METODE

DETERMINATION OF TEXTURE OF TOPOGRAPHY FROM LARGE SCALE CONTOUR MAPS

AUTHOR
Zdeněk Máčka
Naziv: M. Sc., physical geographer
Naslov: Institute of geonics – Branch Brno, Academy of science of the Czech Republic, Drobného 28, 613 00 Brno, Czech Republic
E-pošta: macka@geonika.cz
Telefon: 420 5 45422728
Faks: 420 5 578031

UDC: 556.5:528.9(437.1/.2)
COBISS: 1.02

ABSTRACT
Determination of texture of topography from large scale contour maps
Accurate quantitative data are the crucial premise for the analysis of drainage network geometry and topology. The article deals with the methodological procedure of relief texture (drainage density) determination from large scale contour maps. Cartographic data sets of drainage network characteristics for twenty third order basins located at the SE margin of the Bohemian Massif (Czech Republic) were compared with the actual drainage network length identified in the field.

KEY WORDS
erosional topography, channel network geometry, relief texture, drainage density, channel network length, paired t-test, Bohemian Massif, Czech Republic

IZVLEČEK
Določanje razčlenjenosti površja s topografskih zemljevidov velikega merila
Kakovostna analiza rečnega omrežja temelji na natančnih podatkih. V članku je opisan metodološki pristop preverjanja natančnosti izrisa rečnega omrežja na topografskih zemljevidih merila 1 : 25.000. Primerjava med izrisom na zemljevidu in stanjem na terenu je bila opravljena v dvajsetih porečjih drugega in tretjega reda na jugovzhodnem robu Češkega masiva.

KLJUČNE BESEDE
erozijsko površje, omrežje strug, reliefna razčlenjenost, gostota vodnih tokov, dolžina strug, preizkus parov (parni t-test), Češki masiv, Češka

Uredništvo je prispevek prejelo 4. julija 2001.

1. Introduction

The relief texture was first defined by Johnson (1933) as a mean size of topographic units the landscape is composed of. In other words, the term expresses the measure of landscape dissection into respective morphological units, allowing – with regard to its relatively general definition – the utilisation of numerous morphometric characteristics for its quantification. In this paper, the meaning of this term was restricted to describe only the landscapes predominantly modelled by fluvial erosion and is understood as a measure of erosional dissection by the drainage network consisting of perennial as well as ephemeral channels. It is therefore in this sense the synonym to drainage density or stream frequency (Horton 1945) or possibly texture coefficient (Smith 1950).

There is no doubt that a characteristic most frequently used to quantify the relief texture is drainage density. A cartographic method (contour crenulation method) often utilised to determine the drainage density is the interpretation of contour delineation on large scale topographic maps; valleys are on the maps indicated by blue lines (perennial channels) and by contour crenulations (ephemeral channels). A relatively objective method of channel network delineation from the topographic maps was proposed by Bauer (1980).

Apart of a wide range of natural variables, the value of the detected drainage density depends also on a scale of the map used and on the precision of map plot. The determination of realistic drainage density values is directly proportional to the precision of channel network delineation from the map with special regard to the number and length of first order streams. Accurate quantitative data are the crucial premise for the analysis of drainage network geometry and topology. The paper aims at finding the measure of distortion of the drainage density values due to the map generalisation and inaccuracy, making use of a sample of twenty second and third order drainage basins situated at the eastern margin of the Bohemian Massif (eastern part of the Czech Republic), (see figure 1).

The verification of contour crenulation method, in the conditions of erosional topography on metamorphic rocks of the Bohemian Massif was based on a comparison of the channel network length measured from the topographic maps on a scale 1:25,000 and channel network length detected in the field where channels missing on the map were added. The statistical significance of the differences in the length of the channel network recorded from the map and measured in the field was then tested by the paired t-test. The verification of sufficient accuracy of large and medium scale topographic maps for representing the natural channel networks and other parameters of fluvial morphometry appears especially necessary where large amount of fluvial data must be collected without possibility to check fluvial processes and morphology directly in the field.

