Acta Geographica Croatica	Volumen 35 (2000.)	19 - 43	Zagreb, 2001.

UDK 551.4:551.1](497.5)

MULTIVARIATE APPROACH TO RELIEF CLASSIFICATION AND TYPOLOGY - THE EXAMPLE OF NORTH-WESTERN CROATIA

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Abstract:

This work deals with the multivariate approach to the relief classification and typology from the applied-geomorphological aspect on the example of North-Western Croatia. The researched area is covered by 4495 samples analyzed according to 9 criterion variables (quantitative, geomorphological pedological and lithological variables).

Consonant with the research purposes, a multivariate approach has been approved. It is based on generalization of a larger number of attributes pointing out characteristic features and relations. All this enables the establishment of a hierachial structure and construction of the corresponding models, on the basis of which we realize typology and get an insight into the causes of the relief type differentiation.

Key Words:

classification, typology, North-Westarn Croatia, multivariate methods

MULTIVARIJANTNI PRISTUP KLASIFIKACIJI I TIPOLOGIJI RELJEFA - PRIMJER SJEVEROZAPADNE HRVATSKE

Izvadak:

U radu je, na primjeru Sjeverozapadne Hrvatske, razmotren multivarijantni pristup klasifikaciji i tipologiji reljefa s primijenjeno-geomorfološkog aspekta. Istraživano područje podijeljeno je na 4495 uzoraka (padina) analiziranih prema 9 kriterijskih varijabli (kvantitativne geomorfološke, pedološke i litološke varijable).

U skladu s ciljevima istraživanja, odabran je multivarijantni pristup koji se temelji na generalizaciji većeg broja atributa uz *naglašavanje karakterističnih pojava i odnosa. Ovakav pristup omogućava uspostavljanje hijerarhijske strukture i konstrukciju odgovarajućih modela na temelju kojih je moguće provesti tipologiju reljefa i dobiti uvid u uzroke diferencijacije tipova.*

Ključne riječi:
klasifikacija, tipologija, Sjeverozapadna Hrvatska, multivarijantne metode

INTRODUCTION

Problems of the applied quantitative research in geomorphology connected with slopes and slope processes are exeptionally important. The slope processes are considered as risks because of their connection with soil erosion and slope instability (MIHALIĆ, STANIĆ, 1995). The ecological aspect of this problem is also very significant. Evidently, it is necessary to apply the exact research methods with the purpose of corresponding quantification, typification and evaluation of the relief with regard to the mentioned differences, and with little subjectivity.

The research starting point is the analysis of the modifying influence of the relief on the exogenic geomorphological processes activity, which is expressed to such a degree that its quantitative parameters, together with the basic pedological and lithological features, can be significant assessors of the risk of the slope processes.

Consonant with the basic starting point, the fundamental quantitative parameters of the denudation-tectonic and denudation-accumulative relief of North-Western Croatia have been analyzed (BOGNAR, 1987), with the purpose of estimating and predicting the slope conditions and planning activities with a minor risk of the slope processes. Besides, the quoted quantitative variables were analyzed as well as their ability to explain, together with the pedological and lithological parameters, the spatial variability of various relief types on the researched area.

North-Western Croatia represents the key region of the Republic of Croatia with regard to its geographical position, role and importance. Its area amounts 19,665 km^2 approximately, i. e. it occupies about 35 % of the area of the Republic of Croatia (ŽULJIĆ, 1974). The researched area is somewhat smaller because it occupies the denudation-tectonic and denudation-accumulative relief, i. e. the slope inclinations > 2^o (Fig. 1). All together, 4495 samples were analyzed according to 9 quantitative variables of relief, soil and lithology.

APPROACH AND METHODS

Classification and typhology of particular relief forms are important tasks in geomorphological research, and they are indispensable for organization of often an

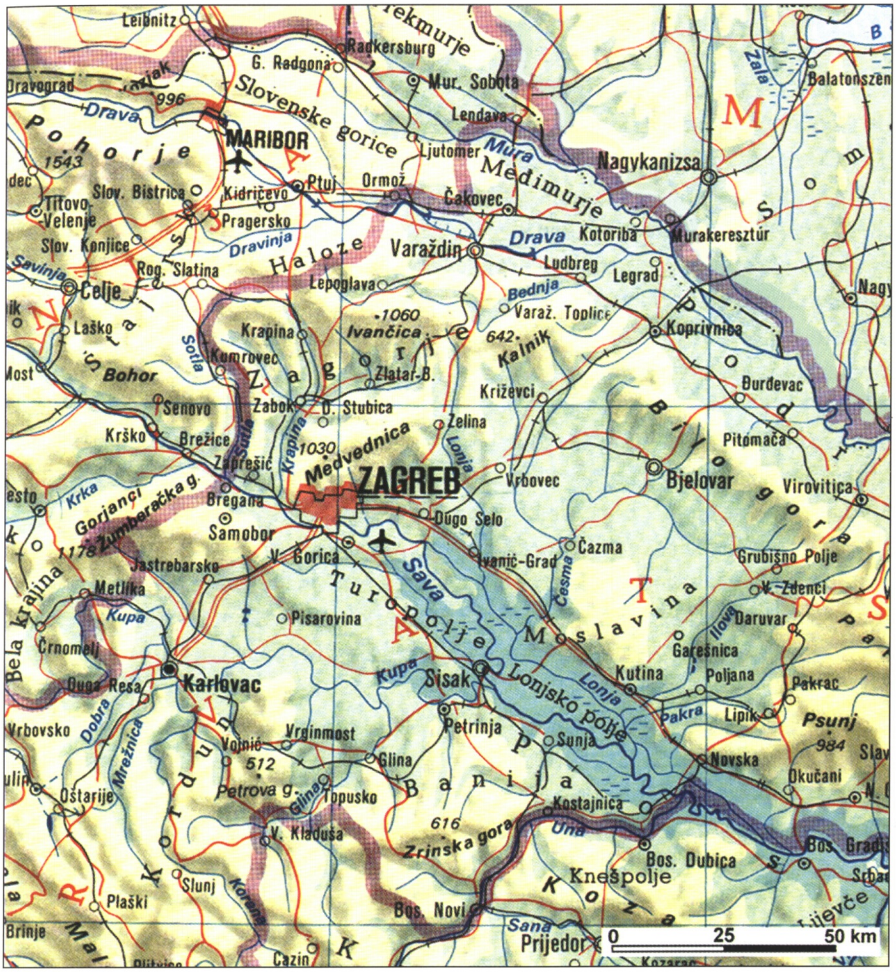

Fig. 1. North-Western Croatia
Sl. 1. Sjeverozapadna Hrvatska

exceptionally large number of numerically expressed relief features. The notions of classification and typology are often used as synonyms, but Horváth (1997), on the basis of researching a large number of various concepts, considers that these two notions must be clearly distinguished and relevantly interpreted. Classification represents the first step in analysis, i. e. identification of categories by a detailed division of the relief units according to the clearly defined quantitative and qualitative criteria. On the contrary, typology represents the integration phase of the data achieved by classification, which implies grouping, i. e. the synthesis of the relief categories defined by the classification method into new units according to a defined common criterion.

In other words, the relief types represent the parts of the researched area distinctly determined in the region, with characteristic features of the group they belong to (e. g. the distance measures). The notion of a relief type can be understood as a theoretical model representing a group of the mutually similar spatial units, but, on the other hand, of the common features essentially different from another relief type.

Connection of forms and processes is one of the fundamental principles of geomorphological research. This connection can be cause-effect and correlative. The correlative connection is marked with simultaneous changes of certain parameters which do not have to be necessarily casually connected (MIHLJEVIĆ, 1995). For that reason, in the analysis of the quoted problems, there are multivariate methods which can quantify the relations among all elements of the geomorphological slope system and, in that way, point to the importance of the processes taking part in their formation (PEH, 1990, 1992). Moreover, through a simultaneous analysis of a larger number of variables, these methods contribute to discovering of the relief features variability cause, and, similar to the system analysis, on the basis of generalization of a larger number of attributes, stress the characteristic features and relations establishing a hierarchial organization. Likewise, these methods enable the construction of the corresponding mathematical models (MATHER, DOORNKAMP, 1970) based on the fundamental variables or functions as optimal descriptors, on the basis of which one can deduce conclusions about the relief dynamic balance condition, which represents the basis of the rational approach to typology and evaluation.

