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Characteristics of the Relief System within the Istrian Hummocy Hills – Factor Approach

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Geomorphological system of the Istrian hummocky hills has been explored by means of the »r« type factor analysis. Four fundamental factors have been extracted. They explain 69,93% of total system variability, and together with the fifth unique factor they account. Analysis of the morphometric maps with initial variables shows that the extreme values of the vallys network parameters are connected with the upstream catchment area of the main third order valleys, wich have been drained twards the SW part of the Ćepić polje basin. By interpretation of isofactor maps it may be concluded that unbalance within single geomorphological subsystems was caused by sudden fluctuation of sea level during the late Würm and Holocene, by the recent subsidence of the Ćepić polje basin bottom and finally by the left horizontal strike slip and a dip slip shift component of Pazin fault.

Key Words: Istrian hills, factor analysis – »R« type, relief system, tectonics

Značajke reljefnog sustava Istarskog pobrda – faktorski pristup.

Reljefni sustav Istarskog pobrda istražen je postupkom faktorske obrade na »r« način. Izdvojena su četiri temeljna faktora koji objašnjavaju 69,93% ukupne varijabilnosti sustava a s petim unikvitetnim, 76,81% varijabilnosti ukupnog sustava. Obrada morfometrijskih karata izvornih varijabli ukazala je da su ekstremne vrijednosti parametara dolinske mreže povezane s izvorišnim dijelovima porječja glavnih dolina trećeg reda koje se odvodnjavaju prema JZ dijelu zavale Ćepićkog polja. Tumačenjem izofaktorskih karata zaključuje se da je neravnoteža unutar izdvojenih geomorfoloških podsustava (faktora) uzrokovana naglim oscilacijama razine mora krajem virma i u holocenu, recentnim spuštanjem dna zavale Ćepičkog polja, te lijevom i normalnom komponentom pomaka duž Pazinskog rasjeda.

Ključne riječi: Istarsko pobrđe, faktorska analiza na »r« način, reljefni sustav, tektonika.

INTRODUCTION

Research on correlations between geomorphological processes and shapes, i. e. how passive and active factors of morphogenesis affect the present relief forms is nowadays recognized as one of the basic principles in geomorphological research. Interaction of relief elements within the geomorphological system has been viewed

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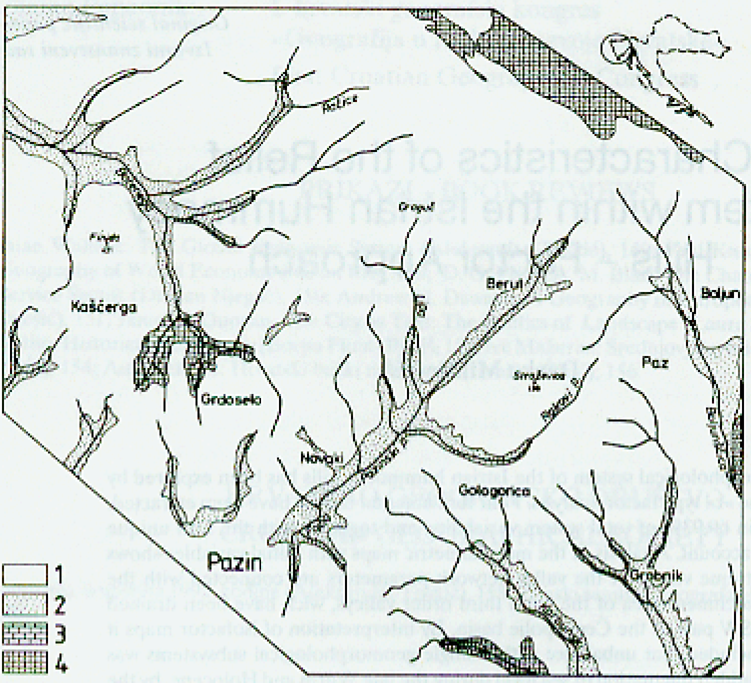

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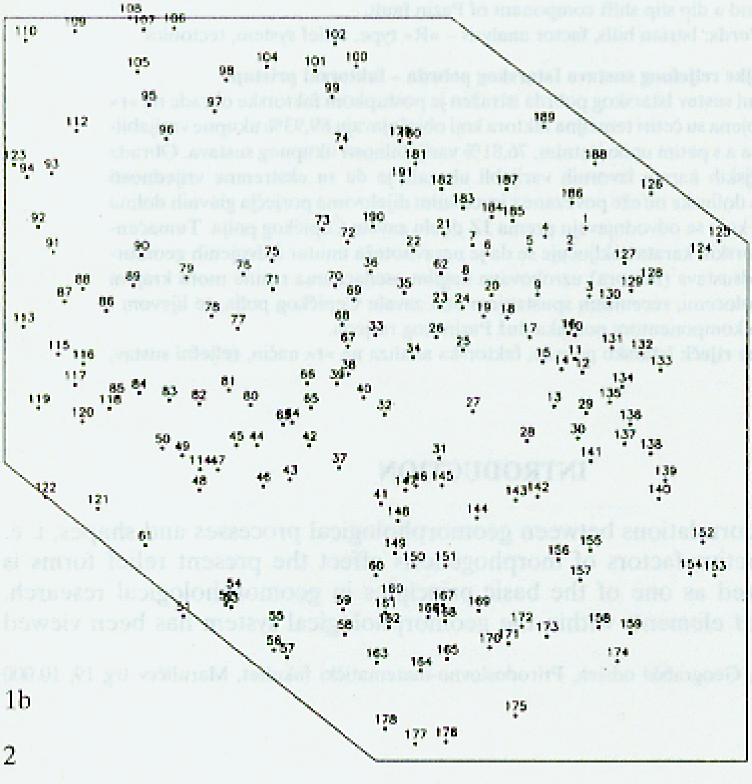

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Fig. 1. a – Geomorphological setting and the geological composition of the area under consideration: 1. flysh, 2. Quaternary sands and silts, 3. Paleogene limestones, 4. Creataceous limestones; b – Position of the samples (The exact position of the samples correspond to the confluence of two valleys of second order within the denudational surface of the third order valley.

Sl. 1. a – Geomorfološki položaj i geološki sastav istraživanog područja: 1. fliš, 2. Kvartarni pijesci, 3. Paleogenski vapnenci, 4. Kredni vapnenci; b – Položaj (točna lokacija uzoraka odgovara lokaciji sutoka dviju dolina drugog reda unutar denudacijske površine doline trećeg reda).

through correlations, by observation of simultaneous changes in relief parameters (variables), among which no mutual »cause-effect« relationship necessarily exists, however, they can be aroused by some other (latent) cause (factor) hidden to the immediate observation. By means of the factor analysis »R« type, it is possible to single out from a large number of correlations of selected variables (morphometric relief parameters) a small number of fundamental variables (factors) explaining such correlations.

This factor analysis of the Istrian hummocy hills aims to find out the key factors, fundamental for such correlation of variables, to find out the nature of correlation between certain variables with singled out factors (factor structure) and to interpret geomorphological significance of the obtained factor structure.

Since the factor structure reflects mutual influence of passive (lithology and geological structure) and active (tectonics and climate) morphogenetic factors, it will be easier to apply and geomorphologically expound factor model of the Istrian hummocy hills, from the following reasons:

- Impervious flysh deposits, in which Istrian hills have developed, greatly increase flow off component and thus decrease precipitation infiltration coefficient. Consequently, a dense network of brook valleys, gulleys and rills will be shaped. Such dense network enables measuring and quantitative expression of numerous (statistically important) relief parameters (variables).
- Valley network, shaped on the low resistant flysh of the Istrian hills gets, due to the dynamics of its development (alometric growth) within geologic time measurement, very quickly adjusted to the existing balance and unbalance between passive and active relief development factors; thus, concerning the given factor structure, diagnosis, based on geomorphological situation and recongnition of causes standing behind the changes in valley network elements is made possible.
- The area under research (Fig. 1a) is completely composed of flysh deposits (except for the small areas of Cretaceous and Paleogene limestones in which a part of steep incised valley of the brook Grdoselo has been shaped), of similar or identical physically-mechanical properties, by which introduction of lithological variables into a factor model has been avoided (Peh, 1994) and such simplified explanation, too.
- On basis of our present knowledge concerning geological structure and tectonics of the Istrian hills (Šikić et al 1969, Šikić et al 1972, Šikić & Polšak 1973, Šikić & Pleničar 1975, Magdalenić 1972), coinciding with the Pazin basin unit (Šikić & Polšak, 1973), no remarkable structural changes have been noted, except on its far north-eastern part, along the contact with Ćićarija hills (Mihljević & Prelogović, 1992). Thus, influence of tectonics within the Istrian hills (excluding the surrounding tectonically active area of Učka and Ćićarija) is reduced in geomorphological interpretation of factor structure.

