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PHYSICAL WEATHERING AND REGOLITH BEHAVIOUR IN A HIGH EROSION RATE BADLAND AREA AT THE PYRENEES: RESEARCH DESIGN AND FIRST RESULTS[1]

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ABSTRACT.- Previous studies on badland areas in the Vallcebre basin (High Llobregat) suggested that the erosion rates are controlled by wheathering rate of mudrocks. The present work was started to characterize the physical weathering processes and rates in relationship with thermic and moisture conditions.

The method used consists of the continuous monitoring of regolith temperatures at different conditions of aspect, depth and lithology (colour), and the periodical sampling of regolith moisture and bulk density, the last taken as an indicator of the weathering status. Besides this quantitative information, the changes of the surface of the regolith have been monitored with the help of photographic thecniques, using a especially designed tripod. To complete the field observations, a laboratory experiment is being performed, analyzing the volumetric changes suffered by undisturbed rock samples subject to thermic and moisture oscillations.

The results obtained emphasize the role of frost action, especially during wet conditions. Aspect and lithologic differences introduce significant nuances in thermic regime and volumetric changes respectively.

RESUMEN.- Estudios anteriores en zonas acarcavadas de la cuenca de Vallcebre (Alto Llobregat) sugieren que las tasas de erosión están limitadas por la meteorización de las rocas arcillosas que las constituyen. El presente trabajo ha sido planteado para caracterizar y evaluar los procesos de meteorización física en relación con los regímenes térmico e hídrico.

El método empleado consiste en la monitorización contínua de temperaturas del aire y del regolito en diversas condiciones de profundidad, exposición y litología (color), así como el muestreo periódico de humedad y densidad aparente, considerada ésta última como indicadora del grado de meteorización. Además de esta información cuantitativa, se ha realizado un

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seguimiento de los cambios en la micromorfología superficial, mediante la utilización de técnicas fotográficas, para lo que se ha diseñado un soporte especial. Para complementar el estudio se diseñó un experimento de laboratorio, en el cual fueron sometidas varias muestras de roca inalterada a una serie de ciclos de variaciones térmicas e hídricas, y se cuantificaron los cambios producidos.

Los resultados provisionales obtenidos remarcan el papel fundamental de las heladas, especialmente en condiciones húmedas, en la meteorización de estos materiales. Las diferencias de exposición y de características litológicas introducen matices significativos respectivamente en el régimen térmico y en los cambios volumétricos observados.

RÉSUMÉ.- Des études préalables sur les zones ravinées du bassin-versant de Vallcebre (haut Llobregat) suggèrent que les taux d'érosion sont limités par les taux de météorisation des roches tendres. Le but du présent travail est la charactérisation des processus et taux de météorisation de ces matériaux en relation avec les régimes thermique et hydrique.

La méthode employée est basée sur la monitorisation des temperatures de l'air et de la couche météorisée sous différentes conditions d'exposition, profondeur et lithologie (couleur comprise). Des échantillonnements périodiques pour la mesure de la teneur en eau et la densité apparente ont été aussi faits, en prenant celle-ci comme indicatrice du degré de météorisation. Cette information quantitative a été completée par un suivi des changes microtopographiques de la surface à l'aide de thechniques photographiques, en utilisant un trépied especialement conçu. Ces travaux de terrain ont été complétées avec un expériment de laboratoire dans lequel on a mésuré les variations volumétriques d'échantillons intacts de roche argileuse soumis à des oscillations thermiques et hydriques.

Les résultats obtenus remarquent le rôle principal du gel, surtout sous des conditions humides. Les différentes expositions et lithologies introduissent des nuances significatives respectivement dans le régime thermique et les variations volumétriques observés.

Key-words: *Badland, weathering, bulk density, soil temperature, soil moisture, swelling frost heaving.*

The Vallcebre basin is located in the Pyrenees range, at the headwaters of Llobregat river. The basin has heights between 900 and 2245 m. a.s.l. and an extension of 21 Km^2 (Fig.1).

The climate is submediterranean mountainous. The mean anual precipitation, measured at Vallcebre station (1119 m. a.s.l.), is about 815 mm affected by both a great annual (interannual variation coefficient about 206 mm.) and monthly variability (3 rainfall peaks in autumn, spring and August, the last one due to convective rainstorms), Winter is the dryest season on the year. The mean temperature measured at Cal Parisa experimental basin (1480 m. a.s.l., sunny aspect) is about 9.2ºC showing a great thermical amplitude (daily oscilations of 20ºC). The cooler months are January, February and March, and the warmer are June, July and August. Freezing occurs about 100 days per year, and snowfalls occur between late Autumn and early spring but can occur as late as early June (LLORENS, 1991).

