General and peculiar morphological characteristics of the drainage system dynamics in alpine basins: the case of the Arvan (French Alps) and Slănic (Romanian Carpathians and Subcarpathians) basins

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Key words: the Arvan, the Alps, the Slanic, The Curved Carpathians and SubCarpathians, geology, morphometric analysis, morphohydrographic basin

General şi particular în studiul dinamicii bazinelor morfohidrografice alpine. Studiu de caz: bazinul Arvan (Alpii Francezi) şi Slănic (Carpaţii Româneşti).

Lucrarea îşi propune să prezinte comparativ specificul dinamicii reţelei hidrografice a două bazine situate în regiunea de orogen: Arvan (Alpi) şi Slănic (Carpaţii şi Subcarpaţii de Curbură), utilizând metoda morfometrică.

Modelul drenajului realizat în ambele bazine şi calcularea unor parametrii morfometrici legat de acesta relevă dinamica deosebit de activă a bazinelor hidrografice şi frecvenţa mare a talvegurilor elementare.

Densitatea segmentelor de râu pentru bazinul Arvan este de 30,65 segmente/km^2, în timp ce pentru bazinul Slănic aceleaşi parametru are o valoare mult mai mică de 13,7 segmente/km^2. Suprafaţa ce revine drenajului segmentelor inferioare la bazinul Slănic este aproape dublă faţă de bazinul Arvan, fapt datorat numărului mare de segmente inferioare care se înscriu în circurile glaciare, în torenţii de grohotiş şi în cadrul culoarelor de avalanşe.

Dinamica activă a reţelei de drenaj din cadrul celor două bazine este ilustrată şi de indicele de realizare a bazinului care pentru Arvan este de 96%, ceea ce arată o stare de echilibru, iar pentru Slănic este de 145 % indicând o stare de dezechilibru la nivelul întregului bazin. Analiza subbazinelor de ordine imediat inferioare relevă şi alte caracteristici ale dinamicii.

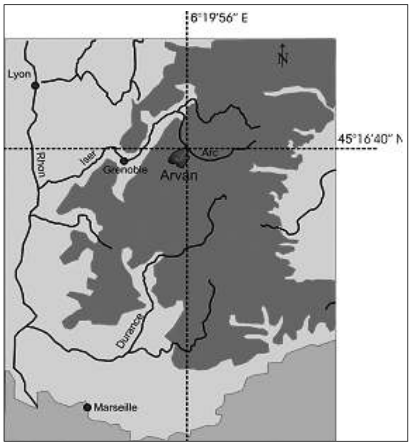
1. General data

Of vital importance for the systematization of slope drainage are the precipitation quantity and the particularities of the topographic surface (rock formation, relief morphometry and morphography, vegetation, etc.) all in the context of the tectonic and neotectonic movements. Consequently all morphohydrographic systems react differently to energy and matter inputs as dictated by the ratio resistance factors/leveling factors of the topographic surface. The theoretical and methodological research of the morphohydrographic basins also results into some general, genesis and evolution related studies of this type of relief such as modeling (based on Horton's laws), analysis based on the morphologic theories (especially that of fractals), systemic analysis (the process - response system, the domino system, etc.), the holistic analysis, etc. In order to exemplify two hydrographic basins were studied– the Arvan and the Slanic (Grecu and all, 2006), located more or less at the western and the eastern ends of the alpine-carpathian orogen greatly similar yet with many particularities.

The Arvan basin is situated in the French Alps of Savoie, the Maurienne region. It mostly overlaps the geographic region Pays des Arves, located south of Arc, between the Belledonne Massif (in the north-west), the Grandes Rousses (in the south-west and south) and the Grande-Chible ridge (in the east), which goes on southwards with glacial cirques and ridges that reach their maximum height in Aiguilles d'Arves (Aiguilles Centrale 3 515 m) the highest in the basin also (Fig. 1).

The basin is drained by the homonym river which flows into the Arc River (tributary on

Fig. 1. Location
of the Arvan hydrographic basin.



