VARIABILITY OF THE MORPHOMETRIC CHARACTERISTICS OF VALLEY NETWORKS CAUSED BY VARIATIONS IN A SCALE

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ABSTRACT

According to their shape, the valley networks are divided into six basic types (Howard 1967; Fairbridge 1968; Demek 1987; Babar 2005; Hugget 2007). Relevance to the given shape tends to be determined only based on the visual similarity to the pattern of the given network shape. The valley networks have a fractal character (Turcotte 1997, 2007a, 2007b; Baas 2002; Mandelbrot 2003) and their analysis is influenced by the scale selection (sensu Bendix 1994). This article indicates the quantitative tools, with assistance of which it is possible to characterize the morphology (shape) of the valley network and determine their variability caused by the scale change. The monitored morphometric characteristics (quantitative tools) are: 1) "number of various order valleys" according to the Gravelius order system; 2) "valley networks' density"; 3) "bifurcation ratio of various order valleys"; 4) "total lengths of various order valleys"; 5) "total length-order ratio of various order valleys"; 6) "average lengths of various order valleys"; 7) "average length-order ratio of various order valleys"; 8) "fractal dimension of various order valleys"; 9) "relative fractal dimension of various order valleys"; 10) "valley junction angles"; 11) "homogeneity of various order valleys". These characteristics have been applied to the paradigmatic examples of the schematic valley networks and have been analyzed in three scales.

In order to analyze the valley networks, the most suitable are "valley junction angles" and "homogeneity of various order valleys", i.e. morphometric characteristics resistant to any increase in the scale, "number of various order valleys" and "total lengths of various order valleys", where the relevant values dropped while increasing the scale, but the normal (Gauss) distribution of values was preserved.

Keywords: valley network, morphometry, fractal dimension, hierarchical scale

1. Introduction

The system of interconnected valleys forms the valley network, i.e. the system of linear depressions that are interconnected. The basic units of the valley networks are individual valleys. Not only valleys are connected into networks, which may be observed with other landscape elements, e.g. the patterned ground (Washburn 1979), drainage patterns (Horton 1945), leaf venation (Zalenski 1904 in Uhl and Mosbrugger 1999), transport routes (Kansky 1963), etc. The shape of the valley network and its density is the result of geomorphological development of the whole area and reflects the influence of the lithological-tectonical base and erosion (Stoddart 1997).

Six basic shapes of the valley networks are distinguished (colour appendix Figure I, Howard 1967; Fairbridge 1968; Horník et al. 1986; Demek 1987; Gerrand 1988; Babar 2005; Huggett 2007): 1) dendritic networks (often formed in the areas with a low vertical division); 2) parallel networks (often formed in the areas with a considerable inclination of slopes; 3) trellis networks and 4) rectangular networks (both of them are formed in the areas with a frequent presence of tectonics); 5) radial networks, and 6) annular networks (both of them are formed, for example, on volcanic cones or on other convex or concave curved landscape parts). For a long time, determination of the valley network shape was solely based on visual estimation without considering the importance of the scale, within which the valley network is evaluated (Howard 1967; Huggett 2007).

The valley networks shape could be characterized by the morphometric parameters describing the topologic and geometric properties of valley networks, which are given by the landscape characteristics. The studied morphometric characteristics are (sensu Horton 1945; Netopil et al. 1984; Babar 2005; Hugget 2007): 1) "number of various order valleys" according to the Gravelius order system (it indicates the number of valleys within the given network and the number of valleys belonging to the given order); 2) "bifurcation ratio of various order valleys" (indicates the rate of the valley networks branching); 3) "average length-order ratio of various order valleys" (allows mutual comparison of the average lengths of valleys); 4) "valley networks' density" (expresses the number of valleys in a certain area). It generally applies that greater "number of various order valleys", greater "bifurcation ratio of various order valleys" and greater "valley networks' density" are in the areas: A) with low inclination of landscape; B) with alternating resistant and less resistant rocks; C) with occurrence of faults and cracks; D) with impermeable rocks; and E) with a higher rainfall (Huggett 2007).