Such an approach aims for the most possible elimination of subjectivity in estimation of features and makes the basis of the exact approach to the relief evaluation from a certain aspect.

When using multivariate methods, a special attention must be paid to the selection of the attributes which are going to be analyzed, and determination of the types must be based on a detailed and homogenous system of criteria, which should, if possible, include the remaining elements of the geographical environment for the sake of a more complex cognition of the relations in lithosphere, hydrosphere, pedosphere and atmosphere (HORVATH, 1991,1997).

Among significant works dealing with the problems of classification, typology and regionalization, it must be mentioned Linton's work about the delimitation of morphological regions (1951) and also "A method for deriving multi-factor uniform regions" (1961) by B. J. L. Berry, where the author singles out the regions of the USA on the basis of the cluster and factor analyses. The classification by means of the cluster analysis was worked out in detail by A. J. Parsons (1977) in his work "A technique for the classification of hillslope forms", on the example of the slope-profiles of several isolated hills of the N. J Wales in Australia. S. Leél-Össy (1984) is preoccupied with the relief typology in Hungary according to the genetic criterion. F. J. Dent, in his work "Land suitability classification" (1978, according to D. A. DAVIDSON, 1986), considers a parameter multivariate approach to the land classification according to the favour for agricultural using. A cluster classification has been carried out according to the characteristics of particular kinds of soil, as well as the soil fertility evaluation on the basis of the main component and factor analyses. In his work "Morphometric analysis of montain drainage basins in the Basin and Range Province, USA" (1989), W. N. Engstrom, on the basis of the cluster analysis classifies the drainage basins in Arizona and brings the results into connection with the relief evolution. G. Horváth (1991, 1997) works out the problems of the relief classification and typology in Hungary.

RELIEF CLASSIFICATION OF NORTH-WESTERN CROATIA

Three groups of criteria make the basic starting point of the analysis: a) **morphometric** criteria (7 variables: the average height, relative height, slope length, length index, inclination, surface and exposition regularity), b) **geological** criteria (variable: the strength coefficient of the rock masses) and c) **pedological** criteria (variable: the ecological depth expressed as the average soil depth of a certain cartographic soil unit, according to Appropriated pedological map of the Republic of Croatia, 1:300 000). Geological and pedological criteria are included in the analysis because of a wider and more complex insight into interdependence among the relief, soil and geological base, which will be important, especially in later relief evaluation.

The size and complexity of the researched area, and need for exact defining of the relief characteristics understand a detailed quantification of every sample and use of the corresponding mathematical-statistical methods which will best meet this aim. In the spatial data typology, the results obtained by means of the classification by the cluster analysis method, were used as the starting point. The essence of this technique is a gradual grouping of a larger number of samples into the cluster groups, the complexity of which grows propor-tionally with the number of iterations. By gradual grouping, the number of clusters decreases, and their size (number of the included members) increases, as well as their mutual variability. In that way the hierarchial grouping simplifies the complexity of relations in nature and sets up a large number of the infinite spatial data into a logical system.

There are several distance measures used in the hierarchial grouping, and the most spread one is the Euclidean distance, which represents a geometrical distance in multi-dimensional space and is expressed as:

$$\text{distance}(x,y) = [\Sigma_i(x_i - y_i)^2]^{1/2}$$

In further phases, when more objects are being grouped according to similarity, new cluster groups generate towards particular grouping rules. These rules specify the moment at which two cluster groups are similar enough to be grouped into a new cluster. There are several grouping rules. Some of them are based on the principle of "the nearest neighbour" or "the furtherest neighbour", unpondered or pondered average of the group pairs, etc.

Here, we come upon the Ward's method, which is somewhat different from the previously mentioned methods, because it is based on the variance analysis, which has enabled distance evaluation among the cluster groups. This procedure was operatio-nalized by Ward (1963.), and the statistical test of differences among medium vectors of two cluster groups was mathematically expressed by Rao (1951.,1965, according to King, 1969):

$$F = \frac{N_a + N_b - p - 1}{p} * \frac{N_a N_b}{(N_a + N_b)(N_a + N_b - 2)} * D^2$$

where N_a and N_b are the cluster groups, D^2 = generalized distance statistics, p = variates.

The sum of two squared hypothetic clusters (formed in any phase) was minimized within the framework of this method. To serve the needs of this research, we used the Euclidean distance measure and the Ward's grouping method.

By means of the cluster technique, the researched area of North-Western Croatia, covered with 4495 samples and 9 variables, was classified into 10 cluster groups and 17 subgroups according to the common characteristics (Fig. 2). The isolated groups and subgroups (Tabl. 1.), make the basis of singling out the relief types and subtypes (Lozić, 1999, 2000).

TESTING OF VARIABLE STATISTICAL IMPORTANCE

There are two basic purposes of the multiple discriminant analysis in typology: a) determination of the relief type variability causes to find mutually most optimal linear combinations of the predictor variables formed in the way that each one takes part in the relief types discrimination to the maximum extent, and b) establishment of the spatial discriminant model (Mather, Doornkamp, 1970) of the relief type relations and dominant slope morphological processes, the indicators of which are combinations of the variables included in discriminant functions. These purposes represent the criteria on the basis of which typology is performed.

The basic step in typology is testing of the results obtained by classification, i. e. determination of the model discriminant power in entirety, which is possible by means of the Wilks' *lambda* test, based on the proportion between the variance determination within a group and total variance determination:

$$\text{Wilks' } \lambda = \det(W) / \det(T)$$

The values of each variable initial cluster group are tested by means of the variance analysis equality. The variance analysis is applied while testing the null-hypothesis that the cluster group centroids

Tab. 1.: Absolute values of the cluster groups and subgroups centroids

Tab. 1.: Apsolutne vrijednosti centroida cluster grupa i podgrupa

Types of the relief slopes	Average height	Relative height	Length of the slopes	Length/ rel. height	Inclination	Number of incl. changes	Exposition index	Ecological depth of the soil	Coef.of rock hardness
1	191,81	55,67	451,6	8.314	3,01	1,00	0,185	105,28	1,02
1a	191,35	53,18	516,7	9.883	2,99	1,00	0,186	106,87	1,00
1b	192,21	57,84	394,7	6.941	3,02	1,00	0,183	103,89	1,05
2	258,6	84,71	645,6	7.749	2,99	1,00	0,318	80,14	6,04
2a	316,2	110,25	885,7	8.121	2,97	1,01	0,391	80,25	4,98
2b	225,0	69,81	505,5	7.531	3,00	1,00	0,276	80,07	6,67
3	207,39	62,52	443,1	7.343	3,05	1,00	0,637	97,51	1,96
3a	188,03	55,77	421,5	7.711	3,01	1,00	0,623	104,55	0,78
3b	214,77	67,92	462,8	6.987	3,03	1,00	0,654	87,47	3,73
4	187,46	55,00	718,9	13.683	2,68	1,01	0,427	108,32	0,97
4a	185,02	56,01	576,0	10.653	2,79	1,00	0,547	109,32	1,07
4b	198,29	60,92	816,3	13.789	2,95	1,03	0,349	106,30	1,06
4c	176,51	44,67	845,3	19.159	2,07	1,02	0,316	109,37	0,67
5	255,31	89,38	424,4	5.065	3,99	1,00	0,200	83,55	2,78
5a	216,67	67,75	357,3	5.393	4,00	1,00	0,194	97,96	0,99
5b	283,77	105,33	473,9	4.824	3,97	1,00	0,203	72,93	4,10
6	230,31	78,62	408,3	5.303	3,99	1,00	0,594	98,18	2,21
7	335,06	127,14	569,9	4.681	3,99	1,01	0,649	71,43	5,39
8	430,17	124,61	489,8	4.296	4,06	1,03	0,387	53,72	10,05
8a	353,79	112,24	426,2	4.116	4,14	1,02	0,392	50,40	8,77
8b	621,11	155,53	649,0	4.747	3,86	1,06	0,375	62,01	13,06
9	249,17	92,32	556,4	6.517	3,53	2,02	0,376	90,18	3,31
9a	216,07	79,11	547,0	7.329	3,35	2,03	0,270	99,71	1,69
9b	289,37	108,36	567,8	5.530	3,74	2,01	0,503	78,60	5,27
10	415,39	266,00	1176,9	4.963	3,91	1,34	0,366	68,38	6,21
10a	445,38	284,14	1062,3	3.978	4,09	1,19	0,399	63,33	6,82
10b	338,28	219,35	1471,7	7.497	3,43	1,72	0,280	81,35	4,65

