Current Trends in Natural Sciences Vol. 7, Issue 14, pp. 12-21, 2018

Current Trends in Natural Sciences (on-line)
ISSN: 2284-953X
ISSN-L: 2284-9521

Current Trends in Natural Sciences (CD-Rom)
ISSN: 2284-9521
ISSN-L: 2284-9521

COMPARATIVE STUDY OF SOME GEOMECHANICAL PROPERTIES OF THE LIMESTONES AND SHISTS IN THE SCREES OF LEAOTA MASSIF (SOUTHERN CARPATHIANS, ROMANIA)

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Abstract
One of the most interesting habitats that has been identified and researched especially by speleologists in the last few decades is the superficial underground environment. These habitats were named mesovoid shallow substratum (MSS), also called shallow subterranean habitats (SSHs). These habitats are mainly represented by the scree, where the free spaces between the clasts (interclastic spaces) are the temporary or permanent host or refuge for some species of animals, especially invertebrates. Similarly, in litosoils, we can find too, free interclastic spaces, but much less generous. The scree formation depends largely on the geological type of rock that undergoes the various mechanical and chemical processes that cause exposed rock to decompose (mechanical, chemical and biochemical weathering). Practically, the behavior of the rocks relative to exogenous modeling factors influences the speed of scree generation. Moreover, the main environmental factors such as relative humidity, temperature in the MSS are influenced by the geomechanical properties of the rocks (the ability to retain water, the way to react to gelling, thermal expansion, chemical reactions between the water by the pores of the rocks and the minerals etc). That is why we considered to be interesting a comparative analysis of geomechanical properties in the case of two types of rock, limestone and crystalline mesometamorphic schist. These limestone and schists outcrops occur oftenly on the slopes in Leaota Mountains, the area where our research been focused has.

Keywords: changes in the apparent volume, compressive strength, freeze-thaw cycles, gelivation degree, geomechanical properties, limestone, schists, softening coefficient, water absorption coefficient by capillary, scree, litosoil, MSS, SSHs.

1. INTRODUCTION

The purpose of these studies is to understand which is the importance of the two rock type (limestone and schists) in the cryoclastic processes in Leaota Massif and also how some geomechanical properties of rocks are different by the rock type and influences the main ecological factors (as relative humidity and temperature) in the screes. These screes are defined by a series of peculiarities of the main ecological factors (temperature and relative humidity) and they are a type of subterranean habitat with an important ecological role, with a characteristic invertebrates fauna. The variation of the main ecological factors causes changes in the type of fauna hosted by the MSS. To determine the geomechanical proprieties of the limestone and the metamorphic crystalline schist as: apparent density, real density, dry compressive strength, compressive strength after freeze-thaw cycles (softening coefficient), degree of the gelivation (the rate of weight - loss by freeze-thaw),

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percentage change of apparent volume after freeze-thaw and water absorption coefficient by capillary we used methods that meet the adopted and applied European and Romanian standards regarding the rocks. These geomechanical properties of the two types of rocks determine directly or indirectly a different susceptibility to disaggregate, but also to maintain specific values of relative humidity and temperature in the different types of MSS (limestone or schist). These things in turn influence the distribution of faunistic components in the MSS. These things in turn influence the differential distribution of faunistic components in MSS, depending on the type of geological substrate.

2. MATERIALS AND METHODS

Within the experiments carried out for the determination of the geomechanical proprieties of the clasts in limestone and quartzo-feldspathic mesometamorphic crystalline schist with biotite and muscovite collected from the field, we have used the methods that are described in the European standards (were also applied in Romania). For each of the two categories of rocks, limestone and crystalline schist, we made experiments and laboratory tests regarding the determination of the following proprieties: *volume of open pores* (V_o), *apparent volume* (V_b), *real density* (ρ_r), *apparent density* (ρ_b), *total porosity* (*p*), *open porosity* (p_0), *compressive strength after freeze-thaw cycles*(R_e), *dry compressive strength* (R_u), *gelivation degree* (μ_g), *changes in the apparent volume during cycles of freeze-thaw* (ΔV_b); *the softening coefficient* (η), *the water absorption coefficient by capillarity* (c_1).

The methods we used within the geomechanical investigations are classified in two categories, destructive and undestructive methods. Destructive techniques can be used for the investigation of the mechanical proprieties (for example, compressive strength), of the physical proprieties (porosity, water absorption etc) or for microscopic analysis for which we need to create thin sections (Balogh et al., 2014; Müller, 1967).

