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Investigation of Rock Weathering and Geochemical Changes in Road Cuts, Central Expressway

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Abstract

Investigation of geochemical changes of different rock types is essential for identifying the degree and intensity of chemical weathering. In this research, three major rock types were identified (granitic gneiss, quartz feldspathic gneiss, and biotite gneiss) and the effect of chemical weathering on them was measured. Identifying the intensity of chemical weathering on these rock types is important to determine the most vulnerable gneissic rock type and to mitigate any risks associated with it at the correct moment. In each rock, three weathering stages were identified (residual soil, weathered rock, and fresh rock) and subjected to AAS and ICP-MS analysis to determine elemental concentrations. Chemical weathering indices such as the Chemical Index of Alteration (CIA), Chemical Index of Weathering (CIW), Weathering Index of Parker (WIP), and Vogt's Residual Index (V) were calculated according to the depth of rock profiles, and weathering trends were developed. Based on these trends, quartz feldspathic gneiss was identified as the most weathered rock type due to rapid leaching of mobile elements even in fresh rock. LAAV values of each rock type were compared with weathering indices, showing a linear relationship.

Keywords: AAS, CIA, CIW, ICP-MS, V, WIP

1 Introduction

Rock weathering is a fundamental geological process that reflects how the rock is affected by different factors, including human activities, environmental changes, and other activities. According to those activities, there are three major weathering types that can be identified as physical, chemical, and biological weathering. Physical weathering is mainly dominated by the disintegration of rocks due to human and animal activities [2]. However, the biological weathering is the least dominated weathering type, and it is mainly caused by plant growth through rock mass.

Chemical weathering is dominated by hydrolysis, oxidation, and dissolution, processes that are intensified by the area's climatic conditions, including annual rainfall between 1000–5000 mm and consistently high temperatures [1], [4], [9]. Hydrolysis transforms feldspars and micas into clay minerals such as kaolinite and illite, while oxidation of minerals like biotite and pyroxene leads to the formation of iron oxides like hematite and goethite. Dissolution, though less common, can significantly affect calcite-bearing rocks. In this study the major concern is the chemical weathering as the most dominant factor for geochemical changes of rocks during weathering [1].

2 Background of the study

As there are several factors that affect the rocks to be weathered, it is important to identify how these rocks change their properties when they are exposed to intense weathering. Among these alterations of rocks due to weathering, the geochemical changes of the rock mass are important to notice, as they are a main reason for the rocks to change their internal chemical composition. In order to change their chemical composition, the rocks should be exposed to processes such as hydrolysis, dissolution, oxidation and carbonation. These are the dominating processes of chemical weathering.

Hence, the main reason for the geochemical changes of rocks is chemical weathering.

Identifying those geochemical changes are critical when it comes to determining how the properties of gneissic rocks change with chemical weathering. They are useful in identifying the degree of chemical weathering a rock has undergone. The intensity of chemical weathering on a particular gneissic rock type is important in identifying the stability analysis of road cuts in the central expressway. Chemical weathering breaks down the chemical compounds in rocks, causing them to lose their strength parameters by loosening their material structure. Hence, the rock will be weak and susceptible to degradation. This will cause the gneissic rock mass to reduce its material quality to use as aggregates. This study helps to identify those changes in gneissic rocks.

The study area that was chosen for the study is on the Kurunegala – Kandy central expressway. This area is mainly composed of gneissic rock types such as granitic gneiss, quartz feldspathic gneiss, and biotite gneiss. For this study, granitic gneiss, quartz feldspathic gneiss, and biotite gneiss rock types were selected.

The main aim of this study is to identify how chemical weathering affects different types of gneissic rocks. The objectives of the study include identifying the least chemically weathered gneissic rock type and the highest chemically degraded gneissic rock type. In addition to that, the changes in aggregate quality of gneissic rocks due to chemical weathering will also be monitored in this study.

