Morphological evolution of riverbeds - case study: inferior sector of CIBIN RIVER upstream OF Sibiu (olt basin – Romania)

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1 Introduction

Fluvial geomorphology and riverbeds are subject of worldwide research (e.g., Blench, 1958; Leopold, Wolman, 1964; Schumm, 1977; Lewin, 1978, Thorne, 1982). Important studies have also been conducted on riverbeds in Romania (Diaconu, 1971; Ujvari, 1972; Ichim et al., 1989; Diaconu, Şerban, 1994), in particular the Danube (Panin, 1976) and rivers such as Moldova, Bistrița, Siret, Prut, Mureşul Superior, Trotuş (Bătucă, 1978; Ichim et al. 1980; Duma, 1988; Rădoane et al. 2003). Yet the riverbed of Cibin River has not been investigated in a systematic geomoprhological study. However, some qualitative and quantitative information and maps on the major streambed of Cibin River and the geomorphology of the Sibiu Depression (Sandu, 1998; Giuşcă, 2006) are available. For the development of the fluvial geomorphology database for the Cibin riverbed upstream of Sibiu we combined field work and complex bibliography including hydrological year-books and current or historical maps to compare and analyse the riverbed and morphometric variability dynamics.

2 Regional Conditions of the Genesis and Evolution of the Cibin Riverbed

The inferior sector of Cibin Valley completely overlaps with the Sibiu Depression situated near the geographical center of Romania. The hydrographical network shaped the relief to the present configuration: in the Miocene-Pliocene formations of the depression, the Cibin River formed in an erosive-accumulative manner with different intensities (differential erosion) a monoclinal structure (Geografia României, vol. III, 1987).

The rocks carved by the Cibin riverbed are friable. The variable thickness of the deposits, but especially their different erosion resistance influenced the Cibin riverbed typology and dynamics. The petrographic structure is represented through clays, marls, sands, gravels, in addition to plasters beds, polygenic conglomerates as well as sandstones. In the sector studied, the oldest formations are those of the Medium Miocene (Badenian) represented by thick deposits of white-grey marls, quartz gravels, and ferruginous sands identified in the south of the Cibin riverbed, in Poplaca. However, the Pannonian is the best represented period, through marl-loamy, loam-arenaceous, sandy deposits and gravels on the superior side. The quaternary formations are represented through weakly consolidated terrace deposits (sands, gravels) and recent alluvial deposits with fine granulometry and different thickness (Ciupagea *et.al*., 1970).

At the level of the entire Sibiu depression we notice a clear asymmetry of the relief which was imposed by the tendency of the Cibin riverbed to move towards the north and north-east. This resulted, on the right bank of the

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river, in an incision and the appearance of several successive forms of relief (submontaneous hills, piedmonts, terraces and floodplain). The Cibin meadow as the lowest level is permanently subject to seasonal flows, but also to the accidental influence of tributaries, floods and droughts. In the Sibiu depression, the Cibin meadow has two clearly differentiated sectors: the sector upstream of Sibiu (Gura Râului – Sibiu) in the west-east direction and the sector downstream of Sibiu (Sibiu – Tălmaciu) with a north-west–south-east orientation (Sandu, 1998). Our paper deals with the first sector.

Cibin is an allochthonous river originating in the Cindrel mountains at altitudes of over 1900m a.s.l. with a nival to pluvial-nival flow regime. The river was impacted by technical constructions upstream of Gura Râului (1973-1980), i.e. a concrete dam with abutments. The main purpose of this reservoir is to ensure the water supply of the city of Sibiu and adjacent towns. In consequence, the flow regime of the Cibin River has changed significantly as dependent on storage/release dam operation and on downstream hydrographical network. Hence, the multi-annual medium flow in Sibiu was reduced from 4.72 m^3/s, to 2.8 m^3/s. The sediments are retained by the dam (Ichim, Radoane, 1986) and only downstream tributaries as well as bank and riverbed erosion contribute to fluvial sediments. Water flow and sediment discharge were monitored during 1975 – 2005 at two hydrometric stations (Tab. 1).

