New Approaches to Evaluation of Chemical Weathering of Rock Materials for Geotechnical Projects

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Abstract: - The chemical weathering of rock proceeds by water-rock interaction. Through weathering geochemically mobile elements, alkali and alkali-earth elements are easily leached from rocks. On the other hand, the residual elements with components from the atmosphere form new minerals. The principal assumption in formulating chemical weathering indices is that the behavior of chemical elements is controlled solely by the degree of weathering. The chemical indexes which have been used in previous studies to characterize the chemical weathering do not consider all the chemical weathering processes. In this study the new chemical indices, which take into account all the chemical weathering processes such as leaching and new mineral forming, are explained. These indices are chemical leaching index (CLI), chemical weathering product index (CWPI) and total chemical weathering index (TCWI). Also cation packing index can be used chemical weathering index representing weatherability, weathered state, chemical leaching and weathering product ratio. P wave-velocity is frequently used for defining the weathering grades, predicting the engineering properties of the weathered rocks and weatherability of rocks. In addition, the P-wave velocity in rock-forming minerals is greater than those in weathering products of these minerals. The P-wave velocity in rock without pores and fissures decreases with an increase in the ratio of weathered mineral/ fresh mineral as a result of the enhancement of the chemical weathering. Due to this, it can be concluded that the P wave-velocity may be used to determine chemical weathering state of rock materials. The indices given in this study are applied to the weathering profiles selected from the Kürtün granodiorite, NE Turkey, for estimation of the states of chemical weathering of rock materials
Key-Words: - Weathering, Chemical weathering Indices, cation packing index, P-wave velocity, granodiorite

1 Introduction

Alteration and weathering concepts are mostly used at the same meaning and in general these concepts express physical and chemical differences existing later in mineral and rocks [1]. There are various definition of weathering and differences between autors seems to steam in part from the different viewpoints of pedologists, geomorphologists, geologists, geochemists and geology engineer. Weathering can be handled from various aspects such as time, form and phases of progress, studies it is majored and research scale. (Figure 1)

Weathering of naturally occurring is divided two types with respect to the timescale; weathering in geological time and weathering in engineering time.

There are different the definition of weathering in geological time and engineering time. Weathering is the process of alteration and breakdown of rock and soil materials at near the Earth's surface by chemical decomposition and physical disintegration [2, 3].The foregoing aspect of weathering concern process which have occurred over long periods of geological time and have combined to produce weathered rock and soil in the state which is found by the engineer the engineer when he arrives on site. However, there are shorter term effects which are concerned with the durability of rocks which may continue to weather in slope or tunnel or during use as construction materials. These short term effects are related to the weatherability of rocks [4]. For the purposes of this review weathering of construction materials within engineering time is defined as "the degradation or deterioration of naturally occurring construction materials under the direct influence of the the hydrosphere, the atmosphere and the activities of man, within an engineering timescale" [5].

The changes the rock experienced in the geological processes from its formation to nowadays can be entitled; a-) weathering existing via superficial effects (phenomena in the atmosphere, hydrosphere, biosphere)

b) hydrothermal alteration. Hydrothermal alteration is the decomposition of minerals and rocks with the effects of waters seeping from the earth to the deeps and then warming up or of the waters and gases with magmatic origin. It is a very complex process involving mineralogical, chemical and textrural change, resulting from the interaction of hot aqueous fluids with the rocks through which they pass, under evolving physico-chemical conditions. Weathering is destructive process or group of processes whereby earthy and rocky materials on exposure to atmospheric agent at or near the Earth's surface are changed in character (colour, texture, composition, firmness or form); specially physical disintegration and chemically decomposition of rocks [6].

