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Frequency Distribution Curves as an Indicator of Evolutionary Trends in Geomorphological Systems: A Case Study from the Northwestern Part of Hrvatsko Zagorje (Croatia)

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Key words: Geomorphological systems, Thermodynamics of nonequilibrium systems, Frequency distribution curves, Horizontal dissection, Vertical dissection, Hypsometric integral, Drainage density, Slope, Erosional levels, Hrvatsko Zagorje, Croatia.

Abstract

Frequency distribution curves can be indicative of the dynamics and evolutionary development of geomorphological systems. Normally distributed geomorphological data are a reliable indicator of the equilibrium fluctuations prevalent within such systems. This occurs, for example, when a delicate balance is established between various types of landforms and geomorphological processes. Landforms that exist in this geomorphological steady state can be properly called "equilibrium" structures. They show no permanent trends of either growth or destruction. On the contrary, a positively skewed frequency distribution curve indicates a type of non-equilibrium conditions and non-linear relationships within geomorphological systems, which may be the result of major external energy inputs (particularly from tectonic uplift). This, in turn, gives rise to new and more complex higher-order landforms. These represent structures of growth, or evolution. Alternatively, a negatively skewed frequency distribution curve, also being a consequence of non-equilibrium conditions, indicates a lack of free energy in the system, which induces destruction of the existing landforms. Such landforms represent structures of degeneration. The fluvial landscape in the northwestern part of Hrvatsko Zagorje, portrayed in terms of an open system, has been used as the geomorphological framework for this study, the primary purpose of which was to apply frequency distribution curves in the interpretation of the processes influencing the creation and destruction of the landscape. Horizontal and vertical dissection, slope and other morphometric characteristics reflect the specific dynamics of the geomorphological processes, which relate a variety of landforms to their geologic framework and climate in the study area.

1. INTRODUCTION

A diligent search for solid proof of how the processes shaping the face of our planet actually work, resulted in the acceptance and application of new concepts in geology. These originate from the domain of fundamental natural sciences, particularly mathematics and physics. However, despite the fact that geology, and geomorphology in particular, has taken a great leap in the last few decades owing to newly promoted ideas, many questions, especially those concerning the problems of evolution of geomorphological systems, remain unanswered. Very often, emphasis is placed on the fact that all natural systems, including geomorphological ones, are too complex for analytical treatment beyond a routine search for the empirical relationships among assessed data (PATEE, 1973; KARCZ, 1980). Nevertheless, many recent ideas may be directly applied, particularly with regard to the problem of structural stability and related fluctuation phenomena (oscillations of system parameters), that are considered to be the main cause of permanent and irreversible change in natural systems. Stability and equilibrium, reflected in the geomorphological steady-state concept, present the generally accepted axioms around which the analysis of various geological and geomorphological systems has revolved in the past few decades (KARCZ, 1980).

One should emphasize, though, that evolution of the natural systems, including landscapes, does not proceed via the equilibrium conditions that prescribe the stable flux of matter and energy. On the contrary, evolution is induced by a shock occurring as a system's response to strong external impulses. Evolutionary processes, triggered as the system reaches the far-from-equilibrium, non-linear regime, eventually increase its structural complexity (NICOLIS & PRIGOGINE, 1977; PRIGOGINE, 1978; KARCZ, 1980; PRIGOGINE & STENGERS, 1985, and others). In geomorphological systems these changes have been exemplified by drainage network expansion, the growing intensity of vertical dissection and the general appearance of new, higher-order features in a landscape. A reliable indicator of such changes are frequency distribution curves of the system parameters. Their analysis, therefore, can be of great importance in understanding geomorphological, and geological processes in a given area.

The aim of this investigation is to place greater emphasis on the potential application of frequency distribution curves in the analysis and appraisal of various geomorphic phenomena and their dynamics in a fluvial landscape (the northwestern part of Hrvatsko Zagorje). Previous studies in this area, carried out to examine the dynamic interplay of various fluvial landforms (PEH, 1990), as well as to elucidate the relationship between the driving forces and resistant geological framework

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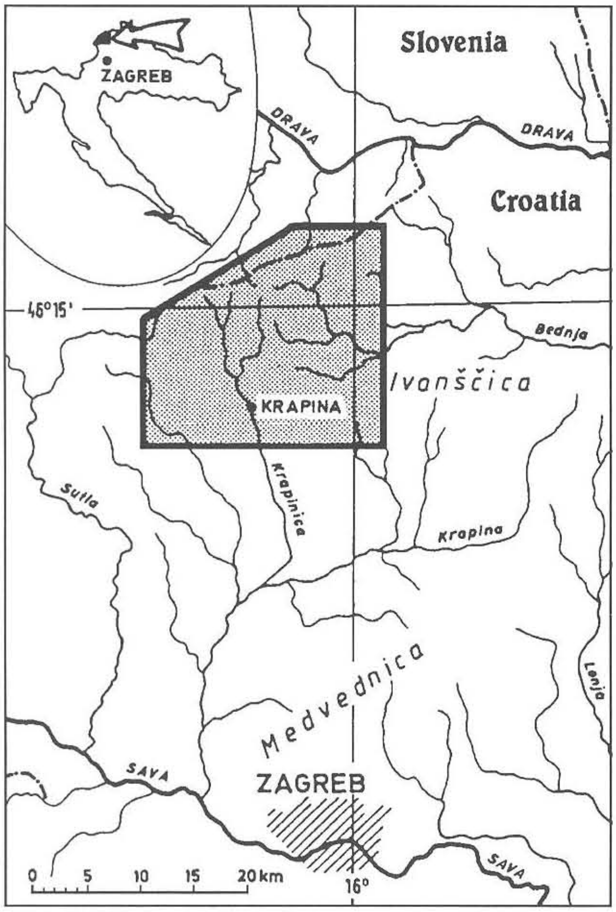

Fig. 1 Location map of the study area.