The valley networks are specific fractals (from Lat. *Fractus* = disintegrate) (Stuwe 2007) and are featured by a hierarchical scale (Bendix 1994) that expresses their self-affinity (Mandelbrot 1967; Stuwe 2007) and self-similarity (Mandelbrot 1982; Voss 1988). Determination of the valley network's shape by means of morphometric parameters is not, with respect to its fractal substance (so called scale independence), quite trivial. It is known that
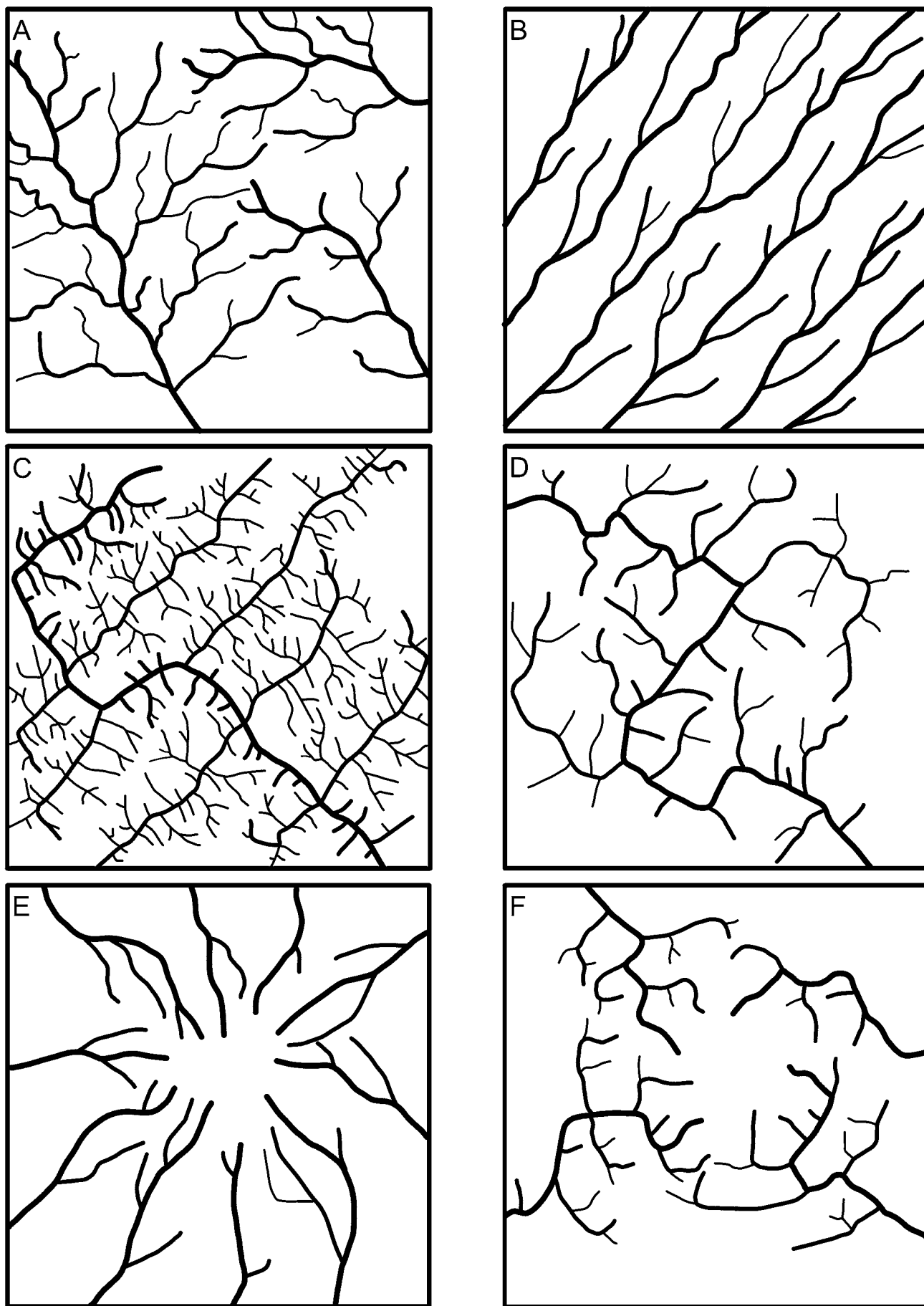
Fig. 1 Howard's schematic valley networks (1967). Note: A – dendritic valley network, B – parallel valley network, C – trellis valley network, D – rectangular valley network, E – radial valley network, F – annular valley network.

the "fractal dimension of various order valleys" and the values of the other morphometric characteristics vary due to different conditions of the investigated territories, but also due to the scale change (sensu Burrough 1981; Tarboton 1996; Sung et al. 1998; Baas 2002; Mandelbrot 2003; Sung and Chen 2004; Turcotte 1997, 2007a, 2007b; Bi et al. 2012). But the real value changes of the "fractal dimension of various order valleys" and other morphometric characteristics within individual shapes of valley networks have not been known so far.

The main goal of this article is to define quantificators, with support of which it is possible to characterize the shape (i.e. morphology type) of the valley network and to determine variability of these quantificators caused by increasing of scale.

2. Methods

2.1 Schematic networks and scale selection

In order to analyse the valley networks, schematic valley networks have been selected (samples of valley networks) (Howard 1967; Fairbridge 1968; Horník et al.

1986; Demek 1987; Gerrand 1988; Babar 2005; Huggett 2007) that have been used for visual classification (Figure 1). Each shape of the valley network (dendritic, parallel, trellis, rectangular, radial, annular) has been represented by one example.

