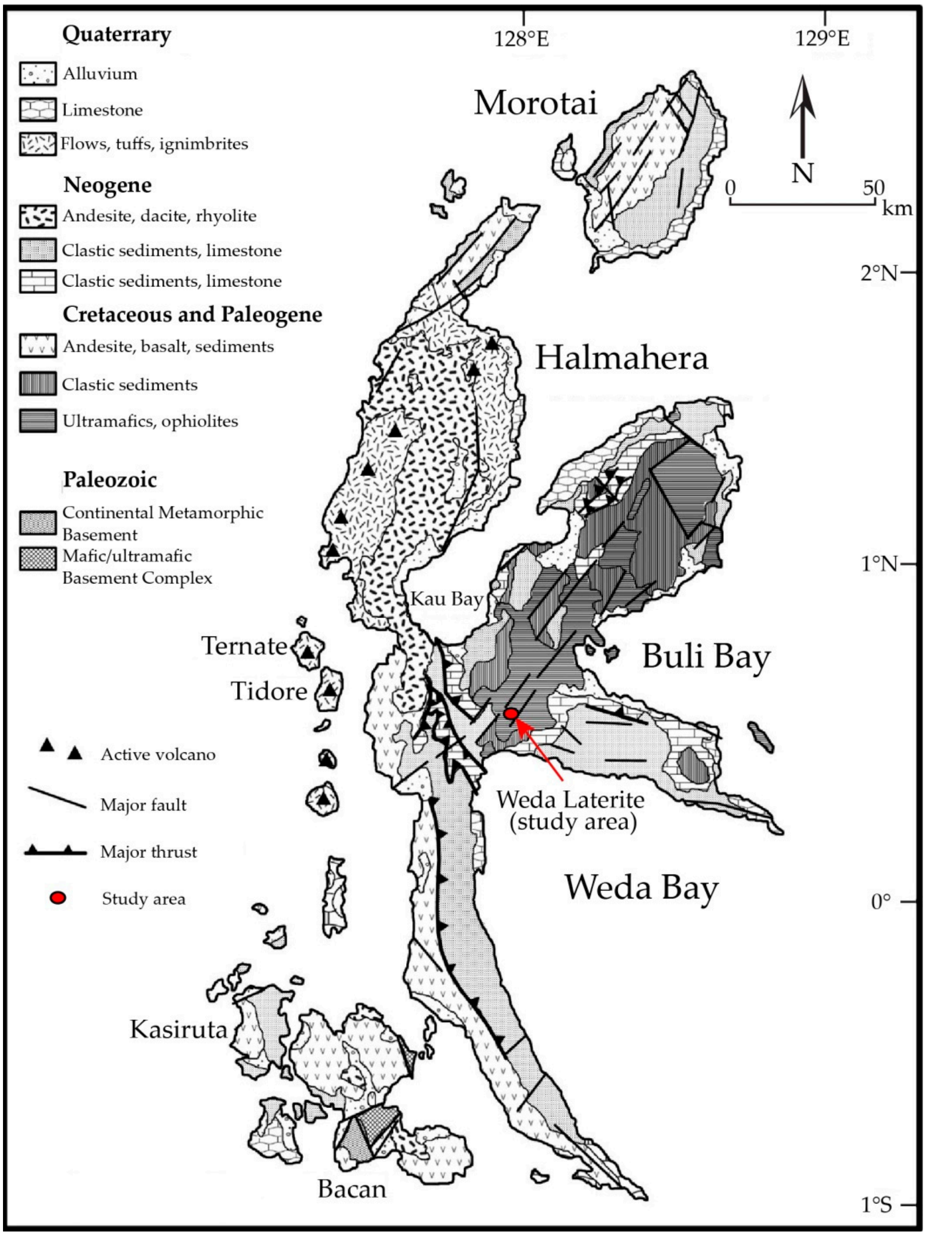

Figure 1. Geological map of Halmahera with the location of the Weda Laterite based on [21].

3. Materials and Methods

3.1. Materials

3.1.1. Study Area

PT. Halmahera Resources Perkasa Ltd. (HRP) has been granted an exploration license in the area (1330 ha) closely adjacent to the lateritic Ni and Co deposit at Halmahera discovered in 1995 [21].

The license area covers ultramafic rocks that form the lowest part of ophiolitic sequence [19]. Preliminary characterization of bedrock samples indicates harzburgite or lherzolite bedrock lithology with olivine concentration over 45%. A high amount of olivine in rocks is crucial to the development of high-grade nickel laterites.

3.1.2. Sampling

Rock samples were collected from the KP (Mining Rights) and IUP (Mining Business Licence) exploration license (Figure 2). Several sampling points are also located in adjacent areas within extensions of continuity of geologic and morphologic structures.

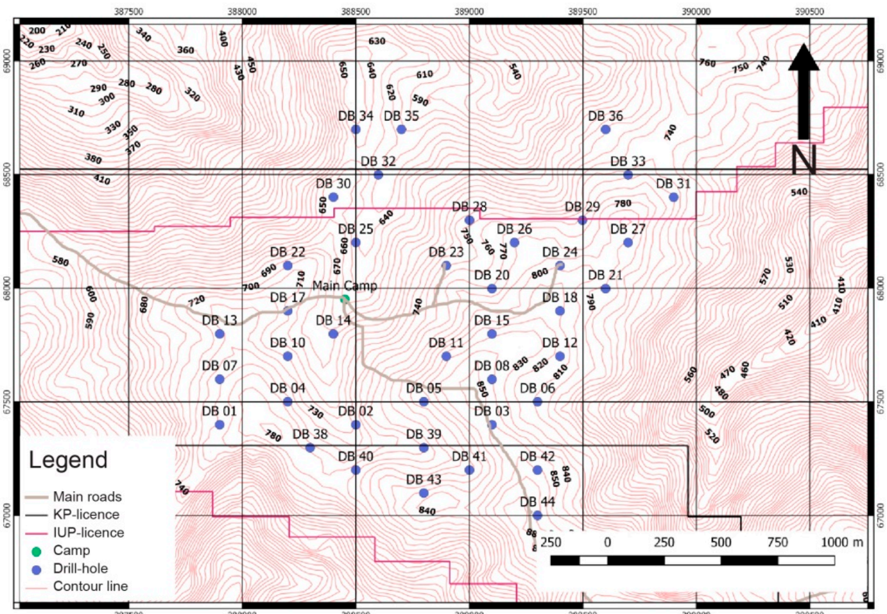

Figure 2. Location of boreholes in the study area of Block B, contours are from processed SRTM data with 30 m resolution obtained from USGS. WGS 84 UTM 52N coordinate system. Scale 1:25 000.

Samples were collected in 2009–2011 in cooperation with Indonesian company HRP as part of a research project with the University of Warsaw. Within the study area, 42 boreholes were drilled (Figure 3A–C) with percussion system (Atlas Copco model Cobra TT hand-held impact sampler). Samples were taken at 1 m intervals from low to moderately compacted weathered rock (Figure 3D) to a maximum depth of 15 m. Additional samples of fresh bedrock and garnierite accumulation as well as other characteristic local occurrences of minerals observed macroscopically in rock outcrops were also collected. In 2010, three exploratory trenches were dug to a maximum depth of 8 meters. The trenches had a square shape with dimensions 3 × 3 m in the upper part (up to 4 m depth) and then diminishing towards the bottom of the trench (Figure 3E).

Averaged samples were taken from these trenches every 1 meter and numerous additional samples from characteristic structures and mineralization visible macroscopically. Fresh and unserpentinized bedrock was also sampled from one trench (No. DB-24).

Figure 3. (**A**) The forested area of Weda Bay where prospecting works were conducted, (**B**) sampling using a hand-held impact sampler, (**C**) borehole, (**D**) coning and quartering of laterite samples, and (**E**) trench excavated for sampling and macroscopic description of ore structure (Photo G. Konopka).

3.2. Methods

3.2.1. EPMA-Electron Probe Microanalysis

Mineral chemistry studies were conducted using a CAMECA SX-100 electron microprobe (Cameca, Cedex, France) equipped with wave dispersive spectrometers (WDS). Analyses were performed at an accelerating voltage of 15 kV, beam current of 47 nA (with a deviation up to 2 nA), beam diameter around 1 µm, peak count time of 20 s, and background time of 10 s. Spectra were analyzed on TAP (thallium acid phthalate), LPET (large pentaerythritol), and LLIF (large lithium fluoride) spectrometers. Samples for analysis were sputtered with a thin layer of carbon. Standards, analytical lines, diffracting crystals, and detection limits are shown in Table 1 Results were corrected based on the CAMECA PAP algorithm by Pouchou and Pichoir [25]. Analytical work was carried out in the Inter-Institutional Laboratory of Microanalysis of Minerals and Synthetic Substances of the Faculty of Geology of the University of Warsaw, Poland.

Table 1. Conditions EMP analyses.

Element	Standard	Analytical Line	Crystal	Detection Limit in wt.%
Si	Wollastonite	Kα	TAP	0.01–0.02
Mg	Diopside	Kα	TAP	0.01–0.02
K	Orthoclase	Kα	LPET	0.01–0.02
Na	Sodalite	Kα	TAP	0.02–0.04
Ti	TiO_2	Kα	LLIF	0.02–0.03
Ca	Wollastonite	Kα	LPET	0.01
Mn	Rhodonite	Kα	LLIF	0.02–0.04
Al	Al_2O_3	Kα	TAP	0.01–0.02
Fe	Fe_2O_3	Kα	LLIF	0.02–0.04
Ni	NiO	Kα	LLIF	0.08–0.10
Cr	Chromite	Kα	LPET	0.05–0.06
Co	CoO	Kα	LLIF	0.03–0.05

3.2.2. X-ray Powder Diffraction (XRD)

The samples were milled in an agate mortar and the next sieved through a 0.063 mm sieve. The phase composition was examined using the Bruker D8 Advance Davinci (Germany) diffractometer in the Bragg–Brentano system. Pressed powder preparations were recorded in the angular range 4–90° 2θ, with a step of 0.026° 2θ, with a sample rotation of 1 rpm/2 s, in filtered CuKα radiation (Fe filter) with current parameters of 25 mA and

40 kV. Identification of the mineral phases was carried out using Bruker Evaluation v.2 software with ICDD PDF-2 v. 2007 and PDF-4+ v. 2011 databases. Quantitative phase analysis of the samples was performed using the Retvield method in TOPAS v4.2 software (Billerica, MA, USA). The research was carried out at the Institute of Ceramics and Building Materials in Warsaw.

3.2.3. X-ray Fluorescence (WDXRF)

Chemical composition testing of the samples was performed in 2010 at Intertek, Jakarta Minerals Head Office and Laboratory, Indonesia. Analytical software XR81 Nickel Laterite Suite was used for analysis. A total of 319 samples of approximately 10 g were grated and then mixed and fused with lithium metaborate. The content of metals in the analytical program was determined using the wavelength dispersive X-ray Fluorescence method. Loss on ignition (LOI) was calculated by weight difference after ignition at 1000°. The level of accuracy and analytical precision can be found in Table 2.

Table 2. Limit of detection and range of analysis for the XRF method.

Oxides or Elements	Range in [%]	Detection Limit in [%]
SiO_2	0.01–100	0.01
Al_2O_3	0.01–100	0.01
Fe_2O_3	0.01–100	0.01
MgO	0.01–100	0.01
CaO	0.01–100	0.01
Na_2O	0.01–100	0.01
K_2O	0.01–100	0.01
TiO_2	0.01–100	0.01
P_2O_5	0.002–100	0.01
MnO	0.01–100	0.01
Cr_2O_3	0.005–100	0.01
LOI	0.01–100	0.10
Ni	0.005–20	0.01
Co	0.005–5	0.01

3.2.4. ICP-MS/ES

Additional chemical analyses were performed at a certified laboratory (ISO 17025) Activation Laboratories Ltd. (Actlabs) in Kamloops, BC, Canada. Two analytical programs available from Actlabs, the 4B2 Research and 1B2-Fire Assay were used for analysis. In the 4B2 Research approximately 10 g of sample was ground and then mixed and fused with lithium metaborate/tetraborate and then dissolved in a mixture of aggressive acids. Oxides and rare earth elements (REE) were analyzed in this program. In the 1B2-Fire Assay program, approximately 50 g of sample was ground and fused with nickel sulphide (NiS). Platinum group elements (PGEs) were analyzed in this program.

All samples in programs were carried out using ICP-MS (Inductively coupled plasma mass spectrometry) and ICP-ES (Inductively Coupled Plasma Emission Spectroscopy) methods. The level of accuracy and analytical precision can be found at (www.actlabs.com; accessed on 24 July 2022). The laboratory (Actlabs) carried out quality control by performing duplicates analyses, analytical blank, and using reference materials. Loss on ignition (LOI) was calculated by weight difference after ignition at 1000°. All chemical analyses can be found in Table A1.

3.2.5. Bulk Density of Ore

The bulk density of the samples was measured on representative samples of weathered rock which were dried at 105 °C. The density was measured using the paraffin method on a RADWAG balance equipped with a hydrostatic system (KIT 195; www.radwag.com; accessed on 24 July 2022) for measuring the density of the samples. The density of the samples is given in Table 3.

Table 3. Average bulk density of ore by horizons.

Horizons	Average Bulk Density [t/m^3]
Limonite	0.99
Transition	1.11
Saprolite	1.22

4. Results and Discussion

4.1. Nickel Laterite Profile

Macroscopic analysis of weathering was carried out by evaluating structures visible in cross-section in the pit walls (Figure 4). A similar sequence of separate levels of weathering was found in all the pits investigated. In the uppermost part, to a depth of approximately 0.25 m there is a red-grey soil layer with strongly disturbed structure. Below the overburden layer from an average depth of about 0.25 m to a depth of about 2 m, there is a red laterite (ferruginous cap) with a strongly disturbed structure in relation to the bedrock. Locally, this layer contains small pisolites. At the depth of 2 to 4 m, there is a yellow laterite horizon. The upper zone of this horizon contains a yellow laterite with a strongly disturbed structure. Below, there is a layer of yellow laterite with a partially preserved structure, in which ferruginous pseudomorphes are present. The lower it gets, the more the proportion of bedrock fragments increases. Large fragments of serpentinite or peridotite occur from a depth of 3–7 m below. Locally occurring structures associated with micro-scale diversity in weathering conditions or the bedrock nature are observed in weathering profiles. Siliceous zones and veins were observed in a few pits. In addition, garnetite crusts are visible on serpentinite.

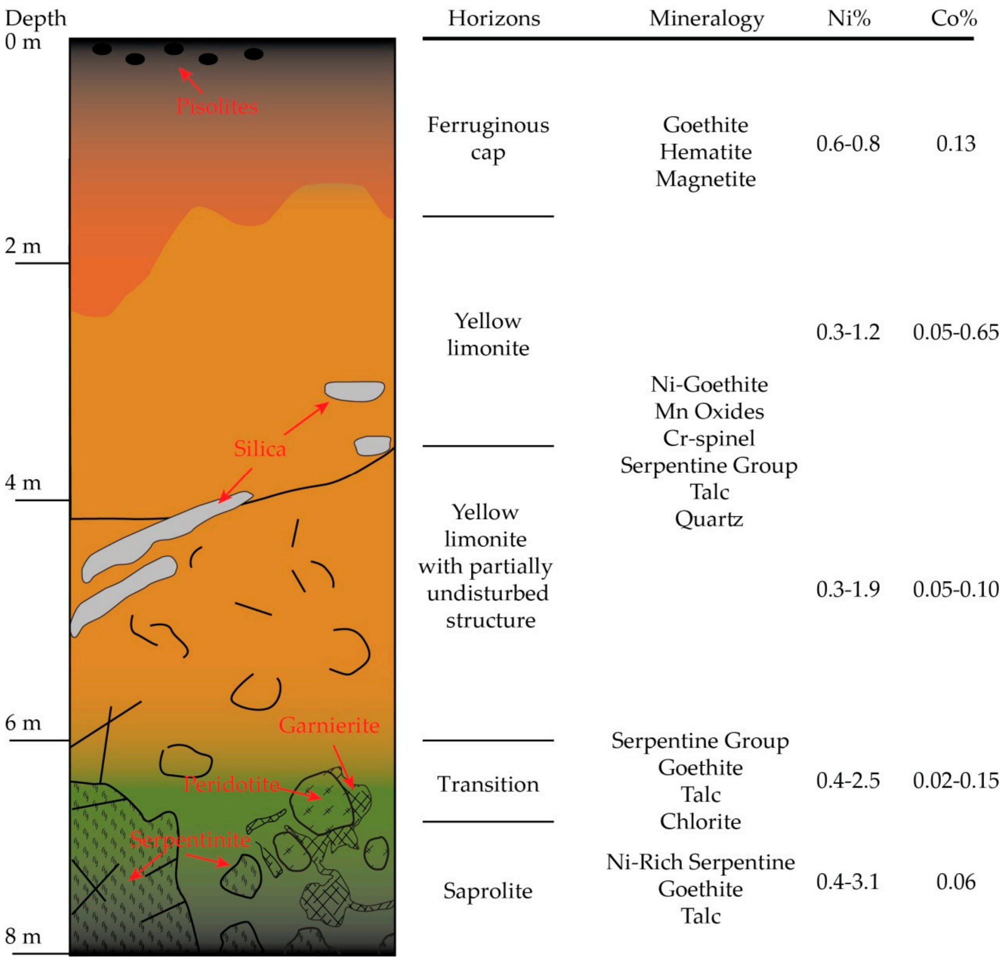

Figure 4. The Weda Bay laterite profile.