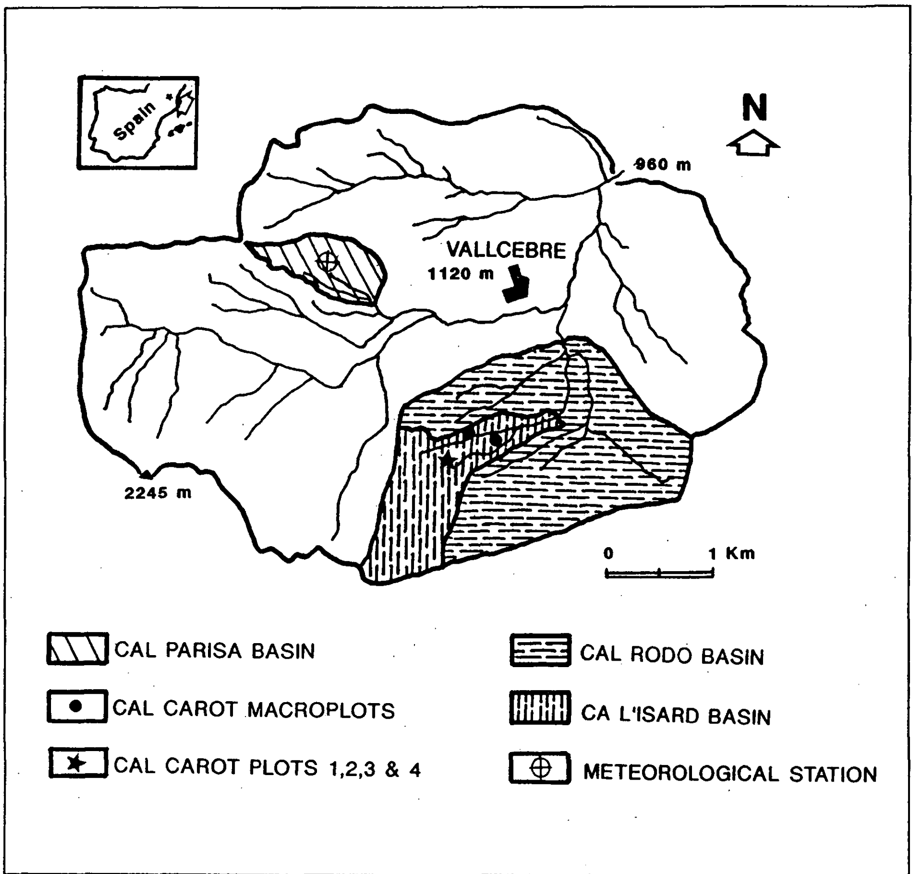


Figure 1. Location of the study plots within the Vallcebre experimental research area (see BALASCH *et al.*, 1992). *(Localización de las parcelas estudiadas en la zona experimental de Vallcebre (ver BALASCH et al., 1992).*

Badland areas on smectite-rich mudrocks in the Vallcebre basin are paramount sources of sediment because of erosion rates as high as 9 mm/ year. It has been suggested after field observations that erosion power is usually able to erode most of the regolith every late summer, the erosion rate being limited by the weathering rate (CLOTET *et al.*, 1988).

The aim of this work is to describe the research design set to analyze to the physical weathering processes of these materials, especially in relation with wet-drying and frost-melting alternances.

The research design has been made following former work from MILLER (1973,1975,1980) and BROWN & PAYNE (1990) who studied the effect of freezing for the alteration of clay soils; FARRES (1978) and HARVEY (1987-1992) who studied temporal changes on surface morphology using periodic photograps; NORRISH & RAUSELL (1963) and GARRISON, PROST & GAULTIER (1983) studied the phenomenon of the expansion on clays, in relation to water contents; and finally HILLEL (1960), MORISAWA (1964), HILLEL & GARDENER (1970), ENGELEN (1973), HAIGH (1978), IMESON & VERSTRATEN (1988) and other authors, studied cracking, rill and popcorn-like formation, runoff and other processes in badland areas and clayey soils.

1. Materials and Methods

1.1. *Characteristics of the materials*

Vallcebre basin lithology is dominated by mudrocks, these are continental clays from Tremp formation, dated at the Cretaceous-Palaeocene boundary. This material presents from 35 to 59% of clays, principally illite, kaolinite and smectite, a low content of chlorite, with carbonate contents from 37.2% to 62.5%, iron content from 1.6% to 3.6% and organic matter up to 0.37%. The particle size distribution is generally rich in silt and clays, and shows a poor content of sand (SOLE *et al.,* 1992).

The more relevant mechanical characteristic of these materials are the high swelling performance, due to the role of smectitic clays. Other physical properties (HARO *et al.*, 1992), shows these values: plasticity index, between 22.04 and 43.91; hydraulic conductivity, 30.6 cm/h and 4.1 cm/h, for the superior level and 15-20 cm respectively; direct shear test, cohesion between 60 and 14 kN m^{-2} and 20-25° of friction angle; and circular shear test showed residual cohesion values of 8 kN m^{-2} and 21-23° of friction angle.

1.2. *Field instrumentation*

We selected four plots in the Carot badlands area (Fig.1, star), the separation between plots is between 1 and 15 m.:

Plot 1 (red regolith) is 5x3 m. of size and dips 38-42°NNE.

Plot 2 (yellow-orange regolith) is 2x5 m. of size and dips 24°NNE.

Plot 3 (red-pinkish stony regolith) is 2x5 m. of size and dips 15°NNE.

Plot 4 (gypsum rich red regolith) is 2x2 m. of size and dips 42-44°NNW.

On these plots we applied the following methods and instruments:

Stereoscopical series of photographs, are periodically taken on the plots 1,2 and 3 as it follows: a Hasselblad MK 70 camera is installed on a tripod especially designed by the first author (Fig.2), completely collapsible to handle easily, that allows to take photographs of the surface, assuring

TABLE 1

Results of mineralogical, physical and chemical analysis for regolith of plots 1, 2, 3, 4.
(Resultados de los análisis mineralógicos físicos y químicos del regolito de las parcelas 1, 2, 3, 4).

PLOT.	GRAINSIZE				MINERALOGY								PD	Fe	pH	EC	MP	Wt
depth	cl.	st.	sd.	gv.	Q	Ca	Do	Sm	It	K	F	Gy						
P1 0-5	37.7	54.7	5.0	2.6	16	0	17	40	15	2	7	3	2.76	0.33	8.55	114	27.2	2
P1 30	40.7	56.4	2.3	0.6	27	3	14	37	16	3	0	0	2.68	0.25	8.76	103	21.0	1
P2 0-5	50.7	39.2	8.9	1.2	18	16	1	56	7	1	0	0	2.64	0.31	8.86	139	26.8	1
P2 30	50.1	43.5	5.2	1.2	20	20	4	28	23	1	0	0	2.64	0.39	8.76	139	13.2	1
P3 0-5	44.8	49.0	5.3	0.9	19	17	7	41	13	3	0	0	2.64	-	8.51	214	24.9	1
P3 30	44.9	50.0	4.1	1.0	12	13	4	48	16	5	2	0	2.64	-	8.44	323	-	2
P4 0-5	-	-	-	-	7	0	10	5	1	2	0	75	2.54	-	7.76	2450	25.8	1
P4 20	-	-	-	-	7	0	8	5	1	2	0	77	2.60	-	7.86	2590	-	1

LEGEND:

cl clay (%).	K kaolinite (%).
st silt (%).	F feldspars (%).
sd sand (%).	Gy gypsum (%).
gv grave (%).	Fe iron (%).
Q quarz (%).	Ec electric conductivity ms/cm^{-1}.
Ca calcite (%).	Mp microporosity (%).
Do dolomite (%).	PD particles density g/cm^3.
Sm smectite (%).	Wt water coherence teste (class).
It illite (%).	

