GEOLOGIA CROATICA	45	163 - 172	3 Fig.	2 Tab.	ZAGREB 1992

UDC 551.4.04 (497.13): 519.24 Sciefintic paper

Factor Model of the Geomorphological System of a Part of Northwestern Croatia

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Key words: factor model, drainage basin system, resistant geological framework, driving forces, geomorphic processes, geological structure, lithology

Ključne riječi: faktorski model, sustav erozijskih površina, rezistentni geološki okvir, aktivne sile, geomorfološki procesi, geološka struktura, litologija

The method of factor analysis (R-mode) is applied as a tool in the system approach to the investigation of a selected geomorphological region in the Northwestern Croatia. The factor model derived from the analysis is a mathematical representation of the fourth-order drainage basin system. It is composed of five orthogonal factors representing an assemblage of mutually uncorrelated subsystems as a framework within which geomorphic processes operate. Lithologic variables included in the analysis prove to be an inseparable part of the investigated geomorphological system. Loaded significantly on the specific factors, not only do they disclose the way the resistant geological framework opposes the activity of driving forces in the study area, but also indicate most straightforwardly the connection between the geologic structure and the areal extent of the certain rock types (lithology). The former is particularly evident in the case of the slope factor, while the latter is characteristic for the factor of vertical dissection.

Faktorska analiza (R-način) je primijenjena kao sistemska analiza u istraživanju odabrane geomorfološke regije u sjeverozapadnoj Hrvatskoj. Faktorski model dobiven analizom predstavlja matematičku predodžbu sustava erozijskih površina četvrtog reda. Sastoji se od skupa međusobno neovisnih podsistema koji čine strukturni okvir za djelovanje geomorfoloških procesa. Litološke varijable uključene u analizu pokazuju se kao integralni dio istraživanog sustava. Značajno opterećujući neke faktore, one otkrivaju ne samo način na koji se rezistentni geološki okvir opire djelovanju aktivnih sila, nego ukazuju i na vezu između geološke strukture i površinskog prostiranja specifičnih tipova stijena. Prvi primjer očigledan je u slučaju faktora nagiba reljefa, a drugi je karakterističan za faktor vertikalne raščlanjenosti.

1. INTRODUCTION

Like any system-based model, the factor model reveals the essence of reality. It is a simplified and idealised representation of the natural system, emphasizing its supposedly significant features and relationships, but eliminating the incidental details (HART, 1986). The interpretation of such a model rests on the fundamental system attributes or variables, pointing at the selection of the "optimal descriptors" (GARDINER, 1978) as one of the crucial elements of the system analysis. As mentioned in the previous works, with the application of the factor analysis with the purpose of treating the generated factor model as the system-based model in the geomorphological research (PEH, 1990a), landforms mirror the delicate balance between driving and resistive forces. Not only do they serve as regulators adjusting inputs and outputs of matter and energy in the system, but they are also modificatory agents to the geomorphic processes.

Full attention in the geomorphological research so far has been paid mainly to the system dynamics or driving forces. The role of climate generating the exogenetic processes has been known for a long time, as well as the role of gravity participating in a number of endogenetic and exogenetic processes. However, their mutual activity, directed to the joint surface between atmosphere and lithosphere, is more or less modified by the resistive force resident in the geological framework as a truly inert structural part of the geomorphological system. Therefore, since landscape comes into being as the outcome of numerous processes wherein driving forces and resistant geology oppose each other, the set of morphometric parameters itself would not be sufficient to fully explain the dynamic nature of landscape, regardless of the variety of landforms it may represent.

Various landforms may be easily measured or described in quantitative terms, while at the same time, other elements of the geomorphological system such as rock, soil and vegetation may present considerable difficulties in quantification (ZAVOIANU, 1985). The strength of the resisting geological framework is implemented through the two essential geologic variables, lithology and structure, where the former is thought to be the dominant resistive force in the geomorphic processes.

This paper presents an endeavour to include lithology in the factor analysis and to study the evidence for the influence of some distinctive types of rocks on the structural qualities of the factor model. By comparison of two factor models, one of them containing morphometric variables only and the other including the lithologic group of variables, one can single out the so-called lithological factors and directly point at the geologi-

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geological processes, wherein the physical and mechanical properties of rocks play a decisive role.

Such an investigation logically follows the outcomes of the factor analysis applied to the study of tectonic relationships in the area amidst Maceljska Gora, Strahinščica and Ravna Gora, and tends to stress more poignantly the effect of geologic structure on landscape development.

2. GEOMORPHOLOGIC AND GEOLOGIC SETTINGS OF STUDY AREA

The study area is situated in the northern part of Hrvatsko Zagorje (Northwestern Croatia), in a region surrounded by the mountains of Ravna Gora, Strahinščica and Maceljska Gora. It lies between 46°10' and 46°17' north latitude, and between 15°50' and 16° east longitude, in the zone of humid temperate climate (Fig.1). Mean annual temperature is 10°C, and annual precipitation averages 1000 mm, with variations depending on height (CRKVENČIĆ et al., 1974). Two different orographic areas can be distinguished. Closer to the borders the landscape is dominated by the mountains of low and moderate altitude, with peaks less then 1000 m. The highest peak is Strahinščica (846 m), with westernmost parts of Ivanščica at 727 m, Ravna Gora (680 m) and eastern reaches of Maceljska Gora (521 m). The central part of the area is characterized by low relief with a mean altitude of about 250 m. Major rivers draining the area are the Bednja in the east and the Krapinica in the west.