(PEH, 1992), dealt with a single fragment on a hierarchical scale of system relationships. Conclusions drawn from this research have adequately described the spatial changes caused by climate and tectonic movements during the particular geologic period defined by the relative age (order) of drainage basins. However, exclusive study of the spatial relationships among geomorphological parameters thus defined, has not established temporal trends of landscape evolution with any degree of certainty. Only after several adjacent, hierarchically ordered geomorphological systems had been analyzed together, could a more explicit reference to the time component involved in the investigation of the dynamics of geomorphologic processes be made (PEH, 1994). It seems possible that the probability distribution curve, illustrating a specific geomorphologic process, can be exceptionally helpful as a very simple indicator of evolution. Therefore, when applied with reference to a particular geological framework, this method can supply the necessary information about the origin of the landscape and its destruction.

The primary objective of this study is to highlight utilization of the frequency distribution curves, with examples of how the drainage network, slopes and other geomorphic parameters develop within hierarchically defined geomorphological systems in the NW part of Hrvatsko Zagorje (Fig. 1). However, the parameters used refer to the recent period in development of the study area, which is defined by the relative age of the drainage basins ranging from the fifth to the third order. Data used in the study derive from the mathematically treated morphometric and geological variables. They are presented in the form of deviations (fluctuations) from standardized means and displayed in appropriate tables and diagrams (PEH, 1994).

2. THERMODYNAMIC BACKGROUND

Earlier investigations of the fluvial geomorphological phenomena, were mostly founded on the concept of energy distribution on the surface of our planet being both stable and uniform in time and space. The steady-state approach assumed that system parameters (variety of landforms presented mainly in the form of morphometric data) uniformly oscillate around an equilibrium position as they adjust (with minimum internal change) to external forces, allowing a system as unity to remain in a stable equilibrium (CHORLEY, 1962; LEOPOLD & LANGBEIN, 1962; HOWARD, 1965; SCHEIDEGGER & LANGBEIN, 1966; KING, 1967 and others). The fact that permanent changes of morphometric parameters do not allow the system to reach stability, even during the long term (SCHUMM & LICHTY, 1965; CHORLEY & KENNEDY, 1971; SCHUMM, 1973; BULL, 1975, and others) had largely been ignored while, at best, a number of temporary steady states can be formed which represent transient phases in the landscape development. The basic idea underlying more recent geomorphological research (COATES & VITEK, 1980; KARCZ, 1980; RITTER, 1988) is founded on the premise that only a particular type of disequilibrium, driven by high fluctuations within the geomorphological system, can generate new landforms.

In the process of adjustment, the mechanisms of self-regulation and self-stabilizing negative feedback formulated in Prigogine's rule of minimum entropy production (PRIGOGINE, 1978), and the Le Châtelier-Brown principle of linear reaction, play the key role. The stability zone in the neighbourhood of equilibrium is usually called the thermodynamic branch (GLANSDORFF & PRIGOGINE, 1971; NICOLIS & PRIGOGINE, 1977). This is a domain of a linear, stationary regime, where the probability distributions of the system components obey the Gaussian law (NICOLIS & PRIGOGINE, 1977; KEIZER, 1987). Landforms described in terms of different morphometric variables do not greatly deviate from the average, which is valid for a system as a whole. Their main feature, defined in the language of thermodynamics, is aptly expressed in the term of "equilibrium structures".

However, strong external energy inputs can upset a system and drive it completely out of equilibrium. These generate fluctuations with sufficiently high potential energy to trigger irreversible loss of structural stability, which manifests itself largely through the mechanism of positive feedback. Instead of being