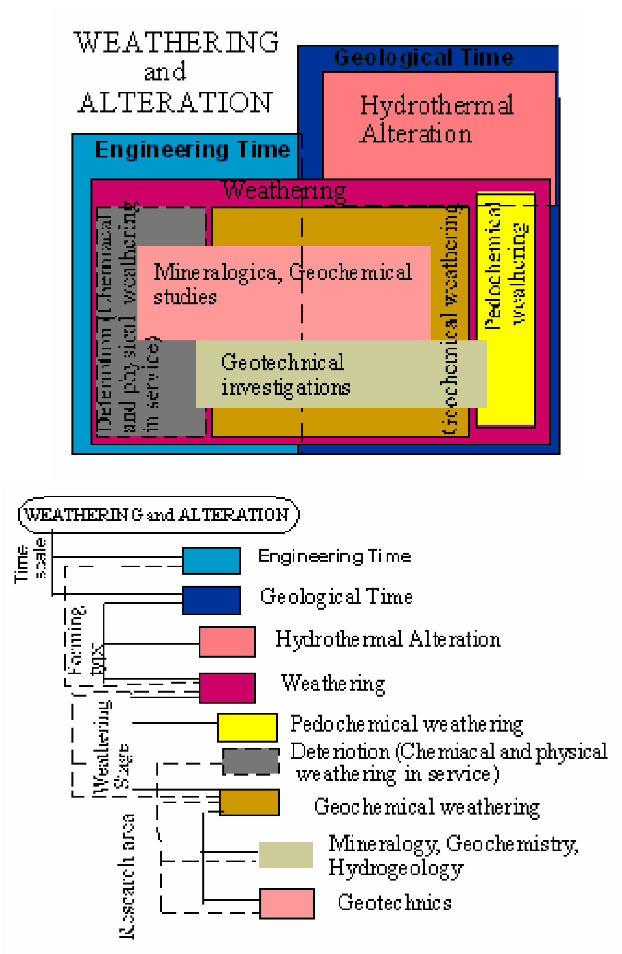


Figure1. Taking up the concept weathering and alteration

Chemical weathering of the outermost part of the lithosphere takes place in two stage; the first stage is the production of the weathered rocks and saprolites (highly weathered and completely weathered rocks), on which the second stage, soil formation, takes place. The first stage is geochemical weathering, and is mostly the inorganic alteration of solid rocks, but in the second stage the effects of metabolism of microorganism living in the geochemically altered rock material, are added to the continued inorganic processes, and this combination procuders a soil [7]. The term pedochemical weathering is used to describe the alterations that take place in geochemically weathered material that lead to the formation of a soil.

Weathered rocks and saprolites can be majored as the studies of many disciplines (with varied purposes, and in varied details and scales). For instance, geochemists and mineralogists examine experimentally the processes resulting in the mineralogical and chemical changes, the interaction of rock-water, the dissolution of minerals in different circumstances. The scale studied on changes from the structure of crystal to the rock exposed in the field [8]. Price (1995) suggested a possible definition for application in geotechnology could be: “Weathering is the irreversible response of soil and rock materials and masses to their natural or artifical exposure to the near surface geomorphological or engineering environment” [9]. From the point of geotechnical applications, it is important to measure the changes of index, strength and deformation properties in the rock materials and masses.

The chemical weathering of rocks proceeds by water-rock interaction. During the weathering, some alkaline and alkali-earth elements easily leached from rock. On the other hand, the residual elements are redistribuded to secondary minerals [10]. This is the fundamental system on the chemical weathering of rocks. Chemical change during weathering and hydrotermal alteration are quantified in several ways including the normalized value of element (or oxide) using their parent rock concentrations or immobile element concentrations in the samples [11, 12], standard cell calculation [13], ratio of elements to immobile elements [13, 14], measurement and calculation of loss of weight (or volume) based on immobile element [15-18] and chemical weathering indices [19-22].

The principal assumption in formulating chemical weathering indices is that the behavior of chemical elements is controlled solely by the degree of weathering. More specifically, it is expected that, as the intensity of weathering increases: (a) certain major oxides, including $A1_2O_3$, Fe_2O_3 and TiO_2, considered as 'immobile', remain constant; (b) Si_2O, Na_2O, K_2O, CaO and MgO, considered as 'mobile', decrease; and (c) LOI content increases [23].

Chemical weathering indices are mainly proposed for felsic and/or intermediate rocks weathered under humid, well-drained conditions [23]. Only a few, such as 'Bases:R_2O3' [13], are particularly proposed for basic rocks, while several others, such as Parker's index [24] are claimed to be applicable for all rocks [23].

There are some correlations between weathering indices and mechanical properties of a weathered rock [25-29]. No single weathering index given in the literature meets the modeling of the process involved in chemical weathering outlined above, and no weathering index would give unequivocal results when applied to the prediction models to assess the mechanical behavior of rocks materials. Taking these into consideration, the various models were developed [30-32].These models were applied to evolution the chemical weathering effects on the rock materials taken from Kurtun granitic rocks

1 Geological Setting

The study area is located in the Eastern Pontides of NE Turkey (Figure 2). The basement unit of the study area is Catak formation, the age of Turonian-Santonian, composed of clay, sandy limestone and andesite interbedded with pyroclastic deposits. Catak formation is conformably overlained by Kızılkaya formation consisting of biomicritic limestone, dacite with marl and pyroclastics. Kızılkaya formation is conformably overlained by Campanian- Maastrichtian. These sequences in the study area are crossly cut by the Kurtun granodiorite intruded during Upper Cretaceous. The intrusion is granodioritic represented by hormblende and biotite. The granodiorite is holocrystalline texture. The constituent minerals are plagioclase, quartz, alkali feldspar, biotite, hornblende and with or without clinopyroxene. Accessory phases are ilmenite, magnetite and sphene. Hydrothermally formed minerals include chlorite, calcite, quartz and epidote [30].