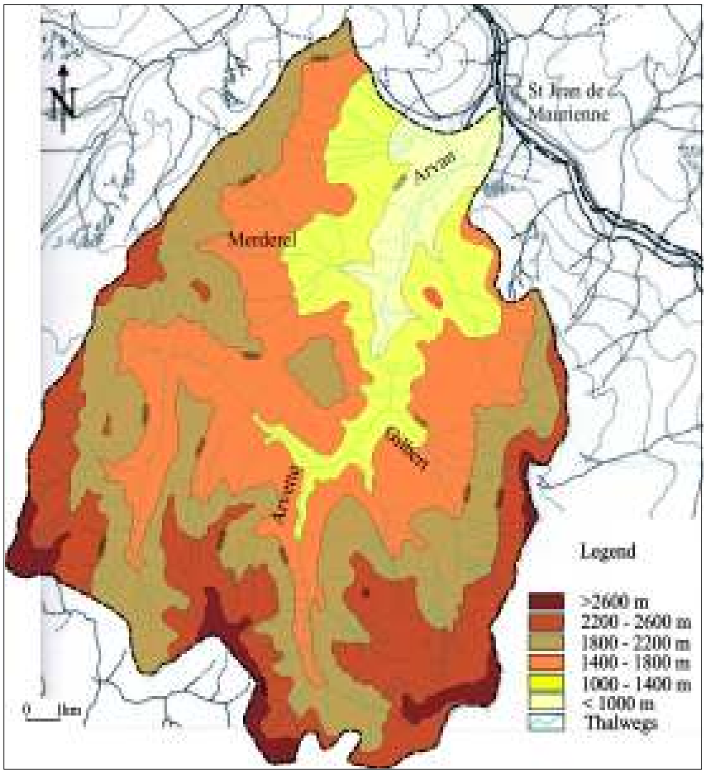


Fig. 2. Hypsometric map of the Arvan hydrographic basin

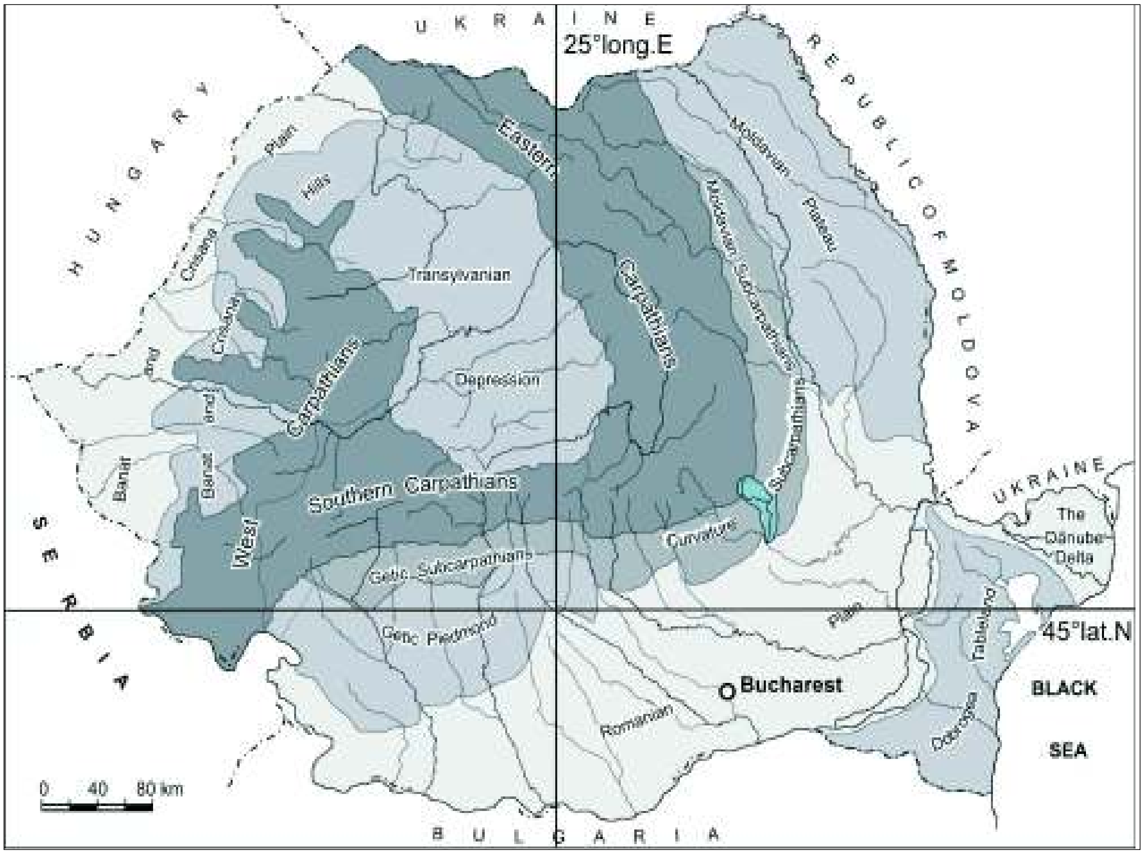


Fig. 3. Location of the Slănic hydrographic basin.

the left of Isere) in the St. Jean de Maurienne settlement located at 550m. Therefore the difference in altitude is of about 2965m on a 25 km distance. The basins surface is of about 220 km^2 or, translated in the Horton-Strahler system a rank 7 basin. The Arvan River springs at the altitude of 1 270 m where the Arvan Gully (west-east oriented, rising from about 2 300 m) flows into the Arvette (south-north oriented, joining along the new formed river) near the Entraigues settlement (Fig. 2). (We consider the Arvette River to be the spring since it rises as a permanent river at the altitude of 2 500 m from the gullies draining the glacial cirque located below Aiguille Centrale, which keep growing regressively up to 3 000 m). The neighboring hydrographic basins are Valloirette in the east and Gordon in the west (tributaries on the left of the Arc River) as well as Romanche in the south (tributary on the right of the Drac River that flows into Isere).

The hydrographic basin of Slanic, located in the curving area of the Carpathians and SubCarpathians, is part of the Buzau basin being its tributary on the left (Fig. 3). The Calnaului and Saratelului Basins form its eastern and western limits. Its north-western limit is given by the Basca Rosilei basin while the Zabalei basin forms its northern limit on a few kilometers. The basin's surface is of 433 km^2, a rank 6 basin as translated in the Horton-Strahler system. The maximum altitude of the basin (1 400 m), the altitude where the river rises (1 350 m) and the altitude where it flows into the Buzău - minimum altitude (125 m) show a difference in altitude of 1 275 m of the basin and 1 225 m of its main drainage course on 64 km only (calculated for the river).

From the above mentioned data is obvious that the Arvan's relief energy is 2, 3 times higher then that of Slanic, fact also evident in the field pointed by the fast deepening valleys and by the major breach located at 1 100–1 300 m. This particularity plays a very important role in the systematization and dynamics of the drainage network.

2. Geology – determining factor for the genesis and evolution of the drainage network

The structural and geologic analysis of a geologic map at a 1:50 000 scale (including its written text) (*Carte géologique de la France à 1/50 000, St.-Jean-de-Maurienne*, 1977 and *La Grave*, 1976) suggest that the Arvan basin belongs to the external area of the Alps, more accurately to the dauphinoise and ultra-dauphinoise area (Fig. 4).

