Assessment of recent tectonic evolution and geomorphic response in SE Carpathians (Romania) using hypsometric analysis

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doi: 10.4316/GEOREVIEW.2014.24.1.265

GEOREVIEW

Article history
Received: October 2014
Received in revised form: November 2014
Accepted: December 2014
Available online: December 2014

ABSTRACT: The study investigates correlations between the recent tectonic evolution of the external South-Eastern Carpathians and the characteristics of the hypsometric curves, derived for various Horton-Strahler basin orders. The analysis focuses on an area of about 8000 km^2, delineated by the Trotuş Fault in the north, the southern limit of the Buzău River catchment, Braşov and Focşani Basins in the west, respectively, east, known to conserve the youngest topography in the Romanian Carpathians. Considering the effects of the Quaternary uplift, these limits include the less elevated region of Subcarpathians. Spatial distribution of the hypsometrical integrals (HI) values was evaluated taking into account basin order, main lithological features and distance from major structural lines as well as some local indices of spatial autocorrelation. The results show that HI reflects both the specificity of regional tectonic evolution and denudation. However this is better sustained for the higher order basins (>3).

KEY WORDS: hypsometric integral, SE Carpathians, spatial analysis, neotectonics

1. Introduction

Landscape in the regions affected by recent or active tectonics can be broadly considered to reflect the interplay between the vertical uplift and denudational processes. In this context the existing topographic features can be progressive eroded or rejuvenated, commonly revealing transient stages. Starting with Strahler (1952) hypsometric curves and hypsometric integrals (HI) are frequently used to infer the development stage of the drainage basins according to a Davisian scheme - where the convex shapes correspond to a youthful, inequilibrium stage (HI > 0.6), the S-shaped to a mature stage (0.4 < HI > 0.6) and the concave ones to the oldest stage (HI < 0.4). Nevertheless subsequent studies emphasized that this scheme can be hardly recognized in the regions where topography is highly eroded during uplift (Ohmori, 1993) and the HI values are sensitive to uplift rates (Hurtrez et al., 1999), erosional resistance of rocks or morphometric characteristics of the catchments such as size, relief or steepness.

Within the exhumation framework of the Carpathian system, South-Eastern Carpathians and the adjacent foredeep basin present some particular features. The available thermocronological data indicate that the internal part of the orogen was affected by an exhumation event that started around 5 Ma, overprinting the older deformations (Merten, 2010). During Pliocene - Quaternary (3–2 Ma), a second post-collisional exhumation affected the most frontal part of the SE Carpathians, suggesting an eastward migration of the maximum uplift rates, coeval with the forward migration of the subsidence in the foreland (Tărăpoancă et al., 2003; Matenco et al., 2007). This late-stage exhumation event was considered responsible for the present deflection (to a more external position) of the highest elevations in the region but also a cause for a concurrent increase in the erosion and sedimentation rates. The unroofing of the Marginal Folds nappe and the exposure of the Lower Cretaceous sediments in the center of the Vrancea half-window since late Early Pleistocene indicates a peak magnitude for the process (Necea, 2010).

This paper aims to discuss the relationships that can be established between the hypsometrical characteristics of the basins draining the external part of the South-Eastern Carpathians, between Oituz and Buzău rivers, and the specific of the recent tectonic evolution.

2. Geological and geomorphological setting

The region analyzed in this study covers most of the external structures of the SE Carpathians and the western part of their foreland - Subcarpathians, within a total area of 8284 km^2 (Figure 1).

