ISSN: 1394-7990
Malaysian Journal of Soil Science Vol. 18: 35-49 (2014) Malaysian Society of Soil Science

Geochemical Characteristics of Serpentinite Soils from Malaysia

Mahsa Tashakor[1], *Wan Zuhairi Wan Yaacob[2], Hamzah Mohamad[3] and Azman A. Ghani[1]

[1]Department of Geology, Universiti Malaya, 50603 Kuala Lumpur, Malaysia
[2]Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia
[3]Center for Global Archaeological Research, Universiti Sains Malaysia, 11800 Penang, Malaysia

ABSTRACT

The geochemistry of ophiolite related serpentinite soils has been one of the most challenging concerns among soil scientists and ecologists for several decades. Despite increasing global knowledge about the specificity of serpentinites, they have received limited attention in Malaysia. Considering the role of climate in the chemical composition of the derived soils, this study focused on tropical serpentinite soils in Malaysia. A total of 27 soil samples was collected from five serpentinite outcrops in Peninsular Malaysia and Sabah and analysed elementally. Based on their major oxide contents, the soils were divided into two groups of 'rich in Fe' and 'rich in Mg' which represent mature and immature soils, respectively. However, the most striking result that emerged from this study was the anomalous concentration of three trace metals of chromium, nickel and cobalt in the studied serpentinite soils in comparison with those of the adjacent sedimentary soils (soils of Crocker). The observed elemental ranges were Cr 2,427-27,863, Ni 850-4,753 and Co 35-167 (in µg g^{-1}), while the ranges for these elements for the soils of Crocker formation were Cr 67-182, Ni 33-270 and Co 11-23 (in µg g^{-1}). It is obvious that the amounts of Cr, Ni and Co in the studied serpentinites soils were 105, 15 and 6 times higher, respectively, than those in Crocker soils comparing with the Dutch List standard and Great London Council guidelines, serpentinite soils of Malaysia can be considered to be heavily contaminated with Cr, Ni and Co.

Keywords: Chromium, nickel, cobalt, geochemistry, serpentinite soils

INTRODUCTION

Ophiolite-related ultramafic rocks, particularly serpentinites, crop out in fold-orogenic belts and on stable interior platforms of every continent. Circulation of the fluids that detach from the subducted block through the hot mantle peridotites which take place during the tectonic displacements and under temperatures of less than 500°C and fluid pH above 10 in the presence of low partial pressures of carbon dioxide (pCO_2) leads to serpentinisation. This process progressively changes the

*Corresponding author : E-mail: mahsa1593@yahoo.com

chemical and mineralogical composition of the initial ultramafic rocks. The sea-water-rock reaction transforms primary silicate minerals of olivine $(Mg,Fe)_2SiO_4$, and pyroxenes $(Mg,Fe)_2Si_2O_6$ to serpentine minerals $Mg_3Si_2O_5(OH)_4$ (Alexander 2004; Coleman 1967; Gough *et al.* 1989; O'Hanley 1996; Oze *et al*. 2004a). Serpentinites are scattered in many places throughout the world including Southeast Asia. In Peninsular Malaysia, they are found in several small isolated lenses along the Bentong-Raub suture zone (Hutchison 2005). In Sabah, the eastern state of Malaysia, serpentinized ultramafic rocks form a widely extended massif of about 3500 km^2 (Repin 1998).

The specific geochemistry of serpentinite rocks is reflected in the derived soils. They are generally very poor in silica content (less than 45% SiO_2) and major plant nutrients such as nitrogen, potassium and phosphorus. In contrast, they are characterised by large amounts of iron and magnesium. It has been well documented that serpentinized-ultramafic rocks produce a high geochemical background with chromium, nickel and cobalt in the soil horizons (Amir and Pineau 2003; Becquer *et al*. 2006; Bonifacio *et al*. 1997; Caillaud *et al*. 2009; Graham *et al*. 1990; Kierczak *et al*. 2007; Lee *et al*. 2004; Lewis *et al*. 2006; Quantin *et al.* 2002; Quantin *et al*. 2008; Schwertmann and Latham 1986; Shallari *et al.* 1998; Siebecker 2010; Skordas and Kelepertsis 2005; Tashakor *et al*. 2012; Turekian and Wedepohl 1961). Serpentinite soils are known to be naturally metal polluted with a high potential adverse impact on the environment and human health (Hseu 2006; Kierczak *et al.* 2008; Oze *et al.* 2004a; Oze *et al*. 2004b). Many plants cannot grow on serpentinite soils (Brearley 2005; Proctor 2003). There are also some accounts of the effects of the chemical properties of serpentinite soils on animals and microorganisms (Alexander *et al*. 2006). Growing awareness of the chemistry of serpentinite soils led to additional importance of these soils in tropical areas. Serpentinite bodies located in tropical climates have tolerated elevated degrees of weathering which eases the liberation of the elemental components of soils. Serpentinite formations in Malaysia have been scarcely studied previously (Baker and Brooks 1988; Proctor 2003). This study set out with the aim of expanding the general knowledge of the geochemistry of serpentinites in Malaysia. Aside from the five serpentinite outcrops of Bukit Rokan, Petasih, Bukit Malim and Cheroh in Peninsular Malaysia and Ranau in Sabah, a clastic sedimentary formation of Crocker soils was additionally studied as a control factor, due to its known low content of the studied elements of Cr, Ni and Co.