The Dauphinoise area includes the western part of the Belledonne Masif as well as the northern part of the Grandes Rousses Massif. This area has a Precambrian-Paleozoic crystalline foundation formed of gneiss and migmatite. The sedimentary layer is of Triassic and Liassic age. The Grand-Châtelard crystalline massif (located in the northern part of the basin) stands representative for the analyzed area.

The Ultra-dauphinoise area develops east from the major tectonic contact suggested by the very thick Triassic gypsum that cross the entire region from north to south, almost along the same alignment as the Arvan. To its east there lies the Jurassic with a similar lithology to that of the dauphinoise area. To the south the Jurassic is represented by the Aiguilles d' Arves flysch.

The Liassic covers large areas between the crystalline massifs of Belledonne, Grandes-Rousses, Grand-Châtelard and the ultra-dauphinoise overlap. Here can be observed two great lithologic formations, an inferior one formed of limestone and a superior one made up of clay and schist separated by a sandstone- limestone formation.

The mid-Jurassic is represented by black and grey clay schist that alternate with sandstone and limestone layers. This formation outcrops on the left of the Arvette River, in Saint Sorlin. It also outcrops on a 200 m distance in the Fontcouverte area more exactly in the Villard point where it is very thick–up to tens of meters being formed of pink-grezoase conglomerates that alternate with black clay schist.

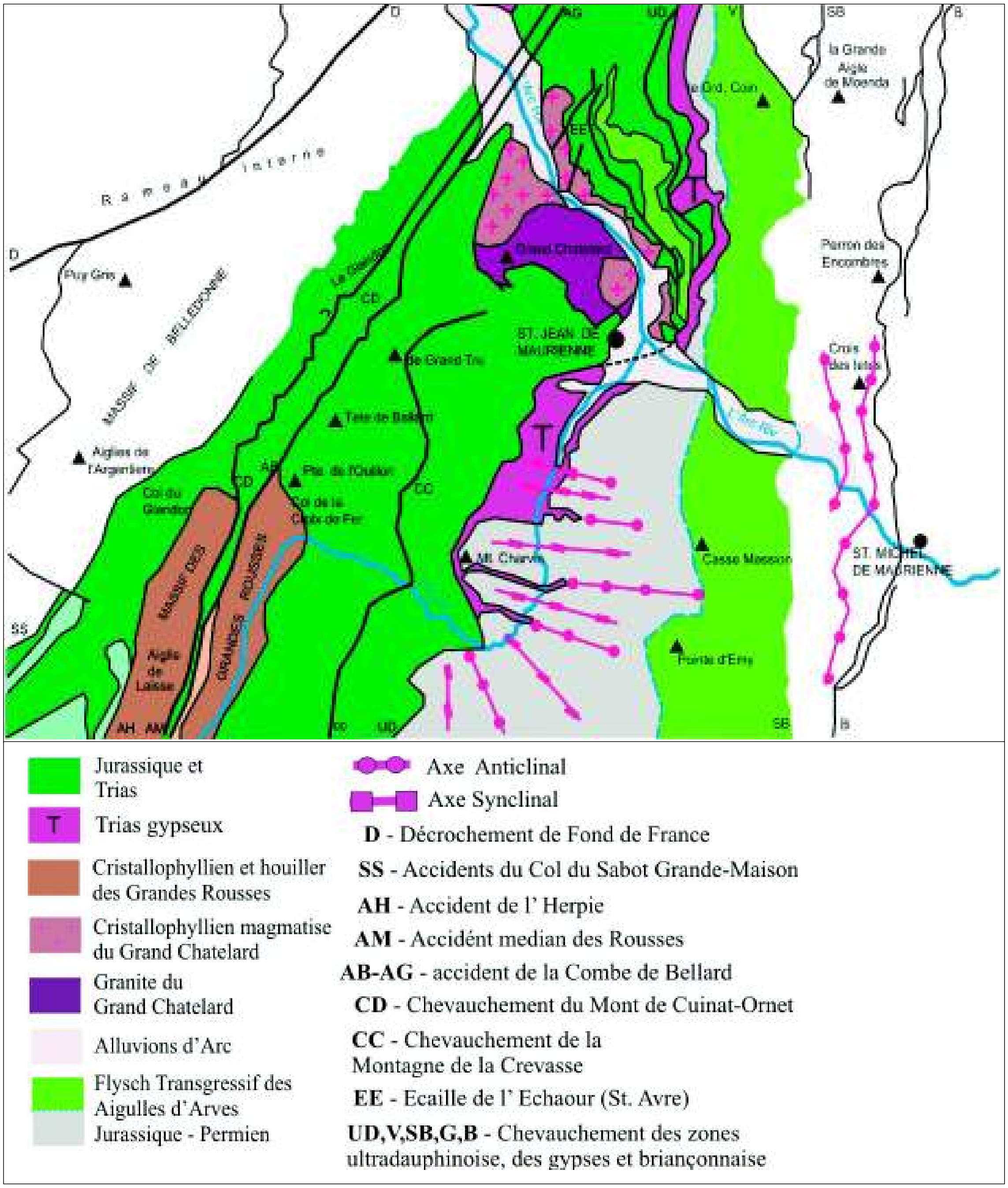


Fig. 4. Geologic map of the Arvan hydrographic basin.

The Triassic is formed of gypsum and anhydrites that outcrop discontinuously along the Arvan. Here also outcrop schists with sandstone intrusions (on the northern slope of Mont Charvin) as well as yellow and purple-greenish clays. The Liassic is similar to that present in the western part of the dauphinoise area but thicker. The same is true for the mid and superior Jurassic from the external areas: black marls, and black grezos limestone.