Schematic valley networks have been analyzed in various scales (sensu Bi et al. 2012). The original analyzed territory of the given (primary) scale corresponded to the patterns of valley networks taken from the literature (e.g. Howard 1967). Furthermore, a secondary square as an inscribed square has been formed from the original image, where its corners are placed in the middle of the original square sides. The newly formed square is half of the area as compared with the original (primary) square and the ratio of side lengths of the original (primary) and secondary square is approximately 1 : 0.7. The territory with the area of 1/4 of the original (primary) square has been derived by analogy from the secondary square – thus the tertiary square has been formed, where the ratio of the side lengths of the original (primary) and tertiary square is 1 : 0.5. The scale increase has been simulated by ascribing the same side lengths of the inscribed squares as are the side lengths of the original (primary) square (Figure 2).
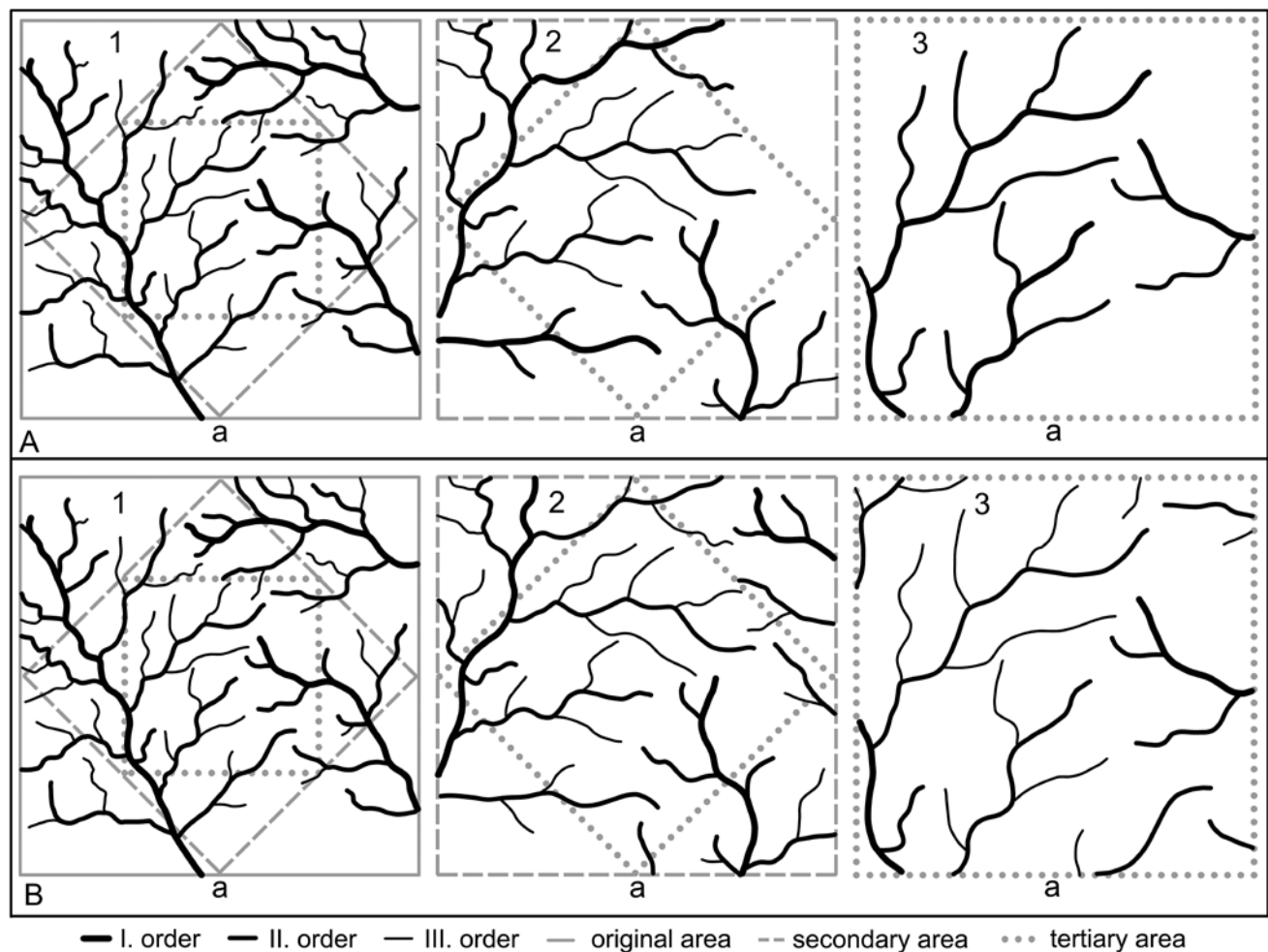

Fig. 2 The valley order during the scale change. Note: A – variant A with main valley defined by length of a valley source; B – variant B with main valley defined by valley junction angle between a valley source and blended valley; 1. – original area (primary scale); 2. – secondary area; 3. – tertiary (cutout) area; a – side length of squares.

As the original schematic images of valley networks do not have same scales, it has been necessary to reflect that fact in the relevant analyses. Therefore variability of morphometric characteristics asociated with changes of scale were monitored and analyzed and/or new characteristics (non-dependant on scale changes such as indices) were defined.

2.2 Determination of the valley networks' order

The valley networks' order has been determined based on the Gravelius order system that defines the valley networks' order in the direction from the outfall towards the valley head. The valley network is formed by the main/primary (i.e. the I. order) valley, into which outfalls the subsidiary/secondary (i.e. the II. order) valley, and into these valleys later outfalls the tertiary (i.e. the III. order) valley, etc. (Gravelius 1914 in Zăvoianu et al. 2009).

The analysis of the valley network is dependent on the mode of determination of the main valley that influences the valley order calculation. The main valley has been determined either by comparing the lengths of blending valleys (variant A) or based on the valley junction angle with respect to the common (joined) valley (variant B) (Figure 2) (sensu Horton 1945). As far as the variant (A) is concerned, the longer valley has been designated as the main valley (and it has been assigned order X). The shorter valley has been identified as a secondary one and has been assigned order X + 1. As far as the variant (B) is concerned, the valley with a smaller angle towards the common valley axis (axis of the valley formed by blending of compared valley sources) has been identified as the main valley and has been assigned the same order as the common valley, i.e. order X. The valley with a greater angle towards the axis of order X valley has been designated as a secondary one and has been assigned order X + 1. As for variant (A), while considering either the secondary or the tertiary square (simulating the scale increase), the order was again re-determined for the specific square (Figure 2), because the ratio of lenghts of valleys was changed by trimming. If new I. order valleys arose by this trimming (from the remainders of the original valleys), such new valleys were not therefore considered (Figure 2). As for variant (B), no order changes occurred from the point of view of formation of the secondary and tertiary squares (Figure 2), because the angle of valleys did not changed by trimming.