The collection of the samples in the field

Within the experiments made for the above mentioned determinations, we have randomly collected from the field, from the ecologic stationaries (Fig.1), samples of rocks, large enough that, by cutting, we have filled the tubes we needed for the tests and the analyses in the laboratory. On the whole, from the ecologic stationaries with scree, we collected a volume of more than 300 kilos of limestone samples (Fig.2) and another almost equal volume of mesometamorphic crystalline schists (Fig. 3).

The limestone in the substratum of the placed ecologic stationaries were geologically identical; so was the case of the crystalline schist, too; (Dorobăț, 2016; Dorobăț et al., 2017; Dorobăț et al., 2018).

In order to not influence the results, the selection of the clasts in the scree was made so that the samples to be as representative as possible, not to contain, on their surfaces, traces of chemical and biochemical alteration and not to have cracks.

The production of the test specimens

In order to meet the methods that are described in the standardized geomechanical analyses experiments, we produced, through debit, test specimens that met the standardized dimensions – cubes, with a size of 50 mm or 70 mm or cylindrical specimens, with a diameter equal to the height, of 50 mm or 70 mm. This was the case also for both the samples in limestone and the ones in mesometamorphic crystalline schist.

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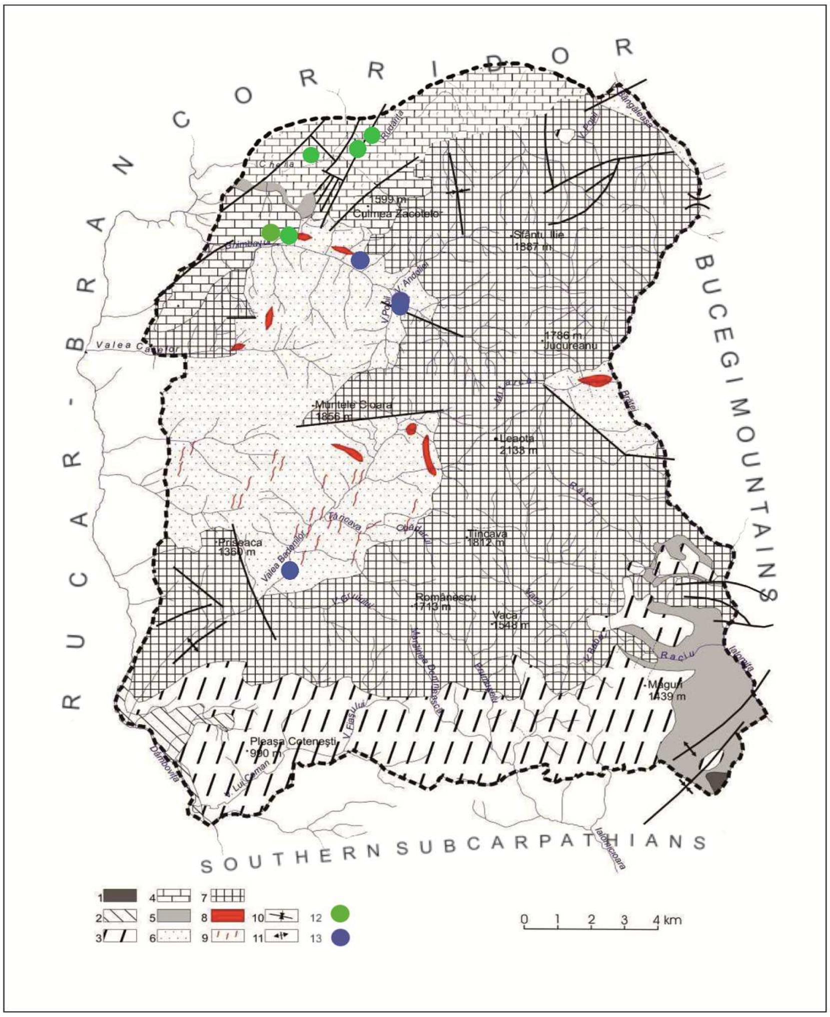

Figure 1. Leaota Mountains – Geological Map (from Murătoreanu, 2009, modified by authors)