3. Weathering Characteristics, Index and Strength Properties

The Kurtun granodiorite exhibits complete weathering profile, from fresh rock to completely weathered rock and locally residual soil. Definitions of the grades of the weathering are classified by following the procedure suggested by IAEG [3]. The weathering zones of the profile are described easily in the field, because the boundaries of the different weathered zones are generally gradual and parallel to the topography. However, the boundaries are sharp in the domains of the shear zones, hydrotermal profiles and colluvium locations. The samples representing different weathering degrees were collected from uniform zones. The residual soils do not have their original volume due to frame collapse. For this reason, no sample was collected from residual soil in the weathering profile. A total of 20 block samples were collected from different zones of weathering profile to determine chemical, physical, mechanical and mineralogical characteristics of the granitic rocks [30,32]. The physico-mechanical properties of the said samples are given in Table 1.

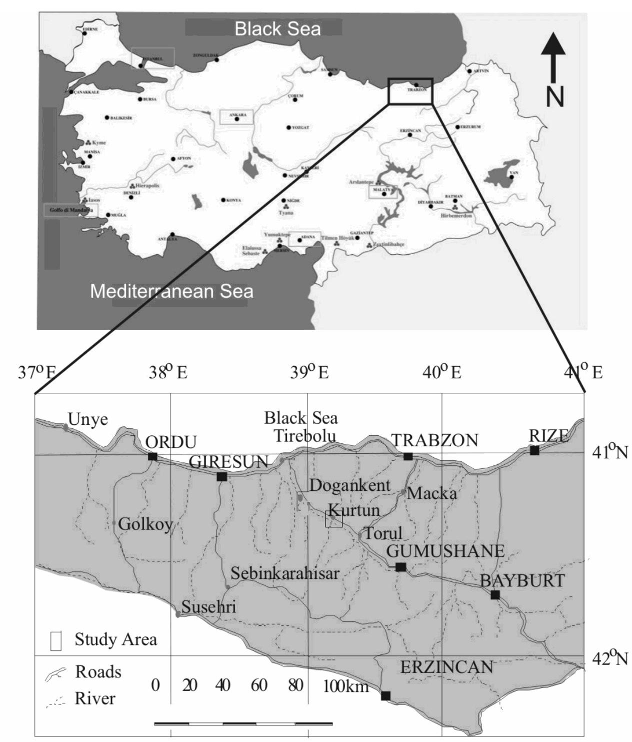


Figure.2. Location of study area

According to the results of the analyses, feldspar is altered into sericite and epidote at the beginning stages of the weathering process after the hydrothermal alterations. At the intermediate stage, clay minerals are formed. Vermiculite, chlorite, epidote and Fe-Ti oxides are the weathering products. Biotite is converted into clay minerals without deteriorating their chemical structures. Hornblende is alterated in the initial stages of the weathering. Quartz grains are scattered and started to dissolve only in completely weathered granitic materials. In the latest stages of the chemical weathering, the soil formation takes place and the granitic material is converted into residual soil.

Table 1. The physico-mechanical properties and the relative variation in mechanical properties of the samples from the weathering profiles on the Kurtun granitic rocks

	γ	n	n_e	Vp	σ_t	σ_C	E_t	E_s	σ_t^*	σ_C^*	E_t^*	E_s^*	WD
KR1a	2.678	1.32	0.72	4932	20,7	195,6	37500	28986	0	0	0	0	F
KR1b	2.638	1.94	1.23	4834	12,2	121,5	20000	15600	41.06	37.88	46.67	46.18	SW
KR1c1	2.553	6.24	5.45	3645	6,1	78,3	12821	8453	70.53	59.97	65.81	70.84	MW
KR1c2	2.561	5.59	5.15	3312	4,1	53,7	11236	6598	80.19	72.55	70.04	77.24	MW
KR1d1	2.457	8.47	7.86	2495	1,4	18,9	4000	2155	93.24	90.34	89.33	92.57	HW
KR1d2	2.375	10.5	10.24	2470	1,2	17,4		1750	94.2	91.1			HW
KR1e1	2.312	16.1	16.03	2218		7,1							CW
KD1a	2.683	1.37	0.77	5318	22,8	200,3	35443	23821	0	0	0	0	F
KD2	2.648	2.45	1.77	4723	14,2	135,8	21053	13451	37.72	32.2	40.6	43.53	SW
KD2B	2.634	2.09	1.41	4582	13,2	143,4	17500	15989	42.11	28.41	50.62	32.88	SW
KD3A	2.544	5.81	5.07	3830	5,6	70,6	11905	7268	75.44	64.75	66.41	69.49	MW
KD3B	2.512	7.1	5.42	4659	4,7	62,2	13514	5875	79.39	68.95	61.87	75.34	MW
KD4A	2.456	13.3	12.58	2878	2,6	33,6	6154	3096	88.6	83.23	82.64	87	HW
KD5	2.324	18.53	18.13	3002		2,8				98.6			CW
KST1	2.644	1.55	0.95	4878	18,2	179,8	27119	21976	0	0	0	0	F
KST2	2.571	3.6	2.48	4297	8,9	99,3	20896	13119	51.1	44.77	22.95	40.3	SW
KST3	2.496	6.37	5.4	3624	4,7	55,2	11628	7526	74.18	69.3	57.12	65.75	MW
KST4	2.408	11.45	10.98	2368	1,3	10,9	5195	1313	92.86	93.94	80.84	94.03	HW
KST5A	2.315	15.54	15.31	2056		4,6				97.44			CW
KST5B	2.332	16.33	16.16	2144		6,1				96.61			CW

