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Relationships between tectonics and drainage network planar geometry of the Povcha and Mizoch uplands, NW Ukraine

ABSTRACT

The Povcha and Mizoch uplands are included in the Volyn Upland and have different geological structure. Unlike the Mizoch Upland, where Miocene limestones form structurally conditioned topography, in the Povcha Upland this strata is preserved only on some small areas. These uplands were selected to evaluate influence of fracture and fault system on development of drainage network in relatively neotectonically stable upland territories. The drainage system was manually derived from 1:10000 scale topographic maps and arranged according to Horton–Strahler ordering using special GIS tools. Some morphometric indices were calculated for estimating of structural control degree on drainage network. Rose diagrams of stream segments direction were created separately for both uplands, and compared with fracture patterns and manually derived valley lineaments.

Results suggest that drainage system of the Povcha and Mizoch uplands is characterized by noticeable degree of adjustment to fracture patterns and reflect the dominant trends of neotectonic strain directions. In the Povcha Upland lower structural adjustment degree on drainage network can be explained by partial superimposition and weakness of Cretaceous marlstones that mainly form geological substrate in this area. In general, some quantitative geomorphology methods, statistical analysis of streams and valley lineaments orientation in conjunction with fracture pattern analysis can be successfully applied for studying tectonic and geological influence on drainage network development in upland areas.

Key words: drainage network, tectonic geomorphology, channel orientation, Povcha Upland, Mizoch Upland, Volyn Upland.

INTRODUCTION

The development of drainage network is significantly affected by tectonic movements in tectonically active regions (Wallace 1977; Scheidegger 1983; Burbank, Anderson 2001; Delcaillau 2001; Keller, Pinter 2002; Scheidegger 2004; Peters, van Balen 2007). Drainage may contain information about the fault development and growth that is difficult to obtain by other methods (Jackson, Leeder 1994). Specific morphotectonic features reflect the influence of tectonics on drainage system structure (Filosofov 1975; Morisawa 1985; Panizza et al. 1987; Della Seta et al. 2004). The planimetric geometry of fluvial networks is an important morphostructural indicator in tectonically active regions or recent chains as Neogene orogenic belts and related foreland areas (Beneduce et al. 2004).

Relationships between recent tectonics and drainage network structure can be detected by applying methods based on azimuthal comparison among drainage channels, lineaments, fracture patterns and propagation of faults (Everette Bannister 1980; Perri and Schiattarella 1997; Beneduce et al. 2004; Capolongo et al. 2005; Gioia, Schiattarella 2006; Ribolini, Spagnolo 2008; Gioia, Schiattarella 2010). Researchers revealed good positive correlation between fracture systems and minor streams distribution and adjustment of main streams parts to fault systems. In some cases high relief value of the area reduce the influence of bedrock fracture pattern (Gioia, Schiattarella 2010). Classical morphometric methods enable to estimate degree of structural control on drainage network development (Horton 1945; Strahler 1957; Avena et al. 1967).

Regions with relatively low tectonic activity rate have become the subject of research in terms of drainage network adjustment to fault and fracture systems more rarely. However relationships between tectonics and drainage network structure were also observed in tectonically less active areas (Harasimiuk 1980; Brzezińska-Wójcik 2002, Hnatiuk 2002).

The aim of this work is estimating dependence of drainage network structure from distribution of joints and faults in platform areas with altitude up to 400 m a.s.l. and relatively low neotectonic activity rate. We chose two neighboring uplands (the Povcha Upland and the Mizoch Upland) that have common neotectonic history but different relief and investigated their drainage systems adaptation to geological structure.

GEOLOGICAL AND GEOMORPHOLOGICAL SETTINGS

The Povcha and Mizoch uplands are most elevated parts of the Volyn Upland (Fig. 1). They are mainly made up of Cretaceous marlstones and Miocene sands and limestones. However, unlike the ring-shaped the Povcha Upland, the Mizoch Upland is characterized by flat-top structure. In terms of tectonic composition both uplands are parts of Volyn-Podolian plate that is part of East European Platform. The tectonic basis of research area is the Ukrainian Crystalline Massif (Ukrainian Shield) that immersed as a monocline toward W and SW at an angle about 1˚ (Uzhenkov et al. 1961; Tsys' 1962). Volyn-Podolian plate is separated from the Ukrainian Crystalline Massif western slope by series of submeridional faults with lowering amplitude of blocks up to 1500 m (Bondarchuk 1959).