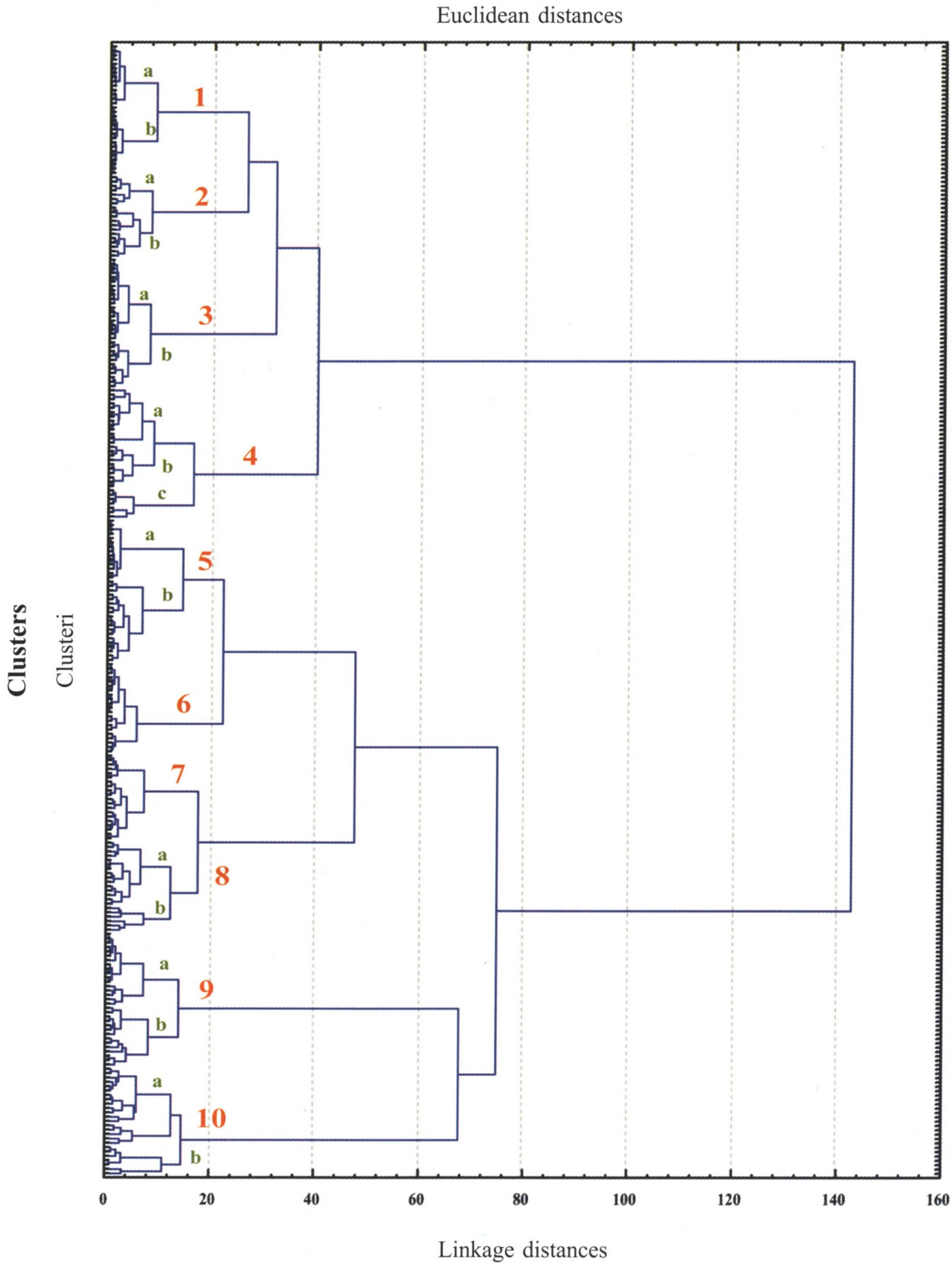

Fig. 2. The dendrogram of 260 initial clusters
Sl. 2. Dendrogram 260 inicijalnih clustera

Table 2: The results of the discrimination analysis for North-Western Croatia according to the variables

Tab. 2.: Rezultati diskriminantne analize za Sjeverozapadnu Hrvatsku prema varijablama

Discrimination analysis Number of variables in model: 9 Wilks Lambda: 0.00067 approx. F (81, 1572)= 40.771 p<0.0000						
N=260	Wilks Lambda	Partial Lambda	F - remove 9,242	p - level	Toler.	1-Toler. (R-Sqr.)
average height	0,0007669	0,8873371	3,414013	0,000568	0,6378364	0,3621636
relative height	0,0010827	0,6284866	15,89467	0,000000	0,4155514	0,5844486
length of slope	0,0008354	0,8145156	6,123235	0,000000	0,4821491	0,5178509
length/rel. height	0,0011085	0,6138716	16,91325	0,001524	0,4047448	0,5952551
inclination	0,0017506	0,3886901	42,28932	0,000000	0,5704204	0,4295796
inclination change	0,0041896	0,1624172	138,6656	0,000000	0,9260848	0,0739152
expositions	0,0017297	0,3933877	41,46325	0,000000	0,9312496	0,0687504
ecological depth of soil	0,0008032	0,847137	4,852009	0,000006	0,8178849	0,1821151
coefficient of rock hardnes	0,0009061	0,7509882	8,915787	0,000000	0,8228545	0,1771455

(arithmetic means) are mutually equal. If the null-hypothesis is rejected, further analyses can be done.

Generally, the values of the Wilks' lambda test range from 1.0 (there is no discrimination power) to 0.0 (absolute discrimination power).

For 10 analyzed cluster groups, the value of the Wilks' lambda test amounts to 0.007 (Tabl. 2.), which means that there is a prominent discrimination power of variables among the groups.

RELIEF TYPE DIFERENTIATION CAUSES

Individual variable testing with regard to the statistical significance is based on the partial Wilks' lambda test, by means of which each individual variable of discrimination within the groups is determined on the basis of the relation: the Wilks' lambda value after including a certain variable into the test and the Wilks' lambda value before that including, which is also indicated by the F-values (Tabl. 2., Fig. 3.).

On the whole model level, we can notice a dominant influence on discrimination of the following variables: surface regularity, inclination and expositions, then index of length and relative height, relative height and lithology. The influence of the average height and ecological depth is least noticeable. If particular variables are observed as indicators of geomorphological processes, we can conclude that, according to the established model, the gravitational slope processes, whose intensity directly depends on the surface regularity, slope inclination (including the index of length and relative height) and slope length, represent the most important causes of particular relief types in the area of North-Western Croatia. Since the variables of the ecological

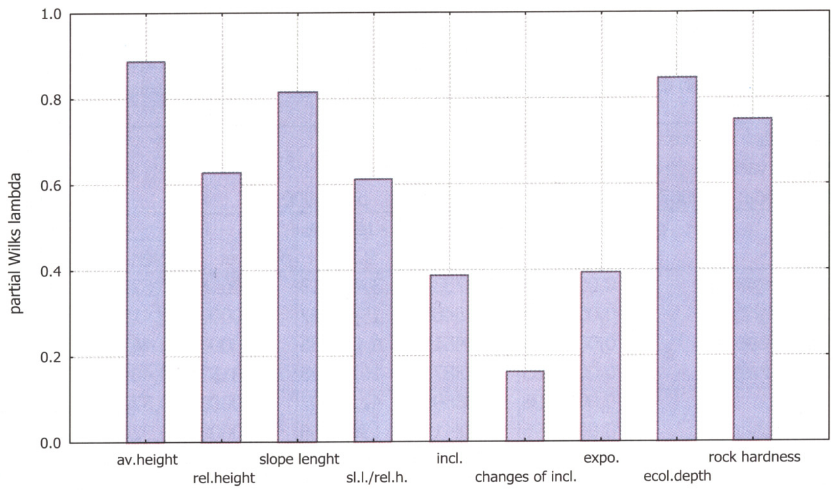

Fig. 3: Partial Wilks lambda according to the variables
Sl. 3.: Parcijalni Wilks lambda prema varijablama

depth and exposition are also somewhat significant, we can say that the relief type features depend, to a large extent, on the pedological structure (feedback mechanism) and climatic element activity. The variables of the average height and lithology have the least share in discrimination.

