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Quantification of relationships between geomorphic and geologic parameters representing rock resistivity (erodibility) in N-Hungary using statistical surface analysis

Introduction, aims

The quantification of petrophysical features instead of descriptive characterisation and the identification of relationships between geomorphic and geological factors has always been of key importance not only in engineering but in geomorphology as well (KAWABATA ET AL. 2001, CLAYTON & SHAMOON, 1998a). This study aims to investigate the relationship between geomorphic and geological endowments based on a wide-scale database using geoinformatics with the aid of statistical methods such as correlation, regression analysis and cluster analysis, and to quantify the rock resistance to erosion by combining and comparing traditional experiments and investigations applied mainly in engineering. The adaptibility and reliability of these methods in measuring rock strength was also investigated.

Methods

The chosen geomorphic parameters were *slope steepness* (%), *height above base level* (m), *distance from base level* (m), while the geological parameters were *UCS* (unconfined compressive strength, modified by the abundance of planes of weakness, i.e. faults based on KERTÉSZ-GÁLOS, 1985, - used in civil engineering to quantify rock resistivity, applied in geomorphology as well by YAŞAR-ERDOGAN, 2004), *attrition resistivity* (%), *freezing resistance* (%) and *porosity* (%). The latter 4 parameters are to represent the resistance to denudation (erosion) of the different rock types. These parameters were the independent variables of the statistical analysis carried out by SPSS for Windows 15. The values representing rock resistivity (erodibility) were compared to the results of denudational classification of LÁNG (1969), controlling the reliability of results.

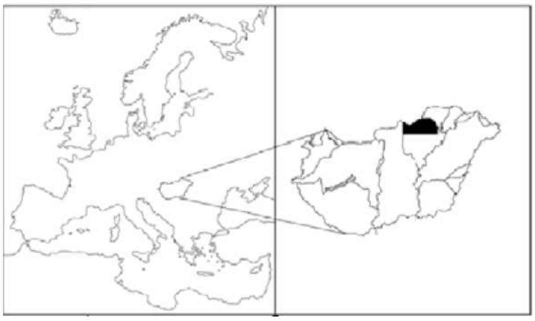

Fig 1. The location of the investigated area

The investigated area ranged up to 1500 square kms (**Fig 1**), consisting of highly consolidated palaeozoic-mesozoic limestones, siliciclastic materials and volcanites, semiconsolidated palaeogeneous sandy rocks and loose neogene schliren, sandstones and tuffs (**Fig 2**). The geological composition of the area is versatile, thus the 67 formations were grouped into 10 petrophysical categories. Morphologically the territory is composed of an elevated mountainous core area (Bükk Mts. N-Hungary), and several hilly regions in the foreland (pedimented piedmont regions, denudational and accumulational glacis).

The database was based on map with a scale of 1:50000 and contour lines of 10 m digitized in Geomedia Professional 5.0. The vector-type data were transformed into raster-type using IDRISI 3.2 resulting a quite fine 25x25 m/pixel resolution (recommended by HUTCHINSON-GALLANT, 2000) and a dataset consisting of more than 2 million pixels (cases). After creating a DEM (**Fig 3**), the derived map of slope steepness (**Fig 4**), and the map of distances from the base level in IDRISI (**Fig 5**), the values of these variables were added to each pixels. The values of geological factors were also incorporated to the database.