The Mizoch Upland is located in southeastern part of the Volyn Upland, between the Ikva and Goryn' rivers and covers an area of about 450 km^2. The Mizoch Upland is elongated from W to E and characterized by elevation up to 350 m above sea level that little more decreasing toward SE. The Cretaceous marlstones form the geological basis of the study area overlapping by Miocene rocks and Quaternary loesses (Fig. 2). Thin strata of Miocene limestones (about 3–5 m) cover underlying weak rocks and protect them from denudation. Consequently, the Mizoch Upland is characterized by pseudo plateau structure dissected by steep slope gullies (Tsys' 1962; Novak 2013).

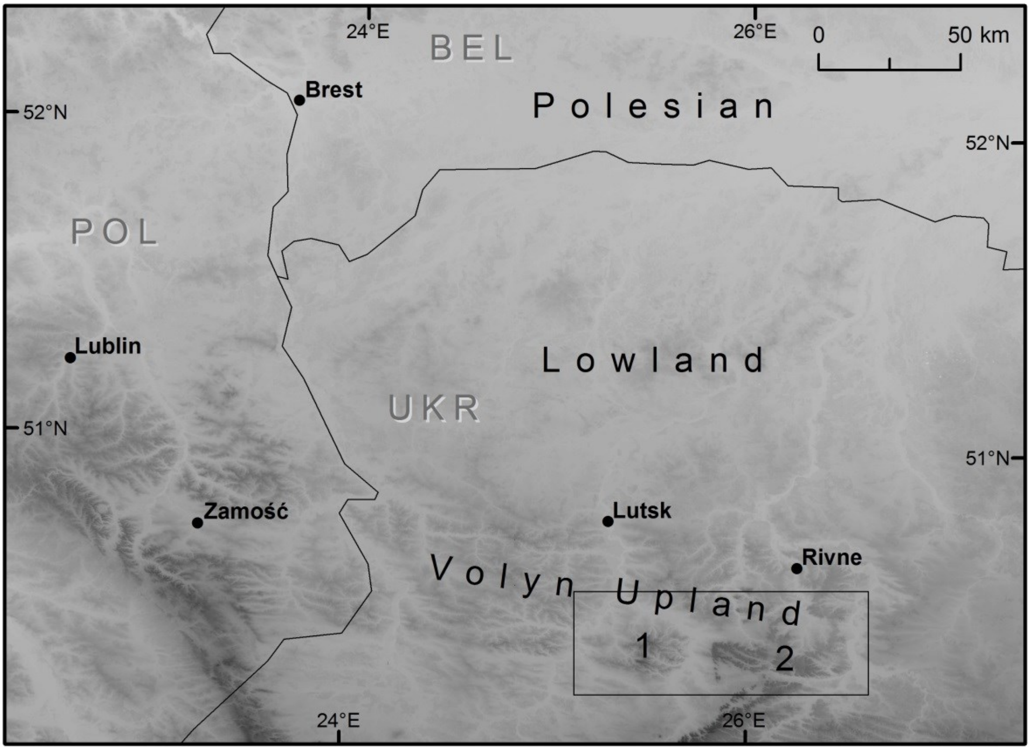

Fig.1. Shaded hypsometric map of the Volyn Upland and adjacent areas. 1: Povcha Upland; 2: Mizoch Upland.

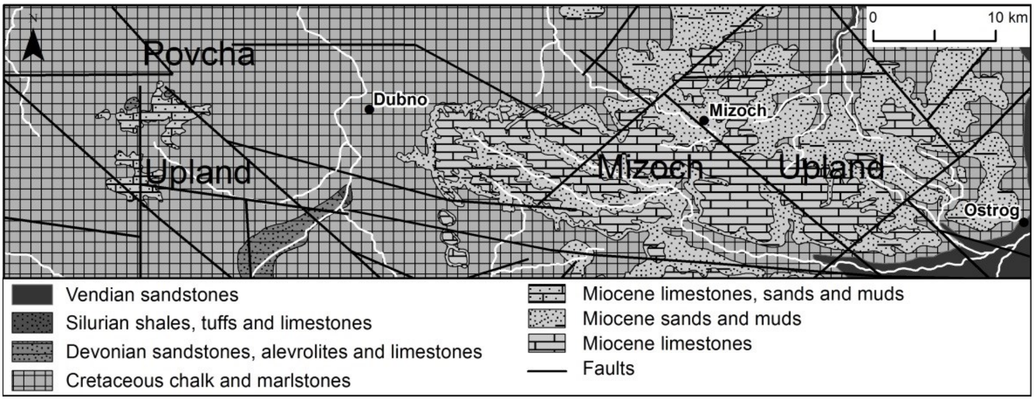

Fig.2. Geological sketch map of the Povcha and Mizoch uplands. (modified after Uzhenkov et al. 1961; Sudovtsev et al. 1984)