MATERIALS AND METHODS

Field and Samples

The studied materials were superficial (less than 10 cm thick) weathered soils developed on serpentinite bodies in Malaysia. A number of 15 soil samples was collected from four serpentinite sites in Peninsular Malaysia, namely at Bukit Rokan (BR) and Petasih (PS) in Negeri Sembilan and Cheroh (CH) and Batu Malim (BM) in Pahang state. In Sabah, the sampling of 12 soils was accomplished from the extended serpentinite massif of Ranau located between N 5 ° 57 ‘- N 6 ° 02 ‘ and E 116 ° 40 ‘- E 116 ° 45. In addition, four samples from sedimentary Crocker soils (formed on shale and sandstone) in the vicinity of serpentinites of Ranau were taken for comparison purposes. The locations of the surveyed areas are shown in *Figure 1*. The choice of the most suitable sampling sites for both serpentinite and Crocker soils were subject to accessibility which was limited by dense forest and the rugged nature of the lands. The mode of serpentinite occurrence in Ranau was mainly road cut and stream banks. In Bukit Rokan, thick layers of serpentinite soils surround the village and housing estate regions. Serpentinite soils of Petasih were collected from an under a construction hill cut. In Cheroh, the serpentinite body was covered by palm trees plantations. The serpentinites in Batu Malim had been exposed through mining.

Serpentinites of all the studied areas have produced thick layers of reddish-brown lateritic soils due to the high degree of weathering under tropical environment.

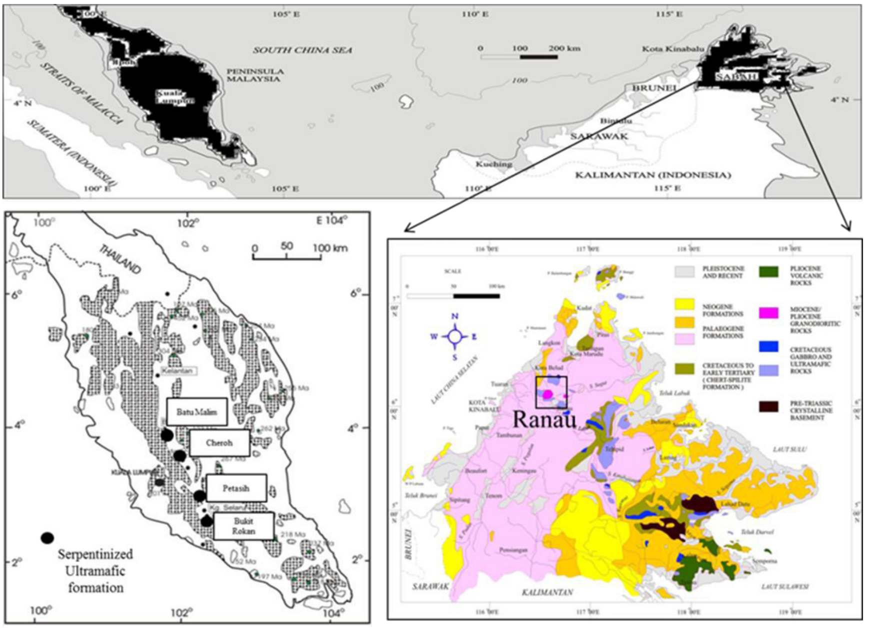

Figure 1: The location of the studied areas in Peninsular Malaysia and Sabah

Elemental Analysis

The bulk chemical composition of serpentinite and Crocker soils comprising 10 major oxides (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5) and 20 trace elements (As, Ba, Ce, Co, Cr, Cu, Ga, Hf, La, Nb, Ni, Pb, Rb, Sr, Th, U, V, Y, Zn, Zr) was determined by X-ray fluorescence spectrometer (XRF, Bruker S8 Tiger). Soil samples were powdered to 30 µm grain size after air-drying and pulverisation. Thereafter, the soils were made into 32 mm diameter fused-beads for determining major oxides. The fused beads were prepared by igniting 0.5g of sample with 5.0g of Johnson-Matthey 110 spectroflux, giving a dilution ratio of 1:10. In order to determine the trace elements, 32 mm diameter press-powder pallets were prepared by applying a pressure of 20 tonnes for one minute to 1g of sample against 6 g of pure boric acid powder.

RESULTS AND DISCUSSION

Bulk Composition of Serpentinite Soils

Table 1 shows the values of major oxides in the analysed soils. The ultramafic nature of the analysed serpentinite soils is obvious from the SiO_2 content which is less than 45% in almost all of the samples. Amounts of Al_2O_3 and Fe_2O_3 in the soils show similar trends, in contrast to the MgO concentration trend. Fe-rich soils in Peninsular Malaysia contain elevated amounts of Al_2O_3 (11.25 - 26.91 wt %) and Fe_2O_3 (23.80-55.65 wt %), whilst the studied samples were devoid of MgO (0.21 - 0.6 wt %). The rest of the Mg-rich samples showed an inverse relationship, with very poor values of Al_2O_3 (0.2 to 0.51 wt %) and Fe_2O_3 (0.02 to 0.1 wt %) and high concentrations of MgO (49.16 to 65.88 wt %). The concentration ranges of Al_2O_3, Fe_2O_3 and MgO in the soils of Ranau were 5.87-22.89, 11.35-45.47 and 0.27-8.71, respectively.

The division becomes clearer after plotting 20 soil samples on (SiO_2, MgO, Al_2O_3+Fe_2O_3) ternary diagram (*Figure 2*). As shown in the triangle, 75 % of the soil samples contained between 60% to >80 % of Al_2O_3 + Fe_2O_3. However, they had been depleted of magnesium oxide as indicated by having only 0.2 to about 10 % MgO. An inverse condition existed for the remaining 25 % of samples which were very poor in Al_2O_3 and Fe_2O_3 content (0.2 % to 0.7 %, respectively) but had high concentrations of MgO (60% to 81%).