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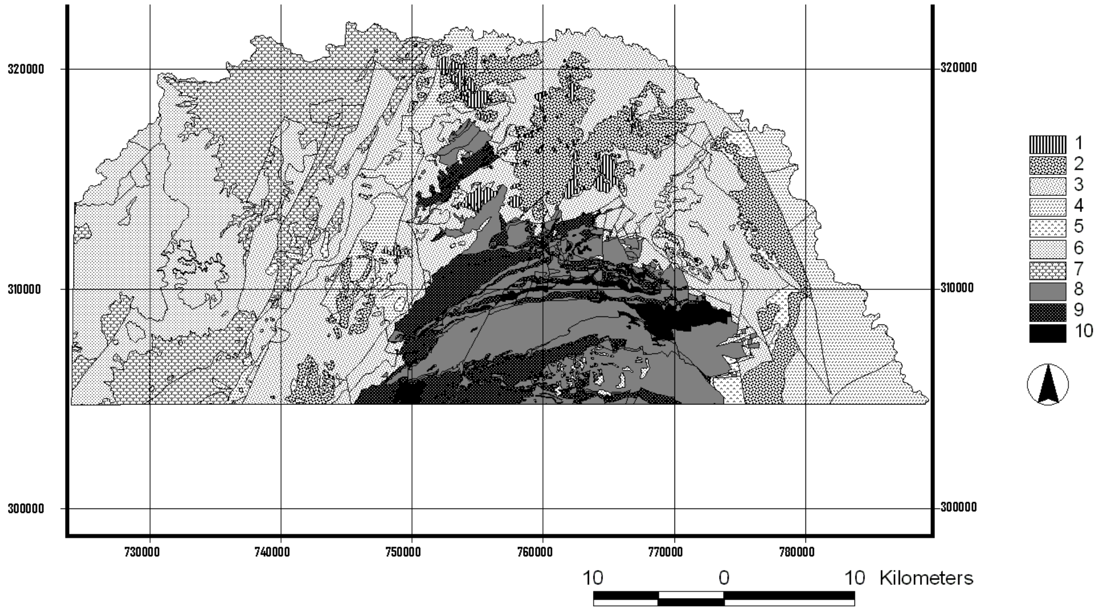

Fig 2. The simplified geological map of the area (after BUDINSZKY et al. 1999.)
Legend: 1. Neogene andesite, 2. Neogene sandstone, 3. Neogene schlieren, 4. Neogene silt, 5. Neogene tuff, 6. Paleogene sandstone, 7. Paleogene silt, 8. Palaeozoic and Mesozoic limestones 9. Palaeozoic and Mesozoic siliciclast, 10. Palaeozoic and Mesozoic igneous rocks.

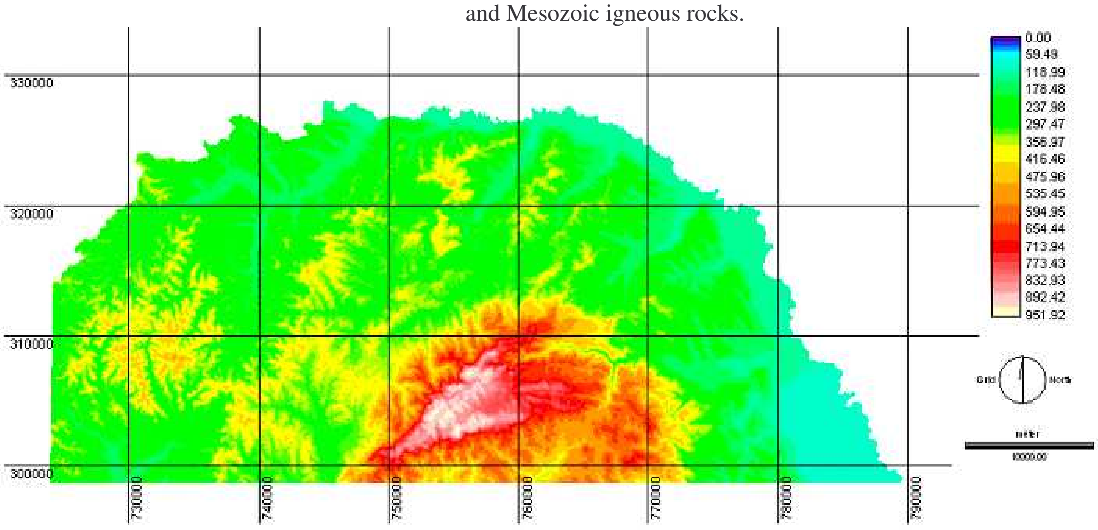

Fig 3. The DEM of the area using 25x25 m/pixel resolution (data in meters)