The Povcha Upland covers an area about 650 km^2, but more than 1⁄3 of this territory is low-altitude planar surfaces that are radically different from rest area. Miocene rocks are rare on the Povcha Upland and distributed only in the central part of area. They apparently denudated during Pliocene–Quaternary period. North from the Povcha village are located "Povcha's dislocations", significant displacement of geologic strata and outcropping of Devonian rocks (Laskarev 1914; Didenko, Cherlenevskaya 1957; Gofshtein, Pomyanovskaya 1964). Probably the Povcha's dislocations conditioned by tectonic movements in zone of intersection of NE and NW fault trends (Bondarchuck 1959).

Current drainage network of investigated area have begun developing until Late Miocene after sea regression and starting tectonic uplift (Tsys’ 1962). Simultaneously continued growth of the Carpathian Mountains, that obviously was closely related with tectonic movements and forming of main streams direction in the territory of the Povcha and Mizoch uplands.

DATA AND METHODS

The drainage network of the study area has been manually derived from the 1:10000 scale M.O.G.C. topographic maps using GIS tools. It should be noted that western part of the Povcha Upland has not been analyzed due to significant relief differences. Derived network includes chiefly ephemeral streams with average length of first-order channels about 200 m. The DEM of the Povcha and Mizoch uplands have been created using the 1:50000 scale M.O.G.C. topographic maps for deriving valley lineaments.

In order to analyze tectonic or geological structures impact on the development and adjustment of drainage network we applied classical approach of the quantitative geomorphology. The drainage streams system has been organized according to the Horton–Strahler method (Horton 1945; Strahler 1957). Major sub-basins have been selected and some special morphometric indices have been evaluated: *bifurcation ratio* ($Rb = N_u/N_{u+1}$, where N_u and N_{u+1} are the number of streams per order u and u+1, respectively; Horton 1945; Strahler 1957), *direct bifurcation ratio* ($Rbd = N_{du}/N_{u+1}$, where N_{du} is the number of streams of u order which flowing in u+1 order and N_{u+1} are the number of streams per order u and u+1, respectively; Avena et al., 1967), *bifurcation index* (R = Rb – Rbd, where Rb is the *bifurcation ratio* and Rbd is the *direct bifurcation ratio*, (Avena et al. 1967). The degree of drainage network adjustment has been estimated taking into account obtained results.

The cumulative lengths azimuthal diagrams (rose diagrams) have been created for 2nd, 3rd, 4th, together 5th and 6th, and totally 2nd–6th stream orders separately for the Povcha and Mizoch uplands. In order to create the diagrams we have cut the drainage channels on straight segments with average length of 280 m and evaluated their azimuthal direction. Each rose diagram have angular interval of 10˚. These data have been compared with azimuthal diagrams of valley aligned features (lineaments) (Fig. 6) and Wulff diagrams of fracture patterns in several geological outcrops (Fig. 4). Only two subvertical “conjugate” tectonically induced joint sets (Scheidegger 2004) have been taken into account omitting subhorizontal joint sets connected with lithology. Unfortunately, we haven't found outcrop of Miocene limestones with a good-expressed joint system, so relevant orientation diagram has only 11 measurements. We have manually derived valley lineaments using created DEM and excluded segments less than 1 km in length for calculating their direction. Finally, resulting rose diagrams have been compared and analyzed (Fig. 3).