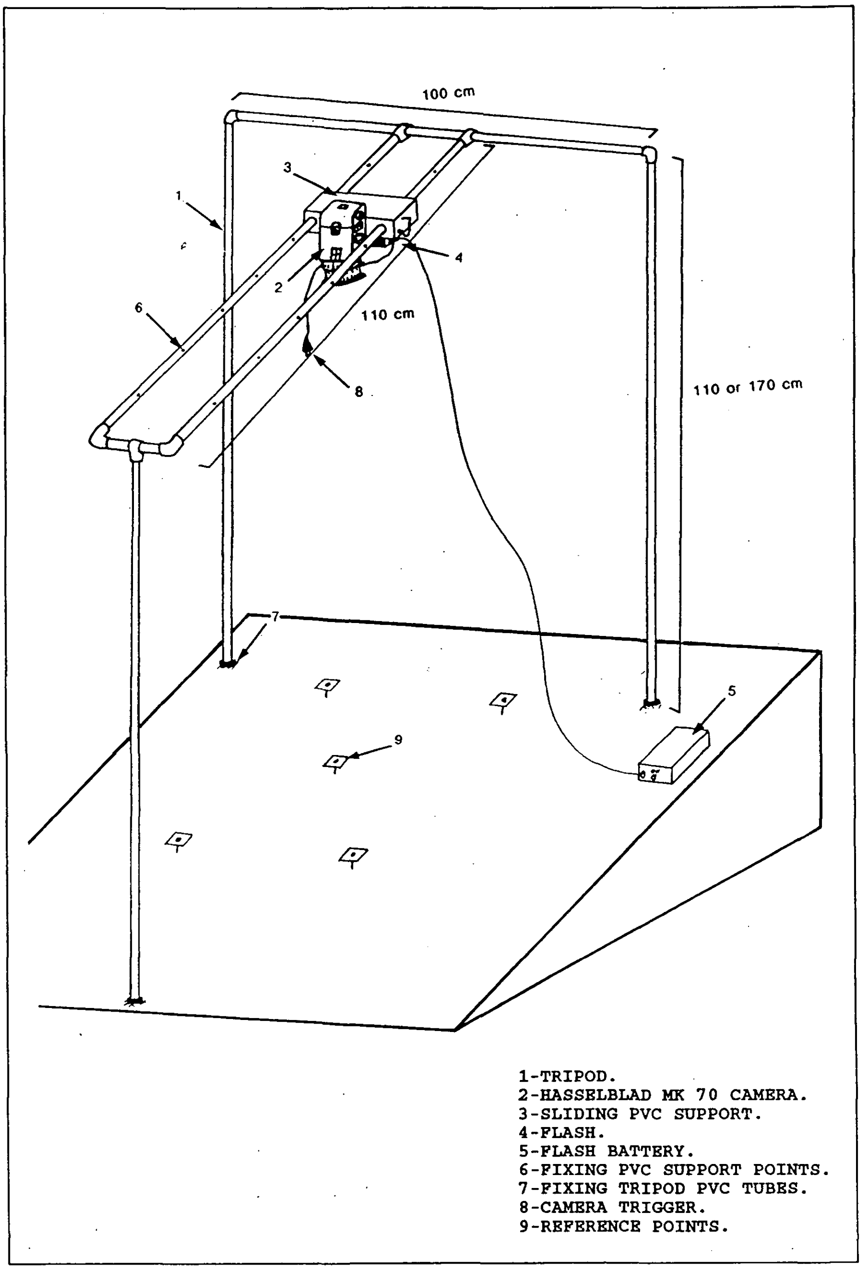


Figure 2. Schematic representation of photographic system. *(Representación esquemática del sistema fotográfico).*

unaltered photograph spatial conditions. The support is "T" shaped and its dimensions are 110 cm length and 110 cm width, it allows the instalation of legs of desired height, 170 cm and 110 cm legs are used respectively on gentler surfaces and steeped surfaces. The surface area covered by the photographs taken from 170 cm is 80x80 cm, and 50x50 cm for those taken from 110 cm. The degree of overlap between two consecutive photograps is more than 60%, to guarantee the stereoscopical effect.

The camera tripod is installed on the plot by introducing its legs into PVC tubes permanently fixed in the soil. On the plots is situated a series of deeply seated reference pins to make easy the comparison between photographs.

The photographs are taken always with flashlight, to provide an homogeneous and constant lighting of the surface.

Photographs are then analyzed with an Image Procesing System (IPS Kontron), to quantify surface cracking, and to perform microtopographical analysis.

Temperature recording, two Dataloggers Thies DLS 5000 have been installed, each of them have 5 temperature sensors, that record soil temperatures every hour. Sensors are distributed as it follows: grass vegetated soil temperature (28°NE, 1 sensor at 5 cm depth); air temperature (1 sheltered sensor at 1.5 m above the ground); north-east sloped red regolith (40°NE, 1 sensor on the surface and 1 sensor at 10 cm depth); north-west sloped gypsum rich red regolith (42°NW, 1 sensor on the surface and 1 sensor at 10 cm depth); south-west sloped red regolith (42°SW, 1 sensor on the surface and 1 sesor at 10 cm depth); horizontal red regolith (1 sensor on the surface and 1 sensor at 10 cm depth).

For recording surficial temperatures the sensor was integrated within the first centimeter of surface crust, the surface of the sensors was covered with regolith material to avoid the metal to appear in case of partial exposition.

Datalogger files are collected with a PC. Here we analyze only maximal, minimal and mean daily temperatures obtained.

Bulk density and moisture, are measured every 15 days. Moisture samples are obtained on all plots at three depths: 1-Surficial crust, 2-Regolith 0-5 cm, 3-Regolith 5-10 cm. Samples are obtained with stainless steel tubes of 2.7 centimeters inner diameter marked with an interval of 5 centimeters; moisture is determined by drying samples in an oven to 40°C (we can not use higher temperature because the p4 regolith has a high gypsum content, whilst p1,p2 and p3 have lower contents). Bulk densities are periodically obtained for regolith 0 to 5 centimeters deep; and also bulk density of unaltered clayrock, between 30 and 35 centimeters in depth, has been measured.

Spatial heterogeneities of regolith bulk density and moisture are analyzed in a seasonal basis (1 or 2 times each season). For that, about 15 samples are taken within every plot, the results are used to test the significance of temporal variations compared to spatial ones.

1.3. *Laboratory setup*

To complement field research we have characterized the regolith materials and designed a laboratory experiment:

Chemical characteristics of regolith materials:

Total iron conten was determined by acid dissolution of the samples and subsequent analysis with Atomic Absorption Spectrophotometry.

Organic matter analysis was carried out by acid dichromate oxidation (LOTTI & GALOPPINI, 1967) (Organic matter values drop below the resolution of the method).

pH and electrical conductivity were determined with conventional electric pH and EC meters.

Physical properties of regolith:

Particle density was performed with an Helium Picnometer (Micromeritics).