Factor processing »R« type

The relief factor analysis has been applied since 1970 (Dornkamp & King, 1971) with many different procedures – research types of factor analysis. Since many authors have discussed modalities of factor processing »R« type (Blackith & Reyment, 1971;

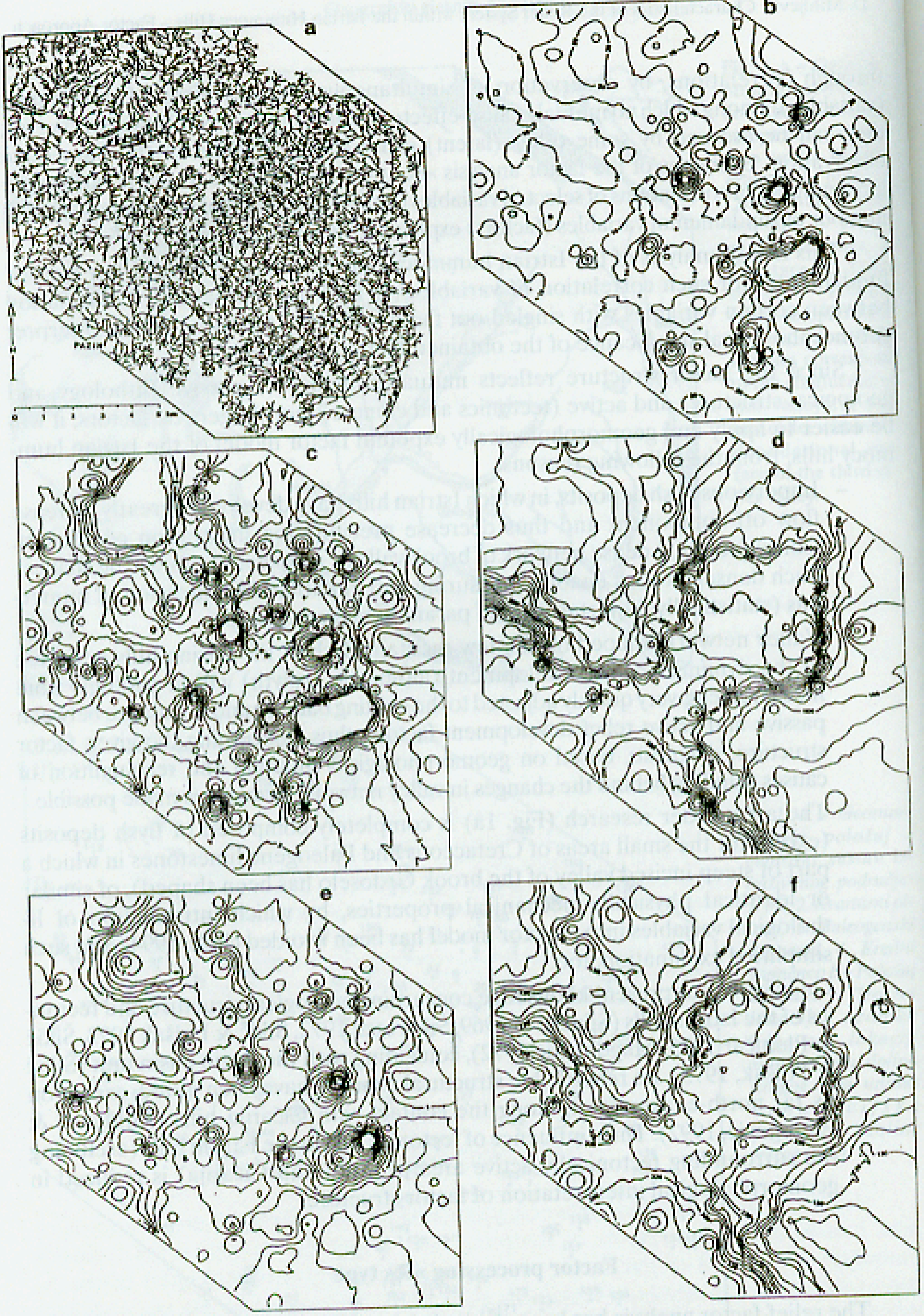
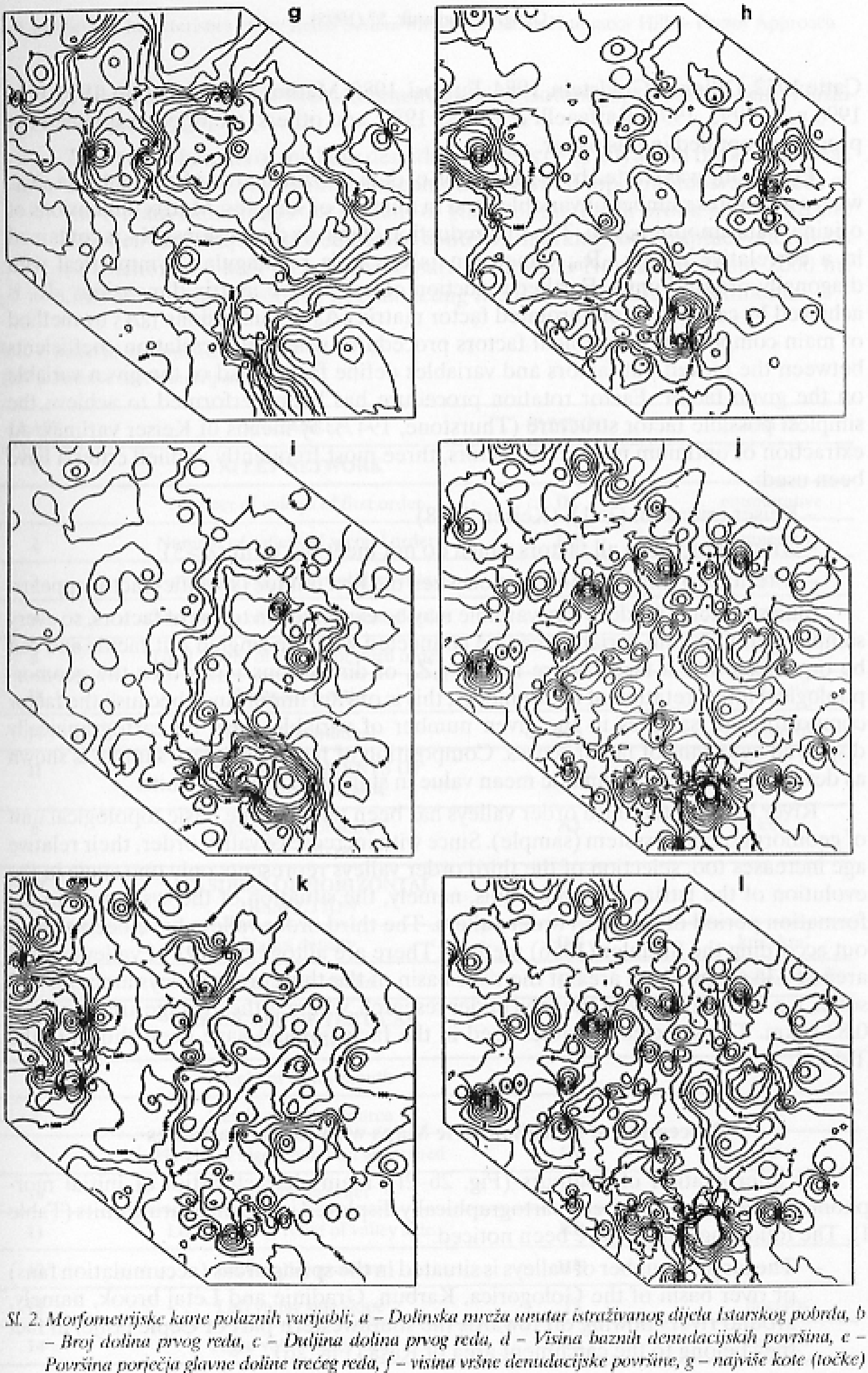


Fig. 2. Morphometric maps of initial variables; a – valleys network within the investigated area of the Istrian hills, b – Number of first order valleys, c – Lenght of the first order valleys, d – Elevation of the basic denudational surfaces, e – Area of the main third order valleys, f – Elevation of the summit denudational surfaces, g – The highest point of the watershed, h – Gradient of the main valleys, i – Valleys frequency, j – valleys density, k – Amount of incision of the main valley, l – Bifurcation ratio.