2. Significance of drainage density for the evaluation of morphology and processes in a drainage basin

Drainage density (D_d) is defined by the equation $D_d = \Sigma L/A_d$ where ΣL is the total length of the channel network and A_d is the drainage basin area; drainage density is considered to be one of the most important single characteristics describing the morphology and processes operating within the drainage basin. The reason is that the drainage density, as a measure of drainage basin surface dissection by streams (either perennial or ephemeral), joins the morphological attributes and operating processes in a drainage basin. On the one hand, the drainage density is a result of interacting factors controlling the surface run-off, on the other hand, it is itself influencing the output of water and sediment from the drainage basin.

Drainage density is controlled by two groups of factors. The first one includes the set of variables determining the amount and properties of precipitation falling onto the earth surface, the second one includes variables influencing further distribution of water over the earth surface and its availability for the performance of erosional work (Knighton 1984). The first group therefore relates to climate while the second one to the joint influence of topography, lithology, soils and vegetation cover.

The effects of climate on the surface run-off are both direct and indirect, the climate itself being the most important variable affecting the actual value of drainage density. The indirect influence of climate functions through the impact on the development of soils and vegetation. The highest values of drainage density may be found in the areas of poor vegetation cover and its value diminishes with increasing share of surface covered with plants (Melton 1957). The maximum values of drainage density are to be found in semiarid regions and are decreasing both towards the more arid environment due to the lack of precipitation as well as to the more humid environment due to the increased protection of earth surface with vegetation. By means of its influence on soils and vegetation the climate is a dominant factor both on global and regional scale. The local variability in drainage density then may be ascribed to the set of topographical and lithological factors (Gregory and Gardiner 1975). In the direct way the climate operate through the precipitation – its amount, seasonal pattern and mainly intensity.

Particularly important factors of the second group are those of rock permeability and resistance to the weathering and erosion. The rock permeability affects the surface/subsurface run-off ratio. The less permeable rocks with the lower infiltration capacity are being usually accompanied with the higher drainage density. Carlston (1963) stated that under the identical conditions of relative relief and climate the higher drainage density occurs on the less resistant lithology.

Precipitation induces in a drainage basin the surface run-off which transport, together with relative relief as a source of potential energy, sediments to the outlet of the basin. It is empirically proved that areas with highest values of drainage density, which may be found in semiarid climatic zone, display the largest quantities of removed sediment at the drainage basin outlet (Langbain and Schumm 1958). The large volumes of sediment at the drainage basin outlet indicate the dynamic development and high effectiveness of the drainage network.