Particle size distribution was performed by wet-sieving to 50 microns. Fractions below 50 microns were analysed by Laser Particles-Analyzer (Malvern, Mastersize/E) .

Microporosity was performed with a Carlo Erba Mercury Intrusion Porosimeter in the range of 0.001-100 microns pore size (LAWRENCE, 1978).

Clasification of the stability soil aggregates, using the Water Coherence Test (EMERSON, 1966).

Mineralogical analysis:

Total mineralogy by dust sample XR difraction.

Clay mineralogy by XR difraction of orientated homoionic agregates.

Laboratory experiments: freeze-thawing and wetting-drying cycles were run on unalterated samples, using big Kubiena boxes (5x10x18 centimeters). Unalterated low weathered mudrock samples were collected at 30 centimeters of depth, in the vicinity at the field plots (p1, p2, p3). The cycles were managed as follows: air drying at room temperature, saturating with distilled water, freezing to -3°C, and air thawing; each time had one week of duration. Cycles were replicated untill regolith samples were structurally similar to the surficial altered regolith.

Surface microtopography measurements of these samples, were carried out at the end of each cycle with a "Laser profile meter", designed at the "Istituto per la Chimica del Terreno" (Pisa, Italy), performing 9 transects per sample. This apparatus allows the measure of soil microprofiles, useful for obtaining soil roughness (PINI *et al.*, 1991), and also to appreciate the volumetric variations of the samples, and therefore sequentially evaluate physical alteration of the regolith profile.

2. Results

2.1. *Characteristics of the materials*, are reported in Table 1. Lithological differences between the materials studied are reflected in the results of the analysis. Red regolith is the more rich in dolomite whereas yellow and yellow stony regoliths are richer in calcite. Smectite and illite contents are high on all lithologies but they are somewhat higher in the yellow regoliths than in the other lithologies. Grainsize distribution shows the relationship between mineralogy and size of particles, with a 89-96 % of silt & clay particles, and there are not great differences between the 3 regoliths (gypsum rich red regolith was not analyzed, because its high content in gypsum); density of solid particles is somewhat higher in red regolith because its major dolomite content, and lower in the gypsum rich one. Porosity in surficial horizons is higher than in deeper ones, the difference is higher in macroporosity (about 100 microns), pH and conductivity show some difference between the gypsum rich regolith and the other lithologies. Water coherence test show there are not significative differences among four litotoghies (all belong to classes 1 & 2).

2.2. *Moisture, bulk density and temperature patterns*, were observed along six months. Moisture values show differences among three depths: surficial values show a great increase (up to 3.77 and 60.95%) since Summer to early Winter, 0-5 cm depth show a more moderate increase (up to 6.68 and 39.04%), and 5-10 cm depth show the minor increase (up to 12.05 and 35.37%) but it is not a constant increase (Table 2).

Bulk density values are relatively high in Summer and show a strong decrease at early Autumn wich is constant and moderate for all Autumn (Table 3).

Air temperature record (Fig.3) show a strong daily range of variation, mainly in Summer (between 16.5°C and 4.9°C) in Autumn the range is a few less (between 14.8°C and 1.5°C) with freezing almost daily since November; but soil temperature shows a more high daily range of variation in Summer, it depends on the lithology and orientation (north red regolith between 18.7°C and 4.2°C, south red regolith between 40.1°C and 11.9°C, and north gypsum rich regolith between 27.7° and 6.2°C). Snow blanket favoured a permanent freezing in Autumn, temperatures are also cooler than air (air daily amplitude between 14.8 and 1.5, north red regolith between 10.2°C and 0°C, and gypsum rich regolith between 13.6°C and 0°C).

Spatial heterogeneity of bulk density and moisture are obtained for p1 and p2, bulk density show a range of variation in p1 between 10-20% and about 20% in p2; and gravimetric moisture show a range of varitation in p1 between 12-19% and about 30% in p2 (table 4).

Bulk density and gravimetric moisture show a negative correlation in three of the four litologhies (fig.4): p1 (R= -0.879), p2 (R= -0.657) and p4 (R= -0.863), significant at the 1-5% level and there is no correlation in p3 (R= -0.469, significant at the 10% level); on the other hand, no correlation can be observed between bulk density and volumetric moisture.

TABLE 2

Percentages of gravimetric moisture, for three different depth samples and four lithologies. (P1H: plot 1, P2H: plot 2, P3H: plot 3, P4H: plot 4). *(Porcentajes de humedad gravimétrica para tres profundidades diferentes y cuatro litologías. P1H: parcela 1, P2H: parcela 2, P3H: parcela 3, P4H: parcela 4).*

0-1 cm.

DATE	P1H	P2H	P3H	P4H	PHOTOG.
8/07/91	---	---	---	---	YES
18/07/91	2.61	3.77	2.84	---	YES
25/07/91	3.82	4.06	4.42	5.56	YES
15/08/91	3.93	5.01	4.35	1.45	YES
29/08/91	4.88	9.61	4.74	4.00	NO
10/09/91	7.54	5.99	8.30	8.16	NO
4/10/91	7.09	10.96	4.22	8.47	NO
18/10/91	5.06*	21.87*	18.02*	16.20*	NO
31/10/91	15.50*	21.23*	18.69*	13.16*	YES
7/11/91	10.14*	12.74*	13.10*	5.12*	YES
15/11/91	20.42	22.11	35.70	9.87	YES
28/11/91	21.36*	26.85*	28.60*	17.39*	YES
24/12/91	57.15*	60.95*	29.54*	33.34*	NO
9/01/92	28.55*	28.83*	33.06*	---	NO

0-5 cm.

DATE	P1H	P2H	P3H	P4H
8/07/91	8.31	9.33	9.72	---
18/07/91	7.49	6.68	8.34	---
25/07/91	9.88	9.49	10.71	5.29
15/08/91	13.13	17.54	15.28	6.04
29/08/91	14.13	17.59	15.14	5.53
10/09/91	12.18	14.17	18.76	7.94
4/10/91	12.60*	15.52*	14.70*	8.53*
18/10/91	14.14*	19.07*	19.97*	12.64*
31/10/91	14.85*	19.66*	19.97*	9.85*
7/11/91	13.68*	13.40	15.83*	8.28
15/11/91	12.96	24.18	20.46	8.69
28/11/91	26.63*	24.31*	25.20*	20.04*
24/12/91	31.82*	35.13*	21.38*	21.10*
9/01/92	26.25*	27.25*	30.66	---

5-10 cm.