The numulitic schist and clay flysch (the Aiguilles d' Arves flysch) is present as four different formations: sandstone with conglomerates in foundation (Casse Massion); limestone based flysch (the western slope of the Grande Chible ridge); schist based flysch (a formation of limestone, sandstone and black silica schist in the upper course of Montricher and Albane); sandstone; limestone and conglomerates, formation made up of limestone and black schist in the upper side (Fig. 4)

The Quaternary deposits resulted through accumulation determined by the glacial (Vivian, 1969) periglacial, gravity determined, and fluvial processes. These vary in thickness and cover different surfaces; the best represented being the glacial and periglacial ones.

The movements that took place in the Miocene, pushing higher the crystalline schists have great importance in the dynamics of this area. At the end of the Miocene and in the Plio-Quaternary new movements took place leading to the folding of the sedimentary formation as well as to the final shaping of today's structures.

In the Slanic basin the superficial deposits, of great importance in the relief's dynamics, develop like almost parallel stripes with a north-south direction, from the oldest to the youngest, these stripes are almost perpendicular to the main drainage course being at the same time in accordance with the main relief (Sandulache and all., 1968; Visarion and all., 1977).

The oldest superficial deposits were formed in the Mesozoic (Senonian-Danian) displayed parallel with Slanic's upper course, these are also known as the Hangu formation composed of tough grey sandstone-limestone (limestone based flysch), marls and grey clays. In the upper side of the formation are present clayey sandstones intrusions similar to Tarcau sandstone while at the base there are microconglomerates with green schist elements.

The largest part of the superior basin, the Carpathian one, up to Lopatari overlaps on the Paleocene flysch made up of: sandstone-schist flysch (the Colti facies), and the grezo-limestone based flysch (the Lesunt formation) of Paleocene-Eocene age; the Fusaru sandstone (mica sandstone) and Kliwa sandstone (quartz sandstone) facies of Oligocene age (Dumitrescu and all, 1970).

Downstream from Lopatari the Slanic basin enters the SubCarpathians, first cutting through Miocene molasse (marls, clays, sandstones, salt and salt breccia) followed by Pliocene molasse (gravels, sands, clays) and near its mouth, through Quaternary deposits (loess and alluvia)

The Slanic basin is located in the Carpathians and the SubCarpathians area of great tectonic mobility (Badea, Niculescu, 1964). The upper basin, up to Lopatari, flows through an area rising up every year with high and very high intensity (+ 2… 4 mm/an), while its middle and inferior basin, excepting its mouth, are rising up with medium-intensity. The area where the Slanic flows into the Buzau River knows a constant lowering movement (Visarion and all., 1977).

As far as the formations' resistance to erosion is concerned it is obvious that the two basins differ very much both regarding the extension of the different formations as well as their disposition compared to the direction of the flow.

In the case of the Slanic basin, the most resistant formations are those forming the Carpathian and inner SubCarpathians flysch. Further downstream there follow mid-tough, erodible and very erodible. The least resistant formations are the Romanian and Quaternary deposits from the inferior basin (Fig. 5). Since these are only partly cemented they are easily washed away by the dynamic unorganized or organized water running down the slopes or flowing through the river's valley. The Arvan basin overlaps entirely the Mesozoic sedimentary formation build of resistant and mid-resistant rocks. Quaternary deposits such as: slide rocks, moraines, slope deposits, etc, are present discontinuously on small surfaces in the entire basin; these are generally mobile not cemented rocks.

3. The present-day morphometry of these morphographic basins, result of the landscape dynamics and evolution

The drainage model is the best tool to illustrate the drainage network's dynamics. This