Legend: 1. graves, sands, gritty clay; 2. shale, silica, massive sandstone, conglomerates; 3. coarse sandstone, clay sandstone, Bucegi conglomerates, limestone breccias; 4 limestones, dolomite limestones and dolomites, radiolarites; 5. shales, sandstones, conglomerates; 6. The Leaota Series – phyllites, chlorite-sericiteschists; 7. Cumpăna Series – metablastic migmatites; 8. Granites; 9. Metablastic magmatites; 10. syncline axis; 11: Anticline axis; 12&13: Areas where limestone samples were taken: green circle =limestone scree; blue circle = schist scree

Figure 2. Limestone scree

Figure 3. Schist scree

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Working method

In the case of the determination of geomechanical parameters: the volume of open pores (V_o), the apparent volume (V_b), the apparent density (ρ_b); the real density (ρ_r), we have used standardized methods according to the SR EN 1936:2007 Standard. Thus, considering this standard, we can mention:

Volume of open pores (V_o):

$$V_o = \frac{m_s - m_d}{\rho_{rh}} \text{ x } 1000$$

Apparent volume (V_b):

$$V_b = \frac{m_s - m_h}{\rho_{rh}} \text{ x } 1000$$

Where $\rho_{rh} = 0.998$ g/cm^3 represents the density of water at 20°C;

(m_d) = mass of the dry specimen;

(m_h) = mass of the test specimen sunk in water;

(m_s) = mass of the specimen saturated in water.

(Results are displayed in milliliters)

Apparent density (ρ_b) is expressed in kg/m^3;

It is calculated as the ratio between the mass of dry specimen (m_s) and its apparent volume, through the formula:

$$\rho_b = \frac{m_d}{m_s - m_h} \rho_{rh}$$

Real density (ρ_r), is expressed through kg/m^3, is calculated as the ratio between the me mass of the grinded and dried test specimen and the volume V_s of the liquid deployed by the me mass.

$$\rho_r = \frac{m_e}{V_s} \text{ x } \rho_{rh}$$

To determine the **dry compressive strength (R_u)**, we apply the standardized method explained in the SR EN 1926: 2007, a standard for natural rocks. Though we need at least 6 test specimens for each type of rock, we used seven test specimens for the limestone and 14 for the mesometamorphic crystalline schist. In the case of the schist, we made seven tests for the perpendicular compression on the schistosity plan and other seven for the testing of the compression exerted parallel to the schistosity plans. We refined, as much as possible, the test specimens through sanding, so that the sides to be perfectly sanded. Teodorescu (1986) warns that any roughness, irregularity of the edges leads, during the experiment, to the more rapid failure of the rock to smaller tasks, by concentrating the tasks in the respective points. The verticality of the cubical test specimens should not overpass the 0.3 mm tolerance, and the sides must be plane, with a tolerance less than 0.1 mm. For the measurements, we used a Fowler electronic display caliper, with a 0.01mm precision. The result is expressed in megapascals (MPa). One must calculate the average of the 6 tests. In the case of the mesometamorphic crystalline schist, we show for which of the tests we calculated the result: the

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perpendicular loading on the schistosity plan to the schistosity plan (anisotropy plan). In the laboratory tests we used a modified Enerpac P 39 device.

To determine the **compressive strength after freeze-thaw cycles (R_e), gelivation degree (μ_g), changes in the apparent volume during the freeze-thaw cycles (ΔV_b),** we used and met the standardized methods according to STAS 6200/15-83 and SR EN 12371:2010. To analyze the proprieties, we have used the 15 cycles variant, with cylindrical test specimens (Fig. 4) with a diameter and height of 50 mm or cubical ones with a side of 50 mm (Fig. 5). We used to 7 test specimens for the limestone probes and 14 for the schist ones, like above, for R_u.

Figure 4. Cylindrical test specimens after the freezing-thawing cycles (schist)

Figure 5. Cubic broken sample to the uniaxial compression test (limestone)

Each of the test specimens is exposed to the 15 freeze-thawcycles, meeting the standard procedures. By increasing the number of freeze–thaw cycles, compressive strength decreased, whereas the porosity values showed an increasing trend. They are introduced in a refrigerating installation and they are gradually cooled until the temperature of -20±2°C, maintaining this temperature for 3 hours. We have used a modified Kirsch Bosch Kältmaschine freezer. The temperature in the refrigerating installation must be, at first, equal to the one of the environment, namely 18±5°C.