The major lithologic units of the study area are

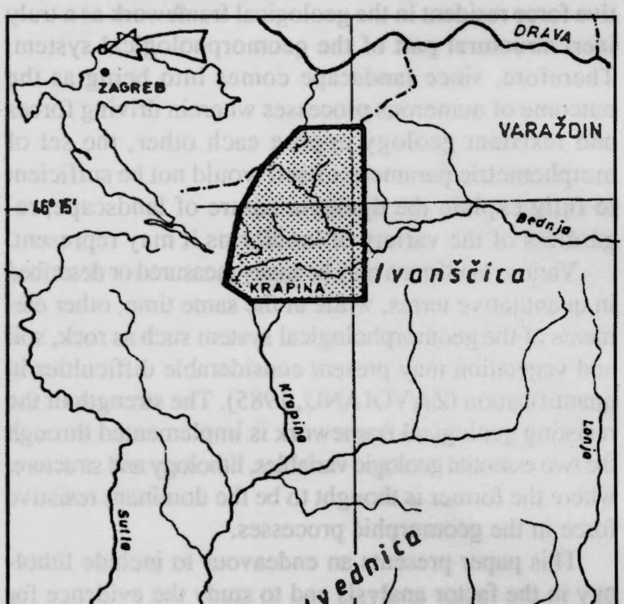

Fig. 1. Map showing location of the study area

Slika 1. Karta s lokacijom područja istraživanja

summarized in Fig.2, while the major structural elements are illustrated in Fig.3. The structural geology is distinguished by almost linear east-west extent of individual structures that build the easternmost part of the Sava Folds tectonic unit (ANIČIĆ & JURIŠA, 1984,1985). Several major uplifted structural blocks, represented by the horst of Strahinščica, horst-anticlinorium of Ravna Gora and horst-anticline of Macelj, encircle the Bednja- Macelj depression as the single markedly subsided structure in the area. Active reverse faulting on the northern flanks of raised structures stresses their asymmetrical forms. The long axis of the Bednja-Macelj depression is shifted to the south, towards Strahinščica, with the presence of locally overthrown strata. This relationship accommodates the regional structural scheme according to which the depth of asymmetrical depressions is always greater in the vicinity of main longitudinal faults (PRELOGOVIĆ, 1975). The southern part of the investigated area is characterized by lateral neotectonic displacements along the system of diagonal faults striking WNW-ESE. Total lateral displacement of the entire system varies from 3 to 6 kms, with maximum lateral-slip along the Velenje-Rogatec fault zone. These movements are accompanied by rotation of minor structural blocks and thrusting of

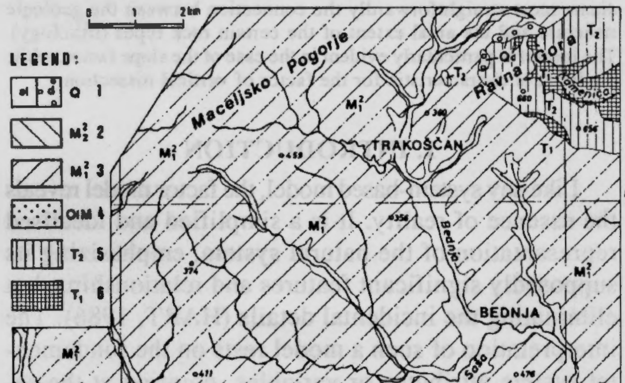

Fig. 2. Generalized geologic map of the study area (modified from ANIČIĆ & JURIŠA, 1984 and ŠIMUNIĆ et al., 1981)

Slika 2. Pregledna geološka karta područja istraživanja (prema ANIČIĆ & JURIŠA, 1984 i ŠIMUNIĆ et al., 1981)

Legend: 1) Quaternary - alluvium (al) and diluvium (d); 2) Tortonian - conglomerates, breccias and limestones; 3)Lower Miocene - sandstones, tuffitic sandstones, conglomerates, andesite tuffs, sandy and silty shales; 4) Oligomiocene - sands, sandstones, sandy shales and sandy marls; 5) Middle Triassic - dolomites, dolomitic limestones, dolomitic breccias, shales, quartzose sandstones, tuffs, cherts, spilitized diabase; 6) Lower Triassic - Werfenian sandstones.

Legenda: 1) Kvartar - aluvij (al) i diluvij (d); 2) Torton- konglomerati, breče i vapnenci; 3) Donji miocen- pješčenjaci, tufitični pješčenjaci, konglomerati, andezitni tufovi, pjeskovite i siltozne gline; 4) Oligomiocen -pijesci, pješčenjaci, pjeskovite gline i pjeskoviti lapori; 5) Srednji trijas - dolomiti, dolomitični vapnenci, dolomitne breče, šejli, kvarcni pješčenjaci, tufovi, čertovi, spilitizirani dijabaz; 6) Donji trijas - Verfenski pješčenjaci.

older, indurated, rocks over Neogene weakly consolidated sediments (PRELOGOVIĆ et al., 1985, an unpublished paper).