DATE	P1H	P2H	P3H	P4H
8/07/91	15.47	15.00	14.08	---
18/07/91	12.05	14.21	12.36	---
25/07/91	13.72	16.27	18.41	9.40
15/08/91	15.69	20.77	17.78	7.97
29/08/91	15.36	18.56	17.36	6.98
10/09/91	13.01	15.83	20.33	7.24
4/10/91	13.17	16.97	17.36	7.27
18/10/91	12.37	18.28	21.53	12.11
31/10/91	16.12	19.42	22.11	9.08
7/11/91	13.68	13.40	15.83	8.28
15/11/91	12.27	20.36	17.81	6.81
28/11/91	13.47	19.17	22.64	12.91
24/12/91	18.40	22.56	16.55	10.70
9/01/92	35.37	36.26	15.46	---

**** mean of two samples***

TABLE 3

Bulk densities of deep (30-35 cm.) and surficial regolith (0-5 cm.) samples for four different lithologies. ***(Densidades de muestras del regolito en profundidad (30-35 cm.) y en superficie (0-5 cm.) para cuatro litologías diferentes).***

DATE	*P1 B.D.*	*P2 B.D.*	*P3 B.D.*	*P4 B.D.*
LOW WEATHERED MUDROCK	1.98	1.59	1.78	1.55
8/07/91	1.34	1.11	1.36	--
18/07/91	1.45	1.30	1.45	--
25/07/91	1.33	1.52	1.10	1.51
15/08/91	1.25	1.37	1.36	1.47
29/08/91	1.26	1.38	1.18	1.29
10/09/91	1.48	1.47	1.47	1.40
4/10/91	1.01	1.01	1.09	1.15
18/10/91	1.08	1.21	1.20	1.11
31/10/91	0.96	1.13	1.16	1.03
7/11/91	0.94	1.22	1.19	1.28
15/11/91	1.10	0.93	0.92	1.10
28/11/91	0.76	1.06	1.11	0.73
24/12/91	0.60	0.92	1.19*	0.92
9/01/92	0.73	1.03	1.08	--

* *sample take under snow*

Relationships between bulk density and surface regolith temperatures were performed with the same method, and we obtained a high correlation between bulk density and surface temperatures in p1 (R= 0.853), p2 (R= 0.794) and p4 (R= 0.792), significant at the 1% level and a lower correlation in p3 (R= 0.542, significant at the 5% level).

2.3. *Photographical analysis,* give a qualitative information of processes (rills, pipes, popcorns, etc..) and a quantitative information of regolith cracking and clay swelling. Cracking behaviour can be related to regolith moisture values. Through image processing analysis we obtained values of cracking pattern in the plots studied. Most significant photographs of three plots, on three different dates: 25/7/91, 31/10/91, 7/11/91, and for different moisture percentages are presented in Fig.5.

A statistical study of clods distribution has been accomplished for three plots (Table 5). We can say that when moisture is under 15% a strong process of cracking occurs in the regolith, wich agrees the wheatering and erosion processes.

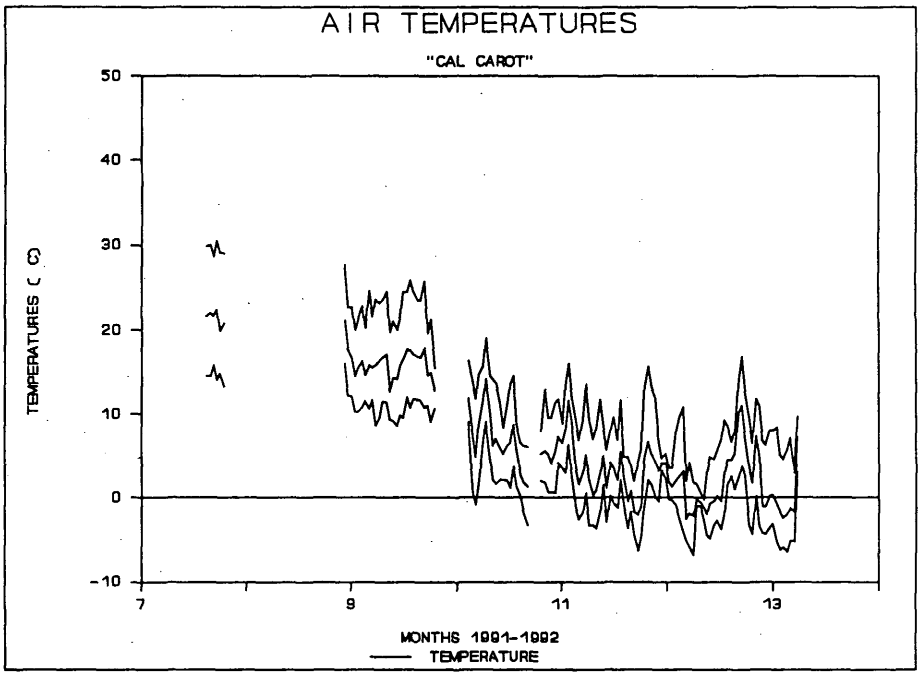


Figure 3. Air temperature graph, as an example of all temperature record. *(Temperatura del aire como ejemplo de todos los registros de temperatura).*

2.4. *Laboratory experiments,* after 7 freezing-thawing and 3 wetting-drying cycles, quantitative information about volumetric changes of the clays and the weatering water-ice effect was obtained; with the Laser Profile Meter, we have measured volumetric changes between 10 and 20% of increase, the highest increases were obtained at freezing-tawing cycles and in the yellow regolith, red regolith shows as more important response a strong granulation of the surface. Bulk density values of laboratory experimental samples were not significantly different from field values, only p1 shows higher bulk density values that field observations. We are working in this way to obtain more significant information along the experiment.

3. Discussion and conclusions

Looking at correlation values we can say that bulk density changes are strongly related with moisture variation and high amplitude of daily temperatures, these relationships are inverse and direct respectively (fig.6).