It is necessary to point out that the variable shares are expressed relatively and independently of their position in the hierarchy; statistically, all variables significantly influence differentiation (p-level).

After determination of the model and particular variable discrimination power, there followed the extraction of the discriminat function by means of the canonical correlation method. This method was mathematically worked out by Hotelling (1935, according to Fulgosi, 1978), who formulated it as looking for "the most predictive criteria". The essence of this method is to connect simultaneously several variables -predictors with the cluster groups, with the purpose to find within a group of variables the most optimal variable combinations, which significantly discriminate the groups. In other words, the discriminant functions, obtained by canonical correlation, represent mutually orthogonal linear combinations of the predictor variables, which are, similar to the factor analysis, formed so that each of them takes part in discrimination to the maximum extent. Then, each linear function is tested by the Wilks' lambda test of significance. The share in discrimination is hierarchial, which means that the first function has the greatest discriminant power, and each next one contains the maximal variance among the groups, which remained after the removal of the variance caused by the previous linear functions. The functions whose share is not significant, are usually eliminated from further analysis.

Table 3.: Features of discriminant functions
Tab. 3.: Značajke diskriminantnih funkcija

Roots removed	EIGEN	CANONICAL R	Wilks Lambda	Chi- Sqr.	df	p-level
0	6.50830	0.93103	0.00068	1819.54	81	0.000000
1	4.31517	0.90103	0.00511	1316.55	64	0.000000
2	2.76420	0.85694	0.02716	899.74	49	0.000000
3	1.40487	0.76431	0.10222	569.02	36	0.000000
4	1.13134	0.72857	0.24582	350.08	25	0.000000
5	0.73334	0.65044	0.52394	161.27	16	0.000000
6	0.05635	0.23096	0.90816	24.04	9	0.004254
7	0.04100	0.19846	0.95933	10.36	4	0.034811
8	0.00134	0.03653	0.99867	0.33	1	0.563786

By means of the canonical analysis 9 discriminant functions were singled out. Their significance degrees were determined by the Chi-square test, which is also evident from their peculiar (Eigen) values (Tabl. 3). The first three functions (0, 1 and 2) are the most significant, because they explain the largest part of the system variance (80.33%), which can be seen from the graph of peculiar values (Fig. 4.).

The standardized coefficients of discrimination were used to interprete the relations between variables and discriminant functions, because they relate to all standardized variables included in the analysis, and use the comparable scale of values. Tabl. 4. shows that the first two discriminant functions are, to the maximum extent, burdened with the variables of the surface regularity, inclination and length. The first function is also considerably burdened with the

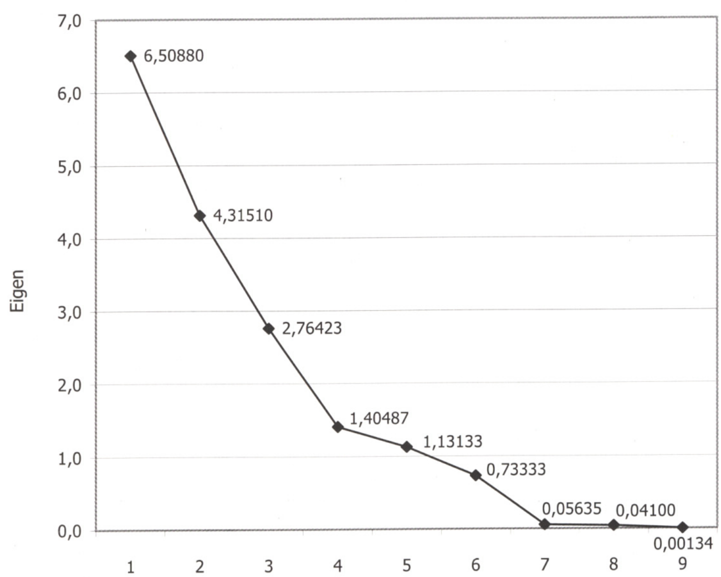

Fig. 4.: Peculiar (Eigen) values of discriminant functions (10 groups)
Sl. 4.: Svojstvene (Eigen) vrijednosti diskriminantnih funkcija (10 grupa)

Tabl. 4.: Standardized coefficients of discriminant functions
Tab. 4.: Standardizirani koeficijenti diskriminantnih funkcija

Varijables	Discr.f. 1	Discr.f. 2	Discr.f. 3	Discr.f4	Discr.f. 5	Discr.f. 6	Discr.f. 7	Discr.f. 8	Discr.f. 9
average height	0.03273	0.15306	-0.25207	0.0846848	0.2938534	-0.2658433	0.6864608	0.3175831	-0.8622544
relative height	0.19419	-0.02843	1.02748	-0.1642334	-0.3033876	-0.0596045	0.5761294	-0.1098867	0.9195857
length of slope	-0.33904	0.41530	0.25913	0.1212889	-0.0924082	0.2939009	-0.9128591	0.1229063	-0.8726023
length/rel. height	0.29363	-0.20913	0.11505	-0.1245805	-0.0154549	-1.390643	0.3088317	-0.1774762	0.50098
inclination	-0.57376	0.48155	-0.50824	0.0488902	-0.5449442	-0.7637675	-0.2124712	0.06148	0.0456568
inclination change	-0.75934	-0.70140	-0.04451	0.011705	0.0644167	-0.0577755	0.0340805	-0.0191196	0.0109851
expositions	0.15880	-0.24788	0.16470	0.9785076	-0.0078711	-0.0264682	-0.0008973	-0.0420609	0.0055688
ecological depth of soil	0.20960	-0.10893	0.02889	0.0158257	-0.432029	-0.0479014	0.0218325	0.9867642	-0.051575
coefficient of rock hardness	-0.17987	0.13243	-0.09932	0.0171997	0.6428728	-0.1598408	-0.3932155	0.600779	0.4481516
Eigenval	6.5083	4.315166	2.764201	1.404871	1.131344	0.7333375	0.0563487	0.0410031	0.0013364
Cum.Prop	0.3838368	0.6383302	0.801353	0.8842074	0.9509301	0.9941797	0.997503	0.9999213	1.00

variables of the index of length and relative height and ecological depth, and the second one is burdened with the variables of the index of expositions and index of length and relative height. The third discriminant function is mostly burdened with the variables of the relative height and inclination, and somewhat significantly with the variables of length and average height.

Taking into consideration the discriminant function features, we can say that the variables **of the surface regularity, slope inclination and length** play first fiddle in differentiation of the relief types of North-Western Croatia. The variables of the average height, relative height, index of length and relative height, and of the ecological depth of the soil, are somewhat less significant. The least is the influence of the variables of the average height and lithology in discrimination within the whole three-dimensional area defined by three discriminant functions. Since the Wilks' lambda test has stated that all variables notably take part in discrimination, the share of each variable will be taken into account on the occasion of the function interpretation.

If we connect the mentioned variable combinations in particular discriminant functions with the corresponding slope processes (Fig. 5), we can say that the discriminant function 1 on the positive side of the axis points to the mostly favourable conditions on the slopes, with the possibility of the excessive phenomena of the land-slide slope processes (on the negative side of the axis the situation is reverse).