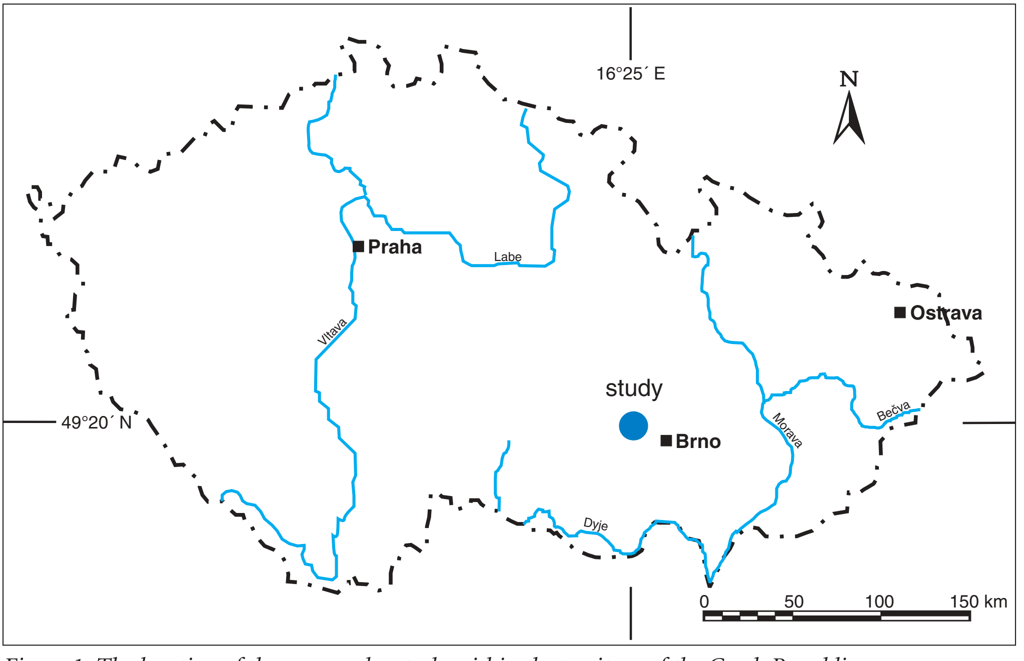

Figure 1: The location of the area under study within the territory of the Czech Republic.

The drainage density holds a central position within the fluvial system, the reason being the fact it may be considered on the one hand the result of the drainage basin input variables on the other hand it determine the quantity and intensity of the output variables (water, sediment) from the drainage basin. While conditioning the run-off characteristics in the shorter time spans, the drainage density itself is being affected by the environmental variables through the run-off characteristics in the longer time spans (Knighton 1984). Melton (1958) claims that the channel network is capable of reaching the state of equilibrium by adaptation to the prevailing conditions of climate, vegetation, lithology and soils.

3. Testing the procedure of drainage density determination from topographic maps

The first stage of verification procedure included the measuring of drainage network length and drainage basin area of twenty selected basins of the second and third order (Strahler 1952), situated in the Sýkořská hornatina (Highlands) and Deblínská vrchovina (Highlands) at the south eastern margin of the Bohemian Massif (SE Czech Republic), from the 1:25,000 topographic maps. The obtained drainage network lengths included streams indicated on the map with blue lines (perennial streams) as well as contour crenulations (ephemeral streams). The drainage network length was measured from

Table 1: The values of channel network length and drainage density in twenty selected drainage basins of second a third order within the geomorphological units Sýkořská hornatina (highland) and Deblínská vrchovina (highland, SE margin of Bohemian Massif), parameters measured from the map (explanation of symbols: SO – stream order according to Strahler, N – number of stream channels, A – drainage basin area, ΣL_{ch} – length of perennial streams network, ΣL_s – channel network length, D_d – drainage density, F_s – stream frequency).

No.	SO	N	A (km^2)	ΣL_{ch} (km)	ΣL_s (km)	D_d (km/km^2)	F_s (n/km^2)
1	3	12	2.258	2.125	4.800	2.126	5.3
2	3	9	1.008	1.375	3.325	3.299	8.9
3	3	23	5.906	4.950	12.000	2.032	3.9
4	3	11	2.520	2.600	5.300	2.103	4.4
5	3	29	9.602	11.450	24.475	2.549	3.0
6	3	61	13.598	17.700	43.000	3.162	4.5
7	3	14	2.174	2.500	6.800	3.129	6.4
8	3	10	0.945	1.150	3.775	3.995	10.6
9	3	12	0.383	0.000	2.550	6.654	31.3
10	3	12	0.782	0.600	3.975	5.081	15.3
11	3	10	3.848	3.700	8.150	2.118	2.6
12	3	7	4.090	2.900	3.150	0.770	1.7
13	3	13	3.444	4.100	8.150	2.366	3.8
14	3	11	2.394	2.650	5.650	2.360	4.6
15	2	6	2.347	4.650	6.800	2.898	2.6
16	3	15	2.357	3.950	8.975	3.807	6.4
17	3	13	1.250	0.900	5.750	4.602	10.4
18	3	29	3.712	7.150	14.400	3.880	7.8
19	3	15	2.877	2.750	8.450	2.937	5.2
20	2	6	0.882	0.000	4.000	4.535	6.8

the map according to recommendations of Bauer (1980). The stream channels were included into the drainage network if the contour lines contained the angle less than 120° and the valley was indicated at least by two contour lines distorted in the same direction. The stream channels meeting these criteria but not continuing in the lower part of the hill slope were also included to the drainage network and linked to the nearest stream channel of higher order.