4.2. Geochemical Variability of the Laterite Profile

4.2.1. Red Limonite (Ferruginous Cap)

This layer consists of ferruginous nodules (with a diameter of 0.5–1.5 cm, max. 10 cm). The nodules are reddish-brown in color and are characterized by a compact but porous structure. Mineralogically, nodules are mainly composed of goethite ($Fe^{3+}O(OH)$) with a small share of Cr-spinel ($Fe^{2+}Cr_2O_4$) and hematite ($Fe^{3+}{}_2O_3$). Trace occurrences of ($Fe^{3+}{}_2Fe_{2+}O_4$) or maghemite ($Fe^{3+}{}_2O_3$) were found. This horizon is dominated by Fe_2O_3 up to 80 wt%. SiO_2 and MgO content is less than 10 wt%. Nickel is present at 0.6 to 0.8 wt%, while cobalt is present in trace amounts of less than 0.13 wt%.

4.2.2. Limonite

Based on the chemical analyses of laterite, two predominant types of the oxide ore and saprolite ore were distinguished. Oxide ore dominates in the upper part of the laterite profile. The oxide ore zone is equivalent to macroscopically distinguished levels of red and yellow laterite with an undisturbed structure and yellow laterite with a partly preserved structure. The major and trace elements concentrations in the horizons are given in Table A1.

Goethite is the main nickel-bearing mineral in laterite ore (Table 4). Magnetite, maghemite, and hematite occur in smaller quantities. The occurrence of nickel is associated with goethite and less frequently with hematite. The Ni is absent in magnetite and maghemite. The Ni content of goethite ranges from 4.60–5.92 wt% (Table 5). In goethite, small amounts of Co and Cr are also present. Hematite has an intermediate composition between goethite and magnetite.

Table 4. Summary of mineral content in different horizons for selected boreholes. Quantitative phase analysis by XRD.

Minerals	**Limonite**	**Transition**	**Saprolite**
	Average in wt%, (Min–Max in wt%)		
Goethite	72.20 (10.70–91.17)	50.84 (17.72–90.50)	12.36 (2.01–77.00)
Magnetite/Maghemite	5.69 (0.18–14.71)	2.03 (0.17–4.23)	0.00
Hematite	0.79 (0.00–6.93)	0.00	0.00
Cr-Spinel	1.41 (0.00–3.27)	0.71 (0.00–1.53)	0.26 (0.00–1.06)
Gibbsite	1.46 (0.00–4.68)	0.48 (0.00–1.92)	0.17 (0.00–1.10)
Bayerite	0.86 (0.00–1.80)	2.18 (0.00–6.72)	0.00
Serpentine Group Minerals	5.59 (0.00–72.56)	13.34 (0.00–28.43)	64.28 (0.00–91.38)
Talc	4.06 (0.00–10.35)	5.15 (2.81–8.56)	3.67 (0.00–18.07)
Quartz	7.54 (0.00–30.21)	13.84 (0.27–40.07)	5.88 (0.16–19.62)
Amphibole	0.13 (0.00–2.02)	0.57 (0.00–1.61)	1.43 (0.00–7.11)
Pyroxene	0.00	0.00	0.68 (0.00–5.51)
Forsterite	0.00	0.00	0.19 (0.00–2.13)
Smectite	0.00	0.00	0.83 (0.00–9.12)
Chlorite	0.25 (0.00–1.92)	10.84 (0.00–33.89)	9.56 (0.00–57-84)

In addition to iron minerals, Mn oxides (asbolane and lithiophorite) were found in some boreholes. They were mainly located in the lower part of the weathering profile, just above (at a depth of 7–8 m) the magnesium discontinuity zone. The Mn minerals are not thermodynamically stable. In a well-developed weathering profile, Mn is concentrated locally in iron oxides and does not form its own phases. The Mn oxides were analyzed using EPMA and are summarized in Table 6. The results indicate compositions between lithophore and asbolane. The NiO_2 content of Mn oxides ranges from 4.60–5.92 wt% and CoO (1.08–9.71 wt%).

Table 5. Chemical composition (wt%) of goethite, hematite, and magnetite from the limonite horizons for selected boreholes.

Minerals	Spot	SiO_2	MgO	Al_2O_3	FeO	Fe_2O_3	NiO	CoO	Cr_2O_3	MnO	CaO	Total
Goethite	DB-10/4	12.79	0.94	1.42	65.80	-	5.78	0.13	1.24	0.90	0.05	89.09
	DB-10/7	13.76	1.18	1.64	65.45	-	5.66	0.13	1.99	0.52	0.14	90.47
	DB-14/23	13.05	0.92	1.58	66.42	-	5.52	0.11	1.52	0.23	0.04	89.39
	DB-14/28	24.17	3.63	1.47	55.47	-	4.70	0.10	1.36	0.33	0.21	91.42
	DB-17/63	12.68	1.24	1.48	58.71	-	4.60	0.05	1.46	0.18	0.03	80.45
	DB-17/78	15.07	1.65	1.32	62.93	-	5.92	0.10	1.76	0.03	0.10	88.88
	DB-20/12	11.92	1.52	1.23	66.23	-	5.30	0.10	1.76	0.26	0.06	88.39
	DB-20/13	13.63	1.83	1.41	63.36	-	4.89	0.12	1.87	0.65	0.10	87.86
	DB-20/14	15.32	1.24	1.47	66.78	-	5.01	0.10	1.45	0.25	0.09	91.71
	DB-24/2	11.67	2.08	1.30	65.32	-	5.76	0.09	1.58	0.37	0.05	88.24
	DB-24/3	12.73	1.43	1.38	64.58	-	5.78	0.10	1.70	0.41	0.12	88.25
	DB-24/4	12.54	1.21	1.36	66.21	-	4.90	0.06	1.62	0.21	0.04	88.16
	DB-24/5	13.45	1.97	1.42	65.17	-	5.57	0.08	1.52	0.33	0.03	89.54
Hematite	DB-24/88	2.16	0.36	1.27	-	93.53	0.47	0.80	0.12	0.91	0.05	99.67
	DB-24/89	2.71	0.40	1.03	-	92.02	0.31	0.72	0.10	0.52	0.02	97.83
	DB-24/90	2.82	0.38	1.47	-	92.00	0.30	0.68	0.10	0.60	0.04	98.40
	DB-24/92	2.63	0.35	1.21	-	92.45	0.42	0.78	0.12	0.65	0.03	98.65
Magnetite	DB-10/54	0.76	1.36	0.00	26.33	67.77	0.07	0.18	0.00	1.72	0.00	98.19
	DB-10/55	1.08	0.75	0.00	27.90	67.92	0.02	0.04	0.03	1.32	0.00	99.03
	DB-14/45	0.43	0.80	0.00	28.79	68.24	0.03	0.17	0.01	0.49	0.00	98.93
	DB-14/46	1.40	0.76	0.00	27.37	66.83	0.09	0.06	0.00	1.35	0.00	97.85
	DB-17/12	1.35	0.79	0.00	27.58	67.38	0.00	0.18	0.00	1.32	0.00	98.61
	DB-17/13	1.96	0.82	0.00	28.40	68.14	0.00	0.02	0.27	0.96	0.00	100.61
	DB-20/72	1.84	0.92	0.00	28.20	68.57	0.00	0.01	0.08	1.05	0.00	100.69
	DB-20/73	1.95	0.72	0.00	28.12	67.71	0.00	0.09	0.03	1.07	0.00	99.68
	DB-20/74	0.89	1.28	0.00	26.53	67.50	0.05	0.06	0.00	1.60	0.00	97.94
	DB-24/82	1.19	0.95	0.00	27.05	65.54	0.31	0.13	0.01	0.74	0.00	95.91
	DB-24/83	0.52	1.10	0.00	26.82	66.32	0.17	0.09	0.02	1.09	0.00	96.16
	DB-24/84	1.76	2.02	0.00	24.93	66.55	0.20	0.03	0.01	1.44	0.00	96.97
	DB-24/85	0.28	0.67	0.00	28.07	66.76	0.11	0.19	0.01	0.78	0.00	96.87

The nickel content of this zone is in the range of 0.3 to 1.86 wt%, mean 0.8 wt% and Co up to 0.65 wt%, mean 0.13 wt%. Ni content is the lowest in this horizon compared to the other weathering horizons, although it increases with depth, while the Co content is the highest, especially in the lower part of the limonite horizon. In this level there is a high content of Fe_2O_3 (23.04–76.17, mean 55.55 wt%), Al_2O_3 (2.52–20.52, mean 9.56 wt%). The average content of chemical components is as follows: SiO_2 (13.93 wt%), MgO (3.86 wt%), Cr_2O_3 (2.93 wt%), MnO (1.05 wt%), and TiO_2 (0.16 wt%). Very low contents form ZnO up to 0.09 wt% and Sc_2O_3 up to 0.01 wt%. The abundance of trace elements Ba (3–880 ppm), Cu (60.0–110.0 ppm) and V (109.0–171.0 ppm), shows variable values. Ga (4.0–6.0 ppm) and Ge (2.5–4.0 ppm) are present in small amounts. The contents of other elements do not exceed normally the lower detection limit of the test method used (ICP-MS and WDXRF). In the upper part of the laterite, there has been no significant enrichment in rare earth elements. As with REE, no enrichment was found in PGM.

Table 6. Chemical composition (wt%) of asbolan–lithophore from the limonite horizons for DB-24 boreholes.

Spot	SiO_2	MgO	Al_2O_3	Fe_2O_3	NiO	CoO	Cr_2O_3	MnO_2	CaO	Total
DB24/101	5.40	1.98	0.30	25.71	18.94	2.43	0.20	38.47	0.09	93.64
DB24/103	6.33	1.31	0.58	7.80	25.46	4.46	0.11	46.97	0.10	93.33
DB-24/109	9.20	1.39	0.06	3.48	24.80	6.69	0.01	41.42	0.06	87.22
DB-24/1110	4.72	1.67	0.11	1.33	23.98	6.39	0.04	46.66	0.06	85.10
DB-24/154	3.30	1.41	0.05	0.78	23.24	7.58	0.00	48.00	0.06	84.53
DB-24/155	0.86	1.31	0.03	0.51	20.46	8.56	0.05	55.10	0.15	87.22
DB-24/145	0.21	0.89	0.01	0.00	21.84	7.71	0.02	53.80	0.09	84.79
DB-24/146	1.28	1.07	0.04	1.83	19.92	9.71	0.04	53.08	0.23	87.34
DB-24/151	4.97	1.73	0.06	0.00	23.23	8.91	0.03	51.27	0.08	90.43
DB-24/153	3.35	4.81	0.01	5.51	17.24	9.49	0.01	49.60	0.06	90.13
DB-24/172	7.07	5.12	0.05	11.10	20.17	4.19	0.04	42.41	0.06	90.30
DB-24/173	6.22	4.82	0.03	6.86	20.55	3.97	0.03	43.13	0.08	85.74
DB-24/174	9.63	3.31	0.04	8.41	22.36	5.58	0.02	41.73	0.08	91.27
DB-24/182	9.06	1.98	0.17	5.70	23.81	6.75	0.02	38.96	0.11	86.83
DB-24/183	3.68	1.15	0.09	2.47	22.96	6.43	0.00	46.64	0.06	83.62
DB-24/188	12.93	5.43	0.07	2.05	21.04	6.00	0.03	40.61	0.07	88.36
DB-24/189	0.29	1.05	0.04	0.21	22.08	7.38	0.02	53.12	0.07	84.44
DB-24/190	2.80	0.59	0.03	1.25	16.90	1.08	0.02	63.84	0.03	86.82
DB-24/192	8.56	4.02	3.47	1.86	23.90	2.43	0.04	41.22	0.07	85.76
DB-24/193	7.01	3.00	2.91	1.62	24.02	2.80	0.05	43.48	0.04	85.05

4.2.3. Saprolite

The saprolite ore is characterized by a different geochemical signature. The zone shows enrichment in SiO_2 (33.38–52.54 wt%, mean 39.80 wt%) and MgO (20.92–35–27 wt%, mean 29.47 wt%). Silicate minerals, such as serpentine, mainly lizardite ($Mg_3Si_2O_5(OH)_4$) and chrysotile ($Mg_3(Si_2O_5)(OH)_4$), are present in the horizon (Figure 5; Table 3).

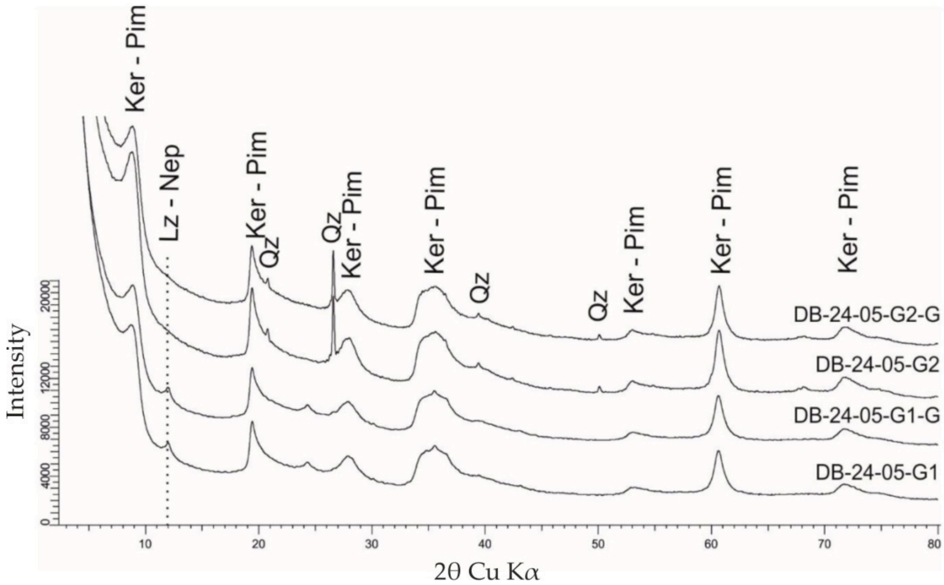

Figure 5. Diffractograms of selected garnierite samples contain a serpentine group minerals. Qz—quartz; Ker-Pim—kerolite-pimelite; Lz-Nep—lizardite-népouite.

The goethite content in the horizon is decreasing. The Ni content is higher than in the limonite and is in a wide range of 0.44 to 3.10 wt%, mean 1.43 wt%. In contrast, the Co concentration decrease markedly, compared to the oxide ore, to a mean of 0.02 wt%. In goethite, was determined the lower concentration than in limonite the following components—Cr_2O_3 (mean 0.75 wt%), TiO_2 (0.01 wt%) and MnO (0.23 wt%).

Rich nickel mineralization is associated with garnierite veins occurring locally in the saprolite horizon, particularly in areas of partially unserpentinized peridotite (Figure 6A,B). Examination of garnierites (Table 7; Figure 6) collected from trenches (depths of 5–6.5 m.a.s.l.) showed that the composition of these nickel-bearing minerals is variable, but there is always a mineral from the lizardite–népouite ($Ni_3Si_2O_5(OH)_4$)/chrysotile–pecoraite ($Ni_3Si_2O_5(OH)_4$) series (serpentine subgroup minerals) and/or kerolite ($(Mg,Ni)_3Si_4O_{10}(OH)_2{\cdot}H_2O$)–pimelite ($Ni_3Si_4O_{10}(OH)_2{\cdot}4(H_2O)$ (the fine crystalline equivalent of the talc ($Mg_3Si_4O_{10}(OH)_2$)–willemseite ($Ni_{2.25}Mg_{0.75}Si_4O_{10}(OH)_2$ series). The Ni content measured for serpentines ranges between 0.24–7.07 wt%. In contrast, an increase in Ni concentration is seen in kerolite–pimelite 2.37–27.40 wt%.

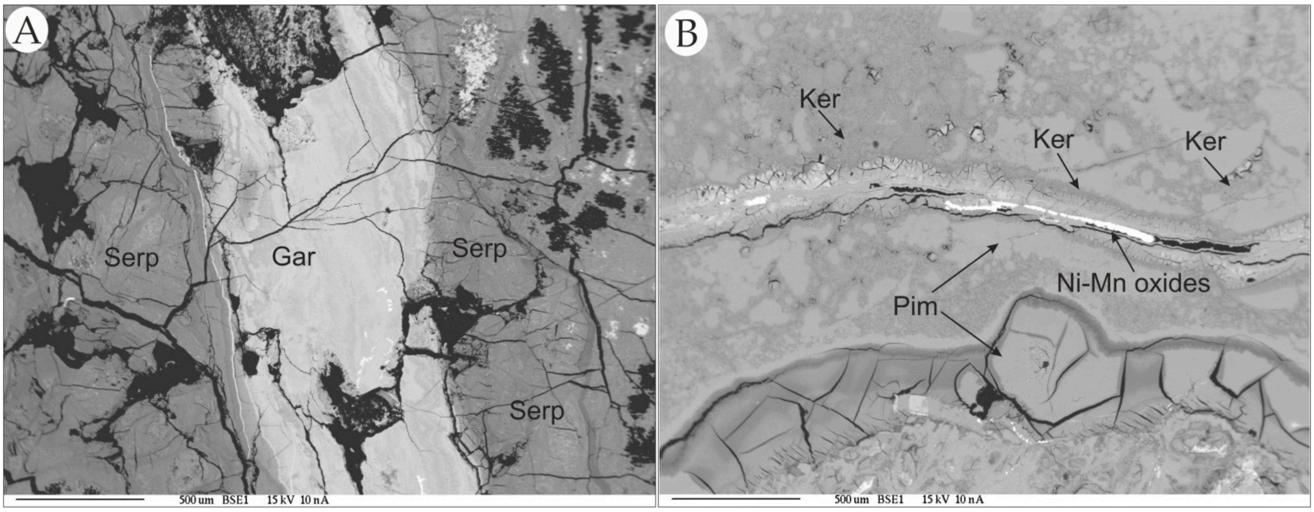

Figure 6. BSE image of partially unserpentinized peridotite with garnierite veins. Gar- garnierite; Serp—serpentinite (**A**); identification of phases in garnierite (**B**): Pim—pimelite; Ker—Kerolite.