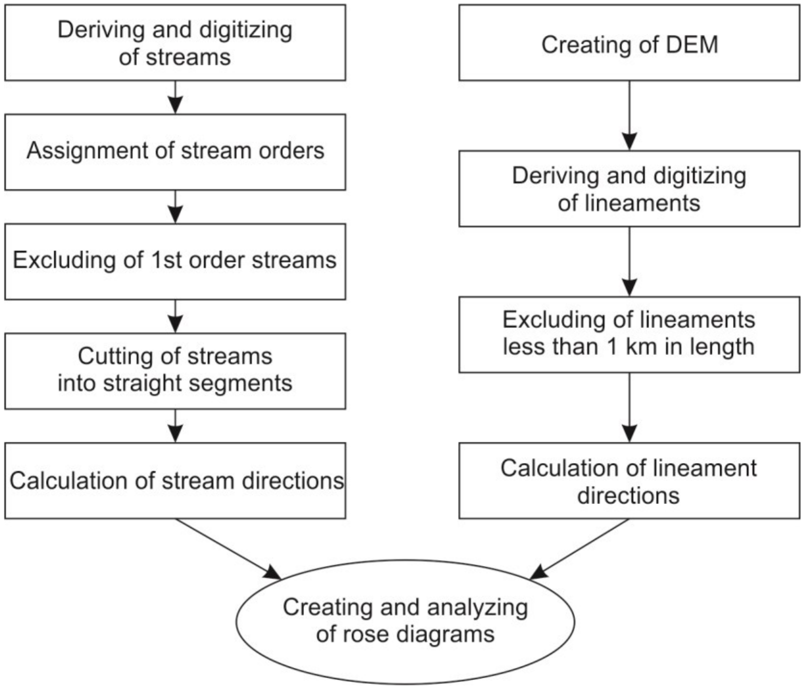

Fig.3. Flow chart of investigation of streams and lineaments orientation in Povcha and Mizoch uplands

RESULTS AND DISCUSSION

The drainage network composition revealed moderate structural control of streams arrangement in most of the investigated area. Drainage system of both Povcha and Mizoch uplands demonstrate high degree of homogeneity. Most of bifurcation ratio values range between 3.5 and 4.5, direct bifurcation ratio range between 2.7 and 3.3 (Tab. 1). Significant differences is revealed only in distribution of bifurcation index value that is lower in basins 2, 3, 4, 5, 6 and higher in basins 1, 7, 8, 9, and 10. Two Mizoch Upland basins bifurcation index values higher than similar values of Povcha Upland basins. These results indicate more strong structural control on Mizoch Upland drainage network and less strong stream adjustment in the Povcha Upland (especially its NE part).

1st order streams were excluded from azimuthal analysis because of their small lengths and distribution mainly on soft loess sediments. Several trends are well defined for the analyzed channels. Most pronounced N120˚–140˚ and N110˚–130˚ trends, respectively for the Povcha and Mizoch uplands (Fig. 5 and 7). Less defined orientation classes are consistent with the N350˚–10˚, N60˚–80˚ trends for the Povcha Upland and N40˚–50˚, N70˚–80˚ trends for the Mizoch Upland. As shown by previous domain analysis, N40˚–50˚ trend tends to NE part of the Mizoch Upland (Novak, 2014). N350˚–10˚ trend defined on rose diagrams of 2nd, 3rd, and 4th stream orders of the Povcha Upland. Valley lineaments rose diagrams reveal good correspondence with azimuthal diagrams of streams (especially 5th–6th order). It should be noted that main orientation trends of low stream orders are much better identified in the Mizoch

Tab.1. Bifurcation ratios for each sub-basin

Parameter	Basin1	Basin 2	Basin 3	Basin 4	Basin 5	Basin 6	Basin 7	Basin 8	Basin 9	Basin 10
Rb I/II	4,2	4,28	3,8	3,94	3,66	4,06	4,44	4,55	4,18	4,01
Rb II/III	4,38	4,84	3,9	3,88	3,91	4,17	3,91	4,55	5,36	4,67
Rb III/IV	5,71	3,57	7,5	3,57	5,83	4,24	4,25	4,13	6,38	6,86
Rb IV/V	3,5	7	4	7	3	4,25	4	3	3,67	3,5
Rb V/VI	2	-	-	-	2	4	2	5	3	2
Rbd I/II	2,96	3,25	3,11	3,3	3,06	3,22	3,25	3,26	3,12	3,28
Rbd II/III	2,97	3,28	3,1	3,08	3,06	3,1	2,74	3,45	3,29	2,96
Rbd III/IV	3,43	3	6,75	2,43	4	3,35	3,25	2,93	3,55	5,29
Rbd IV/V	2,5	7	4	7	3	2,75	3	2,8	3,33	3
Rbd V/VI	2	-	-	-	2	4	2	5	3	2
R I/II	1,24	1,03	0,69	0,64	0,6	0,84	1,19	1,29	1,06	0,73
R II/III	1,41	1,56	0,8	0,8	0,85	1,07	1,17	1,1	2,07	1,71
R III/IV	2,28	0,57	0,75	1,14	1,83	0,89	1	1,2	2,81	1,57
R IV/V	1	0	0	0	0	1,5	1	0,2	0,34	0,5
R V/VI	0	-	-	-	0	0	0	0	0	0