Sl. 2. Morfometrijske karte polaznih varijabli; a – Dolinska mreža unutar istraživanog dijela Istarskog pobrđa, b – Broj dolina prvog reda, c – Duljina dolina prvog reda, d – Visina baznih denudacijskih površina, e – Površina porječja glavne doline trećeg reda, f – visina vršne denudacijske površine, g – najviše kote (točke) razvodnica, h – gradijenti glavne doline, i – frekvencija dolina, j – gustoća dolina, k – dubina usječenosti glavne doline, l – koeficijenti bifurkacije.

Catte 1952, Dillon & Goldstein, 1984; Fulgosi, 1988; Mather & Doornkamp, 1970; Peh, 1990 a, b, 1992, 1994; Raffaaelli & Mutić, 1982; and others) we briefly explained the procedure applied in this paper.

Processing was started by organization of data into the matrix of original data ${}_{n}X_{m}$, where n denotes number of variables and m number of samples. Matrix dimensions of original data amount ${}_{18}X_{191}$. The first reduction of matrix dimensions ${}_{n}X_{m}$ is contained in a correlative matrix ${}_{n}R_{n}$, dimension ${}_{18}R_{18}$. It is rectangular, symmetrical with diagonally ordered units. Further reduction of correlative matrix dimensions ${}_{n}R_{n}$ is achieved by calculation of unrotated factor matrix ${}_{n}A_{q}$ of dimensions ${}_{18}A_{5}$ by method of main components (centroidal factors procedure) whereby correlation coefficients between the picked out factors and variables define factor load of the given variable on the given factor. Factor rotation procedure has been performed to achieve the simplest possible factor structure (Thurstone, 1947), by means of Keiser varimax. At extraction of optimum number of factors, three most frequently applied criteria have been used:

- Keiser criterium (λ>1), (Keiser, 1958)
- criterium to drop all factors which do not meet the term (λ>5)
- criterium to stop factor extraction when the first unique (specific) factor appears.

Since by factor model every variable may be expressed in terms of factors, so every sample within certain variables can be connected with the singled out factor and can be organized into a factor score matrix ${}_{m}Z_{q}$ of dimensions ${}_{191}Z_{5}$. For the geomorphological interpretation of factor model, this is of vital importance because the factor composition of samples in the given number of variables may be cartographically displayed by means of factor scores. Composition of factors in every sample is shown as deviation from the arithmetic mean value in standard deviation units.

River basin of the third order valleys has been taken as the basic topological unit of geomorphological system (sample). Since with increase of valley order, their relative age increases too, selection of the third order valleys represents only one stage in the evolution of the Istrian hummocy hills, namely, the situation of the system up to the formation period of the third order valleys. The third order valleys have been singled out according the Strahler (1956) method. There are alltogether 191 of valleys on the area of 336 sqkm. Total area of the river basin of the third order valleys amounts 158 sqkm, i. e. it covers 47 % of the area under research, whereas the average area amounts 0.83 sqkm. The selected variables used in the factor model have been shown in the Table I.

Processing of Morphometric Maps with Initial Variables

By interpolation of contours (Fig. 2b–2l), main characteristics of initial morphometric variables have been cartographically displayed in the measuring units (Table I). The following details have been noticed:

- The largest number of valleys is situated in the spring areas (accumulation fans) of river basin of the Gologorica, Karbun, Gradinje and Letaj brook, namely, around rivers flowing off towards the southwestern part of Čepić polje, in fact they belong to the catchment area of Raša (Fig. 2b).

- Valleys are longer in the catchment area of Botonega, of Rakov and Vlaški brook (Fig. 2c).
- The largest heights of the base denudation areas (Fig. 2d) are in the spring areas of Pazin brook. Concentration of contours follows 3 topographic watersheds of the 3 main catchments: catchment of Raša, of the Pazin brook and of Mirna. The bell-like shape of concentrated contours, marking topographic watersheds of catchments, with its narrowest part at Pazinski Novaki (at about 2000 m) indicates to the possibility of connecting the Raša and Mirna catchments.

Tab. 1. Initial morphometric variables.
Tab. 1. Polazne morfometrijske varijable.

CLASS	VARIABLES	SYMBOL	UNITS
I	**VALLEY NETWORK**		
1	Number of valleys of first order	D1	enumerative
2	Number of valleys of second order	D2	enumerative
3	Total lenght of valleys of first order	L1	km
4	Total lenght of valleys of second order	L2	km
5	Total lenght of valleys of third order	L3	km
18	Bifurcation ratio	KB	enumerative
17	Bifurcation number	BB	enumerative
II	**GEOMETRY ELEMENTS OF VALLEY NETWORK**		
6	Basen area of third order valleys	A3	km^2
III	**MEASURES OF HORIZONTAL DISSECTION**		
16	Vallys density	DG	km / km^2
15	Frekvencija dolina	FD	$number / km^2$
IV	**MEASURES OF VERTICAL DISSECTION**		
7	Height of valley mouth	H2	m
8	Height of valley source	H1	m
9	Height of higest point on watershed	H0	m
10	Total basin relief	UR	m
11	Local relative relief of valley side	RR	m
12	Main valley gradient	HG	m
13	Left valley side slope	T1	degrees
14	Right valley side slope	T2	degrees

- The largest river basin areas of the third order valleys are in the catchment area of Letajski brook and Botonega (Fig. 2e), and are linked with the present possibilities of the river basin's alometric growth.
- The highest watershed elevations are on the watershed of the Pazin brook and of the Mirna river (Fig. 2g).
- The largest valley gradients (Fig. 2h) are in the river basins of the valleys, drained towards Ćepić polje i. e. towards the catchment area of Raša basin. The significant gradient increase of the Grdoselo brook valleys developed as a result of its incision into limestone deposits.
- Valleys frequency (Fig. 2i) and drainage density (Fig. 2j) are also connected with the valleys drained towards the Raša canyon.
- Incision depth of the main valley (Fig. 2k) is the biggest along Grdoselo brook, as a result of the incision into the limestone basement and along the valleys in the Raša catchment.
- Finally, the largest bifurcation ratio (Fig. 2l), indicating transition of valleys from the lower to the higher order, is registered in the river basins of the valleys drained towards Ćepić polje, i. e. towards the Raša canyon.

By processing of the initial variables, shown by appropriate morphometric maps (Fig. 2b–2l), before their inclusion in factor analysis, it may be concluded that extreeme values of all variables (relief parameters of valley network) are primarily connected with river basins of main valleys (third order) drained towards the southwestern part of Ćepić polje, i. e. they belong to the river Raša catchment.

Interpretation of Factor Structure and Discussion of Results

Rotated factor matrix (Table II) represents the final solution of the factor model. Besides analytic we also have a graphic solution of the factor model by projection of variables into bipolar coordinate system whereof axes are orthogonal factor pairs (Fig. 3a–3d).

Tab. 2. Rotated factor matrix – final solution of the factor model of the Istrian hills.
Tab. 2. Rotirana faktorska matirca – konačno rješenje faktorskog modela Istarskog pobrda.

