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APPLICATION OF PRESENT INDICES OF CHEMICAL WEATHERING FOR PRECAMBRIAN METAMORPHIC ROCKS IN SRI LANKA

DÉFINITION D'INDICES D'ALTÉRATION POUR DES ROCHES MÉTAMORPHIQUES PRÉCAMBRIENNES, SRI LANKA

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Abstract

Weathered and fresh samples of Sri Lancan rocks (metamorphic) were collected from various localities and analysed for major elements by XRF method (Rigaku, KG-X System, Japan). The amount of water was found by ignation method.
The XRF results were used for various weathering indices to find the most suitable chemical index of weathering applicable to Sri Lanka. The values of each index for all samples were obtained and their variations were compared.
Out of eight different chemical indices of weathering Ruxton's Ratio, Product Index and Weathering Potential Index are most suitable to find the variations of the degree of weathering in the Sri Lankan rocks. Measuring of $H_2O(+)$ amount of rock material is a good and reliable method to find the degree of weathering to a certain extent.

Résumé

Des échantillons de roches métamorphiques altérées et saines ont été prélevés dans différents points du Sri Lanka et l'analyse de leurs principaux éléments a été réalisée par spectrométrie de fluorescence X.
Les résultats obtenus ont permis d'établir différents indices d'altération en vue de choisir le mieux adapté pour le Sri Lanka.
Parmi 8 indices chimiques différents le « Ruxton's ratio », le « Product Index » et le « Weathering potential index » sont ceux qui rendent le mieux compte du degré d'altération des roches étudiées. La mesure de la teneur en eau des roches peut également donner des indications intéressantes sur le degré d'altération.

Introduction

Weathering is one of the most important phenomena that affects the dynamic equilibrium of earth's crust. It affects almost all the engineering properties of rocks and in most cases this effect is unfavourable as it reduces both the strength and stability of rocks. Therefore to find the suitability of rocks a proper assessment of rock weathering is needed. This kind of assessment to the Sri Lankan rocks has great importance because those are the rather useful construction materials and the foundation rock for major construction projects in the Island.

The land surface of the country of Sri Lanka has been subjected to a prolonged period of weathering and erosion under different climatic conditions, ranging from the Gondwana glacials (Katz, 1978) to the sub-tropical to tropical monsoonal climates. So far no detailed study of regional weathering under earlier or more recent climatic conditions have been made.

Research on the classification of weathered rocks or degree of chemical weathering of Sri Lankan rocks and a correlation method between the engineering properties and the degree of chemical weathering of Sri Lankan rocks will be very useful for future references and the present projects being implemented. Indices of chemical weathering of silicate rocks are commonly used to compare the extent of weathering of different rocky terrains. So far, this method has not been used in Sri Lanka and no one has made attempt to make a correlation between the engineering and physical properties and the degree of chemical weathering of Sri Lankan rocks.

There are many methods proposed by several authors, to measure the degree of chemical weathering of rocks. Prior attempt to make a correlation between engineering properties and the degree of chemical weathering, the most suitable chemical index of weathering which can be applied to the Sri Lankan rocks must be selected.