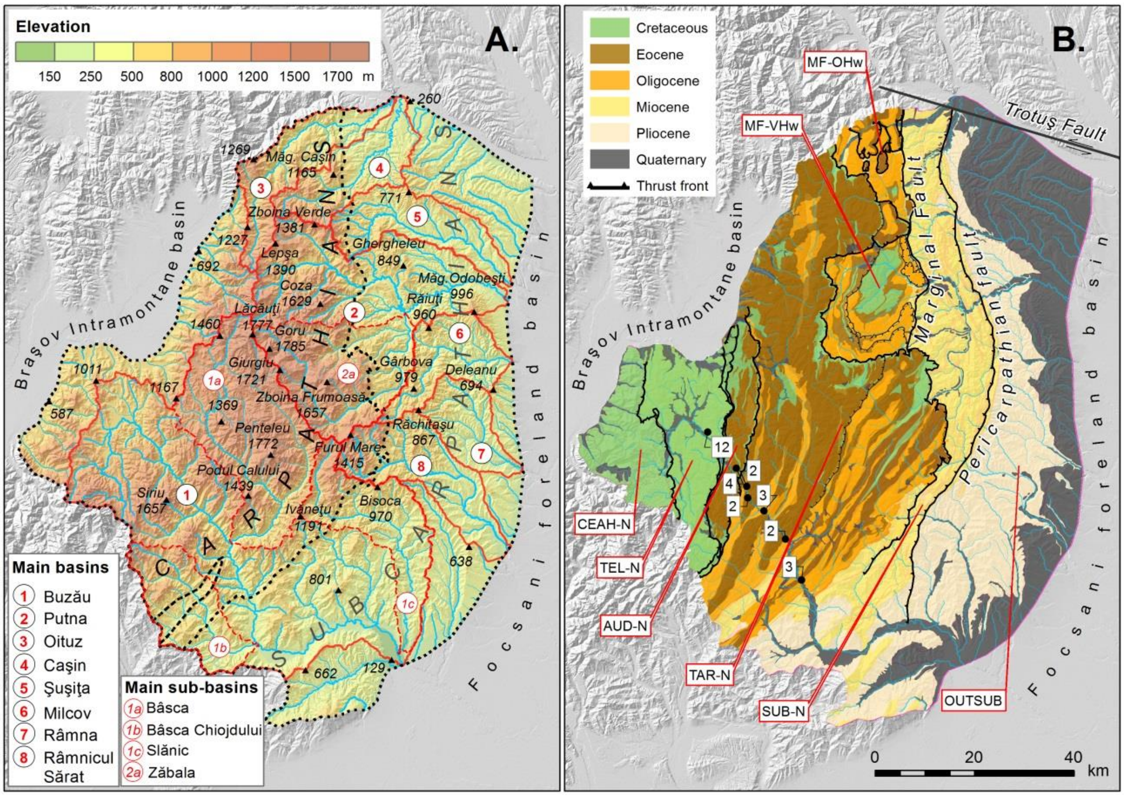


Figure 1. Hypsometry (A) and main geological features in the study area (B). Codes in red boxes represent the name of main tectonic units: CEAH-N for Ceahlău nappe, TEL-N – Teleajăn nappe, AUD-N – Audia nappe, TAR-N – Tarcău nappe, MF – Marginal Folds nappe (Vrancea / VHw and Oituz / OHw half-windows), SUB-N – Subcarpathian nappe and OUTSUB for the tilted Pliocene – Lower Pleistocene foreland deposits. Numbers in boxes correspond to thermochronological (AHe) ages determined by Merten et al. (2010).

This generally corresponds with one of the most intensely seismic areas in Europe - Vrancea Region.

In the Carpathians and the internal part of Subcarpathians, Miocene tectonic deformations generated a specific W-E nappe pile complex (Figure 1, B). Carpathian nappes are composed of Cretaceous to Paleogene flysch sequences of conglomerates, sandstones, limestones, marls and shales with variable thicknesses and strength. A concise presentation of the main lithofacies types occurring in the region based on the 1:100.000 geological map sheets is made in Table 1. In the Subcarpathians, the molasse-type sediments (sandstones, claystones, sands and gravels) are specific. These have a Miocene - Pliocene age and commonly reflects a lower resistance to erosion. Eastward of the frontal nappe thrust - Pericarpathian Fault line, the folded structures (Inner Subcarpathians) are replaced by gradually tilted formations from a near-vertical position to less than 10^0, at the edge of the study area (Outer Subcarpathians).

Table 1. Lithofacies description (based on the 1:100.000 geological map sheets and synthesis of Săndulescu et al., 1984; Ştefănescu et al., 2006) and associated codes used in this research

Lithological classes	Description	Unit	Age	Area (%)
Sinaia - Comarnic Formation (SCF)	Calcareous turbidites – limestones, marls and shales	CEAH-N	Early Cretaceous	3.19
Ciucaş Formation (CIU)	Massive conglomerates and sandstones	CEAH-N	Early Cretaceous	0.64
Teleajen Formation (TEL)	Sandy-shaly turbidites with convolute sandstones	TEL-N	Early-late Cret.	5.82
Audia Formation (AUD)	Black shales interbedded with calcareous sandstones	AUD-N	Early-late Cret.	0.95
Hangu Formation (HAN)	Calcareous turbidites - limestones, marls and clays	TAR-N	Late Cretaceous	1.24
Lepşa Formation (LEP)	Calcareous turbidites – shales, marls, limestones, sandstones and clays	MF-Hw	Early-late Cret.	0.28
Siriu Formation (SIR)	Massive sandstones and sandy turbidites,	AUD-N	Late Cret. – Eoc.	1.12
Caşin/Buciaş Formation (CAS)	Marls, limestones with local massive conglomerates and sandstones	MF-Hw	Paleocene	1.02
Tarcău Sandstone Formation (TAR)	Massive sandstones with interbedded clays, marls and conglomerates	TAR-N	Eocene	16.13
Piepturi - Colţi Formation (COL)	Sandstones, marls and clays	TAR-N	Eocene	3.94
Greşu Formation (GRE)	Marls, clays with interbedded sandstones, limestones and	MF-Hw	Eocene	0.84
Fusaru Sandstone Formation (FUS)	Sandy – shale flysch sequence	TAR-N	Oligocene	3.61
Kilwa Formation (KLW)	Massive quartzitic sandstones with bituminous shales, marls and menilites	MF-Hw	Oligocene	9.22
Miocene Molasse (MM)	Marls, clays with interbedded sandstones and conglomerates (in folds with salt	SUB-N	Miocene	13.71
Pliocene Molasse (PM)	Alternating mudstones, friable sandstones, clays and sands	OUTSUB	Pliocene	24.9
Cândeşti- Frăteşti Formation (CF)	Coarse-grained gravels, slightly consolidated, with thin intercalations of sands and clays (piedmont deposits)	OUTSUB	Early Quaternary	13.38

The highest elevations in the region occur in the Tarcău and Marginal Folds domains. Here several peaks rise above the 1100 – 1200 m general level, up to ~1800 m. One should note that the highest topography in the southern part of the region (Buzău catchment) hardly corresponds with the main Carpathian drainage divide (Figure 1, A). The elevations consistently decrease eastward, in the Subcarpathians, to 300 – 600 m, with highest elevations (up to 1000 m) near the frontal nappe thrust (Inner Subcarpathian Hills) and Lower Pleistocene piedmontane deposits (Outer Subcarpathian Hills).