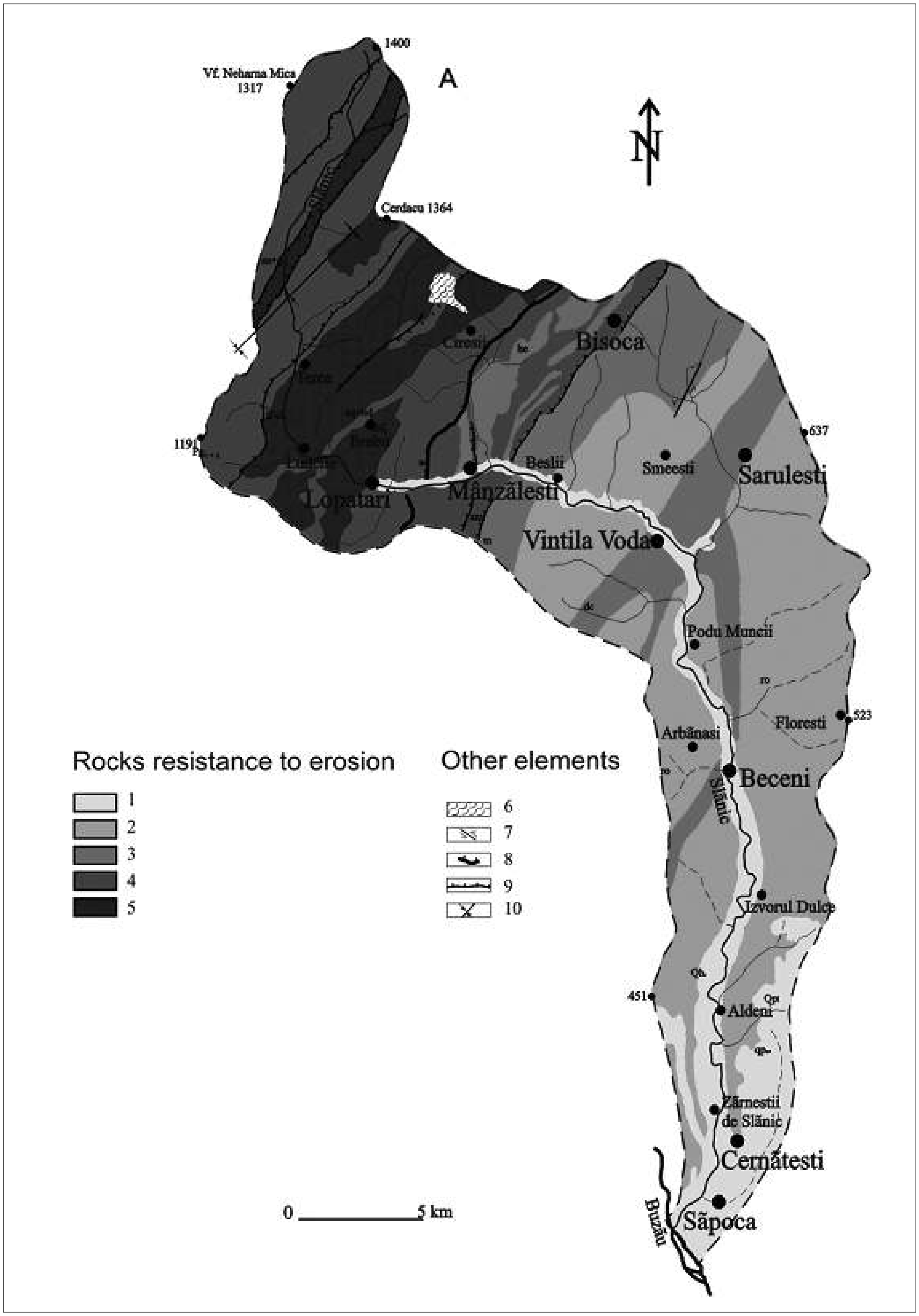


Fig. 5. Rock roughness map. 1. very soft rocks; 2: soft rocks; 3: semihard rocks; 4:hard rocks; 5:very hard rocks; 6: landslides; 7 strike-slip fault; 8: nappe; 9: reverse fault; 10: syncline axis

model is based on the hierarchic system suggested by Horton in 1945, modified by Panov in 1948 (quoted by Zavoianu, 1978) and brought to its final form by Strahler in 1952. Rivers of greater rank are older while those ranked 1 or 2 are younger, therefore it is their morphometric features that are more influenced by the present day state of the basin and by the climatic factors.

The hydrographic network of the Arvan and the Slanic basins was ranked on topographic maps at a 1:25 000 scale by using and checking the laws that define the drainage model (Fig. 6, 7). The river segments ranked between 3 – 6 (7) behave according to the law stating that the number of river segments ranked successively upwards form a reversed geometric progression, where the first element is represented by the number of rank 1 segments the ratio is equal to the junction ratio *Rc* calculated as the average of all individual ratios of two upwards consecutive values: $(N_1/N_2+N_2/N_3+N_3/N_4)/3$. The number of rank 1 and 2 segments was calculated as follows: $N_1=N_2\times R_c$ (Zavoianu, 1978; Grecu, 1980, 1992).

For the Arvan, the river segment density calculated as ration between the total number of river segments (6744 out of which 6649 are ranked 1, 2, and 3) and the basins total surface (about 220 km^2) proved to be quite high 30.65 segments/ km^2. If we only consider rank 1, 2, and 3 river segments then the number per unit is of 30.22 which means that each segment drains a 3.30 ha surface (table 1).

As far as the Slanic basin is concerned with the use of the same method we observe that on each km^2 there are 13.7 river segments out of which 11 are rank 1 rivers; hence their great importance for the drainage systematization, each segment draining an average 9.1 ha. If we also consider rank 2 rivers then the number of segments per unit is higher (13.2) and each segment drains an average 7.5 ha.

An interesting observation is the fact that the surface drained by low ranked segments is almost double for Slanic River as compared to the Arvan. The explanation is simple: the low ranked river segments present in the glacial cirques flow on slide rocks and avalanche scar leading to a subjective overrated evaluation of these segments (Fig. 8, 9).

The high number of low rank river segments in both basins suggests a fast response of the basin to precipitations as well as active erosion. The high partial values of the junction ratio in the case of gullies (rank 1 and 2, between 2 and 3) as well as between the rank 3 and 4 segments for the entire basin and most importantly of rank 5 and 6 segments (eg: Gilbert-Arvan, RC_1 = 5.7; Coca-Slanic RC_2 = 6.8) underlines their high frequency, most of the rank 1, 2, and 3 segments maintaining their rank. These are the gullies from the glacial cirques which directly influence Horton's laws. As a matter of fact for the Arvan basin there is evidently a threshold between the superior basin, where most of the low ranked, gully segments are grouped and the inferior basin (rank 4, 5, 6, 7); this fact is underlined by the junction ratio as well as by the great numeric difference between the low rank segments and the high rank ones.

Length determination of all ranks river segments and adding them up depending on the rank, suggests that the sums of the upwards successive ranks are inclined to form a reversed geometric progression where the first element is represented by the total length of 1 rank segments and the ratio by the lengths' ratio (R_1). Here also the law is better verified for the low rank segments while in the case of the high rank segments there may appear mishaps especially for the extended basins. With the help of the low ranked segments was determined the ratio of all lengths R_L = 2.00 for the Arvan (Fig.8) (table 1) and R_L = 2.50 for the Slanic (Fig.9).