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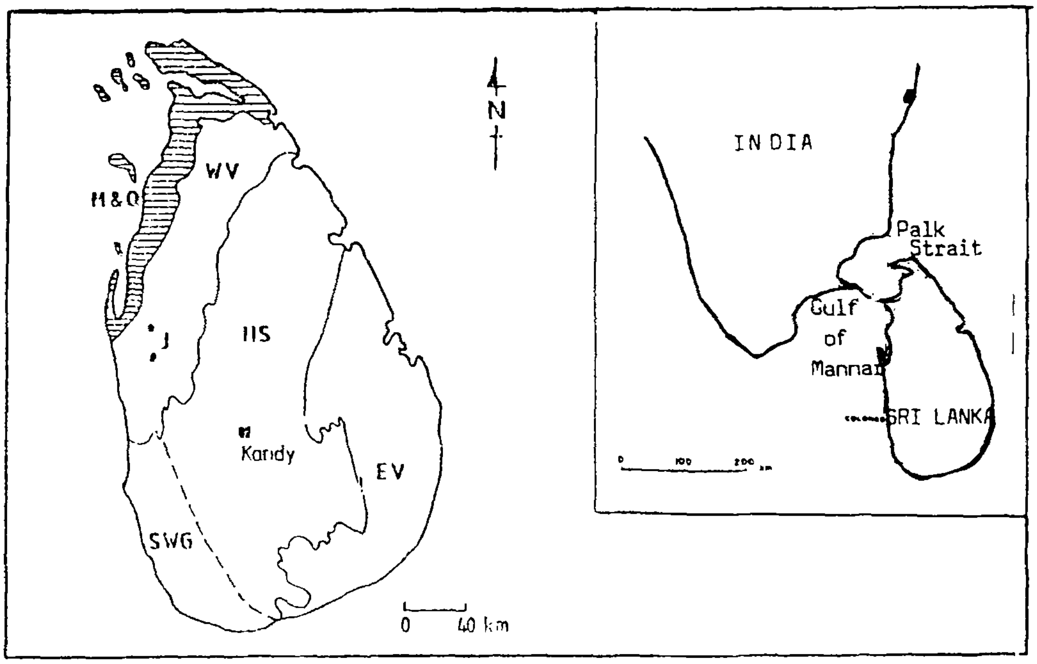

Fig. 1 : Main geological subdivisions of Sri Lanka. HS = Highland Series, EV = Eastern Vijayan Complex, WV = Western Vijayan Complex, SWG = Southwestern group, J = Jurassic, M = Miocene.

The purpose of this paper is to find the most suitable chemical index of weathering applicable to Sri Lankan rocks. This leads to the further research on the classification of weathered rocks and correlation with the engineering properties of decomposed rocks in Sri Lanka.

Geography and geology of Sri Lanka

The Island of Sri Lanka lies between latitudes 6°10′ and 9°50′ north and longitudes 79°42′ and 81°52′ east, situated 32 kilometers east of the southern tip of India, separated by Palk Strait and the Gulf of Mannar (Fig. 1). The total land area measures 65,580 square kilometers in extent 430 km in length from north to south and 225 km in width at the broadest part.

The Island's physiography can be described as consisting of a central mountaneous mass rising from a low flat plain surrounding it in all sides and extending to the sea. Basically the Island may be divided into two main physiographic divisions, the low lying coastal plains with little relief and traversed by rivers which have almost reached their base level of erosion in the coastal plain and the central highlands with immature drainage pattern and marked relief abounding in numerous strike ridges, hills and mountains.

Sri Lanka is considered to have a humid tropical climate. The average annual rainfall varies from below 1 270 mm in the north-west and south-east parts of the lowland zone to 5 076 mm in the south west slopes of the central hill country. The temperature ranges from 14° to 32° within the country. The relative humidity is high throughout the year.

About nine-tenths of Sri Lanka are underlain by Precambrian crystalline rocks. These are mainly high grade metamorphic rocks, which have been subdivided into three groups, namely, The Highland Series, the Vijayan Complex and the Southwestern Group (Cooray, 1967). The remaining rocks are sedimentary rocks of predominently Miocene age in the north west, with some jurassic sediments preserved in small faulted basins. Charnockitic gneiss, quartzites, granulites, garnet-sillimanite graphite gneiss, marble, dolomite, wollastonite-scapolite gneiss, cordierite gneiss, granitic gneiss, migmatites, hornblende biotite gneiss, biotite gneiss and granites are the common Precambrien metamorphic rocks in Sri Lanka. Highland Series rocks are present mainly in the hill country of the Island and Vijayan Complex rocks are found in the low-lying areas on either side of the Highland Series. The Southwestern group rocks occupy the southwestern region of the Island (Fig. 2).

Most of rocks in Sri Lanka have above sea level for millions of years and these rocks have been subjected under varying climatic conditions to considerable weathering.