Table 7. Chemical composition (wt%) of serpentine subgroup minerals and kerolite–pimelite from the saprolite horizons for selected boreholes.

Minerals	Spot	FeO	Cr_2O_3	NiO	CoO	MnO	Al_2O_3	SiO_2	TiO_2	Na_2O	K_2O	MgO	CaO	H_2O	Total
Serpentine subgroup	9-1	12.00	0.02	2.36	0.00	0.17	2.83	36.89	0.00	0.00	0.00	29.49	0.05	11.56	95.36
	9-5	11.88	0.02	2.16	0.04	0.11	2.38	37.57	0.00	0.02	0.00	31.20	0.00	11.80	97.17
	9-15	5.44	0.01	1.52	0.06	0.06	1.06	42.00	0.00	0.03	0.02	37.22	0.09	12.63	100.13
	9-21	4.30	0.00	1.27	0.03	0.05	0.86	39.98	0.00	0.00	0.00	35.44	0.00	11.91	93.84
	S-1	7.95	0.02	2.71	0.00	0.03	1.68	41.81	0.00	0.02	0.02	31.93	0.03	12.56	98.76
	S-2	5.61	1.47	3.08	0.04	0.05	2.45	39.70	0.00	0.02	0.01	30.26	0.05	12.21	94.98
	S-11	11.84	0.75	0.24	0.00	0.10	0.88	38.11	0.00	0.00	0.01	34.57	0.03	11.89	98.41
	S-12	6.28	0.50	0.30	0.00	0.09	1.00	41.61	0.01	0.00	0.00	35.06	0.03	12.53	97.40
	S-89	21.24	0.08	2.19	0.08	0.11	0.02	40.38	0.03	0.38	0.16	17.13	0.34	11.46	93.60
	S-96	11.87	1.18	1.20	0.08	0.11	1.55	36.96	0.02	0.01	0.00	32.68	0.02	11.67	97.36
	S-97	9.60	1.31	1.01	0.04	0.01	2.08	37.81	0.05	0.00	0.00	33.91	0.03	11.96	97.80
	S-103	12.58	0.06	2.53	0.00	0.16	0.95	40.12	0.00	0.05	0.01	28.91	0.07	12.01	97.45
	S-107	11.64	0.00	7.07	0.04	0.04	0.98	43.16	0.00	0.25	0.12	21.94	0.18	12.39	97.81
-Kerolite-Pimelite	DB-24/1	1.30	0.02	27.19	0.03	0.09	0.07	43.48	0.02	0.02	0.04	6.62	0.05	8.16	87.10
	DB-24/6	1.16	0.00	14.85	0.05	0.03	0.03	44.30	0.00	0.02	0.03	13.15	0.03	8.30	81.95
	4-30	0.51	0.04	13.24	0.02	0.02	0.03	48.68	0.01	0.02	0.02	14.54	0.02	9.08	86.25
	4-21	0.20	0.06	18.24	0.00	0.04	0.00	37.89	0.00	0.00	0.03	9.21	0.02	7.11	72/80
	4-46	0.04	0.00	15.88	0.01	0.00	0.01	46.39	0.00	0.00	0.01	14.14	0.00	8.69	85.17
	9-19	0.09	0.00	14.61	0.00	0.01	0.01	51.12	0.02	0.07	0.04	15.86	0.04	9.54	91.40
	9-28	0.43	0.05	15.58	0.03	0.02	0.00	49.40	0.03	0.04	0.03	15.09	0.04	9.24	89.99
	DB-19/11	0.81	0.03	27.40	0.01	0.05	0.01	43.73	0.01	0.11	0.04	6.46	0.08	8.18	86.92
	DB-20/3	6.42	0.02	2.37	0.00	0.00	0.02	50.54	0.00	0.15	0.09	22.63	0.34	9.50	92.08
	DB-23/27	4.37	0.00	2.94	0.00	0.02	0.10	50.99	0.00	0.21	0.03	26.15	0.28	9.63	94.72
	DB-24/1	1.45	0.00	3.58	0.12	0.00	0.02	55.89	0.00	0.15	0.05	25.94	0.07	10.46	97.73
	DB-29/8	0.82	0.01	10.02	0.01	0.00	0.08	54.99	0.00	0.22	0.07	22.65	0.07	10.29	99.23
	DB29/12	0.17	0.00	9.66	0.03	0.00	0.03	56.16	0.00	0.18	0.07	23.30	0.03	10.61	100.24

4.3. Nickel Distribution and Enrichment

Analysis of the chemical and mineralogical composition data from the boreholes in the central Halmahera area (an additional 37 locations) confirms the conclusions drawn from the analysis of the trench samples. A clear division exists between the upper level of weathering, i.e., limonite characterized by a dominance of iron oxides, mainly in the form of goethite and to a lesser extent magnetite and maghemite, and the deeper saprolite containing mainly weathered silicates and magnesium aluminosilicates.

In the weathered profiles, Ni enrichment was found to be residual within the limonite horizon, and there was even a depletion in relation to Fe, although the absolute concentration is almost always higher than in the bedrock. A pronounced supergene enrichment in nickel only occurs in the transition zone and in some saprolite zones. Supergene enrichment in Co occurs, especially in the lower part of the limonite horizon, decreases in the transition zone, and in the saprolite horizon its value is much less than 1, indicating depletion (Figure 7). The residual enrichment in this element, however, occurs in the upper part of the limonite corresponding approximately to the disrupted limonite. The different behavior of the two elements is due to the fact that Ni, unlike Co, enters the structure of many minerals present in the deposit at different levels, i.e., especially goethite, serpentine, talc group minerals, smectites and manganese minerals. On the other hand, Co is bound for the most part by manganese minerals occurring abundantly especially in the limonite level with a partially preserved structure, i.e., in the lower part of the oxidized zone.

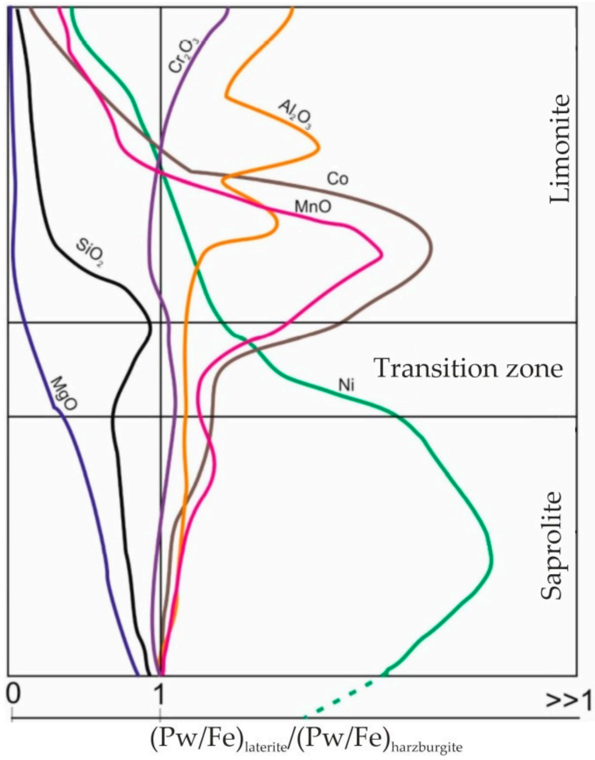

Figure 7. Enrichment/depletion in selected oxides and elements relative to the bedrock (fresh harzburgite).

4.4. Estimated Resources

Deposit resources were estimated using the average abundance method and polygon method with assumptions of marginal cut-off values: Ni ≥ 0.5%; Ni ≥ 0.7%; Ni ≥1.0% and Ni ≥ 1.0%, ≥100 kg/m^2. Laterites with Ni% ≥ 0.9% are considered to be economic [9]. Semivariograms were performed to determine variability. Semivariograms (Figures 8 and 9) obtained for the distribution of various deposit parameters are random in the vast majority of cases, which is probably related to the high variability of deposit parameters in lateritic deposits [22]. Only in the case of Ni content in limonite does the obtained variogram indicate a partly non-random distribution.

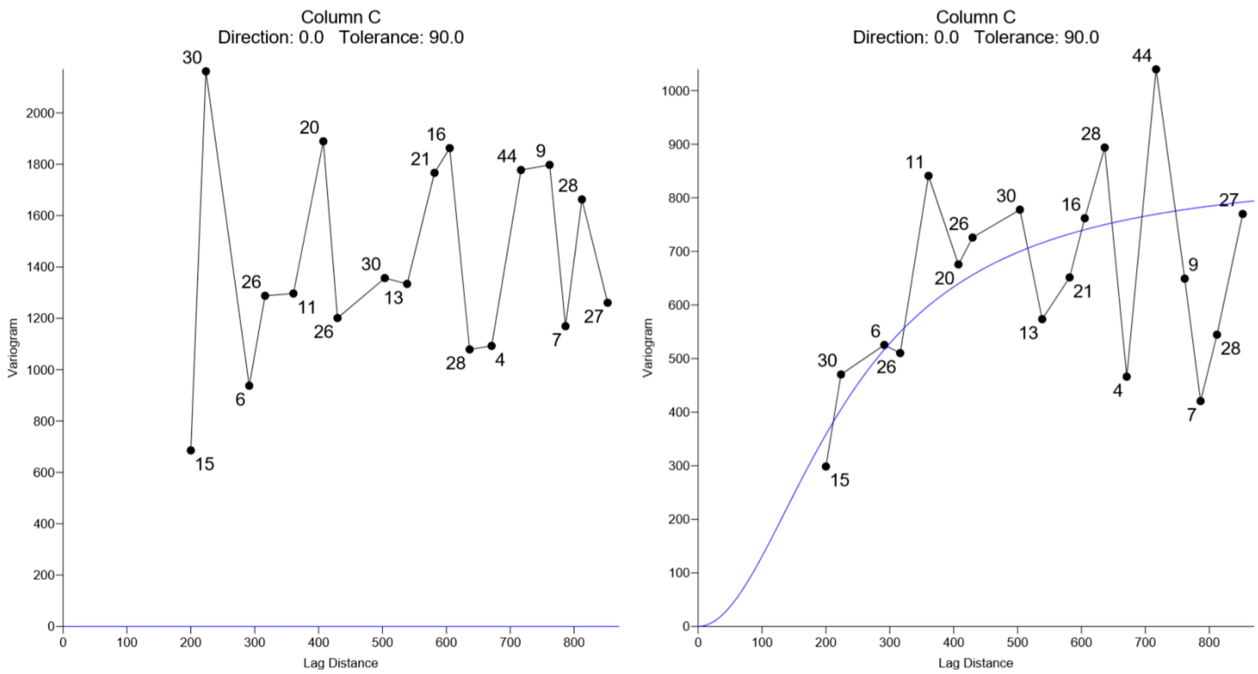

Figure 8. Semivariogram of Ni abundance [kg/m^2] in all studied horizons of the deposit (**left**) and in limonite (**right**). Numbers next to curve nodes indicate number of pairs for which the given quantity was calculated.

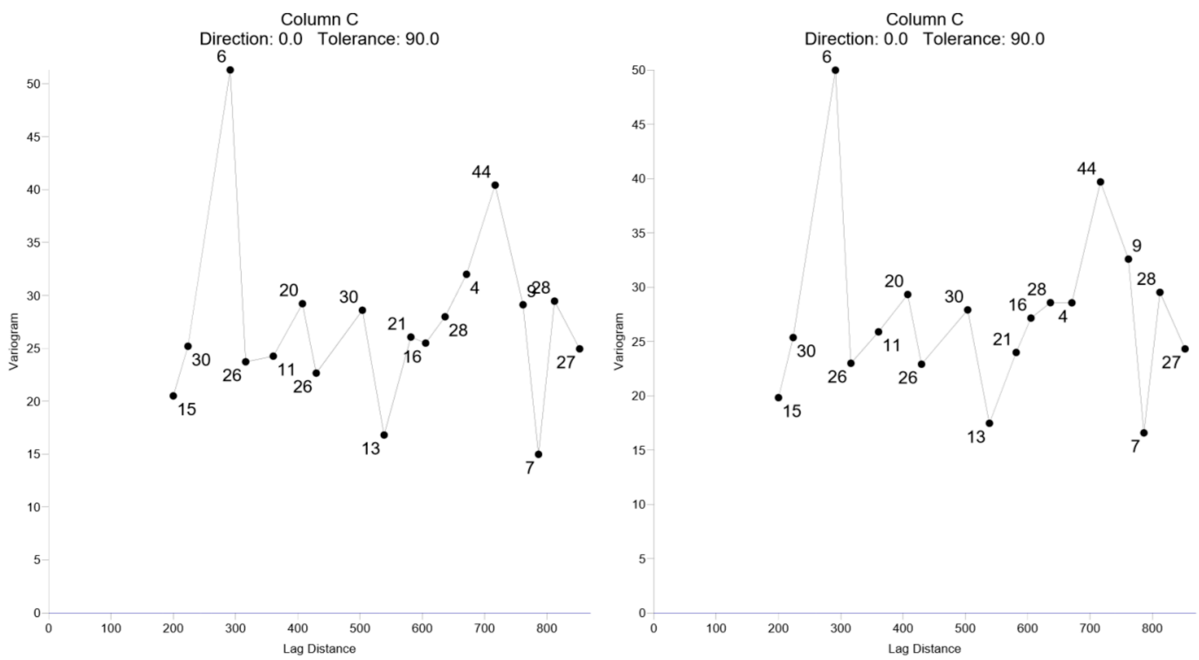

Figure 9. Semivariogram of Co abundance [kg/m^2] in deposit balance zone for Co (limonite horizon and transition zone—right) and in limonite horizon.

In the average abundance method, assuming a random distribution of deposit parameters, the resources were calculated as the product of the average abundance and the area of the deposit area according to:

$$Q = \bar{q} \cdot F \quad (1)$$

where:

Q—resources [t];
$\bar{q}$—abundance [%];
F—the area of the calculation field [m^2].

The average abundance is measured as the product of known deposit parameter values according to the formula:

$$\bar{q} = m \cdot \gamma_o \cdot p \cdot 0.01 \tag{2}$$

where:

$\bar{q}$—abundance [%];
m—thickness [m];
γ_o—bulk density [t/m^3];
p—useful component [%].

Area boundary (Figure 10) of the geologically recognized area was determined, i.e., by the slope criterion calculated using RockWorks 16 software (Golden, CO, USA), on the basis of SRTM data with 30 m resolution. Negative criteria were slope gradient greater than 25° and distance from the survey point > d/2 (outside the internal area defined by the line connecting the external reconnaissance points), where d is the average distance between reconnaissance points (for adjacent holes).

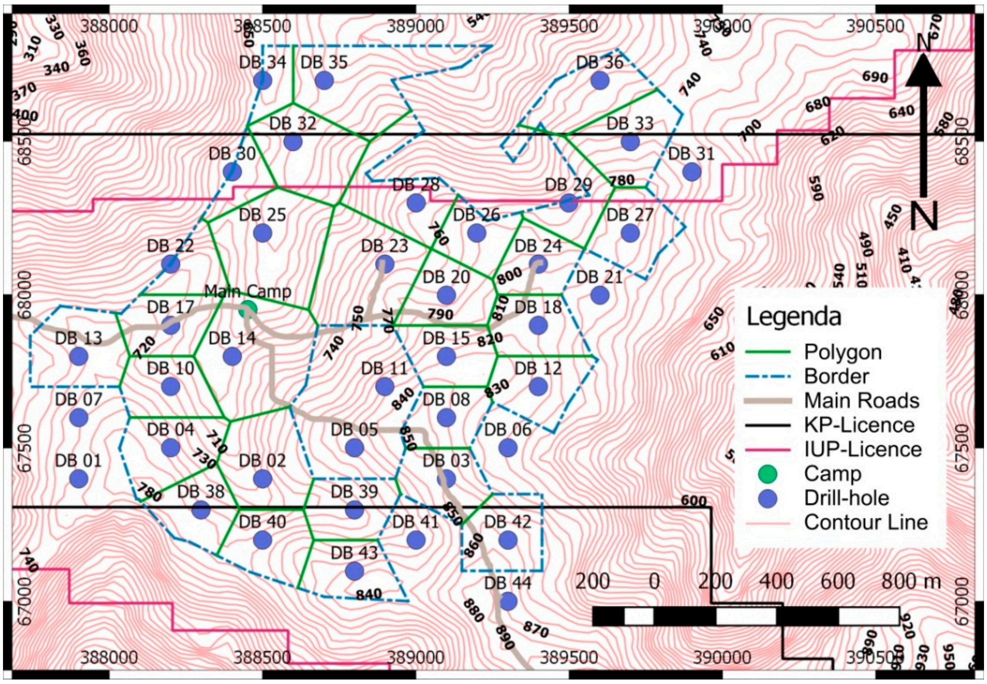

Figure 10. Boundary of the deposit using the cut-off criterion ≥ 0.7%.

Value of deposit parameters for individual drill holes are presented in Table A2. The results of the calculations (Ni and Co) with a breakdown into individual horizons for filed and different cut-off criteria are shown in the Table 8.

Table 8. Resource of useful elements estimated by the average abundance method for the whole identified area.