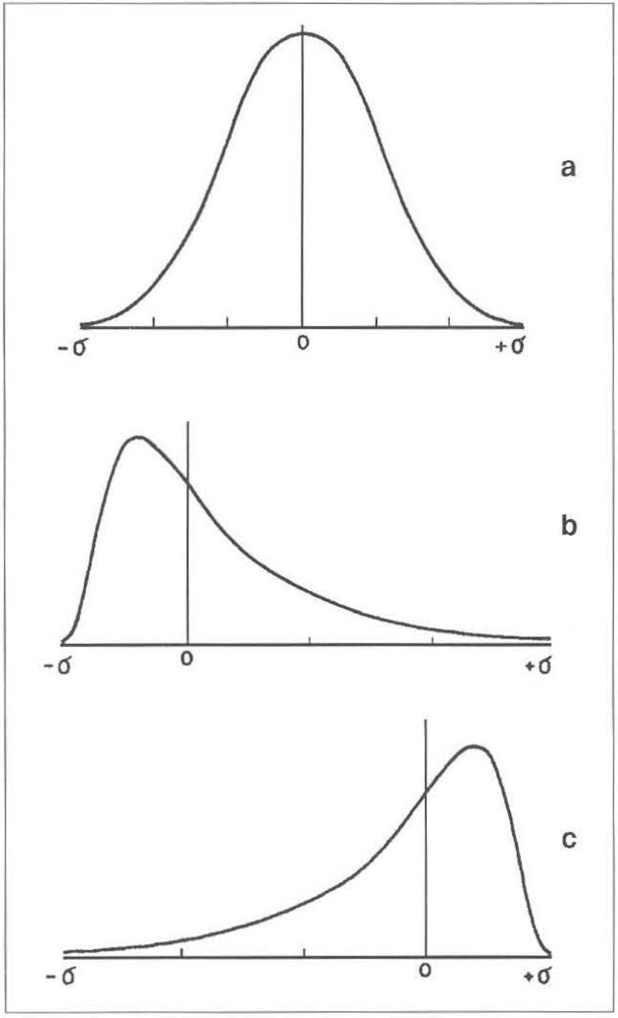

Fig. 2 Typical probability distribution curve of fluctuations: a) Gaussian normal probability distribution curve; b) positively skewed probability distribution curve; c) negatively skewed probability distribution curve. On abscissa σ stands for the measure of fluctuations.

damped, such fluctuations are amplified, leading a system into the domain of a qualitatively different regime of processes, with a distinctively different development nature. Changes at the boundaries of the thermodynamic branch, which cause the onset of the loss of stability, are characterized by the occurrence of non-linear relationships among system parameters, by the shift to a non-Gaussian, skewed frequency distribution of fluctuations (DIMENTBERG, 1989). Landforms originating in such thermodynamic conditions depart considerably from the mean which is characteristic for a system as a whole. Their main properties can be conveniently summarized as being the epitome of "dissipative structures" owing to the strong and continuous dissipation of energy throughout the geomorphological realm (KARCZ, 1980). They are new, self-organized landforms which originated as a result of "order through fluctuations" (GLANSDORFF & PRIGOGINE, 1971; NICOLIS & PRIGOGINE, 1977; PRIGOGINE & STENGERS, 1985; KNORING & DEČ, 1989).

Types of distribution curves

The above considerations lead to the conclusion that the instability of landforms (structural instability when considered in a thermodynamic sense) is caused by great fluctuations which serve as the basic evolutionary impulse in geomorphological systems. In this respect, insight into laws governing the behaviour of the probability distribution of fluctuations is of the greatest importance for the study of their developmental characteristics. In a system which is characterized by structural stability within the limits of the thermodynamic branch, fluctuations will be distinguished by a quite different probability distribution with regard to another system with an unstable response in the neighbourhood of, or beyond the thermodynamic threshold. In the first case, when a system is dominated by an equilibrium regime, the frequency distribution of fluctuations will exhibit a normal (Gaussian) shape of probability curve (Fig. 2a). In the latter, however, when the balance of a system is upset, and relationships approach the non-linear domain, the frequency distribution of fluctuations will assume positive skewness (Fig. 2b). This type of asymmetry is a direct effect of the presence of a very small number of fluctuations carrying a high energy potential. They have the least probability of occurrence owing to the second law of thermodynamics which prescribes that equilibrium in the neighbourhood of the mean system trajectory exemplifies the most probable system state. The greater the magnitude of fluctuations (that is, their potential energy), the smaller the probability of their occurrence, which accounts for a positive skew of their distribution becoming more and more pronounced (DIMENTBERG, 1989).

There is another type of geomorphological process which is also characterized by a skewed frequency distribution curve. In this case, quite a different set of processes is observed, which are distinguished by a lack of energy. This state is characterized by a relatively small number of fluctuations with exceptionally high negative amplitudes. Generally, this is the case when many of the fluctuations are clustered at or near an upper limit of some natural process (KOCH & LINK, 1971), as distinguished from the system processes which tend to maintain the structural stability of existing steady states (normal distribution of fluctuations), or processes that give rise to new, more organized structures (positively skewed distribution of fluctuations). The emphasis here is on the processes of gradual decay of preexisting structures which are surrounded by conditions of decreasing potential energy, necessary either to maintain the stationary state or to spur evolutionary change, thus producing a negatively skewed distribution.

3. A CASE STUDY

Geomorphological processes are distinguished not only by their ample diversity, but also by their specific

	min	max	skewness	kurtosis	KS-	KS+	type of distribution
	PROCESSES CONCERNING DRAINAGE NETWORK						
horizontal dissection	-1.49	4.79	1.42	2.95	0.09	0.11	⇒
drainage density	-2.84	2.90	-0.30	0.42	-0.06	0.04	+
	PROCESSES CONCERNING VERTICAL DIFFERENTIATION						
vertical dissection	-1.55	3.11	0.75	1.60	0.05	0.08	+
slope	-1.78	2.15	-0.11	-0.99	0.08	0.07	⇐
erosional levels	-	-	-	-	-	-	-
hypsometric integral	-3.00	3.64	0.54	1.96	0.06	0.09	+

Table 1 Distribution of fluctuations in the investigated geomorphological system of the 3rd order (N=180). Critical values of K-S test for 180 objects: KS+, KS- = 0.0909 (α=0.05); ⇒ positive skewness; ⇐ negative skewness; + normal distribution.