The major lithologic units exposed in the area of investigation are related to the regional structural scheme. Central part of the raised structures consists of Pre-Tertiary rocks with prevailing Middle Triassic carbonates (Ladinian). The main lithologic types are dolomites, dolomitic breccias and dolomitic limestones (ŠEBEČIĆ, 1970; ŠIMUNIĆ et al., 1981,1982; ANIČIĆ & JURIŠA, 1984,1985). Other lithologic types of the Middle Triassic are of minor importance, being represented mostly by clastic and volcaniclastic sediments - sandy shales, quartz sandstones, cherts and tuffs - and locally by spilitized diabase.

Lower Triassic clastics (predominantly Werfenian sandstones) are exposed mainly in deeply eroded valleys in the central parts of the raised structural blocks (Ravna Gora). Lower reaches are underlain by Oligomiocene and early Miocene clastic sediments (ranging from Egerian to Othnangian) with sporadically

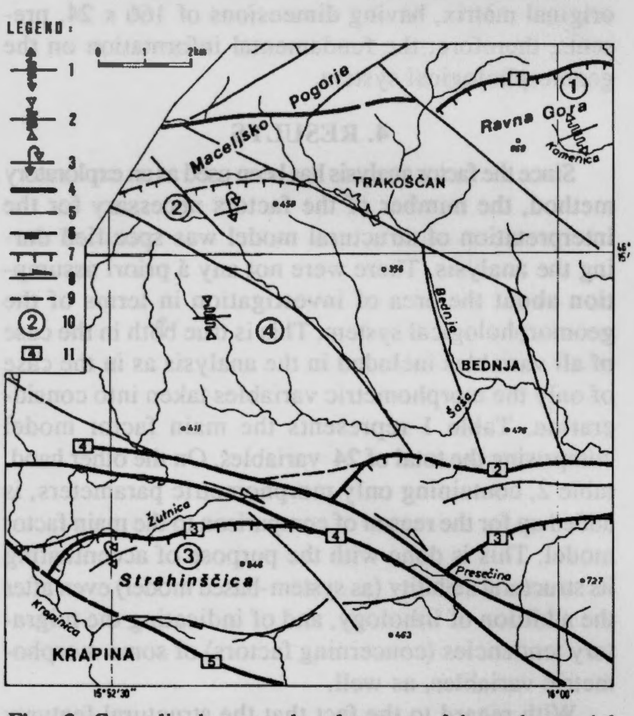

Fig. 3. Generalized structural geology map of the study area (after PRELOGOVIĆ, 1985)

Slika 3. Pregledna strukturno-geološka karta područja istraživanja (prema PRELOGOVIĆ, 1985)

Legend: 1) upright anticlinorium; 2) upright synclinorium; 3) overturned anticline; 4) fault of major importance; 5) fault of minor importance; 6) normal fault; 7) thrust fault; 8) strike-slip fault; 9) inferred fault; 10) major structures: 1. Horst of Ravna Gora, 2. Horst of Macelj, 3. Horst of Strahinščica, 4. Bednja-Macelj Depresion; 11) major faults: 1. Fault of Macelj-Ravna Gora, 2. Fault of Celje-Ivanščica-Nagykanizsa, 3. Northern Fault of Strahinščica and Ivanščica, 4. Zone of Velenje-Rogatec Fault.

Legenda: 1) uspravni antiklinorij; 2) uspravni sinklinorij; 3) prevrnuta antiklinala; 4) značajniji rasjed; 5) manje značajan rasjed; 6) normalni rasjed; 7) reversni rasjed; 8) rasjed s horizontalnim pomakom; 9) pretpostavljeni rasjed; 10) veće strukture: 1. horst Ravne gore, 2. horst Macelja, 3. horst Strahinščice, 4. Bednjansko-maceljska depresija; 11) veći rasjedi: 1. Maceljsko-ravnogorski rasjed, 2. Rasjed Celje-Ivanščica-Nagykanizsa, 3. Sjeverni rasjed Strahinščice i Ivanščice, 4. zona Velenjsko-rogaškog rasjeda.

interbedded volcaniclastic rocks (BOJANIĆ et al., 1978; ŠIKIĆ et al., 1979). Oligomiocene sands, sandy shales and sandy marls crop out in the intramountain valleys of Strahinščica (the valleys of Žutnica and Presečina), with predominantly reverse fault-bounding to the Middle Triassic carbonate rock complex. The Bednja-Macelj depression is built of two different lithologic types of Lower Miocene clastic sediments. One of them is composed of coarse clastics - sandstones, tuffitic sandstones and conglomerates, forming the coarse-grained facies of "Macelj Sandstones" formation. The other lithofacies is represented by fine clastic sediments, mainly by sandy and silty shales. The outermost southern reaches of the study area have local outcrops of Tortonian sediments which, however, are not encompassed within the analyzed geomorphological system.

3. METHODS AND MATERIALS

The principles of factor analysis are well known through many examples in geology and other sciences. Therefore, there is no need for detailed discussion on the aims and purposes of factor analysis and characteristics of factor model. To understand the basics about mathematical principles of the method, the reader should refer to the available textbooks on factor analysis (for example, FULGOSI, 1984). Its applications in geology can be found in the ever increasing number of works of the home investigators (MARCI & RAFFAELLI, 1981; RAFFAELLI & MUTIĆ, 1982; MUTIĆ, 1989; PEH, 1990a,b; DRAVEC-BRAUN, 1990). The foreign literature is extremely abundant and comprises almost all fields of science.