Rb bifurcation ratio (Horton, 1945, Strahler, 1957)

Rbd direct bifurcation ratio (Avena et al., 1967)

R bifurcation index (Avena et al., 1967)

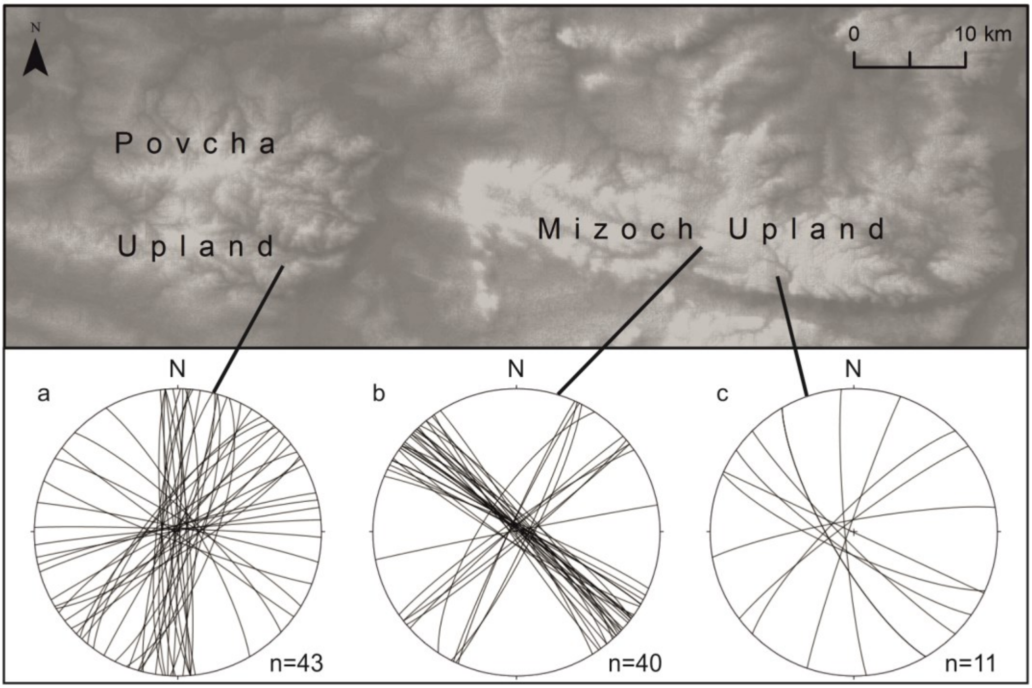

Fig.4. Wulff diagrams of joins surveyed in the Cretaceous marlstones (a, b), Miocene limestones (c) and locations of the outcrops.

Upland. The orientation diagrams of the Cretaceous outcrops joints is characterized by presence well-defined N25˚–35˚, N45˚–55˚, and N125˚–135˚ trends in the Mizoch Upland and vague trends directions (except the N355˚–5˚ class) in the Povcha Upland. As for the Miocene limestones fracture pattern, lack of enough data doesn't allow us to distinguish some trends but available information consistent with relevant dataset of the Cretaceous formation (Fig. 4b,c).