TABLE 4

Spatial bulk density and gravimetric moisture variability, for late Autumn. (n = number of samples, x = arithmetic mean, S_{n-1} = standard deviation). *(Variabilidad espacial de la densidad y de la humedad gravimétrica, a finales de otoño. n = número de muestras, x = media aritmética, S_{n-1} = desviación estandard.*

DATE	*PLOT&SAMP.*	*B.D.*	*W_g.%*	*STATISTICS.* *BULK.D*	*W_g.%*
28/11/91	P1-01	0.86	18.53	n=20	n=20
	P1-02	0.75	24.02		
	P1-03	0.76	21.08	X=0.762	20.63
	P1-04	0.85	17.47		
	P1-05	0.73	18.78	S_{n-1}=0.075	2.44
	P1-06	0.87	18.04		
	P1-07	0.83	19.82		
	P1-08	0.83	23.50		
	P1-09	0.75	24.79		
	P1-10	0.76	18.99		
	P1-11	0.72	19.33		
	P1-12	0.76	18.29		
	P1-13	0.84	19.03		
	P1-14	0.54	23.63		
	P1-15	0.75	24.06		
	P1-16	0.79	19.22		
	P1-17	0.77	19.05		
	P1-18	0.75	19.19		
	P1-19	0.69	22.88		
	P1-20	0.69	23.00		
24/12/91	P1-21	0.41	37.99	n=10	n=10
	P1-22	0.68	27.67		
	P1-23	0.68	32.77	X=0.59	31.82
	P1-24	0.81	18.28		
	P1-25	0.57	31.22	S_{n-1}=0.12	5.96
	P1-26	0.59	37.97		
	P1-27	0.48	36.77		
	P1-28	0.47	30.17		
	P1-29	0.69	30.10		
	P1-30	0.52	35.29		
	P2-01	0.81	49.11	n=10	n=10
	P2-02	0.72	46.23		
	P2-03	1.20	21.40	X=0.88	35.12
	P2-04	1.04	22.06		
	P2-05	1.04	29.01	S_{n-1}=0.17	10.82
	P2-06	0.87	29.34		
	P2-07	0.84	38.50		
	P2-08	0.72	49.78		
	P2-09	0.87	38.85		
	P2-10	0.67	27.00		

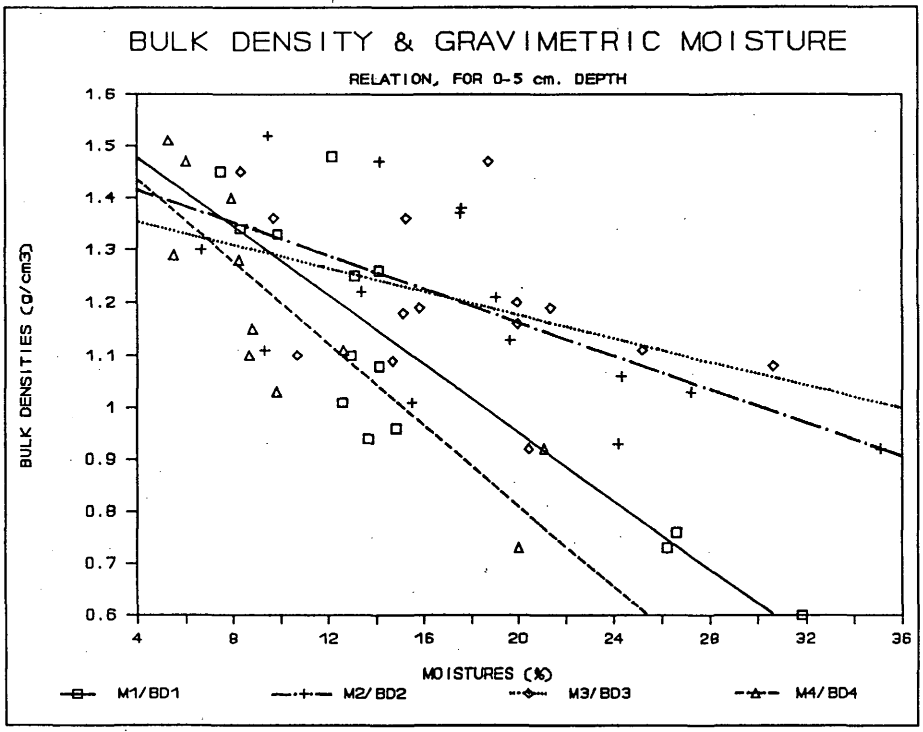


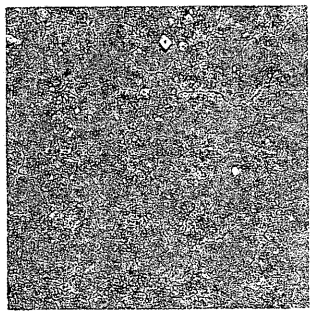
Figure 4. Bulk density (gr/cm³) related with gravimetric moisture (%), for the four sampled lithologies. Correlation coefficients (R) P1 = -0.8257; P2 = -0.6518; P3 = -0.4687; P4 = -0.8652. (M1, M2, M3, M4 = moistures of plots 1, 2, 3, 4; BD1, BD2, BD3, BD4 = bulk densities of plots 1, 2, 3, 4).
(Densidad, en gr/cm³, relacionada con la humedad gravimétrica (%), para cuatro litologías).

This phenomenon depends on the kind of lithology and agrees with the observations of BROWN & PAYNE (1990). Daily freezing-thawing alternance, allow the ice lenses to grow in different regolith levels, being the suction ice effect over the soil water the reason of this phenomenon (MILLER, 1980). This phenomenon produces low density levels, which change distribution of particles and structure, increasing the porosity and slaking the aggregates. When thawing occurs, the pore space occupied by the ice is saturated by the melting water, which further contributes markedly to regolith alteration, because a mild addition of water weak internal cohesion forces of the aggregates (FARRES, 1978), increasing the slaking effect.

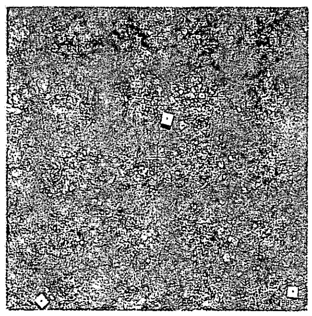
Another important ice-water cycles effect is the popcorn-like formation, which is attributed to daily cycles of swelling and shrinking, especially on steep slopes by IMESON & VERSTRATEN, (1988). This phenomenon has been observed by us only after a large period of time with freezing-thawing cycles.