Since the study of geological control, particularly that of lithology, is presented here as the continuation of the previous work by the same author (PEH, 1990a), some necessary details should be emphasized to clear out the scope of investigation, and the geological implications of the factor model as well. It has already been pointed out that the resistive forces in geomorphology reflect themselves in the strength by which the upper part of lithosphere opposes to the activity of endogenetic and exogenetic forces. However, it is extremely difficult to allocate some numerical value to the rock hardness or its resistance to weathering (DOORNKAMP & KING, 1971). Therefore, an attempt is made in this paper to express numerically the lithology of the investigated area in the form of areal variable, that is, a percentage of the total basin surface which is outcropped by a certain type of rock. Definition of the rock types that would make consistent geomorphological groups according to their behaviour in geomorphic processes has been arbitrary regardless of data available from previous investigations (MELTON, 1957; BRUSH, 1961; YOUNG, 1961; GREGORY & BROWN, 1966, and others). Nevertheless, this can be justified by the fact that particular rock types (for instance sandstones) with different genesis, tectonic setting and other characteristics may similarly respond to driving forces in various geomorphological regions. On the other hand, factor analysis was also conceived to serve as the test of susceptibility of the lithological variables thus defined.

In the area amidst Maceljska Gora, Strahinščica and Ravna Gora four rock types were specified as variables in the factor analysis. These are: 1) dolomites and dolomitic limestones of the Middle Triassic - carbonate Pre-Tertiary rocks (CA), 2) clastics and volcanics of the Lower and Middle Triassic - noncarbonate Pre-Tertiary rocks (PT), 3) sandstones, tuffitic sandstones and conglomerates of the Lower Miocene - coarse-grained clastic sediments (KL), and 4) sandy and marly shales of the Oligomiocene and Lower Miocene - fine-grained clastic sediments (GL).

Morphometric variables that represent linear, areal and relief aspects of landscape do not participate in the analysis in all their diversity, but only by their most important part. Most of them were described in the previous work (PEH, 1990a),but, naturally, some changes were necessary with respect to the previously established factor model. Not only do they refer to the association between lithologic and morphometric variables, but also to the introduction of several new morphometric variables as the most useful optimal descriptors of the geomorphological system, particularly due to their supposed sensitivity to the variations in geology. Apart from variables already used in description of the drainage network, the bifurcation ratio (KB) and confluence number (MB) are added to the analysis. As for the measures involving height and slope, the new variables describe the mean ground slope of the drainage basin (TG), the main-valley cross-section ratio (PP), and the hypsometric integral (HI). Attention should be paid to variables KB and MB, because KB is not presented as a mere arithmetical mean but the weighted bifurcation ratio taking into account the number of valleys of all orders (from first to fourth), while confluence number (MB) specifies the order of valley which the fourth-order joins at its mouth. The potential of the variable MB lies in its possible indication of the locally raised or sunken tectonic blocks in the investigated geomorphological region.

Mathematical definition of certain variables reflecting relief aspects of drainage basins, particularly slopes, should be explained more thoroughly. Mean ground slope of drainage basin (TG) is calculated according to the formula quoted by ZAVOIANU (1985) and other authors, where A stands for the area of drainage basin, Σl stands for the total sum of all contour lines of chosen height interval, while Δh represents difference in height, or the magnitude of the chosen height interval in the drainage basin, respectively. The calculated value gives the tangent of the angle of the average ground slope in the basin.

$$\tan \varphi = \frac{\Delta h \cdot \sum l}{A}$$

The main-valley cross section (PP) is defined as the ratio between breadth (b) and height (h) of the valley in its lowest part. The breadth of a valley was measured as close to the mouth as possible, in such a way that the cross profile would not be affected by distortion of contour lines because of tributaries or any other reasons. The purpose of this variable is to reveal the tendency of a valley to cut a V-shape, or a rounded U-profile, utilizing the appropriate index, as well as to test the variable through the process of factoring.

$$PP = b / h$$

Hypsometric integral (HI) is calculated in the way proposed by STRAHLER (1952b), with $x=a/A$ and $y=h/H$ as the elements of the percentage hypsometric curve.

$$HI = \int_0^1 x\,dy$$

The analysis comprises the total number of 24 variables, 20 morphometric and four geologic ones, that were assessed in 166 fourth-order drainage basins. The original matrix, having dimensions of 166 x 24, presents, therefore, the fundamental information on the geomorphological system.

4. RESULTS

Since the factor analysis has been used as an exploratory method, the number of the factors necessary for the interpretation of structural model was specified during the analysis. There were not any á priori assumption about the area of investigation in terms of the geomorphological system. This is true both in the case of all variables included in the analysis as in the case of only the morphometric variables taken into consideration. Table 1 represents the main factor model comprising the total of 24 variables. On the other hand, table 2, containing only morphometric parameters, is added up for the reason of comparison to the main factor model. This is done with the purpose of accentuating its structural stability (as system-based model) even after the addition of lithology, and of indicating the migratory tendencies (concerning factors) of some morphometric variables, as well.

With regard to the fact that the structural features of the factor models in tables 1 and 2 are not essentially different from the outcomes obtained in the previous work (PEH, 1990a), there is no need for detailed description of factors. Similarity between the cases is logical, because the same geomorphological region has been subdued to study. Certain differences could arise as the effect of increased dimensions of the study area, that is, the increased number of variables and system units (drainage basins) in respect to the earlier investigation.

