

Characterizing the pedogenesis processes of some soils on metamorphic rocks from the sub-humid Mediterranean area in Algeria

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ARTICLE INFO

Article History :

Received : 28/11/2019

Accepted : 05/09/2021

Key Words:

Mediterranean soils;
Metamorphic rock;
Pedogenesis; Profile;
indices; Alteration.

ABSTRACT/RESUME

Abstract: The present work aims to characterize the processes of soil formation on shale metamorphic source rocks in a subhumid Mediterranean area in the north of Algeria (Algiers city). The study of the evolution of the horizon's total chemical composition of some elements (Si, Al, Fe, Ti, Ca, Mg, K, Na and Mn), allowed us to define rocks alteration mechanisms and redistribution of the alteration complex in two main profiles formed on metamorphic rocks. To do so, we conducted physical and chemical analyzes for both profiles. Then, the calculation of the Chemical weathering indices helped us to extract the alteration's balance. The results showed that silicium is the main chemical constituent of the studied soil profiles. The realized geochemical trends indicated enrichment of surface horizons by silicium and a decrease in iron and aluminium elements. Regarding the manganese, there is no clear pattern of distribution in the profiles. The concentrations of titanium, alkali and alkaline earth elements (Na₂O, K₂O, CaO and MgO) are irregular in the profiles and are generally lower than those of the parent materials. The weathering indices seem well suited to detect changes in the alteration intensity in the studied soils. The calculated chemical balances vary according to the targeted chemical elements.

I. Introduction

Mediterranean soils form occidental Mediterranean climate conditions and are known as Terra Rossa (on hard limestone) and Mediterranean red soils [1]. Generally, the weathering and formation of the Mediterranean soils show similar trends to those observed in the subhumid tropics [2, 3].

The main characteristic of the Mediterranean climate is the alternation of two seasons in the year; a cool, wet winter and a hot, dry summer typically exceeding three to four months [3]. Expressed in terms of temperature and soil moisture regimes, Mediterranean soils have a xeric moisture regime; most precipitation occurs after the winter solstice, a relatively long dry period is observed after the summer solstice. Temperature regime is thermal (average annual soil temperature between 15 ° and 22 ° C) or occasionally mesic (8 and 15 ° C) [4].

Mediterranean soil's formation is generally limited to the cool and humid season, while during the hot and dry season, the formation of red compounds of the dehydrated iron oxides occurs in the profile [1].

The characteristic soil type of the Mediterranean region is the red soil which is generally related to the Alf soils as described in the Soil Taxonomy [5]. Generally, the weathering and formation of soils in a Mediterranean climate show similar trends to those observed in the subhumid tropics with summer precipitation acting with a much lower intensity. The result is a well-structured reddish-brown to red color profile characterized by red Mediterranean soil or Terra Rossa [1]. This type of soil is less weathered and leached than the tropical soil and is characterized by: a moderately deep soil profile with more or less well-defined clay illuviation in the subsoil; fairly significant dissolution and leaching of carbonates and other

readily soluble components; the development of a characteristic red matrix color, often identified as reddening in French literature, and a colloidal complex almost completely saturated with divalent cations [2]. Red Mediterranean soils on non-calcareous materials (basalt, schist, granite, gneiss, quartzite or sandstone), present an ABC profile and their main edaphic characteristic is the presence of a textural B horizon of a dark red color and relatively low base saturation ($S / T < 50\%$) [1].

However, Vaudour [6] underlines that the characteristics attributed to fersiallitic soils apply mainly to soils developed on hard limestone. While, according to the French classification CPCS [2], fersiallitic soils include red, almost decalcified, Terra Rossa soils with high base saturation and neutral to slightly acidic pH. Two groups are distinguished, fersiallitic soils with calcium reserve, generally little leached, and fersiallitic soils without calcium reserve, often leached [4].

According to Fedoroff and Courty [7], the fundamental processes of Mediterranean red soils formation are reddening (pairing of the bright red color due to the formation of pedogenetic hematite) and leaching (illuviation or translocation of clays from the alluvial horizon towards the alluvial horizon).

Chemical weathering is the main phenomenon responsible for soil formation, the redistribution of the weathering complex subsequently causes the differentiation of soil horizons. The study of the behaviour of elements during weathering makes it possible to characterize the methods of mobilization and redistribution of elements during soil formation. Thus, the quantitative characterization of

weathering in soils uses weathering indices [8, 9]. They are commonly used to compare the extent of chemical weathering in different materials, and are based on the ratio between the concentrations of mobile elements (such as SiO_2 , CaO , MgO and Na_2O) and immobile elements (Al_2O_3 , Fe_2O_3 , TiO_2) that should decrease over time as the redistribution of the weathering complex occurs [8, 10].

The purpose of this work concerns the characterization of metamorphic rocks alteration processes and the redistribution of alteration complex in two main profiles from the Bainem forest, located at the Bouzareah mountain in the west part of Algiers city. The choice of this Mediterranean forest is based on several reasons: the availability of pedological data, through the cartographic study carried out by Ait Benamar and Ahriz [11] at a scale of 1/10,000th and the availability of different various maps (geological, vegetation, slopes, etc.) and other data (historical, climatic, etc.) that are essential to our study.