spatial dynamics. The system dynamics produce a whole array of landforms, particularly in the fluvial landscape. Investigations have shown (e.g. STRAHLER, 1952; MELTON, 1957; BRUSH, 1961; CARSON, 1971; RITTER, 1978; HART, 1986, and others) that the nature of geomorphological processes is affected not only by the magnitude, duration and direction of driving forces, but equally, if not to a greater extent, by the resistive forces of the underlying geological framework. In the mutual interaction of the driving and resistant forces, energy and material entering a system is transferred either through specific composite landforms, or landscape subsystems, which simultaneously undergo different stages of development. The study of the relationship between typical geomorphological processes and their respective landforms in the NW part of Hrvatsko Zagorje (PEH, 1994), has demonstrated that a geomorphological system, observed as a structural unity over certain period of time, can, if only temporarily, exist in a state of balance with these processes. Nevertheless, its separate parts, or subsystems, can exhibit different stages of non-equilibrium state, the ultimate effect of which would either be evolutionary growth or degeneration. Tectonism and lithological factors are of extraordinary significance owing to their role as regulatory agents moderating the influence of external factors, as they tend to absorb the effects of external disturbance (driving forces, particularly tectonism) and to establish a steady state between form and processes (CHORLEY & KENNEDY, 1971).

The analysis of geomorphological systems of different hierarchical levels (ranked after the order or relative age of the main valleys) in the NW part of Hrvatsko Zagorje (Fig. 1) shows that the study area is composed of several very homogeneous landscape units, or subsystems, being quite distinctive on the local and regional scales of system relationships. These subsystems comprise: horizontal dissection, drainage density, vertical dissection, slope, erosional levels and the hypsometric integral. They develop as a result of two basic types of land forming processes - the processes of horizontal and vertical differentiation. Apparent variations can arise from differences in magnitude involving the spatial and temporal scales on which the relationships in the geomorphological systems of third, fourth and fifth order are observed (PEH, 1994). It is logical, therefore, to expect the nature of fluctuations, typical for particular subsystems, to depend on both the type of geomor-

	min	max	skewness	kurtosis	KS-	KS+	type of distribution
	PROCESSES CONCERNING DRAINAGE NETWORK						
horizontal dissection	-1.30	4.30	1.41	2.50	0.11	0.16	⇒
drainage density	-	-	-	-	-	-	-
	PROCESSES CONCERNING VERTICAL DIFFERENTIATION						
vertical dissection	-1.58	2.99	1.03	0.94	0.06	0.10	⇒
slope	-2.37	1.75	-0.46	-0.38	0.10	0.05	⇐
erosional levels	-2.11	3.21	0.38	0.53	0.04	0.05	+
hypsometric integral	-1.94	4.10	1.06	3.56	0.04	0.05	+

Table 2 Distribution of fluctuations in the investigated geomorphological system of the 4th order (N=160). Critical values of K-S test for 160 objects: KS+, KS- = 0.0964 (α=0.05); ⇒ positive skewness; ⇐ negative skewness; + normal distribution.

	min	max	skewness	kurtosis	KS-	KS+	type of distribution
			PROCESSES CONCERNING DRAINAGE NETWORK				
horizontal dissection	-1.29	2.74	0.61	-0.50	0.10	0.13	⇒
drainage density	-2.72	2.99	0.15	0.91	0.06	0.08	+
			PROCESSES CONCERNING VERTICAL DIFFERENTIATION				
vertical dissection	-1.68	2.83	1.21	1.78	0.06	0.13	⇒
slope	-2.70	1.55	-1.19	1.57	0.13	0.08	⇐
erosional levels	-3.55	1.90	-0.99	2.73	0.13	0.07	⇐
hypsometric integral	-1.97	2.36	-0.32	0.20	0.08	0.05	+

Table 3 Distribution of fluctuations in the investigated geomorphological system of the 5th order (N=102). Critical values of K-S test for 102 objects: KS+, KS- = 0.1208 (α=0.05); ⇒ positive skewness; ⇐ negative skewness; + normal distribution.

phologic process and the scale inferred. If the distributional characteristics of fluctuations are to be properly studied, it is necessary to test the normality of their frequency distribution with respect to each specific subsystem (Tables 1, 2 and 3). This normality test can allow conclusions to be made about the dynamics of the most prominent geomorphological process. Distributional characteristics of fluctuations can be tested by nonparametric statistical tests including the Kolmogorov-Smirnov (KS) test where the critical values (KS_K) can be taken from the appropriate tables (e.g. DAVIS, 1986).