Likeness or difference in relation to different authors (for example MATHER & DOORNKAMP, 1970; DOORNKAMP & KING, 1971; ABRAHAMS, 1972; ONESTI & MILLER, 1974; GARDINER, 1978, and others) are mainly due to the geologic and climatic

VARIABLE	FACTOR					
	F1	F2	F3	F4	F5	h^2
D1	0.9284*	-0.0565	-0.0662	0.1308	0.2190	0.9345
D2	0.8274*	-0.0623	-0.0945	0.1531	-0.1632	0.7475
D3	0.6552*	-0.0331	0.1640	0.2941	-0.2711	0.6172
L1	0.8331*	0.3307	-0.1047	0.0628	0.2497	0.8807
L2	0.7671*	0.2550	-0.0374	0.1092	-0.2551	0.7319
L3	0.6605*	0.3143	0.1271	0.1421	0.1147	0.5846
L4	0.7467*	0.1345	-0.1185	-0.1702	0.3278	0.7261
KB	0.3040	-0.0384	0.0506	-0.0955	0.6938*	0.6870
MB	-0.2433	-0.0956	-0.1331	-0.6377*	0.3955	0.6491
PB	0.7709*	0.5467+	-0.0873	0.0566	0.0681	0.9087
H2	0.1005	0.0137	-0.0862	0.8553*	-0.0931	0.7680
H1	0.2304	0.3480	0.1121	0.7905*	0.1458	0.8329
H0	0.2080	0.7643*	-0.0018	0.4172	-0.1124	0.8142
UR	0.2260	0.8315*	0.0219	0.1922	-0.0781	0.7859
HG	-0.1953	0.4668+	0.4583+	0.2038	0.2445	0.5674
TG	-0.0652	-0.0420	0.7809*	0.1839	-0.0332	0.6507
PP	0.0069	0.3722	-0.5225*	-0.2937	-0.2595	0.5652
FD	-0.3239	-0.7573*	0.1950	0.1408	0.0771	0.7422
DG	-0.2554	-0.6935*	0.1502	0.0710	0.2447	0.6337
HI	-0.2077	-0.0249	0.5226*	-0.0156	0.3673	0.4520
CA	-0.0095	0.8049*	-0.0319	0.0954	0.1740	0.6883
PT	-0.0250	0.5372*	0.1302	0.4639	0.2613	0.5896
KL	0.0771	-0.4473	0.7525*	-0.2290	-0.1999	0.9647
GL	-0.0782	-0.1294	-0.8799	0.0772	0.0523	0.8057
λ	5.4227	4.5724	2.9159	2.6479	1.5574	
%λ	22.59	19.05	12.15	11.03	6.49	
%λcum	22.59	41.64	53.79	64.82	71.31	

Tab. 1. Varimax rotated factor matrix.
Tablica 1. Rotirana faktorska matrica.

VARIABLE	FACTOR					
	F1	F2	F3	F4	F5	h^2
D1	0.9241*	-0.0026	0.1287	-0.0551	0.2535	0.9378
D2	0.8947*	-0.0235	0.1403	-0.1064	-0.2197	0.8803
D3	0.6120*	-0.0082	0.4380	-0.0070	-0.0593	0.5701
L1	0.8075*	0.3887	0.0375	-0.0303	0.2622	0.8742
L2	0.7849*	0.3072	0.1436	-0.0670	-0.2329	0.7898
L3	0.5515*	0.3568	0.2484	0.0710	0.3657	0.6320
L4	0.7500*	0.1776	-0.2079	-0.0905	0.2735	0.7204
KB	0.1622	0.0120	-0.0616	0.0445	0.8863*	0.8178
MB	-0.2253	-0.1125	-0.7114*	-0.0834	0.2825	0.6563
PB	0.7014*	0.6022*	0.1044	-0.0876	0.1813	0.9060
H2	-0.0111	0.0653	0.9228*	-0.1105	0.0940	0.8769
H1	0.1916	0.3611	0.7264*	0.2487	0.1042	0.7675
H0	0.1601	0.8157*	0.3759	0.1518	-0.0785	0.8614
UR	0.2059	0.8680*	0.1288	0.1930	-0.0922	0.8581
HG	-0.0491	0.3778	-0.0456	0.7685*	-0.1768	0.7690
TG	-0.0287	-0.1214	0.1824	0.7404*	-0.0409	0.6121
PP	-0.0083	0.4210	-0.2620	-0.5331	-0.2773	0.6071
FD	-0.1810	-0.8164*	0.0193	0.2798	-0.1457	0.7991
DG	-0.1046	-0.7340*	-0.1087	0.3115	-0.0467	0.6607
HI	-0.1377	-0.1500	-0.1112	0.6111*	0.1451	0.4483
λ	4.9037	3.8960	2.5415	2.1691	1.5345	
%λ	24.52	19.48	12.71	10.85	7.67	
%λcum	24.52	44.00	56.71	67.56	75.23	

Tab. 2. Varimax rotated factor matrix (lithologic variables excluded).
Tablica 2. Rotirana faktorska matrica (bez litoloških varijabli).

characteristics of the studied areas, as well as to the different choice of the relevant morphometric and geologic properties that describe the respective geomorphological systems. With this on mind, the importance of lithology which, as comes to be clear from the close inspection into the tables enclosed, does not leave mark on all factors (or geomorphological processes they represent), tends to be still greater.