2.3 Morphometric characteristics of valley networks

On studied schematic networks (patterns), following morphometric characteristics have been determined: 1) "number of various order valleys" according to the Gravelius order system; 2) "valley networks' density"; 3) "bifurcation ratio of various order valleys"; 4) "total lengths of various order valleys"; 5) "total length-order ratio of various order valleys"; 6) "average lengths of various order valleys"; 7) "average length-order ratio of various order valleys"; 8) "fractal dimension of various order valleys"; 9) "relative fractal dimension of various order valleys"; 10) "valley junction angles"; and 11) "homogeneity of various order valleys".

The "number of order X valleys" n_X has been determined as the number of all order X valleys in the valley network.

Calculation of the "valley networks' density" D has been determined as the ratio of the total lengths of thalwegs L to the valley network area P (Horton 1945), i.e.:

$$D = L / P.$$

The valley network area is understood as the area of a minimum square, in which the valley network has been intercepted.

The "bifurcation ratio of valleys" indicates the rate of valey network's branching (Horton 1945):

$$Rb = n_X / n_{X+1},$$

where n_X is the "number of valleys of the given order" according to the Gravelius order system (Gravelius 1914 in Zăvoianu et al. 2009) and n_{X+1} is the "number of valleys of one degree higher order" in the given valley network.

The "total lengths of order X valley" t_X has been defined as the sum of lengths of all order X valleys in the valley network.

The "total length-order ratio of valleys" T has been defined by the relation (Horton 1945):

$$T = t_{X+1} / t_X,$$

where t_X is the "total lengths of valleys of the given order" according to the Gravelius order system (Gravelius 1914 in Zăvoianu et al. 2009) and t_{X+1} is "the total lengths of valleys of one degree higher order" in the given valley network.

The "average lengths of order X valleys" l_X has been defined by the relation (Horton 1945):

$$l_X = t_X / n_X,$$

where t_X is the "total lengths of valleys of the given order" according to the Gravelius order system (Gravelius 1914 in Zăvoianu et al. 2009) and n_X is the "number of valleys of the given order" in the given valley network.

The "average length-order ratio of valleys" Rr has been defined by the relation (Horton 1945):

$$Rr = l_X / l_{X+1},$$

where l_X is the "average lengths of valleys of the given order" according to the Gravelius order system (Gravelius 1914 in Zăvoianu et al. 2009) and l_{X+1} is the "average valley length of one degree higher order" in the same network.

The "fractal dimension of valleys" D used in this study has been based on the "bifurcation ratio of valleys order X and X + 1" Rb and the "average length-order ratio of valleys order X and X + 1" Rr and has been defined by the relation (Turcotte 1997):

$$D = ln\ (Rb)\ /\ ln\ (Rr).$$

The value of the fractal dimension shows to what extent is the territory covered by valleys

of the given order. Increase in the value of "fractal dimension of valley orders X and X + 1" means that the "number of valleys of the X + 1 order" has increased or the "average lengths of valleys of the X + 1 order" has risen.

The "relative fractal dimension of valleys" Dr has been defined by the relation (Turcotte 1997):

$$Dr = ln\ (Rb)\ /\ ln\ (T),$$

where Rb is the "bifurcation ratio of valleys order X and X+1" according to the Gravelius order system (Gravelius 1914 in Zăvoianu et al. 2009) and T is the "total length-order ratio of valleys order X and X + 1" in the given valley network.

The "valley junction angles" express the angles at which the subsidiary (order X + 1) valleys run into the main (order X) valleys projected on a horizontal plane (Horton 1945).

"Homogeneity of order X valleys" has been defined by comparing the lengths of the longest and the shortest valleys of the given order. This characteristic is based on the analogy of homogeneity of the polygon lengths of the patterned ground (Mangold 2005). The valleys of a given order are homogeneous if the lengths of the longest order valley does not exceed three times the lengths of the shortest valley of the same order. If the valley network is not "homogeneous", it is designated as "variable".

3. Results and discussion

3.1 Changes in the values of morphometric characteristics while increasing the scale

While increasing the scale, the "valley junction angles" and "homogeneity of various order valleys" have been preserved in all types of network (Table 1; Table 2). With respect to the fractal substance that has been described with the valley networks by e.g. Mandelbrot (1967, 1982, 2003), Voss (1988), Tarboton (1996) and Turcotte (1997, 2007a, 2007b), while describing them, the constancy of their characteristics is necessary with regard to the scale change.

Independently from the shape of the valley network and the method of determining the main valley (according to the lengths of source valleys – variant A and

according to the angle error of the source valley from the blended valley – variant B), while increasing the scale 1.43 times from the original to the secondary square, or while increasing the scale 2 times from the original to tertial square (Table 1; Table 2), there occurred:

1) drop in the "number of valleys of the II. order" by 2.3% (for the trellis network) up to 50% (for the parallel network) (while increasing the scale 1.43 times), or by 22.7% (for the trellis network) up to 80% (for the radial network) (while increasing the scale two times);

2) drop in the "number of valleys of the III. orders" by 20% (for the paralel network) up to 100% (for the radial network) (while increasing the scale 1.43 times), or by 40% (for the parallel network) up to 100% (for the dendritic and radial network) (while increasing the scale two times);

3) shortening of the "total lengths of valleys of the II. orders" by 4.2% (for the annular network) up to 44.4% (for the dendritic network) (while increasing the scale 1.43 times), or by 18.1% (for the trellis network) up to 72.2% (for the radial network) (while increasing the scale two times);

4) shortening of the "total lengths of valleys of the III. order" by 6.3% (for the annular network) up to 61.6% (for the rectangular network) (while increasing the scale 1.43 times), or by 1.4% (for the parallel network) up to 76.8% (for the rectangular network (while increaing the scale 2 times).