Starting from the sum of all lengths and the number of river segments of each rank was determined the average segment length per rank for each basin. The three sets of values graphically represented by mid-logarithmic coordinates suggest that the average lengths of the upwards successive segments incline to form a direct geometric progres-

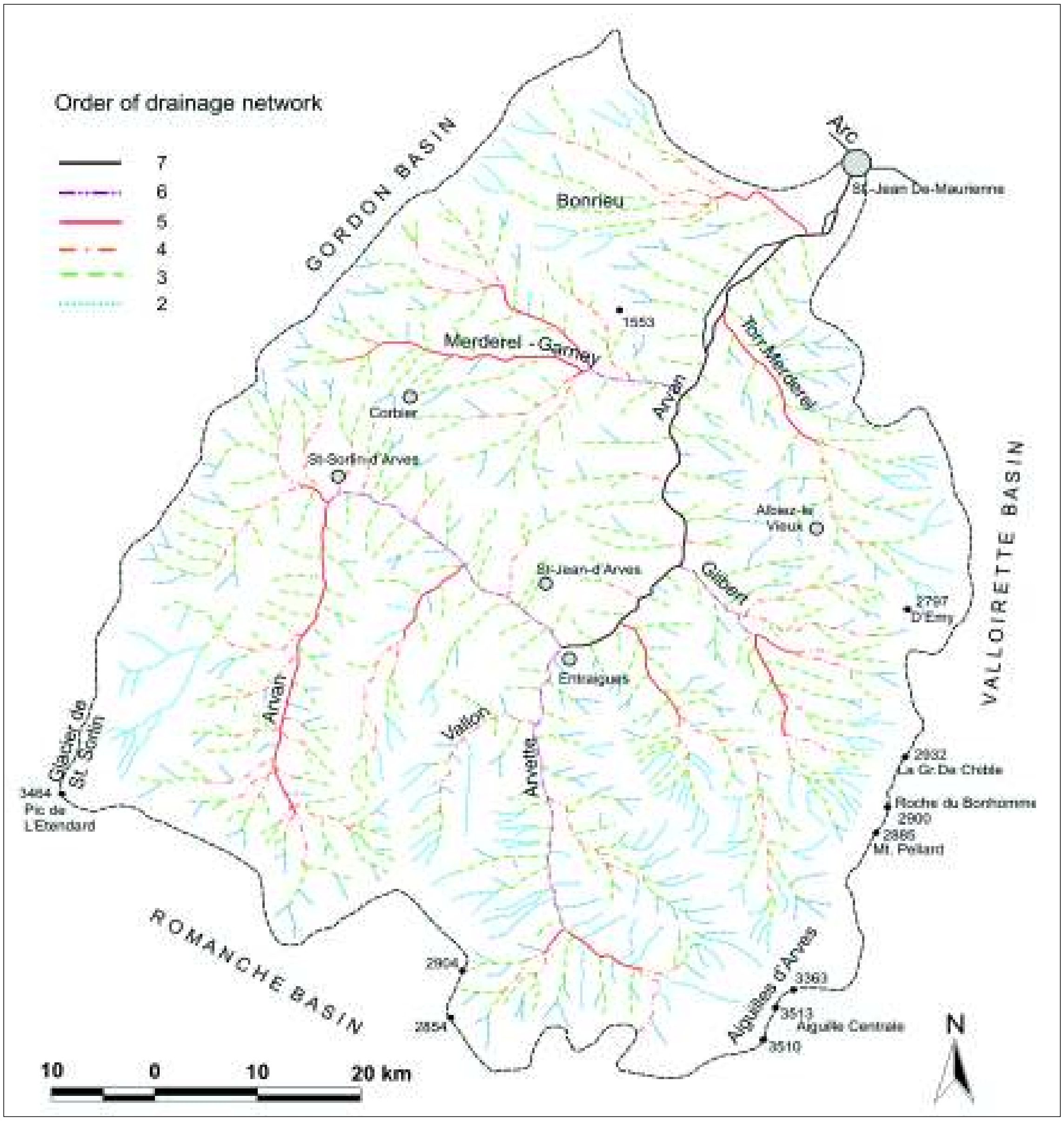


Fig. 6. Stream hierarchy according to the Horton-Strahler system for the Arvan hydrographic basin

sion where the first element is represented by the average length of a rank 1 segment and the ratio is given by the ratio of all average lengths R_l.

This law is important since it enables the evaluation of the average length of rank 1 and 2 segments that are very important for the drainage. Thus the average length of rank 1 segments is 0.14 km (Arvan) and 0.26 km (Slanic) while that of rank 2 segments is of 0.30 km (Arvan) and 0.54 (Slanic) (Fig.8,9).

The length of the drainage slope is shorter for the Arvan then for Slanic suggesting the influence of the steep slope of the glacial cirques (Fig.10, 11A, B).

The average lengths for the inferior course ranked 1 and 2 rivers don't show significant differences between rank 6 basins that rise in the glacial area (Arvette, Arvan – rank 6, Gilbert – only partially). In the entire basin trough, the shortest are the rank 1 and 2 rivers which barely reach 0.09 – 1.6 km. The smallest average length of rank 2 rivers, 0.18 km (the average rank 1 length being 0.07 km) is encountered in the Arvette basin, which is also the longest 1.60 (the average rank 1

Fig. 7. Stream hierarchy according to the Horton-Strahler system for the Slanic hydrographic basin