		Nickel			Cobalt	
Cut-Off	**Horizon**	**Limonite**	**Transition**	**Saprolite**	**Limonite**	**Transition**
≥0.5	Average abundance of horizon [wt%]	0.83	1.25	1.47	0.15	0.06
	Average of abundance [wt%]		1.02		0.14	
	Resources of horizon [t]	90,039	26,858	68,612	16,386	1360
	Resources [t]		185,510		17,747	
≥0.7	Average abundance of horizon [wt%]	0.88	1.27	1.49	0.16	0.06
	Average of abundance [wt%]		1.08		0.14	
	Resources of horizon [t]	82,687	26,532	68,339	15,080	1266
	Resources [t]		177,559		16,346	
≥1.0	Average abundance of horizon [wt%]	1.11	1.44	1.60	0.19	0.06
	Average of abundance [wt%]		1.39		0.15	
	Resources of horizon [t]	29,915	22,144	62,697	5185	925
	Resources [t]		114,755		6110	

In order to verify the applied methodology (average abundance method), calculations using the polygon method (Boldyrev) were also carried out for the same fields and different cut-off criteria. The determination of polygons was performed using GIS software—QGIS (Geographic Information System) and Computer Aided. The density of an exploratory grid covering the tenement area in block B was validated to assess the inferred resource within the survey area. Estimation of inferred resource (Table 9) volume was performed by using the triangular grouping method (Figure 11). The partial and total results of the calculations (Ni and Co) are given in the Table A2.

Table 9. Resources of useful elements estimated by the polygon method (Boldyrev) for the whole identified area.

Cut-Off	**Nickel**	**Cobalt**
	Resources [t]	
≥0.5	179,440	17,988
≥0.7	171,214	16,604
≥1.0	108,167	5832

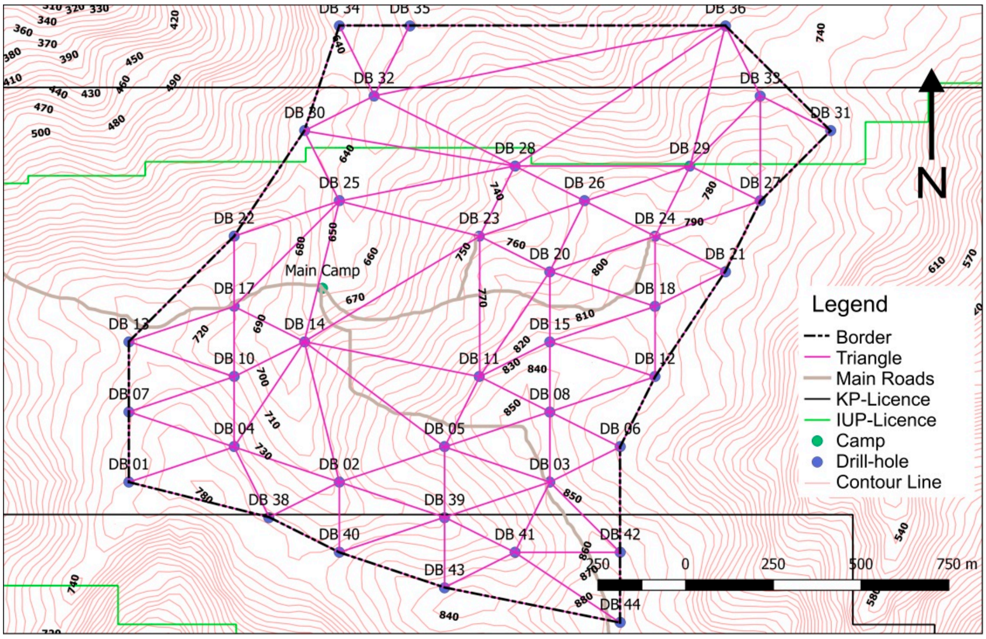

Figure 11. Map of triangles used for Ni and Co resources estimation.

Comparison of results of resource estimation by two methods (average abundance method and polygon method) for different cut-off criteria allows to state that differences between results obtained by particular methods characterized by various deposit geometries are small and practically negligible. Resulting inferred resource volumes in block B [14,26] have been estimated on (in wet metric tons):

- limonite zone: 13,659,116 t;
- transition-saprolite zone: 4,380,430 t.
- Total inferred resources of metals in block B [14,26] survey area are estimated as (in metric tons):
- Nickel: 185,510 t;
- Cobalt: 17,747 t.

The zones with the highest nickel abundance are located in the central and north-western parts of the deposit. Such distribution is a function of measured thickness of nickel-rich saprolite, which is the highest in these parts of the deposit (Figure 12). In the case of the central area located in the near study drill holes DB-08, DB-11 and DB-15, despite the low average content of the nickel (0.67–0.86 wt%), the abundance is high due to the large measured thickness of limonite (11–15 m). It is likely that the spatial distribution of Ni abundance would change with a full in-depth reconnaissance of the weathering profile. In case of cobalt, the highest abundance is found in the central belt running in SE–NW direction between holes DB-03, DB-11, and DB-25, and in the NE part of the deposit (Figure 13). Both in case of nickel and cobalt the distribution of abundance seems to be quite random, between individual boreholes, which is probably due to high variability of deposit parameters and too rare reconnaissance boreholes grid.

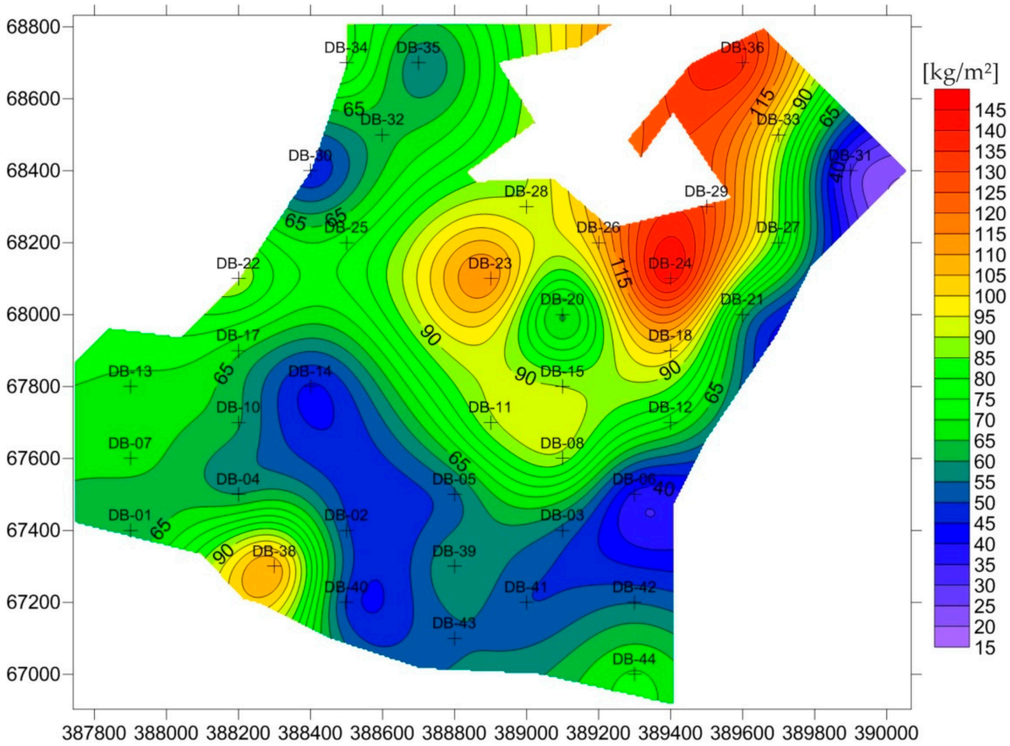

Figure 12. Nickel resources (kg/m^2) throughout the deposit profile in the area of block B. Inter- and extrapolation of data between exploration points performed for illustration purposes using the Radial Basis Function (RBF) method. WGS 84 UTM 52N coordinate system. Made in Surfer 9 software (Golden, CO, USA).

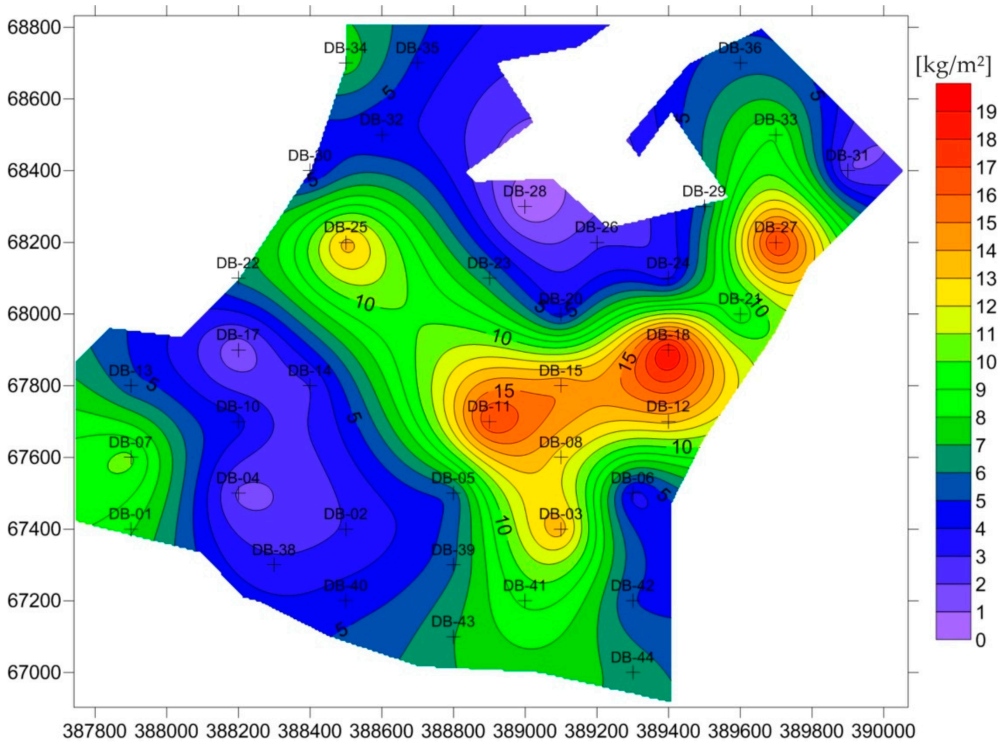

Figure 13. Cobalt resources (kg/m^2) for limonite and transition horizons. Inter- and extrapolation of data between exploration points performed for illustration purposes using the Radial Basis Function (RBF) method. WGS 84 UTM 52N coordinate system. Made in Surfer 9 software (Golden, CO, USA).

It is important to stress that only the uppermost part of the weathering profile was sampled, and one can assume that economically valuable concentrations of elements continue at least a few meters below the end of sampled zone. It is necessary to conduct further detailed prospecting studies with the use of rotary drilling machine (hydraulic machine) in order to obtain the maximum depth down to the bedrock. In addition, there are other potential areas indicated as laterite zones and expected to have the same characteristics as the central area. They should be investigated too. It is then suggested to plan drillings that reach at least 25–30 m deep below ground level in order to reach the expected deeper parts of the deposit. A dense network of boreholes is necessary in order to achieve the required level of deposit recognition. Boreholes should not be further away from each other than 25 m.

Comparing the size and quality of the estimated resources of Block B to other Ni deposits around the world (Figures 14 and 15), it can be concluded that the preliminarily proven deposit belongs to the category of small or very small deposits and of low or average quality depending on the cut off criterion applied. With cut-off Ni $\geq$ 0.5 wt%, the deposit has an overall low average Ni content, whereas with cut off Ni $\geq$ 1.0 wt%, the Ni abundance of the deposit is slightly higher than the average for the 117 deposits analyzed worldwide [4].

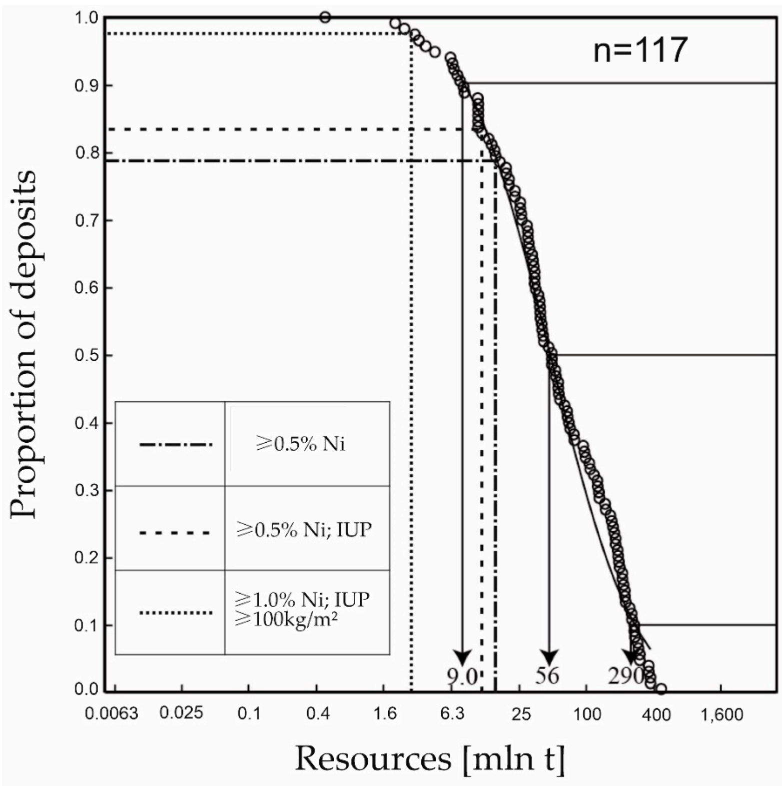

Figure 14. Compilation of Ni laterite ore resources data for 117 global deposits with plotted resource estimation results for Block B of the Central Halmahera deposit for several selected cut-off criteria. On the basis of [4] modified. Intercepts for the 90th, 50th, and 10th percentiles of the observed distribution are provided.

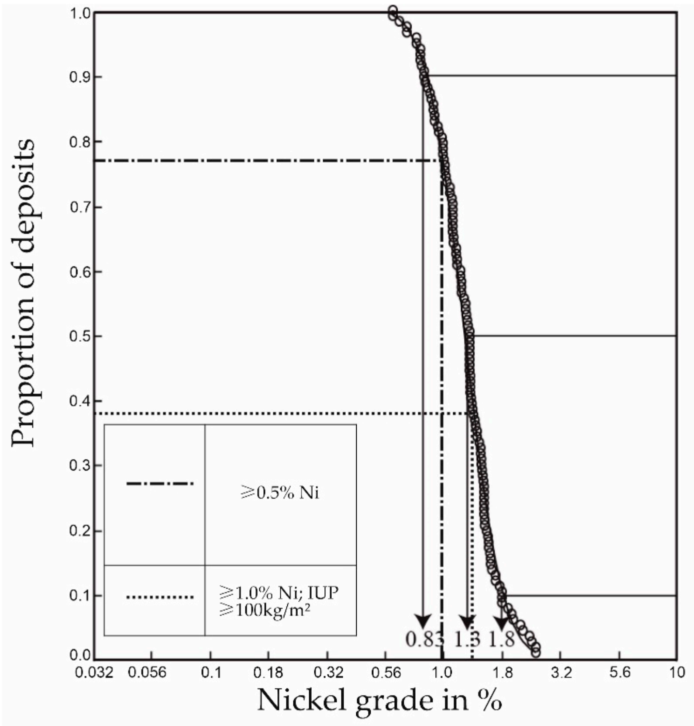

Figure 15. Summary of Ni concentration data for 117 global laterite Ni deposits with plotted Ni concentration results for Block B of the Central Halmahera deposit at several selected cut-off criteria. On the basis of [4] modified. Intercepts for the 90th, 50th, and 10th percentiles of the observed distribution are provided.

5. Conclusions

The base of the laterite weathering profile is mainly serpentinites probably formed from harzburgites. Locally, almost non-serpentinized harzburgite was found in the basement.

In the studied deposit zone, oxide ore was found to be dominant over saprolite ore, which allows classifying this deposit as a mixed oxide-saprolite type.

The main mineral in the limonite horizon is goethite prevailing over hematite, which significantly distinguishes the Halmahera deposits from other lateritic deposits of Indonesia.

In the limonite horizon the deposit minerals are: Ni-goethite, asbolane, and other manganese minerals. In the saprolite horizon, the deposit minerals are mainly weathered primary lysardite and chrysotile. These minerals are enriched in Ni, which probably migrated with solutions from the limonite horizon. The enrichment in Ni is both residual (typically in the upper part of the limonite horizon) and supergene (in the lower part of the limonite horizon and in the transition and saprolite horizons).

The formation of the deposit is probably related to the disintegration of primary minerals, i.e., minerals from the serpentine group and magnesium silicates building harzburgites. In both cases the disintegration led to the formation of ferruginous weathering with a dominant share of goethite.

In the deposit profile, goethite from the lower part contains more Ni than goethite from the upper part. Furthermore, the goethite in the lower part of the profile was found to be weakly crystalline and the average crystal size was larger in the upper part. This can probably be related to the transformation and recrystallization processes resulting in the release of Ni^{2+} into solutions.

Garnierites were found in the deposit profile and occur depending on the degree of serpentinization of the underlying rock. Garnierites occur only where the degree of serpentinization of harzburgite is low and appear in zones of loosening and voids. Garnierites are composed of two types of minerals: minerals belonging to the lysardite–népouite series and minerals belonging to the kerolite–pimelite series.

Local occurrence of very good quality saprolite ore (2–3% Ni) was found in the deposit. However, low quality limonite ore (approximately 1% Ni) dominates in terms of quantity and its extraction under the present conditions is economically unprofitable.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Results of chemical analyses of samples taken from different horizons. Data from ICP-MS/ES in wt %.