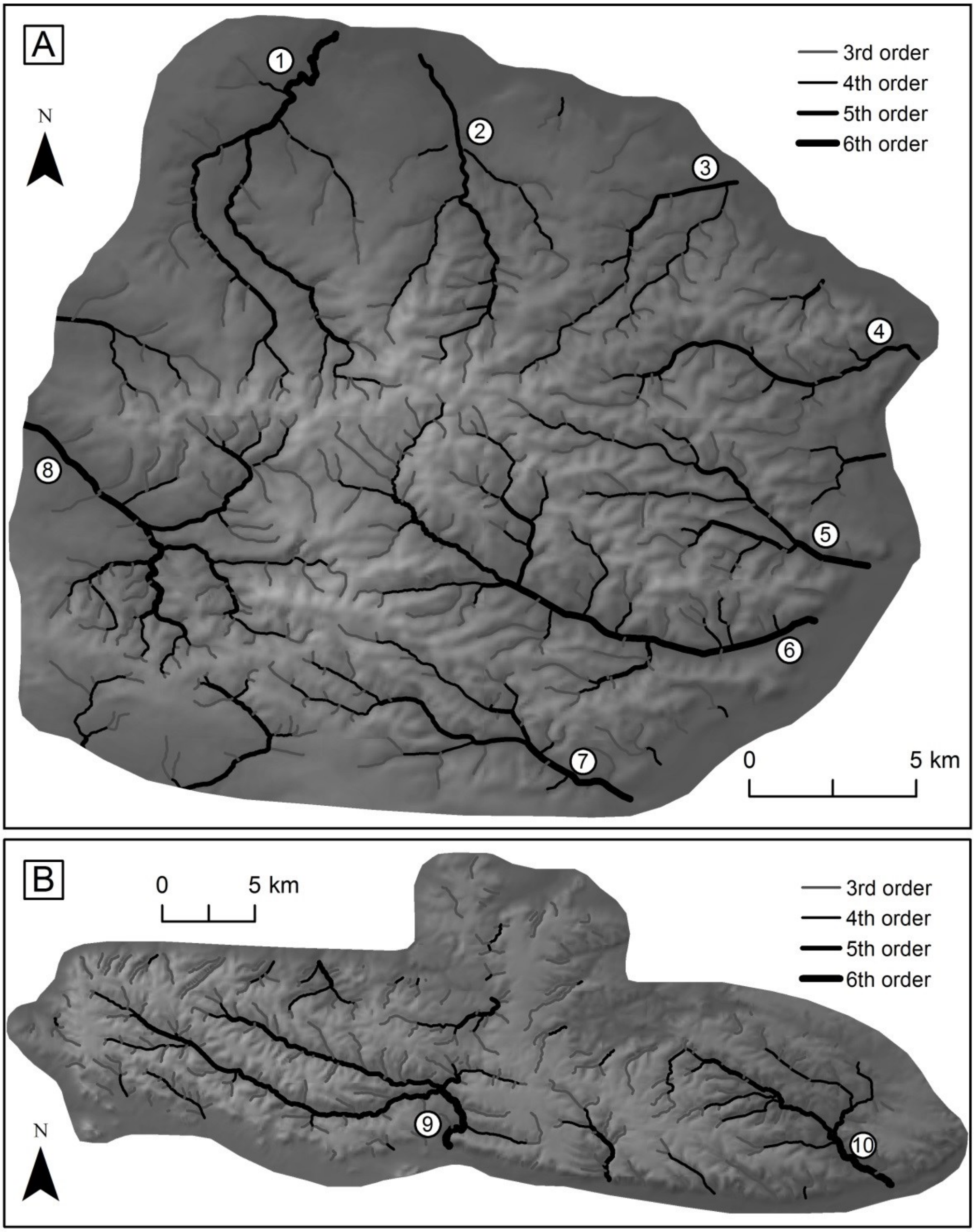

Fig.5. The drainage networks of Povcha Upland (A) and Mizoch Upland (B) to the channels from the 3rd order onwards. The major drainage basins marked by numbers.