Of the many rock types, generally charnockitiv gneisses are most resistant to weathering. These rocks, with medium to steep dips, form prominent strike ridges, while in areas low dips, they are characterized by structural terraces. The migmatites and migmatitic gneisses show variable patterns of weathering. Pink feldspar hornblende granites and granitic gneisses are more resistant to weathering as in the case of acidic charnockitic gneisses. The quartzites are highly fractured with two or three sets of joints but resistant to chemical weathering. Boulders and fragments with reddish soil cover are a surface feature of quartzite ridge. The granulites and granulitic gneisses are similar to the quartzites in their weathering habits. Those are resistant to both chemical and physical weathering. The Precambrian marbles, calc gneiss bands and the Miocene limestone are the least resistant of these carbonate rocks. The marble beds form depressions and valleys and they are capped by chocolate brown soils, and in some areas iron concretionary laterites. The Miocene rocks are marked by swallow holes, solution caverns and lakes.

Vitanage (1983 and 1972) has indicated that under tropical climatic condition with high rainfall and temperature the well developed fracture system in almost all rocks have influenced both deep and differential weathering. Series of shear zones, fault and the fracture density (joints) give rise to extensive deep belt of weathering. In some areas the highly weathered zones are penetrated to a depth over 50 m. Most of the weathered zones have probably been eroded away and are now covered by alluvium.

The main climatic controls of weathering in Sri Lanka are related to water; the total rainfall, run off and the precipitation-evaporation ratio. In the wet zone, where precipitation exceeds evaporation, a characteristic weathered product is laterite. Well developed weathered profiles can be seen along the road cuttings and other earth cuttings made for civil engineering constructions in the hilly areas. The rocks have been subjected to chemical weathering and in situ weathering products in different grades can be seen above the parent rocks in most of the places.

Method od study

Sample Collection

Different localities were selected to collect the test samples (Fig. 2). Samples were collected from different rock types and in situ weathered formations above the particular parent rock. The physical differences among various rock types were distinguished in the field by careful examination of the fresh rock surfaces. The different layers or horizons and the degree of weathering above the fresh rocks were examined carefully and identified according to the field recognition method of decomposed rocks by Fookes and Horswill (1969). The top materials about one meter depth from the surface level were not considered as the residual soils and treated as transported surface materials. Soils were black in color (near the residual soil level) were also rejected assuming the mixture of organic materials. Samples were collected into a transparent polythene bags separately, safely sealed and numbered in the field itself. Total number of samples was 52.

Preparation of Samples

About ten grams of each sample either weathered or fresh rocks were pulverised by employing the vibrating sample mill, Heiko, Model No. T1-100, Heiko Seisakusho Ltd, Japan. Every attempts were made to avoid contamination among the powdered materials.

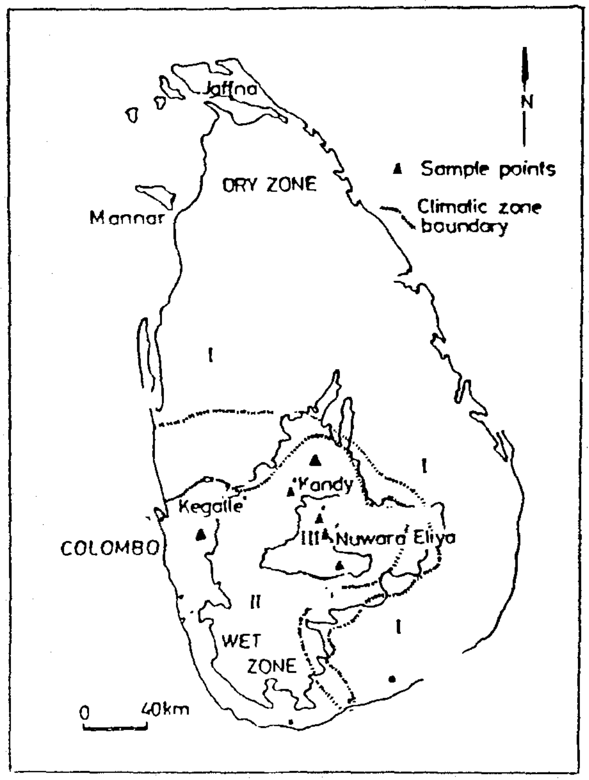

Fig. 2 : Sample sites and main morphological regions of Sri Lanka. I : Lowlands; II : Uplands; III : Highlands.