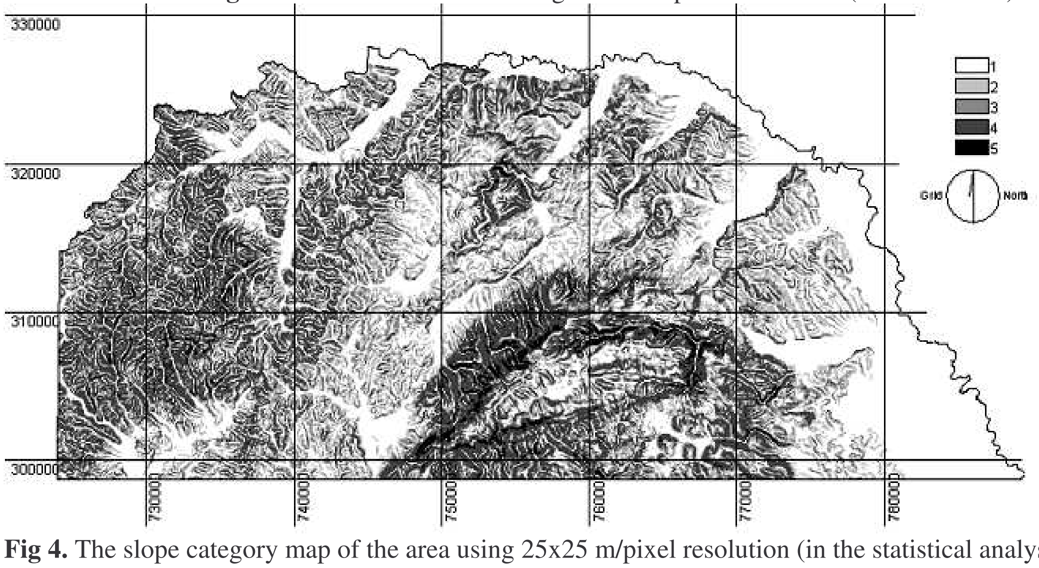

Fig 4. The slope category map of the area using 25x25 m/pixel resolution (in the statistical analysis the data were not grouped into intervals). Legend: 1: 4-10 %; 2: 10-16 %; 3: 16-22 %; 4: 22-44 %; 5: above 44 %

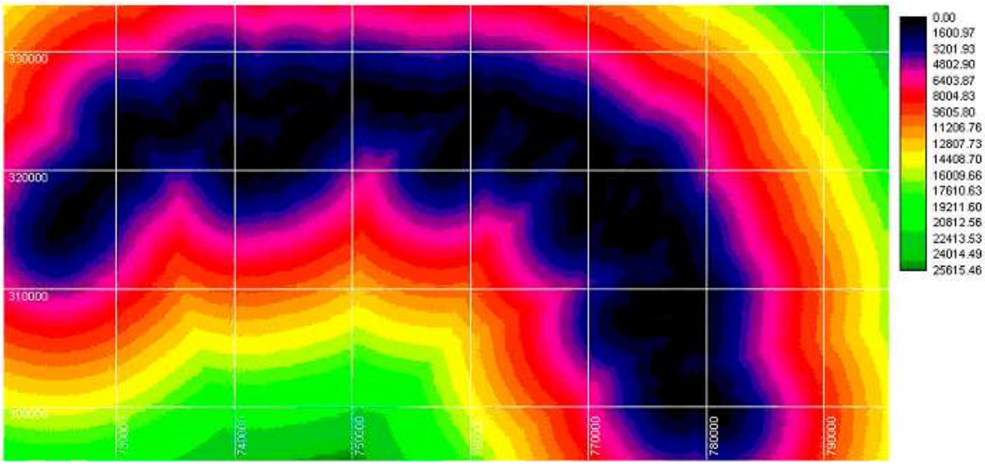

Fig 5. Distances from the regional base level in meters using 25x25 m/pixel resolution (the Sajó river was considered the base level of erosion)

To each petrophysical category the value of the UCS - based on 350 data available from the literature (KLEB ÉS VÁSÁRHELYI, 2003; RAINCSÁK, 1992; 1996) and further 30 samples measured in the Debrecen University - was added. When measuring UCS a constantly growing pressure is exerted on a cylinder-shape sample until it breaks. UCS is an important factor of investigating slope evolution and mass movements.

The data on attrition resistivity and freezing resistance were measured in the Debrecen University as well. 50 samples (5 for each rock groups) were tested in a Los Angeles cylinder to measure attrition resistivity. The experiment lasted for 30 minutes (900 rotations), representing 1.5 km distance, the weigth loss of wet samples due to attrition was measured after each 7.5 minutes, enabling us to draw the tendencies of attrition resistivity of the different rock types (**Fig 8**). To measure frost resistivity we used a frost chamber where the daily temperature was fluctuating between -20 ^{o}C and +20 ^{o}C. 30 wet samples (3 for each petrophysical group) were used in the experiment in order to reach quick weigth loss. Low temperature was necessary since the water in the capillary tubes freezes at only -10 ^{o}C. The frequency of frost and thaw also influences the rate of weigth loss, such as porosity, fractures and foliage (sheeted structure) of the samples. The experiment lasted for 15 days, then the weight of the samples was measured again.