While increasing the scale, a drop in the "number of various order valleys" and shortening of the "total lengths of various order valleys" takes place. However, while increasing the scale, both of these characteristics have preserved the normal (Gauss) distribution of values (Table 1; Table 2). Preservation of the normal (Gauss) distribution shows that the reduction in the "number of various order valleys" and shortening of the "total lengths of various order valleys" was similar for all valley orders.

5) increase in the "average lengths of the II. order valleys" by 8.9% (for the dendritic network) up to 57.3% (for the annular network) (while increasing the scale 1.43 times), or by 2.8% (for the trellis network) up to 82.4% (for the annular network) (while increasing the scale two times);

6) increase in the "average lengths of the III. order valleys" by 19.0% (for the parallel network) up to 84.9% (for the rectangular network) (while increasing the scale 1.43 times), or by 15.6% (for the radial network) up to 182.5% (for the rectangular network) (while increasing the scale 2 times).

In order to describe the shapes of valley networks, the most appropriate characteristics are those that are resistant while changing the scale (sensu Burrough 1981; Bi et al. 2012). From the definition of the "average lengths of various order valleys" it results that this characteristic is based on the "number of various order valleys" and on the "total lengths of various order valleys". Since the scale increase resulted in the increasein the "average lengths

Tab. 1 Variability of the morphometric characteristics of valley networks caused by variations in a scale by variant A. Note: 1 – original (primary) square; 2 – secondary square; 3 – tertiary square; f – from.

Method	Change of scale (order)	Shapes of the valley networks											
		Dendritic		Parallel		Trellis		Rectangular		Radial		Annular	
		f 1. to 2.	f 1. to 3.	f 1. to 2.	f 1. to 3.	f 1. to 2.	f 1. to 3.	f 1. to 2.	f 1. to 3.	f 1. to 2.	f 1. to 3.	f 1. to 2.	f 1. to 3.
Change of numbers of valleys [%]	I.	0.0	0.0	−16.7	−16.7	0	0	0	0.0	+40.0	+20.0	0.0	−25.0
	II.	−42.3	−57.7	−47.8	−73.9	−2.3	−22.7	−28	−64.0	−40.0	−80.0	−39.0	−73.8
	III.	−55.6	−100.0	−40.0	−80.0	−53.8	−83.4	−70	−87.0	−100.0	−100.0	−40.0	−85.0
Change of bifurcation ratio [%]	I. and II.	−42.3	−57.7	−37.4	−68.7	−2.3	−22.7	−28.0	−64.0	−57.2	−83.4	−39.0	−71.0
	II. and III.	−23.1	−100.0	+15.2	−23.0	−52.7	−78.6	−57.7	−63.8	−100.0	−100.0	+0.6	−31.0
Change of average length of valleys [%]	I.	+4.8	+11.2	+2.5	−14.4	+15.8	−39.5	+7.5	−3.0	−20.8	−31.7	−17.7	−14.3
	II.	+8.9	+15.2	+33.8	+19.1	−7.2	+2.8	+19.5	+38.7	+26	+38.6	+57.3	+82.4
	III.	+45.8	–	+17.8	+83.6	+43.7	+71.1	+84.9	+157.7	–	–	+57.3	+63.5
Change of avcerage length-order ratio [%]	I. and II.	−4.0	−3.4	−23.5	−28.1	+24.8	−41.4	−10.0	−30.0	−36.9	−50.9	−47.5	−53.0
	II. and III.	−25.5	–	+13.6	−34.3	−34.0	−38.5	−36.3	−46.2	–	–	0.0	+11.7
Change of fractal dimension of I. and II. order [%]		−23.1	−37.9	−20.0	−82.1	−8.7	+18.0	−6.4	−19.3	–	–	+34.1	−35.7
Change of total length of valleys [%]	I.	+4.6	+11.5	−14.8	−11.8	+15.9	+21.0	+7.3	−2.8	+10.9	−18.8	−17.9	−35.9
	II.	−35.9	−50.4	−30.3	−71.1	−8.0	−18.1	−13.6	−49.8	−24.4	−72.2	−4.2	−60.3
	III.	−35.3	–	−32.4	−64.8	−38.7	−70.5	−61.6	−76.8	–	–	−6.3	−75.7
Change of total length-order ratio [%]	I. and II.	−38.6	−55.6	−18.3	−59.1	−20.7	−32.2	−19.4	−48.4	−32.4	−66.2	+16.8	−39.8
	II. and III.	+2.0	–	−4.1	+22.6	−33.5	−64.0	−55.8	−53.9	–	–	−3.2	−38.7
Change of relative fractal dimension of I. and II. order [%]		+52.9	+309.7	–	–	+22.1	+6.6	+17.8	+151.4	–	+294.7	−50.1	–
Change of valley networks´ density [%]		+2.08	−6.25	+9.38	+3.12	+1.92	+1.92	+30.43	−4.35	+36.36	+22.73	+21.74	−13.04

Scale		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Valley junction angles [°]		60	60	60	30	30	30	90	90	90	90	90	90	30	30	30	90	90	90
Homogeneity of various order valleys	I. order	yes	yes	no	no	yes	no	–	–	yes	–	–	–	yes	yes	yes	yes	yes	yes
	II. order	no	no	no	no	no	no	no	no	no	no	no	no	no	no	yes	no	no	yes
	III. order	no	no	–	yes	yes	yes	no	no	no	yes	yes	yes	–	–	–	yes	yes	yes
	IV. order	–	–	–	–	–	–	no	no	no	yes	–	–	–	–	–	yes	–	–
	V. order	–	–	–	–	–	–	yes	yes	yes	–	–	–	–	–	–	–	–	–

of various order valleys", it means that shortening of the "total lengths of various order valleys" was not so noticeable as the decrease in the "number of various order valleys" (Table 1; Table 2). Consequently, the "total lengths of various order valleys" is more suitable characteristic for describing the valley network than the "number of various order valleys".

