Feldspar-based chemical weathering index of shales in Korea

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ABSTRACT

This study calculated the weathering index using whole rock analysis (X-ray fluorescence analysis) of shale in Korea. Evaluation of the weathering index using the quantitative element composition of rocks is very effective for predicting the degree of weathering of rocks. Shale showed higher significance of Wp, CIA, CIW and PIA, the feldspar-based weathering index, while chemical species with low mobility and index considering SiO_2 ratio had no significance. One of the feldspar-based indexes, the Chemical Index of alteration (CIA) has the advantage of predicting weathering, weathering pathway and clay mineral production. However it is effective to consider together chemical index of weathering index (CIW) simultaneously to improve accuracy.

Keywords: Shale, Whole rock analysis, Weathering index, CIA, CIW

1. INTRODUCTION

Mostly applied standards such as RMR (Rock Mass Rating) and Q-system (Rock Mass Quality) of weathering involve qualitative standards based on visual observation which does not reflect the changes due to weathering process. Also, the ground investigation at the time of designing is based on the engineering condition at the time of construction which often fails to reflect the decrease in the durability of the rocks. The mechanical weathering during the excavation process and the environment exposing the surface of the rocks accelerate the weathering which involve a speedy process of secondary weathering. Each rock has its unique critical load (Werner and Spranger, 1996) and when a rock reaches its critical load, its physical strength decreases and the rock property changes from the designing condition, which results in increased uncertainty of a structure. Weathering from the air and water takes place when rocks are exposed over the ground. At the initial stage of weathering, eluviation of silicates in rock forming materials and elements with high mobility happens. The amount and mobility of elements eluviated by chemical weathering differ by the element composition of each mineral. Examples of the alkali metals and alkali earth metals, the chemical species with high mobility, in rock forming minerals are K_2O, Na_2O, CaO, and MgO. On the other hand, examples of the chemical species with low mobility are TiO_2, Al_2O_3, FeO, MnO, and P_2O_5. The elements composing the minerals slowly eluviate due to weathering, and the amount and speed of eluviating elements differ generally. Na_2O, CaO, K_2O, and MgO have relatively high mobility among the chemical species with low mobility, while TiO_2, Al_2O_3, and Fe_2O_3 have very low mobility. By measuring the ratio of the chemical species with different mobility, the generation of altered minerals and degree of weathering are discovered. Weathering index are about measuring the deficiency of elements with high mobility to elements with low mobility. There have been much effort made to observe quantitative weathering through an analysis of the whole rock elements in each weathering phases, and various weathering indexes are suggested However the weathering indexes used in the previous studies are not applicable for every rock, because each rock has different weathering properties (Werner and Spranger, 1996).

In this study, a whole rock analysis is conducted on the shale, identifying the mineral composition, and calculating weathering index in each weathering phase. Also, a careful approach is made for assessment of rational index considering the features of sedimentary rocks from the weathering index proposed by the previous studies. Especially, it is focused on the feldspar-based weathering index such as Wp, CIA, CIW, and PIA.

2. RESEARCH METHOD

2.1 Sampling

For this study, 33 rock samples of shale are collected among the sedimentary rocks in Korea. The samples are collected from the Mesozoic stratum of Gyeongsang Supergroup and the Paleozoic stratum of Pyeongan Supergroup. The locations are indicated in Fig. 1.
The X-ray fluorescence analysis and X-ray diffraction analysis are conducted on the samples. Using the chemical composition of the rocks to select various chemical weathering index and analyzed correlation.

2.2 Chemical weathering indexes

The chemical weathering is a method to quantify not only the current state, but also expected weathering during the maintenance period. The whole rock analysis is conducted to verify the chemical composition of mineral and to predict the weathering by analyzing the content ratio of SiO_2, TiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, MnO, K_2O, Na_2O, and P_2O_5 of a rock.

Table 1 indicates the weathering indexes applied in this study. In the calculation of weathering indexes using the chemical species of elements, CaO is limited as silicate rock is weathered, thus written as CaO^* to indicate elimination of apatite (Price and Velbel, 2003).

Table 1. Summary of weathering indices (if calculated using molecular proportions of elements oxides) evaluated in this study (modified from Price and Velbel, 2003).

Index	Formula	Fresh value	Weathered value
V	$(Al_2O_3+K_2O)/(MgO+CaO+Na_2O)$	<1	Infinite
SAR(R)	SiO_2/Al_2O_3	>10	0
Wp(WIP)	[(2Na2O/0.35)+(MgO/0.9)+(2K2O/0.25)+(CaO/0.7)×100	>100	0
CIA	$[Al_2O_3/(Al_2O_3+CaO^*+Na_2O+K_2O)]\times100$	≤50	100
CIW	$[Al_2O_3/(Al_2O_3+CaO+Na_2O)]\times100$	≤50	100
Si-Ti Index	$[(SiO_2/TiO_2)/((SiO_2/TiO_2)+(SiO_2/Al_2O_3)+(Al_2O_3/TiO_2))]\times100$	>90	0
PIA	$[(Al_2O_3-K_2O)/(Al_2O_3+CaO-Na_2O-K_2O)]\times100$	≤50	100