II. Material and methods

II. 1. Study area description

The Bainem forest is located in Bouzareah mountain in the west part of Algiers city (northern of Algeria). Geographically, it is located between the latitudes $36^\circ 47' 52''$ and $36^\circ 48' 30''\text{N}$, and the longitudes $2^\circ 56' 59''$ and $2^\circ 59' 08''\text{E}$, and at an altitude ranging between 60 and 320 m (Fig.1). It covers an area of 508 ha, of which 50 ha have a heterogeneous and fairly uneven topography, especially on the northern slope which dominates the coastal strip (slope of 12 to 45%), with less uneven terrain in the central part and generally moderate to gentle slopes on the southern exposure.



Figure 1. The geographic location of study area

Geologically, this forest belongs to the geological set of Bouzaréah's mountain, which corresponds to a metamorphic terrain originating from sediments deposited in the primary era. The most frequently encountered facies corresponds to mica schists which appear under different facies (two mica and feldspar mica schists and biotite mica schists).

The climate is characterized by a maximum temperature of 31.5°C in August recorded during the dry period extending from June to September, and a minimum temperature of 8.5°C in January, recorded during the wet period which stretches from October to May. The average annual rainfall for the period 1983-2009 is 580 mm.

The red fersiallitic soils are the dominant soil type in this forest and deposited on hard limestone, on schists and mica-schists and gneisses, the less evolved non-climatic soils of lithic erosion on schists, the brown mesotrophic soils on schists, and the less evolved non-climatic colluvial input on colluvium [11].

II. 2. Soil sampling

We took fourteen (14) soil samples from two major profiles:

- Profile 1 is located in the middle of the slope (latitude 36°48'13.1"N, longitude 2°57'49.1"E, altitude 187 m). The vegetation is dominated by eucalyptus, with Aleppo pine and mastic tree

formations. This profile corresponds to a leached fersiallitic red soil, without calcium reserve, without stony load on schists (WRB: Luvisols). This type of soil is found in the south and the north of the forest and covers an area of 101 ha.

- Profile 2 is located in the southern part of the forest (latitude 36°47'52.6 ", longitude 2°57'55", altitude 235 m). It is colonized by a stand of Aleppo pine accompanied by various hardwoods. This profile corresponds to a red fersiallitic leached soil with a stony load on mica schists (WRB: Luvisols). This type of soil covers most of the forest northern part, it occupies an area of 158 ha.

The color of the horizons is determined based on the Munsell chart.

II. 3. Laboratory analyzes

We dried the soil samples in the open air, crushed and then sieved at 2 mm, to undergo physical and chemical analyzes, and at a diameter <0.2 mm for a total elemental analysis by X-ray fluorescence spectrometry (XRF) [10].

II. 3.1. Physical and chemical analyzes

The physical and chemical characterization concerned the following determinations: particle size analysis by the international Robinson pipette method, bulk density according to the cylinder technique, pH with a pH meter (soil/water ratio = 1

/ 2.5), electrical conductivity using a conductivity meter (soil/water = 1/5), total limestone with the Bernard calcimeter, organic carbon with the Walkley Black method, total nitrogen with the Kjeld-Hal method and the cation exchange capacity with ammonium acetate [12].

II. 3.2. Total elemental analysis by X-ray fluorescence spectrometry (XRF)

We mixed the soil samples with cellulose (a binder for obtaining compact and solid pellets). The mixture undergoes a homogenization step; it is then compacted in aluminium capsules approximately 5g and 3mm thick under a pressure of 20T for 20s to form compressed pellets of a few micrometres thick which allows the determination of the total concentrations of major chemical elements [13]. The elemental concentration of SiO₂, Al₂O₃, Fe₂O₃, K₂O, MgO, TiO₂, CaO, Na₂O, MnO and Zr was measured at the nuclear techniques laboratory of the CRNA-Algiers (Table III), the equipment used is MAGIXpro type (Panalytical ex. Philips). This method is widely used for the qualitative and quantitative elemental analysis of soil samples [14, 15], it has the advantage of avoiding a preliminary extraction of the elements and allows a global multi-elemental chemical analysis [16]. It allows the analysis of all chemical elements ranging from sodium (Na) to uranium (U), the detectability is at the ppm level and the analytical precision of about

1% [13]. Thus, nine major elements were determined, the total contents of these elements in form of oxides are expressed in percent (%).

II. 4. Calculations

II. 4.1. Alteration indices

For the quantification of the alteration [17, 18, 19, 20, 21], we considered several chemical alteration indices (Table I). In general, most of the indices came up with conclusive results, but they provide dispersed data according to the weathering type, the heterogeneity of the rocks studied and the weathering rate [22]. Thus, the usual chemical alteration indices in pedogenesis propose to characterize the alteration by the use of major chemical data in equations for each horizon [17, 21]. The most widely used are Ruxton's indices [23], Parker [24]: the calculation of this index does not consider aluminium and includes only the highly mobile alkaline and alkaline earth elements. The denominators in this equation reflect the molecular bond strength of each oxide, Nesbitt and Young [25], Jayawardena and Izawa [26]. The most common chemical elements in the form of oxides used in the calculation of weathering indices are K₂O, Na₂O, CaO, MgO, Al₂O₃, SiO₂, Fe₂O₃, FeO and TiO₂. These elements are chosen for their respective mobility or their resistance to leaching [27] (Table I).