FAKTORI VARIJABLE	F1	F2	F3	F4	F5	h^2	ε
D1	**0.91**	-0.03	0.2	0.04	0.23	*0.92*	*0.08*
D2	**0.92**	0.01	0.13	0.04	-0.23	*0.92*	*0.08*
L1	**0.95**	-0.05	-0.12	-0.01	0.15	*0.94*	*0.06*
L2	**0.75**	-0.06	-0.11	-0.13	0.13	*0.61*	*0.39*
L3	**0.89**	0	-0.12	0.04	0.05	*0.81*	*0.19*
A3	**0.89**	-0.05	-0.36	-0.03	0.1	*0.94*	*0.06*
H2	0.03	**0.94**	0.14	-0.17	-0.09	*0.94*	*0.06*

FAKTORI **VARIJABLE**	**F1**	**F2**	**F3**	**F4**	**F5**	**h^2**	**ε**
H1	-0.15	**0.87**	0.22	-0.33	-0.16	***0.96***	***0.04***
H0	0.1	**0.86**	-0.24	-0.01	0.2	***0.85***	***0.15***
UR	0.27	*-0.4*	*-0.48*	*0.44*	*0.39*	***0.81***	***0.19***
RR	*0.41*	-0.17	-0.27	**0.55**	0.1	***0.58***	***0.42***
HG	-0.28	0.06	0.01	**0.6**	0.12	***0.46***	***0.54***
T1	-0.01	-0.09	0.1	**0.77**	-0.07	***0.62***	***0.38***
T2	0.06	-0.04	0.07	**0.77**	-0.04	***0.60***	***0.40***
FD	-0.16	-0.02	**0.92**	0.12	0.06	***0.89***	***0.11***
DG	0	-0.06	**0.85**	0	0.11	***0.74***	***0.26***
BB	0.11	**-0.52**	0.13	-0.22	0.13	***0.36***	***0.64***
KB	0.2	-0.1	0.17	0.01	**0.89**	***0.87***	***0.13***
λ	***5.16***	***2.88***	***2.29***	***2.27***	***1.24***	**13.82**	**4.18**
λ%	***28.66***	***15.98***	***12.70***	***12.59***	***6.88***		
λ% cum	***28.66***	***44.64***	***57.34***	***69.93***	***76.81***		

In the rotated factor matrix (Table II), factor loads of variables on 5 singled out factors have been shown, i. e. correlation coefficients of variables with factors. Factors are mutually orthogonal (cos 90 = 0) so they do not show interrelations.

Factor loads of variables with high coefficient correlation of the given factor are marked by boldface numbers. These are so called diagnostic variables and they differ from italicised secondary variables, the factor loads of which range between 0.39 and 0.49 while their influence is not neglected in geomorphological interpretation, due to the still comparatively high factor loads.

The key structure indicators of the factor model may be considered, Peh (1989, 1994) as follows:

- variance
- polarity or factor load sign of diagnostic and secondary variables
- character of diagnostic and secondary variables serving as identification basis, namely, for determination of geomorphological factor significance
- structural identification (name) of factors
- connection of certain variables with other factors

Since the area of samples (Fig. 1a and 1b) is located on almost completely homogenous lithological base (Eocene flysh deposits), introduction of lithological variables into the factor model of the Istrian hummocy hills, has been avoided. Moreover, absence of lithologic variables due to the comparatively homogenous lithologic field structure offers possibility that certain manifestations of variables at the singled out factors might be interpreted as internal specific differences within the complex of flysh deposits in the sense of increased siltite or sandstone component within flysh deposits, which in return affect the manifestations of certain variables. On the other hand, since according to our present knowledge, the flysh deposits in the central part of Istrian hills have not been subjected to bigger recent tectonic movements, or at least not to those which could be recognized in the structural reshaping of layers, the possibility of lithofactor interpretation becomes even more important.

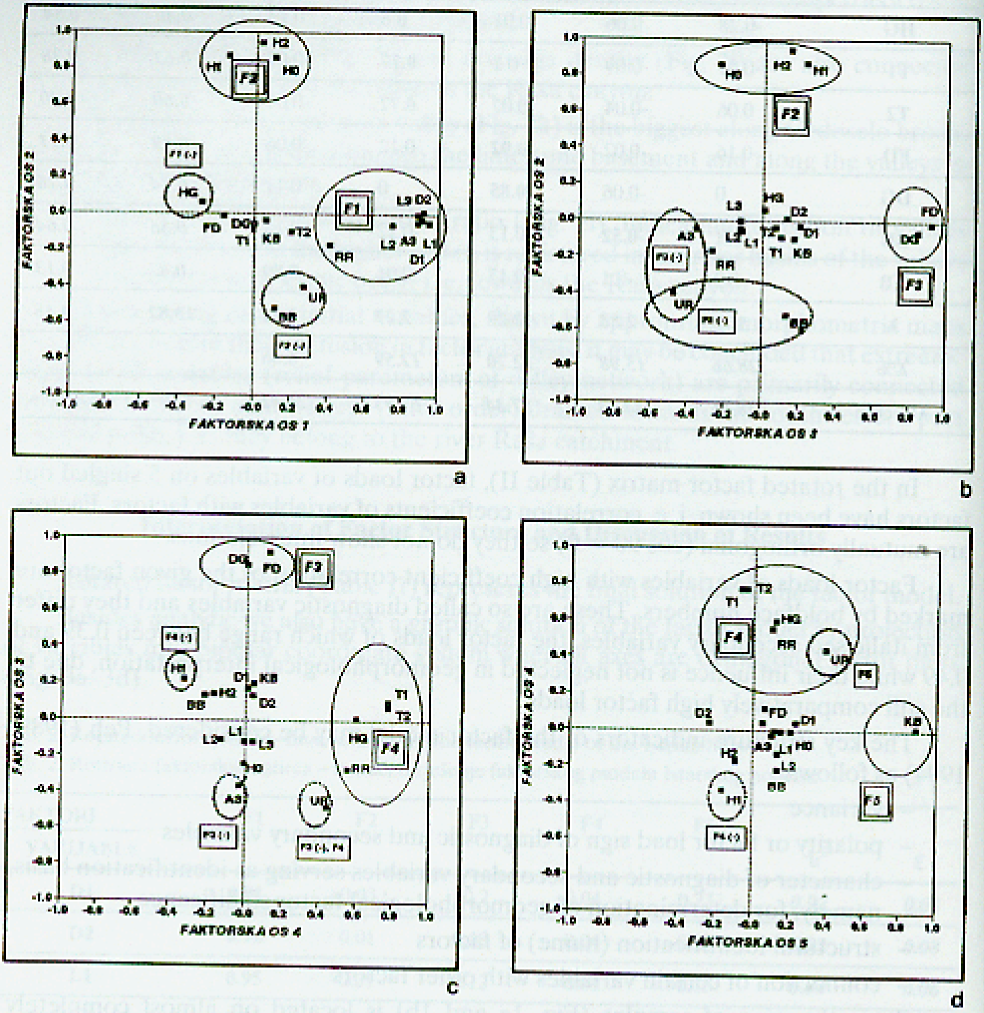


Fig. 3. Graphic solution of the factor model of the Istrian hills. Variables projection on: a – the first and the second factor axsis, b – the second and the third factor axsis, c – the third and the fourth factor axsis, d – the fourth and the fifth factor axsis.

Sl. 3. Grafičko rješenje faktorskog modela Istarskog pobrđa. Projekcije varijabli na: a – prvu i drugu faktorsku os; b – drugu i treću faktorsku os; c – treću i četvrtu faktorsku os; d – četvrtu i petu faktorsku os.

The First Factor F1. The first factor explains 28,66 % of the total variance within the system. It is positively monopolar, highly loaded by diagnostic variables D1, D2, L1, L2, L3 and A3; all of them representing elements of horizontal relief dissection. Quite important is also the load of secondary variable RR, indicating the correlation with diagnostic variables.

Regarding the geomorphological significance of diagnostic variables, this factor may be called: **the factor of horizontal relief dissection.** Figure 3a shows graphic solution of the model for the first two factor axes, explaining 44.64 % of system variability.