This rather contradictory result is perhaps due to the degree of weathering. The intensity of weathering diverse in six grades (Arikan and Aydin 2012): fresh (I), slightly weathered (II), moderately weathered (III), highly weathered (IV), completely weathered (V) and residual soil (VI). During the weathering and pedogenesis of the serpentinites, clay minerals destabilise. Therefore, highly mobile elements such as Mg and Si are leached entirely from the soil profile at early stages and the newly formed clay minerals become enriched with less mobile elements. Consequently, as the weathering process progresses, soils especially in well drained profiles become devoid of Mg and Si, and the stable minerals with higher valency such as Al and Fe accumulate. This phase usually occurs in a tropical climate and produces ferralitic mature soils (Dissanayake and Chandrajith 2009). However, in soils rich in Mg it seems possible that some ferromagnesium minerals are still in solid form because of the low weathering grade and they are not integrated and flushed out from the system. They create immature soils which have closer composition to parent rocks. This loss and accumulation pattern is very similar to those pedalogical observations on serpentinite weathering under

TABLE 1
The concentration of major oxides (in weight %) and trace elements (in $\mu g\ g^{-1}$) in Serpentinite and Crocker soils of different study areas in Peninsular Malaysia and Sabah

		Major elements (wt %)												Trace metals ($\mu g\ g^{-1}$)		
		SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	L.O.I	Total	Co	Cr	Ni
Serpentinite peninsular	BM.1	20.96	0.4	13.32	55.55	0.38	0.38	0.17	0.06	0.22	0.08	9.56	101.08	233	8339	841
	BM.2	21.13	0.05	0.46	0.09	14.18	53.35	0.19	0.29	0.21	0.31	9.43	99.69	340	8996	1070
	BM.3	21.41	0.04	0.36	0.1	11.45	53.28	0.18	0.36	0.2	0.44	12.54	100.36	252	1397	861
	BM.4	22.83	0.43	13.28	53.64	0.29	0.37	0.23	0.05	0.22	0.08	11.48	102.9	212	8110	664
	BR.1	9.44	0.02	0.2	0.02	9.15	65.88	0.18	0.72	0.12	0.45	10.89	97.07	464	9487	1687
	BR.2	21.15	0.8	12.16	49.7	0.31	0.33	0.19	0.5	0.21	0.06	15.48	100.89	154	2133	435
	BR.3	32.85	2.12	26.91	23.08	0.36	0.3	0.18	0.03	0.18	0.05	17.53	103.59	98	1248	189
	BR.4	23.84	0.5	0.51	0.04	10.82	52.11	0.18	0.04	0.21	0.08	12.49	100.82	236	11276	483
	CH.1	23.71	0.33	11.25	51.9	0.41	0.58	0.2	0.05	0.21	0.09	12.91	101.64	171	8437	536
	CH.2	19.84	0.32	11.92	55.65	0.44	0.6	0.18	0.03	0.21	0.07	10.96	100.22	208	11980	784
	CH.3	27.25	0.42	11.87	45.58	0.17	0.54	0.19	0.05	0.16	0.07	15.97	102.27	286	10141	1095
	PS.1	21.52	0.09	0.44	0.06	16.27	49.16	0.18	0.56	0.21	0.74	12.75	101.98	104	4164	371
	PS.2	23.36	0.8	17.41	44.03	0.3	0.5	0.18	0.03	0.14	0.07	14.3	101.12	149	9297	587
	PS.3	25.98	0.97	20.12	37.65	0.21	0.33	0.19	0.03	0.14	0.06	9.39	95.07	126	8128	526
	PS.4	30.72	1.32	25.15	27.34	0.17	0.21	0.18	0.06	0.13	0.06	16.21	101.55	95	4523	342
Serpentinite Sabah	S1	60.5	0.63	16.84	11.35	0.08	0.76	0.36	0.09	1.95	0.12	6.8	99.48	136	13929	1675
	S3	26.4	0.25	9.77	41.04	0.73	8.47	0.1	0.05	0	0.05	12.25	99.11	122	14720	2237
	S4	14.57	0.47	17.75	38.82	0.59	2.83	0.03	0.01	0	0.03	25.84	100.94	146	16381	1573
	S5	5.17	0.94	22.89	42.69	0.29	0.31	0.04	0.03	0.005	0.05	26.39	98.8	112	14029	850
	S6	17.64	0.24	12.85	42.9	0.75	7.97	0.17	0.07	0.003	0.049	17.85	100.49	167	19025	4753
	S7	13.67	0.61	19.34	45.47	0.81	0.86	0.02	0.02	0.005	0.046	19.61	100.46	127	17233	1219
	S8	58.05	0.61	10.18	11.47	0.17	3.7	0.13	0.16	0.63	0.029	16.21	101.33	35	2427	865
	S10	19.12	0.99	22.63	42.05	0.4	1.31	0.09	0.04	0.017	0.068	13.2	99.91	114	15807	1311
	S12	25.38	0.29	5.87	25.62	0.12	0.29	0.1	0	0.014	0.048	43.18	100.91	93	11277	972
	S13	54.6	0.57	11.88	12.78	0.18	8.71	0.33	0.11	1.266	0.027	9.46	99.91	46	2828	1418
	S14	19.37	0.91	20.99	41.82	0.8	0.27	0.02	0.01	0.037	0.049	14.98	99.26	141	14972	1203
	S15	17.68	0.9	22.78	40.91	0.19	1.68	0.02	0.05	0.002	0.037	15.26	99.51	105	27863	1693
Crocker Sabah	S2	60.50	0.83	19.03	7.93	0.17	1.09	0.03	0.19	3.63	0.09	6.52	100.01	21	182	270
	S9	69.81	0.71	13.69	6.27	0	0.47	0.03	0.21	1.47	0.03	7.21	99.9	16	173	35
	S11	65.95	0.35	20.17	3.29	0	0.25	0.03	0.03	0.94	0.01	9.11	100.13	11	67	33
	S16	63.21	0.84	20.97	11.88	0.3	3.96	0.33	0.41	4.77	0.17	4.6	111.44	23	121	91