Analysis

Major and minor elements in the pulverised samples were analysed by X-ray fluorescence spectrometry on a Rigaku, KG-X system manufactured by Rigaku Denki Kogyo Co Ltd, Japan using a computer programme, developed by the Department of Mining of Kyushu University. The samples were arranged by pressing about 20 kgf-sq.cm. using the testing machine Model 30t, of the same Co.Ltd. mentioned above.

Direct reading of major elements percentage of each sample was obtained separately. Minor elements were calculated from the peak height of the chart and corrected by a computer programme for X-ray intensity correction.

About one gram of sample was kept in a desiccater for about two days and then kept in an electric oven for a period of two hours to find the amount of $H_2O(-)$. Then the sample was heated upto 900 ^oC to remove the water content of the internal structure of the mineral and found $H_2O(+)$ by measuring the difference of weights of the sample before and after the heating.

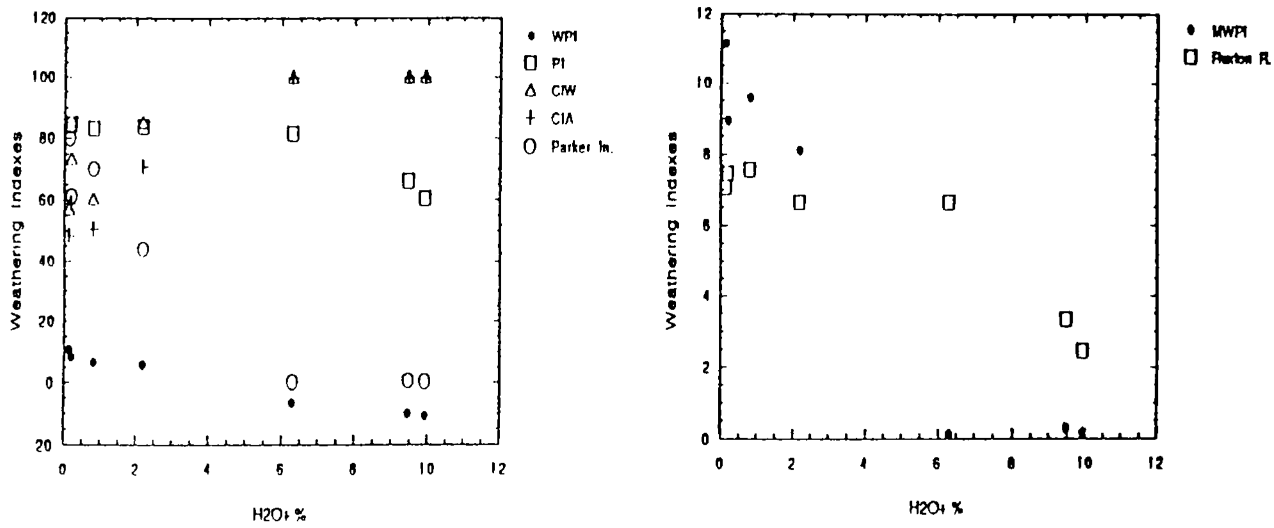

Fig. 3 : Variation of Different Weatehring Indices with $H_2O(+)$.