Table 1. *Morphometric elements of the Cibin River basin and Cibin River flow rates.*

Point section	Distance from source (km)	Point altitude (m)	Basin surface F (km^2)	Average altitude Hmed (m)	Average slope of basin Imed (m/km)	Medium multiannual flow Q (mc/s) / q ($l/s/km^2$)	Average volume W_R (to/year)
p.h.Sibiu	51.6	403.0	506	943	35.7	4.72 / 9.4	34084.8
p.h. Talmaciu	76.4	364	2210	714	24.6	14.3 / 6.5	100992.0

3 Methodology

The present research was based on the analytical methods frequently used in fluvial geomorphology, on field mappings and on the quantitative methods used to obtain morphometric parameters; all these methods were adapted to the specific conditions of the Cibin River and the Sibiu depression. The dynamics of the major and minor bed of Cibin River was studied on the basis of several topographic maps: the *Hermannstadt mit seinem Umgebungen* military map – 1838, 1:28,800 scale; General-Karte von Mitteleuropa, the Hermannstadt-Sibiu sheet – 1898, 1:200,000 scale; the Nagy-Szeben (Hermannstadt) Austrian map – 1907, 1:75,000 scale; the topographic map 1:25,000 for the Sibiu Depression 1982 edition; and orthophotoplans produced during 2005. In order to update the information on older maps we made use of similar information on the topographic map of 1982 and the orthophotoplan. For geo-references and accurate morphometric measurements we used GIS software. The field research and the detailed morphometric analysis enabled us to identify the morphological changes of the Cibin meadow between Orlat and Sibiu. The data obtained through calculations and measurements was not fully introduced in this material. The emphasis was on changes in the major riverbed in the sector upstream of Sibiur where the meandering is more significant as well as in the minor riverbed.

4 Results and data interpretation

The quantitative analysis of the relief and the morphometric indexes illustrate the spatial distribution of the forms of relief and the intensity of current geomorphologic processes and the different stages of evolution of the sector. The morphometric measurements were performed in the alluvial plain of Cibin, respectively in the active strip

(Ichim et.*al*., 1989) located on both sides of the minor riverbed with elevations from 10 to 15 m; this strip includes the major riverbed and the first terrace – with a relative height of 5 – 10 m. At the edge of the major riverbed several human settlements, i.e. Gura Râului, Orlat, Cristian, Sibiu, and communication networks (DN1-E81, railway) are located. Morphometric measurements have been performed in this perimeter, on the major riverbed through cross sections perpendicular to the minor riverbed, drawn at distances of 1 km (fig.1; Tab.2). The meanders of Cibin River were numbered from upstream to downstream (fig.2) and bend radius, wave amplitude and length were measured (Tab.3). In order to determine the riverbed type we calculated sinuosity coefficients on representative sectors by comparing the minor riverbed length to the wave length of the meander (Tabs.2, 3); values below 1.5 indicate a sinuous riverbed, values equal or greater than 1.5 indicate a meandering riverbed (Leopold, Wolman 1957, qtd by Ichim et al., 1989). The data obtained was statistically processed on classes of values, frequencies of distribution in order to highlight the morphometric variability of riverbed and to study river behavior on the sector. Finally we resorted to the mapping of riverbed sectors and identified evolution phases and tendencies.

4.1 The Major Riverbed

The Cibin meadow between Gura Râului and Sibiu is wide, with bilateral development depending on the fluctuations in time of the water flow and sediment discharge of Cibin River. The width of the meadow varies between 1,300 – 2,500 m, with a maximum value in Orlat.