The Second Factor F2. The second factor accounts for 15.98 %, i. e. together with the first 44.64 of total variance within the system. It is bipolar with highly positive factor loads on variables H2, H1 and H0 and negative on the variable BB. It is obvious that the parameters of relief height (H2, H1 and H0) are inversely dependent to the confluence type of the main valley into the same or higher order valley; thus – the hypsometrically lower the main valley is, the confluence will be realized with the higher order valleys. From the secondary variables, the variable UR indicates comparatively high negative factor load, which means that in the highest relief zones larger values of vertical relief dissection appear.

Concerning the geomorphological significance of variables which on other factor achieve high factor loads, this factor may be recognized as the **denudation level factor.**

It is very interesting that geomorphological descriptor UR appears as the second bipolar variable with comparatively high factor loads (0.38–0.49) on all five singled out factors, which points to the fact that its behaviour has been affected by several different geomorphological and geological process, represented by the singled out factors.

The Third Factor F3. The third factor accounts for 12.70 %, and with the former two factors for 57.34 % of variability within the entire system. Concerning diagnostic descriptors, it is positively monopolar (FD and DG), showing bipolarity regarding secondary variables UR and A3. Since the variables FD and DG represent from geomorphological aspects outstanding parameters of valley density, their negative dependance on variables UR and A3 is understandable. It is possible to interpret this factor as the **valley density factor or denudation potential factor.**

Graphic solution of the factor model by projection of variables onto the third and fourth factor axis is displayed on Fig. 3b.

The Fourth Factor F4. The fourth factor explains a slightly smaller variability of the system (12.59 %) regarding the third factor, and together with the former three factors accounts for 69.93 % of total variance within the system. It is positively monopolar with high factor loads of diagnostic variables T1 and T2 and with somewhat lower variables HG and RR. From secondary variables, there is UR of positive sign.

Factor structure points to positive correlative connections between slope inclinations and dips as well as to incision of the main valley. In other words, the larger dip and incision of main valley is, the more abrupt its slopes are. Graphic solution of the factor model for the third and fourth factor axis is shown on Fig. 3c.

This factor may be identified as a **slope inclination factor** of the main valleys.

The Fifth Factor F5. The fifth factor accounts for 6.88 % of variance and together with previously singled out factors, accounts for 76.81 % of variability within the entire system.

This is unique factor with a positively polarized diagnostic variable KB and with a secondary variable UR. The graphic solution of the fourth and fifth factor axis is shown on Fig. 3d.

On Fig. 4A – 4D we displayed (by contours and isometrically) isofactor maps obtained by interpolation of factor »quantity« values in every sample (191), from the rotated factor scores matrix, expressed in standard deviation units.

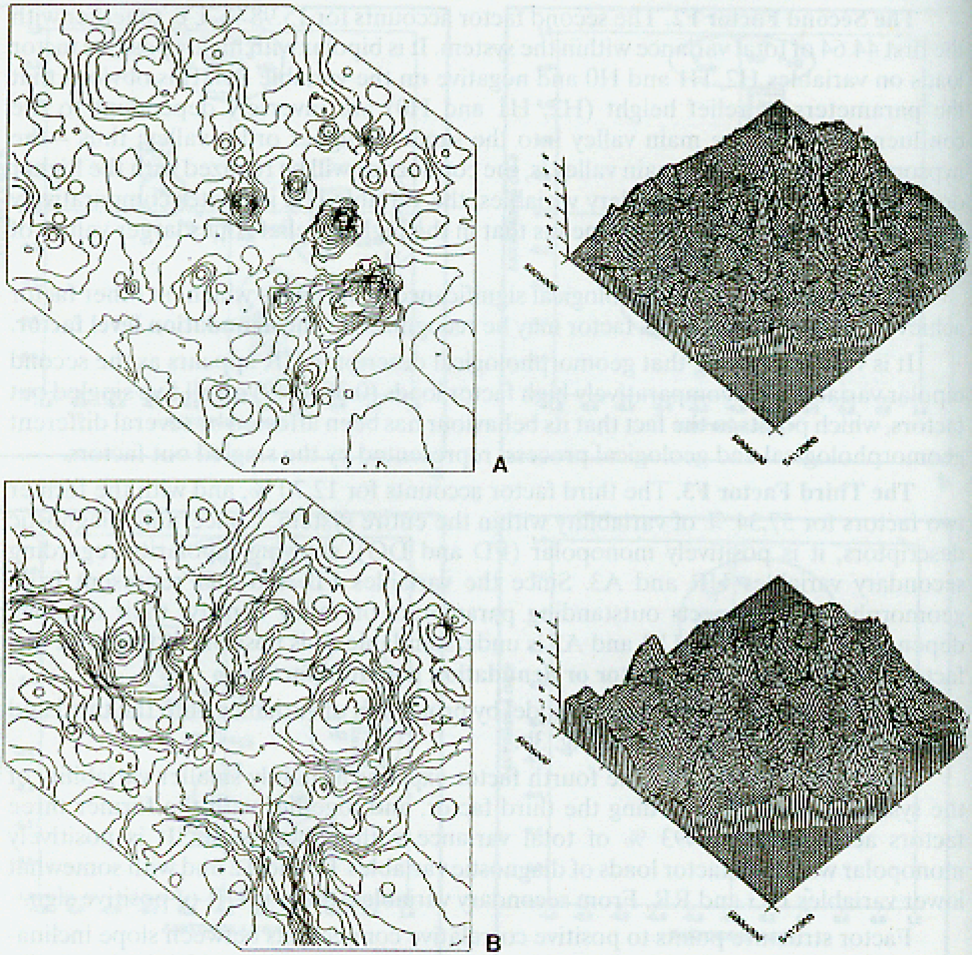
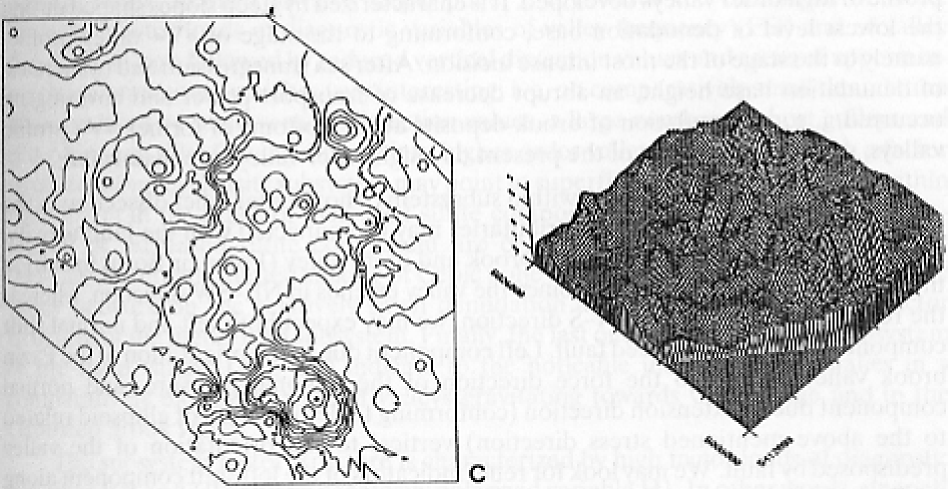


Fig. 4. Isofactor maps of the Istrian hills; A – Isofactor map of the subsystem of horizontal relief dissection, B – Isofactor map of the subsystem of denudational levels, C – Isofactor map of the subsystem of valleys density, D – Isofactor map of the subsystem of slope inclination.

Sl. 4. Izofaktorske karte Istarskog pobrđa; A – Izofaktorska karta podsustava horizontalne raščlanjenosti reljefa, B – Izofaktorska karta podsustava denudacijskih nivoa, C – Izofaktorska karta podsustava gustoće dolina, D – Izofaktorska karta podsustava nagiba padina.

Isofactor map of horizontal relief dissection (Fig. 4A) points to the greatly increased descriptor values of horizontal dissection (D1, D2, L1, L2, L3) in accumulation parts of Vlaški and Rakov brook and in valleys flowing from the north into the Pazin brook valley. All subsystem variables of horizontal relief dissection stand in mutual positive corrrelation (Table II, Fig. 3a) and are also positively correlated with the appertaining area of their development (A3), pointing to the fact that the development of valley network within the Istrian hummocy hills has been affected by allometric growth, that is to say, by extension of valley network according to the available area. Growth and development of the valley network occurs by constant (retrograde) shaping of low order valleys.