The procedure of how the frequency distributions compare to a normal curve is shown in Tables 1-3, for each separately investigated geomorphologic system. Analysis of frequency distributions yields some very significant results for the interpretation of the development of the investigated geomorphological systems. It is obvious from Tables 1-3 that the individual subsystems have followed different paths of development in the various geomorphological systems. Morover, proceeding from lower to higher level relationships, a regular transformation of the shape of the distribution curve is apparent. This change manifests itself by a decrease of potential energy contained in the fluctuations, which cause a shift toward the sinistral, negative skewness with regard to specific geomorphological processes. The factors governing the migration of the mean system state trajectory ($\bar{x}=0$) toward the negative values (the probability of the appearance of negative fluctuations decreases) can be numerous, but for the most part they arise from the effect of serial autocorrelation which becomes conspicuous as the higher-order geomorphological systems increase their structural complexity (CHORLEY & KENNEDY, 1971). Namely, intricate and mutually perplexed relaxation paths, paved by serial autocorrelation due to the presence of the same morphometric variables, especially in the systems of a higher rank, can considerably damp the effect of individual inputs of external forces causing their activity to fall under some significant energy threshold (CHORLEY & KENNEDY, 1971). In addition, it must be emphasized that the increase of a system rank (both enlargement of the phase space and expansion of its physical borders) unavoidably leads a system to a state of higher entropy (WOOD & FRASER, 1977). Thus, one can logically expect a system of the fifth-order drainage basins to have higher entropy with respect to one of the fourth-order, and the latter with respect to the one of the third-order.

Examination of Tables 1-3 and Figs. 3-5 reveals that only the processes concerning the development of horizontal dissection cause data to assume a markedly positive skew of distribution, irrespective of the hierarchical order under consideration. Such a trend can be explained by the continuous reorganization of the subsystem of horizontal dissection which manifests itself at all hierarchical levels. When a drainage basin with expanding drainage network of a given order **u** exceeds some limiting size, there is a jump in the reorganization of drainage texture. This produces a new drainage basin of higher order **u+1** (CHORLEY & KENNEDY, 1971). In accordance with the earlier consideration about stability, the new drainage basin of order **u+1** exhibits the features of dissipative structures which are distinctly different in relation to the rest of the drainage basins of order **u** to which it previously belonged. A positively skewed frequency distribution curve (also histogram of fluctuations), which is indicative of the processes concerning development of horizontal dissection, serves as a sure indicator of the drainage network evolution in local (third-order drainage basin system), and regional (fifth-order drainage basin system) boundaries of system relationships. It is also characteristic of the high energy potential of the climatic factor (insolation, precipitation) in the study area, which operates approximately with the same intensity, regardless of the space-time scale defined by the hierarchical order of the investigated geomorphological system (Fig. 3).

The processes of vertical dissection are also distinguished by an expressly positively skewed distribution, with the exception of the third-order drainage basin sys-

