# Relation between tectonics and meandering of river channels in the Romanian Plain. Preliminary observation

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**Relatia dintre tectonica şi meandrarea râurilor în Câmpia Română. Observaţii preliminare.** Pornind de la concepţia potrivit careia, meandrele sunt forme de echilibru în dinamica şi evoluţia albiilor de râu, ne propunem să analizăm morfometria şi morfografia unor râuri din Câmpia Română. Au fost supuse analizei cursuri de diferite mărimi incercând să surprindem relaţia dintre tectonică şi meandrare. Procesul de menadrare reprezintă unul din reperele evoluţiei Câmpiei Române pe parcursul Holocenului (Grecu et. all., 2009, Grecu, 2010). Acelaşi mod de evoluţie a fost observat şi în bazinul panonic (Popov et. all., 2008, Timar et all., 2005).

Pentru înţelegerea caracteristicilor actuale ale albiilor meandrate, au fost realizate măsuratori pe 6 cursuri de apă, de ordine diferite: Siret, Ialomiţa, Argeş, Milcov, Câlniştea, Mostiştea. Au fost delimitate sectoare meandrate cu lungimi variabile cuprinse între 15-25 km. Coeficientul de corelaţie între lungimea de undă şi amplitudinea meandrelor este mic, valori sub 0,3 cu excepţia Siretului (0,55), care atestă cele mai bune condittţi de meandrare: dezvoltarea pe o falie importantă (Peceneaga-Camena), debit mare, şes aluvial deosebit de extins, mişcări neotectonice de coborâre.

**Cuvinte cheie**: râuri, dinamică, tectonică, meandrare, Câmpia Română
**Key words**: rivers, dynamic, tectonic, meandering, Romanian Plain

## 1. Introduction

The tectonics and its relation to the relief and the river network were treated in scientific works, especially geomorphic ones, since the end of the XIXth century (Mrazec, 1889) and the beginning of the XXth century (De Martonne, 1902; Valsan, 1916; Mihailescu, 1925) and continued afterwards by the detailed researches of the second half of the last century up to the present (Popp, 1947; Radulescu, 1956, 1957; Cotet, 1976, Posea, 1983, 1987, 2002, 2005; Grecu, 2010;Grecu si colab., 2006, 2007, 2008, 2009; Badea, 2009; detailed references can be consulted in *Geografia Romaniei*, vol. 5, 2005).

Classification of rivers is done accroding to various criteria. Most studies use complex morphometric, morphographic and morfogenetic criteria of the riverbeds, taking into account: sinuosity, meandering index, multiplication degree of channels, gradient of river's longitudinal profile, sediment characteristics, flow types in riverbeds (Leopold & Wolman, 1957; Brice, 1964; Schumm; 1977; Richards, 1985, Ichim si colab., 1989; Bravard si Petit., 2000; Rinaldi 2003; Grecu & Palmentola, 2003; Radoane, 2005, 2008 etc.).

## 2. Methods and data

*Morphometric and morphographic method.* For the understanding of the present features of meandered riverbeds, measurements were conducted on 6 river courses of different orders: Siret, Ialomita, Arges, Milcov, Calnistea, Mostistea (Fig.1). Meandered sectors were delimited with variable lengths between 15-25 km, on which the main morphometric parameters have been computed: curvature radius, meander wavelength and amplitude. All the measurements were done on meander bends. Brice (1964) classification was taken into account: linear channels, Is>1,05; sinuous channels, 1,05<Is<1.50 and meandered channels, Is>1.50.

By overlapping seismic-structural maps with the hydrographic ones, there could be established some relationships between the system faults and the hydrographic network (Milcov Miostistea, Calnistea). The dynamics of riverbeds was coursed in the last 100 years through mixing the cartographic materials in different editions (Szatmary map from 1856 and on the topographic one from 1972). The cartographic materials and satellite images were georeferenced using the extension of ArcGis-ArcMap/Gis or Global Mapper in Stereographic 1970 projection, S_42 ROMANIA datum. The older maps (Szatmary) and the recent ones were georeferenced by choosing some common fixed points (church towers, main road intersections etc.), and the statistical data resulted from the digitisation of geographical information using ArcGis-ArcMap/Gis programme were ranked and interpreted, with different margins of error.