3.2 Suitability of morphometric characteristics for the analysis of valley networks

The characteristic that best describes the shape of the studied valley network was the "valley junction angles" (Table 1; Table 2), as the networks shape is determined by the angles between interconnecting sections forming the network (Horák et al. 2007). The characteristic of the "valley junction angles" may include an information on the tectonic influence upon the studied territory or the inclination of slopes. The "valley junction angles" were similar for the trellis, rectangular and annular networks (ca 90°; Table 1; Table 2). As the tectonic disturbances are largely parallel or orthogonal to each other (Howard 1967; Fairbridge 1968; Demek 1987), it is possible to assume that the intersecting valleys, whose "valley junction angles" are about 90°, are bound to tectonic failures. The most frequent value of "valley junction angles" of the radial and parallel networks reached about 30° and those of the dendritic networks reached about 60° (Table 1; Table 2). Similar angle values corresponding to the individual types of valley networks were traced at the real valley networks by the remote sensing methods, by Burr et al. (2013); trellis and rectangular networks reached 80–90°, dendritic networks reached 40–80°, radial and parallel networks less than 40°.

For the complete differentiation of valley network groups, the characteristic of the "valley junction angles"

Tab. 2 Variability of the morphometric characteristics of valley networks caused by variations in a scale by variant B. Note: 1 – original (primary) square; 2 – secondary square; 3 – tertiary square; f – from.

Method	Change of scale (order)	Dendritic		Parallel		Trellis		Rectangular		Radial		Annular	
		f 1. to 2.	f 1. to 3.	f 1. to 2.	f 1. to 3.	f 1. to 2.	f 1. to 3.	f 1. to 2.	f 1. to 3.	f 1. to 2.	f 1. to 3.	f 1. to 2.	f 1. to 3.
Change of numbers of valleys [%]	I.	0.0	−33.3	−33.3	−50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	II.	−34.6	−65.4	−43.5	−65.2	−50.0	−63.6	−4.0	−44.0	−15.0	−45.0	−21.7	−52.2
	III.	−30.8	−53.8	−20.0	−40.0	−46.2	−71.0	−34.7	−69.9	0.0	0.0	−30.0	−70.0
Change of bifurcation r atio [%]	I. and II.	−34.6	−48.1	−15.2	−30.3	−50.0	−63.6	−4.0	−44.0	−15.0	−45.0	−21.7	−52.2
	II. and III.	+6.0	+33.3	+41.9	+72.8	+7.0	−20.3	−57.7	−45.7	+18.0	+82.0	−10.6	−37.4
Change of average length of valleys [%]	I.	−23.1	−41.7	+13.1	−1.8	−29.0	−41.5	+7.3	−16.3	−10.5	−35.3	−17.1	−31.4
	II.	+23.4	+73.9	+35.9	+58.5	+33.3	+47.5	+16.9	+42.7	+18.7	+31.3	+36.9	+24.2
	III.	+48.6	+105.7	+19.0	+69.3	+58.0	+108.7	+82.5	+182.5	+49.8	+15.6	+54.5	+87.3
Change of average length-order ratio [%]	I. and II.	−37.6	−69.1	−16.8	−38.0	−46.7	−60.3	−8.2	−41.3	−24.6	−50.9	−39.3	−44.6
	II. and III.	−14.7	−15.1	+14.6	−6.3	−15.7	−29.4	−35.9	−49.4	−20.5	+13.7	−11.2	−33.7
Change of fractal dimension of I. and II. order [%]		+33.5	+767.0	+1.0	+11.3	+8.7	+15.3	+2.1	+6.4	+4.7	−59.4	+34.9	+1.6
Change of total length of valleys [%]	I.	−48.2	−61.0	−24.7	−51.0	−29.0	−77.8	+7.9	−15.73	−10.3	−35.3	−17.1	−32.3
	II.	−44.4	−38.2	−20.8	−43.3	−37.5	−46.0	+2.5	−19.23	+1.3	−27.4	+7.8	−40.6
	III.	−33.2	−7.8	−8.5	−1.4	−14.5	−40.0	−17.4	−40.5	+55.0	+15.0	+7.2	−44.1
Change of total length-order ratio [%]	I. and II.	+7.3	+58.3	+5.4	+15.1	−12.1	+143.7	−4.8	−4.0	+13.2	+11.8	+30.8	−11.9
	II. and III.	+20.0	+50.0	+16.4	+13.7	+36.6	+10.9	−18.6	−25.5	−85.1	−83.6	0.0	−6.5
Change of relative fractal dimension of I. and II. order [%]		−25.1	−52.9	–	–	−8.91	−57.4	+4.5	−14.1	–	–	−50.9	−10.4
Change of valley networks´ density [%]		+19.6	+30.0	+9.4	+12.5	+15.4	+19.2	+30.4	+39.1	+36.3	+45.5	+30.4	+17.4