Generally, the slopes discriminated by this function with the positive sign, are stable and aspire to increase their stability. The positive side of the axis of the discriminant function 2 points to a different condition, that means to a low balance degree, with a great probability of the gravitational processes of slope-wash and gullyng. The land-slide processes are not observable to an increased extent because of the rock strength (on the negative side of the axis the conditions are reverse). The

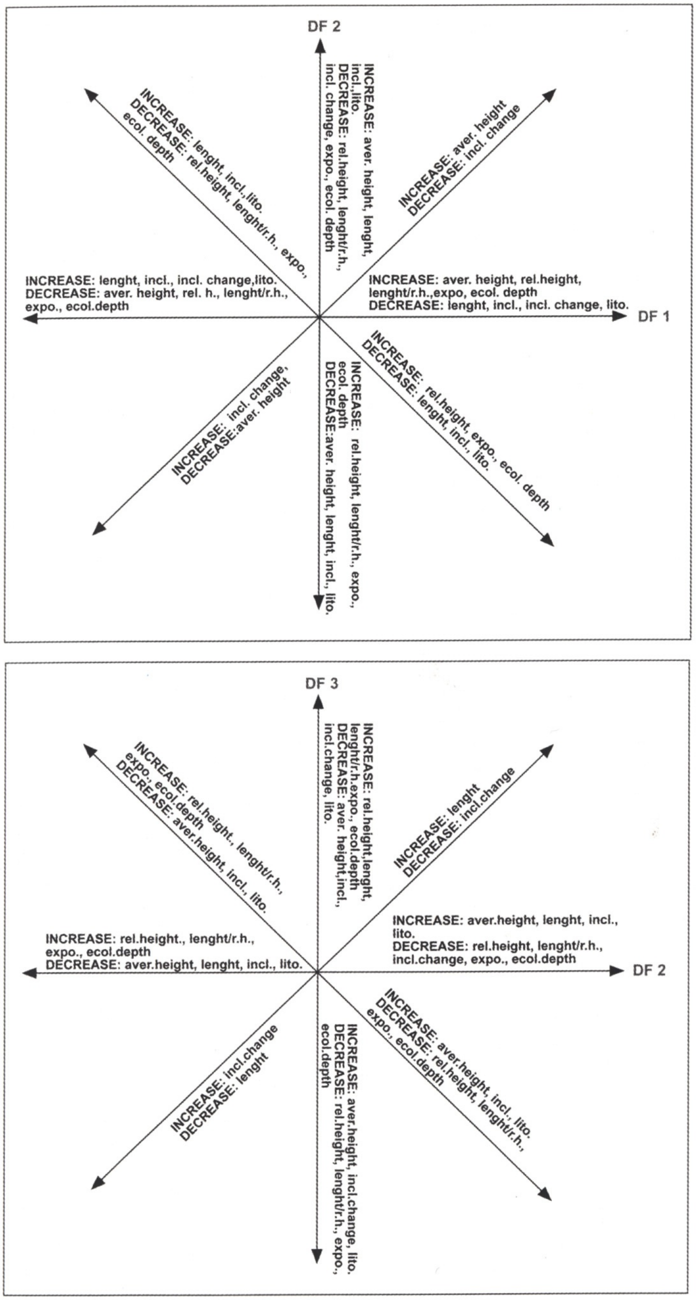

Fig. 5.: Scheme of the model representing relations between variables and discriminant functions
Sl. 5.: Shema modela odnosa varijabli i diskriminantnih funkcija

third discriminant function points to relatively unfavourable conditions, because, although there are the inclination decrease, increase of the index of length and relative height and exposition index, there are simultaneously the increase of the average and relative height, slope length and surface irregularity, which essetially decreases the stability of the slopes discriminated by this function to an increased degree. Considering the strength coefficient value decrease, there is a danger of intensification of the land-slide destruction processes. The balance is minor, but not to such a degree as it is on the slopes discriminated by the second function. Generally, there are not prominent differences between the positive and negative side of this discriminant function axis.

MODELS REPRESENTING RELATIONS BETWEEN TYPES AND SUBTYPES OF RELIEF AND DISCRIMINANT FUNCTIONS

One of the basic purposes of the multivariate approach in this research are the construction and application of the spatial models aiming at abstraction and synthesis of a great number of attributes into a logical system, on the basis of which one will be able to identify the spatial systems differentiated concerning the relation between the forms and morphological processes. As the models represent the relief subsystems differentiated by the interior homogeneity of the forms and processes connected with them, there is a significant possibilty of their application for practical purposes.

The influence of particular variables on the whole system variability being determined, we can come up to the next phase of the analysis which deals with the determination of the influence of variables or variable combinations included in discriminant functions on variability of particular relief types and subtypes within the slope system of North-Western Croatia. For this purpose, it is necessary to perform the analysis of the canonical variable means for each cluster group (Tabl. 5.).

The arrangement of the discriminant function values according to types (Fig. 6)

Tabl. 5.: Canonical variable means for 10 relief types
Tab. 5.: Sredine kanoničkih varijabli za 10 tipova reljefa

Grupe	Diskr.f. 1	Diskr.f. 2	Diskr.f. 3	Diskr.f. 4	Diskr.f. 5	Diskr.f. 6	Diskr.f. 7	Diskr.f. 8	Diskr.f. 9
G_1:1	2.20446	-0.55764	-0.36122	-1.69750	-0.28988	0.74815	0.25493	0.20113	-0.04443
G_2:2	1.31700	0.28953	0.43534	-0.62679	1.92161	0.91746	-0.63258	0.02814	-0.00630
G_3:3	2.46879	-1.17127	0.15095	1.55317	0.12164	1.18766	0.18808	-0.13018	0.04348
G_4:4	3.46299	-1.63537	1.24432	-0.17430	0.05504	-1.75670	-0.03040	-0.05790	0.00499
G_5:5	-0.52504	1.81805	-1.72209	-1.32767	-1.03122	-0.05550	-0.07471	-0.28074	0.02618
G_6:6	0.18849	0.85615	-1.45052	1.51718	-1.70895	-0.25424	-0.25235	0.42752	0.01218
G_7:7	-0.55327	1.72176	-0.28660	1.93505	0.00332	-0.14519	0.01283	-0.25577	-0.09307
G_8:8	-1.62643	2.72797	-1.52604	0.18053	2.23438	-0.76816	0.29608	0.16796	0.02546
G_9:9	-4.54423	-4.03085	-0.58942	-0.07916	0.12416	-0.06936	-0.01379	-0.01179	-0.00321
G_10:10	-2.78602	2.02746	4.16190	-0.26471	-0.56136	0.22204	0.05435	0.05255	0.01221

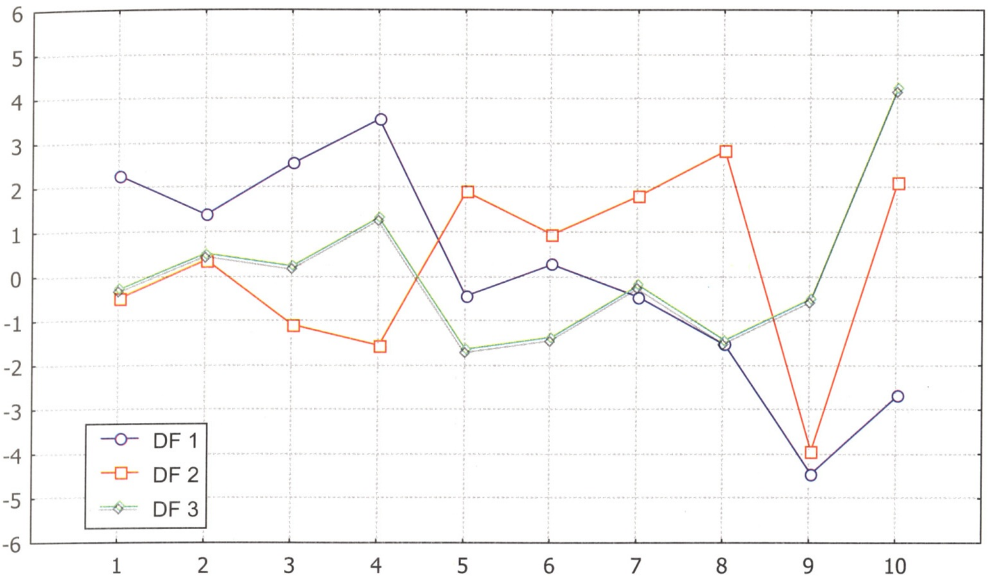

Fig. 6: Values of the discrimin. funct. 1,2 and 3 according to the relief types
Sl. 6.: Vrijednost diskriminantnih funkcija 1, 2 i 3 prema tipovima reljefa

shows that the first discriminant function discriminates most intensively the type 9 (with the negative sign), the type 4 (positive sign), and, to a somewhat smaller extent, the type 10 (negative sign), 3 (positive sign) and 1 (positive sign).

The discriminant function 2 discriminates most intensively (like DF 1) the type 9 (negative sign), and, to a somewhat smaller extent, the type 8 (positive sign) and the type 10 (positive sign). The influence on the types 7 (positive sign), 4 (negative sign) and 5 (positive sign) is also significant.

The discriminant function 3 discriminates most intensively the type 10 (positive sign), and to a smaller extent the types 5 and 6 (negative sign).