Table 1. The average values of the investigated geomorphic and geologic parameters for each rock-type

Average values	UCS (MPa)	Slope steepness (%)	Height above sea level (m)	Distance from base level (m)	attrition resist. (%)	Porosity (%)	Denudation (m/million years)	Frost resistivity (%)
neogene andesite	20	16	326	3878	61	8	30	81
neogene sandstone	4,8	13	282	3789	35	6,4	45	55
neogene schlier (sandy)	6,6	13,7	285	6979	46	3,5	60	15
neogene silt	6,5	12,8	293	7672	n.a.	n.a.	45	n.a
neogene tuff	7,3	13	269	6494	15	12,5	35	66
palaeogene sandstone	35	22	316	6705	75	2,5	30	82
palaeogene schlier	5	15	236	6349	35	20	60	15
palaeozoic-mesozoic limestones	98	22	571	9577	60	1	10	100
palaeozoic-mesozoic siliciclasts	86	26	510	13225	63	1	25	97
palaeozoic-mesozoic volcanites	150	23	529	7573	95	0	15	100

Results

The differences in frost and attrition resistivity of the rock types are shown on **Table 1**. Having created the database a correlation matrix of the variables was calculated including all the 2 million cases (**Table 2**). Since i.e. in the case of slope steepness and distance from base level gentle slopes may occur near the river and far away as well due to the abundance of surface remnants (decreasing the correlation) the correlation matrix was also calculated for the average of the data grouped by rock types (**Table 3**). The latter resulted better correlations. After this the dendrogram of variables was created using hierarchic cluster analysis by SPSS for Windows. The data were standardised before clusterisation using the following equation: y=lg(x+1). The results show the strength of the connection between the different variables used in the research (**Fig 5**). Of course omitting factors or incorporating new variables or predicting denudation (time as a new variable) the relationships may change.

Table 2. Correlation matrix of variables based on all data using two-tailed Pearson correlation

R value	Height (m)	Slope steepness (%)	Dist. from base level (m)	UCS (MPa)	Attrition resist. (%)	Denudation (m/million years)	Porosity (%)
Heigh	1	0,278**	0,507**	**0,739****	0,398**	**-0,672****	-0,452**
Slope steepness	0,278**	1	0,121**	0,340**	0,325**	-0,346**	-0,199**
Dist. from base level	0,507**	0,121**	1	0,274**	0,148**	-0,198**	-0,158**
UCS	**0,739****	0,340**	0,274**	1	**0,644****	**-0,888****	-0,526**
Attrition resistance	0,398**	0,325**	0,148**	0,644**	1	**-0,681****	**-0,660****
Denudation	**-0,672****	-0,346**	-0,198**	**-0,888****	**-0,681****	1	0,553**
Porosity	-0,452**	-0,199**	-0,158**	-0,526**	**-0,660****	0,553**	1

* p= 0.05 ** p= 0.01

Table 3. The correlation matrix of the variables based on average values using two tailed Pearson correlation

R value	UCS (MPa)	Slope steepness (%)	Height (m)	Dist. from base level (m)	Attrition resist. (%)	Porosity (%)	Denudation (m/million years	Frost resistance (%)
UCS (MPa)	1	**0,833****	**0,931****	0,548	**0,780***	**-0,661**	**-0,810****	**0,741***
Slope steepness	**0,833****	1	**0,831***	**0,697***	**0,781***	**-0,656**	**-0,740***	**0,748***
Height	**0,931****	**0,831***	1	0,666*	0,661*	**-0,722***	**-0,850****	**0,784***
Dist. from base level	0,548	**0,697***	0,666*	1	0,29	-0,438	-0,393	0,407
Attrition resistance	**0,780***	**0,781***	0,661*	0,291	1	**-0,703***	-0,606	0,606
Porosity.	**-0,661**	**-0,656**	**-0,722***	-0,438	-0,703*	1	0,636	**-0,648**
Denudation	**-0,810****	**-0,740***	**-0,850****	-0,393	-0,606	0,636	1	**-0,973**