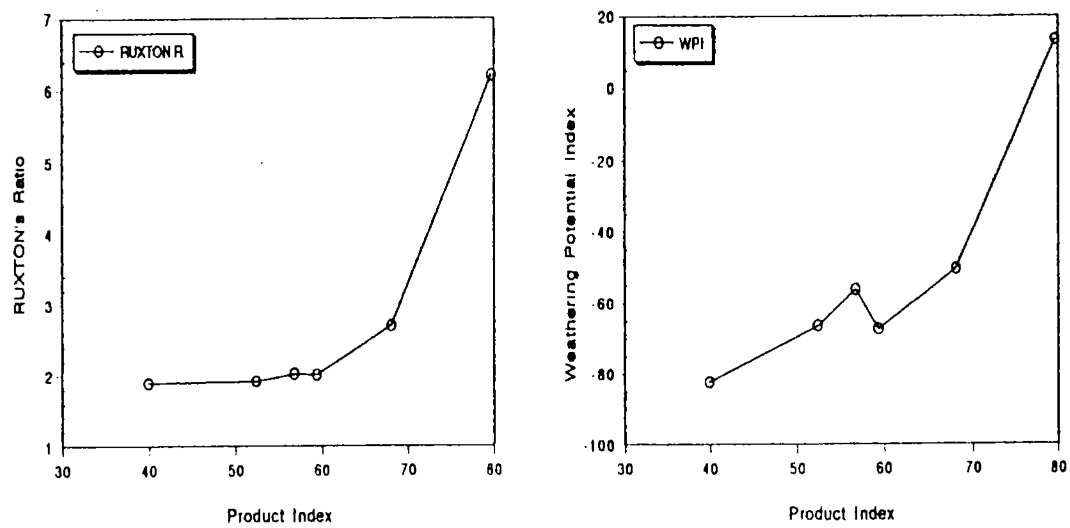

Fig. 4 : Variations of Ruxton's Ratio and WPI with Product Index.

CALCULATION

The XRF results or the weight percentage of major elements adjusted as the total weight constant or 100.00. The following weathering indices (presently using) were applied for each sample to find the grade of weathering. All calculations were according to the molecular proportions of each oxide as described by Barth (1952).

(a) Weathering Potential Index, WPI, (Reiche, 1943)

$$WPI = \frac{[K_2O+Na_2O+CaO+MgO-H_2O\ (+)] \times 100}{[SiO_2+Al_2O_3+Fe_2O_3+FeO+TiO_2+CaO+MgO+Na_2O+K_2O]}$$

(b) Product Index, PI, (Reiche, 1943)

$$PI = \frac{SiO_2 \times 100}{[SiO_2+TiO_2+Fe_2O_3+FeO+Al_2O_3]}$$

(c) Modified Weathering Potential Index, MWPI, (Vogel, 1973)

$$MWPI = \frac{[Na_2O+K_2O+CaO+MgO] \times 100}{[Na_2O+K_2O+CaO+MgO+SiO_2+Al_2O_3+Fe_2O_3]}$$

(d) Ruxton's Ratio (Ruxton, 1968)

$$= \frac{SiO_2}{Al_2O_3}$$

(e) Vogt Ratio (Vogt, 1927, Roaldset, 1972)

$$= \frac{Al_2O_3+K_2O}{MgO+CaO+Na_2O}$$

(f) Chemical Index of Weathering, (CIW), (Harnois, 1988)

$$CIW = \frac{Al_2O_3 \times 100}{Al_2O_3+CaO+Na_2O}$$

Table 1.