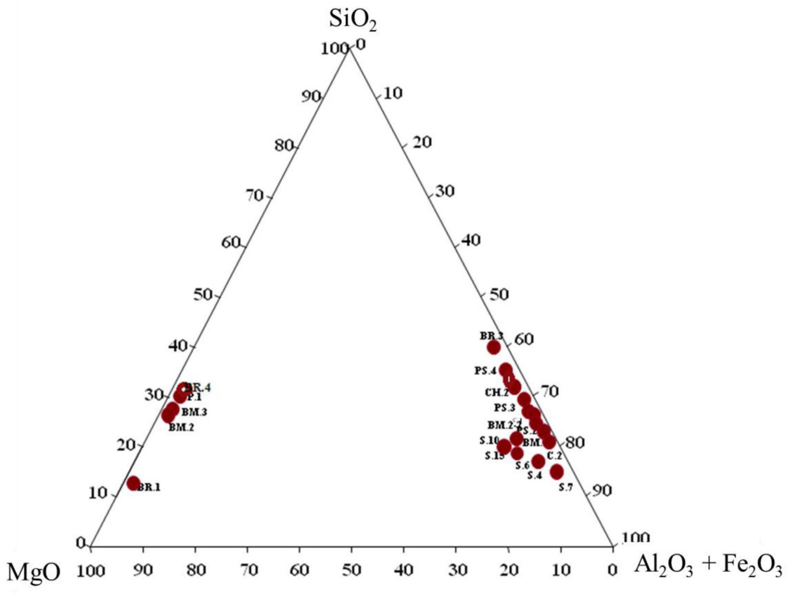

Figure 2: The location of 15 Peninsular Malaysia and 5 Sabah serpentinite soil samples on the (SiO_2 - MgO- Al_2O_3+Fe_2O_3) ternary diagram

humid tropical conditions reported by other researchers (Brooks 1987; Caillaud *et al.* 2009).

The other striking result that emerges from Table 1 is the contents of CaO, Na_2O, K_2O and P_2O_5 which are detected in almost negligible amounts in all of the samples (a similar average of 0.1% wt). The obtained values of major oxides from serpentinite soils in Malaysia are consistent with the chemical composition of the many ultramafic massifs from throughout the world as listed by Brooks (1987).

Among the 20 analysed trace elements in the serpentinites, chromium, nickel and cobalt show anomalous elevated values. As seen in Table 1, the concentration range of these metals in serpentinite soils of Peninsular Malaysia is as follows: Cr 1,248-11,980 µg g^{-1}, Ni 189-1,687 µg g^{-1} and Co 95 – 464 µg g^{-1}. In Sabah, the concentration ranges of the trace metals were Cr 2,427-27,863; Ni 850-4,753; and Co 35-167 (in µg g^{-1}). On average, the concentration ranges of Cr, Ni and CO of the studied serpentinite soils of Peninsular Malaysia and Sabah were 10,302 µg g^{-1}, 1120 µg g^{-1} and 166 µg g^{-1}, respectively.

The findings of this research are in agreement with those of other studies which suggest the occurrence of the highest geogenic concentration of Cr, Ni and Co in Malaysian ultramafic soils (Osama 2007). According to Kabata-Pendias and Mukherjee (2007), the world average content of chromium in soils is 54 µg/g, while the Cr content can reach up to 125000 µg g^{-1} in serpentinised ultramafic soils (Shanker *et al*. 2005; Adriano 2001). The common background range of average soil Ni content is less than 100 µg g^{-1} but in the presence of ultramafic bedrocks such as serpentinites, values of more than 10,000 µg g^{-1} have been cited

(Hseu 2006). According to Mattigod and Page (1983), high amounts of heavy metals due to parent materials constitute natural cases of metal pollution.

For a comparison of the elemental composition of serpentinite soils with that of non-serpentinite soils, clastic sedimentary formations of Crocker were additionally analysed. As shown in Table 1, the following major oxides were observed: SiO_2 60.5-69.81, Al_2O_3 13.69-20.97, Fe_2O_3 3.29-11.88, MnO 0.0-0.3, MgO 0.25-3.96, CaO 0.03-0.33, Na_2O 0.03-0.41, K_2O 0.94-4.77 and P_2O_5 0.01-0.17 (in wt %). Moving to the trace elements, none of them showed any notable concentration. The values of Cr, Ni and Co varied in range from 67-182, 33-270 to 11-23 (in µg g-^{1}), respectively. The average amounts of Cr, Co and Ni were 136, 18 and 107 µg g^{-1}, respectively.

Comparison Between Cr, Ni and Co in Serpentinite and Crocker Soils of Ranau

Comparative values of the minimum, average and maximum amounts of some representative major and trace elements from the serpentinite and Crocker soils of Ranau are presented in Table 2. The data show that Crocker soils contain between 60.50 to 69.81 wt % SiO_2, but this amount is only between 5.17 to 60.50 wt % in serpentinite soils. On the other hand, the average Fe_2O_3 (33.08 µg g^{-1}) and MgO (3.10 µg g^{-1}) in serpentinite soils is considerably higher than that of the Crocker soils (Fe_2O_3 7.34 and MgO 1.44 µg g^{-1}).