Generally following the exhumation history of the geologic structures and the presence of two subsidence basins, in the east (Focşani Basin) and west (Braşov Basin), rivers are oriented nearly transversal to the tectonic lineaments. The main deflections can be roughly associated with an increase in the tectonic activity near Carpathian and Subcarpathian frontal thrusts, eventually determining a specific pitchfork drainage pattern. Moreover, previous studies regarding drainage evolution in the region emphasized the effects of the Late Pliocene–Quaternary tectonic deformation on the fluvial system, such as disruption of an older, foreland-ward, river network due to the formation of the Braşov intramontane basin during Pliocene and the development of the westward oriented catchments (Fielitz and Seghedi, 2005), captures in the upper reaches (e.g. Buzău River, Fielitz and Seghedi, 2005), increased incision (up to 280 m) and the formation of the degradational (strath) terraces (Necea et al., 2013), downstream tiling of fluvial terraces (Necea et al., 2005), young longitudinal river profiles (Rădoane et al., 2003) etc.

3. Methodology

The hypsometric curve / integral of a catchment represents the relative area below (or above) a given altitude (Strahler, 1952). It can be therefore used to describe the distribution of elevations within a drainage basin and allows comparisons between different basins. As for rather different curve shapes, the hypsometric integral can have similar values, Harlin (1978) and Luo (2000) suggested the analysis of some related statistical attributes like the skewness and kurtosis of the curve and skewness and kurtosis of its density function. For example, increases in the hypsometric skewness were associated with large amount of headward erosion and density skewness, with changes in the basin slope (Harlin, 1978). Currently, DEM-based computation of the hypsometric integrals using special developed tools (e.g. TecDEM for Matlab, CalHypso for ArcGIS) provides a fast way to analyze regional-scale interactions between landscapes and tectonics (Andreani et. al., 2014).

Hypsometric characteristics of the study area, at catchment level, were investigated based on the Shuttle Radar Topography Mission (SRTM) 1 arc-second surface elevation model, further resampled to a 30 m grid resolution. In order to assure the accuracy of catchment delineation in the flat landscapes, major streams were extracted from the topographic maps and further “burned” into the DEM using ArcGIS and ArcHydro. Using this modified elevation model, TecDEM (Shahzad and Gloaguen, 2011) and considering the Horton-Strahler order of the streams, catchments were eventually extracted. The threshold contribution area used for stream initiation was 0.1 km^2. For every catchment of Strahler order greater than 2, hypsometric integrals and their statistical moments were computed using CalHypso (Pérez-Peña et al., 2009), based on the original DEM.

Geographical distribution of HI was evaluated based on selected local factors such as geological structures and lithology, along with distance of the central point (mid-point) of each basin from the main structural lines – Trotuş and Marginal Faults. For the 3rd and 4th order catchments, spatial pattern of the HI values was analyzed using local indices of spatial autocorrelation, such as Anselin Local Moran's I (Anselin, 1995) and Getis Ord Gi*(Ord and Getis, 1995). These generally indicate the spatial clustering of values, up to a specific distance around observations, based on standardized (normally distributed) Z-scores and the associated probability (p-value). The Z-scores are measures of standard deviations used to reject or not the null hypothesis - that there is no spatial pattern among values (no global autocorrelation). Probability is a measure of chance to falsely reject the null hypothesis. In this research if $p \leq 0.05$ results were considered significant.

Table 2. Statistics of the hypsometric integrals for the main basins in the region (delineated in Fig. 1)

Main basin	Hi	6th Order			5th Order			4th Order			3rd Order		
		No.	Mean Area (km²)	Mean HI	No.	Mean Area (km²)	Mean HI	No.	Mean Area (km²)	Mean HI	No.	Mean Area (km²)	Mean HI
1	0.37	6	343.06	0.37	26	66.35	0.41	120	14.64	0.44	516	3.62	0.47
2	0.42	2	526.17	0.44	11	70.54	0.44	52	13.67	0.47	219	3.26	0.49
3	0.41	1	329.86	0.41	2	130.67	0.43	10	14.72	0.47	57	3.14	0.49
4	0.37	1	315.40	0.37	3	40.35	0.48	10	16.62	0.42	53	3.71	0.45
5	0.29	1	333.50	0.29	2	71.04	0.29	11	14.15	0.42	49	4.11	0.45
6	0.31	1	273.97	0.31	4	45.72	0.37	10	15.06	0.39	44	3.56	0.46
7	0.33	1	219.88	0.33	3	62.90	0.41	8	18.67	0.45	33	3.38	0.49
8	0.35	1	427.44	0.35	3	61.74	0.42	14	18.21	0.45	67	3.36	0.49