3. Chemical weathering indices

The geochemical changes will occur in different rocks as chemical weathering progresses. These alterations should be calculated in order to identify the intensity of chemical weathering on a particular rock type. In the calculation, the leaching of mobile elements (Na, Mg, Ca, K) and the accumulation of immobile elements should be taken into consideration since the removal of mobile elements is the main result of chemical weathering. In order to identify these changes, there are formulas called chemical weathering indices. Chemical weathering indices are mathematical tools used to quantify the degree and intensity of such weathering. Key indices include the CIA, CIW, WIP, and V [1], [2]. Those can be described as follows.

$$\text{CIA} = \frac{Al_2O_3}{(Al_2O_3+Na_2\,O+K_2O+CaO)}$$

$$\text{WIP} = 100\left(\frac{2Na_2O}{0.35}+\frac{MgO}{0.9}+\frac{2K_2O}{0.25}+\frac{CaO}{0.7}\right)$$

$$\text{CIW} = \frac{Al_2O_3}{(Al_2O_3+Na_2\,O+CaO)}$$

$$\text{V} = \frac{\{Al_2O_3+K_2O)}{MgO+Na_2\,O+CaO)}$$

Equations 1: Weathering Indices

Chemical weathering indices use various chemical compounds in their equations, which must be expressed in molar form [15]. Mobile elements such as Na, Ca, and K are leached from the upper parts of the weathering profile as weathering progresses into the residual soil. In contrast, these elements tend to remain in the fresh rock, which is less affected by chemical weathering. Therefore, the Chemical Index of Alteration (CIA) is generally lower in fresh rock due to higher concentrations of Na_2O, K_2O, and CaO. Moving upward through the profile, the CIA increases as mobile elements are lost and secondary minerals form [16]. To identify these geochemical changes along a weathering profile, it is essential to evaluate the weathering indices of that profile as the indices mainly focus on elemental changes of a particular rock sample. Since this study primarily focuses on the impact of chemical weathering on different types of rocks, it aims to identify their geochemical changes and assess the changes in aggregate quality of different rocks resulting from chemical weathering.

4. Methodology

4.1. Sample collection

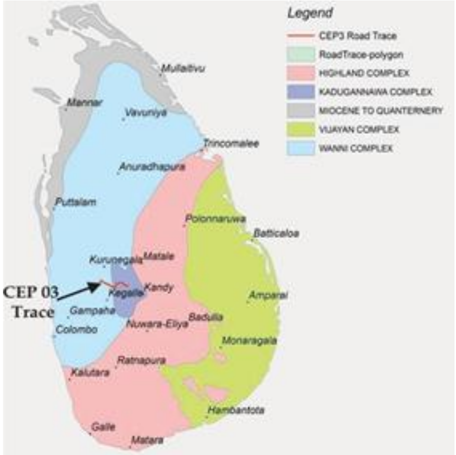

Figure 1: Central expressway section 3

The samples were collected from the central expressway along the trail of Pothuhara to Galagedara area (Section 3). Three locations were selected along this area in the chainages of 6+155 km, 9 +580 km, 9 + 820 km (See figure 1).

The rock types that were selected along these chainages are granitic gneiss, quartz feldspathic gneiss and biotite gneiss respectively (See figure 2, figure 3, figure 4). From each rock type three rock samples were selected according to their weathering grade depending on their physical appearance and details. Hence, for each gneissic rock type, weathered rock sample, fresh rock sample and residual soil sample were collected from their weathering profiles.