V: Vogt ratio (Vogt, 1927), SAR(R): Silica-Alumina Ratio (Ruxton, 1968), Wp (WIP): Weathering Index of Parker (Parker, 1970), CIA: Chemical Index of Alteration (Nesbitt and Young, 1982), CIW: Chemical Index of Weathering (Harnois, 1988), Si-Ti Index: Silica–Titania Index (De Jayawardena and Izawa,1994), PIA: Plagioclase Index of Alteration (Fedo et al., 1995)

Table 2. Descriptive statistics of chemical weathering indices on shales

Rock type	Index	Sum	Stand. error	Medi.	Stand. dev.	Varia.	Kurto.	Skew.	Range	Min.	Max.	Confi. level
Shale	V	2.3	0.3	1.7	2.0	3.8	4.4	1.9	9.1	0.1	9.1	0.7
	SAR	7.2	0.4	6.7	2.2	4.8	3.8	1.5	10.6	4.5	15.1	0.8
	Wp	59.5	3.4	58.2	19.5	381.0	-0.1	0.3	77.8	27.2	105.0	6.9
	CIA	58.2	2.8	57.6	16.3	265.5	0.8	-0.7	72.7	9.6	82.3	5.8
	CIW	67.6	3.7	64.4	21.1	445.4	0.0	-0.5	88.4	9.6	98.0	7.5
	CWI	3.4	0.1	3.3	0.5	0.2	-0.2	0.5	1.8	2.6	4.4	0.2
	Si-Ti	83.4	0.6	83.0	3.5	12.5	-1.0	0.5	11.6	78.2	89.8	1.3
	PIA	63.2	3.8	59.7	22.0	483.8	-0.6	-0.2	87.9	9.6	97.5	7.8

3. RESULTS AND DISCUSSIONS

3.1 Weathering indexes of shales

Utilizing the method suggested in Table 1, chemical weathering indexes shown on Table 2 are calculated. As weathering process went on, the total amount of CaO and Na_2O decreased from eluviation while total amounts of Al_2O_3, Fe_2O_3, and TiO increased.

3.2 CIA weathering index and discussion

CIA can be stated in a triangular diagram (Fig. 1). Weathering indexes of fresh bedrocks are in 45-55 range, and when the weathering process completes, it reaches 100 which refers kaoline.

Fig. 1 presented CIA of shales in a triangular diagram. The weathering indexes of each sample type indicate linear increase as it goes through weathering process. However, in Fig. 1, some samples of shale has CIA below 45, the range is lower than the weathering indexes in a very fresh state, so it is stated that it is an irrelevant error. To compare the generation of secondary minerals in rocks and weathering indexes, shale samples are classified based on the CIA and X-ray diffraction analysis are conducted on them. Shale samples within 60-70 CIA range refer to the unweathered state in visual inspection composed mostly of quartz and feldspar with a small amount of mica and illite (Fig. 2a). Shale samples close to the surface have 70 or above CIA range with notable desquamation in visual inspection. Their mineral composition indicates secondary minerals of chlorites, and the peak of mica and illite became apparent (Fig. 2b). Fig. 2c is the results of analysis of shale samples with calcite veinlet. When calcites is excluded, it is observed that it has the same results with weathered shale samples. Upon the calculation of chemical alteration indexes, it is adjusted to eliminate the carbonate influence. However, they had about 30 CIA, lower than the shale samples in a fresh state, which is a result below the appropriate range to determine the weathering phase. Such results mean that it is most significant to select the representative samples of weathering and acquire their analytic data in the calculation of weathering indexes of chemical species.

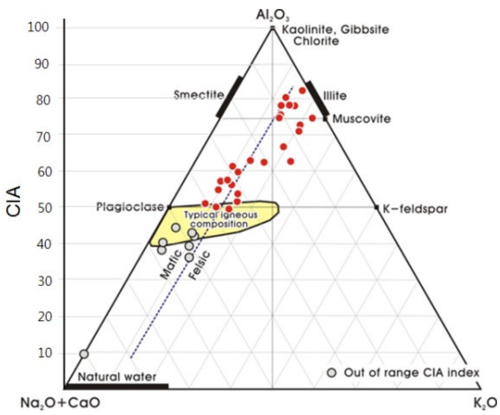
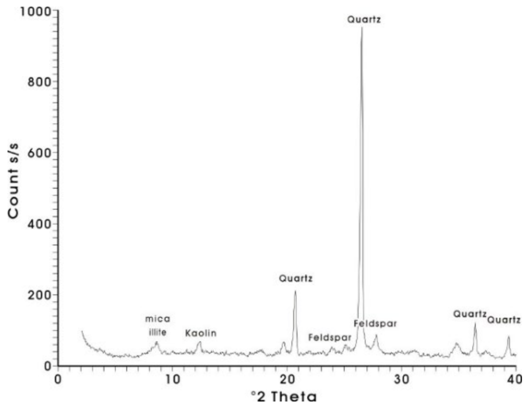
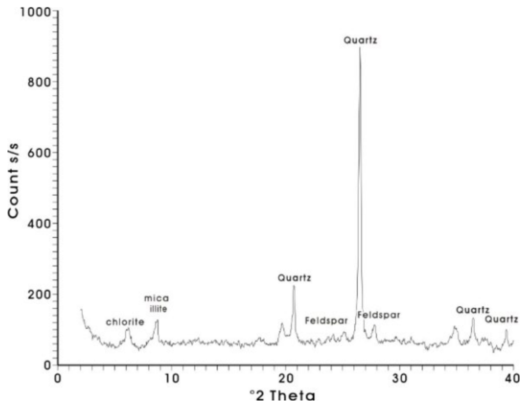