	J	WPI	MWPI	PI	Vogt R.	Ruxton R.	CIW	CIA	Parker In.	H2O+
1	Kd/GI-Sill, Gneiss									
2	47-Fresh Rock	7.09	9.11	85.42	3.43	7.52	71.75	57.95	64.79	0.52
3	5-Weathered Rock	-31.05	0.07	78.24	300.39	4.47	100.00	100.00	0.08	7.21
4	4-WR	-20.97	0.20	69.98	404.59	2.89	100.00	99054	1.19	4.77
5	2-WR	-56.63	0.12	58.65	383.02	2.13	100.00	99.96	0.17	10.65
6	3-WR	-66.36	0.21	61.81	226.49	1.95	100.00	99.87	0.51	12.86
7	1-Residual Soil	-66.88	0.13	62.86	337.82	2.07	99.71	99.65	0.57	13.21
8										
9	Kd/Gt-Bt-Hb Gneiss									
10	14-Fresh Rock	13.63	14.32	79.68	1.72	6.21	64.84	60.44	51.10	0.14
11	8-Weathered Rock	-50.37	0.09	68.10	1162.81	2.71	100.00	99.93	0.20	10.52
12	13-WR	-67.19	0.20	59.36	247.96	2.02	100.00	99.79	0.65	12.78
13	11-WR	-56.10	0.09	56.73	579.05	2.03	100.00	99.93	0.23	10.48
14	10-WR	-66.32	0.13	52.38	263.64	1.93	100.00	99.92	0.28	11.61
15	12-Residual Soil	-82.24	0.14	39.90	230.09	1.90	100.00	99.88	0.25	12.17
16										
17	Kd/Gt-Hb									
18	7-Fresh Rock	25.11	26.64	73.42	0.81	5.45	65.03	63.75	46.00	0.28
19	15-Weathered Rock	-68.17	0.08	60.36	676.50	1.91	100.00	99.94	0.23	13.15
20	16-WR	-68.55	0.16	55.66	343.94	2.12	100.00	99.92	0.25	12.15
21	17-WR	-73.35	0.15	53.82	249.92	2.06	100.00	99.91	0.28	12.67
22	18-Residual Gravel	-73.56	0.40	34.54	79.72	1.69	100.00	99.80	0.48	10.38
23										
24	PR/Gt-Bt Gneiss									
25	Fresh Rock*	8.10	9.49	91.58	1.43	11.57	58.27	48.03	57.93	0.39
26	21-Weathered Rock	-18.29	2.25	85.42	34.95	6.63	98.03	85.94	21.97	5.18
27	22-WR	-73.88	0.06	61.39	658.06	2.00	100.00	99.97	0.14	14.27
28	23-Residual Soil	-69.81	0.03	60.26	1301.99	1.99	100.00	99.97	0.11	13.54
29										
30	PR/Quartzite									
31	24-Fresh Rock	-0.42	0.12	99.67	8.50	431.85	100.00	89.88	0.40	
32	25-Weathered Rock	-5.03	0.94	95.68	11.31	27.51	98.82	85.12	7.88	
33	26-WR	-2.82	1.55	95.80	28.54	26.49	96.67	70.67	17.99	
34	27-WR	-28.01	6.48	82.19	10.85	7.11	88.95	86.67	9.30	
35										
36	PR/Hb-Bt Gneiss									
37	29-Weathered Rock	3.24	8.58	91.05	1.95	13.97	89.99	58.76	53.62	1.44
38	30-WR	-8.71	7.96	82.95	1.83	7.02	99.57	90.62	21.98	4.09
39	31-Residual Soil	-34.65	12.41	62.14	2.17	2.73	100.00	91.20	30.11	9.50
40										
41	PS/Ac. Chn. Gneiss									
42	Fresh Rock**	12.72	13.38	85.66	0.77	9.25	52.55	48.58	60.11	0.14
43	32-Weathered Rock	-49.96	0.97	69.45	44.37	2.84	100.00	98.49	4.21	10.75
44	33-WR	-63.18	0.30	68.26	241.92	2.59	100.00	99.37	1.67	13.05
45	36-WR	-55.37	0.44	63.08	129.01	2.39	100.00	99.19	2.12	11.01
46	35-WR	-52.36	0.34	63.91	160.56	2.88	100.00	99.20	1.70	10.23
47	34 Residual Soil	-70.89	0.33	49.10	132.49	1.95	100.00	99.50	1.13	11.74
48										
49	EP/Apatite Rock									
50	37B Fresh Rock	85.98	96.15	22.81	15.25	3.08	87.94	84.58	0.40	2.57
51	40-Weathered Rock	73.03	89.38	4.02	0.00	0.34	100.00	78.66	4.26	3.57
52	39-WR	70.68	89.57	20.51	17.06	0.61	89.42	88.64	2.73	4.47
53	41-WR	31.11	72.73	9.34	222.24	0.22	100.00	99.52	0.48	6.76
54	38MX-WR	-30.31	7.80	75.00	10.80	4.98	89.58	86.87	11.23	7.50
55	38-Graval	-95.57	23.34	17.90	15.36	0.40	89.64	89.57	10.16	14.23
56	38-Clement	-100.60	28.67	18.18	10.47	0.31	84.19	84.11	19.32	15.52
57										
58	BW/Chn. Gneiss									
59	42A Fresh Rock	8.28	10.33	86.90	3.15	7.94	58.48	46.95	87.27	0.54
60	43 Weathered Rock	7.27	10.80	85.70	3.89	6.97	64.51	49.74	92.89	0.91
61	44-WR	-27.80	2.02	77.28	11.24	4.93	99.67	96.24	7.82	6.84
62	45-WR	-40.79	0.82	69.36	99.02	3.22	99.74	97.12	5.84	8.70
63	46 Residual Soil	-58.40	1.38	62.31	45.24	2.14	100.00	98.25	5.20	11.68
64										
65	BW/Gt-Sill Gneiss									
66	47 Fresh Rock	7.09	9.11	85.42	3.43	7.52	71.75	57.95	64.79	0.52
67	48 Weathered Rock	0.99	8.06	82.19	4.01	6.11	78.14	64.78	57.55	1.78
68	49-WR	-46.90	0.26	73.11	658.08	2.77	100.00	99.16	2.27	10.54
69	50-WR	-44.92	0.34	71.84	98.11	3.20	100.00	99.53	1.33	9.77