Figure 2: Location 1 - Granitic gneiss - ch. 6+155 km

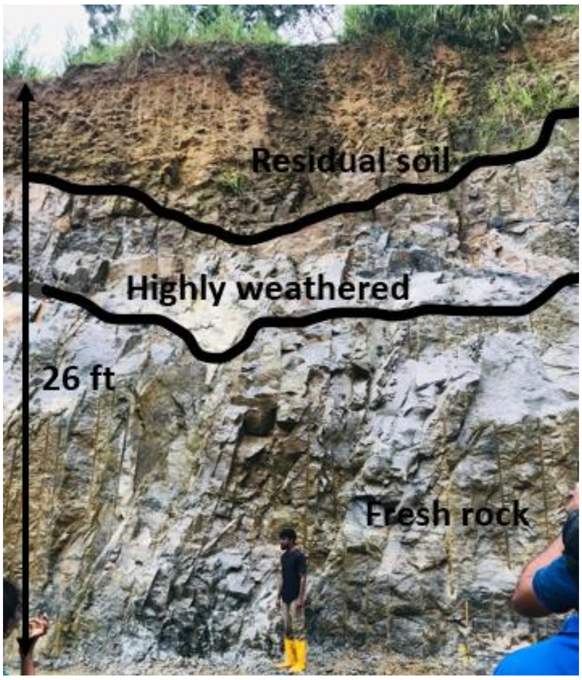

Figure 3: Location 2 - Quartz feldspathic gneiss - ch. 9+580 km

4.2. Sample preparation

Following the field-collection procedures, all rock and soil samples were subjected to a series of rigorous preparation protocols before laboratory analysis to maintain consistency, purity, and reproducibility.

Figure 4: Location 3 - Biotite gneiss - ch 9 + 820 km

At first, the rock samples were air-dried, then they were crushed by a geological hammer and jaw crusher down to manageable sizes, while the crushed samples were ground into a very fine powder by the laboratory-grade Tema mill and passed through a 63-micron sieve to attain uniform particle size for geochemical testing. For the digestion, aqua regia digestion method was used following ISO 11466:1995 'Soil quality — Extraction of trace elements soluble in aqua regia. The digestion can be explained as follows. An accurate 0.5 g weight of each powdered sample was taken for digestion. An oxidative agent, such as hydrogen peroxide, was first added to break down any organic matter present within the rock samples. Following this step, hydrochloric acid (HCl), nitric acid (HNO_3), and hydrogen peroxide (H_2O_2), in a 3:1:1 ratio were then applied to the samples for digestion of metal-bearing minerals; this mix was then introduced on a hot plate at 120°C for about 2 hours and 45 minutes to ensure complete digestion of silicate and oxide matrices. Once the digestion procedure was completed and the digestions were allowed to cool to room temperature, the digested samples underwent one more dilution operation as per the need of specific analytical techniques. For concentrations of Aluminum (Al) analyzed in each sample using Inductively Coupled Plasma Mass Spectrometry (ICP-MS), 1 ml of the digested solution was taken and diluted with deionized water to 10 ml. This dilution coefficient was to keep the concentration of analytes well within the linear detection range of this instrument, which would also reduce the matrix effect and, therefore, allow for accurate quantification.

In Atomic Absorption Spectroscopy (AAS) methodology, a slight modification from the initial procedure was invoked due to the preliminary test results showing high concentrations of the trace elements in the order of mg/l. From each sample after digestion, a 5 ml aliquot was taken and diluted to 50 ml with deionized water. Since the concentrations were too high for direct analysis by AAS, further serial dilutions were carried out to enable the concentrations to enter the lower sensitivity range of the AAS instrument. Then, after the samples were diluted again to 10X level by taking 1 ml of the sample and diluting it to 10 ml.

In addition to this LAAV test was performed on samples (excluding residual soil samples) according to ASTM C131 and C535 standards.

4.3. Developing weathering trends

A weathering trend is a diagram, which is in a form of a triangle, and in the corners, it has 3 values called A, CN, and K. A defines how much aluminum oxide percentage a rock sample contains. CN and K values indicate how much Ca and Na, a rock sample contains and how much K, a rock sample, contains, respectively. These three values were calculated for each sample of each gneissic rock type. After obtaining these three values for one rock sample, that coordinate can be placed on the weathering trend triangle. For fresh rock, weathered rock and Residual soil of these rock samples, these coordinates were calculated. Then they were plotted on the weathering trend triangle. Then the weathering path was created by connecting those coordinates on the triangle. The following equations show how the weathering trend coordinates can be calculated. (see equations below)

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

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

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

Equations 2: Equations for A, CN and K coordinate calculation

These A, CN and K values were calculated for all three rock types. Then The following graphs were obtained as weathering trends for each rock type. (See figure 5, figure 6, figure 7)