* p= 0.05 ** p= 0.01

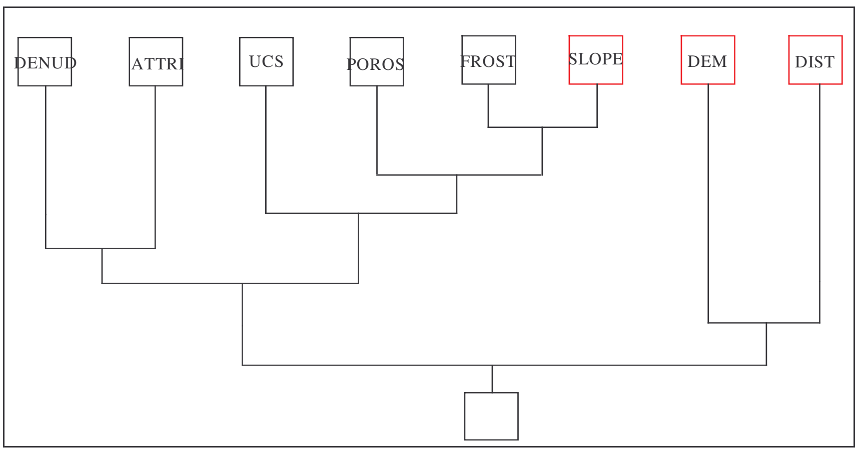

Fig 5. The hierarchic cluster analysis of the variables shown in a dendrogram

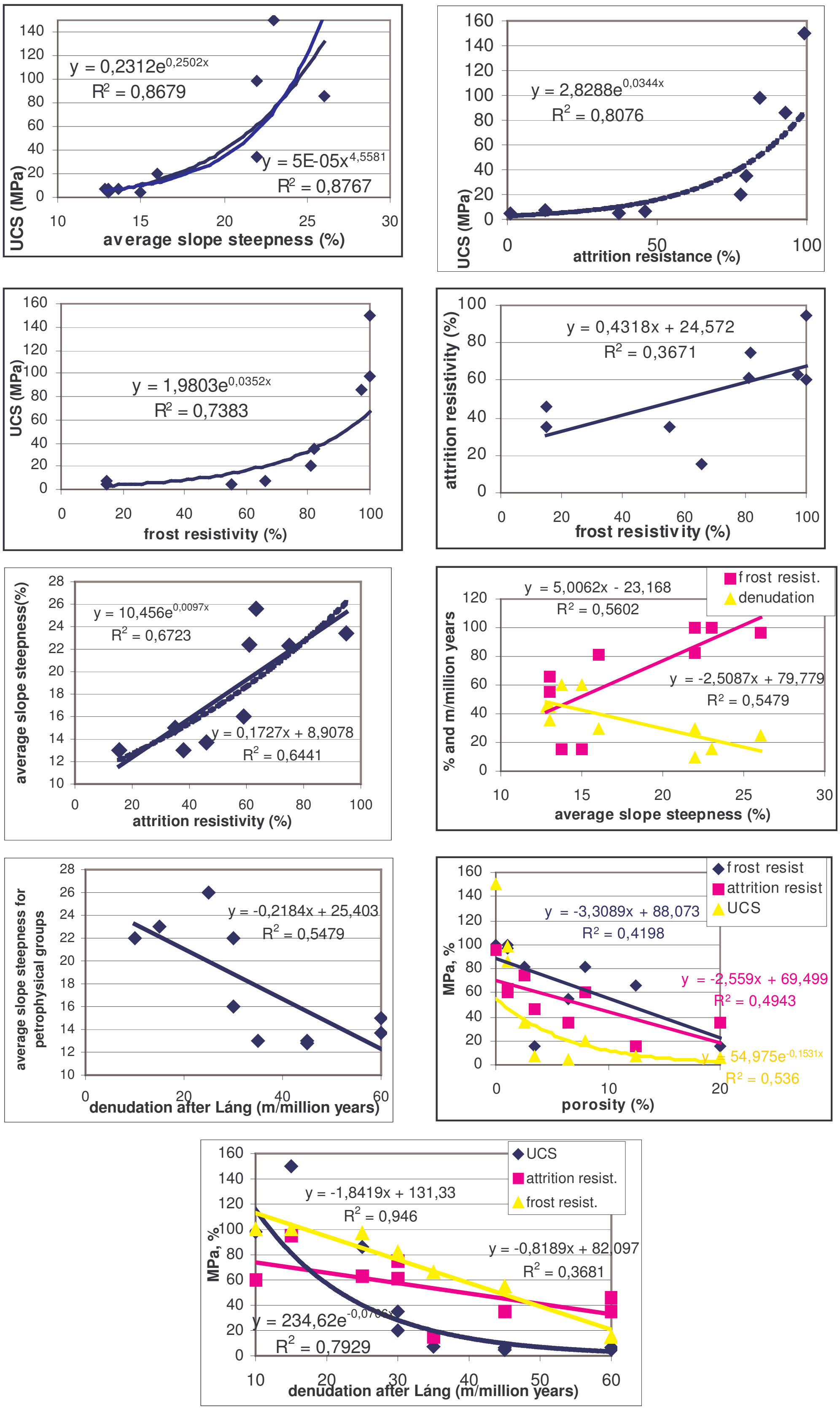

Fig. 6. Relationship between the average (per rock type) of the investigated parameters

Identifying relationship between variables used in engineering or in geomorphology can be important because they reveal the connection between the geologic factors all representing some kind of resistibility or erodibility (**Fig. 6-7-8**). In the case of the relationship between the morphometric and geologic parameters we must be aware of the fact that sometimes quite tight correlations are the results of the specific features of the area. Although it is often stated that solid rocks form