(γ : dry density (gr/cm^3), n: total porosity (%); n_e: effective porosity (%); σ_C: uniaxial compressive strength (MPa), σ_t: tensile strength(MPa); E_s: the module of deformation(MPa); E_t: tangent elasticity module(MPa); * indicate the relative variation in mechanical properties of fresh samples and weathered samples)

The relative variation in mechanical properties of the samples were determined by using the following equation,

$$X^* = \frac{(X_f - X_w)}{X_f} x100 \qquad (2)$$

where X*, is the relative change of mechanical property, X_f, is the measured value of the mechanical property on fresh rock. X_w, is the measured value of the mechanical property on weathered samples.

4. Modeling of Chemical Weathering Processes

The model developed depends on isovolumetric approach and takes the definition of Loughnan [10] into consideration (Figure 3). In order to explain the change of the volumetric concentration of major oxides across a weathering profile, the following stages are applied

(a)Modal analysis and whole rock chemical analyses on the samples collected from a weathering profile are performed.

(b)The weight percentage of the major oxide calculated from whole chemical rock analyses of fresh samples are multiplied by dry density of the same sample. Then Amob value in Figure 3 is obtained. By means of this Amob value, a parallel line (OA) is obtained.

(c)For each sample weathered in various degrees, the weight percentage of the major oxide is multiplied by dry density. By this way, upon plotting of the dry density as a function of the volumetric concentration of the major oxide, the OB line in Figure 3 is obtained.

(d)By microprobe analysis of the fresh minerals, the major oxide composition of the minerals in the sample is determined.

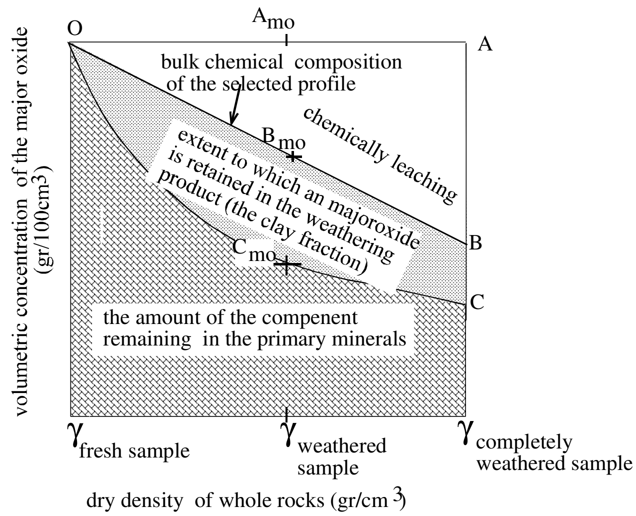
(e)To calculate total amount of the major oxide in unaltered portion of the sample, the following equation [33] is employed

$$Wmo = \left[\sum_{i=1}^{n} Mv(i) \times Ow(i) \right] \qquad (1)$$

where; Wmo, is the weight percentage of the major oxide in weathered sample; i values represent minerals such as plagioclase (i=1), orthoclase (i=2), hornblende (i=3), biotite (i=3), pyroxene (i=4), quartz (i=5), opaque minerals (i=6); Mv is the volume percentage of minerals found by the modal analysis; Ow is the concentration (in weight percentage) of the major oxide in minerals calculated from the microprobe analysis.