Sample	Ni	Co	Al_2O_3	CaO	Cr_2O_3	Fe_2O_3	Fe	K_2O	MgO	MnO	Na_2O	P_2O_5	P	SiO_2	TiO_2	LOI	Total	Horizons	Type No	Limonite [m]	Transition [m]	Saprolite [m]
DB01-1	0.58	0.01	15.76	0.04	2.90	58.48	40.90	0.01	2.16	0.24	0.06	0.03	0.01	6.85	0.51	12.40	100.04	Limonite	1			
DB01-2	0.79	0.04	8.90	0.00	2.52	67.33	47.08	0.00	2.72	0.58	0.04	0.02	0.00	6.35	0.18	10.70	100.13	Limonite	1			
DB01-3	0.82	0.15	10.82	0.02	2.48	64.39	45.03	0.00	2.19	1.19	0.08	0.01	0.00	5.91	0.15	11.00	99.21	Limonite	1			
DB01-4	0.87	0.24	8.07	0.00	2.48	60.05	41.99	0.00	4.76	1.86	0.06	0.01	0.00	10.81	0.09	10.00	99.25	Limonite	1			
DB01-5	0.90	0.17	7.81	0.00	2.47	56.50	39.51	0.00	6.29	1.55	0.08	0.01	0.00	14.40	0.06	9.60	99.86	Limonite	1			
DB01-6	0.96	0.09	7.25	0.01	2.73	55.86	39.06	0.00	6.77	0.93	0.11	0.01	0.00	15.17	0.07	9.80	99.75	Limonite	1			
DB01-7	0.97	0.13	6.98	0.00	2.74	56.30	39.37	0.00	6.36	1.24	0.09	0.01	0.00	14.80	0.05	9.60	99.24	Limonite	1	7.00	0.00	0.00
DB02-1	0.89	0.10	8.07	0.01	4.40	65.10	45.53	0.00	2.62	0.86	0.07	0.03	0.01	6.11	0.13	11.40	99.80	Limonite	1			
DB02-2	1.03	0.22	7.91	0.00	4.22	67.07	46.90	0.00	1.83	1.57	0.06	0.02	0.01	5.21	0.08	10.40	99.59	Limonite	1			
DB02-3	1.26	0.08	4.03	0.04	1.98	33.11	23.16	0.01	19.62	0.62	0.04	0.01	0.00	25.97	0.04	12.60	99.41	Transition	2			
DB02-4	1.54	0.02	0.64	0.01	0.70	14.55	10.18	0.00	30.84	0.21	0.00	0.00	0.00	38.61	0.00	12.40	99.50	Saprolite	3	2.00	1.00	1.00
DB03-1	0.98	0.07	7.20	0.03	2.73	60.49	42.30	0.00	3.25	0.58	0.06	0.02	0.00	10.76	0.11	13.30	99.53	Limonite	1			
DB03-2	1.03	0.18	9.22	0.01	3.06	60.32	42.18	0.00	2.66	1.25	0.05	0.02	0.00	8.23	0.05	13.30	99.37	Limonite	1			
DB03-3	0.81	0.18	6.50	0.01	3.08	59.21	41.41	0.00	3.97	1.48	0.08	0.01	0.00	12.28	0.02	12.10	99.72	Limonite	1			
DB03-4	0.56	0.20	8.80	0.01	2.67	48.80	34.13	0.00	6.20	1.28	0.06	0.01	0.00	19.24	0.01	11.70	99.50	Limonite	1			
DB03-5	0.71	0.30	13.74	0.02	2.79	49.91	34.90	0.00	2.91	2.01	0.04	0.01	0.00	13.22	0.04	13.70	99.36	Limonite	1			
DB03-6	0.61	0.24	12.80	0.03	2.51	48.90	34.20	0.00	3.77	1.69	0.05	0.01	0.00	16.33	0.07	12.10	99.11	Limonite	1			
DB03-7	0.69	0.24	9.74	0.03	2.91	57.31	40.07	0.00	3.50	1.71	0.06	0.01	0.00	11.54	0.05	11.50	99.33	Limonite	1			
DB03-8	0.56	0.09	4.26	0.12	1.39	28.06	19.62	0.00	22.65	0.72	0.01	0.00	0.00	29.62	0.00	11.70	99.14	Transition	2	7.00	1.00	0.00
DB04-1	0.88	0.15	6.93	0.03	2.67	54.37	38.02	0.00	3.29	0.84	0.08	0.03	0.01	17.54	0.14	12.10	99.06	Limonite	1			
DB04-2	1.01	0.10	3.98	0.02	2.44	47.99	33.56	0.00	6.70	0.65	0.05	0.02	0.00	27.63	0.03	9.10	99.70	Limonite	1			
DB04-3	1.31	0.04	1.29	0.00	1.89	18.84	13.18	0.00	28.60	0.24	0.03	0.00	0.00	36.09	0.00	11.70	100.03	Saprolite	3			
DB04-4	1.57	0.04	1.05	0.02	1.10	18.84	13.18	0.00	26.98	0.30	0.02	0.00	0.00	37.77	0.00	11.40	99.08	Saprolite	3	2.00	1.00	0.00
DB05-1	0.30	0.00	20.52	0.02	3.38	49.52	34.63	0.00	1.15	0.09	0.04	0.04	0.02	6.37	1.02	16.60	99.03	Limonite	1			
DB05-2	0.49	0.00	13.60	0.02	2.63	63.61	44.48	0.00	1.28	0.32	0.07	0.02	0.00	3.60	0.51	13.50	99.62	Limonite	1			
DB05-3	0.47	0.00	12.76	0.01	2.54	57.57	40.26	0.00	3.52	0.34	0.03	0.02	0.00	10.34	0.32	12.20	100.16	Limonite	1			
DB05-4	0.51	0.03	13.31	0.02	2.61	58.71	41.06	0.00	2.93	0.39	0.07	0.01	0.00	7.42	0.31	12.90	99.20	Limonite	1			
DB05-5	0.52	0.08	14.21	0.01	2.64	55.68	38.93	0.00	3.15	0.68	0.04	0.01	0.00	8.30	0.24	13.40	99.00	Limonite	1			
DB05-6	0.78	0.15	7.16	0.01	2.78	55.32	38.69	0.00	5.91	1.35	0.07	0.01	0.00	15.40	0.08	9.90	98.97	Limonite	1			
DB05-7	0.67	0.13	11.58	0.01	3.04	57.74	40.38	0.00	3.63	1.01	0.07	0.02	0.00	9.38	0.22	12.20	99.63	Limonite	1			
DB05-8	0.91	0.11	4.63	0.05	2.75	50.70	35.46	0.00	8.02	1.07	0.04	0.01	0.00	21.74	0.06	9.30	99.36	Limonite	1			
DB05-9	0.78	0.03	2.08	0.04	0.85	18.76	13.12	0.00	28.10	0.26	0.01	0.00	0.00	35.98	0.03	12.20	99.17	Saprolite	3	8.00	0.00	1.00
DB06-1	0.51	0.03	13.52	0.03	4.11	57.71	40.36	0.00	1.59	0.17	0.04	0.04	0.02	5.35	0.39	15.90	99.38	Limonite	1			
DB06-2	0.52	0.03	10.71	0.00	5.09	66.52	46.52	0.00	1.05	0.25	0.06	0.04	0.02	2.87	0.24	12.50	99.90	Limonite	1			
DB06-3	0.58	0.20	12.38	0.02	3.40	64.09	44.82	0.00	1.16	1.74	0.05	0.02	0.00	3.58	0.12	12.50	99.79	Limonite	1			
DB06-4	0.74	0.05	2.85	0.10	1.42	28.23	19.74	0.00	23.19	0.54	0.02	0.00	0.00	30.48	0.02	12.30	99.92	Transition	2	3.00	1.00	0.00

Table A1. *Cont.*

Sample	Ni	Co	Al_2O_3	CaO	Cr_2O_3	Fe_2O_3	Fe	K_2O	MgO	MnO	Na_2O	P_2O_5	P	SiO_2	TiO_2	LOI	Total	Horizons	Type No	Limonite [m]	Transition [m]	Saprolite [m]
DB07-1	0.33	0.01	19.85	0.03	3.56	50.71	35.46	0.00	0.79	0.11	0.04	0.04	0.02	6.04	0.84	17.00	99.36	Limonite	1			
DB07-2	0.66	0.01	14.41	0.01	2.90	60.80	42.52	0.00	0.94	0.18	0.05	0.02	0.00	4.51	0.45	14.90	99.83	Limonite	1			
DB07-3	0.80	0.04	9.28	0.00	3.62	66.30	46.36	0.00	1.76	0.74	0.05	0.02	0.00	4.59	0.21	11.80	99.17	Limonite	1			
DB07-4	0.84	0.15	8.75	0.00	2.77	61.05	42.69	0.00	3.36	1.46	0.06	0.01	0.00	9.56	0.11	11.60	99.73	Limonite	1			
DB07-5	0.77	0.08	5.25	0.00	2.64	50.89	35.59	0.00	6.61	0.80	0.05	0.01	0.00	22.72	0.06	9.50	99.38	Limonite	1			
DB07-6	0.71	0.11	3.67	0.00	2.17	43.75	30.59	0.00	9.09	0.90	0.09	0.00	0.00	30.62	0.00	8.10	99.18	Limonite	1			
DB07-7	0.70	0.12	4.12	0.02	2.10	41.58	29.07	0.00	8.91	1.11	0.14	0.01	0.00	32.44	0.05	8.30	99.57	Limonite	1			
DB07-8	0.68	0.26	6.26	0.00	1.56	27.42	19.17	0.00	4.12	2.49	0.02	0.00	0.00	48.87	0.02	7.80	99.47	Limonite	1			
DB07-9	0.61	0.11	3.09	0.00	1.71	32.73	22.89	0.00	8.16	1.00	0.02	0.00	0.00	44.08	0.03	7.60	99.18	Limonite	1			
DB07-10	0.64	0.11	3.10	0.00	1.73	32.86	22.98	0.00	8.17	1.00	0.08	0.00	0.00	43.94	0.02	7.80	99.48	Limonite	1			
DB07-11	0.88	0.09	4.55	0.00	2.23	42.89	29.99	0.00	6.16	0.91	0.10	0.00	0.00	32.16	0.06	9.20	99.27	Limonite	1	11.00	0.00	0.00
DB08-1	0.46	0.02	16.38	0.02	2.89	51.14	35.76	0.00	1.69	0.19	0.02	0.03	0.01	10.15	0.59	15.50	99.04	Limonite	1			
DB08-2	0.46	0.02	14.05	0.01	4.58	56.93	39.81	0.00	1.70	0.18	0.04	0.04	0.02	7.30	0.52	13.90	99.70	Limonite	1			
DB08-3	0.74	0.02	12.53	0.00	3.37	59.50	41.61	0.00	1.84	0.25	0.05	0.02	0.01	7.13	0.34	13.70	99.52	Limonite	1			
DB08-4	0.64	0.03	15.35	0.00	2.39	58.03	40.58	0.00	1.76	0.30	0.05	0.01	0.00	6.30	0.18	14.80	99.89	Limonite	1			
DB08-5	1.01	0.11	9.35	0.01	2.64	52.07	36.41	0.00	5.23	1.00	0.08	0.01	0.00	15.20	0.10	12.70	99.50	Limonite	1			
DB08-6	0.97	0.22	9.54	0.00	2.78	59.03	41.28	0.00	2.32	1.77	0.05	0.01	0.00	9.33	0.07	13.00	99.14	Limonite	1			
DB08-7	1.33	0.17	7.51	0.00	2.87	63.37	44.32	0.00	1.36	1.78	0.06	0.01	0.00	9.16	0.05	12.10	99.76	Limonite	1			
DB08-8	1.06	0.16	7.65	0.02	2.87	58.69	41.04	0.00	3.66	1.70	0.06	0.01	0.00	11.30	0.05	12.00	99.22	Limonite	1			
DB08-9	0.80	0.11	6.41	0.00	3.21	60.88	42.57	0.00	3.99	1.50	0.06	0.02	0.00	10.15	0.05	12.10	99.30	Limonite	1			
DB08-10	0.76	0.09	6.33	0.00	2.70	52.80	36.93	0.00	7.05	1.25	0.07	0.01	0.00	16.53	0.06	11.40	99.05	Limonite	1			
DB08-11	0.90	0.21	8.16	0.00	2.64	51.03	35.69	0.00	5.99	2.85	0.07	0.01	0.00	15.09	0.02	12.30	99.26	Limonite	1			
DB08-12	1.11	0.07	4.11	0.02	1.51	30.06	21.02	0.00	19.76	0.92	0.02	0.00	0.00	28.73	0.03	12.70	99.02	Transition	2			
DB08-13	0.91	0.04	2.54	0.05	1.06	22.75	15.91	0.00	23.49	0.52	0.01	0.00	0.00	35.10	0.02	12.60	99.09	Transition	2	11.00	2.00	0.00
DB10-1	0.60	0.01	11.38	0.01	2.75	61.35	42.90	0.00	1.99	0.36	0.04	0.02	0.00	9.25	0.27	12.00	99.98	Limonite	1			
DB10-2	0.70	0.04	8.50	0.00	2.86	55.20	38.60	0.00	6.08	0.45	0.04	0.02	0.00	14.29	0.12	11.00	99.27	Limonite	1			
DB10-3	0.79	0.22	7.02	0.00	2.41	46.95	32.83	0.00	9.11	1.18	0.08	0.01	0.00	20.96	0.05	10.40	99.15	Limonite	1			
DB10-4	1.06	0.06	3.24	0.01	1.40	26.50	18.53	0.00	23.17	0.37	0.05	0.00	0.00	31.99	0.04	11.30	99.24	Transition	2			
DB10-5	1.24	0.03	2.79	0.02	1.09	19.82	13.86	0.00	26.78	0.28	0.02	0.00	0.00	35.12	0.03	11.80	99.08	Transition	2			
DB10-6	1.31	0.04	3.26	0.04	1.29	26.40	18.46	0.00	23.10	0.36	0.03	0.00	0.00	31.78	0.05	11.30	98.96	Transition	2			
DB10-7	1.29	0.05	3.82	0.03	1.51	29.53	20.65	0.00	20.88	0.38	0.03	0.00	0.00	30.31	0.06	11.20	99.12	Transition	2	3.00	4.00	0.00
DB11-1	0.48	0.00	14.06	0.01	3.77	59.94	41.92	0.00	1.60	0.26	0.05	0.03	0.01	4.84	0.52	14.40	99.97	Limonite	1			
DB11-2	0.62	0.01	11.70	0.00	2.92	63.74	44.57	0.00	1.98	0.33	0.04	0.02	0.00	4.93	0.28	12.90	99.50	Limonite	1			
DB11-3	0.67	0.00	14.24	0.01	2.67	56.55	39.55	0.00	3.16	0.22	0.06	0.02	0.00	8.14	0.31	13.80	99.82	Limonite	1			
DB11-4	0.94	0.00	7.87	0.00	5.45	68.38	47.82	0.00	2.10	0.46	0.04	0.03	0.01	4.42	0.10	10.20	100.02	Limonite	1			
DB11-5	0.81	0.03	8.92	0.00	4.57	69.94	48.91	0.00	1.25	0.47	0.06	0.02	0.00	3.39	0.11	9.80	99.39	Limonite	1			
DB11-6	0.72	0.25	9.55	0.00	2.85	61.68	43.13	0.00	2.71	2.11	0.04	0.01	0.00	9.41	0.05	10.20	99.56	Limonite	1			
DBI 1-7	0.62	0.10	8.43	0.01	2.59	58.35	40.81	0.00	4.91	0.89	0.07	0.01	0.00	14.59	0.03	9.40	99.99	Limonite	1			
DB11-8	0.57	0.13	12.15	0.01	2.47	52.62	36.80	0.00	4.10	1.15	0.06	0.01	0.00	15.74	0.12	10.70	99.79	Limonite	1			
DBI 1-9	0.74	0.13	8.65	0.01	2.80	52.76	36.90	0.00	4.62	1.21	0.05	0.01	0.00	18.61	0.05	9.50	99.13	Limonite	1			
DB11-10	0.61	0.12	10.08	0.00	2.29	42.51	29.73	0.00	7.93	0.98	0.03	0.01	0.00	24.42	0.05	10.30	99.33	Limonite	1			
DB11-11	0.47	0.22	16.08	0.02	1.89	38.31	26.79	0.00	6.25	1.76	0.04	0.00	0.00	21.31	0.12	12.80	99.27	Limonite	1			
DB11-12	0.63	0.22	11.84	0.01	2.05	42.09	29.43	0.00	7.56	1.97	0.05	0.00	0.00	22.03	0.06	10.90	99.37	Limonite	1			
DB11-13	0.67	0.24	10.17	0.02	2.64	43.56	30.46	0.00	6.95	2.06	0.07	0.01	0.00	22.55	0.08	10.00	99.02	Limonite	1			
DB11-14	0.80	0.18	8.29	0.01	2.65	46.68	32.64	0.00	7.84	1.63	0.04	0.01	0.00	21.06	0.06	9.90	99.14	Limonite	1			
DB11-15	0.77	0.16	6.96	0.02	2.87	45.65	31.92	0.00	8.11	1.54	0.05	0.01	0.00	23.86	0.05	9.00	99.00	Limonite	1	15.00	0.00	0.00