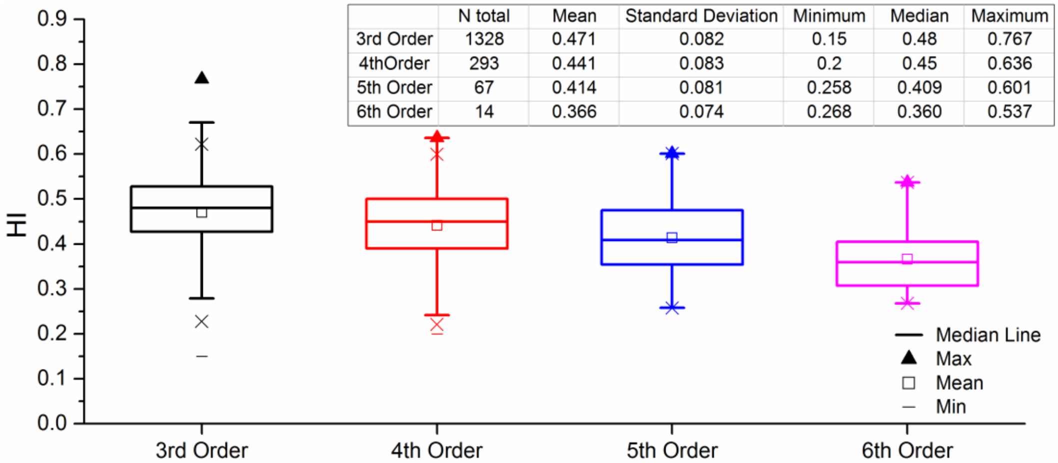
These statistics measure different concepts of spatial association. The positive Gi* statistic identifies significant spatial associations of high values (hot-spots), while the negative one a spatial clustering of low values (cold-spots). Conversely positive Local Moran's I is related to spatial clustering of similar values around an observation (high values in a high value neighborhood or low values in a low value neighborhood), while the negative ones reflect the presence of nearby dissimilar values. Because of the local character of the computations a fixed distance band has been used in order to define the neighbors included in the analysis (the weight). This was determined by measuring the global spatial autocorrelation at multiple scales and considering the largest Z-score obtained for each dataset: 17 km for the 3rd order basins (Moran's I – 0.128) and 15 km for the 4th order (Moran's I – 0.339).

4. Results and discussion

A synthesis of the determined HI values for the main basins is presented in Table 2, as well as for the entire study area – Figure 2. Considering the Horton – Strahler rank and for a 0.1 significance level (Shapiro-Wilk test), basin data follow a normal distribution in case of the 4 - 6th orders and is slightly skewed to the right, in case of the 3rd order. The higher the catchment order, the lower the mean HI value.

Given the hypsometric integral values and associated statistical moments of the main basins in the region it is seen that there are important variations, possibly indicating different stages of land mass removal by erosion. In case of the fluvial basins draining the Carpathians thrust sheets (including Subcarpathian nappe) the hypsometric curves have a much or less contoured S-shape, based on the degree of headward development of the main river and its tributaries (Figure 3, A).

The less developed curves are corresponding to the Bâsca and Zăbala catchments and are characterized by a negative density skewness (-0.23 and -0.14 respectively) - Table 3.



	N total	Mean	Standard Deviation	Minimum	Median	Maximum
3rd Order	1328	0.471	0.082	0.15	0.48	0.767
4thOrder	293	0.441	0.083	0.2	0.45	0.636
5th Order	67	0.414	0.081	0.258	0.409	0.601
6th Order	14	0.366	0.074	0.268	0.360	0.537

Figure 2. Box-plots showing the distribution of the HI values for different Horton-Strahler basin orders.

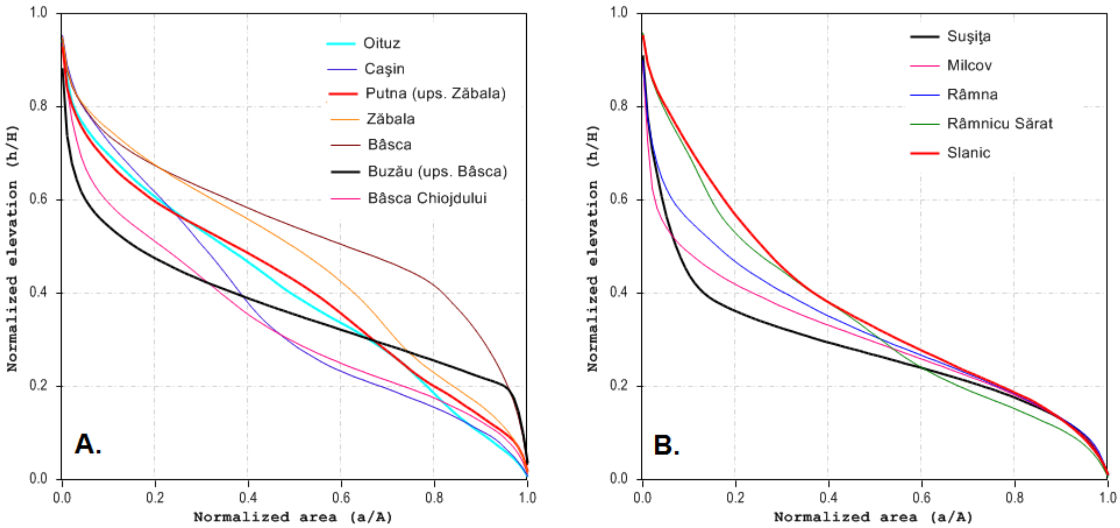


Figure 3. Hypsometric curves of main basins draining the SE Carpathians-Subcarpathian nappes (A) and Subcarpathian nappe-Outer Subcarpathians tilted formations (B).

HI curves gradually change northward and southward to rather concave ones and the integrals accordingly decrease from 0.54 to less than 0.4. Based on the previous studies, when the density skewness is negative it shows greater erosion in the lower reaches - such as is found in basins at the inequilibrium stage (Luo, 2000), while the values around 0 (meaning equally distributed erosion in the upper and lower reaches – Harlin, 1978) is an indicator for a equilibrium stage. Putna basin (upstream of the confluence with Zăbala river) is such a latter case (Table 3). The main catchments incising mostly in the Miocene to Lower Quaternary formations have lower HI values (mean value – 0.33) increasing southward, concurrently with a decrease in the upper concavity of their curves (Figure 3, B). In this case HI is better correlated with the skewness parameter (Pearson – 0.88, with a 0.05 significance level).