(f) The total amount of any major oxide from the Eq. 10 is multiplied by its dry density and then the volumetric concentration of the major oxide in the unaltered portion of the sample is found

(g) The volumetric concentration of the major oxide in the unaltered parts of the samples versus the dry density of the samples weathered to various degrees are drawn and then the OC line in Figure 3 is obtained.



A_{mo} : the volumetric concentration of the major oxide in fresh sample

B_{mo} : the volumetric concentration of the major oxide in the weathered sample

C_{mo} : the volumetric concentration of the major oxide in in theunaltered parts of the weathered sample

$A_{mo}-B_{mo}$: the amount of leaching of the major oxide examined, in the weathered sample

$B_{mo}-C_{mo}$: the amount of major oxide a retained in weathering productsin the weathered sample

Figure 3. A hypothetical model illustrating the behavior of major oxides during chemical weathering (modified [33])

5 Chemical Leaching Index, Chemical Weathering Products Index and Total Chemical Weathering Index

Ca, Na, Mg, and K are geochemically mobile elements. Chemical leaching results in a significant decrease of the oxides of these elements. The ratio of thevolumetric concentration of ($CaO+MgO+Na_2O+K_2O$) in a weathered sample to those in the fresh sample taken from the same weathering profile gives the amount of leaching for the weathered sample. Therefore, this ratio is defined as the *chemical leaching index* (CLI).

$$CLI = \frac{100(A_{mob} - B_{mob})}{A_{mob}} \quad (3)$$

where A_{mob} and B_{mob} are the total volumetric concentration of mobile oxides in fresh sample and weathered sample, respectively. If y axis in the Figure 3 represents the volumetric concentration of the mobile elements, likewise CLI can be found for the weathered sample.

Al, Fe, and Ti are less affected by chemical leaching than alkali and alkali-earth elements, but tend to concentrate in weathering products (e.g. [10]). If the drainage is well-developed, Si moves away, if not, it also tends to concentrate in the weathering products. The ratio of the total amount of these oxides in weathering product to those in the respective sample yields the amount of weathering products. Therefore, the *chemical weathering product index* (CWPI) is defined through the following equation:

$$CWPI = \frac{100(B_{immob} - C_{immob})}{B_{immob}} \quad (4)$$

where B_{immob} and C_{immob} are the total volumetric concentration of immobile oxides in the whole sample and unaltered portion of the sample, respectively. If y axis in the Figure 3 represents the volumetric concentration of immobile elements, CWPI can be found for the weathered sample as defined above.

Considering the definition of Loughnan [10], t*otal chemical weathering index* can be defined as the sum of CWPI and CLI. Since the rock material can be weathered 100% at most, TCWI value should be also at most 100. Therefore, (CWPI+CLI) value has been divided by 2 in order to get TCWI given by the following equation (Figure 4)

$$TCWI = \frac{(CWPI + CLI)}{2} \quad (5)$$

Weathering indices based on P-wave velocity, mineralogical and chemical weathering indices for the said samples are given in Table 2.

Table 2. Mineralogical and chemical weathering indices for the samples at various weathering stages from the Kurtun granitic rocks [30-32]

	FM	SM	Ip	Imp	Ifp	CLI	CWPI	TCWI	Ks	k-value	k*-value
KR1a	97.35	2.21	0.03	20.36	1.7	0	0	0	1.781	4.833	4.833
KR1b	84.29	14.51	0.19	21.94	13.22	10.34	10.6	10. 47	1.3248	4.71	4.114
KR1c1	65.1	27.77	0.54	41.14	26.49	24	24.62	24.31	1.0589	4.326	3.158
KR1c2	63.09	32.01	0.59	46.52	30.02	27.71	28.44	28.08	1.0288	4.411	3.065
KR1d1	46.74	41.35	1.14	59.71	38.98	40.07	39.61	39.84	0.8478	3.993	2.234
KR1d2	43.98	40.57	1.27	60.12	39.52	46.06	38.68	42.37	0.8232	3.823	2.11
KR1e1	33.9	47.88	1.95	64.19	43.05	53.64	48.3	50.97	0.7626	3.672	1.619
KD1a	99.05	0.4	0.01	14.05	1.79	0	0	0	2.1171	4.773	4.773
KD2	85.66	12.7	0.17	23.66	14.29	6.34	10.95	8.65	1.5605	4.64	4.106
KD2B	85.58	12.9	0.17	25.94	12.27	8.67	10.4	9.54	1.6021	4.66	4.117
kd 3A	73.15	21.72	0.37	38.1	18.81	13.72	18.18	15.95	1.3925	4.463	3.587
KD3B	67.17	23.43	0.49	40.86	23.05	16.82	22.38	19.60	1.2292	4.233	3.25
KD4A	52.49	30.8	0.91	53.48	30.46	25.2	30.1	27.65	1.1705	3.855	2.582
KD5	42.15	35.54	1.37	51.48	37.29	36.58	38.75	37.67	1.1004	3.534	2.074
KST1	96.79	2.81	0.03	20.01	3.21	0	0	0	1.5436	4.735	4.735
KST2	80.87	17.17	0.24	29.53	18.59	8.63	15.94	12.29	1.1627	4.584	3.842
KST3	65.94	27.61	0.52	40.57	29.89	11.98	25.83	18.91	0.8538	4.311	3.143
KST4	44.63	40.87	1.24	61.17	41.63	30.58	41.67	36.13	0.6994	3.836	2.197
KST5A	30.71	52.21	2.26	66.28	49.44	49.37	54.39	51.88	0.6435	3.602	1.441
KST5B	31.45	50.89	2.18	64.84	48.51	51.16	53.93	52.55	0.8139	3.564	1.469