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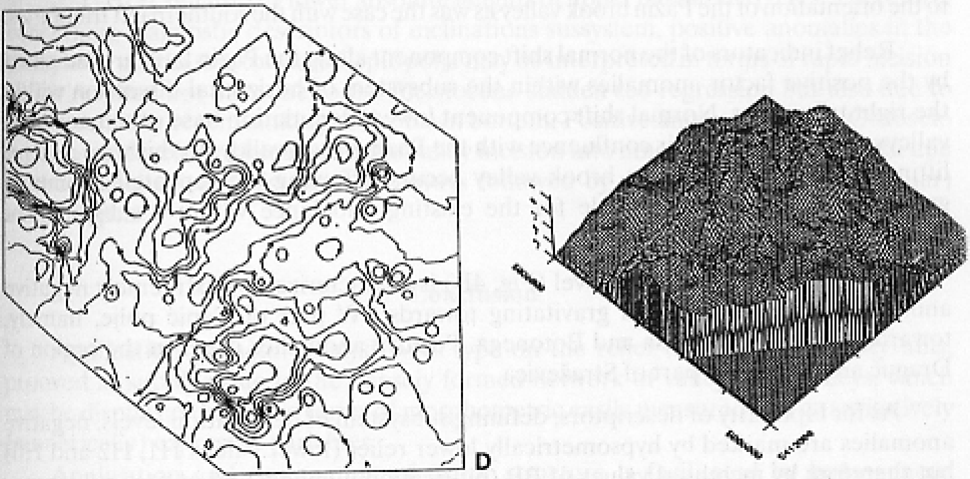

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The assumption of allometric growth is an increase of field area where valley network will be further developed. Aerial increase in concrete example may be spurred by relative lifting of central Istrian hills, i. e. by sinking of marginal area and/or by sudden fluctuations of medium sea level during Quarternary Era, which would be reflected in change of denudation base heights. Lowering of denudation base will fairly increase hydraulic gradient of valleys and thus greatly contribute to denudation processes. The most recent valleys developed very fast, as shown by the morphometric map with initial variable KB. (rapid increase of bifurcation ratio between the first and the second order valleys). During the late Würm and Holocene Era, a rapid transgression of sea level occurred, which affected transport power of rivers, so in the high order valleys the brook deposits accumulated. In this way, typical trapezoidal cross-section profile of high order valleys developed. It is characterized by steep slopes shaped during the lowest level of denudation base, conforming to the stage of »V« valley profile, namely to the stage of the most intense incision. After sea transgression and by increase of denudation base height, an abrupt decrease of transport power and covering up occurred, i. e., accumulation of brook deposits at the bottoms of former »V« profile valleys, so that the bottoms of the present day high order valleys are mainly flat.

Increase of descriptor value within subsystem of horizontal relief dissection in the northern area of the Pazin brook tributaries may be connected with the fault activity, indicated by the linear flow of Pazin brook and of its valley (Fojba or Borut brook) in the length of about 11 kilometers. Since the valley extends in NE–SW direction, whereas the regional stress occurrs in N–S direction, we may expect both left and normal shift component along the assumed fault. Left component due to the orientation of the Pazin brook valley related to the force direction of the regional pressure, and normal component due to extension direction (conforming to deformation of ellipsoid related to the above mentioned stress direction) vertical to the orientation of the valley predisposed by fault. We may look for relief indicators of the left shift component along the Pazin fault, in the confluence of north exposed valleys, with the Pazin brook valley, under the angle of 45 degrees. (Otherwise we should expect confluence which is normal to the orientation of the Pazin brook valley as was the case with the southern left tributaries.

Relief indicators of the normal shift component along the Pazin fault are indicated by the positive factor anomalies within the subsystem of horizontal dissection within the right tributaries. Normal shift component lowers denudation base of the northern valleys on the spot of their confluence with the Pazin brook valley. In this way, relative lifting to the north of Pazin brook valley occurs, affecting the repeated allometric growth of valley network, liable for the existing unbalance within a subsystem of horizontal dissection.

Subsystem of denudation level (Fig. 4B) is characterized by extreemely negative anomalies in the valley area gravitating towards SW part of Čepić polje, namely, towards catchment of Raša and Botonega. Positive anomalies occur in the region of Draguć and in the top part of Straževica.

As for bipolarity of descriptors, defining subsystem of denudation levels, negative anomalies are marked by hypsometrically lower relief (lower values H1, H2 and H0) but therefore by increased values of BB (bifurcation number) and of vertical component of relief dissection (UR). Since bifurcation number, Peh (1994), marks transition of main valley into the same or higher order valley, increased BB values denote the areas of active relief structures. Increased values of anomalies within the Draguć hills and Straževica, concerning the geomorphological significance od descriptors within the subsystem, point to the hypsometrically higher relief but of small vertical dissection and bifurcation values. Concentration of isofactor lines in SE part of the map (Fig. 4B) points to the abrupt changes in anomaly gradients (and thus to the situation in geomorphological system) which may be explained by the recent sinking of Ćepić polje bottom, as a result of field »closing« due to the retrograde rotation of Učka, Mihljević & Prelogović (1992).

Isofactor map representing the subsystem of valley density or a subsystem of denudation potential (Fig. 4C), shows explicit positive anomalies in the catchment of Karbun brook, drained towards Ćepić polje, i. e. towards the catchment of Raša. Increased factor loads of diagnostic variables of valley frequency (FD) and of valley density (DG) are followed by reduced vertical dissection values and areas of appertaining denudation areas which is very interesting; i. e. on comparatively small denudation areas, marked by small vertical dissection values, a large number of short gulleys and rills (drainage rills) flowing directly into higher order valleys are shaped. Such a factor structure of valley density subsystem may point to superficial lithological changes within flysh layers in the sense of increased siltite component. Since flysh deposits characterized by increased siltite component are of very low resistance, we may expect (besides the already quoted sinking of Ćepić polje bottom) the development of a dense valley network on the relatively small denudation areas, as indicated by the factor structure of the mentioned subsystem. Finally, the last one, slope inclination subsystem of the main valleys (Fig. 4D) indicate to the noticable increase of anomalies in a comparatively elongated zone of valleys gravitating towards Ćepić polje and in the Grdosleo brook valley.

The subsystem factor structure is characterized by high factor loads of diagnostic variables RR and HG and by negatively polarized variable H1. In other words, steepely incised slopes of main valleys are followed by deeper incision (RR) and by bigger dip gradient (HG), but aslo by lower absolute heights of upper base areas (-H1). Therefore, concerning diagnostic descriptors of inclinations sussystem, positive anomalies in the valley area gravitating towards Ćepić polje may be interpreted in terms of rapid incision which resulted not only due to the Pleistocene sudden sea regression but also due to the present day recent sinking of the basin bottom. Positive anomalies in the Grdoselo brook area developed because of the valley incision into limestone deposits, which due to their mechanical resistance are always followed by steep (almost perpendicular) valley slopes.

Conclusion

Application of factor analysis »R« type on the relief of Istrian hummocy hills, prooved as suitable due to the densely formed network of valleys and gulleys, which may be displayed through a series of morphometric easily measured and quantitatively (numerically) expressed variables.

Application and explanation of factor structure is facilitated by homogenous lithologic composition (flysh) and by negligible structural displacement of lithological members within flysh deposits, especially in the central part of the Istrian hills and by low resistance of flysh deposits to weathering, whereby valley network relatively quickly adjusts to the possible structural and (or) tectonic changes.

Elaboration of morphometric maps composed on basis of initial variables expressed the remarkable unbalance within the geomorphological system particularly in the valley areas drained toward Ćepić polje, namely, towards the river Raša catchment and towards valleys of the Botonega catchment, i. e. towards the river Mirna.

Final solution of the factor model is contained in the rotated factor matrix. Rotated matrix of factor scores served as a basis for elaboration and interpretation of isofactor maps.