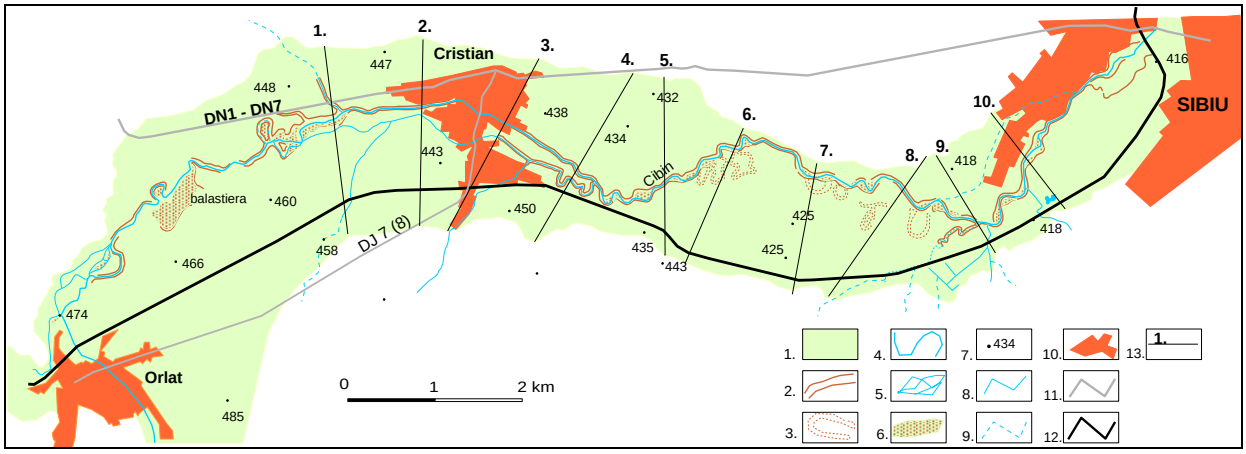

Figure 1. *The major Cibin riverbed upstream of Sibiu: 1. major riverbed; 2. steep banks; 3.abandoned meanders – ancient riverbed ; 4. current meanders; 5. scatterings; 6. sands and gravels accumulations in the minor riverbed; 7. heights; 8. permanent water flow; 9.temporary water flow; 10. settlements; 11. road; 12. railway; 13. sections*

Table 2. *Morphometric characteristics of the Cibin riverbed (for selected cross-sections)*

Nr. Sect.	Actual floodplain width (m)			Riverbed length Lr (m)					Distance (m) from	
	total	left	right	L dr.	Actual L sin.	Actual K sin.	1838 L sin	1838 K sin	Railway Left/right	Road DN1-E81
1.	2200	750	1450	1000	1050	1.05	1123	1.12	-/1025	125/1700
2.	2250	800	1450	1000	1075	1.08	1267	1.27	-/1000	200/1300
3.	2250	900	1350	1000	1050	1.05	1785.6	1.79	-/775	675/-

4.	2300	1425	875	1000	1738	1.74	1324.8	1.33	-/275	1425/-
5.	2550	1175	1375	1000	1400	1.4	1238.4	1.24	-/750	675/-
6.	1775	175	1600	1000	1175	1.18	1526.4	1.55	-/1475	-
7.	1600	150	1450	1000	1300	1.3	2282.0	2.82	-/1275	-
8.	2075	875	1200	1000	1050	1.05	1872	1.87	-/1050	-
9.	1375	975	400	1000	1300	1.3	1584	1.58	-/175	-

To the west of Turnişor and in the Ştrand district (districts of Sibiu), the meadow is 0.5 – 1 km wide. The slope is very low (0 – 2°) and the altitude of the meadow decreases in the flowing direction of Cibin River, the last one being developed along the river at altitudes of 485 – 470 – 460 m a.s.l. between Gura Râului and Orlat, at 410 - 418 m a.s.l. on the west side upstream of Turnişor and gradually descending to 396 m – 405 m a.s.l. on the south-eastern side of Sibiu city. Between Cristian and Sibiu, the major riverbed of Cibin River displays a clear asymmetry between sections 5 and 8 and morphometric variability on the two sides of the river due to the migration of the Cibin River flow and to the deflecting gravel cones discharged by tributaries. In this sense, Ichim et al. (1980) considered that the meandering of the minor riverbed entailed the meandering of the major riverbed as well, and this is quite apparent in this sector of Cibin River.