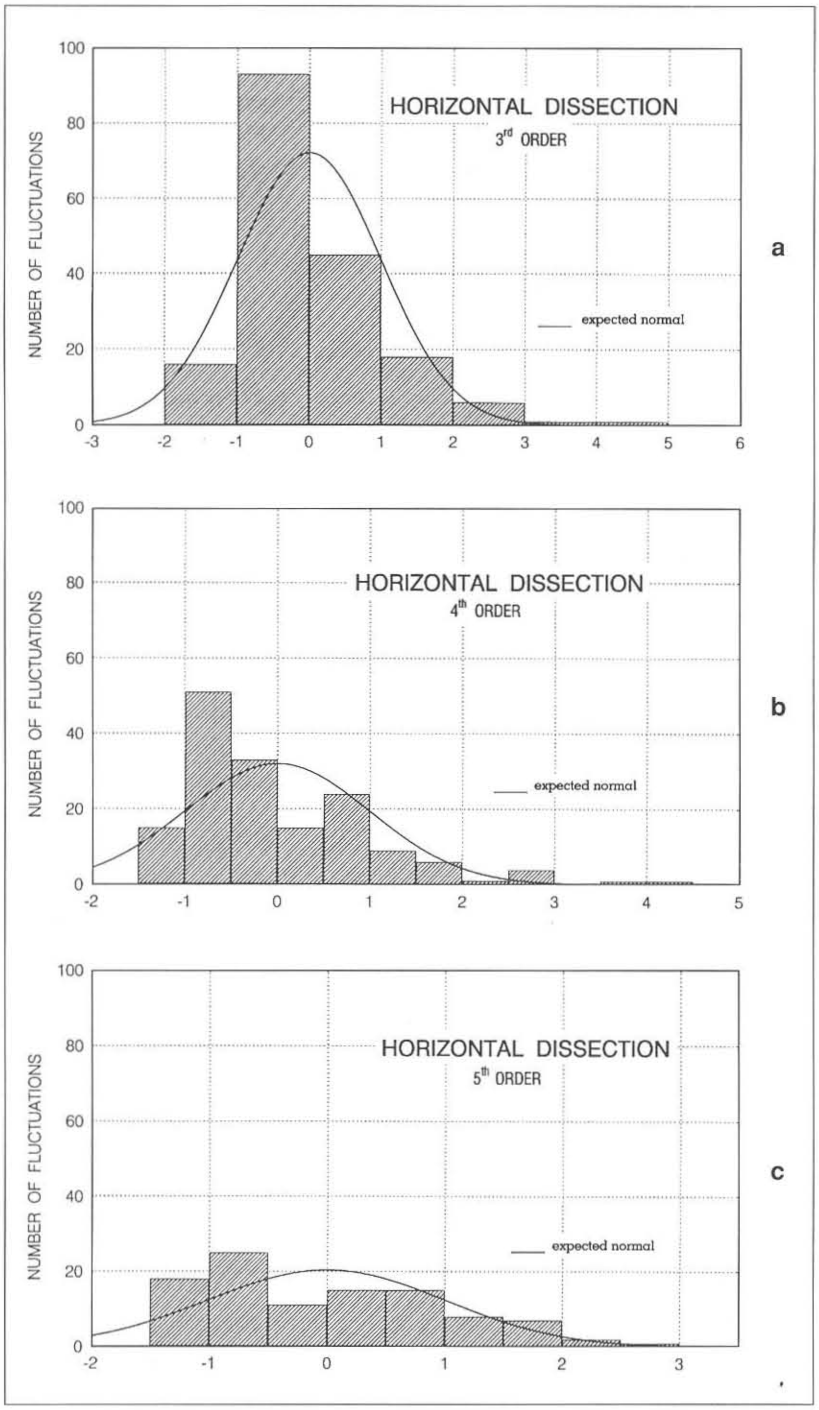

Fig. 3 Frequency distribution histogram of fluctuations for the horizontal dissection, 3-5th order, in the area of investigation.

tem, where the subsystem of vertical dissection is found to be in stable equilibrium. This stability, irrespective of the slightly prominent positive asymmetry of the frequency distribution curves (Table 1), can be explained as a result of the complex response to external variables. The characteristic properties of vertical dissection such as, for instance, the third-order drainage basin relief, are combined with other altitudinal aspects of drainage basins - valley-side slope, for example - which increases the multiplicity of possible linkages among variables. This allows many alternatives for potential adjustments among the landscape properties. Additional relaxation paths occur so that a stationary state can be achieved relatively easily and quickly, even under great variations in the external regime including both endogenetic and exogenetic forces (CHORLEY & KENNEDY, 1971). In the fourth- and fifth-order drainage basins (Tables 2 and 3), where the vertical dissection is dominantly characterized by the highest point on a watershed, and the total relief inside the basin (PEH, 1990, 1992), such a possibility is considerably reduced. On this account the subsystem of vertical dissection, as an integral part of the fourth- and fifth-order drainage basin system, adjusts to external impulses through the reorganization of its structural properties, and development of dissipative structures in the zones where the structural stability has been irreversibly lost. Since horizontal and vertical dissection represent the dominant

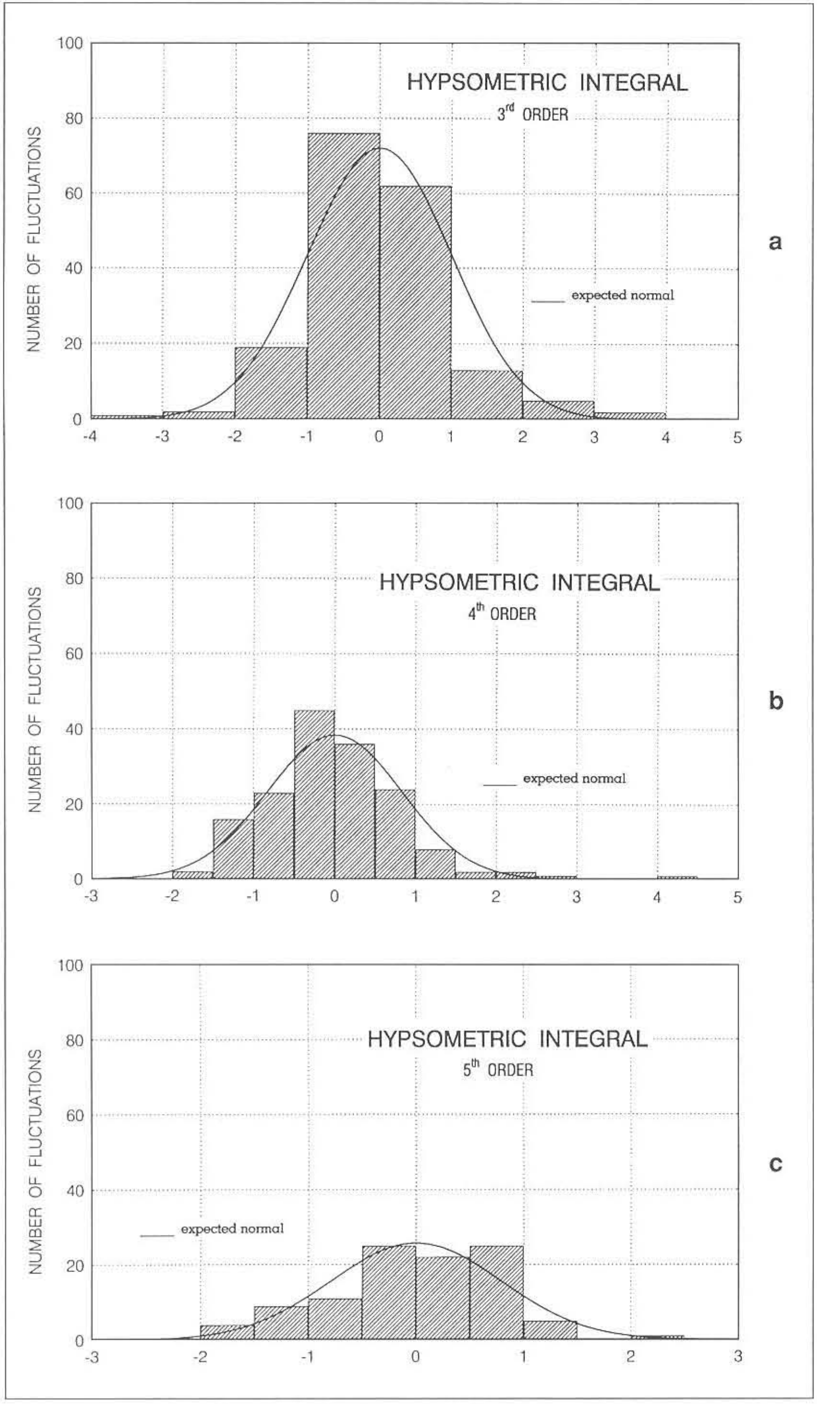

Fig. 4 Frequency distribution histogram of fluctuations for the hypsometric integral, 3-5th order, in the area of investigation.

geomorphological processes in the landscape of the study area, it is logical to assume that they will mostly reflect the evolutionary trends of the observed geomorphological systems.