The main factor model (table 1) is composed of five factors, namely the factor of horizontal dissection F1, the factor of vertical dissection F2, the factor of slope F3, the factor of erosional levels F4 and the factor of the bifurcation ratio F5. Their functional characteristics are discussed in the next section.

5. DISCUSSION

Assuming that factor analysis enables an open system to be defined by mathematical criteria, the factor model is a mathematical expression of the inherent structure of such a system, with individual factors directly or indirectly indicating certain processes characteristic to its internal dynamics. The question remains to be answered as to how much the common factors, defined in such a way, represent all the active and passive participants in the landscape development. The answer is far from being straightforward. Although factors mirror genetic relationships among individual variables, it is extremely difficult to identify them with some specific geomorphic process. For example, in reference to the slope factor F3, it is undetermined if it can explain the influence of all those variables controlling the behaviour of valley slope, valley-side slope, ground slope or hypsometric integral. Explanation of the factor variability may be additionally burdened by the high factor loading of the same variable on more than one factor, as in the case of variable PB (F1-F2), and to the somewhat lower degree in the case of variable HG (F3-F4).

Geomorphic processes that lead to the appearance of various landforms originate in the action of opposing forces operative on the surface of the Earth. They are seen as the result of the mutual work of driving forces that provide energy, and the resistant geological framework which counteracts the former by the strength of its physiographic constitution (RITTER, 1978; HART, 1986). From this point of view, the form and process relationship does not depend only on the amount of energy applied, but also on the properties of materials being worked on by the driving forces. Lithology and structure exert considerable influences on the transfer of mass and energy through the system, regardless of wheather the main driving forces are endogenetic or exogenetic in nature. Furthermore, there is a tendency of establishing a delicate balance between form and process, a kind of very subtle equilibrium which is manifested through significant statistical correlations among the system variables (STRAHLER, 1956; HACK, 1957; CHORLEY, 1962; HOWARD, 1965; CHORLEY & KENNEDY, 1971; POZDNJAKOV, 1988 and others). Such a close association between form and process offers a possibility that careful examination of relationships among the variety of landforms, as well as the geological features of the area, may lead to the recognition of the processes which created them, provided that the mechanism of resistance to the operative forces is known.

If the assumption is accepted that the factor model represents a mathematical expression of the system in balance, with factors forming an assemblage of geomorphic processes in some kind of "statistical equilibrium" with various landforms, then it may prove possible to reveal the evidence of geologic control in certain factors. Here it must be emphasized that according to the accepted opinions, the bedrock lithology is probably the most important resistive component in the process of landscape development (ZAVOIANU, 1985).

5.1 LITHOLOGY

Various rock types, because of their resistance to weathering, differently affect the behaviour of certain morphometric variables such as the ground slope (MELTON, 1957; YOUNG, 1961; GREGORY & BROWN, 1966, and others), drainage density (HORTON, 1945; CARLSTON, 1963 and others) and longitudinal valley profile (HACK, 1957; BRUSH, 1961 and others) among other.

Rock resistance to erosion is defined by its physical and mechanical properties. According to prevailing opinion, porosity and permeability, which directly affect the relationship between overland flow and infiltration, are the most important physical properties of rocks. Drainage density is probably the most sensitive morphometric parameter which reacts to them. On the other hand, strength, hardness and resistance to weathering appear to be the most prominent mechanical properties (ZAVOIANU, 1985), and slope variables are most susceptible to their variations.

Before broaching the subject of how lithology loads on individual factors, it is necessary to explain the meaning of the sign the lithologic variables bear in the correlative relationships with other variables. Lithologic variables as presented in this work do not reflect some physical or mechanical rock property in the form of a numerical parameter, but simply the relative presence of a certain rock type in a drainage basin as a whole. That is why the sign of a particular lithologic variable in the factor model does not define the character of its association with morphometric variables explicitly, which is the question when their loadings on the same factor are charged oppositely. This can be interpreted in two ways. If the loading of a specific lithological variable is negative, while at the same time, the loading of the morphometric variable representing, for example, the highest point on divide H0 is positive on the same factor, it may reveal the scarce appearance of the respective rock type in the area of high relief. However, this association can also be expressed inversely, as an abundant occurrence of the same rock type in the area of low relief. The sign of factor loading has no intrinsic significance in itself with no information on dependency between variable and the factor (KIM & MUELLER, 1978). That is why both way of reasoning can be utilized to present the outcome of the analysis.

Two lithologic factors are revealed in the factor model. Lithologic variables are strongly built in the frame of the F2 and F3 factors, suggesting that rock type controls the behaviour of morphometric variables such as drainage density or ground slope.

Although its influence on process has been recognized, lithology is often thought to be a more or less passive or static participant in landscape development. On that assumption, the factor model resulting from the factoring of the same set of data should not be essentially different if the lithologic variables were removed. In other words, fundamental relationships among the morphometric variables would not be affected by the presence or absence of lithologic variables (at least regarding the way they are defined in this work). The comparison between tables 1 and 2 shows that after the lithologic variables CA, PT, KL and GL had been removed, the inner structure of the system remained without substantial alterations. This, of course, implies the strong effect of other, "active" variables in geomorphic processes leading to a particular landform assemblage. Relocation of F3 and F4 factors by this procedure does not play an important role in the hierarchy of factors. It is more important to point out the communalities of some morphometric parameters, especially of the variables KB and HG. Lithologic variables once been removed, the communalities of KB and HG considerably increase. KB enlarges its communality by 28.2%, and HG by 26.2%, which means that rock type imposes some additional constraints on the relationships among the system components. Practically, it means that if lithology is excluded, the variable HG firmly takes its place on the slope factor, while the dominance of variable KB on the F5 factor becomes still greater. Likewise, there is an increase in the communality of variables D2 (+15.1%) and H2 (+12.4%) which indicates lithology imposes additional constrictions in their behaviour as well.