On the right side, the alluvial plain gradually and subtly makes the transition towards the superior terraces of the Cibin River, while on the left side it is clearly delimitated from the terrace front-side of the river's second terrace. Between Cristian and Sibiu the major riverbed records the lowest width on the left side (150 – 175 m). The main cause is the migration of the Cibin River flow towards north as a result of the meandering processes, which determined the evolution on the right side of some cut-off meanders, loops and hillocks. The large quantity of clay, from the alluvial deposits of Cibin River and of its tributaries and their impermeability determines in this sector the rising of the groundwater level in the meadow and some permanent or temporary plashes which maintain the phytocenoses of wetlands. The human settlements of Gura Râului, Orlat, Cristian and Sibiu are crossed by the minor riverbed of Cibin River which is channellized in the incorporated area**.** Nevertheless, the risk of being affected by floods is quite high.

4.2 The Minor Riverbed

Upstream of Sibiu, Cibin River presents a sequence of types of riverbeds: unitary, right, sinuous, meandering and anabranching (Schumm, 1985; Leopold et.al,1964, qtd by Ichim et. al., 1989). The differentiation between these sectors was made on the basis of the morphometric parameters of the minor riverbed: length, width, sinuosity coefficient, scattering coefficient (Tab.2, 3; fig.2). The type of meandering-interlaced riverbed with islets and lateral banks can be seen downstream of Orlat, given the existence of an alluvial bed mainly built up of blocks (40 x 20 x 30 cm), coarse gravels (2 – 5 cm) and coarse sands. This type is conditioned also by the significant contribution of the Sălişte creek, left tributary of Cibin River downstream of Orlat at an altitude of 474 m a.s.l. The interlaced riverbed can be seen near Cristian village on a length of about 3 km, out of which 1 km is channellized. The scattering coefficient is 1.91. In the scattered area, the minor riverbed has a width of 11 m, a depth of 0.6 m and the bottom is made up of sands. Predominant are lateral accumulations in the form of sandy banks with a width of 50 – 100 m. In the interlacing area, at about 1.250 km downstream of Cristian the sinuosity of the minor riverbeds of the two running channels increases, and the inferior one becomes even more meandered (Ks - 2.35).

Between Cristian and Sibiu, Cibin River has a sinuous riverbed with lateral bar (Thorne, 1982). The alluvial flow influences the mobility of the riverbed in this sector; the annual average sediment discharge is 34084.8 to/year, and the multi-annual average silt charge is 240 g/m^3. Of great significance for the formation of sediment discharge is the composition of the lithologic substrate mainly consisting of marls and clays. Because of the decrease in coarse sediment transport (due to the upstream dam) and the predominance of suspended material, the banks resistance increases and the river erodes in depth. Thus, the banks of the minor riverbed have heights ranging from 1.5 to 3 m, mostly fixed. In this situation, the discharged alluvia are mainly the result of instream erosion rather than basin-wide processes.