Scale		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Valley junction angles [°]		60	60	60	30	30	30	90	90	90	90	90	90	30	30	30	90	90	90
Homogeneity of various order valleys	I. order	yes	yes	yes	no	yes	yes	–	–	yes	–	–	–	yes	yes	yes	yes	yes	yes
	II. order	no	no	no	no	no	no	no	no	no	no	no	no	no	no	yes	no	no	no
	III. order	no	no	no	yes	yes	yes	no	no	no	yes	no	yes	–	–	–	yes	yes	yes
	IV. order	–	–	–	–	–	–	no	no	yes	yes	–	–	–	–	–	yes	–	–
	V. order	–	–	–	–	–	–	yes	yes	yes	–	–	–	–	–	–	–	–	–

must be completed by the characteristics "number of various order valleys" and the "total lengths of various order valleys". From the definitions of characteristics of the valley networks it results that the "bifurcation ratio of various order valleys", "total length-order ratio of various order valleys", "average lengths of various order valleys", "average length-order ratio of various order valleys", "fractal dimension of various order valleys", "relative fractal dimension of various order valleys", are based on the "number of various order valleys" and the "total lengths of various order valleys", and therefore they correlate with these characteristics (Figure 3).

"Valley networks' density", which Slaymaker (2004) and Huggett (2007) consider to be the basic characteristic of the valley network description, also contains information about landscape in which the valley network developed. The largest "valley networks' density" at the trellis and dendritic networks (Table 1; Table 2) may be caused

by their occurrence in the areas: A) with a low inclination of landscape; B) with alternating resistant and less resistant rocks; C) with occurrence of faults and cracks; D) with impermeable rocks; or E) with a higher rainfall (sensu Demek 1987; Tarbotton 1996; Huggett 2007). In contrast with that, the lowest "valley networks' density" with the parallel and radial networks (Table 1; Table 2) may be caused by their occurrence: A) in the areas with a considerable inclination of slopes; B) in the areas with permeable subsoil or in the karst areas; or C) in the arid areas (sensu Demek 1987; Tarbotton 1996; Huggett 2007). Although the "valley networks' density" is mentioned in the literature as one of the most frequently referred to characteristic describing all types of networks (e.g. Davis 1913 in Goudie et al. 2004; Zalenski 1904 in Uhl and Mosbrugger 1999; Horton 1945; Kansky 1963; Howard 1967; Fairbridge 1968; Demek 1987; Babar 2005; Huggett 2007), the comparison of the mutual relation of the
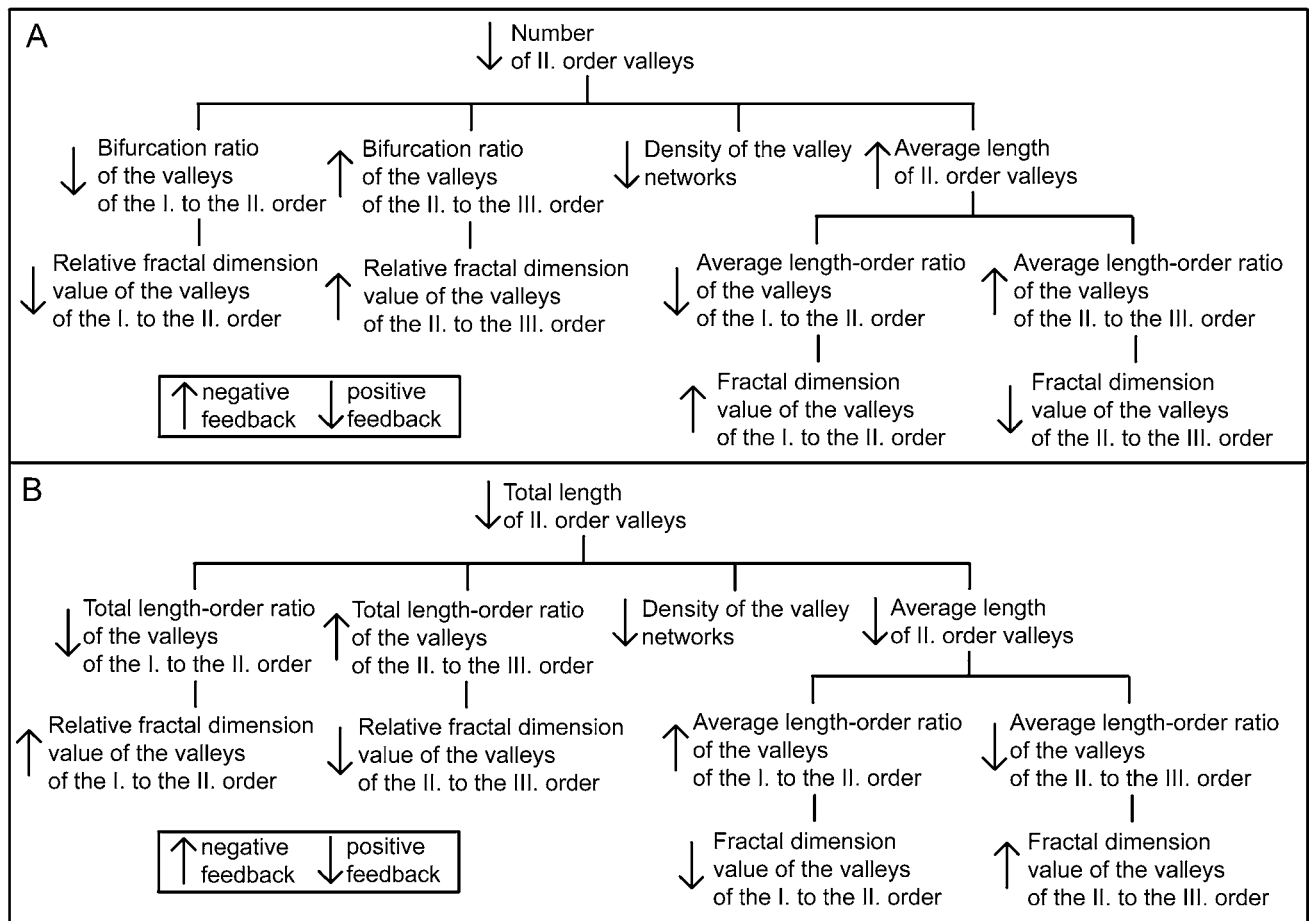
Fig. 3 Relation of morphometric characteristics to: A) "number of valleys of the II. orders"; B) "total length of valleys of the II. orders".