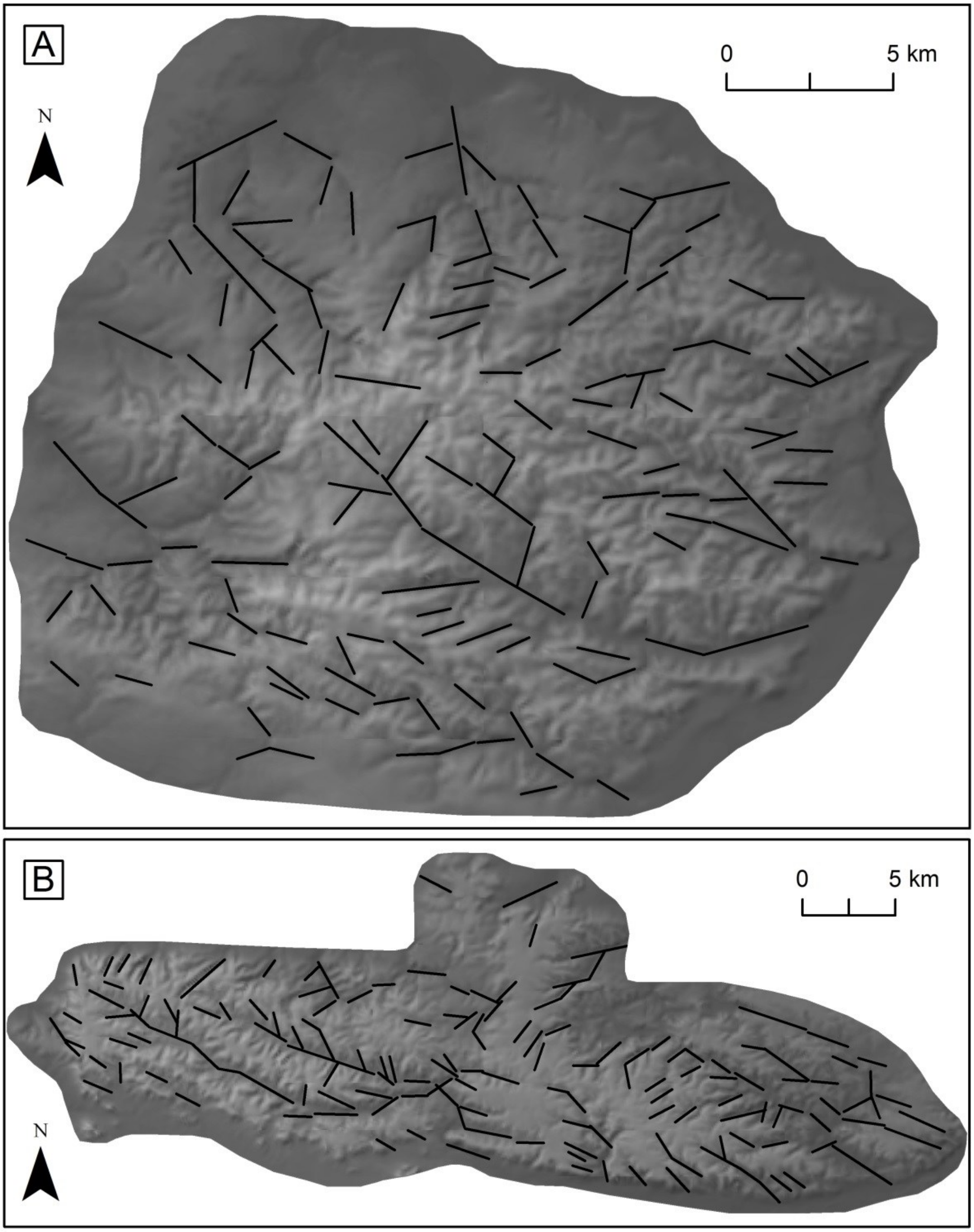

Fig.6. Identified valley lineaments of the Povcha (A) and Mizoch (B) uplands.