Fig. 1 Chemical index of alteration(CIA) of shales

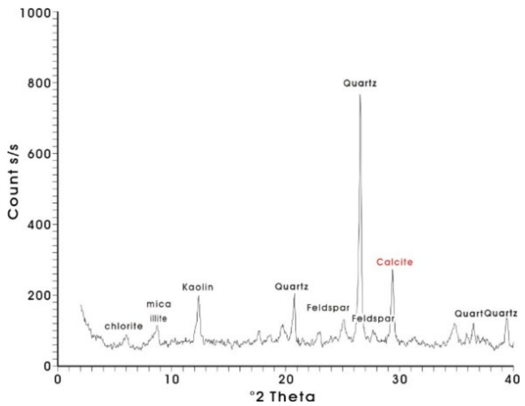
As it is seen from Figs. 1 and Fig. 2, rocks with high CaO volume have weathering indexes that may present results with the irrelevant range depending on the content ratio of CaO. In this sense, rocks with high calcite volume or carbonate rocks such as limestone or dolomite are unreliable to explain the weathering process. Fedo et al.(1995) examined effects of CaO chemical species on CIA and CIA indexes on the same samples to suggest using CIA to eliminate the influences of calcite, dolomite, and apatite. As CIW does not explain K-feldspar related aluminum, it can be calculated with rich K-feldspar regardless of the chemical weathering state, and be use as a measure of feldspar weathering (Nesbitt and Young, 1982; Maynard, 1992; Fedo et al., 1995).



(a) Fresh shale



(b) Weathered shale



(c) Containing calcite veins

Fig. 2 Result of X-ray diffraction in shale.

Fig. 3 is CIA and CIW of shales used in our analysis. Although applied the correction equation suggested by Fedo et al. (1995), the effects of phosphate and carbonate rocks other than CaO in silicate are failed to eliminate, thus there is a result out of the interpretable range. For analysis of weathering of shale, the results with significant weathering indices based on feldspar weathering yet out of range should be excluded.

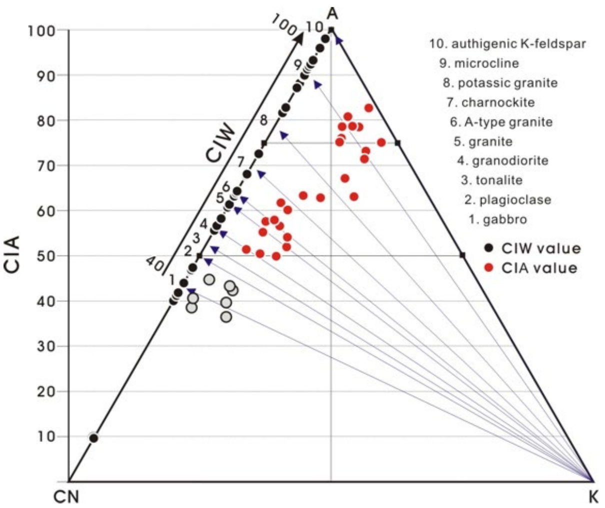


Fig. 3. Red circles are CIA values for shales corresponding black circles show CIW for same samples.

4. CONCLUSIONS

Various weathering indexes are calculated through whole rock analysis of shale in Korea, and significance of each index are drawn and improvements needed for application of weathering index.

The weathering indexes of shale indicated high significance with Wp, CIA, CIW, and PIA, the feldspar-based weathering index, while chemical species with low mobility and index considering SiO_2 ratio had no significance. Among the indexes, CIA and CIW, excluding K_2O, increased in proportion to the increase in weathering degree. In this sense, it is concluded that CIA and CIW are effective measures of evaluating weathering of shales and visibly predicting the generation of secondary mineral.

CIA and CIW indexes applying corrective measures to eliminate the effects of carbonate minerals such as calcite and dolomite, and phosphate minerals such as apatite indicated values out of interpretable range. Therefore, to make the accurate measure of weathering indexes of shales, samples with a high volume of carbonate minerals should be excluded through X-ray diffraction analysis.

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