Table 1. The applied chemical weathering indices

Indices	Formula	Optimal fresh value	Optimal altered value	Ideal trend of the index	References
RR	SiO ₂ /Al ₂ O ₃	> 10	0	Negative	Ruxton (1968)
WIP	$(100) \left[\left(\frac{2Na_2O}{0.35} \right) + \left(\frac{MgO}{0.9} \right) + \left(\frac{2K_2O}{0.25} \right) + \left(\frac{CaO}{0.7} \right) \right]$	> 100	0	Negative	Parker (1970)
CIA	$(100) \left[\left(\frac{Al_2O_3}{Al_2O_3} + CaO + Na_2O + K_2O \right) \right]$	≤ 50	100	Positive	Nesbitt and Young (1984)
PIA	$(100) \left[\left(\frac{Al_2O_3 - \frac{K_2O}{Al_2O_3} + CaO + Na_2O - K_2O}{Al_2O_3} \right) \right]$	≤ 50	100	Positive	Fedo et al. (1995)
STI	$(100) \left[\left(\frac{SiO_2}{TiO_2} \right) / \left(\frac{SiO_2}{TiO_2} \right) + \left(\frac{SiO_2}{Al_2O_3} \right) + \left(\frac{Al_2O_3}{TiO_2} \right) \right]$	> 90	0	Negative	Jayawardena and Izawa (1994)
MWPI	$100 * (Na_2O + K_2O + CaO + MgO) / (Na_2O + K_2O + CaO + MgO + SiO_2 + Al_2O_3 + Fe_2O_3)$	>1	Infinité	Positive	Vogel (1973)

RR : Ruxton Indice ; WIP : Weathring Indice of Parker ; CIA : Chemical Indice of Alteration ; PIA : Indice of Fedo et al. ; STI : Chemical Alteration Indice of silice-titan ; MWPI : Modified Weathring Potentiel Indice.

II. 4.2. Quantification of elementary gains and losses

According to the literature [28, 29, 30, 18], the equation of Kurtz et al. (2000), is used to express the relative mass value of an element "j" during weathering using the following formula:

$$\tau_{i,j} = \left[\frac{C_{i,p}}{C_{i,w}} \times \frac{C_{j,w}}{C_{j,p}} \right] - 1 \quad (1)$$

$\tau_{i,j}$: Relative elementary balance τ (fractional unit relating to the initial content in the original material) of j element

$C_{j,p}$: Concentration of the mobile element j in the bedrock

$C_{j,w}$: Concentration of the mobile element j in the soil

$C_{i,p}$: Concentration of the stationary element i (Zr) in the bedrock

$C_{i,w}$: Concentration of the stationary element i (Zr) in the soil

$\tau_{i,j} = 0$: the concentration is identical to that of the parental material

$\tau_{i,j} < 0$: there is an elementary loss

$\tau_{i,j} > 0$: there is an elementary gain

and $\tau_{i,j} = -1$: there is a loss of 100% of the element j [18].

To choose a non-mobile element, Mourier [30] underlined that the refractory elements (Nb, Ta, Zr, Hf and Th) are characterized by strong ionic potentials. Such as, they are very difficult to dissolve and therefore potentially immobile. For this purpose, several authors assume that the zircon (Zr) is stationary to calculate the values of $\tau_{Zr,j}$ [18, 29].

III. Results and discussions

III. 1. Physical and chemical properties

Table II displays the physical and chemical properties of the analyzed soil samples.

The particle size distribution of the soils shows a significant variation in the horizons texture.

On the surface, the profiles have a silty texture; in the subsurface, the texture is silty-clayey to silty; at the base of the profiles, the texture is silty-sandy (Fig 2). The profiles have an eluvial horizon (E) which indicates the leaching of clays from the surface horizon to the depth horizons to form an accumulation horizon (Bt). The latter is subdivided

into two horizons (Bt1 and Bt2), due to the lack of similarity between the clay contents and the CEC which are respectively 30.6% and 14.4 Cmol (+) / kg in the Bt1 horizon and 39.15% and 33.6 Cmol (+) / kg in the Bt2 horizon in addition to the difference in compaction between these two horizons (the second is more compact than the first).

The soil texture is a determining parameter, particularly in the development of the soil structure, which conditions the flows [31]. Therefore, the vertical transfer of soil particles is the engine of leaching, which is one of the major processes in soil evolution [32, 33]. Fedoroff and Courty [7] have shown that red Mediterranean soils, when not eroded, appear as soils with contrasting texture characterized by a clay horizon. While the silty and sandy fractions are considered chemically and physically stable, and unable to significantly migrate in a metamorphic environment [34].

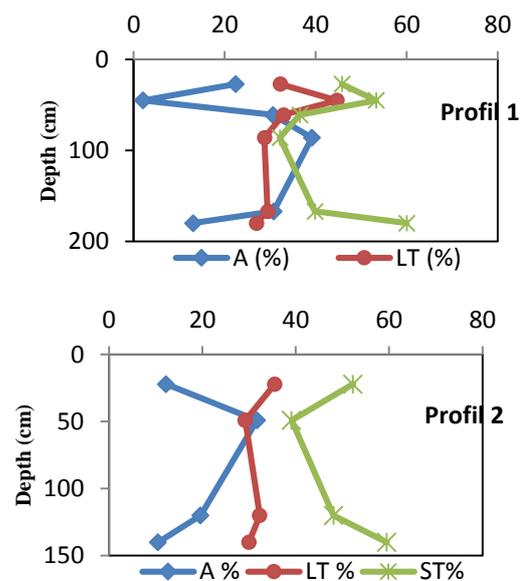


Figure 2. The textural profiles

The soil pH varies from 6.1 to 7.6 globally reflecting slightly acidic to slightly alkaline soils, these values are in agreement with those of Torrent and Hillel [2] which underline that the pH of Mediterranean soils ranges from slightly acidic to moderately alkaline.