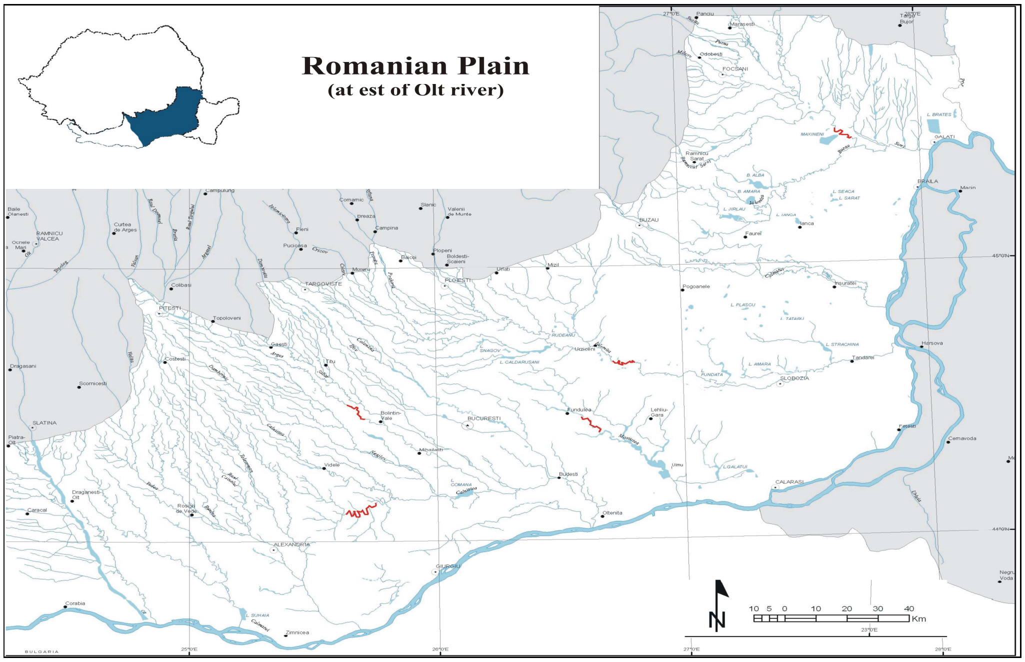


*Fig. 1*: **Romanian Plain to the east of Olt river and sectors analyzed**

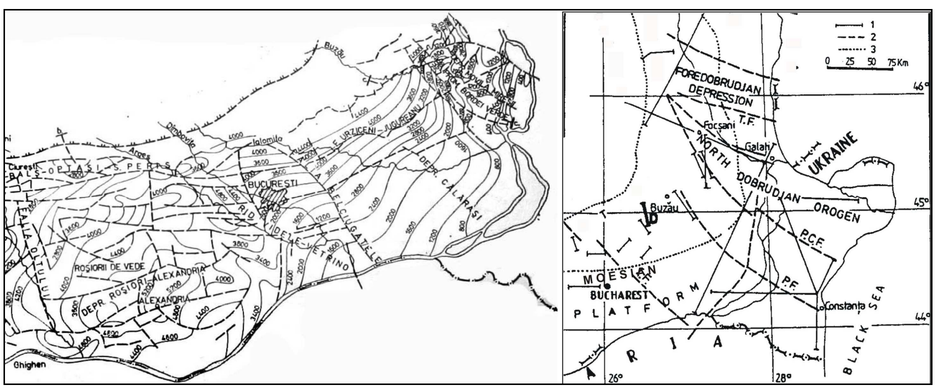


*Fig. 2*: **The main faults and deep seismic reflection lines in the eastern sector of Moesian Platform**
1 – seismic lines; 2 – faults; 3 – limit between tectonic units; I.F. – Intramoesic fault; P.F – Palazu (Capidava-Ovidiu) fault; P.F.C.– Peceneaga-Camena fault; T.F. – Trotuş fault; V.F. – Vaslui fault (after Diaconescu C. et. al., 1996).

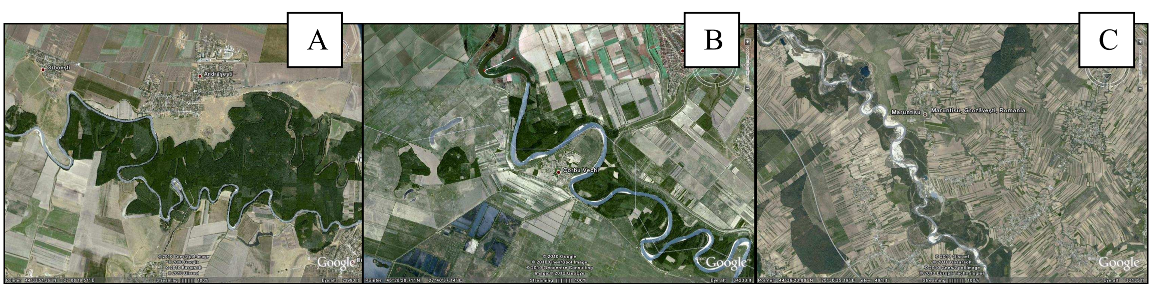


*Fig. 3*: **Satellite images with the analyzed river sectors** (A – Ialomita, B – Siret, C – Arges)

The study was completed with field observations during the period 2004-2010.