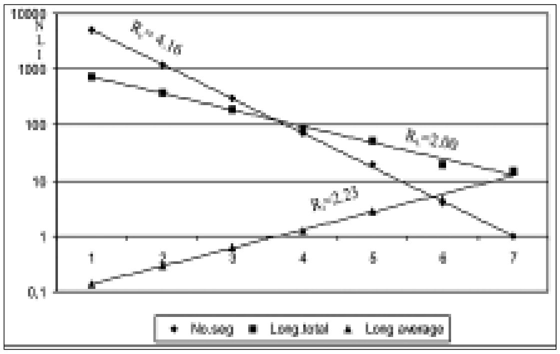


Fig. 8. Drainage Model for the Arvan hydrographic basin

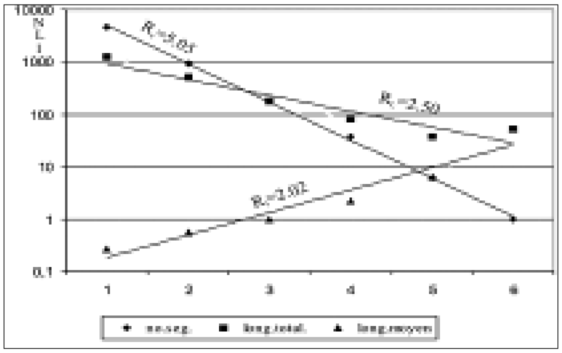


Fig. 9. Drainage Model for the Slanic hydrographic basin

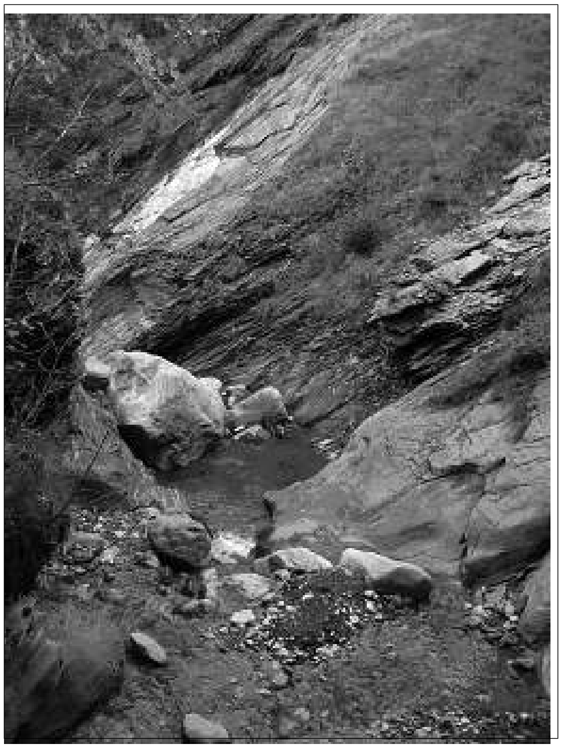


Fig. 10 B - Downward erosion of the Garney river

Fig. 10 A - Expansion through regressive erosion of the hydrographic network in Garney 's upper basin

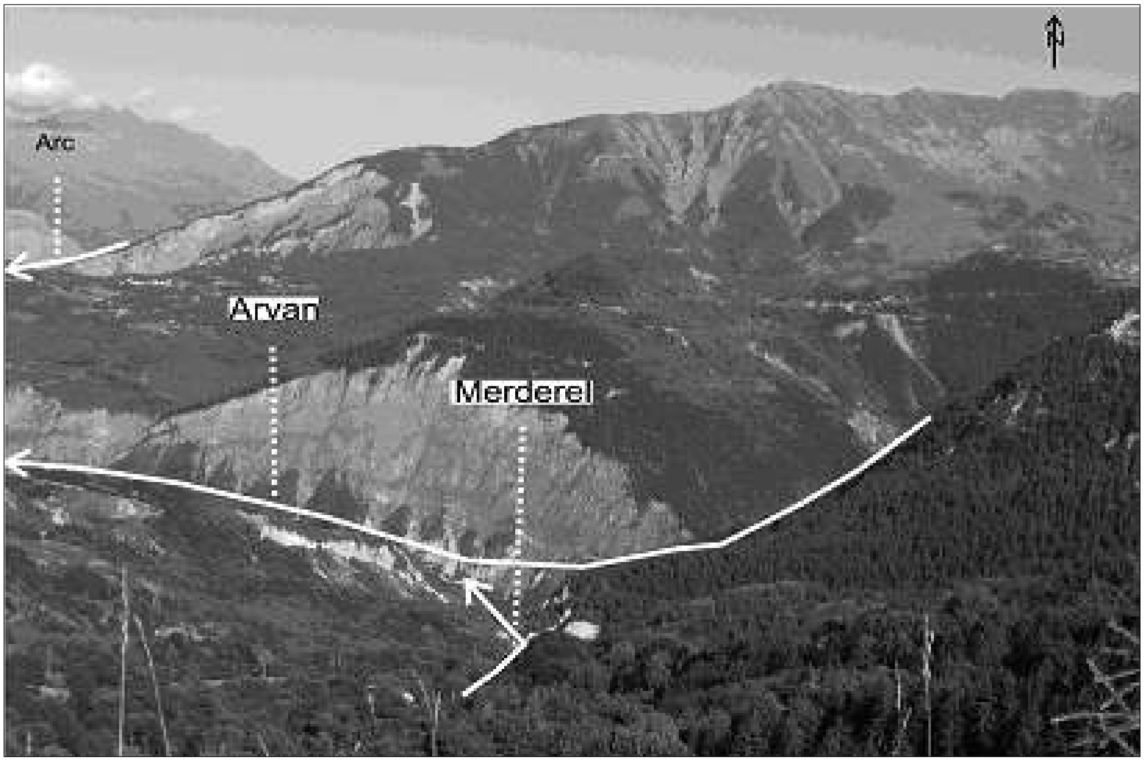


Fig.11 A. Leveled surface on the right of the Arvan River along its upper and middle course (1400)

Fig. 11 B. South eastern watershed of the Arvan basin. Order 1 and 2 streams developed in glacial cirques

Parameters	M C	Ord.1	Ord.2	Ord.3	Ord.4	Ord.5	Ord.6	Ord.7	Ratio
Nomber of river (N)	M	-	-	296	71	19	4	1	R_C =4.16
	C	5122	1231	296	71	17	4.75	0.96	
Summed length (*L*) (km)	M	-	-	187.72	89.17	52.50	19.65	14.72	R_L=2.00
	C	751	375.44	187.72	94.00	47	23.5	11.75	
Medium length (*l*) (km)	M	0.14	0.30	0.63	1.25	2.80	4.52	14.72	R_l=2.23
	C	0.09	0.20	0.45	1.01	2.27	4.52	10.07	