Table 3. Main statistical moments of the hypsometric curves selected in Fig. 3

Basin	HI	Skewness	Kurtosis	Density skewness	Density kurtosis
Oituz	0.41	0.52	2.27	0.08	1.60
Caşin	0.37	0.75	2.65	0.60	2.24
Putna (ups. Zăbala)	0.42	0.50	2.23	0.04	1.62
Zăbala	0.47	0.47	2.21	**-0.14**	1.69
Bâsca	**0.54**	0.28	1.95	**-0.23**	1.42
Buzău (ups. Bâsca)	0.37	0.36	1.96	0.38	1.56
Bâsca Chiojdului	0.34	0.59	2.29	0.54	1.88
Suşiţa	0.29	0.44	1.98	0.52	1.57
Milcov	0.31	0.45	2.08	0.30	1.49
Râmna	0.33	0.51	2.15	0.42	1.64
Râmnicu Sărat	0.35	0.68	2.45	0.62	2.05
Slănic	0.38	0.62	2.32	0.59	1.93

4.1. Lithological influence on the distribution of the HI values

The influence of main lithological formations on the HI values was evaluated taking into account only the catchments where the main lithofacies represents more than 80 %.

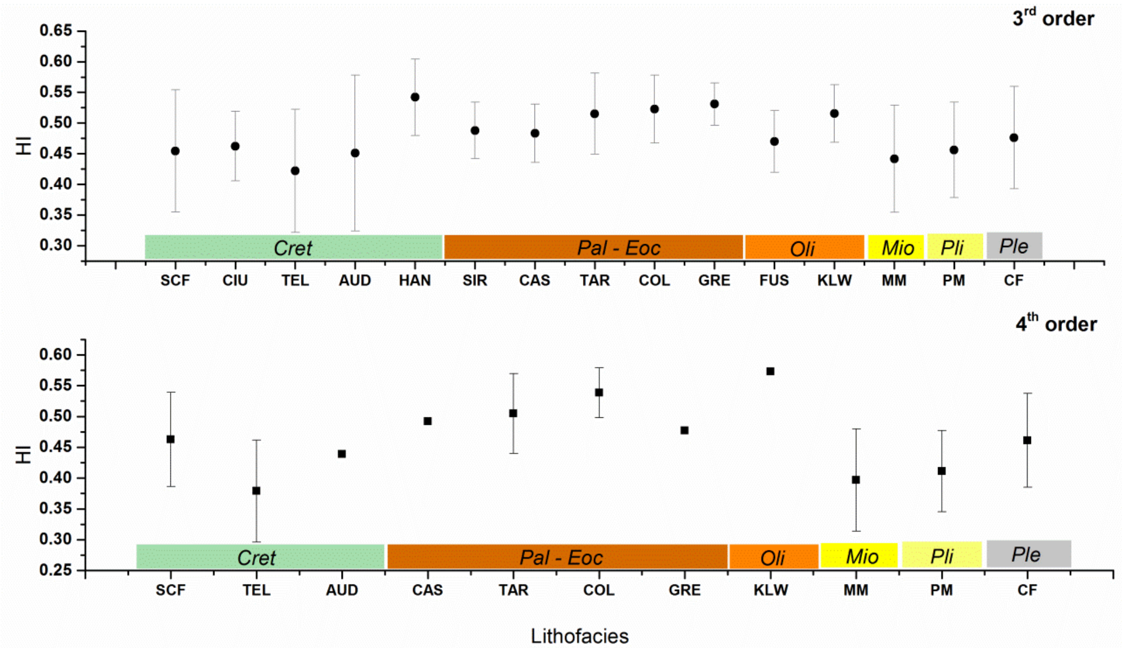


Figure 4. Mean HI values obtained for the 3rd and 4th order basins with homogeneous lithofacies (see Table 1 for the abbreviations). Age of the formations is indicated with colors on the horizontal axis. The error bars represent computed standard deviations (1σ).

About 70 % of the 3rd order catchments fulfill this condition. Here the highest computed mean values (reported to the number of observations) were positively associated with more resistant formations, such as Tarcău (0.52) and Kliwa (0.52); still other Eocene classes with increased proportions of soft sedimentary rocks (Greşu and Colţi) have comparable or even slightly higher HI means (Figure 4). Comparatively, in the foreland region, the catchments developed in the Lower Pleistocene deposits generally present higher values (0.48) than those supported by the Miocene and Pliocene deposits (0.45 – 0.46). However the standard deviations are too high to consider a significant correlation.

At the scale of the 4th order catchments the relationships established between rock facies and HI values would be relatively similar, although the number of homogenous features is much lower (162 from 292, about 55 %). Catchments developed mostly in the Cretaceous formations generally have HI < 0.5, the values increase up to 0.57 in the Paleogene domain and further decrease again to less than 0.5 in the Carpathian foreland (Neogene – Quaternary sediments). Taking into account the dominant west to east thrusting direction of the nappes and related progressive decrease in the age of the geological deposits one should note that, for comparable lithologies or ages, the more eastern the position of the facies, the higher the mean HI value. Nevertheless this is not so obvious for the Paleogene facies in the Vrancea half-window, where Greşu and Caşin Formations occur.

4.2. HI vs. distance from major structural lines

Distribution of the HI values against distance from the Marginal Fault (Carpathian front line) was plotted in Figure 3 and further modeled using linear and non-linear functions (Figure 5). Regardless of a relative weak correlation for the 3rd order basins, the strength of the linear correlation and trend slope clearly increase in case of those with higher orders. The correlation is negative for the Carpathians, as the HI values are usually greater than 0.5 near the frontline and gradually decrease westward, but positive in case of the Subcarpathians, where values increase towards the Focşani subsidence area. In case of the 5th order basins a slight increase of HI can be noticed near the Pericarpathian Fault line, suggesting a possible tectonic cause. Similarly, the non-linear functions indicate for the higher order basins important HI variations - from 0.3 to 0.5, between the internal and external flysch zones and SE Carpathians and Subcarpathians as well.