Cracking is a process which occurs by very low moisture percentages

P1 25/07/91
S. G. MOIS. 3.8 %



P1 31/10/91
S. G. MOIS. 15.5 %



P1 07/11/91
S. G. MOIS. 10.1 %

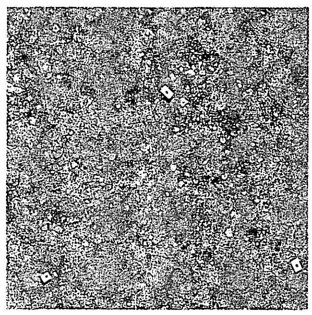
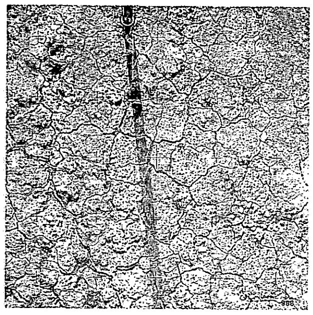
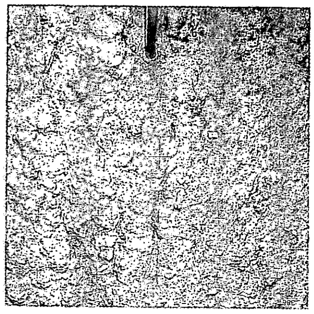


Figure 5a. Repeated photographs on the P1 plot. We can observe the surface differences between summer (with cracking) and Autumn. *(Fotografías repetidas en la parcela P1. Puede observarse las diferencias superficiales entre el verano, con agrietamiento, y el otoño).*

P1 25/07/91
S. G. MOIS. 4.1 %



P1 31/10/91
S. G. MOIS. 21.2 %



P1 07/11/91
S. G. MOIS. 12.7 %

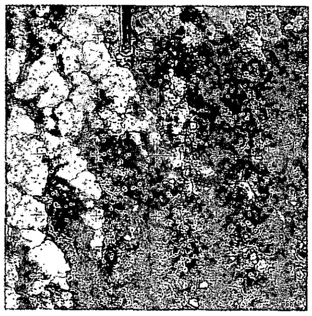
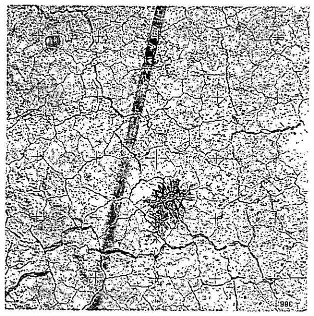
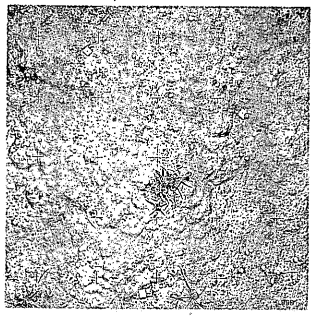


Figure 5b. Repeated photographs on the P2 plot; Autumn microrill formation can be related with some summer cracks. *(Fotografías repetidas en la parcela P2. La formación de microincisiones en otoño puede relacionarse con algunas grietas estivales).*

P1 25/07/91
S. G. MOIS. 4.4 %



P1 31/10/91
S. G. MOIS. 18.7 %



P1 07/11/91
S. G. MOIS. 13.1 %

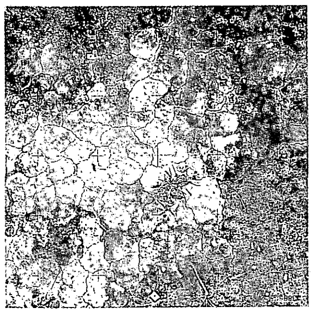


Figure 5c. Repeated phogographs on the P3 plot; Summer cracking is very important for water infiltration into the regolith; In Autumn it shows a surface seal or a less important cracking. *(Fotografías repetidas en la parcela P3. El agrietamiento estival es muy importante para la infiltración del agua en el regolito. En otoño muestra sellado superficial o agrietamiento menos importante).*

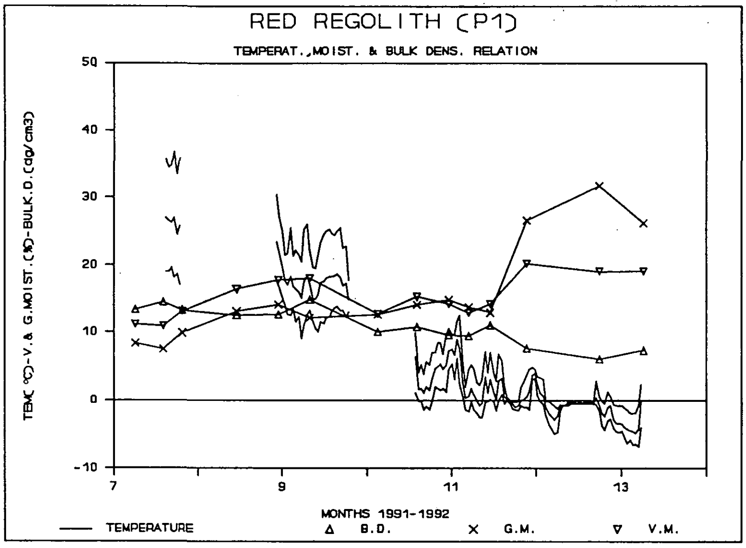


Figure 6a. Plot 1, red regolith. Bulk density variation related with temperature an moisture oscillation. (B. D. = bulk density; G. M. = gravimetric moisture; V. M. = volumetric moisture). *(Parcela 1, regolito rojo. Variación de la densidad en relación con la oscilación de temperatura y humedad. B. D. = densidad; G. M. = humedad gravimétrica; V. M. = humedad volumétrica).*

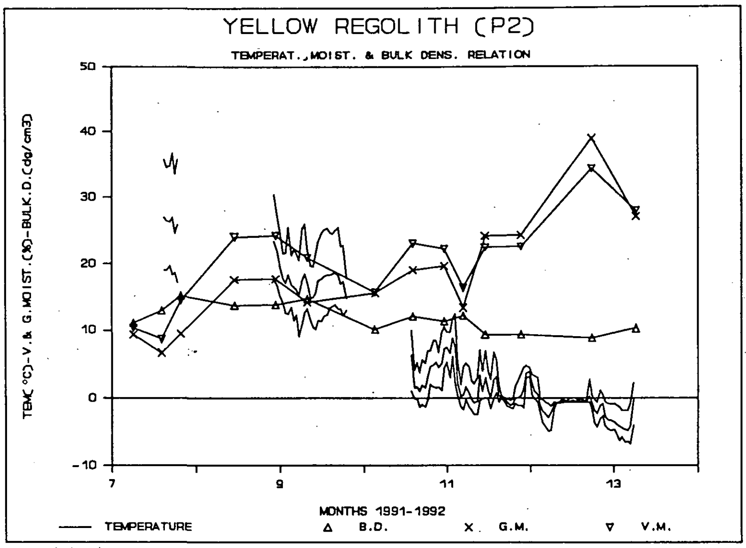


Figure 6b. Plot 2, yelow regolith. The relation between bulk density variation, with moisture and temperature oscillations, is not as high as in the red regolith. (B. D. = bulk density; G. M. = gravimetric moisture; V. M. = Volumetric moisture). *(Parcela 2. Regolito amarillo. La relación entre la variación de densidad y las oscilaciones de temperatura y humedad no es tan alta como en el regolito rojo. B. D. = densidad; G. M. humedad gravimétrica; V. M. = humedad volumétrica).*