	J	WPI	MWPI	PI	Vogt R.	Ruxton R.	CIW	CIA	Parker In.	H2O+
70	52 Residual Soil	-46.66	0.18	69.53	236.98	2.78	100.00	99.78	0.65	9.97
71										
72	NE/Chn. Gneiss									
73	51A Fresh Rock	8.15	8.93	84.64	5.54	7.45	73.50	58.81	61.23	0.19
74	51B-Discoloured	10.56	11.14	84.03	3.10	7.07	57.18	48.52	80.15	0.13
75	51C Slightly Wred	6.36	9.57	83.28	3.48	7.57	60.36	50.58	70.24	0.80
76										
77	NE/Chn. Gneiss									
78	51A Fresh Rock	8.15	8.93	84.64	5.54	7.45	73.50	58.81	61.23	0.19
79	53-Weathered Rock	5.61	8.10	83.77	5.61	6.65	85.33	70.87	44.18	2.19
80	54-WR	-6.69	0.13	81.62	129.58	6.65	100.00	99.87	0.31	6.29
81	56-WR	-10.33	0.29	66.15	88.13	3.33	100.00	99.76	0.70	9.46
82	55 Residual Soil	-11.12	0.13	60.56	344.62	2.45	100.00	99.84	0.42	9.92
83										

(g) Chemical Index of Alteration, CIA, (Nesbitt and Young, 1982)

$$CIA = \frac{Al_2O_3 \times 100}{Al_2O_3 + CaO + Na_2O + K_2O}$$

(h) Parker Index (Parker, 1970)

$$= \left[\frac{2\,Na_2O}{0.35} + \frac{MgO}{0.9} + \frac{2\,K_2O}{0.25} + \frac{CaO}{0.7}\right] \times 100$$

Results and discussion

The major rock types selected for this study were charnockitic gneiss, garnet-sillimanite gneiss, garnetiferous hornblende biotite gneiss, hornblende biotite gneiss and quartzite. All of these are major metamorphic silicate rocks which belongs to the Precambrian age. Also, these samples were collected within the Wet Zone (Fig. 2) where the rainfall is generally high in the country. In Dry Zone, the weathering profiles are considerably thin and therefore no samples were collected within it.