Another group of geomorphological processes is distinguished by a normal frequency distribution curve of fluctuations, indicating structural stability of the pertaining subsystems, which is a consequence of their ability to maintain their structural attributes in the existing regime of external forces. Such is the case of the subsystem of hypsometric integral (Fig. 4) and the subsystem of drainage density being integral parts of the fourth- and fifth-order drainage basin systems. System components fluctuate within the limits of the thermodynamic branch, sustaining the existing stationary state. In other words, potential energy carried by the fluctuations is neither too high to spur evolutionary changes, nor too low to bring about degeneration of the present structures. The normal frequency distribution curve of fluctuations in the subsystem of drainage density supports the general concensus of opinion that drainage density in its present extent reflects a balance between the input and output of the hydrological cycle. Its pattern discloses a number of mutual adjustments providing for the maximum and most efficient surface runoff in the drainage basin (CHORLEY & KENNEDY, 1971). Conversely, the subsystem of the hypsometric integral (Fig. 4) reflects equilibrium tendencies in the processes

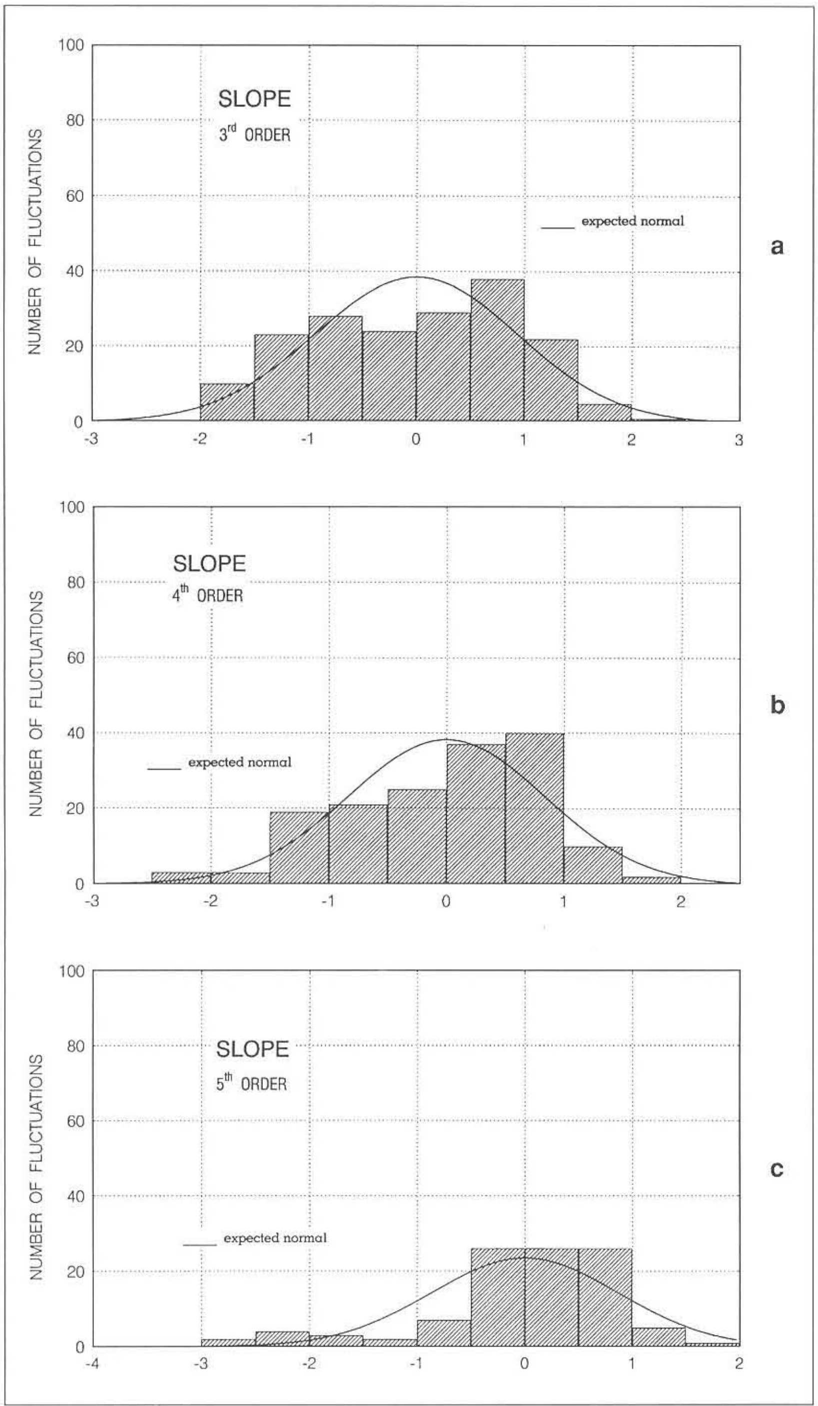

Fig. 5 Frequency distribution histogram of fluctuations for the slope, 3-5th order, in the area of investigation.

of denudation, erosion, transportation and aggradation. In lower-order drainage basins the balance is established owing to the negative feedback between total relief and hypsometric integral (that is, among morphometric properties only). In the higher-order drainage basins lithology plays the role of moderator in the process of mutual adjustment of the two morphometric variables - channel gradient and valley-side slope (PEH, 1992).