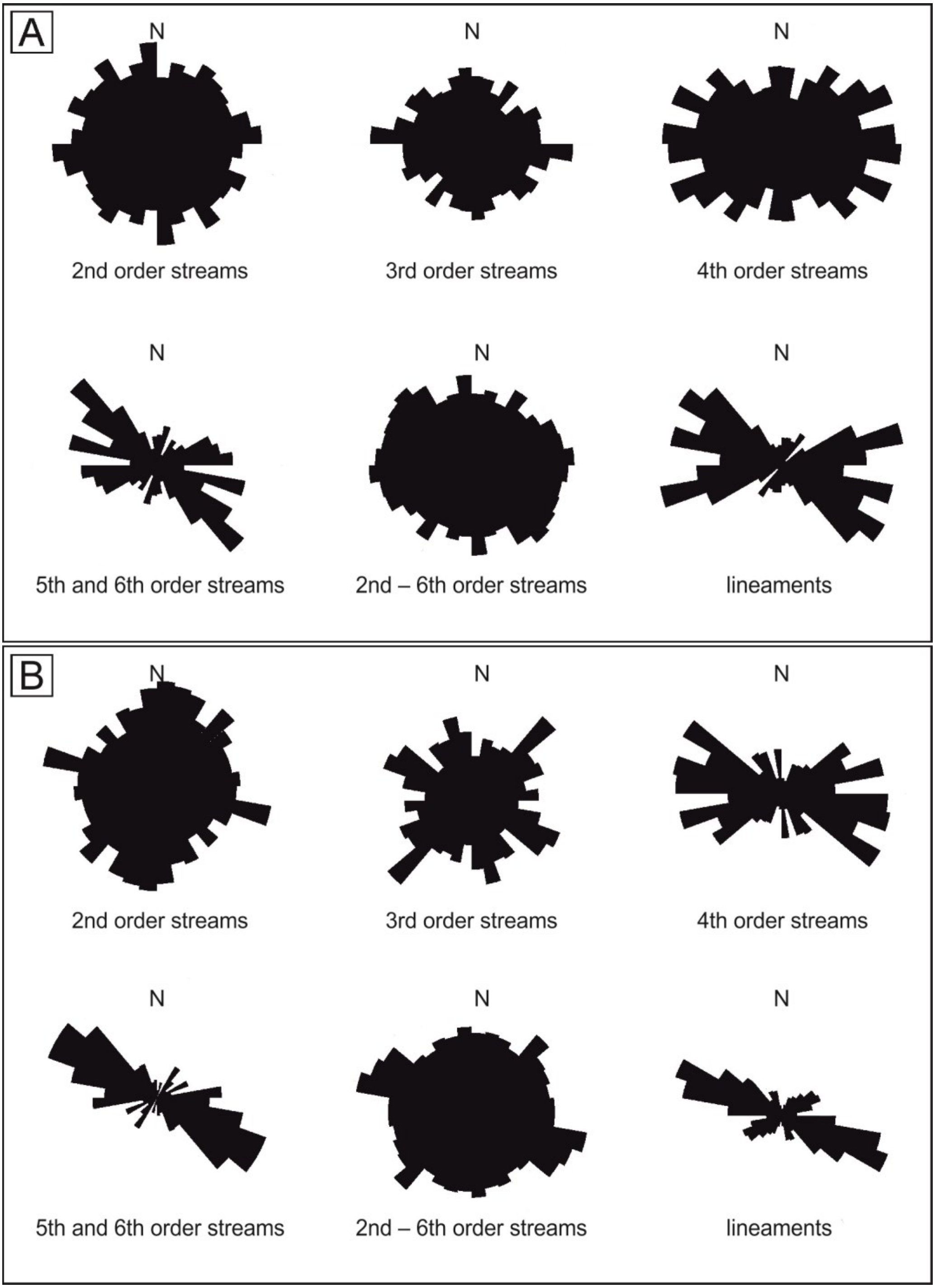

Fig.7. Cumulative lengths rose diagrams relative to the drainage channels and valley lineaments of Povcha (A) and Mizoch (B) uplands.

NW–SE trending of main high-order streams coincides with Carpathian main structural trend and may be conditioned by tectonic movements, associated with growth of the Carpathian Mountains. Dominance of this trend in the Povcha Upland and its absence in Cretaceous joint sets suggests to the much wider distribution of Miocene sediments in the past. Consequently, significant part of modern drainage network of the Povcha Upland has superimposed character. Also there are several places in the Povcha Upland where segments of drainage network adapt to the Createaceous fracture and fault system (for example submeridional drainage segments in the placement of the Povcha's dislocations). NEE trending may be related with movements that formed Podolian ledge.

The Createaceous rocks of the Povcha Upland are weaker and less resistant to erosion than limestones that form a "roof" of the Mizoch Upland. Consistently, they provide lower degree of structural control on drainage network development. As a result, streams orientation rose diagrams of the Povcha Upland has strong "background noise" intensified by complicated neotectonic activity of this area and changes of strain direction. In contrast, the Mizoch Upland located on more stable part of Volyn-Podolian plate, where the vertical blocks uplift was dominated over horizontal displacement.

CONCLUSIONS

The drainage networks of the Povcha and Mizoch uplands have been investigated in terms of relationships between their channel orientation and fracture patterns. Received data confirm conclusions concerning partial arrangement of minor streams according to the same trends of the fracture system there surveyed (Beneduce et al. 2004; Capolongo et al. 2005) also for areas with relatively stable tectonics. The better minor stream adjustment is revealed in territories with more strong structural control and solid rocks resistant to denudation. Drainage network of investigated area is characterized by the presence of several main stream direction trends and good correlation with fracture pattern, reflecting the nature of neotectonic movements and strain direction. In the Povcha Upland some parts of fluvial system are superimposed on exhumed Cretaceous surface and less adjusted to its fracture and fault patterns. Main stream directions are better expressed in the Mizoch Upland because of presence of relatively hard limestone rocks and absence of noticeable multidirectional horizontal neotectonic deformations in this area.

The stream direction statistical analysis, in combine with the drainage network hierarchy analysis, fracture pattern investigation, and analysis of topolineaments distribution, is often successfully used for studying of active tectonics. This work provides the applicability of this approach for relatively stable areas too. So, planar geometry analysis of drainage systems is a powerful tool for reconstruction of neotectonic history.

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