The Fig. 7 presents the models of the relations between the relief types and variables from the area of North-Western Croatia. For the easy reference, the relations of the relief types with the discriminant functions 1 and 2, then 2 and 3 are presented separately.

The position of the groups 4, 3 and 1, determined by the positive sign of the discriminant function 1 and negative sign of the discriminant function 2, points to mainly favourable characteristics of the slopes belonging to these types. This is also pointed to by variable combinations and their signs characterized by these two axes. So, the positive side of the axis of the discriminant function 1 is marked by the increase of the ecological depth, length and relative height index, and the index of expositions and surface regularity. On the other hand, there is a value decrease of the average height, relative height,

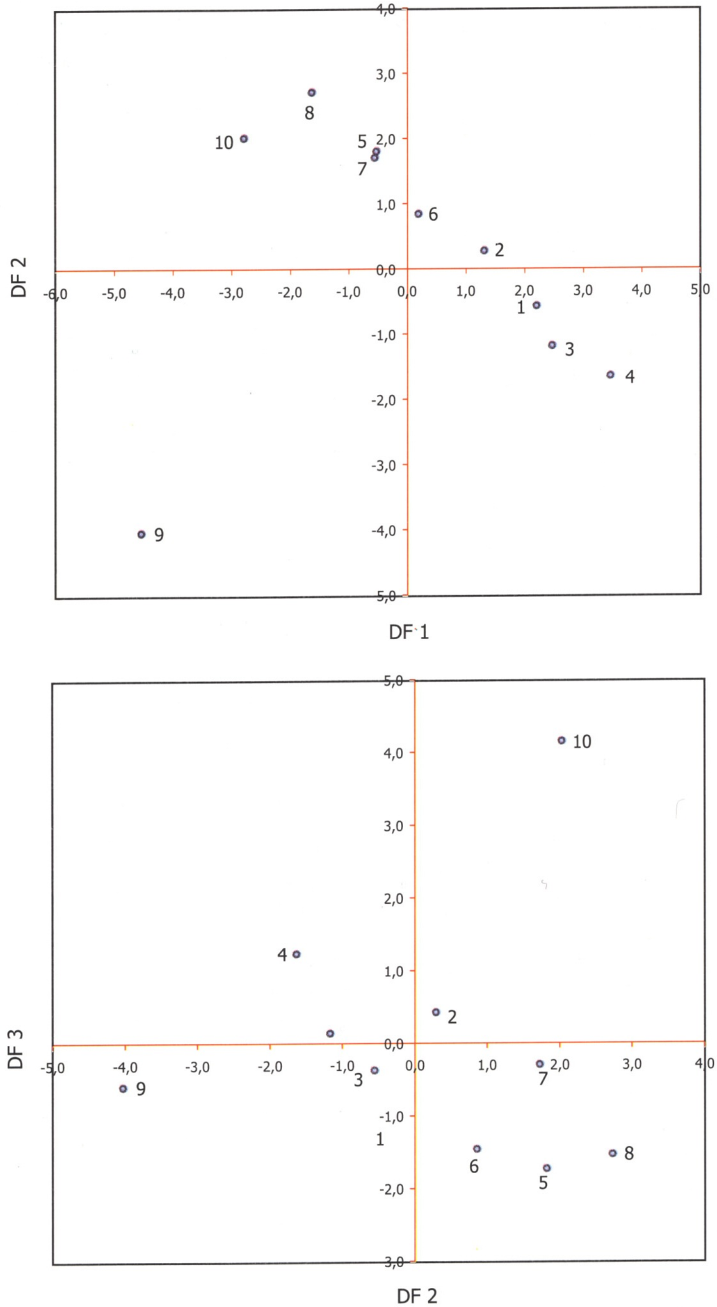

Fig. 7.:Models of the relationship of the relief types and discriminant functions 1, 2 and 3

Sl. 7.: Modeli odnosa tipova reljefa i 1.,2. i 3. diskriminantne funkcije

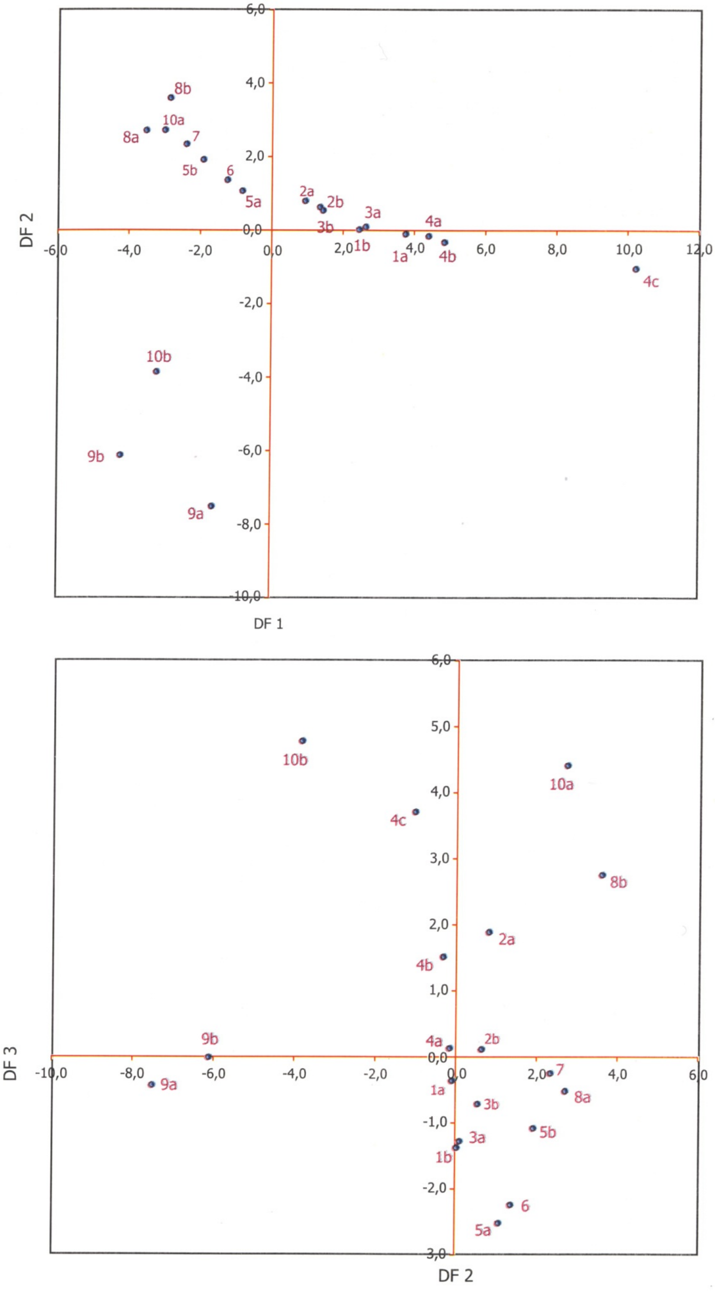

Fig.8.: Models of the relationship of the relief subtypes and discriminant functions 1, 2 and 3
Sl.8.: Modeli odnosa podtipova reljefa i 1., 2. i 3. diskriminantne funkcije

inclination, slope length and strength coefficient. The negative side of the axis of the discriminant function 2 is marked by the increase of the length and relative height index, exposition and ecological depth index, and by the value decrease of the surface regularitiy, relative height, inclination, length, average height and strength coefficient. In that way, the quoted types are clearly singled out by the positive characteristics of the variable combinations on both discriminant functions.

A similar trend can be noticed from the position of these groups, which is determined by the discriminant functions 2 and 3.

Contrary to the types 4, 3 and 1, the types 8, 10, 7 and 5 are determinated by the variable combinations pointing to an increased instability and greater risk of the slope processes, especially of slope-wash, gullying and rock-fall (with regard to the higher values of the strength coefficient). The position of these groups is determined by the discriminant function 1 negative sign and by the positive sign of the discriminant function 2, which is quite opposite from the position of the types 1, 3 and 4. Expressed by the variable features, it means the increase of the average height, inclination relative height, slope length and strength coefficient, and, on the other hand, the decrease of the length and relative height index, and of the expositions and ecological depth index. The similar goes for the position in relation to the discriminant functions 2 and 3.