Table A1. *Cont.*

Sample	Ni	Co	Al_2O_3	CaO	Cr_2O_3	Fe_2O_3	Fe	K_2O	MgO	MnO	Na_2O	P_2O_5	P	SiO_2	TiO_2	LOI	Total	Horizons	Type No	Limonite [m]	Transition [m]	Saprolite [m]
DB12-01	0.78	0.01	9.76	0.01	3.41	67.22	47.00	0.00	1.60	0.33	0.07	0.03	0.01	3.49	0.25	13.20	100.16	Limonite	1			
DB12-02	1.02	0.01	7.67	0.01	3.71	68.55	47.94	0.00	2.04	0.38	0.06	0.02	0.00	4.25	0.15	11.90	99.81	Limonite	1			
DB12-03	0.92	0.09	8.05	0.00	3.61	69.94	48.91	0.00	1.62	0.93	0.08	0.02	0.00	3.18	0.11	10.80	99.31	Limonite	1			
DB12-04	0.95	0.22	8.99	0.00	3.47	65.20	45.59	0.00	2.17	1.72	0.08	0.02	0.00	4.90	0.06	11.80	99.61	Limonite	1			
DB12-05	1.13	0.17	9.86	0.00	2.68	57.56	40.25	0.00	2.89	1.36	0.05	0.01	0.00	11.35	0.08	12.40	99.54	Limonite	1			
DB12-06	0.64	0.16	15.56	0.00	2.40	53.05	37.10	0.00	2.12	1.18	0.05	0.01	0.00	11.38	0.08	12.50	99.14	Limonite	1			
DB12-07	0.72	0.12	14.30	0.00	2.25	47.37	33.13	0.00	2.74	0.87	0.03	0.01	0.00	18.16	0.08	12.70	99.35	Limonite	1			
DB12-08	0.78	0.22	12.19	0.01	2.46	50.33	35.19	0.00	2.57	1.56	0.05	0.01	0.00	16.45	0.07	12.60	99.31	Limonite	1			
DB12-09	0.61	0.21	11.09	0.00	2.22	44.24	30.94	0.00	3.34	1.47	0.03	0.01	0.00	25.12	0.08	10.90	99.32	Limonite	1			
DB12-10	0.95	0.13	4.91	0.20	1.89	35.44	24.78	0.00	15.42	1.05	0.02	0.00	0.00	28.85	0.01	10.30	99.20	Transition	2	9.00	1.00	0.00
DB13-1	0.66	0.01	8.57	0.00	3.75	70.57	49.35	0.00	1.13	0.36	0.08	0.02	0.01	3.16	0.16	11.50	99.95	Limonite	1			
DB13-2	0.73	0.01	7.40	0.20	3.73	67.87	47.46	0.03	2.48	0.39	0.16	0.03	0.01	6.57	0.10	9.40	99.07	Limonite	1			
DB13-3	0.69	0.02	5.52	0.00	4.54	76.19	53.28	0.00	1.36	0.42	0.06	0.02	0.00	2.24	0.04	9.10	100.18	Limonite	1			
DB13-4	0.87	0.02	5.83	0.00	3.60	75.57	52.84	0.00	1.14	0.44	0.06	0.02	0.00	2.50	0.05	9.30	99.40	Limonite	1			
DB13-5	0.72	0.08	5.88	0.00	2.69	75.72	52.95	0.00	1.10	0.65	0.05	0.01	0.00	4.08	0.03	8.80	99.79	Limonite	1			
DB13-6	0.80	0.08	9.79	0.00	1.68	60.73	42.47	0.00	2.36	0.38	0.04	0.00	0.00	13.34	0.15	10.60	99.96	Limonite	1			
DB13-7	1.27	0.15	7.79	0.12	1.96	50.85	35.56	0.00	6.00	1.12	0.04	0.01	0.00	20.05	0.06	9.70	99.17	Limonite	1			
DB13-8	1.45	0.15	19.99	0.13	0.78	22.74	15.90	0.00	7.81	1.14	0.04	0.00	0.00	32.08	0.09	12.90	99.28	Transition	2	7.00	1.00	0.00
DB14-1	0.62	0.03	13.36	0.02	2.35	54.23	37.92	0.00	3.16	0.21	0.05	0.03	0.01	9.69	0.39	15.20	99.38	Limonite	1			
DB14-2	0.82	0.16	8.70	0.00	2.48	62.67	43.82	0.00	3.41	0.92	0.09	0.02	0.00	8.27	0.17	12.10	99.81	Limonite	1			
DB14-3	1.06	0.12	9.02	0.03	2.01	46.97	32.85	0.00	9.31	0.66	0.10	0.02	0.00	17.36	0.20	13.10	100.00	Limonite	1			
DB14-4	1.06	0.02	2.21	0.07	0.63	12.98	9.08	0.00	29.17	0.19	0.02	0.00	0.00	40.16	0.03	13.10	99.62	Saprolite	3	3.00	0.00	1.00
DB15-1	0.36	0.00	19.86	0.02	2.93	49.22	34.42	0.00	1.63	0.10	0.04	0.03	0.01	7.72	0.92	16.40	99.20	Limonite	1			
DB15-2	0.62	0.02	13.38	0.02	2.99	57.31	40.08	0.00	3.60	0.21	0.05	0.02	0.00	7.23	0.46	13.80	99.69	Limonite	1			
DB15-3	0.59	0.02	12.40	0.01	3.46	63.02	44.07	0.00	1.81	0.21	0.06	0.02	0.01	4.96	0.34	13.30	100.16	Limonite	1			
DB15-4	0.89	0.29	12.10	0.00	3.89	59.65	41.72	0.00	2.23	2.06	0.05	0.02	0.00	5.89	0.15	12.40	99.67	Limonite	1			
DB15-5	0.70	0.16	11.57	0.00	2.89	57.99	40.55	0.00	3.49	1.31	0.06	0.02	0.00	8.73	0.21	12.50	99.66	Limonite	1			
DB15-6	0.82	0.12	8.31	0.00	3.25	62.53	43.73	0.00	3.57	1.04	0.07	0.01	0.00	9.05	0.11	11.00	99.94	Limonite	1			
DB15-7	1.00	0.14	6.78	0.00	3.40	64.53	45.13	0.00	3.21	1.28	0.06	0.02	0.00	7.56	0.10	11.00	99.03	Limonite	1			
DB15-8	1.09	0.13	6.02	0.00	2.92	61.80	43.22	0.00	4.96	1.35	0.08	0.01	0.00	10.86	0.03	10.40	99.66	Limonite	1			
DB15-9	1.09	0.23	6.63	0.00	2.63	58.36	40.81	0.00	4.69	2.30	0.07	0.01	0.00	12.51	0.05	10.70	99.23	Limonite	1			
DB15-10	0.94	0.17	7.40	0.00	2.91	54.60	38.18	0.00	6.50	1.71	0.07	0.01	0.00	14.52	0.08	10.50	99.39	Limonite	1			
DB15-11	0.99	0.16	7.10	0.00	2.56	55.54	38.84	0.00	6.26	1.42	0.07	0.01	0.00	14.60	0.05	10.40	99.17	Limonite	1			
DB15-12	0.91	0.07	3.13	0.04	1.60	28.44	19.89	0.00	23.25	0.66	0.03	0.00	0.00	30.39	0.02	10.50	99.09	Transition	2	11.00	1.00	0.00
DB17-1	0.57	0.17	8.58	0.02	2.45	51.89	36.29	0.00	4.38	1.09	0.07	0.02	0.00	18.72	0.11	11.10	99.13	Limonite	1			
DB17-2	1.42	0.07	3.38	0.02	1.06	22.68	15.86	0.00	24.85	0.41	0.02	0.00	0.00	33.91	0.04	12.00	99.85	Transition	2			
DB17-3	1.62	0.04	2.34	0.03	0.87	18.05	12.62	0.00	27.79	0.28	0.05	0.00	0.00	36.58	0.05	11.90	99.59	Saprolite	3			
DB17-4	1.24	0.05	2.83	0.02	1.20	24.49	17.13	0.00	23.27	0.37	0.02	0.00	0.00	34.59	0.05	11.00	99.10	Saprolite	3			
DB17-5	0.93	0.03	2.91	0.02	0.82	17.25	12.05	0.00	28.09	0.29	0.02	0.00	0.00	37.73	0.07	11.70	99.82	Saprolite	3	1.00	1.00	3.00

Table A1. *Cont.*

Sample	Ni	Co	Al_2O_3	CaO	Cr_2O_3	Fe_2O_3	Fe	K_2O	MgO	MnO	Na_2O	P_2O_5	P	SiO_2	TiO_2	LOI	Total	Horizons	Type No	Limonite [m]	Transition [m]	Saprolite [m]
DB18-1	0.57	0.04	18.43	0.02	2.37	50.70	35.45	0.00	1.29	0.31	0.09	0.02	0.00	8.93	0.27	16.30	99.31	Limonite	1			
DB18-2	0.56	0.05	14.42	0.02	4.04	53.88	37.68	0.00	1.90	0.38	0.06	0.02	0.00	11.16	0.16	13.60	100.22	Limonite	1			
DB18-3	0.69	0.14	13.61	0.01	3.15	50.79	35.52	0.00	1.61	0.95	0.05	0.02	0.00	14.32	0.13	13.60	99.00	Limonite	1			
DB18-4	0.79	0.24	9.52	0.00	3.26	62.36	43.61	0.00	2.11	1.86	0.05	0.01	0.00	7.65	0.04	11.20	99.11	Limonite	1			
DB18-5	0.92	0.26	8.38	0.00	3.47	65.84	46.04	0.00	2.30	2.36	0.06	0.02	0.00	6.58	0.04	9.70	99.91	Limonite	1			
DB18-6	0.79	0.17	9.55	0.00	3.13	64.48	45.09	0.00	1.93	1.60	0.06	0.01	0.00	6.56	0.06	11.10	99.48	Limonite	1			
DB18-7	0.98	0.33	9.07	0.00	3.19	63.66	44.52	0.00	2.50	2.72	0.05	0.01	0.00	6.11	0.02	10.60	99.21	Limonite	1			
DB18-8	0.98	0.34	11.55	0.00	2.59	53.98	37.75	0.00	4.01	2.75	0.05	0.01	0.00	11.21	0.03	11.90	99.35	Limonite	1			
DB18-9	0.95	0.29	10.71	0.03	2.74	53.36	37.32	0.00	4.55	2.27	0.07	0.01	0.00	13.18	0.04	11.40	99.64	Limonite	1			
DB18-10	1.12	0.25	7.20	0.06	2.44	57.33	40.09	0.00	5.11	2.10	0.05	0.00	0.00	13.47	0.02	10.20	99.31	Limonite	1			
DB18-11	1.12	0.03	1.26	0.03	0.80	15.90	11.12	0.00	30.63	0.33	0.02	0.00	0.00	38.00	0.00	11.40	99.56	Saprolite	3			
DB18-12	1.22	0.02	1.07	0.04	0.77	12.46	8.72	0.00	32.17	0.22	0.03	0.00	0.00	40.16	0.00	11.80	99.91	Saprolite	3	10.00	0.00	2.00
DB20-1	0.48	0.02	16.42	0.02	3.50	56.93	39.81	0.00	1.13	0.55	0.06	0.04	0.02	5.97	0.62	14.40	100.19	Limonite	1			
DB20-2	0.50	0.00	18.61	0.02	2.63	53.53	37.43	0.00	0.99	0.11	0.04	0.03	0.01	6.78	0.72	15.80	99.73	Limonite	1			
DB20-3	1.08	0.24	9.54	0.00	2.77	66.14	46.25	0.00	1.10	1.89	0.08	0.02	0.00	4.39	0.15	12.40	99.85	Limonite	1			
DB20-4	1.01	0.14	10.04	0.00	3.49	62.74	43.87	0.00	1.28	1.20	0.06	0.03	0.01	7.46	0.26	12.10	99.76	Limonite	1	4.00	0.00	0.00
DB21-1	0.65	0.04	13.80	0.02	3.44	60.43	42.26	0.00	1.15	0.35	0.05	0.03	0.01	3.88	0.26	15.90	100.01	Limonite	1			
DB21-2	0.61	0.15	15.25	0.03	3.15	59.24	41.43	0.00	1.55	0.92	0.05	0.02	0.00	4.45	0.12	14.60	100.17	Limonite	1			
DB21-3	0.64	0.25	9.69	0.03	3.21	67.14	46.95	0.00	1.53	1.60	0.07	0.02	0.00	4.73	0.05	10.80	99.72	Limonite	1			
DB21-4	0.61	0.21	8.34	0.01	2.30	54.74	38.28	0.00	5.86	1.30	0.08	0.00	0.00	15.52	0.06	10.40	99.44	Limonite	1			
DB21-5	0.70	0.16	10.67	0.04	2.82	54.68	38.24	0.00	5.86	1.02	0.07	0.02	0.00	10.85	0.10	12.60	99.51	Limonite	1			
DB21-6	0.96	0.04	1.31	0.15	0.77	16.27	11.38	0.00	30.43	0.29	0.00	0.00	0.00	37.43	0.00	12.10	99.69	Saprolite	3	5.00	0.00	1.00
DB22-1	0.94	0.27	9.16	0.01	4.45	57.81	40.43	0.00	2.77	1.42	0.06	0.03	0.01	8.79	0.10	13.20	99.05	Limonite	1			
DB22-2	1.10	0.41	6.39	0.00	5.71	64.93	45.40	0.00	2.41	1.90	0.07	0.03	0.01	5.13	0.04	10.90	99.00	Limonite	1			
DB22-3	1.37	0.12	2.06	0.03	1.93	33.42	23.37	0.00	21.02	0.64	0.07	0.00	0.00	28.21	0.00	10.30	99.19	Transition	2			
DB22-4	1.65	0.09	3.98	0.12	1.77	29.25	20.45	0.00	18.75	0.47	0.11	0.01	0.00	33.50	0.04	9.60	99.32	Transition	2			
DB22-5	3.10	0.03	4.98	0.11	0.70	11.28	7.89	0.02	27.71	0.23	0.08	0.00	0.00	39.86	0.05	11.30	99.43	Saprolite	3			
DB22-6	1.60	0.06	2.17	0.16	1.16	19.58	13.69	0.00	27.89	0.36	0.08	0.00	0.00	38.81	0.00	7.80	99.66	Saprolite	3	2.00	2.00	2.00
DB23-1	0.86	0.23	12.72	0.01	2.70	56.20	39.30	0.00	1.44	1.49	0.03	0.02	0.00	8.23	0.18	15.70	99.77	Limonite	1			
DB23-2	1.17	0.35	9.78	0.00	2.48	59.31	41.47	0.00	2.15	2.33	0.08	0.01	0.00	7.62	0.07	14.30	99.66	Limonite	1			
DB23-3	0.66	0.16	5.31	0.00	3.61	37.50	26.22	0.00	1.49	1.32	0.01	0.02	0.00	40.72	0.01	8.30	99.08	Limonite	1			
DB23-4	0.45	0.08	2.52	0.01	1.43	23.04	16.11	0.00	1.63	0.56	0.00	0.00	0.00	64.80	0.01	5.10	99.58	Limonite	1			
DB23-5	1.45	0.03	2.84	0.12	0.80	17.61	12.32	0.00	24.30	0.25	0.03	0.00	0.00	40.65	0.05	11.50	99.69	Transition	2			
DB23-6	1.34	0.02	1.12	0.05	0.65	14.45	10.10	0.00	23.68	0.21	0.00	0.00	0.00	47.80	0.00	10.60	99.93	Transition	2			
DB23-7	1.25	0.03	2.38	0.19	0.57	12.81	8.95	0.00	27.45	0.22	0.05	0.00	0.00	43.31	0.03	11.80	100.07	Saprolite	3			
0B23-8	1.15	0.02	1.77	0.34	0.50	11.07	7.74	0.00	31.05	0.20	0.02	0.00	0.00	41.66	0.02	11.90	99.73	Saprolite	3			
DB23-9	1.31	0.03	1.77	0.21	1.09	17.82	12.46	0.00	24.54	0.29	0.02	0.00	0.00	41.46	0.02	11.20	99.76	Saprolite	3			
DB23-10	0.84	0.02	4.81	0.89	0.56	14.83	10.37	0.00	26.46	0.28	0.04	0.00	0.00	39.19	0.18	11.70	99.82	Saprolite	3			
DB23-11	1.31	0.03	0.51	0.02	0.71	16.96	11.86	0.00	23.90	0.22	0.00	0.00	0.00	45.12	0.00	10.80	99.53	Saprolite	3			
D823-12	1.28	0.02	0.57	0.09	0.58	13.05	9.13	0.00	29.39	0.22	0.00	0.00	0.00	42.27	0.00	11.80	99.24	Saprolite	3	4.00	2.00	6.00