The second stage included a field inspection of the studied drainage basins and the mapping of missing streams, which were not drawn in the maps. In the majority of cases these missing forms were gullies – small ephemeral stream channels of first order, exceptionally creating small channel systems of second order. In the smaller number of cases larger but short dry valleys were found at the periphery of drainage network by field inspection, which were not indicated on the topographic maps. They were in all cases the first order stream channels.

The paired t-test was used to check the significance of differences between the drainage density values obtained by the two methods; the mean values of both data sets were compared. For testing were used pairs of drainage density values for all drainage basins measured from the map and found in the field (see table 1 and table 2). The testing was made for the two variant cases: a. cross-testing of data from maps against data from the field, b. cross-testing of data from maps against data from the field, when length of gullies was excluded from the channel network. The reason for excluding slope gully systems from calculations in the second case of testing was the different character of morphology and processes operating within these small erosional forms. They differ from ordinary valleys both peren-

Table 2: The values of channel network length and drainage density in twenty selected drainage basins of second a third order within the geomorphological units Sýkořská hornatina (highland) and Deblínská vrchovina (highland, SE margin of Bohemian Massif), parameters measured in the field (explanation of symbols: SO – stream order according to Strahler, N – number of stream channels, ΣL_s – channel network length, ΣL_{s+g} – channel network length including gullies, D_d – drainage density, $D_{d\text{-}s+g}$ – drainage density including gullies, F_s – stream frequency, F_{s+g} – stream frequency including gullies).

No.	SO	N	ΣL_s (km)	ΣL_{s+g} (km)	D_d (km/km^2)	$D_{d\text{-}s+g}$ (km/km^2)	F_s (n/km^2)	F_{s+g} (n/km^2)
1	3	20	4.800	5.550	2.126	2.458	5.316	8.859
2	3	12	3.455	3.455	3.428	3.428	9.921	11.905
3	4	48	14.500	15.350	2.455	2.599	3.894	8.127
4	3	16	5.790	6.040	2.298	2.397	5.159	6.349
5	4	61	24.815	27.545	2.584	2.869	3.020	6.353
6	4	91	43.510	44.780	3.200	3.293	4.486	6.692
7	3	53	6.975	9.705	3.209	4.465	6.441	24.385
8	2	6	2.700	2.700	2.857	2.857	6.349	6.349
9	2	5	1.350	1.350	3.523	3.523	13.046	13.046
10	3	9	1.725	3.425	2.205	4.378	3.835	11.505
11	3	12	8.500	8.800	2.209	2.287	2.599	3.118
12	3	11	2.850	3.400	0.697	0.831	2.201	2.690
13	3	19	8.925	9.255	2.591	2.687	4.646	5.517
14	3	18	6.150	6.585	2.569	2.751	4.595	7.519
15	3	16	7.160	7.945	3.051	3.386	2.131	6.818
16	3	15	8.975	9.200	3.807	3.903	5.515	6.363
17	3	11	4.325	4.325	3.461	3.461	8.003	8.804
18	3	44	12.975	15.725	3.496	4.237	7.274	11.854
19	3	14	6.500	6.800	2.259	2.364	3.823	4.866
20	3	11	2.300	4.400	2.608	4.989	3.401	12.472

nial and ephemeral by their size, i. e. by the volume of material removed from the earth surface during the erosional history of the drainage basin. Further difference is in the character of operating processes, while gullies are predominantly modelled by concentrated flow of water during storm or snowmelt events of sufficient magnitude, the morphology of the valley forms is a result of a joint action of stream channel and hill slope processes. Thus, the valley form consists at least from two mutually linked sub-systems: the stream channel sub-system and hill slope sub-system. In contrast, gullies are rather forms with more simple functioning, the dominating process being the linear run-off. However, in spite of their smaller dimensions gullies play an important role in the dynamics of the contemporary landscape evolution being the indicator of crossing the threshold conditions and start of the new phase of drainage network expansion (Schumm and Hadley 1957; Patton and Schumm 1975). Further, the active gullies supply the stream beds of larger streams with large quantities of eroded material. These are the reasons for separate testing of data sets with gullies included and excluded.