TABLE 2

The comparison between the concentration of SiO_2, Fe_2O_3, MgO (in wt %) and Cr, Ni and Co (in µg g^{-1}) in serpentinite and Crocker soils of Ranau, Sabah

	Serpentinite soil			Crocker soil		
Element	Min.	Ave.	Max.	Min.	Ave.	Max.
SiO_2	5.17	27.68	60.50	60.50	64.87	69.81
Fe_2O_3	11.35	33.08	45.47	3.29	7.34	11.88
MgO	0.27	3.10	8.71	0.25	1.44	3.96
Co	35	112	167	11	18	23
Cr	2427	14208	27863	67	136	182
Ni	850	1647	4753	33	107	270

The significant differences between SiO_2, Fe_2O_3 and MgO contents indicate that parent rocks and mineralogical context of serpentinite and Crocker soils are very different. Another important finding is the concentration level of Cr, Ni and Co. *Figure 3* compares these amounts in the serpentinite and Crocker soils. Concentration levels of Cr, Ni and Co in serpentinite soils were 2,427-27,863, 850-4,753 and 35-167 (in µg g^{-1}) respectively. However, soils of Crocker formation show these amounts to be 67-182 for Cr and 33-270 for Ni and 11-23 for Co (in µg g^{-1}). It is obvious that the amounts of Cr, Ni and Co in the studied serpentinites soils are respectively 105, 15 and 6 times higher than the amounts in Crocker soils.

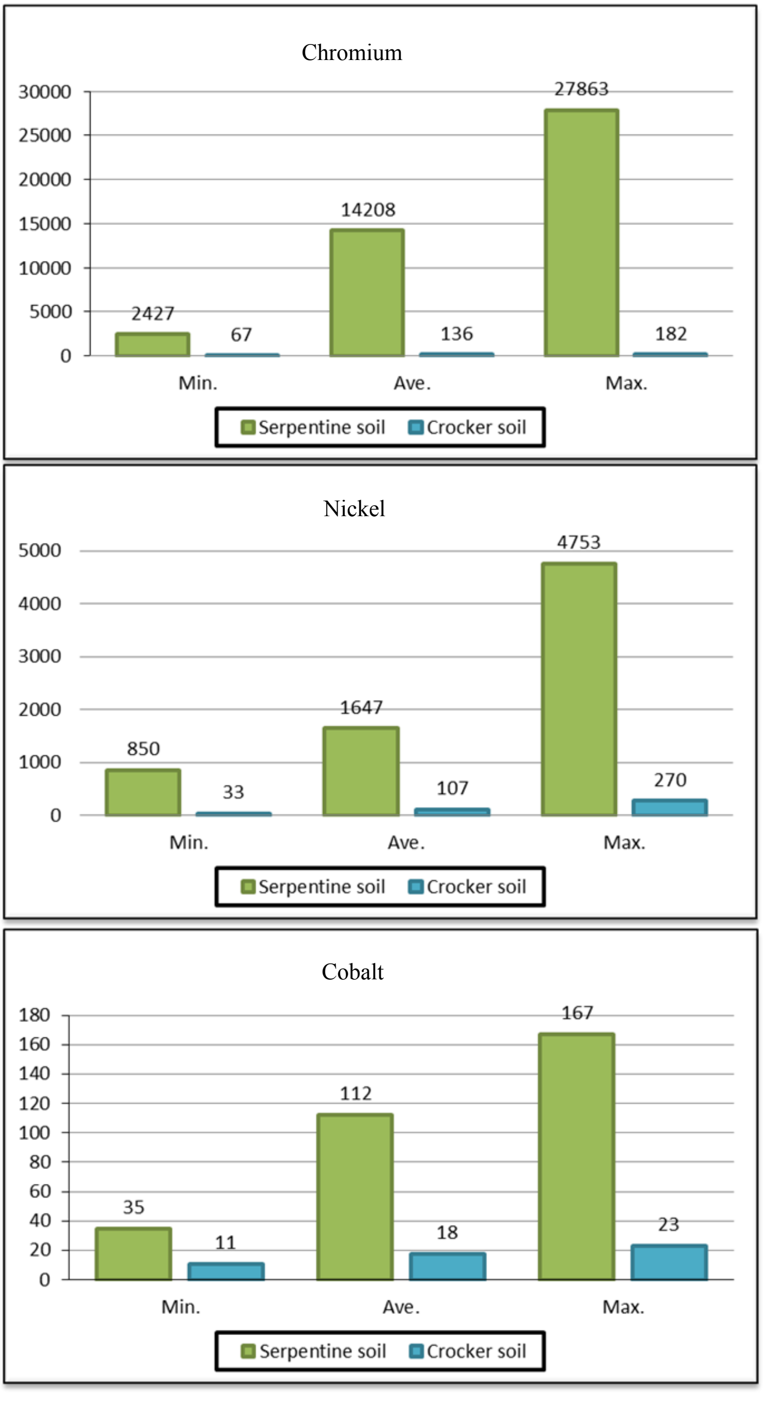

Figure 3: Comparison between maximum, average and minimum amounts of Cr, Ni and Co (in µg g^{-1}) in serpentinite and Crocker soils of Ranau, Sabah

There is a noticeable difference in elemental composition between the two groups of soils. The elevated values of heavy metals are strongly associated with serpentinite soils. The reason is that soil composition always reflects the geochemistry and mineralogy of the underlying parent materials. Ionic substitutions of ferromagnesian minerals during alterations enrich chromium, cobalt and, nickel in serpentinite rocks (Brooks 1987). These elements (sidrophile) substitute cations of Fe, Mn, and Mg in octahedral sheets of the primary serpentinite minerals. Therefore, soils developed from serpentinite rocks contain elevated amounts of heavy metals. Being naturally metal-loaded, serpentinites might specifically pose serious ecological risks.