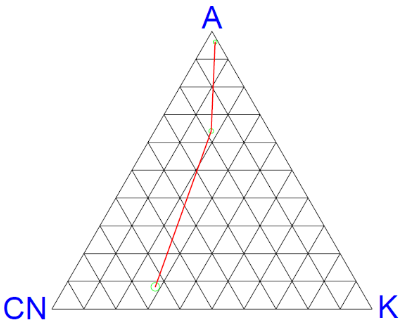

Figure 5: Weathering trend of granitic gneiss

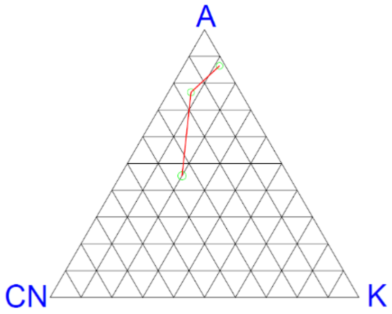

Figure 6: Weathering trend of quartz feldspathic gneiss

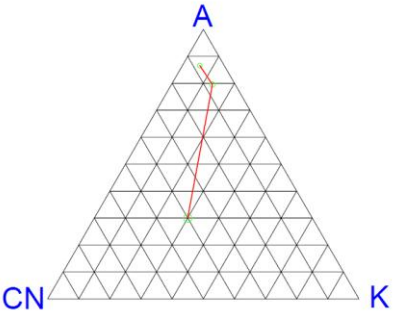

Figure 7: weathering trend of biotite gneiss

5. Results and discussion

After testing samples for their elemental concentration using ICP-MS and AAS, they have been subjected to schematic ratios for their oxide percentage measurements, and the following results have been obtained. (See table 1, table 2, table 3)

Table 1: Elemental oxide percentages of different rocks at different

Rock Type	Weathering state/ Oxide (%)	Na_2O (%)	MgO (%)	CaO (%)	K_2O (%)	Al_2O_3 (%)
Granitic gneiss	Residual soil	0.13	0.50	0.01	0.67	23.90
	Weathered rock	0.47	0.16	0.01	0.71	2.79
	Fresh rock	0.12	0.13	0.20	0.23	0.07
Quartz feldspathic gneiss	Residual soil	0.08	0.60	0.01	0.83	6.70
	Weathered rock	0.74	0.67	0.01	0.52	5.89
	Fresh rock	0.46	0.57	0.25	0.62	1.62
Biotite gneiss	Residual soil	1.62	0.15	0.01	1.75	29.50
	Weathered rock	0.51	0.64	0.02	1.45	9.50
	Fresh rock	1.28	2.94	0.25	1.98	2.17

Table 2:Oxide molar values

Rock Type	Weathering state/ Molar values	Na_2O ($\times 10^{-5}$)	MgO ($\times 10^{-5}$)	CaO ($\times 10^{-5}$)	K_2O ($\times 10^{-5}$)	Al_2O_3 ($\times 10^{-5}$)
Granitic gneiss	Residual soil	1.05	6.00	0.089	3.56	117.00
	Weathered rock	3.79	2.00	0.089	3.78	11.40
	Fresh rock	0.97	2.00	1.790	1.22	3.00
Quartz feldspathic gneiss	Residual soil	0.65	8.00	0.089	4.41	32.80
	Weathered rock	5.97	8.00	0.089	2.77	28.90
	Fresh rock	3.71	7.00	2.230	3.30	7.09
Biotite gneiss	Residual soil	13.10	2.00	0.089	9.31	145.00
	Weathered rock	4.11	8.00	0.179	7.71	46.60
	Fresh rock	10.30	3.70	2.230	10.50	16.00