(FM : unaltereted minerals content in the rock materials (%); SM: secondary minerals content (%), CD : micro-fracture plus void ratio (%), Ip: Micropetrographic Index, Ks : Weatherability index (Ks=(Wm/PrI); Hodder 1984), k-value (mole/cm^3 x10^{-2}): cation packing index (for whole rock), k-value* (unalterated part of rock. According to unaltered minerals determinig by using modal anayses)

Good correlations between the chemical weatherability index (Ks) and rock durability as well as mechanical properties are determined in the literature [34,35]. Weatherability index (Ks) of rocks depends on the amount of fresh minerals (FM) and its type. In the same kinds of rocks, consequently, Ks decreases as the amount of the fresh minerals [30]. Hence, TCWI and Ks are used together for the estimation of the strength and deformational properties and the following statistical relationships are obtained:

$$\sigma_t = 3.61 + 7.488Ks - 0.25TCWI \quad \text{(N=14, } R^2\text{=0.86)}$$

$$\sigma_c = 35.3 + 71.4Ks - 1.93TCWI \quad \text{(N=18, } R^2\text{=0.88)}$$

$$E_t = 25080 + 1906.3Ks - 646.8TCWI \quad \text{(N=13 } R^2\text{=0.81)}$$

$$E_s = 14031 + 4268.95Ks - 477.7TCWI \quad \text{(N=13 } R^2\text{=0.8)}$$

where σ_C is uniaxial compressive strength (MPa), σ_t is tensile strength (MPa); E_s is the modulus of deformation(MPa), E_t is tangent elasticity modulus (MPa). N gives the number of the samples investigated, R^2 is coefficient of determination.

6 Cation Packing Index (k-value)

According to Olier [36], the weatherability of a rock depends on the number of cation replaceable with hydrogen in a mineral. The k-value is defined as the number of cation in a mole (Equation 10).

$$k_i = \frac{C_i}{N_L V_{Mi}} \tag{10}$$

where k_i is k-value of a mineral, C_i is number of cations per mole, N_L is Avogadro's number and V_{Mi} is molar volume. For a certain rock, k-value can be calculated by using the following expression;

$$k = \sum x_i k_i \tag{11}$$

where k_i is the k value of the i mineral phase, x_i is is amount of the i mineral in the rock determined by modal analysis.

When considering this definition, it is possible to say that the k-value can be used for characterizing the weathering state and weatherability of a rock. Thermal conductivity, density, elastic wave velocity, and k-value are interrelated [37-39]. The petrophysical properties directly depend on k-value, while k-value changes, petrophysical properties also vary. This situation is valid for rock-forming minerals and the weathering (Table 3).

Table 3.The weatherability index (Ks), k-value (mole/cm^3 x 10^{-2}) and P-wave velocity of selected rock-forming minerals and their weathering products (m/sn) from [32])

Minerals		Ks	k-value	V_p
Olivine	*Fayalite*	3.385	6.85	8400
	Forsterite	1.813	6.80	
Pyroxene	*Diopside*	1.829	6.05	7330-7200
	Enstatite	1.6431	6.37	
Amphibole	*Tremolite*	1.004	5.54	6800
	Hornblende	0.5296	5.309	
	Labradorite	0.144		
Plagioclase	*Andesine*	0.088	4.99-4.97	7250-6250
	Oligooclase	0.048		
Alkali Feldspar	*Orthoclase*	-0.0007	4.58	5800
Quartz			4.41	6050
Mica	*Moscovite*	-	4.98	5880
	Biotite	0.5791	4.66	5360
Vermiculite		1.8176	3.95	-
Chlorite		1.6406	4.10	5000
	Sericite	-0.4151	4.52	
Clay	*İllite*	0.0435	4.099	2400-1800
	Smectite	0.0697	3.997	
	Kaolinite	-0.0325	4.058	

According to Table 3, while the amount of the mineral having more weatherability and bigger k-value, increases, P-wave velocity in the rock which would have lacked pores and fissures, V_p^*, increases. Weatherability Index and k-value found for rock-forming minerals are greater than the ones found for the weathering products of these minerals. P-wave velocity in rock-forming minerals is greater than one in the weathering products of these minerals (Table 3). This situations is in accordance with the studies performed researchers [37-40]. Based on the findings summarized above, it can be said that as long as the ratio of weathered mineral/ fresh mineral increases as a result of the enhancement of the chemical weathering, k-value and V_p^* decreases.