We analyze and make notes of the visible deteriorations, such as cracks, exfoliation, ruptures etc which resulted, mentioning the freezing-thawingcycles when they appeared. We eliminate the test specimens on which we registered visible deteriorations if they are reported for more than 3 test specimens, and, at the end of the freezing-thawing cycles, we consider that the rock is not resistant to gelivation (gelifraction). We consider that a test specimen presents visible deteriorations when it is affected by at least one of the following phenomena: the surface of one or two of the sides (in the case of cubical test specimens) was shrunk with at least 10%, or the total surface of the test specimen decreased with at least 5%, or the mass of the test specimen shrunk with more than 5%.

If the notable deteriorations criteria is not enough to determine if the rock is gelivation resistant or not, we apply another criteria, through the calculus of the gelivation coefficient.

To determine the **gelivation coefficient (μ_g),** also named the **mass loss coefficient** (Florea, 1983), we used the procedures specified in the STAS 6200/15-83. It is calculated for each test specimen that was not affected by “visible deteriorations”.

The used formula is:

$$\mu_g = [(m_2 - m_3) : m_1] \times 100$$

(m_1 is the mass of the dry test specimen; m_2 is the mass of the wet test tube until maturation; m_3 represents the mass of the test specimen after the last freezing-thawingcycles).

For a rock sample, we calculate the average of the gelivation coefficient for at least 5 test specimens, calculated with two decimals.

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According to the standards, we consider that, if $\mu_g \geq 0.3\%$, the rock is not resistant to gelivation. If $\mu_g \leq 0.3\%$, the criteria of the gelivation coefficient is not conclusive, we apply another criteria, the one of the **reduction coefficient of compression strength after the freezing-thawing cycles (η),** also known as **softening coefficient**.

When determining this reduction coefficient (η), we met the indications of the SR EN 12371:2010.

The softening coefficient is calculated according the following formula:

$$\eta = [(R_u - R_e) : R_u] \times 100, \text{ where:}$$

R_u represents the dry compressive strength of the dry test specimen; R_e represents the compressive strength after freeze-thaw cycles.

If the value of the softening coefficient is ≥ 25%, we consider that the rock is not resistant.

Concluding, we claim that rocks are not resistant after freeze-thaw cycles, if at least one of the three criteria is not available for the respective samples, after the cycles they were exposed to:

There are visible deteriorations;

The gelivation coefficient is $\mu_g \geq 0.3\%$;

The softening coefficient is $\eta \geq 25\%$.

In the case of the modification percentage of the apparent volume (ΔV_b), we consider the specifications of the SR EN 12371:2010 standard, which also supposes 15 freeze-thaw cycles for the test specimens, measuring the volume loss caused by the detachment of the material from the test specimen.

A value higher than 1% shows that the rock is not resistant to the freeze-thaw cycles.

To determine the **water absorption coefficient by capillarity (c_1)** we act according to the indications in the method described by the SR EN 1925:2001 Standard.

We used cubical test specimens with a size of 70 ± 5 mm, or cylindrical ones, with the diameter and height of 70 ± 5mm.

Considering that the rocks we used were little absorbent, we used the intervals of 30, 60, 180, 480, 1440, 2880 and 4320 minutes. Time measurement must be with a tolerance of maximum 5%. We made seven measurements for each type of rock that was the subject of testing, schist or limestone.

We consider that the determination if finished, when the difference between two consecutive weighing of each test specimen is less than 1% of the mass of the water absorbed by the test specimen.

The water absorption coefficient bycapillarity can be calculated using this formula:

$$c_1 = (m_i - m_d) / A \times \sqrt{t},$$

where c_1 is the absorption coefficient through perpendicular capillarity on the schistosity (in case of limestone, it does not matter on which side the determination is made, as there is no schistosity); m_i represents the mass of the test specimen at maximum absorption; m_d represents the dry mass of the test specimen; A = the surface of the immersed side.

RESULTS AND DISCUSSIONS

By analyzing the results reached subsequently to the determinations of some geomechanical features of the samples in the two categories of rocks, we can make a comparison between limestone and schist regarding their behavior to the respective experiments.

In the case of total porosity (p) and of the open porosity (p_o),the situation has been already presented in two previous papers (Dorobăț et al., 2017; 2018), the result of the determinations showing that the total porosity of limestone, $p_{limestone} = 1.46\%$, is significantly higher than the one of schist, $p_{schist} = 0.84\%$, and the open porosity is, in the case of schist, $p_{o\ schist} = 0.69\%$ and in the case of limestone, $p_{o\ limestone} = 0.38\%$.