Factor structure is characterized with 5 singled out factors, whereof the fifth one is unique (specific). As for their factor structure, these factors may be identified as:

F1 – horizontal relief dissection factor
F2 – denudation levels factor
F3 – valley density factor or denudational potential factor
F4 – slope inclination factor of the main valleys

By interpretation of isofactor maps we came to the conclusion that the unbalance within individual geomorphological subsystem is caused by rapid changes in sea level fluctuations during the Quarternary Era, which brought about an increased hydraulic gradient and denudation intensity, too.

Further elaboration of isofactor maps pointed to the recent sinking of the basin bottom of Ćepić polje and to the left and normal shift component along the Pazin fault indicated by relief, which is reflected through an instability of geomorphological valley system situated to the north of the Pazin brook valley.

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SAŽETAK

Značajke reljefnog sustava Istarskog pobrđa – faktorski pristup

Darko Mihljević

Reljefni sustav Istarskog pobrđa istražen je postupkom faktorske obrade. Primjena faktorske obrade »r« modaliteta na reljef Istarskog pobrđa, pokazala se pogodnom iz više razloga:

– zbog gusto oblikovane mreže dolina i jaruga, koju je moguće izraziti kroz niz morfometrijskih varijabli, koje se lako mjere i kvantitativno (brojčano) izražavaju.

– zbog relativno homogenog litološkog sastava (fliš) i neznatnom strukturnom poremećenošću litoloških članova unutar flišnih naslaga, osobito u središnjem dijelu Istarskog pobrđa

– slabe otpornosti fliša na trošenje, čime se dolinska mreža relativno brzo prilagođava eventualnim strukturnim i (ili) tektonskim promjenama.

Obrada morfometrijskih karata sastavljenih na osnovi polaznih varijabli naznačila je izraženu neravnotežu geomorfoloških sustava osobito u zoni dolina koje se odvodnjavaju prema zavali Čepićkog polja, odnosno slivu rijeke Raše i dolina u slivu botonege odnosno rijeke Mirne.

Rotirana faktorska matrica (Tab. II) predstavlja konačno rješenje faktorskog modela.

Osim analitičkog prikazano je i grafičko rješenje faktorskog modela projekcijom varijabli u bipolarni koordinatni sustav čije osi predstavljaju ortogonalne parove faktora (sl. 3a–3d).

U rotiranoj faktorskoj matrici (Tab. II) prikazana su faktorska opterećenja varijabli na pet izdvojenih faktora, odnosno koeficijenti korelacije varijabli s faktorima. Faktori su međusobno ortogonalni (cos 90° = 0) pa ne pokazuju međusobnu korelativnost.

Kako je područje uzoraka (Slika 1a i 1b) locirano na gotovo potpuno homogenoj litološkoj podlozi (naslage eocenskog fliša), izbjegnuto je uvođenje litoloških varijabli u faktorski model reljefa Istarskog pobrđa. Tim više, odsustvo litoloških varijabli zbog relativno homogene litološke građe terena, pruža mogućnost da se određene manifestacije varijabli na izdvojenim faktorima tumače kao interne specifične razlike unutar kompleksa flišnih naslaga u smislu povećane siltitne ili pješčenjačke komponente u naslagama fliša koje povratno utječu na manifestacije pojedinih varijabli. S druge strane, kako se prema dosadašnjim spoznajama, naslage fliša u središnjem dijelu istarskog pobrđa nisu podvrgavane značajnijim novijim tektonskim učincima, ili barem ne onim koji bi bili prepoznatljivi u strukturnom preoblikovanju slojeva, mogućnost litofaktorske interpretacije još više dobiva na značenju.

Prvi faktor F1 tumači 28,66% ukupne varijance sustava. Pozitivno je monopolaran, visoko opterećen dijagnostičkim varijablama D1, D2, L1, L2, L3 i A3 koje sve predstavljaju elemente horizontalne rašclanjenosti reljefa. Značajno je i opterećenje sekundarne varijable RR, koja ukazuje na povezanost s dijagnostičkim varijablama.

S obzirom na geomorfološko značenje dijagnostičkih varijabli, ovaj se faktor može identificirati kao *faktor horizontalne raščlanjenosti reljefa.*

Na slici 3a prikazano je grafičko rješenje modela za prve dvije faktorske osi koje objašnjavaju 44,64% varijabilnosti sustava.

Drugi faktor F2 tumači 15,98%, odnosno zajedno s prvim 44,64% ukupne varijance sustava. Bipolaran je, s visokim pozitivnim faktorskim opterećenjima na varijablama H2, H1 i H0 i negativnim na varijabli BB. Očito je da su parametri visine reljefa (H2, H1 i H0) u obrnuto zavisnom odnosu s načinom utoka glavne doline u doline istog ili višeg ranga i to na taj način da što se glavna dolina nalazi hipsometrijski niže, to će njezin sutok biti ostvaren s dolinama viših redova.

Od sekundarnih varijabli relativno visoko negativno faktorsko opterećenje pokazuje varijabla UR, što znači da se u zonama najvišeg reljefa javljaju veće vrijednosti vertikalne raščlanjenosti reljefa.

S obzirom na geomorfološko značenje varijabli koje na drugom faktoru postižu visoka faktorska opterećenja, ovaj se faktor može prepoznati kao *faktor denudacijskih nivoa.*

Zanimljivo je da se geomorfološki deskriptor UR javlja kao sekundarna bipolarna varijabla s relativno visokim faktorskim opterećenjima (0,38 – 0,49) na svih pet izdvojenih faktora, što ukazuje da je njegovo ponašanje utjecano s više različitih geomorfoloških i geoloških procesa, koje reprezentiraju izdvojeni faktori.

Treći faktor F3 objašnjava 12,70%, a s prethodna dva 57,34% varijabilnosti cijelog sustava. S obzirom na dijagnostičke deskriptore je pozitivno monopolaran (FD i DG), a pokazuje bipolarnost u odnosu na sekundarne varijable UR i A3. Kako varijable FD i DG s obzirom na geomorfološko značenje predstavljaju izrazite parametre gustoće dolina, to je i razumljiva njihova negativno zavisna veza s varijablama UR i A3. Ovaj faktor moguće je tumačiti kao *faktor gustoće dolina ili faktor denudacijskog potencijala.*

Grafičko rješenje faktorskog modela projekcijom varijabli na treću i četvrtu faktorsku os prikazano je na slici 3b.

Četvrti faktor objašnjava neznatno manju varijabilnost sustava (12,59%) u odnosu na treći, a zajedno s prethodna tri 69,93% ukupne varjance sustava.

Pozitivno je monopolaran s visokim faktorskim opterećenjima dijagnostičkih varijabli T1 i T2, i nešto nižim varijabli HG i RR. Od sekundarnih varijabli prisutna je UR pozitivnog predznaka.

Struktura faktora ukazuje na pozitivne korelativne veze između nagiba padina i pada te usječenosti glavne doline. Drugim riječima što je veći pad i usječenost glavne doline to će biti i strmije njene padine. Grafičko rješenje faktorskog modela za treću i četvrtu faktorsku os prikazano je na slici 3c. Ovaj se faktor može identificirati kao *faktor nagiba padina.*

Peti faktor F5 objašnjava 6,88% varjance, a s prethodno izdvojenim 76,81% varijabilnosti cijelog sustava.

To je unikvitetni faktor s jednom pozitivno polariziranom dijagnostičkom varijablom KB, i sekundarnom varijablom UR. Grafičko rješenje za četvrtu i petu faktorsku os prikazano je na slici 3d.

Na slici 4A–4D (izolinijama i izometrijski) prikazane su izofaktorske karte dobivene interpolacijom vrijednosti »količine« faktora u svakom uzorku (191), iz matrice rotiranih faktorskih bodova, izražene u jedinicama standardne devijacije.