The remaining three types, 2, 6 i 9, according to their position, find themselves somewhere between these two extremities, i. e. they have neither markedly positive nor negative features. This is indicated by appearance of the lessening of the variable combination positive character of a certain discriminant function by variable combinations of negative character of other discriminant functions. So, in the case of the groups 2, 6 and 9, the positive character of the discriminant function 1 overlaps with the negative character of the discriminant function 2, and, partly, with the negative character of the discriminant function 3.

Besides the position of the main relief types, it is sometimes necessary to know the position of the subtypes, which will be of particular importance in the later relief evaluation. For this reason, it is necessary to make up the models of the relations between the relief subtypes and discriminant functions, on which we will be able to recognize the subtype positions in relation to the variable combinations included in discriminant functions (Fig.8.).

RELIEF TYPES OF NORTH-WESTERN CROATIA

The results of the cluster and discriminant analyses, i. e. the absolute values of the centroid cluster groups and subgroups (Tabl. 1.) and centroid positions in the mathematical three-dimensional space defined by the discriminant function

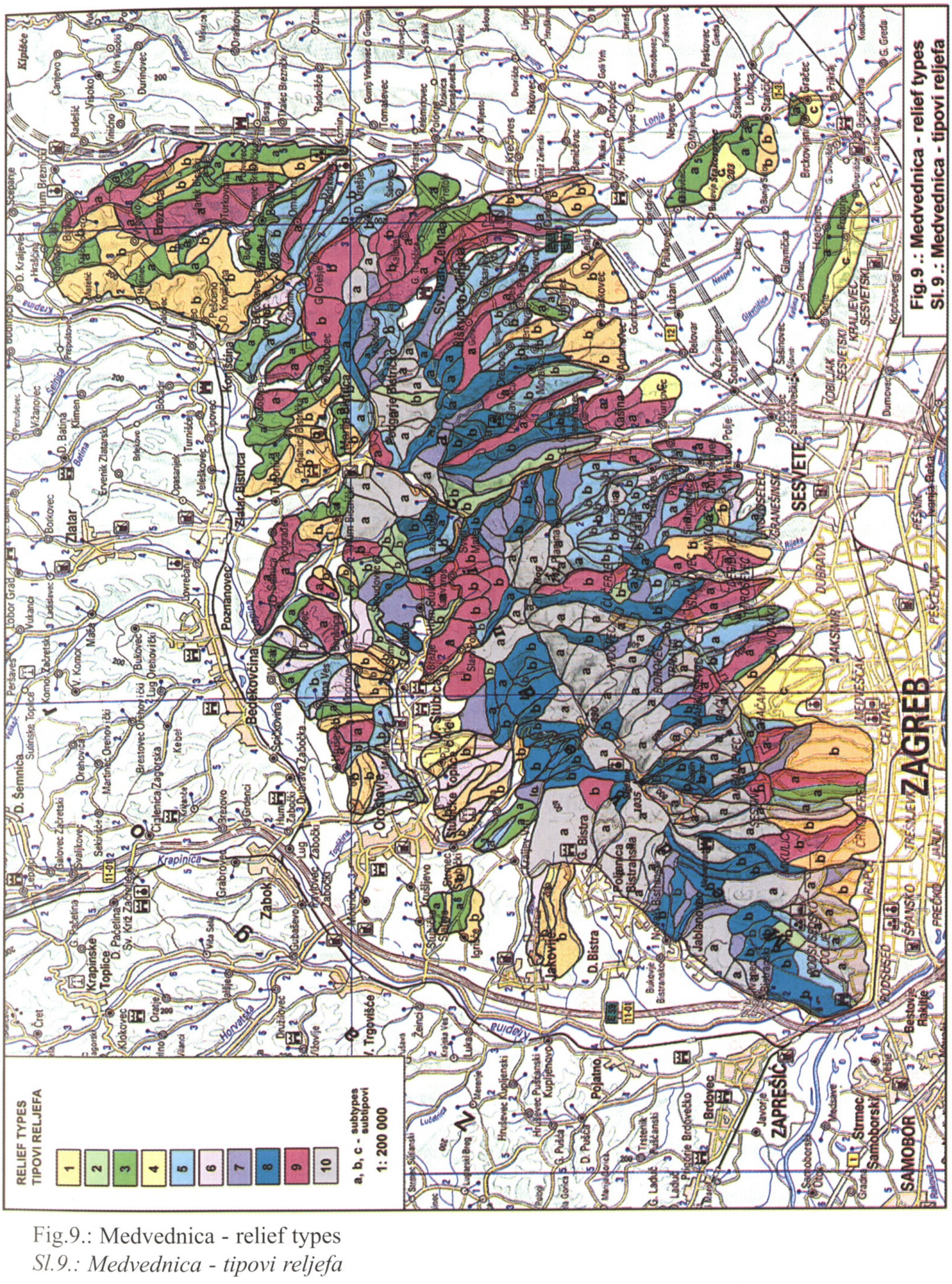

Fig.9.: Medvednica - relief types
Sl.9.: Medvednica - tipovi reljefa

features, have served as criteria of the spatial isolating of the relief types and subtypes.

The following relief types and subtypes were singled out:

Type 1 – a slightly dissected hilly relief of the lower height above sea-level,of more gentle slopes exposed to the humid air masses, of great ecological depth of the soil; formed on the softer sediments. This type has 2 subtypes.

Type 2 – a moderately dissected hilly relief of more gentle slopes and average ecological depth of the soil; formed in the rocks. Type has 2 subtypes.

Type 3 – a slightly dissected hilly relief of a lower height above sea-level, of more gentle slopes, mainly not exposed to the humid air masses, and of a relatively large ecological depth of the soil; formed in the softer rocks. Type has 2 subtypes.

Type 4 – a slightly dissected hilly relief of a lower height above sea-level, of gentle slopes, of a great ecological depth of the soil; formed on the markedly soft sediments. Type has 3 subtypes.

Type 5 – a moderately dissected hilly relief of more prominent inclinations, exposed to the humid air masses, with the average ecological depth of the soil; formed in the soft rocks. Type has 2 subtypes.

Type 6 – a moderately dissected hilly relief of more prominent inclinations, mainly protected from the humid air masses, with a relatively large ecological depth of the soil; formed in the soft rocks. Type has no subtypes.

Type 7 – a moderately dissected hilly relief of prominent inclinations, protected from the direct activity of the humid air masses, with the average ecological depth of the soil; formed in the harder rocks. Type has no subtypes.

Type 8 – a markedly dissected hilly and mountainous relief of a larger height above sea-level, of prominent inclinations, with a markedly small ecological depth of the soil; formed on the prominently hard rocks. Type has 2 sybtipes.

Type 9 – a moderately dissected hilly relief of markedly irregular slopes, with the average ecological depth of the soil; formed on the softer or medium-strengthed rocks. Type has 2 subtypes.

Type 10 – a markedly dissected hilly and mountainous relief of a larger height above sea-level, of to a large extent irregular slopes with prominent inclination and length, with smaller ecological depth of the soil; formed on the hard rocks. Type has 2 subtypes.

On the basis of the isolated relief types and subtypes, i. e. of belonging of every single sample to a determined type or subtype, it is possible to work out the corresponding typological relief maps. An example of typological relief map based at multivariate criteria is shown at Fig. 9 (Medvednica mountain).

CONCLUSION

On the basis of the multivariate criteria analysis, by application of the cluster techniques and discriminant analysis, we have performed a relief classification and typology, as well as the prognostic models of the slope processes risk based on the relations between the relief types and discriminant functions defined by the quantitative variable combinations. Such an approach enabled determination of the variability cause of the conditions on the slopes on the basis of the morphological, pedological and lithological variable combinations which indicate character, volume and intensity of the slope processes.

The approach to the relief classification and typology according to the multivariate analysis criteria, is the basis of more exact estimate of the recent condition of the relief dynamic stability, of the risk prognosis of the possible future balance disturbance, but also of the evaluation from the mentioned aspects, which is of great practical importance for almost all fields of human activity. The application of the typology based on the multivariate criteria is supported by its sinthetic character, accessibility of information about individual influences of the exogenic morphological processes expressed by particular variables, and by taking into account the ecological aspect, considering the fact that, besides the quantitative geomorphological variables, the soil and lithological base characteristics are also included in the analysis.