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Apparent density (ρ_a) in the case of analyzed samples was determined for dry rocks, reaching the following results: $\rho_{a\ schist}$ = 2681 kg/m^3; $\rho_{a\ limestone}$ = 2886 kg/m^3.
Real density (ρ_r), determined subsequently to the experiments, reaches values that are almost equal for both types of rocks: $\rho_{r\ schist}$= 2704 kg/m^3, respectively $\rho_{r\ limestone}$ = 2726 kg/m^3.
The water absorption coefficient by capillarity (c_1) is another physical parameter which shows the ability of rocks to allow water circulation through the capillary pores whose diameters might vary between 0.1- 0.001 mm (Scrădeanu & Gheorghe, 2007). In the case of the samples was analyzed, we reached the following results: for crystalline schist, $c_{1schist}$ = 0.73 g/m^2 x s; for limestone, $c_{1limestone}$ = 0.36 g/m^2 x s.
The freezing of water is produced at temperature as low as the pores are smoother. By increasing the volume, ice crystals produce a higher pressure on the unfrozen water and it forces it to go through the walls of the pores. We thus reach an inflation pressure inside the rock and, as a result, a tension, a stress status which, if overpasses the value of the rock's stretching resistance, will lead to the apparition of micro-cracks in its structure (Hîrhui, 1995; Gutiérrez, 2013). Water begins the following freeze-thawcycles again, in the micro-cracks formed due to the previous freezing. Previous cracks are filled with water and the process repeats itself, having a cumulative feature. Through repeated widening, we reach the breaking (detachment from the slope) and the development scree (Dorobăț, 2016).
We notice that the water absorption coefficient by capillarity has a more than double value in the case of schist reported to the one of limestone. This gains shape through the ability of schist of allowing an easier circulation of water by capillarity and thus a higher capacity of absorbing it.
This feature of schist doubles its vulnerability to gelivation, alongside the open porosity which is also approximately two times higher compared to the one of limestone.
Dry compressive strength (R_u) represents the resistance of the rock in dry state to the uniaxial compression. The higher the difference between the dry compressive strength (R_u) and compressive strength after freeze-thawcycles (R_e), the more vulnerable the rock is in front of freezing.The determined values of this parameter are displayed in table 1.

Table 1. The value of resistance to dry compressive strength for schist and limestone

Test specimen no.	**SCHIST - Value of R_u (N/mm^2)**		**LIMESTONE Value of R_u (N/mm^2)**
	Value of $R_{u\parallel}$ on ∥ plan with schistosity	**Value of $R_{u\perp}$ on ⊥ plan with schistosity**	
1	46	60	35
2	43	57	35
3	43	54	34
4	39	58	34
5	45	50	37
6	40	52	34
7	45	57	36
$R_{u\ average}$	**43**	**55.4**	**35**

The resistance to compressive strength after the freeze-thaw cycles (R_e) shows the extent to which the rock loses its resistance after gelivation, thus becoming more brittle, breaking itself easier. Scree develops especially due to the gelivation process, so that this feature of rocks is significant from this perspective, presenting the vulnerability degree of the rock to crioclasty. Using standardized

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methods, we determined the resistance to compressive strength after 15 freeze-thawcycles: $R_{eschist\perp}$ = 44 N/mm^2 ; $R_{eschist\parallel}$ = 32.6 N/mm^2 and for the limestone:
$R_{elimestone}$ = 29 N/mm^2. The values of the R_e were determined according to the standardized method, on 7 test specimens (Table 2).

Table 2. Value of resistance to compressive strength after freeze-thaw cycles for schist and limestone

Test specimen no.	SCHIST - Value of R_e (N/mm^2)		LIMESTONE Value of R_e (N/mm^2)
	Value of $R_{e\parallel}$ on ∥ plan with schistosity	Value of $R_{e\perp}$ on ⊥ plan with schistosity	
1	36	47	32
2	33	46	29
3	32	43	27
4	34	41	26
5	29	45	28
6	30	44	30
7	34	42	31
$R_{e\ average}$	**32.6**	**44**	**29**