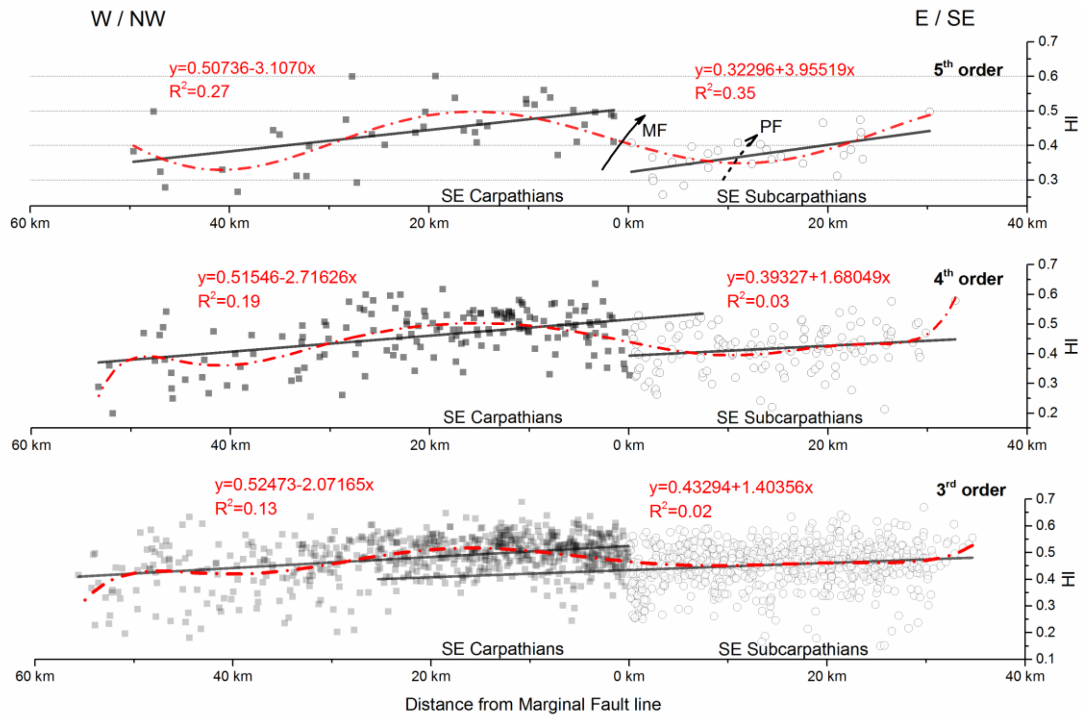


Figure 5. Plots of HI vs. basin mid-point distance from the Carpathian front thrust for different basin orders; MF = Marginal Fault, PF = Pericarpathian Fault.

Considering the distance from the Trotuş crustal strike-slip fault (separating the Eastern and SE Carpathians), HI values can hardly be fitted using linear functions and a best fit (with the highest R^2) polynomial approach was preferred. For the basins with central-points located in the Marginal Folds (MF-OHw, MF-VHw) and Tarcău (TAR-N) thrust sheets and those located in the Subcarpathian nappe (SUB-N), polynomial shapes determined are highly similar. By contrary, for the basins located eastward of the Pericarpathian Fault (Outer Subcarpathians - OUTSUB), the fitted shape indicates inverse tendencies. These differences are also better exposed in case of the higher order basins (Figure 6).

For the most frontal part of SE Carpathians, HI consistently increase (>0.55) between 90 to 60 km towards Trotuş Fault, roughly corresponding with the major flexure point of the Carpathians (Zăbala, Bâsca Mică and Bâsca Mare catchments). Subsequent noticeable decreases below the 0.5 level can be observed for the 5th and 4^{th} basins centered in the exhumed half-window areas (Vrancea and Oituz). This is also highly consistent, in terms of position, with the maximum thickness of the Quaternary deposits in the foreland (top plot in Figure 6), suggesting therefore a correlation between tectonic denudation (unroofing of the Marginal Folds) and subsidence-determined base level fall.