Content of Cr, Ni and Co in Peninsular Malaysia and Sabah

The chemical composition of serpentinite soils in Peninsular Malaysia was compared to that of Sabah. *Figure 4* shows the concentrations of Cr, Ni and Co in the soils of the surveyed outcrops in Bukit Rokan, Petasih, Batu Malim and Cheroh in Peninsular Malaysia and the serpentinite outcrop of Ranau in Sabah. The first striking result that appeared in the data was that Cr and Ni had higher concentrations in Ranau soils, but Co was highest in Bukit Rokan soils.

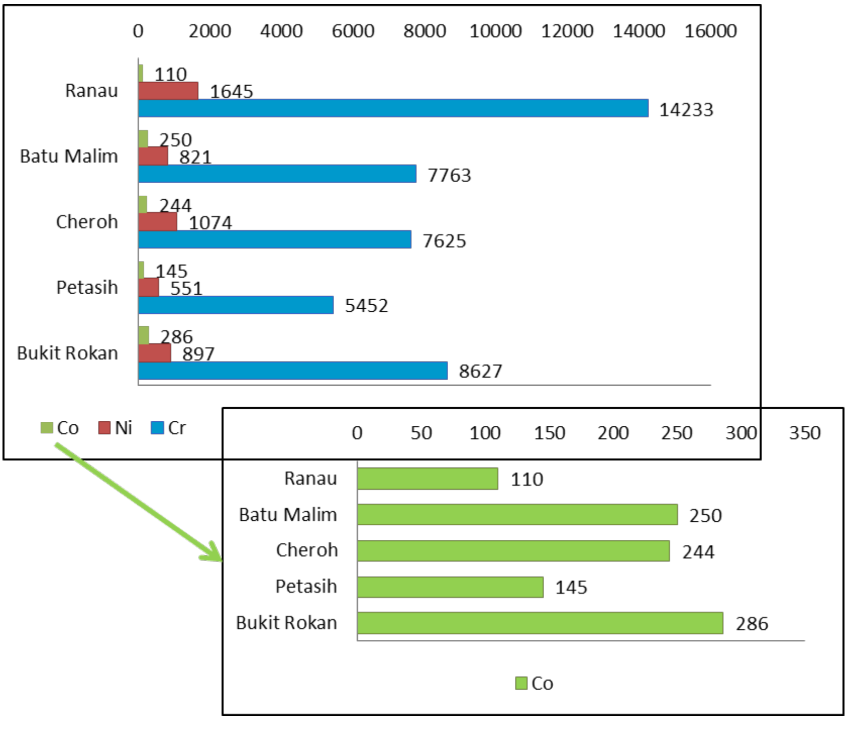

Figure 4: Bar charts of chromium, nickel and cobalt distribution (in µg g^{-1}) in the five studied areas of Peninsular Malaysia and Sabah

The amount of Cr in Ranau ranged between a minimum of 2,427 μg g^{-1} and a maximum of 27,863 μg g^{-1}, with an average of 14233 μg g^{-1}. However, in Bukit Rokan, Batu Malim and Cheroh, the average amounts of Cr were 8,627, 7,763, and 7,625 μg g^{-1}, respectively. The lowest amount of Cr was observed in Petasih where it ranged from 2,512 to 9,297 μg g^{-1} (average of 5,452 μg g^{-1}). Ni content in the studied areas showed almost the same trend as Cr. Ranau had the largest amount of Ni (between 850-4,753 μg g^{-1}) in comparison with other areas. Ni in Ranau averaged 1,645 μg g^{-1} with Cheroh being a close second with Ni amounts ranging from 536 to 1,622 μg $g^{-1}$with the average being 1074 μg g^{-1}). Ni concentration level decreased from 897 μg g^{-1} in Bukit Rokan to 821 μg g^{-1} in Batu Malim. The least amount of Ni with an overall mean of 551 μg $g^{-1}$was found in Petasih. The element of Co was dominant in Bukit Rokan with an average value of 286 μg g^{-1} (*Figure 4*). Batu Malim and Cheroh areas had almost a similar overall mean of Co (250 and 244 μg g^{-1}, respectively), while the average amount of Co in Petasih was 145 μg g^{-1}. Interestingly, Ranau had the lowest concentration of Co at 110 μg g^{-1} (on average).

It is apparent from the data that the elemental concentrations in serpentinite soils of the four areas in Peninsular Malaysia show similar patterns with a relatively small standard deviation from the concentration level trends in Ranau area. This dissimilarity possibly occurred as a result of the difference in the genesis, geo-setting and parent bedrocks of the ultramafic clans in West and East Malaysia.

Evaluation of the Quality of Serpentinite Soils of Peninsular Malaysia and Sabah

In order to assess the quality of serpentinite soils, the average amounts of Cr, Ni and Co in Peninsular Malaysia and Sabah samples were compared with the average soil composition of the Earth (Siegel, 1975), Dutch List Standard (2001) and G.I.C guidelines (2001) (Table 3). A comparison of the metal concentration with the global average soil composition showed that all of the analysed soils presented Cr, Ni and Co concentrations that were significantly higher than the average soil composition given by Siegel (1975). The average amounts of Cr, Ni and Co in serpentinite soils of Peninsular Malaysia were respectively 72, 17 and 21 times higher than the average soil composition. Similarly, the values of Cr, Ni and Co in Sabah soils were 142, 41 and 11, times, respectively, larger than the average soil composition.