The graphs showing the changes of density depending on k-value are given in Figure 4 for each profile. The density and the k-value decrease depending on the weathering,. If there is no weathering, the k-values and the densities remain constant. When the weathering degree increases, both the density and k-value decrease. The region 1 on Figure 4 represents the chemical leaching ratio while the region 2 on Figure 4 gives the weathering product ratio. This has a curical importance because there is not a chemical weathering index characterizing both the weathering product ratio and the chemical leaching ratio.

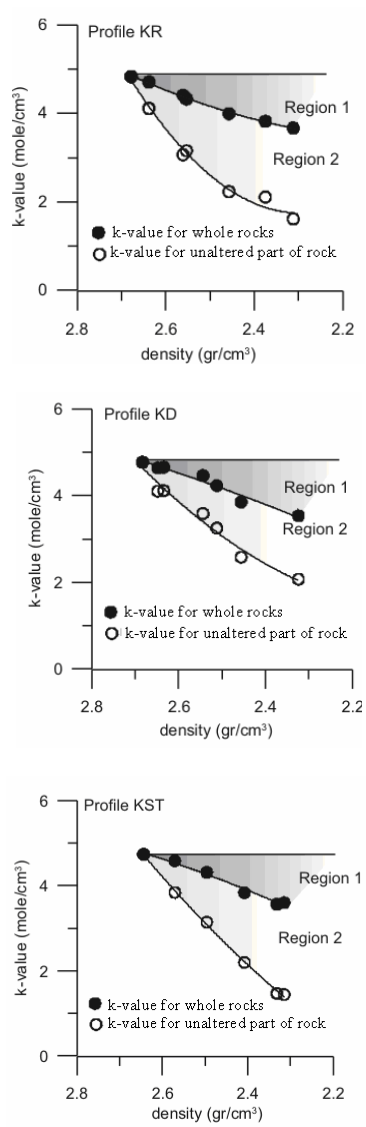


Figure 4. The graphs showing the relationships between the density and the k-value. from the weathering profiles developed on the Kurtun granitic rocks

There are strong relationships between the k-value and the physical and mechanical parameters of the Kurtun granitic rock samples are obtained [32]. k-value representing representing chemical leaching ratio and k-value representing chemical weathering products ratio are used together for the estimation of the strength and deformational properties and the following statistical relationships are obtained

$$\sigma_c = 173 - 36(kf - k) - 71(k - k*) \quad (12)$$
(N=18, R^2=0.91)

$$E_t = (31 - 2.33(kf - k) - 1.567(k - k*))10^{-3} \quad (13)$$
(N=13, R^2=0.87)

where σ_C is uniaxial compressive strength (MPa), E_t is tangent elasticity modulus (MPa), k is cation packing index (k-value) of investigated samples of fresh sample, kf is k-value of fresh sample, k* is the k-value of the unaltered part of the sample. N gives the number of the samples investigated, R^2 is coefficient of determination.

7 Mineralgical Change Parameter and Physical Change Parameter

According to Table 3, it is said that the change in V_p^* value which is P-wave velocity in the rock which would have lacked pores and fissures measured in the fresh sample taken from the same profile of the V_p^* value of the sample which the weathering grade is demanded to be determine, will be the indication of the chemical weatheringthis change was defined as the Mineralogical Change Parameter, Imp, [31]

$$\text{Im}\, p = \frac{100(V_{pf}^* - V_{pw}^*)}{V_{pf}^*} \quad (14)$$

Where V_p^* is P-wave velocity in the samples which would have lacked pores and fissures [41], w refers to weathered rocks, while f refers to fresh rocks. If the mineral composition of the samples is known, V_p^* can be calculated by employing the Equation 15 [41].

$$\frac{1}{V_p^*} = \sum_{i=1}^{n} \frac{xi}{V_{pi}} \quad (15)$$

Where x_i is mod of the mineral in the rock and V_{pi} is P-wave velocity in the mineral constituent (i).