F1 is completely free from any lithologic control (as is shown on table 1). Being considered as the size factor (DOORNKAMP & KING, 1971) it simply points to the fact of linear basin elements developing within the area available. But the total number and length of valleys of various orders, as well as the area of drainage basin, do not react to differences in lithology among sandstones, shales and dolomites. Some authors have indicated that a relationship exists between various rock types and average area needed for drainage basin development (ZAVOIANU, 1985), although physiographic properties of rocks seem to influence the development of drainage network primarily by variables which control drainage density DG (and FD).

F2 is heavily loaded by lithologic variables. The fact that its character is virtually unaffected by removing the lithologic variables (tables 1 and 2), except that loadings on the key morphometric variables become still heavier, leads to the conclusion that they are more or less inertly loaded on the factor. The high positive loading on the group CA-PT mirrors most straightforwardly the geologic setting of the study area, since Triassic dolomites and, to the somewhat lower degree, Triassic clastics and volcanics occur in the hearts of the regional mountains of Strahinšćica and Ravna Gora. The Bednja-Macelj depression, which is built of Lower Miocene sandstones and shales, is characterized by low relief. This latter relationship is partly mirrored in the factor model by the significant loading on the variable KL with negative sign (-0.45). No stronger relationship is established between the relief aspects and the occurrence of weakly consolidated Lower Miocene and Oligomiocene sediments GL (-0.13).

Drainage density is one of the most significant component parts of the landscape assemblage, and terrain transmissibility, depending on the bedrock and soil permeability, occurs as a dominant factor that controls it (CARLSTON, 1963). Since the terrain transmissibility and drainage density vary inversely to each other (HORTON, 1945; CARLSTON, 1963),the highly permeable areas will not stimulate development of dense drainage network. At the same time, low drainage density will be conditioned by high bedrock resistance to weathering (STRAHLER, 1952a). Triassic dolomites (CA) in the study area are distinguished by their very high degree of fracturing, and, at some places (particularly on Ravna Gora), with well developed karst landforms, so that this variable quite nearly fits in F2 factor, where the relationship between drainage density and occurrence of dolomite rocks are inversely proportional. Proportional relationship between drainage density and occurrence of Lower Miocene sandstones may be the reflection of their low transmissibility. This statement is also supported by the evidence of sandstones abounding in perennial and ephemeral streams, which indicates that most of the precipitation, less amount of evapotranspiration, ends in surface runoff.

F3 reveals the lithological control most conspicuously. The fact that lithologic variables cause the relocation of the slope factor in the hierarchy of factor significance (amount of information contained), as well as the fluctuating status of important morphometric variable HG (similar loadings on both F2 and F3) speaks on behalf of significant lithologic control. The most important feature of F3 is the inversely proportional relationship between the variables KL and GL; both have heavy loadings, except that their behaviour is entirely different relative to the set of morphometric variables involving the slope aspects of landscape. Positive correlation of variable KL with the slope characteristics indicates that sandstone areas are distinguished by steep ground slope, steep fourth-order valley slopes, V-shaped fourth-order valleys and high hypsometric integral. On the contrary, negative correlation of the variable GL with the slope characteristics reveals that areas occupied by Lower Miocene shales are dominated by gentle slopes, U-shaped valleys and low hypsometric integral. At the same time, very low factor loading on the CA-PT group of variables shows that the slope is not essentially influenced by the physiographic properties of Triassic rocks. The slope characteristics in the area of Strahinščica and Ravna Gora are probably under control of other variables. The relationship between the morphometric and lithologic variables loaded on the slope factor F3 supports the general conclusion about the behaviour of some rock types in the process of landscape development. In this case, the most prominent trait appears to be the difference between sandstones and shales, because they have direct impact on the slope parameters. Relationship resulting from the analysis is in accordance with the opinions of many authors that sandstones are more resistant to erosion than shales in the temperate climate zones (BRUSH,1961). Sandstones possess sufficient internal strength in respect to shales to permit steeper characteristic and maximal slope angles. This is reflected in more pointed landforms (+TG) and characteristic V-shaped valley transverse profile (-PP) in the portion of the Bednja-Macelj depression underlain by sandstones. The main valley slope (HG) is also steeper in sandstones, but the double entity of this variable (0.47F2+0.46F3) points to a conclusion that valleys with high values of slope are typical of Triassic carbonate rocks as well.

Finally, the hypsometric integral as a rather specific morphometric variable also indicates greater resistance of sandstones with regard to shales. An interesting feature of this variable is its directly proportional relationship to the other slope parameters in the area of heterogeneous lithology. This relationship can result from some other variables operative in the area, particularly from vertical neotectonic movements which tend to rejuvenate the landscape and create (through reinforcement of erosion processes in the valleys) steeper relief, regardless of lithology.

A brief inspection into the factor matrix (table 1) can affirm that erosional levels (loaded on F4) and bifurcation ratio (loaded on F5) are not in the least affected by the variations in lithology.