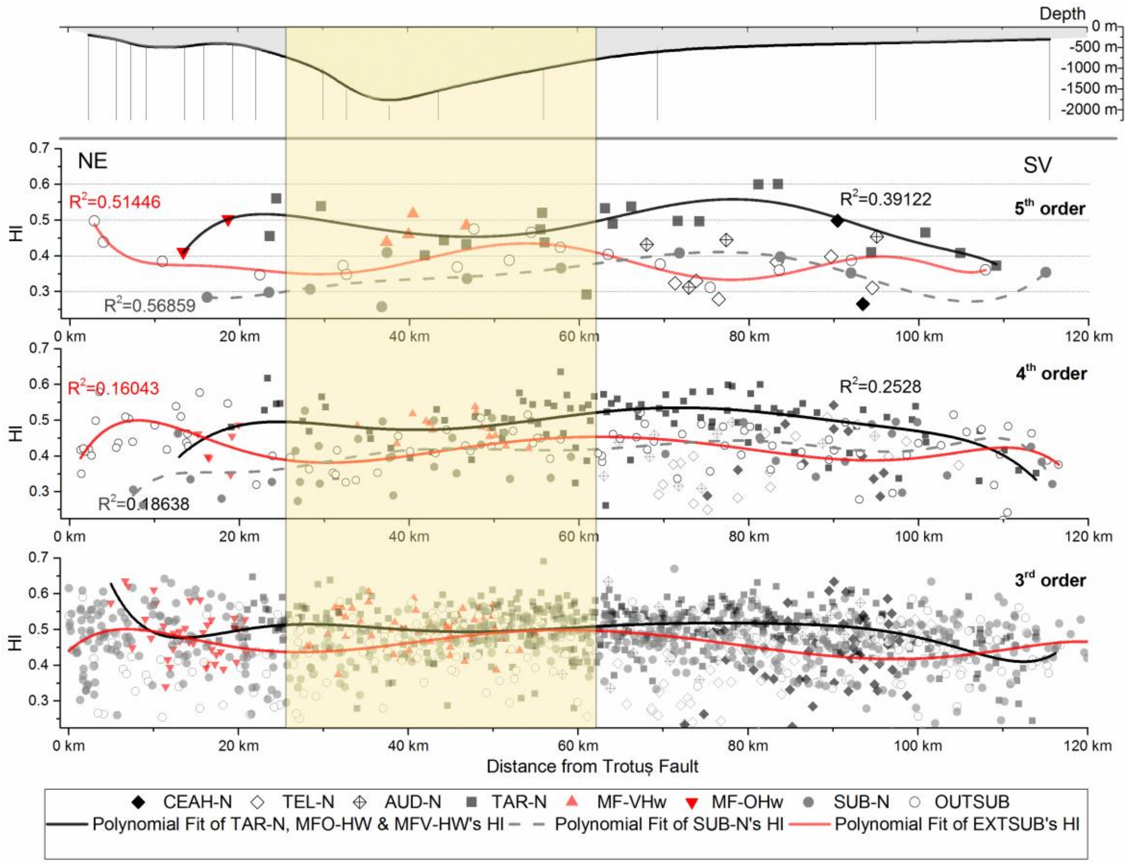


Figure 6. Plots of HI vs. basin mid-point distance from the Trotuş strike-slip fault, for different basin orders and considering the main tectonic units (see Fig. 1 or text for abbreviations). Top profile indicates the corresponding depth of Quaternary deposits in the Focşani Basin (Matenco et al., 2007).

One should note also, for the corresponding Outer Subcarpathians data, that the trend is "positively" reversed. The fact may be a consequence of the coeval uplifting of the western flank of the subsiding basin, up to elevations of 1000 m in case of the Lowermost Pleistocene strata.

4.3. Spatial-cluster and hot spot analyses

Spatial-cluster analysis and hot/cold-spots detection play important parts in exploratory spatial data analysis (ESDA) and may complete the much more visual GIS mapping techniques. Accordingly, the spatial variations visually identified based on raw data were statistically tested using Local Moran's I and Getis Gi*.