For the cartographic analysis the following were used :

- historical cartographic documents: Austrian Map Szatmary (1856)
- topographic maps, scale 1: 25 000, 1: 50 000 (1970-1971);
- aerial photographs (ortophotoplanes) (2004), scale 1:5000 (National Agency for Land Registry and Real Estate Publicity) and Google Earth images.

*Table 1* - **General data related to the analysed river courses**

| Nr. crt. | River | Main steam | Sb (km²) | Total length L (km) | Qm (m³/s) | Sector length (m) | Sector Sinuozity index |
|---|---|---|---|---|---|---|---|
| 1 | Siret | Danube | 42 274 | 544 | 254,0 | 23195 | 2.28 |
| 2 | Ialomiţa | Danube | 10430 | 416.5 | 10,1 | 17047 | 2.19 |
| 3 | Argeş | Danube | 12590 | 338.3 | 13.3 | 12201 | 1.67 |
| 4 | Mostistea | Danube | 1802 | 115 | 0,667 | 19150 | 1.85 |
| 5 | Calnistea | Neajlov | 1748 | 112 | 2,95 | 26964 | 2.89 |
| 6 | Milcov | Putna | 458 | 84 | 1.39 | 18720 | 2.11 |

## 3. The Role of Tectonics in Rivers' Dynamics

Tectonics and paleogeographical evolution of the rivers from the Romanian Plain in general and, especially, Quaternary evolution regards two issues:

1. Hydrographic network evolution with the formation of river basins (catchments, changes in courses, digressions etc.);
2. Dynamics of riverbeds that give to riverbeds certain morphometric and morphographical features.

A main feature of Romanian Plain's foundation is the north and north-east continuous and gradual descent reaching even - 9000 m in the area of subsidence from the Curvature (Fig. 2).

The Romanain Plain is crossed in a north-south and west-east direction by a series of Danube's tributaries. The tectonic conditioning has been analysed on all valleys independently of their size (Badea, 2009). For the big rivers with origins in the Carpathians, the transition from anastomosing/ undone river channels to sinous and meandered ones, has been observed. Each such sector extends on lengths of tens of kilometers.

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The relationship between river's slope, energy of transport and sedimentation changes in the area of subsidence. Thus, the rivers accumulation lead to increased height in the bed of rivers, the river being forced to change its course, thus eroding laterally in its own sediments, resulting new meanders. This is appropriate to Siret and Milcov in the inferior sector. It is also observed a phenomenon of imposing of the meandered riverbeds in areas that rise. For example Calnistea is developed on the northern border of Burnaz Plain, that is affected by positive current movements, and apparently directed by a fault that is also common for Arges and Neajlov Valleys (Mrazec, 1898). This line explains the morphological contrast between the plains from the north and south of it (Popp, 1947).

The big river courses in the Romanian Plain, Siret, Ialomita si Arges, being the oldest ones, followed the main areas of negative neotectonic movements. These corresponded most probably also to secondary faults associated to the major ones: Peceneaga –Camena in the east and the Intra-Moesic one in the centre. At present, the meandered courses of the main Danube's tributaries are overlayed on areas of subsidence plains. Characteristic for these rivers is the existence of the paleomeanders which attest an active dynamics during the entire Holocene period. Recent changes through self-capture and strengthening of river banks are noticed, reducing the river floodplain.

For the smaller, autochtonous rivers, Mostistea, Calnistea, the meandering process also appears on the lower sector in regions of positive neotectonic movements, but also along some faults.

*Table 2* - **The main Morphometric parameters measured in the meander loops** (average)

| Nr. crt. | River | Radius of Curvature (m) | Wavelength (m) | Amplitude (m) | Correlation coefficient *r* | Sinuousity index |
|---|---|---|---|---|---|---|
| 1 | Siret | 312,8 | 870,3 | 719,1 | 0,74 | 2,28 |
| 2 | Ialomiţa | 112,1 | 296,4 | 245,2 | 0,33 | 2,19 |
| 3 | Argeş | 156,7 | 402,5 | 187,4 | 0,41 | 1,67 |
| 4 | Mostistea | 287,7 | 805,3 | 563,8 | 0,54 | 1,85 |
| 5 | Calnistea | 178,9 | 568,5 | 482,5 | 0, 15 | 2,89 |

## 4. Analisys and results

### 4.1. Autochtonous rivers (Mostistea, Calnistea)

Mostistea River generally overlaps Inter-Moesic fault, along which are recorded earthquakes at depths of shallow below 40 km, at the base of the crust (Radulian, Popescu, 2003).