Izofaktorska karta horizontalne raščlanjenosti reljefa (Sl. 4A) ukazuje na izrazito povećanje vrijednosti deskriptora horizontalne raščlanjenosti (D1, D2, L1, L2, L3) u prikupišnim dijelovima Vlaškog i Rakovog potoka i dolinama koje sa sjevera utječu u dolinu Pazinskog potoka. Sve varijable podsustava horizontalne raščlanjenosti reljefa međusobno su pozitivno korelirane (Tablica II, Slika 3a) a pozitivno su korelirane i sa pripadnom površinom na kojoj se razvijaju (A3), što ukazuje da je razvoj dolinske mreže u okviru Istarskog pobrđa uvjetovan alometrijskim rastom, tj. širenjem dolinske mreže u skladu s raspoloživim prostorom. Rast i razvoj dolinske mreže odvija se neprestanim oblikovanjem dolina najnižeg ranga (retrogradno). Pretpostavka alometrijskog rasta jest povećanje površine terena na kojem će se dalje razvijati dolinska mreža. Povećanje površine u konkretnom primjeru može biti potaknuto relativnim izdizanjem središnjeg dijela Istarskog pobrđa odnosno spuštanjem rubnog područja i (ili) naglim oscilacijama srednje razine mora tijekom kvartara, što će se odraziti u promjeni visine baze denudacije. Snižavanje denudacijske baze naglo će povećati hidraulički gradijent dolina i tako ekstremno pojačati procese denudacije. Dolazi do brzog oblikovanja najmlađih dolina na što ukazuje morfometrijska karta polazne varijable KB. (nagli porast koeficijenta bifurkacije između dolina prvog i drugog reda). Krajem virma i u holocenu dolazi do nagle transgresije mora, što pak utječe na smanjenje transportne moći tekućica pa se u dolinama viših redova akumulira potočni nanos. Na taj način oblikuje se znakoviti trapezoidni i poprečni profil dolina viših redova. Obilježen je strmim padinama oblikovanim za najnižeg nivoa denudacijske baze, koji odgovara fazi oblikovanja »V« poprečnog profila dolina, odnosno fazi najintenzivnijeg usijecanja. Nastupajućom transgresijom mora i povećanjem visine denudacijske baze, dolazi do naglog opadanja transportne moći i do zatrpavanja, odnosno akumulacije potočnog nanosa na dnima prethodnih dolina »V« profila, tako da su dna današnjih dolina viših redova uglavnom ravna.

Povećanje vrijednosti deskriptora podsustava horizontalne raščlanjenosti reljefa u području sjeverno položenih pritoka Pazinskog potoka mogu se povezati s aktivnošću rasjeda koji je indiciran ravnocrtnim pružanjem toka i doline Pazinskog potoka (Fojbe ili Borutskog potoka) u dužini od 11 kilometara. Budući da je pružanje doline SI–JZ a smjer regionalnog pritiska približno S–J za očekivati je, i lijevu i normalnu komponentu pomaka duž pretpostavljenog rasjeda. Lijevu komponentu zbog orjentacije doline Pazinskog potoka s obzirom na smjer sile regionalnog potiska, a normalnu komponentu pomaka zbog smjera ekstenzije (sukladno deformaciji elipsoida s obzirom na spomenuti smjer stresa) okomite na pravac pružanja rasjedom predisponirane doline. Reljefni pokazatelj lijeve komponente pomaka duž Pazinskog rasjeda mogu se tražiti u sutoku sjeverno položenih dolina, s dolinom Pazinskog potoka, pod kutom od 45 stupnjeva. (u protivnom bi trebalo očekivati konfluenciju koja je normalna na pravac pružanja doline Pazinskog potoka, kao što je to slučaj s južno položenim, odnosno lijevim pritocima). Reljefni pokazatelji normalne komponente kretanja duž Pazinskog rasjeda indicirani su upravo pozitivnim faktorskim anomalijama unutar podsustava horizontalne raščlanjenosti u okviru desnih pritoka. Normalna komponenta pomaka snižava denudacijsku bazu sjeverno položenih dolina na mjestu njihova sutoka s dolinom Pazinskog potoka. Na taj način dolazi do relativnog izdizanja sjeverno od doline Pazinskog potoka što utječe na opetovani alometrijski rast dolinske mreže, koja je odgovorna za postojeću neravnotežu unutar podsustava horizontalne raščlanjenosti.

Podsustav nivoa denudacije (Sl. 4B) obilježen je izrazito negativnim anomalijama u području dolina koje gravitiraju JZ dijelu zavale Čepićkog polja, odnosno slivu Raše i slivu Botonege. Pozitivne anomalije nalaze se u području Dragućа i vrha Straževica. S obzirom na bipolarnost deskriptora koji definiraju podsustav denudacijskih nivoa, negativne anomalije obilježene su hipsometrijski nižim reljefom (niske vrijednosti H1, H2 i H0) ali zato povećanim vrijednostima BB (bifurkacijskog broja) i vertikalne komponente rasčlanjenosti reljefa (UR). Kako bifurkacijski broj, Peh (1994), označava način prelaska glavne doline u dolinu istog ili višeg reda, povećane vrijednosti BB ukazuju na područja aktivnih struktura. Povećane vrijednosti anomalija u okviru Dragućkog pobrđa i Straževice, a s obzirom na geomorfološko značenje deskriptora opisanog podsustava, ukazuju na hipsometrijski viši reljef ali malih vrijednosti vertikalne rasčlanjenosti i bifurkacijskog broja. Zgušnjavanje izofaktorskih linija u JI dijelu karte (Slika 4B) ukazuju na nagle promjene gradijenata anomalija (a time i stanja geomorfološkog sustava) što se može tumačiti recentnim tonjenjem dna zavale Čepićkog polja, kao posljedice »zatvaranja« polja uslijed retrogradne rotacije struktura Učke, Mihljević i Prelogović (1992).

Izofaktorska karta koja predstavlja podsustav gustoće dolina ili podsustav denudacijskog potencijala (Slika 4C) pokazuje izrazite pozitivne anomalije u slivu Karbunskog potoka koji se odvodnjava prema zavali Čepićkog polja, odnosno slivu Raše. Povećane vrijednosti faktorskih opterećenja dijagnostičkih varijabli frekvencije dolina (FD) i dolinske gustoće (DG) praćene su, što je zanimljivo, smanjenim vrijednostima vertikalne rasčlanjenosti i površina pripadnih denudacijskih površina, tj. na relativno malim denudacijskim površinama, obilježenim malim iznosima vertikalne rasčlanjenosti, oblikovan je veliki broj kratkih jaruga i vododerina (odljevnih jaraka) koji direktno utječu u doline višeg reda. Ovakva faktorska struktura podsustava gustoće dolina može indicirati litološke promjene u okviru kompleksa flišnih slojeva na površini i to u smislu povećane zastupljenosti siltitne komponente. Budući da su flišne naslage, obilježene povećanom siltitnom komponentom lakše trošive, za očekivati je (uz već naznačeno spuštanje dna zavale Čepićkog polja) razvoj gušće dolinske mreže na relativno malim denudacijskim površinama, na što faktorska struktura spomenutog podsustava i ukazuje. Konačno posljednji, podsustav nagiba padina glavnih dolina (Slika 4d), ukazuje na znatna povećanja vrijednosti anomalija u relativno izduženoj zoni dolina koje gravitiraju prema zavali Čepićkog polja, te u dolini Grdoseljskog potoka. Faktorska struktura podsustava obilježena je i visokim faktorskim opterećenjima dijagnostičkih varijabli RR i HG, i negativno polariziranom varijablom H1. Drugim riječima, strmije usječene padine glavnih dolina praćene su većom dubinom usječenosti (RR) i većim gradijentom pada (HG), ali nižim apsolutnim visinama gornjih baznih površina (-H1). Zato se s obzirom na dijagnostičke deskriptore podsustava nagiba, pozitivne anomalije u zoni dolina koje gravitiraju zavali Čepićkog polja mogu tumačiti kao posljedica naglog usijecanja koje je posljedica ne samo pleistocenske nagle regresije mora, već i današnjeg recentnog spuštanja dna zavale. Pozitivne anomalije u zoni Grdoseljskog potoka rezultat su usijecanja doline u vapnenačke naslage, koje su zbog svoje mehaničke otpornosti uvijek praćene strmim (gotovo vertikalnim) dolinskim padinama.

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