The mean drainage density deviation for twenty drainage basins under study between map and field data when gullies were included was 0.607 km/km^2; when gullies were not included 0.596 km/km^2. Testing at the significance level 5% proved that deviation is too large to be of an accidental character and thus there is a statistically significant difference between both data sets. In the second case, when length of gullies was not included to the drainage density values, the statistical insignificance of the deviation between data sets was proved. The results of testing indicate the necessity of differential approach to the delimitation of channel networks according to a purpose for which it is conducted. The drainage network delimitation from the topographic maps of the scale 1:25,000 proved to be a good tool for regional analysis of variability in drainage network geometry (e. g. texture of relief). On the other hand, when process oriented research of channel network systems should be undertaken (e. g. balance of sediment output from the drainage basin), it would be necessary to conduct time consuming field mapping of erosional topography at least at the scale 1:10,000.

4. Erosional dissection of studied drainage basins

The field reconnaissance of the studied drainage basins showed some interesting facts about the evolution of erosional dissection of the SE margin of Bohemian Massif (Sýkořská hornatina (highland) and Deblínská vrchovina (highland)). The following comments concern mostly the morphology and development of gullies.

- In some of the studied drainage basins the evolution of gully systems reached the higher stage of progress. Gullies create locally simple branching networks. If the gully systems are included to the overall drainage network, they may significantly change its geometric and topological characteristics (see table 2 and figure 3).
- Gullies are not randomly distributed within the drainage basins but rather concentrated at particular areas. Thus, values of drainage density varies considerably from place to place and local values of drainage density may exceed many times the average value for the whole drainage basin. Extensive systems of gullies are usually developed in the closures of larger valley forms, which may be caused by the concentration of surface run-off by the funnel effect in some types of valley closures (Knighton 1984; Karásek 1990). The higher concentration of gullies may similarly occur at the concave valley slopes of incised meander bends.
- A frequent phenomenon, occurring particularly within the valleys of perennial streams of the Deblínská vrchovina (highland), is the presence of broad shallow valleys with gently inclined slopes in the upper reaches of streams, gradually deepening and with steeper slopes in the downstream direction. Gullies occur mainly on the gentle slopes in the upper reaches of streams at the periphery of the drainage network where the cover of deluvial sediment is quite deep. The frequency of gullies diminishes towards the steeper slopes of internal parts of drainage network, where deluvial cover is shallow, and where