Table A1. *Cont.*

Sample	Ni	Co	Al_2O_3	CaO	Cr_2O_3	Fe_2O_3	Fe	K_2O	MgO	MnO	Na_2O	P_2O_5	P	SiO_2	TiO_2	LOI	Total	Horizons	Type No	Limonite [m]	Transition [m]	Saprolite [m]
DB24-1	1.01	0.12	9.55	0.02	3.06	56.31	39.38	0.00	2.92	0.98	0.06	0.02	0.01	10.25	0.19	14.70	99.14	Limonite	1			
DB24-2	1.07	0.06	10.63	0.01	3.44	61.47	42.99	0.00	1.58	0.37	0.07	0.02	0.00	7.89	0.21	13.10	99.92	Limonite	1			
DB24-3	1.03	0.08	11.49	0.02	3.61	59.69	41.74	0.00	1.51	0.59	0.08	0.02	0.00	8.19	0.18	13.40	99.86	Limonite	1			
DB24-4	1.23	0.12	8.23	0.10	3.20	48.86	34.16	0.00	6.05	1.19	0.05	0.02	0.00	18.94	0.13	11.00	99.15	Limonite	1			
DB24-5	2.55	0.03	2.95	0.17	1.08	23.01	16.09	0.00	23.47	0.39	0.05	0.00	0.00	34.95	0.01	10.90	99.57	Transition	2			
DB24-6	2.87	0.00	0.41	0.10	0.40	8.88	6.21	0.00	33.01	0.14	0.01	0.00	0.00	42.90	0.00	11.00	99.70	Saprolite	3			
DB24-7	2.42	0.01	0.75	0.09	0.65	12.52	8.76	0.00	30.90	0.18	0.03	0.00	0.00	40.34	0.00	11.70	99.61	Saprolite	3			
DB24-8	2.16	0.02	0.84	0.08	0.73	13.24	9.26	0.00	31.12	0.22	0.03	0.00	0.00	39.38	0.00	11.90	99.75	Saprolite	3			
DB24-9	2.04	0.02	0.74	0.03	0.75	14.55	10.17	0.00	30.92	0.20	0.00	0.00	0.00	38.16	0.00	12.20	99.82	Saprolite	3	4.00	1.00	4.00
DB25-1	0.57	0.12	12.55	0.01	2.05	52.29	36.57	0.00	2.94	0.61	0.05	0.02	0.01	13.02	0.35	14.40	99.02	Limonite	1			
DB25-2	0.67	0.15	9.63	0.00	2.46	59.27	41.44	0.00	3.03	0.74	0.06	0.02	0.00	10.49	0.19	12.30	98.99	Limonite	1			
DB25-3	0.66	0.17	6.93	0.00	2.29	53.86	37.66	0.00	6.41	0.96	0.09	0.01	0.00	18.53	0.09	10.00	99.98	Limonite	1			
DB25-4	0.77	0.18	6.02	0.00	3.55	61.57	43.06	0.00	3.36	1.06	0.07	0.02	0.00	12.85	0.08	9.80	99.34	Limonite	1			
DB25-5	0.55	0.11	4.95	0.00	3.41	46.42	32.46	0.00	3.03	0.69	0.05	0.02	0.00	33.02	0.06	7.10	99.43	Limonite	1			
DB25-6	0.56	0.19	5.01	0.00	2.11	38.36	26.82	0.00	7.23	0.98	0.06	0.01	0.00	36.56	0.04	8.10	99.21	Limonite	1			
DB25-7	0.72	0.19	6.26	0.00	2.59	49.31	34.48	0.00	4.61	1.15	0.06	0.01	0.00	25.23	0.07	9.20	99.36	Limonite	1			
DB25-8	0.72	0.18	4.79	0.00	2.41	44.60	31.19	0.00	4.06	1.04	0.05	0.01	0.00	33.42	0.06	7.80	99.16	Limonite	1			
DB25-9	0.76	0.19	4.50	0.00	2.47	47.47	33.20	0.00	3.32	1.13	0.04	0.01	0.00	31.82	0.05	7.80	99.58	Limonite	1			
DB25-10	1.17	0.07	2.58	0.11	1.75	26.03	18.20	0.00	19.98	0.48	0.02	0.00	0.00	36.55	0.04	10.50	99.26	Transition	2			
DB25-11	0.84	0.02	0.97	0.04	0.68	12.94	9.05	0.00	29.51	0.19	0.02	0.00	0.00	43.44	0.05	11.40	100.08	Saprolite	3	9.00	1.00	1.00
DB26-1	0.87	0.15	10.25	0.02	2.86	60.47	42.29	0.00	2.74	1.14	0.08	0.02	0.00	9.21	0.11	11.70	99.63	Limonite	1			
DB26-2	1.32	0.23	7.80	0.03	2.88	57.48	40.20	0.00	4.51	1.39	0.08	0.01	0.00	12.77	0.06	11.40	99.96	Limonite	1			
DB26-3	1.21	0.35	8.12	0.00	3.10	50.12	35.05	0.00	5.36	2.04	0.10	0.01	0.00	17.72	0.02	10.90	99.04	Limonite	1			
DB26-4	1.86	0.33	4.30	0.00	3.14	56.94	39.82	0.00	6.79	1.63	0.06	0.01	0.00	12.20	0.00	11.80	99.03	Limonite	1			
DB26-5	1.91	0.05	0.79	0.02	0.96	17.86	12.49	0.00	30.21	0.30	0.02	0.00	0.00	34.94	0.00	12.50	99.55	Saprolite	3			
DB26-6	1.81	0.03	0.61	0.03	0.68	13.70	9.58	0.00	32.63	0.21	0.02	0.00	0.00	37.61	0.00	12.50	99.81	Saprolite	3			
DB26-7	1.91	0.02	0.25	0.02	0.51	11.28	7.89	0.00	33.87	0.16	0.01	0.00	0.00	39.17	0.00	12.60	99.81	Saprolite	3			
DB26-8	1.66	0.02	0.57	0.02	0.53	11.03	7.71	0.00	33.34	0.16	0.00	0.00	0.00	39.99	0.00	12.50	99.84	Saprolite	3	4.00	0.00	4.00
D827-1	0.79	0.19	8.19	0.01	2.63	60.18	42.08	0.00	1.55	1.57	0.07	0.02	0.00	12.57	0.09	12.10	99.93	Limonite	1			
DB27-2	1.20	0.65	7.53	0.00	1.63	53.77	37.60	0.00	1.11	4.31	0.05	0.00	0.00	18.39	0.00	11.00	99.65	Limonite	1			
DB27-3	1.05	0.41	7.95	0.02	2.52	53.01	37.07	0.00	3.72	2.69	0.07	0.01	0.00	18.25	0.00	9.30	99.01	Limonite	1			
D927-4	0.99	0.19	5.26	0.25	1.93	41.37	28.93	0.00	12.23	1.35	0.06	0.00	0.00	26.90	0.00	8.60	99.17	Limonite	1			
DB27-5	1.54	0.11	2.86	0.16	1.27	28.19	19.71	0.00	20.69	0.79	0.04	0.00	0.00	33.24	0.00	10.30	99.14	Limonite	1			
DB27-6	1.32	0.18	4.24	0.14	1.62	39.66	27.74	0.00	12.25	1.22	0.05	0.00	0.00	29.39	0.00	8.90	99.00	Limonite	1			
DB27-7	1.45	0.34	5.07	0.14	1.81	39.48	27.61	0.00	12.84	2.05	0.07	0.00	0.00	26.26	0.01	9.60	99.10	Limonite	1			
DB27-8	1.43	0.05	1.33	0.06	0.84	17.56	12.28	0.00	29.01	0.38	0.02	0.00	0.00	37.89	0.00	11.30	99.86	Saprolite	3	7.00	0.00	1.00
DB28-1	1.67	0.04	2.28	0.05	1.23	23.81	16.65	0.00	23.10	0.36	0.04	0.01	0.00	33.47	0.05	13.30	99.42	Transition	2			
DB28-2	2.10	0.01	0.62	0.03	0.49	10.08	7.05	0.00	32.66	0.15	0.03	0.00	0.00	40.21	0.00	13.10	99.50	Saprolite	3			
D628-3	1.62	0.02	0.72	0.03	0.69	15.45	10.80	0.00	28.32	0.20	0.00	0.00	0.00	40.82	0.00	11.60	99.51	Saprolite	3			
DB28-4	1.67	0.02	0.61	0.00	1.17	16.07	11.23	0.00	26.26	0.23	0.00	0.00	0.00	42.79	0.00	11.10	99.91	Saprolite	3			
D828-5	1.55	0.02	0.81	0.02	1.17	12.40	8.67	0.00	27.01	0.16	0.00	0.00	0.00	45.90	0.00	10.70	99.78	Saprolite	3	0.00	1.00	4.00

Table A1. *Cont.*

Sample	Ni	Co	Al_2O_3	CaO	Cr_2O_3	Fe_2O_3	Fe	K_2O	MgO	MnO	Na_2O	P_2O_5	P	SiO_2	TiO_2	LOI	Total	Horizons	Type No	Limonite [m]	Transition [m]	Saprolite [m]
DB29-1	0.84	0.18	11.43	0.02	3.70	57.71	40.36	0.00	2.02	1.36	0.07	0.03	0.01	8.24	0.10	13.50	99.18	Limonite	1			
DB29-2	0.83	0.19	9.89	0.01	3.04	60.53	42.33	0.00	4.05	1.38	0.09	0.02	0.00	9.11	0.03	10.20	99.36	Limonite	1			
DB29-3	1.27	0.23	6.68	0.08	3.21	63.62	44.49	0.00	3.68	1.67	0.09	0.02	0.00	10.55	0.02	8.50	99.65	Limonite	1			
DB29-4	1.44	0.14	5.70	0.10	3.01	62.32	43.58	0.00	4.97	1.11	0.10	0.01	0.00	12.60	0.04	7.90	99.45	Limonite	1			
DB29-5	2.06	0.03	0.98	0.03	0.71	14.42	10.08	0.00	30.87	0.21	0.00	0.00	0.00	37.66	0.00	12.10	99.08	Saprolite	3			
DB29-6	2.06	0.02	0.70	0.03	0.51	10.87	7.60	0.00	33.02	0.16	0.00	0.00	0.00	39.52	0.00	12.20	99.13	Saprolite	3			
DB29-7	1.84	0.03	1.66	0.05	0.84	16.74	11.70	0.00	29.45	0.27	0.02	0.00	0.00	35.94	0.00	12.40	99.26	Saprolite	3			
DB29-8	1.84	0.02	0.75	0.04	0.58	11.94	8.35	0.00	33.09	0.17	0.02	0.00	0.00	38.92	0.00	12.20	99.54	Saprolite	3	4.00	0.00	4.00
DB30-2	0.60	0.21	5.36	0.00	1.74	37.48	26.21	0.00	4.48	1.18	0.02	0.01	0.00	40.40	0.07	7.70	99.22	Limonite	1			
DB30-3	0.68	0.22	3.47	0.00	2.16	45.97	32.14	0.00	3.39	1.27	0.04	0.00	0.00	35.91	0.00	6.20	99.28	Limonite	1			
DB30-4	0.73	0.08	1.57	0.00	1.34	30.83	21.56	0.00	12.11	0.52	0.05	0.00	0.00	45.24	0.00	6.80	99.25	Transition	2			
DB30-5	1.18	0.03	0.71	0.02	0.81	15.64	10.94	0.00	25.60	0.21	0.00	0.00	0.00	44.28	0.00	10.80	99.30	Transition	2	2.00	2.00	0.00
DB31-1	0.55	0.04	12.66	0.02	3.12	57.26	40.04	0.00	2.26	0.54	0.08	0.02	0.01	10.75	0.26	11.90	99.42	Limonite	1			
DB31-2	0.66	0.09	13.18	0.02	2.37	52.97	37.04	0.00	2.46	0.66	0.06	0.02	0.00	15.07	0.34	11.40	99.32	Limonite	1			
DB31-3	0.67	0.05	16.19	0.02	2.30	45.69	31.95	0.00	2.01	0.57	0.06	0.03	0.01	18.70	0.50	12.30	99.13	Limonite	1	3.00	0.00	0.00
DB32-1	0.59	0.02	16.06	0.02	1.99	43.15	30.17	0.00	2.84	0.12	0.04	0.02	0.00	19.54	0.36	14.70	99.43	Limonite	1			
DB32-2	0.70	0.06	10.76	0.01	2.61	55.35	38.71	0.00	3.79	0.48	0.07	0.02	0.00	14.64	0.19	11.30	100.02	Limonite	1			
DB32-3	0.77	0.13	8.19	0.01	3.47	60.94	42.61	0.00	2.91	0.95	0.08	0.02	0.00	12.29	0.11	9.50	99.32	Limonite	1			
DB32-4	0.84	0.15	6.83	0.00	2.93	63.44	44.37	0.00	1.92	1.14	0.05	0.01	0.00	12.95	0.06	8.90	99.25	Limonite	1			
DB32-5	1.54	0.06	7.26	0.14	1.62	32.40	22.66	0.00	12.31	0.52	0.19	0.01	0.00	32.96	0.06	10.10	99.17	Transition	2			
DB32-6	2.02	0.02	1.92	0.08	0.68	14.13	9.88	0.00	28.06	0.20	0.13	0.00	0.00	41.01	0.00	11.40	99.71	Saprolite	3	4.00	1.00	1.00
DB33-1	0.51	0.02	16.57	0.02	2.42	51.03	35.68	0.00	1.81	0.29	0.04	0.03	0.01	12.27	0.57	13.70	99.32	Limonite	1			
DB33-2	0.73	0.04	13.75	0.03	2.43	58.25	40.73	0.00	1.63	0.34	0.05	0.02	0.00	8.80	0.39	13.30	99.77	Limonite	1			
DB33-3	0.63	0.05	13.31	0.00	3.31	53.23	37.23	0.00	2.12	0.53	0.06	0.03	0.01	14.74	0.37	11.70	100.13	Limonite	1			
DB33-4	0.76	0.35	10.05	0.00	3.28	58.70	41.05	0.00	2.48	2.61	0.06	0.02	0.00	11.84	0.16	9.20	99.53	Limonite	1			
DB33-5	0.75	0.29	8.44	0.01	2.86	58.32	40.78	0.00	4.27	2.07	0.06	0.02	0.00	13.26	0.14	8.90	99.35	Limonite	1			
DB33-6	0.59	0.07	5.89	0.11	1.83	36.61	25.60	0.00	6.83	0.55	0.00	0.01	0.00	39.08	0.13	7.40	99.12	Limonite	1			
DB33-7	0.75	0.08	6.60	0.18	2.20	44.29	30.97	0.00	7.23	0.67	0.06	0.01	0.00	28.77	0.15	8.40	99.38	Limonite	1			
DB33-8	0.98	0.05	5.38	0.08	1.63	31.42	21.97	0.00	17.56	0.48	0.03	0.00	0.00	30.05	0.12	11.20	99.00	Transition	2			
DB33-9	1.22	0.02	1.11	0.12	0.69	13.69	9.57	0.00	31.34	0.20	0.02	0.00	0.00	39.04	0.00	12.30	99.72	Saprolite	3			
DB33-10	1.22	0.01	0.65	0.06	0.55	11.34	7.93	0.00	31.21	0.16	0.02	0.00	0.00	42.29	0.00	11.70	99.16	Saprolite	3			
DB33-11	0.82	0.01	0.52	0.08	0.40	9.04	6.32	0.00	34.86	0.13	0.00	0.00	0.00	41.84	0.00	12.30	100.00	Saprolite	3			
DB33-12	0.48	0.01	0.43	0.05	0.37	8.15	5.70	0.00	35.19	0.12	0.03	0.00	0.00	43.09	0.00	12.20	100.11	Saprolite	3	7.00	1.00	4.00
DB34-1	0.41	0.01	16.19	0.03	2.28	40.89	28.59	0.00	1.93	0.11	0.04	0.02	0.01	23.28	0.54	13.30	98.99	Limonite	1			
DB34-2	0.62	0.01	14.84	0.02	2.29	48.34	33.80	0.00	2.33	0.15	0.03	0.02	0.00	17.60	0.46	12.30	98.98	Limonite	1			
DB34-3	0.64	0.09	11.55	0.00	2.78	54.05	37.80	0.00	2.13	0.62	0.04	0.02	0.00	16.18	0.20	10.90	99.22	Limonite	1			
DB34-4	1.01	0.16	6.65	0.00	2.81	62.05	43.39	0.00	1.94	1.29	0.06	0.01	0.00	12.91	0.07	10.30	99.25	Limonite	1			
DB34-5	0.68	0.12	4.14	0.00	2.48	43.73	30.58	0.00	2.99	1.19	0.04	0.01	0.00	37.85	0.03	6.00	99.27	Limonite	1			
DB34-6	0.77	0.16	4.44	0.00	2.39	47.54	33.24	0.00	5.42	1.23	0.08	0.01	0.00	29.91	0.03	7.20	99.15	Limonite	1			
DB34-7	0.91	0.16	4.40	0.00	2.52	53.17	37.18	0.00	3.81	1.37	0.09	0.01	0.00	24.65	0.02	8.20	99.29	Limonite	1			
DB34-8	0.43	0.05	2.57	0.01	1.25	26.50	18.53	0.00	2.30	0.47	0.00	0.00	0.00	61.86	0.02	4.30	99.79	Transition	2			
DB34-9	1.80	0.03	2.07	0.06	1.19	24.34	17.02	0.00	22.37	0.34	0.01	0.00	0.00	36.55	0.00	10.50	99.29	Transition	2			
DB34-10	2.04	0.02	0.85	0.05	0.61	13.40	9.37	0.00	29.52	0.19	0.05	0.00	0.00	40.98	0.00	11.60	99.25	Saprolite	3	7.00	2.00	1.00