Moreover, the gelivation coefficient (μ_g), also known as the mass loss coefficient after the freeze-thaw cycleshas a much higher value (0.23%) for the schist, compared to the limestone (0.14%). Subsequently to the cycles, from the test specimens that were the subject of experiments, a larger volume of schist detached compared to the limestone. This is also confirmed by the modification percentage of the volume after freeze-thaw cycles, higher in the case of schist (ΔV_b = 0.3%), reported to the limestone (ΔV_b = 0.2%).
The result of the determinations regarding the resistance to compression strenght (R_e) after the freeze-thaw cycles, the softening coefficient (η), the modification percentage of the apparent volume after freeze-thawcycles (ΔV_b) can be displayed in a centralized manner in table 3, thus confirming the lower resistance of mesometamorphic crystalline schist to freeze-thaw cycles.
We present below a comparative table with the values of these two types of rock, in order to emphasize the differences between them, from the geomechanical perspective.
At first, we have to mention the fact that both the schist samples and the limestone ones are located in the normal range of resistance to uniaxial compression. Thus, in the case of schist, this resistance varies between 10 - 100 N/mm^2, and in the case of limestone, between 30 and 250 N/mm^2 (Pârvu et al., 1979; Folk, 1980; Arad & Danciu, 2012; Arad et al., 2016).
Disaggregation of rocks is also generated by the thermic dilatation differences of various mineral that are part of them, a phenomena that might also occur during summer, in areas where the temperature at the surface of nude rocks, on southern exposure slopes, can reach more than 40°C during warm days (Dorobăț, 2016).

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Table 3. Value of the geophysical parameters for the schist and limestone samples

Rock type	R_u N/mm^2		R_e (15 cycles) N/mm^2		η (%) (15 cycles)		ΔV_b (15 cycles) %	μ_g (15 cycles) %
	$R_u\parallel$	$R_u\perp$	$R_e\parallel$	$R_e\perp$	$\eta\parallel$ %	$\eta\perp$ %		
Schist	**43**	**55.4**	**35**	**44**	**31.9**	**25.9**	**0.3**	**0.23**
Limestone	**35**		**29**		**17.14**		**0.2**	**0.14**

Such significant differences between the temperature of the rocks on the soil in shadowed ares, compared to the ones located in sunny areas, are registered during the summer; the alternating shadowing- sun exposure, but especially a more accentuated cooling during evenings might lead to internal tensions in the rock, generated by minerals with different dilatation coefficient and to the apparition of cracks. For the type of climate in Romania, the significance of this phenomenon is very low from the perspective of disaggregation, compared to the gelivation (Rădoane et al., 2000).

4. CONCLUSIONS

Limestone is more resistant to the freeze-thaw processes compared to the analyzed crystalline schist. The determined softening coefficient is higher in the case of schist and confirms their lower resistance.

Analyzed crystalline schist is more vulnerable to freeze-thaw cycleson the parallel direction with schistosity, as it is a surface of minimal resistance in the rock, both before and after the freeze-thaw cycles. Although initially crystalline schist was more resistant to the compression strength compared to limestone (the value of R_u), after the 15 freeze-thawcycles, they lost a higher percentage of the resistance to compression.

The softening coefficient in the case of crystalline schist is higher on both directions (perpendicular: 25.9% and parallel: 31.9% on/with the schistosisty plan) reported to limestone, which has a coefficient of only 17.14%.

The capacity of schist to absorb larger volumes of water by capillarity, as well as the nearly double open porosity compared to the one of limestone, make it more vulnerable both to the weathering, as the gelivation and the (bio)chemical alteration.

Open porosity, secondary porosity, as well as the absorption coefficient through capillarity, higher in the case of schist, compared to the one in limestone, leads to a higher vulnerability of crystalline schist to the mechanical disaggregation caused by gelivation. This is also accentuated by the mineralogical (chemical) composition of schist.

The same capacity of the studied crystalline schist to an easy absorption of water, along side a higher open porosity reported to the limestone, leads to a microclimate with a higher relative humidity in the MSS of crystalline shale than in the MSS of limestone ones; this was confirmed through the numerous and lengthy evaluations and monitoring sessions of the main ecologic factors of relative humidity and temperature, made during approximately three years in different type of MSS (SSHs). These different values of the relative humidity lead, in turn, to differences in the distribution of some biocoenotical components in the two different types (limestone or schist) of scree or lithosoil.

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5. ACKNOWLEDGEMENTS

This paper of Magdalin Leonard Dorobăţ was supported by the strategic grant POSDRU/159/1.5/S/138963 - PERFORM, co-financed by the European Social Fund – Investing in People, within the Sectorial Operational Programme Human Resources Development 2007-2013.

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