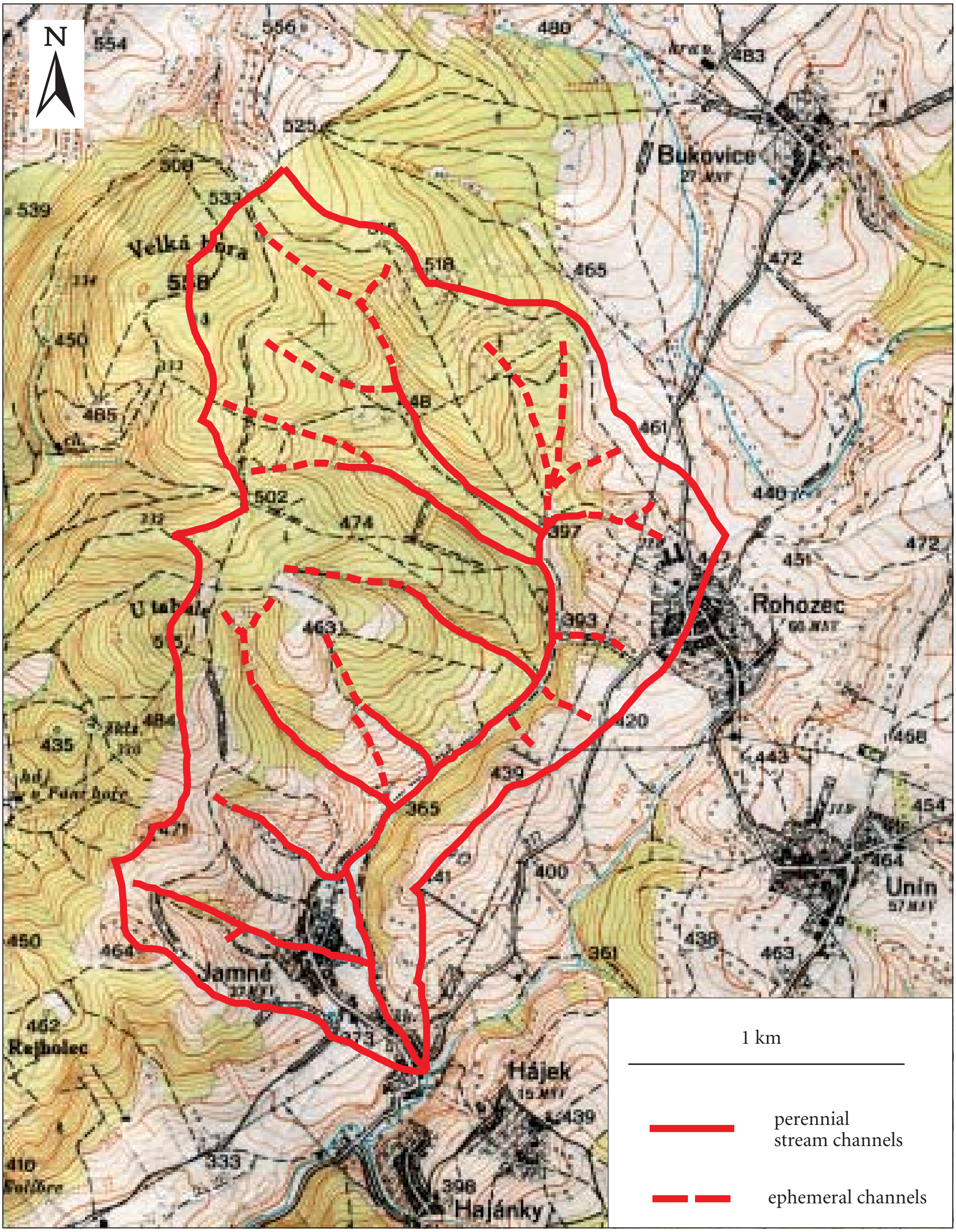

Figure 2: An example of the drainage network delineation from the topographic map 1:25,000 (General map of the Czech Republic, sheet 24-321). The picture illustrate the drainage basin of the third order in the Sýkořská hornatina (highland) bounded with its drainage divide. During the field survey missing dry valleys and gullies are added to the basic skeleton of the drainage network delinated from the map.