The soils are unsalted (EC varies from 0.06 to 0.4 dS / m) and non-carbonated (CaCO₃ contents varying between 1.7% and 2.6%).

Table 2. Physical and chemical characteristics of the studied soils

Profils	Horizons	A (%)	Lf (%)	LG (%)	Sf (%)	SG (%)	Textural class	pH	CaCO ₃ (%)	CE (dS/m)	MO (%)	N (%)	C/N	CEC (Cmol(+)/kg)	Da (g/cm ³)	Color (fresh state)	Leaching index
P1	P1H1 (A)	22,35	11,5	20,73	29,53	16,24	L	7,5	2,03	0,07	1,51	0,056	15,71	25,6	1,65	2,5 YR 4/4	
	P1H2 (E)	2,05	24,25	20,42	32,44	20,83	LS	6,7	2,03	0,07	0,95	0,028	19,64	14,4	1,70	5 YR 4/4	
	P1H3 (Bt1)	30,6	11,4	21,5	23,44	13,05	LA	6,5	2,03	0,1	0,86	0,028	17,86	14,4	1,46	2,5 YR 4/6	14,93
	P1H4 (Bt2)	39,15	7,2	21,53	21,3	10,81	LA	6,4	2,03	0,1	0,71	0,028	14,64	33,6	1,42	2,5 YR 4/6	19,10
	P1H5 (C)	30,75	8,25	21,18	20,18	19,64	LA	6,1	2,03	0,1	0,36	0,056	3,75	25,6	1,48	2,5 YR 3/6	
	P1H6 (R)	13,05	6,95	20,04	25,29	34,67	LS	7,5	2,03	0,06	0,17	ND	ND	ND	ND	ND	
P2	P2H1 (A)	12,2	12,1	23,43	27,04	25,22	L	7,2	1,76	0,3	4,06	0,056	42,14	25,6	1,20	10 YR 4/3	
	P2H2 (Bt)	31,7	11,2	17,98	12,29	26,82	LA	7,16	2,16	0,1	2,00	0,056	20,71	22,4	1,36	7,5 YR 4/4	2,6
	P2H3 (c)	19,6	14,8	17,48	12,34	35,76	L	7,16	2,6	0,2	2,51	0,056	26,07	25,6	1,54	10 YR 5/6	
	P2H4 (R)	10,5	17,4	12,57	13,04	46,48	LS	6,9	2,4	0,4	1,67	0,056	17,32	6,4	ND	ND	

ND: not available information

The organic matter content ranges between 0.17% and 5.85%. The total nitrogen contents are between 0.028 and 0.084%. In Profile 1, the C / N ratio ranges from 3.75 (P1H5) to 19.64 (P1H2) indicating rapid mineralization of the organic matter. In profile 2, it varies between 17.32 and 42.14 indicating slow mineralization of the organic matter, which causes nitrogen immobilization. This may be due to the stony load contained in this profile.

As for the bulk density, it varies from 1.42 to 1.70 for profile 1 and from 1.20 to 1.54 for profile 2. P1 has the highest densities since it contains the most important levels of clay fractions, unlike profile 2. The bulk density is directly related to the porosity [35]. Hubert [36] underlines that the alteration of minerals (primary and/or secondary) generates an increase in the surrounding environment's porosity, the geometry and especially the connectivity of which varies over time.

The calculation of the leaching index shows values greater than 1.2 indicating a transfer of suspended clay or leaching towards the accumulation horizon by settling on the void's walls or the periphery of the structural units, for both profiles. Duchaufour [37], mentioned that in forest's soil, leaching results from an increase in the mechanical processes of colloidal substances entrainment, linked to a decrease in biological activity, and moderate acidification of the humus favouring the clay dispersion.

III. 2. Geochemical composition and weathering indices

The total major chemical element composition expressed in (%) and the chemical alteration index values are presented in Table III.

III. 2.1. Major chemical elements

Changes in major elements concentration show a decrease in the surface horizons (A) and an increase in the depth horizons. These variations can be explained by the primary alteration of minerals in the surface horizons that then release elements that migrate in solution [38]. The high silicium concentrations in the horizons reflect the relative accumulation of weathering resistant minerals such as quartz. A tendency to eliminating iron from the eluvial horizon and its illuvial translocation to clay horizons is observed.

Manganese oxides (MnO) decrease slightly in clay horizons. However, there is no clear pattern of distribution with depth in the profiles. Noulas et al.

[3] reported that many authors found similar trends and that higher values were usually reported in soils with high Fe and organic matter contents in semi-arid environments.

The concentrations of TiO₂, alkaline and alkaline-earth elements (Na₂O, K₂O, CaO and MgO) are variable and irregularly distributed along with the two profiles, while the highest contents are generally recorded in the parent material.

Saikia et al. [39] noted that the negative correlations of SiO₂ with the major elements illustrate the presence in some quartz grains on one hand and the strong negative correlation of SiO₂ with Al₂O₃ ($r = -0.84$ at a probability threshold $p = 5\%$) in the other hand, indicative of clay fraction increase.

Table 3. Total major element composition of the studied horizons (% by weight) and the values of the calculated chemical alteration indices.