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Sažetak

MULTIVARIJANTNI PRISTUP KLASIFIKACIJI I TIPOLOGIJI RELJEFA - PRIMJER SJEVEROZAPADNE HRVATSKE

SANJA LOZIĆ

Osnovno polazište istraživanja temelji se na pretpostavci o modificirajućem utjecaju reljefa na djelovanje egzogenih geomorfoloških procesa, koji je izražen u tolikoj mjeri da njegovi kvantitativni parametri, zajedno s temeljnim pedološkim i litološkim značajkama, mogu biti značajni procjenitelji rizika od derazijskih procesa. U skladu s navedenom pretpostavkom, kvantificirani su temeljni parametri denudacijsko-tektonskog i denudacijsko-akumulacijskog reljefa Sjeverozapadne Hrvatske. Nakon toga testirana je sposobnost navedenih kvantitativnih varijabli da zajedno s pedološkim i litološkim parametrima objasne prostornu varijabilnost različitih tipova reljefa na istraživanom području.

Osnovno polazište analize čine tri grupe kriterija (varijabli): a) morfometrijski (varijable srednje visine, relativne visine, dužine padina, indeksa dužine i relativne visine, nagiba i regularnosti površine), b) geološki (varijabla koeficijent čvrstoće stijenskih masa) i c) pedološki kriterij (varijabla ekološka dubina tla izražena kao prosječna dubina tla određene kartografske jedinice tla, prema Namjenskoj pedološkoj karti RH, 1 : 300 000). Geološki i pedološki kriterij uključeni su u analizu radi šireg i kompleksnijeg uvida u međuovisnost reljefa, tla i geološke podloge.

Primjenom multivarijantne cluster tehnike, istraživano područje Sjeverozapadne Hrvatske (4495 uzoraka) klasificirano je prema zajedničkim osobinama 9 varijabli. Hijerarhijskim grupiranjem izdvojeno je 10 temeljnih cluster grupa. Na nižem stupnju grupiranja, bližem inicijalnom stadiju postupka, uočeno je da clusteri 1, 2, 3, 5, 8, 9 i 10 imaju po dvije podgrupe, cluster 4 tri podgrupe, dok su clusteri 6 i 7 homogeni, tj. nemaju podgrupa. Izdvojene grupe i podgrupe temelj su izdvajanju tipova i podtipova reljefa. Problem utvrđivanja vjerodostojnosti prethodno izdvojenih cluster grupa koje reprezentiraju tipove reljefa Sjeverozapadne Hrvatske riješen je primjenom diskriminantne analize, čije je osnovno polazište matrica od 260 inicijalnih cluster-grupa kodirana prema pripadnosti članova glavnim grupama i podgrupama.

Vrijednosti inicijalnih cluster grupa na svakoj varijabli testirane su jednadžbom analize varijance, koja je primjenjena pri testiranju nul - hipoteze da su centroidi (aritmetičke sredine) cluster grupa međusobno jednaki. Analiza je pokazala da su razlike između 10 glavnih clustera veće nego razlike unutar svakog pojedinačnog clustera čime je uspješnost cluster klasifikacije.

Diskriminacijskom analizom, na temelju Wilk's *lambda* testa, potvrđeno da

postoji izrazita diskriminacijska snaga varijabli između grupa.

Pojedinačno testiranje varijabli s obzirom na statističku značajnost temeljeno je na parcijalnom Wilk's *lambda* testu, pomoću kojeg je određen pojedinačni udio svake varijable na diskriminaciju unutar grupa. Na razini modela u cjelini, utvrđen je dominantni utjecaj na diskriminaciju koji imaju varijable regularnosti površine, nagiba i ekspozicija, zatim indeksa dužine i relativne visine, relativne visine i litologije. Ako se pojedine varijable promatraju kao indikatori geomorfoloških procesa, može se ustvrditi da najvažnije uzroke diferencijacije pojedinih tipova reljefa na području Sjeverozapadne Hrvatske predstavljaju derazijski gravitacijski procesi čiji intenzitet direktno ovisi o regularnosti površine, nagibu padina i dužini padina. Budući da su donekle značajne i varijable ekološka dubina i ekspozicije, može se reći da su značajke tipova reljefa u velikoj mjeri ovisne i o pedološkom sastavu (povratna veza) i djelovanju klimatskih elemenata. Najmanji udio u diskriminaciji imaju varijable srednja visina i litologija.

Nakon ove faze, izvršeno je ekstrahiranje diskriminantnih funkcija. Kanoničkom korelacijom izdvojeno je 9 diskriminantnih funkcija, za koje su Hi - kvadrat testom utvrđeni stupnjevi značajnosti. Od 9 izdvojenih funkcija najznačajnije su prve tri (0, 1 i 2), jer objašnjavaju najveći dio varijance sustava (80.33 %).

Prve dvije diskriminantne funkcije su u najvećoj mjeri opterećene varijablama regularnosti površine, nagiba i dužine, s tim da je za prvu funkciju značajno i opterećenje varijablama indeksa dužine i relativne visine i ekološke dubine, a za drugu varijablama indeksa ekspozicija i indeksa dužine i relativne visine. Treća diskriminantna funkcija najviše je opterećena varijablama relativne visine i nagiba a donekle je značajno opterećenje varijablama dužine i srednje visine.

Na temelju analize standardiziranih koeficijenata diskriminantnih funkcija uočljivo je da najznačajniju ulogu u diferencijaciji tipova reljefa Sjeverozapadne Hrvatske imaju varijable regularnosti površine, nagiba padina i dužine. Nešto manji značaj imaju varijable srednje visine, relativne visine, indeksa dužine i relativne visine i ekološke dubine tla, dok je unutar ukupnog trodimenzionalnog prostora definiranog s tri diskriminacijske funkcije utjecaj varijabli srednja visina i litologija u diskriminaciji najmanji. Budući da je Wilk's *lambda* testom utvrđeno da sve varijable značajno sudjeluju u diskriminaciji, prilikom interpretacije funkcija uzet je u obzir doprinos svake varijable.

Povezivanjem kombinacija varijabli na pojedinim diskriminantnim funkcijama s odgovarajućim derazijskim procesima, utvrđeno je da diskriminantna funkcija 1 ukazuje na uglavnom povoljne uvjete na padinama, s mogućnošću ekscesivne pojave derazijskih procesa puženja i klizenja. Generalno, padine diskriminirane ovom funkcijom u stanju su ravnoteže i teže daljnjem povećanju stabilnosti. Diskriminantna funkcija 2 ukazuje na drugačije uvjete, a to znači nizak stupanj ravnoteže, uz veliku vjerojatnost pojave gravitacijskih procesa, spiranja i jaruženja. Kliženja i puženja zemljišta nisu izražena u većoj mjeri s obzirom na veću čvrstoću stijena. Treća diskriminantna funkcija ukazuje na relativno nepovoljne uvjete, jer iako se zamjećuje pad nagiba, porast indeksa dužine i relativne visine i indeksa ekspozicija, istovremeno je prisutan porast srednje i relativne visine, dužine padina i neregularnosti površine, što bitno umanjuje stabilnost padina diskriminiranih u većoj mjeri ovom funkcijom. S obzirom na pad vrijednosti koeficijenta čvrstoće, postoji opasnost intenziviranja destrukcijskih procesa kliženja i puženja. Ravnoteža je umanjena ali ne u tolikoj mjeri kao na padinama diskriminiranim drugom funkcijom.

Radi egzaktnije identifikacije reljefnih sustava sličnih značajki konstruirani su modeli odnosa tipova i podtipova reljefa s kombinacijama varijabli izraženih diskriminacijskim funkcijama, na temelju kojih je provedena tipologija. Treba naglasiti da svaka kombinacija varijabli upućuje na različitu relativnu važnost određenih morfoloških procesa u oblikovanju pojedinih tipova reljefa i upućuje na rizik od određenih derazijskih procesa. Izdvojeno je 10 temeljnih tipova i 17 podtipova reljefa što je prikazano na odgovarajućim tipološkim kartama u mjerilu 1: 200 000.

Podaci dobiveni primijenjeno-geomorfološkom tipologijom kvantitativnih geomorfoloških, pedoloških i litoloških pokazatelja mogu biti vrlo korisni pri prostornom i urbanističkom planiranju lokacije, razvoja i rekonstrukcije urbanih i agrarnih prostora, radi informacija o recentnom stanju dinamičke stabilnosti reljefa ali i prognoze rizika od eventualnog narušavanja ravnoteže u budućnosti.

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