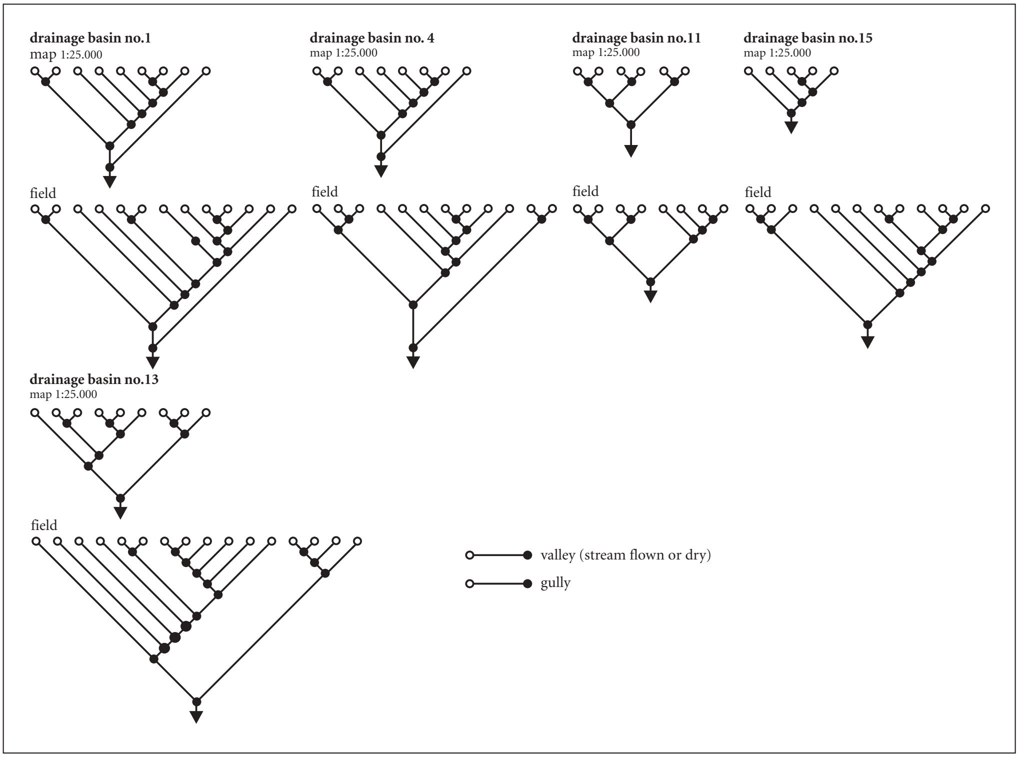

Figure 3: Diagrammes illustrating the differences in the drainage topology of five selected drainage basins when using two different methods of drainage delineation: cartometric from the topographic maps scale 1:25,000 and by reconnaissance in the field.

rock outcrops becomes the dominant feature of the valley slope morphology. Gullies as a concave elements of drainage basin morphology and rock outcrops as a convex elements play an important role in the balance of material fluxes over the slopes and through the drainage network of Deblínská vrchovina (highland). These two types of slope elements, disturbing the continuity of smooth slope surface, supply stream channels with a considerable amounts of sediment. Gullies becomes due to their relatively high gradients powerful streams when containing water and perform erosion and transport of large volumes of fine grained sediment. This sediment then becomes a part of suspended load of perennial stream channels (compare Casalí, López and Giráldez 1999).The slopes of stream valleys are usually lithologicaly uniform, built by only one type of rock; in this situation the rock outcrops are not in the condition of equilibrium, since the material is being removed more rapidly from their surface than from the surrounding parts of slope which are less inclined. These non-equilibrium parts of slopes supply stream channels with coarse clastic sediment, which becomes part of their bedload.

- Some of the gullies exhibit a certain measure of sinuosity.
- Valleys of some perennial streams show signs of the polycyclic development (especially smaller brooks). On the longitudinal profiles and cross profiles of these valleys are detectable traces of two or three erosional cycles (knickpoints, abrupt changes of valley slope inclination), which have produced the valley-in-valley effect on some streams. The recent erosional development of small drainage basins within the studied orographical units resulted rather from internal causes, e. g. land use changes in historical period (deforestation, cultivation of arable land) or possibly from local fluctuations of stream

channel bed levels of higher order streams connected with episodic scour and storage of bedload induced e. g. by building of weirs. The above mentioned erosional events may be hardly assigned to tectonically or climatically induced phases of stream channel incision.

- Bottoms of some dry valleys are at the present time activated by the new generation of incisions (gullies), which appeared as a consequence of backward erosion from the lower reaches of valleys. Frequently, ephemeral springs appear in the upper reaches of these incisions supplying them with water in wetter periods of the year.

5. Conclusion

The length of the drainage network of twenty second and third order basins in the Sýkořská hornatina (highland) and Deblínská vrchovina (highland) was studied in order to test the validity of the commonly utilised procedure of the drainage density delineation from topographic maps on a scale 1:25,000 in the physiographic conditions of SE margin of Bohemian Massif. The length of drainage network was measured: a. on the topographic map 1:25,000, when blue lines (perennial streams) and contour crenulations (ephemeral streams) was included to the drainage net, b. in the field, when additional dry valleys and gullies missing on the topographic map 1:25,000 were inserted to the working map on the scale 1:10,000 and their length was measured by the survey tape.