Comparing with the Dutch list standard, the concentration values of Cr (Peninsular Malaysia 7,177 and Sabah 14,208 μg g^{-1}) and Ni (Peninsular 698 and Sabah 1,647 μg g^{-1}) in both the studied areas were categorised into group C which indicates the presence of crucial pollution and is considered a serious threat to the environment (Table 3). Based on the Co content in the soils of Peninsular Malaysia (209 μg g^{-1}) and Sabah (112 μg g^{-1}), the studied soils were categorised in group B of the Dutch list. Group B refers to polluted soils with possible hazardous impact on the environment. Further investigation on the soils of this nature is necessary. Values of Cr, Ni and Co of the studied serpentinite soils exceeded the values provided by the Dutch List standard, with Cr being 9-18 and Ni being 1-3

TABLE 3
The average elemental composition of Cr, Ni and Co in Peninsular and Sabah Malaysia in comparison with the average soil composition, the Dutch List standard and the C.L.C guideline (in µg g^{-1})

	Average Serpentinite soil		Average Soil composition[1]	Dutch List Standard[2]			G.L.C guidelines[3]				
Elements	Peninsular	Sabah		A	B	C	I	II	III	IV	V
Cr	7177	14208	100	100	250	800	100	200	500	2500	>2500
Ni	698	1647	40	50	100	500	20	50	200	1000	>1000
Co	209	112	10	20	50	300	-	-	-	-	-

1. Average soil composition from (Siegel, 1975)
2. Dutchlist (2001) standard adopted in Netherland for soil contaminations:
   A. Reference value below which soils are completely uncontaminated
   B. Value above which for further investigation is required
   C. Value above which a clean-up is needed
3. G.L.C guidelines(2001); definitions of contaminated soils - suggested range of values:
   I. Typical values for uncontaminated soils
   II. Slight contamination
   III. Contaminated
   IV. Heavy contamination
   V. Unusually heavy contamination

times higher than critical values and Co being 2-4 times higher than optimum values.

Comparing these values to the Great London Council (G.L.C), Peninsular Malaysia and Sabah serpentinite soils (by containing more than 2,500 µg g^{-1} chromium) are registered as unusually heavy contaminated soils (category V). The elevated concentration of Ni (698 µg g^{-1}) in the serpentinite soils of Peninsular Malaysia puts them in the category of a heavy contaminated soil (category IV). Serpentinite soils of Sabah are unusually heavily contaminated (category V) as they contain 1647 µg g^{-1} Ni. The G.L.C guideline has not furnished a classification for Co values. With regard to the mentioned contamination criteria, the studied serpentinite soils of all the areas are polluted by the aforementioned metals.

Heavy metal contamination of soils is an issue of great concern in environmental studies. Metal contaminants are serious threats to the environment because they are very persistent and irreversible even after many years. They can cause soil infertility and paucity of vegetation. They are also able to affect the health of people adversely by penetrating into the water system or entering into the food chain.

CONCLUSION

Serpentinite soils from Peninsular Malaysia and Sabah have been depleted of silica and essential plant nutrients such as calcium, potassium and phosphorus In contrast, they are remarkably rich in Cr, Ni and Co. The significant differences between the elemental compositions of the serpentinite soils with their adjacent sedimentary soils in Ranau Sabah clearly support geogenic hyperaccumulation of Cr, Ni and Co. The concentration of the concerned metals within all the investigated serpentinite soils exceeds the values given by the Dutch list and

Great London Council standards which corroborate the occurrence of serious natural pollution. Hence, the studied serpentinite derived soils are assumed to be non-conducive environments for fauna and flora.

REFERENCES

Adriano, D.C. 2001. *Trace Elements in Terrestrial Environments: Biogeochemistry, Bioavailability, and Risks of Metals* (2 ed.). USA: Springer.

Alexander, E.B. 2004. Serpentine soil redness, differences among peridotite and serpentinite materials, Klamath Mountains, California. *International Geology Review*. 46(8): 754-764.

Alexander, E.B., R.G. Coleman, T. Keeler-Wolfe and S.P. Harrison. 2006. *Serpentine Geoecology of Western North America: Geology, Soils, and Vegetation.* USA: Oxford University Press.

Amir, H. and R. Pineau. 2003. Relationships between extractable Ni, Co, and other metals and some microbiological characteristics of different ultramafic soils from New Caledonia. *Soil Research.* 41(2): 215-228.

Arikan, F. and N. Aydin. 2012. Influence of Weathering on the Engineering Properties of Dacites in Northeastern Turkey. *ISRN Soil Science.* 2012:15.

Baker, A.J.M. and R.R. Brooks. 1988. Botanical exploration for minerals in the humid tropics. *Journal of Biogeography.* 15(1): 221-229.

Becquer, T., C. Quantin, S. Rotte-Capet, J. Ghanbaja, C. Mustin and A.J. Herbillon. 2006. Sources of trace metals in Ferralsols in New Caledonia. *European journal of Soil Science*. 57(2): 200-213.

Bonifacio, E., E. Zanini, V. Boero and M. Franchini-Angela. 1997. Pedogenesis in a soil catena on serpentinite in north-western Italy. *Geoderma.* 75(1–2): 33-51.

Brearley, F. 2005. Nutrient limitation in a Malaysian ultramafic soil. *Journal of Tropical Forest Science.* 17(4): 596-609.

Brooks, R.R. 1987. *Serpentine and its Vegetation: A Multidisciplinary Approach.* Portland: Dioscorides Press.

Caillaud, J., D. Proust, S. Philippe, C. Fontaine and M. Fialin. 2009. Trace metals distribution from a serpentinite weathering at the scales of the weathering profile and its related weathering microsystems and clay minerals. *Geoderma.* 149(3–4): 199-208.

Coleman, R.G. 1967. *Low-temperature Reaction Zones and Alpine Ultramafic Rocks of California, Oregon and Washington*. USA: Government Printing Office.

Dissanayake, C.B. and R. Chandrajith. 2009. *Geochemistry of the Tropical Environment*. Introduction to Medical Geology. Berlin Heidelberg: Springer. 19-45.