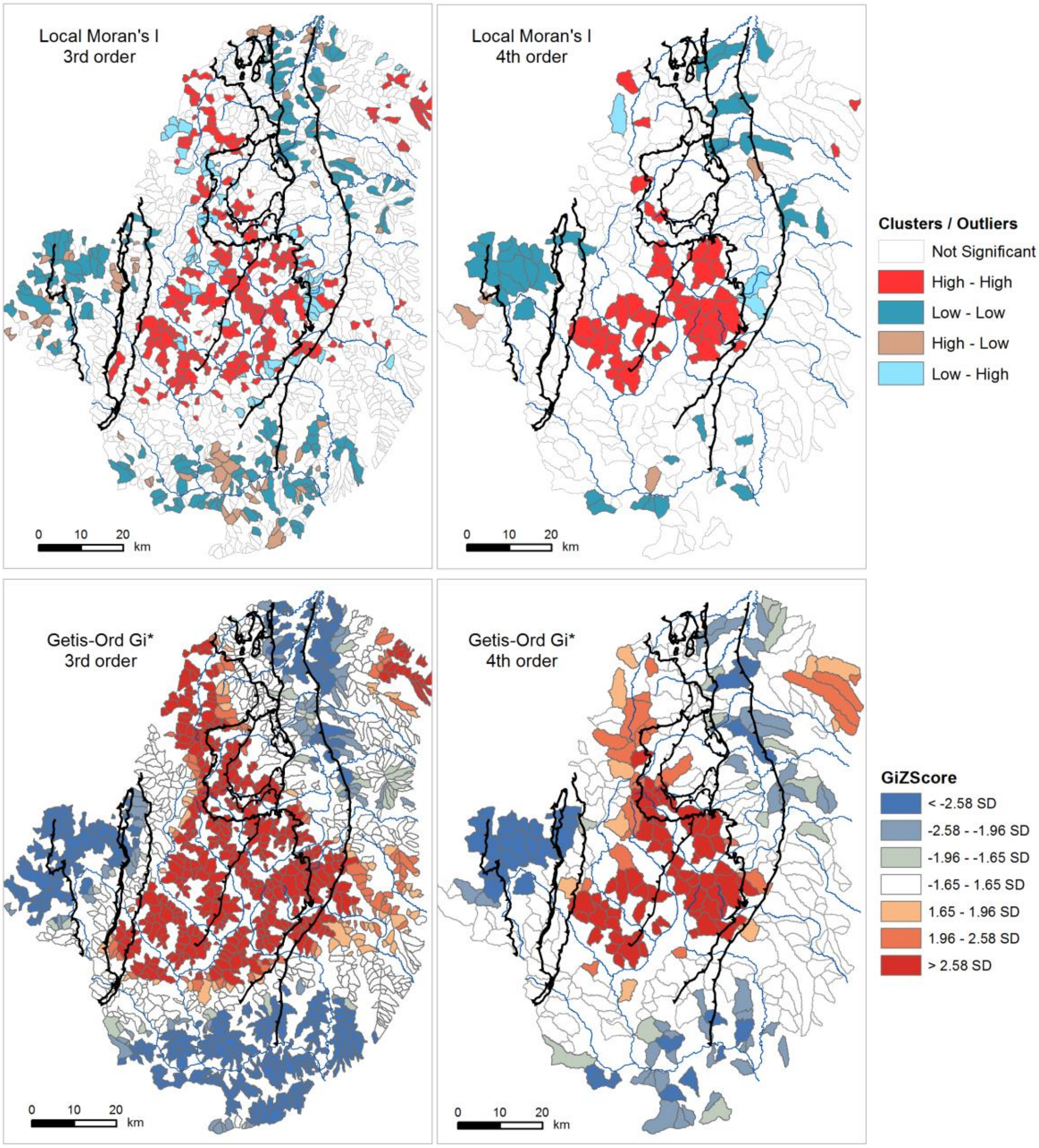


Figure 7. Results of the Local Moran's I and Getis-Ord Gi* statistical analysis. The figure shows the presence of the high and low HI clusters in the study region. See text for further explanations.

Both methods revealed (Figure 7) the presence of a large high–high spatial cluster extending mostly in the Bâsca Mare, Bâsca Mică (tributaries of the Buzău River) and Zăbala (tributary of the Putna River) basins, while basins developed in the Internal Flysch (western part of the study area) and Subcarpathians were statiscally associated in low values clusters (cold-spots). However in case of the latter morphological unit, some more or less significant anomalous high scores can be noticed especially for the 3rd order basins draining the north-eastern part of the region (Zăbrăuţi Piedmont – p = 0.01) or near the major flexure point of the Carpathian mountain range (Râmna and Râmnicu Sărat basins – p = 0.01 in case of the Inner Subcarpathians and 0.05-01 for the Outer Subcarpathians). One should notice that in some of these cases edge effects must be considered.

Unlike the Gi* scores, which offers a much more synthesized image on the HI magnitude, Local Moran's I index is sensitive to outliers. Consequently, the influence of the major structural lines can be better evaluated. For example, basins crossing the Marginal Fault normally would have lower scores than the fully-developed Carpathian ones (due to the Carpathians – Subcarpathians differences in rock strenght and erosion potential), but this can hardly be noticed south of Zăbala River using the Getis-Ord Gi*. By opposite, Local Moran's I analysis show for this region the presence of some low values outliers, mainly located closely to the high–high spatial cluster area.

5. Conclusions

A large number of studies indicate, from different perspectives, that South-Eastern Carpathians conserve the youngest topography in the Romanian Carpathians (Sanders, 1998; Necea, 2010; Merten, 2011), reflecting a multiple-phase Pliocene – Pleistocene exhumation of the nappes, towards foreland (e.g. Matenco et al., 2007; Merten et al., 2010). Accordingly, the internal flysch nappes were slowly exhumed from the Late Miocene to present at average rates of 0.1 mm/yr, the Audia nappe was rapidly exhumed (1.7 mm/yr) around 6 – 5 Ma, whilst the Carpathian frontal part (sediments in Tarcău and Subcarpathian nappes) was uplifted from 3 Ma to present at rates of 1.6 mm/yr (Merten et al., 2010) to 3.2 mm/yr, in the Marginal Folds area (Necea, 2010). These exhumation rates were competed by an important denudation, responsible for the gradual filling of the Focşani Basin (> 2000 m of Quaternary deposits; Matenco et al., 2007).

Both concurrent factors were found to be reflected in the HI values, although other factors such as lithology and basin morphometry also have specific influences. The HI values are generally larger than 0.5 in the Carpathian areas experiencing the most recent tectonic deformations (external flysch) and significantly lower in the internal part. However, few basins (draining Zboina Frumoasă – Furul Mare, Penteleu and Podu Calului Massifs) have Strahler's expected convex curves (Hi>0.6). Moreover these higher values are slightly decreasing in the Vrancea half-window, where the oldest Cretaceous formations in the area were exposed starting with the late Early Pleistocene (youngest U-Th/He ages in the region – 1 Ma; Necea, 2010). This confirms Ohmori's (1993) empirical statement that the hypsometrical integral indicates the state of denudational processes rather than the stage of the Davisian geomorphic cycle. The same issue may be invoked in case of the Subcarpathian basins, with relatively lower HI values (~4.5).

Considering the order of the basin and related mean area, recent exhumational history of the SE Carpathians is less clearly indicated by the analysis of the lower order basins (≤3). This should be related to the predominance of similar, regional, hillslope processes at catchment level and, eventually, suggests that local fluvial processes and geomorphic characteristics are more likely to reflect the interplay between tectonics and denudation. Concurrent uplift (near the Carpathian thrust front) and subsidence driven base level change (in the Focşani foreland basin) - with highest documented rates in the Putna basin, are more likely to be responsible for the decreasing of the HI towards the northern structural limit of the SE Carpathians (Trotuş Fault). Conversely, south of Zăbala River, lack of an equally important depocenter, has limited the denudation, conserving topography. Nonetheless this may be the best expression of the SE Carpathians topographic steady-state (equilibrated erosion - rock uplift rates; Montgomery, 2001).

Acknowledgements

This paper has been financially supported within the project entitled „SOCERT. Knowledge society, dynamism through research”, contract number POSDRU/159/1.5/S/132406. This project is co-financed by European Social Fund through Sectoral Operational Programme for Human Resources Development 2007-2013. Investing in people!

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