The cross-testing was made between the data sets obtained from the map and from the field for variant cases with and without gullies included to the field data set. The results of testing by the paired t-test proved a good agreement between drainage densities obtained from the map and from the field when gullies were not included to the data set from the field (significance level 5%). When length of gullies was included to the data set from the field, testing proved statistically significant difference between data sets, which could not be caused by random factors. The testing proved that the drainage density values detected cartographically from the topographic maps on the scale 1:25,000 provide a sufficiently precise image of the actual situation in the field. It seems more convenient to neglect the gullies when processing the inter-regional comparisons of drainage density values and drainage network geometry due to their different morphology and operating processes. The specific controlling variables which cause non-random distribution of gullies, thus great local variability in gully density could distort results of an inter-regional analysis. On the other hand, when detailed local analysis of erosional dissection (relief texture) of a basin is required e. g. for purposes of sediment supply investigations, it is necessary to conduct the field research on the scale at least 1:10,000.

6. References

Bauer, B. 1980: Drainage density – an integrative measure of the dynamics and the quality of watersheds. Zeitschrift für Geomorphologie 24. Berlin.

Carlston, C. W. 1963: Drainage density and streamflow. US Geological Survey Professional Paper 422C. Denver.

Casalí, J., López, J. J., Giráldez, J. V. 1999: Ephemeral gully erosion in southern Navarra (Spain). Catena 36. Amsterdam.

Gregory, K. J., Gardiner, V. 1975: Drainage density and climate. Zeitschrift für Geomorphologie 19. Berlin.

Horton, R. E. 1945: Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology. Geological Society of America Bulletin 56. Boulder.

Johnson, D. 1933: Available relief and texture of topography. Journal of Geology 41. Chicago.

Langbain, W. B., Schumm, S. A. 1958: Yield of sediment in relation to mean annual precipitation. Transactions of the American Geophysical Union 39. Washington.

Karásek, J. 1990: O tvarech uzávěrů erozních rýh. Zprávy krajského vlastivědného muzea Olomouc 263. Olomouc.
Knighton, D. 1984: Fluvial forms and processes. London.
Melton, M. A. 1957: An analysis of the relations among elements of climate, surface properties, and geomorphology. Office of Naval Research, Geography Branch, project NR 389-042, technical report 11. Washington.
Melton, M. A. 1958: Correlation structure of morphometric properties of drainage systems and their controlling agents. Journal of Geology 66. Chicago.
Morisawa, M. 1957: Accuracy of determination of stream lengths from topographic maps. Transactions of the American Geophysical Union 38. Washington.
Patton, P. C., Schumm, S. A. 1975: Gully erosion, nortwestern Colorado: a threshold phenomenon. Geology 3. Boulder.
Schumm, S. A., Hadley, R. F. 1957: Arroyos and the semiarid cycle of erosion. American Journal of Science 255. New Haven.
Smith, K. G. 1950: Standards for grading texture of erosional topography. American Journal of Science 248. New Haven.
Strahler, A. N. 1952: Hypsometric (area-altitude) analysis of erosional topography. Geological Society of America Bulletin 63. Boulder.

7. Povzetek: Določanje razčlenjenosti površja s topografskih zemljevidov velikega merila

(prevedel Mauro Hrvatin)

V članku je predstavljeno terensko preverjanje postopka določanja erozijske razčlenjenosti površja, ki se običajno opravlja s pomočjo zemljevidov velikega merila (1 : 25.000). Avtor je s preizkusom parov (parni t-test) ugotavljal statistično pomembnost razlik v dolžini vodnih strug v naravi in na zemljevidih. Obravnavana so bila porečja drugega in tretjega reda v Sýkořskem hribovju in Deblínskem gričevju na jugovzhodnem robu Češkega masiva. Preverjanje ni pokazalo statistično pomembnih razlik med gostoto strug na topografskih zemljevidih in na terenu. Statistično pomembna razlika se pojavlja le ob upoštevanju najmanjših razčlemb (erozijskih jarkov), ki na zemljevidih niso prikazani. Po mnenju avtorja so občasni vodni tokovi v erozijskih jarkih pomembni preoblikovalci površja, vendarle jih je treba ločiti od pomembnejših stalnih in občasnih vodotokov v dolinah in grapah. Erozijske jarke je treba vključiti v analizo rečnega omrežja le v primeru kompleksnih raziskav razčlenjenosti površja in erozijskih procesov. Pri širših regionalnih raziskav pa je smiselno občasne vodne tokove v erozijskih jarkih zanemariti.