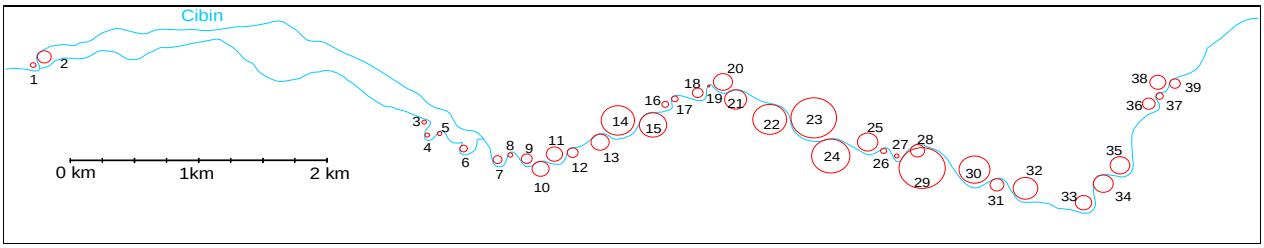

Figure 2. *Meandering sectors upstream Sibiu – model for calculating the morphometric parameters*

Table 3. *Morphometric parameters of the meanders of the Cibin River upstream of Sibiu (centralized data model)*

No. Meand.	Rc (m)	A (m)	L(m)	No. Meand.	Rc (m)	A (m)	L (m)	No. Meand.	Rc (m)	A (m)	L (m)
1.	35.95	125	500	14.	150.62	125	450	27.	32.14	150	212.5
2.	70.27	125		15.	185.65	75		28.	71.31	-	525
3.	32.55	150	250	16.	40.86	75	275	29.	202.81	375	
4.	32.00	150		17.	40.57	150		30.	139.88	375	

The sinuosity of the Cibin riverbed significantly increases (Tab.3) because the sediment load is mainly composed of fine alluvia (mud, sands) and fine stratified and well-compacted gravels, becoming even **a highly-meandered riverbed** between sections 4-5, 5-6, 7-8, 9-10 (fig.1). The meandering is free because of the low resistance of the alluvial bed. The meanders have amplitudes ranging from 25 to 375 m, a wave length of 200 – 575 m and a bend radius (Rc) ranging from 22 to 202 m. The most frequent are the free meanders with a bend radius of 50 – 100 m (fig.3, Tab.3). Riverbed mobility in this sector is proved on the basis of cartographic materials dating from 1838, 1898, 1907, 1982, and 2005 which show the position of the minor riverbed in those respective years (fig.1, Tab.2). In the last century, the migration of the Cibin River towards north is obvious; meanders shifted downstream and formed oxbows. The comparison of maps reveals a meandering running channel with numerous oxbows featuring marshes in the meadow landscape. They have eroded deep banks (-2; - 3 m) in the concave loops and accumulated banks in the convex loops. In the minor riverbed, there is a new meadow level, as a result of sediment accumulation and bank stabilization by hydrophilic grassy vegetation.

5 Conclusion

In conclusion, the changes in the Cibin riverbed in the Gura Râului - Sibiu sector are the result of a complex interaction of natural morphodynamics and anthropogenic impacts. The most significant lateral expansion was recorded after 1900. Downstream of Gura Râului the hydraulic power transmission reduces and the river meanders to achieve balance profile. The river energy remains quite high because of the slope between Gura Râului and Sibiu which is around 4.7 m/km. The change in the horizontal plane of the riverbed is an expression

of water energy in the conditions of small-size alluvial constitutes of riverbed. The time range 1950 - 1975 was characterized by an unevenness of the hydrological regime due to the variability of the rainfall regime which surpluses during 1970 to 1975. The instability in the horizontal plane can be explained by the amount of silt carried by the river, which was higher during this period. The gravel pave of Orlat has maintained the meandering tendency of the river.The riverbed becomes clogged downstream, increasing the opportunities of flooding and mobility because of the deepening of thalweg in the exploitation perimeter. This is obvious for the secondary channel in Cristian as well as for the secondary channel of 1898, upstream of Turnisor which has gradually become the running channel with tendency to meander. The evolution of the riverbed has also an environmental significance by changing the aquatic habitats and the riparian habitats or the meadow by creating wetlands habitats of a great societal and scientific interest. Moreover, agriculture and human settlements are affected through changes in channels and hydraulic parameters after the dam construction (1980). Within this framework, the study of the dynamics of riverbeds is given an interdisciplinary character.

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