Processes involved in shaping the slope subsystem (Fig. 5) and the subsystem of erosional levels are distinguished by the progressive modification of the frequency distribution curve which shifts from normality towards negative skeweness as the order increases. The slope subsystem in the third-order drainage basin system is characterized by the normal distribution of fluctuations. In the fourth- and fifth-order drainage basin system the distribution is more negatively skewed (Fig. 5). The subsystem of erosional levels, which dissociates from the subsystem of vertical dissection in the fourth-order drainage basin system, is at this hierarchical level characterized by normal distribution of fluctuations, but becomes negatively skewed in the fifth-order drainage basin system. It can be stated that in this case only the minority of system components in these basin subsystems oscillates in the proximity of the lower limit of the thermodynamic branch (that is, the probability of exceptionally high negative fluctuations is very small).

It suggests that the potential energy in specific parts of a system is so low that existing structures (landforms) undergo spontaneous degeneration in the places where its magnitude falls below some critical value necessary for maintaining the stationary state. A reason for this can be found either in the unfavourable mechanical properties of the underlying bedrock (high permeability and low cohesion of rock and soil material), or in varying rates of uplift that affect some major tectonic blocks in the area of investigation. If the former is case, the valley-side slopes tend to form lower angles due to ineffective stream downcutting (caused chiefly by relatively high infiltration capacity), which is most conspicuously reflected in higher-order and larger drainage basins (fourth- and, particularly, fifth-order). In the latter, denudation processes give way to aggradation processes when the uplift only slightly exceeds or even tends to be lower than the rates of denudation. As an example, in the subsystem of erosional levels one of the key variables - the main-valley mouth (which is also the mouth of a referring drainage basin) - represents an overt indicator of uplift and subsidence that can be helpful in disclosing "active" and "inactive" geologic structures in a landscape. Obviously, due to their relative lag in respect of the general uplift typical for the study area (PRELOGOVIĆ, 1975), some tectonic blocks have considerably lower potential energy with respect to the surrounding area, inducing the processes of aggradation and development of "inactive" geologic structures. Both examples show that the energy expenditure in these subsystems occurs mostly at the lower hierarchical levels (PEH, 1992, 1994).

4. CONCLUSIONS

Examples presented in this study show that various landforms in the fluvial landscape, such as the northwestern part of Hrvatsko Zagorje, can pursue different evolutionary schemes which can be discerned from the corresponding frequency distributions of fluctuations. The thermodynamic theory of non-equilibrium states and related fluctuations as the source of instability is the key element in the interpretation of evolutionary trends in geomorphological systems and their subsystems. This results from utilizing new insights in fundamental physics in the geological sciences.

It has been shown in this study that three types of frequency distribution curves exist which, in a thermodynamic sense, can be indicative of equilibrium and non-equilibrium relationships between driving and resisting forces in land forming processes. They show how landforms try to adjust themselves with minimum internal change to the external driving forces. The example of the processes responsible for the development of the subsystem of drainage density and subsystem of hypsometric integral is presented.

Non-normal frequency distribution of system parameters indicates non-equilibrium conditions which give rise to non-linear relationships between process and form and, accordingly, to structural instability within specific subsystems. Such a case is demonstrated by both the positive and negative skew of distribution frequency curves. Positive skew is indicative of structural change which is the response to strong energy inputs from the system surroundings. The loss of structural stability and emergence of new and more complex landforms is the final result which spurs landscape evolution. An example of this was shown by the processes accounting for drainage network expansion (horizontal dissection) and, to some extent, by the processes of valley incision (vertical dissection). Negative skew, on the contrary, can suggest structural changes distinguished by the lack of energy in a system, which is insufficient to reinstate the original equilibrium conditions and, thus, to sustain existing landforms. This case predicts the downward path to landscape degeneration, that is, its involution. Such a case is exemplified by the processes affecting valley-slope angles and erosional levels.

Although the relevant space and time scales have been taken into consideration, this study has been put into a frame which, in a geomorphological and geological sense, could not be strictly viewed upon as regional. However, the results point to distinct evolutionary laws that rule the development of a fluvial landscape in the temperate climate zones. Further investigations should therefore be directed toward the spatial evaluation of thermodynamically specified geomorphological parameters with assistance of the relevant maps ("process maps", PEH, 1994). Attention should also be paid to the concept of geomorphological thresholds and boundary values delimiting landform stability. This would allow individual landforms and their evolutionary (or, contrarily, degenerative) changes to be directly related to geological structures, lithological characteristics and tectonic activity.

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