forms of greater heights while loose sediments constitute forms of smaller vertical extension (CLAYTON & SHAMOON, 1998a; b; 1999), the strong correlation between the height and the UCS is not necessary. In this case the hard rocks are usually elevated but they also reach the base level as well. However, it is also possible that loose rocks occur in greater heights not reaching the base level and consolidated materials are the underlying rocks.

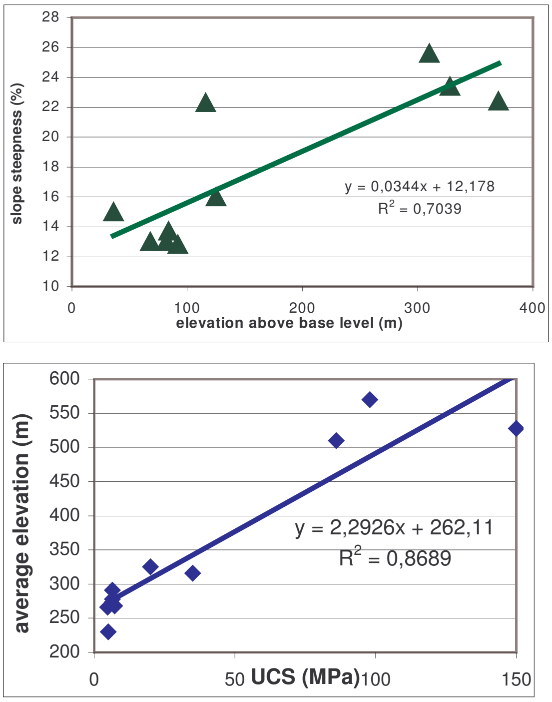

Fig. 7. Connection between the averages (per rock type) of investigated parameters

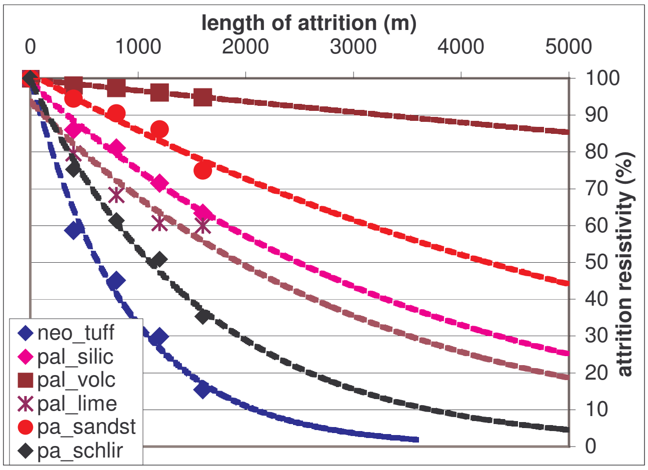

Fig 8. Resistance of rocks to attrition at 5000 metres (measured to 1500 metres and extrapolated)

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