Table 1 - The drainage model-Arvan basin

Parameters	M C	Ord.1	Ord.2	Ord.3	Ord.4	Ord.5	Ord.6	Ratio
Nomber of river (N)	M	-	-	73	18	4	1	R_C = 4.20
	C	1305	311	74	18	4.28	0.95	
Summed length (*L*) (km)	M	138	75	41.2	22	13	6.65	R_L = 1.83
	C	135	74	41.2	22	12	6.56	
Medium length (*l*) (km)	M	010	0.25	0.55	1.22	1.25	6.65	R_l = 2.29
	C	0.10	0.23	0.53	1.22	2.79	7.44	

Table 2 - The drainage model -Arvan Torr basin (upper to Arvette basin confluence)

Parameters	M C	Ord.1	Ord.2	Ord.3	Ord.4	Ord.5	Ord.6	Ratio
Nomber of river (N)	M	-	-	73	17	6	1	R_C = 4.37
	C	1395	319	73	17	4	1.37	
Summed length (*L*) (km)	M	100.4	60.12	36	18.3	8.95	8.85	R_L = 1.67
	C	85.22	51.03	30.56	18.3	10.95	6.55	
Medium length (*l*) (km)	M	0.07	0.18	0.49	1.07	1.49	8.85	R_l = 2.61
	C	0.05	0.153	0.40	1.07	2.79	7.28	

Table 3 - The drainage model -Arvette basin

Parameters	M C	Ord.1	Ord.2	Ord.3	Ord.4	Ord.5	Ord.6	Ratio
Nomber of river (N)	M	-	-	37	9	3	1	R_C = 3.36
	C	418	124	37	11	3.27	0.97	
Summed length (*L*) (km)	M	-	-	27.8	11.575	9.65	2	R_L = 2.8
	C	217.95	77.84	27.8	9.92	3.54	1.26	
Medium length (*l*) (km)	M	0.52	0.62	0.75	1.28	3.21	2	R_l = 1.2
	C	0.50	0.61	0.75	0.95	1.14	1.36	

Table 4 - The drainage model - Merderel basin (Garney)

Parameters	M C	Ord.1	Ord.2	Ord.3	Ord.4	Ord.5	Ord.6	Ratio
Nomber of river (N)	M	549	96	24	6	2	1	R_C = 3.74
	C	391	104.6	28	7.48	2	0.53	
Summed length (*L*) (km)	M	185	65.8	22.95	8.07	1.72	2.15	R_L = 2.84
	C	185	65.8	22.95	8.07	2.84	1.00	
Medium length (*l*) (km)	M	0.34	1.6	0.96	1.54	0.86	2.15	R_l = 1.3
	C	0.51	0.73	0.96	1.25	1.62	1.70	

Table 5 - The drainage model -Gilbert basin

Parameters	M C	Ord.1	Ord.2	Ord.3	Ord.4	Ord.5	Ord.6	Ratio
Nomber of river (N)	M		944	179	37	6	1	R_C = 5.05
	C	4767	944	186	37	7.32	1.45	
Summed length (*L*) (km)	M		507	179	81	38	53	R_L = 2.50
	C	1267	507	203	81	32	13	
Medium length (*l*) (km)	M		0.537	1	2.19	6.33	53	R_l = 2.02
	C	0.266	0.537	1.08	2.19	4.43	8.94	

Table 6 - The drainage model -Slanic basin

Parameters	M C	Ord.1	Ord.2	Ord.3	Ord.4	Ord.5	Ratio
Nomber of river (N)	M	134	35	5	2	1	R_C = 3.83
	C	73.3	19.5	5	1.3	0.33	
Summed length (*L*) (km)	M	49	14.17	3.37	5.65	2.25	R_L = 2.87
	C	27.7	9.67	3.37	1.17	0.4	
Medium length (*l*) (km)	M	0.36	0.4	0.67	2.82	2.25	R_l = 1.18
	C	0.37	0.5	0.67	0.89	1.18	

Table 7 - The drainage model -Coca basin

length being 0.34 Gilbert basin). These values agree with those of the junction ratio and are due to the development of these segments in the glacial cirques with high relief energy. The gully segments of the Gilbert basin develop in glacial cirques with low relief energy and on quaternary deposits, which are less steep then those of Arvette (Fig.11A, B).

The active dynamics of the drainage network is also suggested by the accomplishment index of the basin (I_n) regarding the rank (related to the number of river segments) valid for both basins (Grecu, 2004). The value of this index (I_n =96%) suggests an equilibrium state for Arvan. Its value for the low ranked basins is of 0.53 (53%) (the Gilbert basin) suggesting a disequilibrium state of the basin. The same state of evolution is suggested by the accomplishment index of the lengths' sum I_L = 60% and of the average length of river segments I_l = 78% (Table 1–5). Its value within the Slanic river basin (1.45 that is 145%) is greater then 1 (100% - equilibrium) and suggests a disequilibrium state of the basin, having too many river segments for a rank 6 river. At the same time, some rank 5 basins (part of the middle course of the Slanic) have not reached the equilibrium state (the Coca basin I_n = 33%).

Conclusions

The results of the comparative analysis between the Slanic and the Arvan hydrographic basins show that:

-the law of stream numbers, the law of stream total and average length applies both to the Arvan and the Slanic, hydrographic basins located in orogeny areas with pretty different geologic, evolution and geomorphologic features;

- the comparative analysis of the drainage models (Fig.8, 9) shows similitude in their morphography making the two models comparable as far as their drainage is concerned;

-the different morphometric parameters were calculated (the density of each order streams, the thalweg density for the first two orders, their average and summed lengths, the area necessary for 1st order streams to develop, and the accomplishment index of the drainage basins), their results evidencing differential morphodynamics for the two drainage basins.

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