Profiles and Horizons	P1H1	P1H2	P1H3	P1H4	P1H5	P1H6	P2H1	P2H2	P2H3	P2H4
Skyline symbols	A	E	Bt ₁	Bt ₂	C	R	A	Bt	C	R
Depth (cm)	0-27	27-45	45-61	61-86	86-167	> 167	0-22	22-49	49-120	> 120
SiO ₂	61,01	65,65	55,37	55,31	52,01	52,14	58,87	44,24	45,45	43,36
Al ₂ O ₃	17,26	15,73	19,96	19,59	21,37	22,78	17,05	24,18	25,50	24,04
Fe ₂ O ₃	6,51	5,51	9,09	8,70	9,79	9,02	5,90	10,08	7,92	11,66
K ₂ O	3,36	3,24	3,31	3,26	3,24	3,89	3,79	4,94	5,53	5,21
MgO	1,27	1,18	1,43	1,36	1,46	2,04	1,61	1,76	1,82	1,98
TiO ₂	1,23	1,34	1,04	1,01	1,04	1,26	1,18	0,90	1,10	1,01
CaO	0,70	0,53	0,47	0,49	0,42	1,13	1,36	0,66	0,48	1,09
Na ₂ O	0,87	1,04	0,57	0,58	0,60	2,41	1,15	0,46	0,85	0,88
MnO	0,07	0,09	0,10	0,07	0,09	0,06	0,17	0,08	0,04	0,23
PAF (%)	7,33	5,38	8,28	9,27	9,56	4,89	8,47	12,34	10,95	10,22
Zr	0,08	0,08	0,06	0,06	0,05	0,10	0,06	0,03	0,02	0,03
RR	3,53	4,17	2,77	2,82	2,43	2,29	3,45	1,83	1,78	1,80
WIP	34,23	33,95	32,00	31,61	31,53	48,79	40,57	45,07	51,77	50,48
CIA	77,80	76,57	82,11	81,91	83,40	75,39	73,05	79,95	78,82	77,00
MWPI	6,81	6,45	6,41	6,37	6,43	10,14	8,81	9,06	9,90	10,39
PIA	89,85	88,81	94,13	93,87	94,70	84,19	84,13	94,49	93,79	90,53
STI	73,86	75,50	70,79	71,13	68,52	67,01	73,61	63,14	62,34	62,64

III. 2.2. Alteration indices

The chemical alteration indices are shown in Figure 3.

- The Ruxton Index (RR) ranges from 2.29 to 4.17 (P1), and from 1.78 to 3.45 (P2). It decreases with depth, but these variations are not regular in the profiles. The lowest values are coming from the bedrock of profile 1 and the C horizon of profile 2, while the highest values are recorded in the surface horizons (A) of profile 2 and at the level of the E horizon of profile 1. According to Adeigbe and Abimbola [40], RR values greater than 30 suggest weak chemical alteration, while those with a value below 10 indicate an average level of chemical alteration. The obtained results show that all samples have a value <10 , implying average levels of alteration for the two profiles. Dubey et al. [9], noted that fersiallitic soils have an RR ratio generally greater than 2. In addition, the Si/Al molar ratio used to assess the loss of SiO_2 with weathering is less than 2 in the subsurface horizons of profile 2 indicating the presence of kaolinite (an advanced weathering mineral in the form of clay) and aluminium chloride with more weathering [37]

- The Weathering Index of Parker (WIP) varies between 31.53 and 48.79 for profile 1, and between 40.57 and 51.77 for profile 2. Unaltered soil sequences generally have WIP values >100 , while the altered samples have zero WIP values [8, 9]. Unlike RR, the low values are recorded at the surface horizons of profile 2, and in the C, Bt2 and Bt1 horizons of profile 1. However, the variations are not regular. In this case, the decreases in WIP values in the surface horizons indicate the elimination of alkali and alkaline earth elements and suggesting a higher degree of alteration [15].

- The Chemical Index of Alteration (CIA) varies between 75.39 and 83.40 for profile 1, and 73.05 and 79.95 for profile 2. It allows assessing the progressive alteration of plagioclases and potassium feldspars [18]. Therefore, low CIA values (40-50) indicate low chemical weathering while high values (approaching 100) assume intensive alteration and leaching of mobile cations relative to residual

aluminium during alteration [15, 39]. Thereby, the CIA values observed in the studied samples are between 67.87 and 83.40 and correspond to a moderate degree of alteration [20, 39]. Bulourde [28] and Saikia et al. [39], reported that the alkaline and alkaline earth elements (Na^+ , K^+ , Mg^{++} and Ca^{++}), resulting from the hydrolysis of silicates, are leached from weathering profiles. Other elements, such as aluminium, iron and titanium are less soluble and therefore less mobile. They do not escape or a little, from weathering systems where they precipitate to secondary minerals forms (clays, oxides and hydroxides). Dubey et al. [9] indicate that the Chemical Index of Alteration CIA and Plagioclase Alteration Index (PIA) serve as examples of unstable minerals decomposition.

- Plagioclase alteration Index (PIA) values are generally used to quantify the degree of the bedrock alteration. They vary from 84.19 to 94.70 in profile 1, and from 84.13 to 94.49 in profile 2. The predominant plagioclase alteration is observed in the subsurface horizons and the bedrock of profile 2 ($\text{PIA} > 90$). According to Dubey et al. [9], the high PIA values (of P1 and P2) indicate that the plagioclases in the bedrock and the deep horizons of the profiles show intense chemical alteration.