Dutchlist. 2001. Intervention values and target values - soil quality standards (online) *http://www.contaminatedland.co.uk/std-guid/dutch-l.htm.* The Ministry of Housing, Spatial Planning and Environment [Retrieved 7 May 2009].

Gough, L.P., G. Meadows, L. Jackson and S. Dudka. 1989. B*iogeochemistry of a Highly Serpentinized, Chromite-Rich Ultramafic Area, Tehama County, California*. USA: Government Printing Office.

Graham, R.C., M.M. Diallo and L.J. Lund. 1990. Soils and mineral weathering on phyllite colluvium and serpentinite in Northwestern California. *Soil Science Society of America Journal.* 54(6): 1682-1690.

Great London Council. 2001. *Guidelines for Contaminated Soils* (on-line) *http://www.contaminatedland.co.uk/std-guid/kelly-l.htm*. Society of the Chemical Industry [Retrieved 11 May 2009].

Hseu, Z.-Y. 2006. Concentration and distribution of chromium and nickel fractions along a serpentinitic toposequence. *Soil Science* 171(4): 341-353.

Hutchison, C.S. 2005. *Geology of North-West Borneo: Sarawak, Brunei and Sabah.* Netherlands: Elsevier Science.

Kabata-Pendias, A. and A.B. Mukherjee. 2007. *Trace Elements from Soil to Human.* New York: Springer.

Kierczak, J., C. Neel, U. Aleksander-Kwaterczak, E. Helios-Rybicka, H. Bril and J. Puziewicz. 2008. Solid speciation and mobility of potentially toxic elements from natural and contaminated soils: A combined approach. *Chemosphere.* 73(5): 776-784.

Kierczak, J., C. Neel, H. Bril and J. Puziewicz. 2007. Effect of mineralogy and pedoclimatic variations on Ni and Cr distribution in serpentine soils under temperate climate. *Geoderma.* 142(1–2): 165-177.

Lee, B.D., R.C. Graham, T.E. Laurent and C. Amrhein. 2004. Pedogenesis in a wetland meadow and surrounding serpentinitic landslide terrain, Northern California, USA. *Geoderma*.118(3–4): 303-320.

Lewis, J.F., G. Draper, J. Espaillat, J. Proenza and J. Jiménez. 2006. Ophiolite-related ultramafic rocks (serpentinites) in the Caribbean region: A review of their occurrence, composition, origin, emplacement and Ni-laterite soil formation. *Geologica Acta: An International Earth Science Journal.* 4(1): 237-264.

Mattigod, S. and A. Page. 1983. *Assessment of metal pollution in soils.* Applied Environmental Geochemistry. London: Academic Press. 355-394.

O'Hanley, D.S. 1996. *Serpentinites: Records of Tectonic and Petrological History.* New York: Oxford University Press

Osama, A.A.T. 2007. A study on the alternative resources of chromium, cobalt and nickel from ultrabasic soils of Sabah, Malaysia. Ph.D thesis, School of Environmental and Natural Resource Sciences, Universiti Kebangsaan Malaysia.

Oze, C., S. Fendorf, D.K. Bird and R.G. Coleman. 2004a. Chromium geochemistry in serpentinized ultramafic rocks and serpentine soils from the Franciscan complex of California. *American Journal of Science.* 304(1): 67-101.

Oze, C., S. Fendorf, D.K. Bird and R.G. Coleman. 2004b. Chromium geochemistry of serpentine soils. *International Geology Review*. 46(2): 97-126.

Proctor, J. 2003. Vegetation and soil and plant chemistry on ultramafic rocks in the tropical Far East. *Perspectives in Plant Ecology, Evolution and Systematics.* 6(1-2): 105-124.

Quantin, C., T. Becquer, J. Rouiller and J. Berthelin. 2002. Redistribution of metals in a New Caledonia Ferralsol after microbial weathering. *Soil Science Society of America Journal.* 66(6): 1797-1804.

Quantin, C., V. Ettler, J. Garnier and O. Šebek. 2008. Sources and extractibility of chromium and nickel in soil profiles developed on Czech serpentinites. *Comptes Rendus Geoscience.* 340(12): 872-882.

Repin, R. 1998. Preliminary survey of serpentine vegetation areas in Sabah. *Sabah Parks Nature Journal*. 1: 19–28.

Schwertmann, U. and M. Latham. 1986. Properties of iron oxides in some new caledonian oxisols. *Geoderma.* 39(2): 105-123.

Shallari, S., C. Schwartz, A. Hasko and J.L. Morel. 1998. Heavy metals in soils and plants of serpentine and industrial sites of Albania. *Science of The Total Environment.* 209(2–3): 133-142.

Shanker, A.K., C. Cervantes, H. Loza-Tavera and S. Avudainayagam. 2005. Chromium toxicity in plants. *Environment International*. 31(5): 739-753.

Siebecker, M. 2010. Nickel speciation in serpentine soils using synchrotron radiation techniques. *19th World Congress of Soil Science: Soil Solutions for a Changing World.* Brisbane Australia, August 1-6

Siegel, F.R. 1975. *Applied Geochemistry.* New York: Wiley.

Skordas, K. and A. Kelepertsis. 2005. Soil contamination by toxic metals in the cultivated region of Agia, Thessaly, Greece. Identification of sources of contamination. *Environmental Geology.* 48(4): 615-624.

Tashakor, M., W.Y. Wan Zuhairi and M. Hamzah. 2012. Does rock and soil geochemistry of ultrabasic land affect the run-off water? A case study at Ranau, Sabah. pp. 252-256. *3rd International Conference on Environmental Research and Technology (ICERT),* Penang, Malaysia

Turekian, K.K.and K.H. Wedepohl. 1961. Distribution of the elements in some major units of the earth's crust. *Geological Society of America Bulletin*. 72(2): 175-192.