Significant loading on F4 with the variable PT can be explained by the strong influence of a single object, an outlier, in the set of original data. It is the case of the valley of Kamenica in the heart of Ravna Gora, which is distinguished by exceptionally high erosional levels (H2=297m, H1=488m). Middle Triassic dolomites have been removed by erosion, so that the Kamenica presently has been cutting its way into Lower Triassic clastics.

6. CONCLUSIONS

Factor analysis proves to be a valuable method in the exploration of geomorphological systems, largely due to its basic feature of being a multivariate technique allowing insight into simultaneous relationships among system elements. The analysis has been applied to a selected geomorphological region wherein the system has been defined by the set of fourth-order drainage basins as the fundamental system units. Factoring of the original set of data (R-mode factor analysis) resulted in a factor model which can be defined as a geomorphological system-oriented model (HART, 1986). To a certain degree, that model simplifies the complex relationships in the geomorphological system and permits a look into the basic structure of data.

A factor model is composed of five orthogonal factors which implicitly disclose processes operating in the general scheme of landscape development. It is an arduous task to associate each of the concerned factors with a specific geomorphic process (or processes), but still it can be said without doubt that the main reason for individual system variables grouping or loading on a certain factor lies in their high mutual correlations originated in the activity of driving forces upon a resistant geological framework.

A factor in a mathematical sense represents a latent variable (FULGOSI, 1984) the character and significance of which depend on entanglement of interrelations of original or manifestable variables. The process, again, represents a unifying variable (RITTER, 1978), which ties together active forces providing energy (tectonics, climate) and passive geology (lithology, texture) in their mutual creation of surface features of the Earth. Thus, connection between the factor and process, although not explicitly shown, becomes obvious.

The most striking characteristic of the factor model is its susceptibility to the variations in bedrock geology. Strong geologic control is present in the factors of vertical dissection F2 and slope F3. While the factor of vertical dissection seems to reveal the dominant control of the structural setting of the Triassic carbonate complex underlying the most uplifted parts of the regional mountains, the slope factor points at a causal relationship between physiographic properties of Lower Miocene and Oligomiocene sediments on one hand, and slope aspects on the other. The main factor model reveals this profound relationship in both cases by the very high factor loadings of lithological variables. Carbonate and clastic Pre-Tertiary rocks (CA, PT) come into prominence in the case of the factor of vertical dissection, while coarse-grained and fine-grained clastics of the Oligomiocene and Lower Miocene characterize the slope factor.

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Faktorski model geomorfološkog sustava dijela sjeverozapadne Hrvatske

Z. Peh

Faktorska analiza se pokazuje vrlo značajnom u istraživanju geomorfoloških sustava budući da kao multivarijantna matematska metoda pruža uvid u simultane odnose među njihovim elementima. Analizom je obrađena odabrana geomorfološka regija u kojoj je sustav definiran kao skup erozijskih površina četvrtog reda s ulogom osnovnih sistemskih jedinica. Faktorizacijom izvornih podataka (R-način) stvoren je faktorski model koji se može definirati kao geomorfološki, sistemski orijentirani model (HART, 1986). Do stanovite mjere takav model pojednostavnjuje složene odnose u geomorfološkom sustavu, ali istovremeno otkriva i osnovnu strukturu morfometrijskih podatka.

Faktorski model se sastoji od pet ortogonalnih faktora koji implicitno ukazuju na procese oblikovanja reljefa. Vrlo je teško povezati svaki od promatranih faktora s nekim određenim geološkim procesom (ili procesima), ali se sa sigurnošću može reći da je uzrok grupiranja sistemskih varijabli na pojedinim faktorima skriven u visokim međusobnim korelacijama koje nastaju u procesu djelovanja aktivnih sila na rezistentni geološki okvir. Faktor se u matematskom smislu može smatrati latentnom varijablom čiji karakter i značenje ovise o spletu međusobnih odnosa izvornih ili manifestnih varijabli (FULGOSI, 1984). Proces, pak, predstavlja unificirajuću varijablu koja povezuje aktivne sile (energija) i pasivni geološki okvir (rezistentna masa uobličena u litološkim i strukturnim značajkama promatrane geomorfološke regije) u zajedničkom stvaranju reljefa (RITTER, 1978). Veza između faktora i procesa postaje tako očigledna.

Najbitnijom značajkom faktorskog modela pokazala se njegova osjetljivost na varijabilnost geološke podloge. Jak utjecaj geoloških činitelja prisutan je u faktorima vertikalne raščlanjenosti F2 i nagiba reljefa F3. Međutim, dok faktor vertikalne raščlanjenosti ipak u prvi plan ističe dominantan utjecaj strukturnog smještaja trijaskog karbonatnog kompleksa, koji tvori jezgru najviše izdignutih dijelova regionalnih struktura, faktor nagiba ukazuje na uzročno-posljedičnu vezu između fiziografskih osobina oligomiocenskih i donjomiocenskih sedimenata s jedne i nagiba reljefa s druge strane. U oba slučaja se glavni faktorski model (tablica 1) odlikuje visokim faktorskim opterećenjima litoloških varijabli. Karbonatne i klastične predtercijarne stijene (CA, PT) karakteriziraju faktor vertikalne raščlanjenosti, dok krupnozrnasti i sitnozrnasti klastiti oligomiocena i donjeg miocena (KL, GL) opterećuju faktor nagiba reljefa.

Manuscript received March, 31.1992.
Revised manuscript accepted June, 10.1992.