- The Chemical Alteration Index of silicium-titan (STI) values are between 67.01 and 75.50 for profile 1, and between 62.34 to 73.61 for profile 2. When the values of this index are > 90 , the degree of alteration is weak whereas when these approaches (0) the alteration is intense. Our results show that the weathering is moderate along with the profiles, with a non-clear tendency of weathering intensity between the surface horizons and the rock.

- The Modified Weathering Potentiel Index (MWPI) ranges from 6.37 to 10.14 for profile 1, and from 8.81 to 10.39 for profile 2. Values > 1 indicate unaltered material while high and extreme values indicate extreme alteration. In our study, the low values are observed at the level of the subsurface horizon of the P1 profile, the A and C horizon of profile 2, while the high values are observed in the R horizons of the studied profiles.

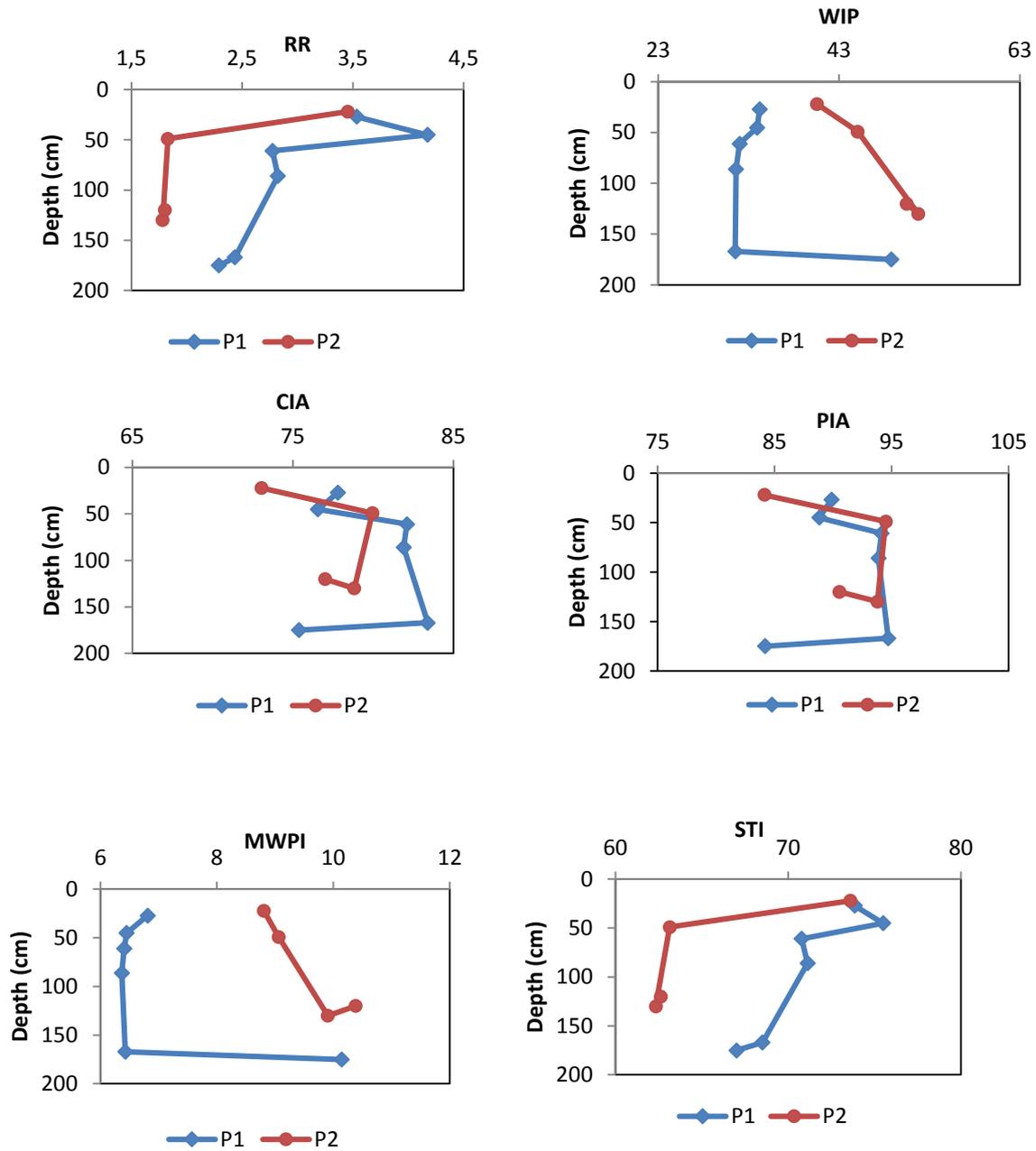


Figure 3. Representation of the chemical alteration indices of the studied profiles

III. 3.1. The first Profile

Figure 4 shows a positive balance for some elements and negative for others, meaning going deep down or out of the profile. As shown, a positive balance of the silicium potassium and titanium elements is noted for the whole profile, it is more important at the C horizon level, the silicium gains are increasing going from the surface to the depth (C). Nevertheless, negative balances of aluminium, iron, calcium and magnesium are recorded in the surface horizons while gains (accumulation in depth) in these elements, generally increasing with depth are noted. The losses are total, i.e., starting of the profile, for the sodium and calcium elements is for the whole the profile, and in

the surface horizons for aluminium and magnesium and in the subsurface horizon for iron.