The weathering causes the decrease in the P-wave velocity in the dry rock material, V_p, (i.e.; [42-48]).

The reason of the decrease of V_p depending on weathering is that fresh mineral contents in the sample decreases, and micro-fracture and voids increases. Taking into consideration of the solid part and voids forming a rock material, it should be expected that the P-wave velocity in dry samples, V_p, decreases as long as the micro-fracture and void ratio increases in case of the stable V_p^*. The mean of the stable V_p^* is that the samples have the same mineralogical composition and fabric. It is said that amount of micro-fracture and void increased and the P-wave velocity decreased [35,41,43,46-50]. According to the findings given above, the physical change caused by the weathering can be expressed as the "Physical Change Parameter, Ifp, given in the Equation 16.

$$Ifp = \frac{100(V_p^* - V_p)}{V_p^*} \quad (16)$$

where Ifp is the Physical Change Parameter, V_p is P-wave velocity of the investigated dry sample and V_p^* is P wave velocity of the same samples which would have lacked pores and fissures [41]

The change parameters suggested to evaluate weathering effects were used to estimate the relative variation in mechanical properties in the rock materials from the Kurtun granitic rocks.

$$\sigma_t^* = 0.198\,\text{Im}\, p + 2.222 Ifp + 2.40 \quad (17)$$
(N= 10 R^2=0.88)

$$\sigma_c^* = 0.472\,\text{Im}\, p + 1.66 Ifp - 1.924 \quad (18)$$
(N= 20 R^2=0.92)

$$E_t^* = 0.55\,\text{Im}\, p + 1.595 Ifp - 1.37 \quad (19)$$
(N= 15 R^2=0.79)

$$E_s^* = 0.232 mp + 2.158 Ifp + 0.476 \quad (20)$$
(N= 15 R^2=0.89)

Where σ_C*, σ_t*, E_t* and E_s* are the relative variation (%) in uniaxial compressive strength, tensile strength, the tangent elasticity modulus and the modulus of deformation, relatively.

7 Conclusion

There are various definition of weathering and differences between autors seems to steam in part from the different viewpoints of pedologists, geomorphologists, geologists, geochemists and geology engineer. Weathering can be handled from various aspects such as time, form and phases of progress, studies it is majored and research scale. The definition of weathering for application in geotechnology was suggested many researchers. According to researchers, weathering is the irreversible response of soil and rock materials and masses to their natural or artifical exposure to the near surface geomorphological or engineering environment

The chemical weathering descriptions are checked by chemical and petrographical weathering indices. Although some chemical weathering indices were proposed, there is not a chemical weathering index describing the weathering process. In contrast to the former chemical weathering indices, *Chemical leaching index (CLI)* and *Chemical weathering product index* (CWPI) regard the whole chemical processes involved the chemical weathering, and quantify the overall effects of the chemical weathering. CLI is defined depend on the the amount of the geochemically mobile element leached from rocks. CWPI represents the ratio of the immobile elements in the weathering products to that in the whole rock. *Total chemical weathering* index (TCWI) is defined as the sum of CLI and CWPI. Statistically significant correlations are found between TCWI and the variation of the mechanical properties of the granitic materials in relation to the fresh rock. The strength and deformational properties of the weathered materials are correlated with the values of TCWI and *weatherability index*. TCWI and Ks can be used together for the estimation of the strength and deformational properties of weathered rock materials.

Descriptions of mineralogical and physical changes seperately allow making a comparison between two. During the P-wave velocity tests, the samples are not disturbed and hence, the test can produce many results using one sample. By using this comparison, it is possible to assess the weathering process. Both physical and mineralogical changes on the rocks materials due to weathering can bedescribed separately using Mine-ralogical Change Parameter and Physical Parameter defined based on ultrasonic waves in rocks materials. It is possible to construct some correlations between these change parameters the engineering properties of rocks. By using these correlations, the engineering properties of weathered rock material can be predicted easily and reliably.

The weatherability of a rock depends on the number of cation replaceable with hydrogen in a mineral [36]. The k-value is defined as the number of cation in a mole. When considering this definition, it is possible to say that the k-value can be used for characterizing the weathering state and weatherability of a rock. In addition;

(a) By using the k-value, the amount of the removed minerals by chemical leaching can be estimated,

(b) The amount of weathering products can be found by the k-value,

(c) The petro-physical properties of a rock can be expressed depending on weathering degree by k-value,

(d) Although the chemical weathering indices are calculated by results of the chemical analyses, the k-value is obtained from modal analyses.

When compared with the other chemical weathering indices, the k-value can be used as a weathering index without chemical analyses, because it can be determined by mineralogical analyses.

To check the validity of the results obtained from the present study, further studies should be applied.

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