Type of results obtained are :

(a) weight percentage of major elements (oxides) – SiO_2, TiO_2, Al_2O_3, Fe_2O_3 (total Fe), MnO, MgO, CaO, Na_2O, K_2O and P_2O_5

(b) selected minor elements as ppm – Sr, Rb, Ba, Zr, Ga, Co, Ni, Cu, Zn, Pb, As, Y and Nb

(c) weight percentage of $H_2O(-)$ and $H_2O(+)$.

The amount of $H_2O(+)$ in fresh rocks were very low (less than 1 %). It is increasing with increasing weathering towards residual soil. It shows that the amount of $H_2O(+)$ can be used a good indicator of chemical weathering for these rocks. This may be the most economical method to find a degree of chemical weathering. But when it is applying to completely weathered rocks or residual soils, the amount of $H_2O(+)$ may vary with the types of clay minerals. Therefore to find the difference between residual soils and completely weathered rocks the amount of $H_2O(+)$ may not be true always. Generally during the weathering of silicate rocks Si, Mg, Ca, and Na are leached and Al and Ti remain in the system and accumulate in the residue where as Fe and K they have more complicated behaviours (Harnois, 1988). Hence to find the degree of chemical weathering mobile and immobile chemical elements are very important.

As described by Singh (1987) the field recognition gives only the physical difference of the materials. It can be used to differentiate the grade of weathering qualitatively but the values of the content of $H_2O(+)$ in each section shows that it may be a good indicater to get a general idea about its grade or condition. Therefore the values obtained from the difference indices of chemical weathering which are given in Table 1 can be employed to compare with $H_2O(+)$ content without considering their physical or qualitative difference.

In general, the values of WPI, MWPI, PI, Ruxton's Ratio and Parker are higher in fresh rocks and lower in residual soils. In the other hand, CIA, CIW and Vogt Ratio do not show a continuous decreasing or increasing towards residual soils from fresh rock condition. To find a variation, the values of each weathering index was plotted against the amount of $H_2O(+)$ (Fig. 3). The diagrams indicate that WPI, PI and Ruxton's Ratio are decreasing with increasing $H_2O(+)$ %. All other indices are not regularly varying and therefore cannot be applied to measure the grade of weathering for metamorphic rocky regions in this Island.

Parker's Index is based on the proportions of the alkaline earth metals present. These are considered to be the most mobile of the major elements. But in these samples Na_2O, K_2O, CaO and MgO amounts are decreasing rapidly with increasing $H_2O(+)$ and the remaining amounts in some samples cannot be measured by XRF method (show zero values). Therefore Parker's method cannot be applied.

Generally SiO_2, TiO_2 and Al_2O_3 amounts are increasing with $H_2O(+)$ content. Therefore this indicates that some relationships may occur among these oxides. CIA, CIW and Vogt Ratio are mainly based on the presence of Al_2O_3 and the alkaline metals. Due to the very low percentage of alkaline metals their values do not show regular variations with $H_2O(+)$.

Weathering index of Reiche (1943), WPI, is based on alkali metals, SiO_2, Al_2O_3, Fe_2O_3 and TiO_2 and the amount of $H_2O(+)$. Therefore it already has a relationship with $H_2O(+)$. This index was modified by Vogel (1973) deleting the amount of $H_2O(+)$. It does not show a regular relationship due to very low values of alkaline metals and absence of the amount of $H_2O(+)$. Ruxton's ratio and Product Index which are based on the major metal oxides indicate a regular variation with increasing water content.

Conclusion

Measuring of $H_2O(+)$ amount of rock material is a good and reliable method to find its degree of weathering or weathering condition upto certain level. This can be used to compare the values of each chemical index of weathering with considering degree of weathering of samples. WPI, PI and Ruxton's Ratio show regular variations with increasing of $H_2O(+)$ content of the materials or increasing weathering. These three chemical indexes can be applied to the Sri Lankan rock materials and soils to find their weathering conditions and for future research works.

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