According to Courchesne et al. [38], the existence of positive balances testifies the intensity of the eluviation - illuviation mechanism of aluminium, iron and titanium in this profile. However, the solubility of silicium can be modified by the presence of certain elements such as magnesium, iron and especially aluminium, which considerably reduce the possibility of solubilization of the silicium [41].

Sodium is a very mobile element from the early stages of weathering, is among the surface elements that show significant variation with the substratum [42].

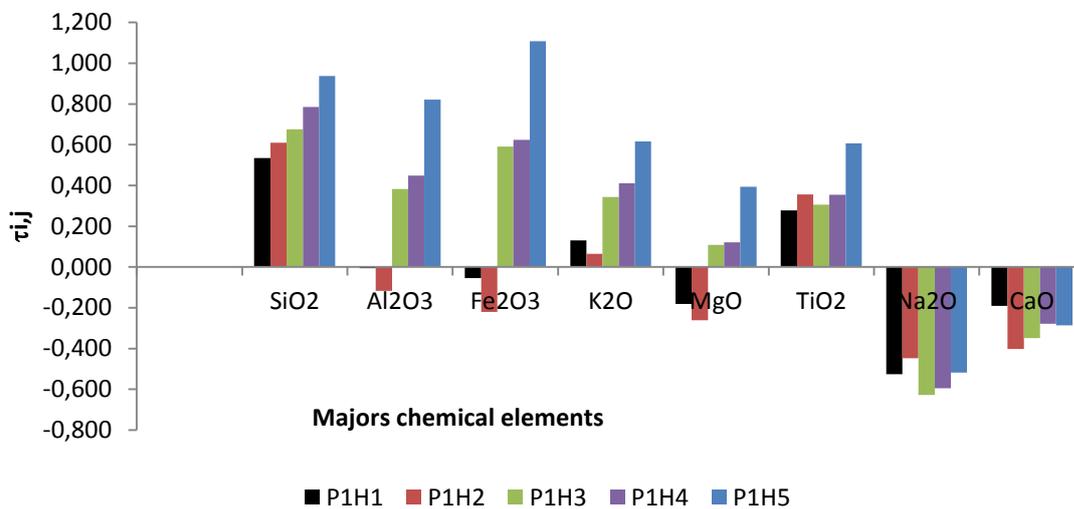


Figure 4. Elementary mobility between the horizons of profile 1

III. 3.2. The second Profile

An overall negative balance for all the major elements is recorded at the level of the horizon of profile 2, except for the C horizon where a positive

balance is noted for the silicium, aluminium, potassium, titanium, and sodium elements (Fig.5).

We notice that all the elements have a value > -1 which indicates a total loss of those elements outside the profile. Hence, aluminium is the most varying element with the substratum [42, 43].

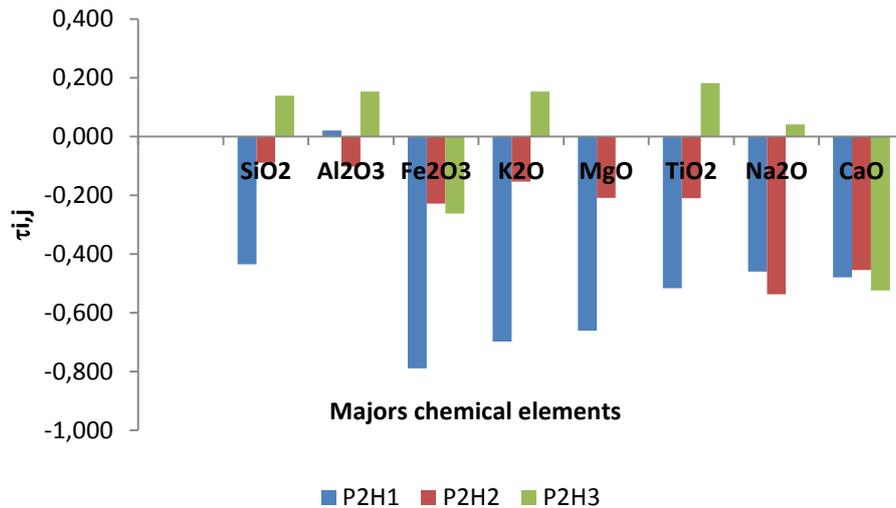


Figure 5. Elementary mobility between the horizons of profile 2

These results indicate a tendency to intense leaching, from the bedrock, of the major elements in the overlying horizons towards the C horizon and their accumulation in it.

According to Millot [44], soluble cations behave differently. Basic cations, in particular Na, Ca, Mg, attract water molecules due to their ionic potential and form a hydration envelope. They obey the stock law, and they do not easily attach themselves to the soil. Whereas K ions are easily fixed by soils, after their dissolution by weathering [45].

Aluminium is among the surface elements that show a significant variation with the substratum. In the context of leaching of the various major elements, aluminium remains stable (low mobility) generating a relative concentration compared to the other major elements. Sodium is, however, a very mobile element from the early stages of weathering [42].