characteristics (Figure 3) indicates it as being correlated with the "number of various order valleys" and the "total lengths of various order valleys", and therefore already expressed in these characteristics.

A suitable additional characteristic of the "valley junction angles", "number of various order valleys" and the "total lengths of various order valleys" may be the "homogeneity of various order valleys" that remained preserved while increasing the scale. When comparing the "homogeneity of various order valleys" among various authors it is necessary to expect that various authors use various and incompatible order systems of valleys (e.g. Gravelius 1914 in Zăvoianu et al. 2009; Horton 1945; Strahler 1957; Shreve 1966; etc.).

As no short valleys have been considered with variant A that arose by trimming the remainders of the original valleys while magnifying the scale, as compared with variant B (always considered all of the valleys), in variant A a greater drop in the "number of valleys of the II. to the III. order" occurred. If the valley order was re-determined again while increasing the scale (variant A), then shortening of the "total lengths of valleys" was greater with the growing number of the valleys order (Table 1). If the valley order was preserved when changing the scale (variant B), the shortening of the "total lengths of valleys" was

smaller with the growing order of valleys (Table 2).The results of chapters 3.1. and 3.2. imply that the values of the "number of various order valleys", "total lengths of various order valleys" and the characteristics influenced by them (Figure 3) depend on the scale, in which the valley networks have been analyzed and on the mode of determining the main valley, or the order system of valley networks.

4. Conclusion

In order to analyze the valley networks, the most suitable characteristics are "valley junction angles" and "homogeneity of various order valleys" that are resistant against any changes (increase or decrease) in the scale, and the "number of various order valleys" and "total lengths of various order valleys" that are influenced by the choice of scale, however, the normal (Gauss) distribution of their values is retained.

Any changes in the values of characteristics like the "number of various order valleys" and the "total lengths of various order valleys" influence the values of the characteristics "bifurcation ratio of various order valleys", "total length-order ratio of various order valleys", "average

lengths of various order valleys", "average length-order ratio of various order valleys", "fractal dimension of various order valleys", "relative fractal dimension of various order valleys" and the "valley networks' density".

Increase in the "average lengths of various order valleys" while increasing the scale shows that the "total lengths of various order valleys" is a more suitable for analysis of the valley networks than the "number of various order valleys" because a smaller change (i.e. decrease) in its values took place there.

In order to compare the "number of various order valleys", "total lengths of various order valleys" as well as morphometric characteristics influenced by them, the same scale and the same method of selecting the main valley (variant A or B) have to be selected. While analysing the schematic or real valley networks of different shapes, it is more suitable to determine the main valley by the size of angular deviation of the source valley from the blended valley (variant B) for conservation of valley order of valleys while increasing the scale.

Acknowledgements

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RESUMÉ

Proměnlivost morfometrických charakteristik údolních sítí způsobená změnami měřítka

Údolní sítě se dle tvaru rozlišují na šest základních typů (Howard 1967; Fairbridge 1968; Demek 1987; Babar 2005; Hugget 2007). Příslušnost k danému tvaru bývá určována jen na základě vizuální podobnosti se vzorem daného tvaru sítě. Údolní sítě mají fraktálový charakter (Turcotte 1997, 2007a, 2007b; Baas 2002; Mandelbrot 2003) a jejich analýza je ovlivněna volbou měřítka (sensu Bendix 1994).

Tento článek ukazuje kvantitativní nástroje, s jejichž pomocí lze charakterizovat morfologii (tvar) údolní sítě a určit jejich proměnlivost způsobenou změnou měřítka. Sledovanými morfometrickými charakteristikami (kvantitativními nástroji) jsou 1) „četnost údolí různých řádů" dle Graveliova systému řádovosti; 2) „hustota údolních sítí"; 3) „bifurkační poměr údolí různých řádů"; 4) „celková délka údolí různých řádů"; 5) „poměr celkové délky údolí různých řádů"; 6) „průměrná délka údolí různých řádů"; 7) „poměr průměrných délek údolí různých řádů"; 8) „fraktálová dimenze údolí různých řádů"; 9) „relativní fraktálová dimenze údolí různých řádů"; 10) „velikosti úhlů mezi údolími"; a 11) „homogenita údolí různých řádů". Tyto charakteristiky byly aplikovány na vzorové příklady schématických údolních sítí dle Howarda (1967) a byly analyzovány ve třech měřítkách.

Pro analýzu údolních sítí jsou nejvhodnější „velikosti úhlů mezi údolími" a „homogenita údolí různých řádů", tj. morfometrické charakteristiky rezistentní vůči zvětšení měřítka, a „četnost údolí různých řádů" a „celková délka údolí různých řádů", u kterých došlo při zvětšení měřítka k poklesu hodnot, ale bylo zachováno normální (Gaussovo) rozdělení hodnot.

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