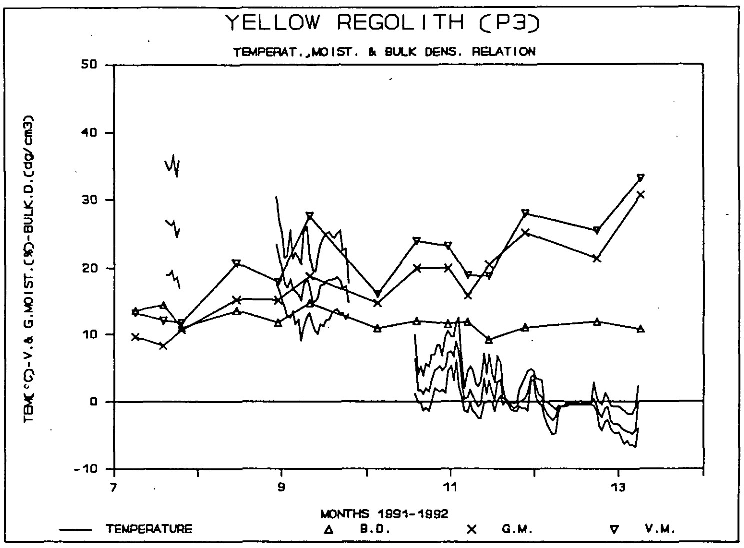


Figure 6c. Plot 3, yelow stony regolith. The relation between bulk density variation, with moisture and temperatures oscillations is not good. (B. D. = bulk density; G. M. = gravimetric moisture; V. M. = Volumetric moisture). *(Parcela 3. Regolito amarillo pedregoso. La relación entre la variación de densidad y las oscilaciones de humedad y temperatura no es buena. B. D. = densidad; G. M. = humedad gravimétrica; V. M. = humedad volumétrica).*

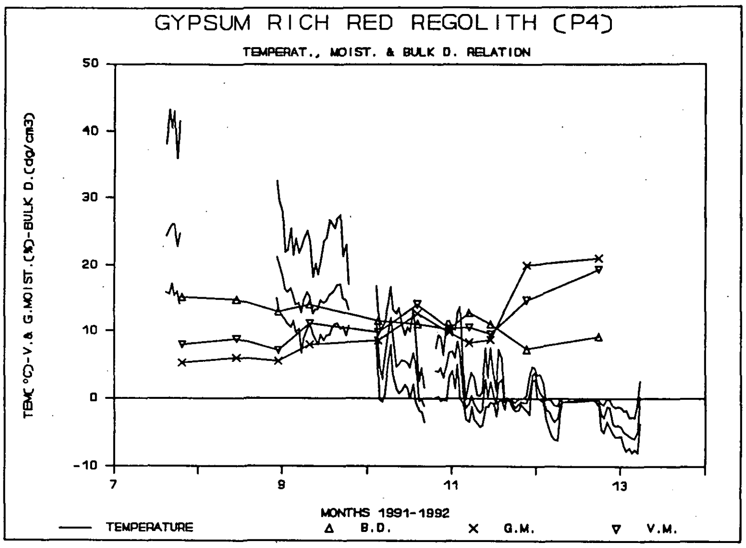


Figure 6d. Plot 4, gypsum rich red regolith. This material shows a good relation between its bulk density changes with temperature and moisture variations. (B. D. = bulk density; G. M. = gravimetric moisture; V. M. = volumetric moisture). *(Parcela 4. Regolito rojo rico en yeso. Este material muestra una buena relación entre sus cambios de densidad y las variaciones de temperatura y humedad. B. D. = densidad; G. M. = humedad gravimétrica; V. M. = humedad volumétrica).*

TABLE 5

Cracking regolith analysis, for three lithologies. *(Análisis de agrietamiento del regolito, para tres litologías).*

D	25/07/91			31/10/91			07/11/91		
P	P1	P2	P3	P1	P2	P3	P1	P2	P3
MS.	3.82	4.06	4.42	15.50	21.23	18.69	10.14	12.74	13.10
M5.	9.88	9.49	10.71	14.85	19.55	19.97	13.68	13.40	15.83
NP.	112	145	222	-	-	-	8	11	57
AM.	17.8	25.4	15.5	-	-	-	205.9	444.9	88.6
DV.	78.2	129.9	79.4	-	-	-	221.0	212.9	106.6

D : DATE
P : PLOT
MS.: SURFACE GRAVIMETRIC MOISTURE (%)
M5 : O-5 cm GRAVIMETRIC MOISTURE (%)
NP.: NUMBER OF PLATS
AM.: AREA MEAN

(under 15%), and induces the microrill formation (ENGELEN, 1973); these may act as a way of sediment transport when rainstorm occurs (HAIGH, 1978), favouring the erosion and transport processes.

Laboratoring experiment showed a quick and strong swelling response on yellow regolith, red regolith response was not so significant, but probably it could show similar changes of volume with a higher number of cycles; this can be related with the great percentages of dolomite and calcite in red and yellow regoliths respectively, because dolomite is more stable than calcite and can act as a bonding agent. All this suggests the importance of lithology in the weathering processes.

As main conclusions we can say that the surficial alterations on smectitic rich clay regolith depends, in this area, on moisture and surficial temperatures (0-5 cm.), mainly when these parameters are extreme. The main weathering rates were recorded on two seasons:

1. Autumn, when daily freezing-thawing cycles occurs (daily amplitudes between 13.6°C and 0°C) and regolith shows high gravimetric moisture values (more than 20%); this produces an increase of the porosity, and weaken the internal cohesion forces.

2. Summer, with strong daily surficial temperature amplitudes, (between 27.7°C and 4.2°C) and with a very low gravimetric moisture (3-5%); the surficial dessication crack system developed on these conditions induce the weathering and erosion processes.

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