Table A1. *Cont.*

Sample	Ni	Co	Al_2O_3	CaO	Cr_2O_3	Fe_2O_3	Fe	K_2O	MgO	MnO	Na_2O	P_2O_5	P	SiO_2	TiO_2	LOI	Total	Horizons	Type No	Limonite [m]	Transition [m]	Saprolite [m]
DB35-2	0.78	0.04	9.44	0.01	2.72	61.28	42.85	0.00	2.56	0.47	0.10	0.02	0.00	10.07	0.22	11.90	99.56	Limonite	1			
DB35-3	0.87	0.08	7.72	0.00	2.76	64.96	45.43	0.00	2.45	0.74	0.10	0.02	0.00	9.53	0.11	9.90	99.28	Limonite	1			
DB35-4	0.86	0.22	8.33	0.00	3.03	60.81	42.52	0.00	1.67	1.35	0.08	0.02	0.00	13.69	0.04	9.60	99.65	Limonite	1			
DB35-5	1.40	0.08	4.53	0.03	2.01	42.13	29.46	0.00	13.48	0.57	0.09	0.01	0.00	24.10	0.07	10.60	99.16	Limonite	1			
DB35-6	1.07	0.10	5.42	0.04	2.35	53.16	37.18	0.00	7.32	0.81	0.08	0.01	0.00	20.84	0.05	8.30	99.50	Limonite	1	5.00	0.00	0.00
DB36-1	0.67	0.00	15.48	0.02	2.02	50.83	35.55	0.00	2.42	0.14	0.05	0.02	0.00	12.50	0.57	14.40	99.04	Limonite	1			
D636-2	0.72	0.04	11.87	0.02	2.15	54.63	38.20	0.00	3.99	0.40	0.09	0.02	0.00	13.17	0.23	12.60	99.92	Limonite	1			
DB36-3	0.85	0.10	12.41	0.01	2.20	51.89	36.28	0.00	5.24	0.70	0.12	0.01	0.00	13.54	0.14	12.90	100.16	Limonite	1			
D636-4	0.93	0.19	8.37	0.00	2.55	56.05	39.20	0.00	4.75	1.32	0.10	0.01	0.00	12.73	0.10	12.40	99.48	Limonite	1			
D636-5	1.13	0.20	7.36	0.02	2.07	46.52	32.53	0.00	6.28	1.33	0.08	0.01	0.00	22.91	0.05	11.40	99.36	Limonite	1			
D836-6	2.15	0.03	2.51	0.07	1.08	22.14	15.48	0.00	24.16	0.30	0.04	0.00	0.00	34.94	0.03	12.30	99.71	Transition	2			
0636-7	2.11	0.02	2.00	0.06	0.78	16.56	11.58	0.00	27.88	0.21	0.03	0.00	0.00	37.34	0.03	12.70	99.75	Saprolite	3			
DB36-8	1.75	0.01	0.88	0.06	0.56	11.56	8.09	0.00	30.02	0.15	0.03	0.00	0.00	41.91	0.00	12.20	99.17	Saprolite	3			
DB36-9	1.32	0.05	4.12	0.08	1.20	25.81	18.05	0.00	20.95	0.40	0.04	0.00	0.00	33.38	0.07	12.50	99.94	Saprolite	3			
DB36-10	1.09	0.02	1.54	0.04	0.67	13.14	9.19	0.00	20.92	0.19	0.00	0.00	0.00	52.54	0.02	9.80	99.94	Saprolite	3			
DB36-11	1.10	0.01	0.84	0.12	0.51	9.73	6.81	0.00	33.04	0.13	0.02	0.00	0.00	41.27	0.00	12.60	99.38	Saprolite	3	5.00	1.00	5.00
DB38-1	0.73	0.14	7.56	0.01	2.53	49.99	34.96	0.00	5.24	0.87	0.07	0.02	0.00	19.43	0.12	12.40	99.14	Limonite	1			
DB38-2	1.00	0.15	6.45	0.00	6.45	60.32	42.18	0.00	3.01	1.02	0.08	0.04	0.02	10.23	0.06	10.80	99.59	Limonite	1			
DB38-3	0.89	0.18	4.56	0.02	2.79	41.34	28.91	0.00	7.00	1.04	0.12	0.02	0.00	32.30	0.02	8.90	99.20	Limonite	1			
0638-4	1.79	0.03	1.32	0.05	0.77	16.59	11.60	0.00	29.17	0.24	0.04	0.00	0.00	38.10	0.00	11.90	99.98	Saprolite	3			
DB38-5	1.47	0.04	2.89	0.06	1.27	20.62	14.42	0.00	25.82	0.34	0.04	0.00	0.00	35.76	0.00	11.50	99.79	Saprolite	3			
DB38-6	1.42	0.04	1.34	0.06	1.15	19.00	13.28	0.00	26.15	0.29	0.03	0.00	0.00	39.03	0.00	10.80	99.33	Saprolite	3			
DB38-7	1.22	0.04	1.41	0.11	1.17	20.48	14.32	0.00	24.18	0.31	0.06	0.00	0.00	40.44	0.00	9.80	99.26	Saprolite	3			
DB38-8	1.45	0.03	1.11	0.09	0.95	16.73	11.70	0.00	26.85	0.26	0.03	0.00	0.00	41.00	0.00	10.70	99.17	Saprolite	3			
DB38-9	1.27	0.02	4.39	1.16	0.66	13.09	9.16	0.03	27.29	0.21	0.10	0.00	0.00	40.45	0.10	10.90	99.65	Saprolite	3			
DB38-10	1.06	0.01	0.92	0.21	0.56	10.58	7.40	0.00	32.66	0.15	0.03	0.00	0.00	42.25	0.00	11.50	99.91	Saprolite	3			
DB38-11	0.81	0.02	1.15	0.16	0.64	11.92	8.33	0.00	31.55	0.17	0.05	0.00	0.00	42.06	0.00	11.40	99.94	Saprolite	3	3.00	0.00	8.00
DB39-1	0.76	0.01	11.63	0.02	2.34	56.98	39.84	0.00	3.72	0.17	0.11	0.02	0.01	9.30	0.40	14.40	99.82	Limonite	1			
DB39-2	0.93	0.06	9.96	0.01	2.48	60.81	42.53	0.00	3.66	0.54	0.10	0.02	0.00	8.59	0.24	12.50	99.88	Limonite	1			
DB39-3	0.75	0.13	9.98	0.00	2.62	59.32	41.48	0.00	4.18	1.01	0.08	0.02	0.00	9.88	0.11	11.90	99.96	Limonite	1			
DB39-4	0.85	0.16	8.63	0.00	2.73	59.46	41.58	0.00	4.40	1.25	0.07	0.01	0.00	10.15	0.08	11.70	99.53	Limonite	1			
DB39-5	1.13	0.13	6.36	0.02	3.16	65.01	45.46	0.00	3.29	1.17	0.10	0.02	0.00	8.43	0.06	10.90	99.73	Limonite	1			
DB39-6	1.44	0.09	3.61	0.01	1.61	36.13	25.27	0.00	17.47	0.79	0.04	0.00	0.00	24.82	0.03	13.30	99.31	Transition	2			
DB39-7	1.59	0.03	2.00	0.03	0.91	19.93	13.94	0.00	25.32	0.32	0.06	0.00	0.00	37.47	0.00	12.10	99.71	Saprolite	3	5.00	1.00	1.00
DB40-1	0.58	0.03	13.42	0.01	2.55	62.05	43.39	0.00	1.02	0.26	0.05	0.03	0.01	3.93	0.42	14.90	99.23	Limonite	1			
DB40-2	0.71	0.15	9.91	0.00	2.58	66.80	46.71	0.00	1.22	1.08	0.08	0.02	0.00	4.66	0.15	12.00	99.30	Limonite	1			
DB40-3	0.75	0.25	12.84	0.02	2.72	60.99	42.65	0.00	2.30	1.72	0.08	0.02	0.00	6.16	0.14	11.60	99.63	Limonite	1			
DB40-4	1.38	0.06	3.98	0.02	1.53	30.05	21.02	0.00	21.16	0.46	0.06	0.00	0.00	28.38	0.06	12.30	99.44	Transition	2	3.00	1.00	0.00
DB41-1	0.74	0.01	11.68	0.01	2.54	55.79	39.02	0.00	2.87	0.12	0.09	0.02	0.01	9.76	0.45	15.20	99.26	Limonite	1			
DB41-2	0.86	0.09	8.71	0.00	2.79	58.50	40.91	0.00	3.57	0.55	0.07	0.02	0.00	10.58	0.16	13.40	99.30	Limonite	1			
DB41-3	0.72	0.17	9.54	0.00	2.45	55.69	38.94	0.00	4.68	1.03	0.08	0.01	0.00	11.75	0.11	13.10	99.36	Limonite	1			
DB41-4	0.66	0.31	11.56	0.01	2.40	55.36	38.71	0.00	4.00	1.78	0.06	0.01	0.00	9.46	0.10	13.90	99.57	Limonite	1			
DB41-5	0.68	0.24	9.07	0.03	2.41	52.83	36.94	0.00	6.17	1.48	0.08	0.01	0.00	13.94	0.09	12.80	99.83	Limonite	1			
DB41-6	0.84	0.13	6.70	0.12	1.84	40.05	28.00	0.00	13.97	0.77	0.06	0.00	0.00	22.00	0.11	12.60	99.13	Limonite	1			
DB41-7	0.57	0.02	0.98	0.16	0.68	12.32	8.61	0.00	32.82	0.19	0.03	0.00	0.00	40.65	0.00	11.80	100.17	Saprolite	3	6.00	0.00	1.00

Table A1. *Cont.*

Sample	Ni	Co	Al_2O_3	CaO	Cr_2O_3	Fe_2O_3	Fe	K_2O	MgO	MnO	Na_2O	P_2O_5	P	SiO_2	TiO_2	LOI	Total	Horizons	Type No	Limonite [m]	Transition [m]	Saprolite [m]
DB42-1	0.69	0.01	10.98	0.02	2.78	57.44	40.17	0.00	3.49	0.22	0.10	0.02	0.00	8.62	0.25	14.80	99.36	Limonite	1			
DB42-2	0.74	0.08	8.72	0.01	3.37	66.52	46.52	0.00	2.81	0.77	0.09	0.02	0.00	6.07	0.10	10.60	99.88	Limonite	1			
DB42-3	0.88	0.13	8.25	0.01	3.71	66.26	46.34	0.00	2.33	1.04	0.07	0.02	0.00	5.01	0.11	11.40	99.22	Limonite	1			
DB42-4	0.80	0.19	8.04	0.00	3.39	63.59	44.47	0.00	3.52	1.44	0.10	0.01	0.00	7.69	0.04	10.80	99.59	Limonite	1			
DB42-5	0.88	0.08	4.43	0.05	1.87	36.54	25.55	0.00	18.81	0.64	0.04	0.00	0.00	24.27	0.03	11.50	99.18	Transition	2			
DB42-6	1.00	0.02	0.81	0.11	0.60	13.18	9.22	0.00	32.60	0.18	0.02	0.00	0.00	39.42	0.00	11.80	99.69	Saprolite	3			
DB42-7	0.93	0.03	1.78	0.09	0.93	19.73	13.80	0.00	27.79	0.27	0.00	0.00	0.00	36.16	0.01	11.50	99.21	Saprolite	3			
DB42-8	0.45	0.01	0.65	0.08	0.50	9.73	6.81	0.00	35.06	0.13	0.02	0.00	0.00	40.90	0.00	12.20	99.69	Saprolite	3			
DB42-9	0.44	0.01	0.57	0.09	0.47	9.32	6.52	0.00	35.27	0.14	0.06	0.00	0.00	41.45	0.00	12.40	100.19	Saprolite	3	4.00	1.00	4.00
DB43-1	0.49	0.02	14.51	0.03	2.56	55.04	38.49	0.00	2.76	0.22	0.06	0.02	0.00	7.61	0.51	15.80	99.59	Limonite	1			
DB43-2	0.66	0.08	11.67	0.01	2.65	66.21	46.30	0.00	1.12	0.65	0.06	0.01	0.00	3.03	0.17	13.00	99.28	Limonite	1			
DB43-3	0.64	0.11	11.48	0.01	2.85	65.13	45.55	0.00	1.30	0.99	0.08	0.01	0.00	3.23	0.15	13.20	99.22	Limonite	1			
DB43-4	0.73	0.21	10.17	0.00	2.91	66.20	46.29	0.00	1.18	1.54	0.08	0.01	0.00	2.99	0.10	13.70	99.80	Limonite	1			
DB43-5	0.82	0.23	8.91	0.00	3.29	67.42	47.14	0.00	1.12	1.97	0.06	0.01	0.00	2.78	0.07	12.40	99.03	Limonite	1			
DB43-6	1.14	0.07	4.79	0.05	1.82	36.80	25.73	0.00	16.99	0.70	0.02	0.00	0.00	23.60	0.07	13.00	99.09	Transition	2			
DB43-7	1.13	0.03	2.23	0.08	1.12	21.61	15.11	0.00	25.95	0.34	0.02	0.00	0.00	34.65	0.02	12.50	99.67	Saprolite	3	5.00	1.00	1.00
DB44-1	0.75	0.00	10.18	0.01	2.49	60.87	42.56	0.00	2.99	0.16	0.05	0.02	0.00	7.06	0.33	14.80	99.71	Limonite	1			
D844-2	0.79	0.00	9.19	0.00	2.50	58.45	40.87	0.00	4.61	0.15	0.08	0.02	0.00	9.88	0.25	13.40	99.33	Limonite	1			
D844-3	0.87	0.01	10.38	0.00	2.69	57.85	40.46	0.00	4.05	0.18	0.06	0.01	0.00	9.58	0.14	13.80	99.63	Limonite	1			
DB44-4	0.88	0.06	7.67	0.00	3.04	61.92	43.30	0.00	3.90	0.58	0.08	0.01	0.00	8.75	0.05	12.80	99.77	Limonite	1			
DB44-5	0.77	0.07	9.64	0.00	2.67	54.13	37.85	0.00	5.97	0.59	0.11	0.01	0.00	12.85	0.08	13.10	99.99	Limonite	1			
DB44-6	0.72	0.10	8.50	0.00	2.86	57.07	39.91	0.00	5.43	0.99	0.09	0.01	0.00	11.87	0.04	12.20	99.82	Limonite	1			
DB44-7	0.72	0.22	7.24	0.00	2.77	56.06	39.20	0.00	5.74	1.71	0.08	0.01	0.00	14.20	0.02	10.90	99.61	Limonite	1			
DB44-8	0.71	0.22	10.71	0.00	2.44	53.07	37.11	0.00	5.19	1.74	0.07	0.01	0.00	12.56	0.03	13.30	100.05	Limonite	1			
DB44-9	0.91	0.02	1.18	0.15	0.72	15.19	10.62	0.00	30.94	0.23	0.00	0.00	0.00	38.65	0.00	11.80	99.77	Saprolite	3			
DB44-10	0.97	0.01	0.62	0.06	0.55	12.64	8.84	0.00	32.72	0.16	0.00	0.00	0.00	39.72	0.00	12.10	99.54	Saprolite	3	8.00	0.00	1.00

Table A2. Parameters of individual polygons used for resource estimation using the polygon method and results of calculations. Cut-off Ni ≥ 1.0 wt%. Calculations for the whole studied area (also outside the IUP concession boundary).

No. Polygon	Borehole	Area [m^2]	Thickness of Ore Deposit Ni [m]	Volume [m^3]	Bulk Density [t/m^3]	Resources of Mineral [t]	Abundance Ni [wt%]	Resources Ni [t]	Thickness of Ore Deposit Co [m]	Volume [m^3]	Bulk Density [t/m^3]	Resources of Mineral [t]	Abundance Ni [wt%]	Resources Co [t]
4	DB-02	79,566	3	238,697	1.10	263,363	1.28	3362	2	159,132	1.05	167,088	0.15	250.6
11	DB-03	54,715	1	54,715	0.99	54,168	1.03	558	1	54,715	0.99	54,168	0.18	97.5
2	DB-04	68,257	3	204,771	1.10	225,930	1.30	2930	2	136,514	1.05	143,339	0.07	100.3
22	DB-08	47,994	5	239,969	1.01	243,328	1.04	2531	5	239,969	1.01	243,328	0.14	350.4
14	DB-10	55,022	4	220,089	1.11	244,298	1.23	2993	4	220,089	1.11	244,298	0.05	109.9
24	DB-12	57,956	4	231,825	0.99	229,506	1.01	2307	4	231,825	0.99	229,506	0.12	281.1
16	DB-13	72,587	2	145,173	1.05	152,432	1.36	2073	2	145,173	1.05	152,432	0.15	228.6
13	DB-14	121,937	2	243,873	1.10	268,260	1.06	2844	1	121,937	0.99	120,717	0.12	144.9
25	DB-15	55,032	3	165,097	0.99	163,446	1.06	1733	3	165,097	0.99	163,446	0.17	272.4
17	DB-17	54,754	3	164,262	1.18	193,282	1.43	2757	1	54,754	1.11	60,777	0.07	42.5
26	DB-18	54,921	3	164,764	1.14	187,282	1.15	2160	1	54,921	0.99	54,372	0.25	135.9
27	DB-20	55,986	2	111,972	0.99	110,853	1.05	1158	2	111,972	0.99	110,853	0.19	210.6
18	DB-22	36,567	5	182,834	1.13	205,871	1.76	3632	3	109,700	1.07	117,379	0.21	242.6
20	DB-23	105,901	11	116,4906	1.13	131,8461	1.11	14,635	5	529,503	1.04	549,624	0.13	703.5
28	DB-24	48,947	8	391,580	1.12	436,611	1.92	8388	4	195,790	1.02	199,706	0.07	144.8
19	DB-25	110,960	1	110,960	1.11	123,166	1.17	1441	1	110,960	1.11	123,166	0.07	86.2
32	DB-26	42,764	7	299,350	1.12	333,989	1.67	5573	3	128,293	0.99	127,010	0.30	385.3
30	DB-27	57,448	7	402,133	1.02	410,750	1.28	5269	6	344,685	0.99	341,238	0.31	1069.2
33	DB-28	73,148	4	292,594	1.21	354,038	1.74	6143						
31	DB-29	48,295	6	289,772	1.14	329,374	1.75	5770	2	96,591	0.99	95,625	0.19	176.9
35	DB-30	29,124	1	29,124	1.11	32,327	1.18	381	1	29,124	1.11	32,327	0.03	9.7
34	DB-32	80,402	2	160,804	1.16	186,532	1.78	3320	1	80,402	1.11	89,246	0.06	53.5
39	DB-33	68,479	2	136,958	1.21	165,719	1.22	2022						
36	DB-34	24,251	2	48,501	1.16	56,262	1.92	1080	1	24,251	1.11	26,918	0.0	8.1
37	DB-35	111,086	2	222,172	0.99	219,950	1.24	2716	2	222,172	0.99	219,950	0.1	198.0
38	DB-36	62,865	7	440,056	1.16	512,351	1.52	7795	2	125,730	1.05	132,017	0.1	151.8
3	DB-38	52,971	9	476,740	1.16	553,548	1.29	7116	2	105,942	0.99	104,883	0.2	173.1
6	DB-39	53,962	3	161,885	1.10	178,613	1.39	2477	2	107,923	1.05	113,319	0.1	124.7
5	DB-40	56,917	1	56,917	1.11	63,178	1.38	872	1	56,917	1.11	63,178	0.1	37.9
10	DB-42	60,386	1	60,386	1.21	73,067	1.00	731						
7	DB-43	53,223	2	106,446	1.16	123,478	1.14	1401	1	53,223	1.11	59,078	0.07	41.4
Total		1,956,422		7219,323		8013,434		108,167		4017,302		4,138,989		5831.5
Average for the deposit			4		1.11		1.34		2		1.04		0.13	

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