The calculation of element mobility has shown that the behaviour of chemical elements differs from one profile to another depending on the composition and properties of each studied profile. On one hand, profile 1 allowed the gain in immobile elements (Al, Si, etc.) and a loss in mobile elements (Na, Ca, etc.) along with the profile following the bedrock. On the other hand, the alteration of profile 2 revealed significant losses in major elements that accumulate at the C horizon. Indeed, Chatelin [41] considers three categories of elements: Na and Ca that are the most mobile; Si, Mg, K that give very variable results because they can be eliminated or compose new minerals; Al and

Fe that are the most stable elements although they also sometimes experience some mobility. Lelong [31], supposes that in oxidizing media, the low solubility of iron is due to the presence of organic matter. In the soil, it forms mobile complexes or chelates with iron and aluminium. Riebe et al. [45] showed that in rich organic matter soils, Al could be depleted compared to Si where it can form stable complexes with organic compounds. Also, plants displace chemical balances by extracting certain elements from the soil. They can also have a direct action in the alteration [41].

Lelong, [31], mentions that an American study compared the behaviour of the elements in some soil profiles of Oklahoma and Georgia states. It has shown that Ca and Na are the most mobile elements, Al and Fe are the least leachable and that K, Mg, Si and Mn have intermediate behaviour. However, for the elements Ca, K, Mg, Mn, Na and Si, there is no zone demonstrating their long-term retention in the mineral profile [38], whereas Ti depends mainly on the solubilization of the biotite structure, by chemical weathering, and its precipitation in the form of newly formed mineral phases [15].

The pH is an important factor in the transformation mechanisms and formation of oxides [46]. Microorganisms also play a major role in the dissolution and dynamics of iron oxides [47, 48]. On the surface, Mn is rapidly oxidized to oxides and oxyhydroxides. Both the pH conditions and the electrical potential control the formation and dynamics of manganese oxides [49].

Chatelin [41], points out that for the seven major elements of the earth's crust, Smyth and Polynov established a mobility scale that goes in a downward order, Ca - Na - Mg - K - Al - Fe. While for three types of weathered rock from the USA [50], three different mobility orders were determined in a downward order:

Na - Ca - Mg - K - Si - gain of Fe ;
Ca - Mg - K - Na - Si - gain of Fe ;
Ca - Na - Mg - Fe - Si - gain of K.

Another study carried out on different crystalline rocks in the USA [51], showed that the magnesium is the most mobile element. The mobility sequence is Mg - Ca - Na - K - Si - Al, Fe. In Ivory Coast, the following sequence is established: Mg - Na - Ca - K, Si [52].

Tardy [43] showed that the mobility order differs from one station to another. It depends on the composition of the starting materials, the pedoclimate and the drainage. The mobility of an element depends on the ease of its release from primary minerals. It is also conditioned by the possible reactions in solution, adsorption on solid bodies and clay neoformations [41].

The weathering of a rock or a soil takes place according to various mechanisms. Some minerals hydrolyze and disappear, while others transform or remain stable, and others appear. It is recognized that silica and alumina are the fundamental elements of alterations [43].

The results of this research give a picture of the solubility of minerals and the relative mobility of elements in the Mediterranean forest soils.

IV. Conclusion

The purpose of this study is to characterize the weathering processes of metamorphic rock and the weathering complex redistribution in two main profiles taken from a Mediterranean forest in the Algerian north.

The adopted methodology consisted of studying the two soil profiles representing the dominant soil types in the studied area, by performing physical, chemical and geochemical characterization, and by determining the degrees of alteration through the calculation of indices and alteration balance assessment.

The obtained results show that profile 1 is marked by two pedogenetic processes which are the

leaching of clays and reddening. Leaching causes the differentiation of an eluvial horizon E and two clay horizons Bt1 and Bt2. The reddening marked by the red color (2.5 YR) is due to the dehydration of iron oxides caused by desiccation. Pedogenesis caused the formation of a red leached fersiallitic soil, without calcium reserve, and stony load on schists. This type of soil is deep and well developed.

Regarding profile 2, the most important pedogenetic processes are also the leaching of clays and reddening. However, some browning of the A horizon is observed (color 10 YR), this may be due to its high organic matter content (4.06%) which plays an important role in the browning process of soils. Pedogenesis led to the formation of a leached fersiallitic red soil with a stony load on mica-schists.

The resulted geochemical trends in both profiles indicate enrichment of the surface horizons with silicium and a decrease in iron sesquioxide and Al_2O_3 during the weathering process. A tendency to iron elimination from the eluvial horizon and its illuvial translocation to clay horizons is observed in both profiles. Manganese oxides (MnO) decrease slightly in the clay horizons of the profiles. The concentrations of TiO_2 , of alkaline and alkaline-earth elements (Na_2O , K_2O , CaO and MgO) are variable and irregularly distributed along with the two profiles while the highest contents are generally recorded in the parent material.

RR index values showed that all the samples have a value <10 implying average levels of alteration of the two profiles. The decrease in WIP index values in the surface horizons indicates the elimination of alkali and alkaline earth elements suggesting a higher degree of weathering. The predominant plagioclase alteration is observed in the subsurface horizons and profiles 2 rock (PIA > 90).

The CIA index values observed in the studied samples indicate a moderate degree of alteration. The MWPI and STI indices revealed results that contradict the logic of the soil genesis and the results of the other calculated indices. As a result, these indices are not suited to the conditions of soil formation in the study area.

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Please cite this Article as:

Dilmi A., Daoud Y., Characterizing the pedogenesis processes of some soils on metamorphic rocks from the sub-humid Mediterranean area in Algeria., *Algerian J. Env. Sc. Technology*, 9:1 (2023) 2923-2937