Table 3:Weathering indices and LAAV values

Rock Type	Weathering state/ Indices	CIA (%)	CIW (%)	V	WIP	LAAV (%)
Granitic gneiss	Residual soil	96.1	99.0	16.40	0.041	-
	Weathered rock	64.1	77.9	2.97	0.054	44.46
	Fresh rock	7.9	11.1	0.35	0.019	18.80
Quartz feldspathic gneiss	Residual soil	86.4	97.8	4.52	0.047	-
	Weathered rock	76.6	82.7	2.19	0.065	22.75
	Fresh rock	46.2	57.2	0.86	0.058	18.98
Biotite gneiss	Residual soil	86.6	91.7	10.30	0.150	-
	Weathered rock	79.5	91.6	4.42	0.094	53.93
	Fresh rock	31.5	45.6	0.43	0.187	24.23

In the table, it can be seen that the CIA value gets high when it is residual soil and becomes lower when it goes to fresh rock state. The lower CIA value indicates lower Al_2O_3 levels and higher mobile element percentage which can be seen in fresh rock state. Higher CIA values indicate more weathered and residual soil which has more Al_2O_3 and less mobile oxides. It goes same for the CIW value and can be seen in the graph.

In addition to that, the relationship between the CIA values and the LAAV values of same gneissic rock samples were recorded. Then after the points were positioned on a graph as follows (See figure 8).

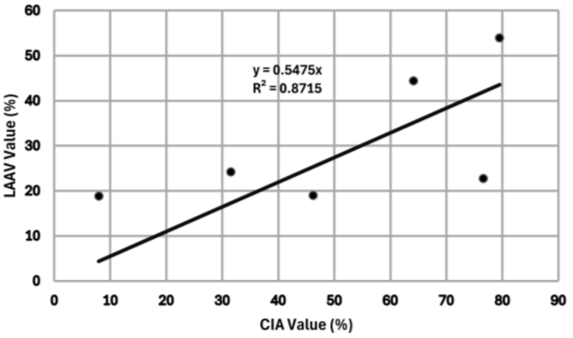

Figure 8: LAAV vs CIA graph

The resulting graph showed a value for R^2 to be 0.8715, which means this is in the acceptable range.

6. Conclusion

Among these rock types, quartz feldspathic gneiss is the highest weathered rock type, due to its extreme loss of mobile elements in the fresh rock state. When comparing the other two rock types, it is obvious they have a slower weathering rate than quartz–feldspathic gneiss, as their fresh rock state has a long way to go until it moves toward A apex. In the same weathering conditions, quartz feldspathic gneiss tends to degrade more than the other two rock types.

In addition to that, in the granitic gneiss graph, the weathering path indicates a rapid K_2O reduction and Al_2O_3 accumulation, which leads to the formation of clay minerals like kaolinite. In the quartz feldspathic gneiss, the weathering path leads to the retention of K_2O before clay formation, which creates the clay mineral formation, such as Illite. Biotite gneiss tends to move towards K base, which indicates the accumulation of CaO and Na_2O and the reduction of K_2O, which finally leads to form clay minerals like smectite.

The relationship between LAAV and CIA shows a positive relationship between the parameters with an acceptable correlation coefficient. It says that when the chemical weathering is high, gneissic rocks will have a high LAAV value. That simply means that when the chemical weathering is high, the material quality degrades. This graph can also be used for the prescreening process for the LAAV test. When the CIA value of a gneissic rock sample is out of the pink zone, it does not need to be tested for aggregate quality by LAAV again as it has a higher CIA value. That means it has been exposed to intense chemical weathering.

The aggregates with a LAAV value below 35% are suitable for foundation purposes in road construction (ASTM C131 and ASTM C535). Hence, according to that, the rocks that have a CIA value below 63.93 are suitable for road surface construction. In addition to that, when a certain rock type has a CIA value below 54.79, (in which case, the LAAV value is below 30%) those are suitable for the foundation construction of roads. Hence, this is important to identify unsuitable material for construction purposes. These threshold limits are critical when it comes to serious applications like road construction. It should be able to withstand traffic conditions, heavy vehicle burden, and durability issues. Hence, the CIA (i.e. - Chemical Weathering Index) value of gneissic rocks can be used as a proxy for aggregate suitability for construction when they are used for such applications

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