By overlaying the seismic-structural map (Visarion et. al., 1988) to the fluvial system map of Mostiştea, it is noted how the parallel disposal of tributaries on the left side of Mostistea coincides in many sectors with the major fault lines that have seismic activity or with secondary faults.

One of the possible scenes of Mostiştea's system genesis and of the parallel direction of its tributaries on the left side, can be the existence of an alluvial river-flow that was abandoned by a larger river (ante-loessian - possibly Ialomita, Dambovita or Arges), after which the courses were built only on the borders. But to affirm this, it would require some actual samplings in the area between the two directions (between the current river-flow of Mostistea and the parallel line formed by the tributaries) to highlight the psephite alluvial formations, characteristic to a powerful stream of the Carpathians.

The sediments age between the two parallel courses should indicate an oscillation of the ante-loessian river.

The parallel configuration of the tributaries can easily be attributed to the structure, the Inter-Moesic fault contributing to a more pronounced dynamic of Mostiştea, channeled to the axis of a structural depression, and the microfaults, arranged in accordance with the descendent slope of the left flank, helped to direct, towards NE-SW, the inferior courses of Colceag, Vânăta, Argova, and their higher order segments. Dissymetric depression mentioned at the beginning of the XX$^{th}$ century by Murgoci Gh, Protopopescu P., 1907, Vîlsan G., 1915, with a larger and mild left flank is visible on 1:1000000 and 1:50,000 topographic maps and even more visible on digital model of the terrain. The line with the lowest points follows Burduf Valley towards Ialomita (near Sitaru between Fierbinţi and Grădiştea) (Ghita, 2009).

*Table 3* - **The morphometry of the meanders of Mostitea's river bed** (1970)

| **Parameter** | **M1** | **M2** | **M3** | **M4** | **Average** | **Total Mostistea (km)** |
|---|---|---|---|---|---|---|
| Amplitude $A$ (km) | 1,4 | 1,55 | 2,22 | 2,4 | 1,83 | |
| Length of onde $\lambda$ (km) | 2,15 | 3 | 4,2 | 4,1 | 3,36 | 13,45 |
| Length of talweg $L$ (km) | 5 | 7 | 9,5 | 14 | 8,87 | 35,50 |
| Index of meanders $I_m$ | 2,32 | 2,33 | 2,26 | 2,41 | 2,58 | **2,63** |

The results obtained from measurements lead us to the following conclusions:

- the average width of the flood-plain has a high value in this area (320 m), due to the numerous ponds along the valley that follow the line;
- the index of sinuosity of the river in this sector is high (2) and shows an advanced stage of evolution of the river in soft loessic deposits and with an extremely low draining slope;
- the length of the meanders is increasing from upstream to downstream from 2.15 to 4.1 km, with an average of 3.36 kilometers;
- the meanders' amplitude presents values that become greater and greater towards downstream, the highest value is 2.4 kilometers for Gurbăneşti meander; this whole meander has the largest coefficient of sinuosity (3.41) because it is very tight and complex, indicating a high degree of evolution of the river (fig. 4).

**Câlniştea** is an atypical course for the Romanian Plain, because of its direction of flow, the middle and the inferior sectors being imposed a possible fault (Vâlsan 1916, Cotet, 1976). It was taken for analyze the sector between the localities Drăgăneşti Vlaşca-Cămineasca, an area with its river bed known as having a highly rate of meandering, a series of close meanders, shackled, a distinct example of meanders for the whole spread of the Romanian Plain (Fig. 3, 4).

Analyzing the data from the measurements we can establish the following conclusions:

- a tendency towards equilibrium, highlighted through the sinuosity index reduction (from 2.89 to 2.45), indicating also a slight buckling out of the course;
- the amplitude of meanders is increasing in the case of some loops (1, 3, 4, 7), showing a slight inclination of them to widen. But overall, in 1972, there was a decrease in meanders' amplitude compared to the year 1867.
- in 1867 the length of meanders had an upward inclination, but in 1972 there was a certain tendency to balance out the length of the meanders; also the meanders' length is also increasing, being inversely

proportional to the amplitude meanders. But the sinuous length has a clearly tendency of decreasing, which leads to the decrease of the index of sinuosity (Table 4);

- there is an inverse proportion between the sinuous length and the amplitude of the meander on the one hand, which have a direct relationship, and the length of the meander on the other hand; thus the meanders with the higher amplitude are wider and obviously have a more sinuous length; sometimes they can even be complex or compound meanders.

*Table 4* - **The meanders' morphometry of Câlniştea river bed** (1972)

| Parameter | M1 | M2 | M3 | M4 | M5 | M6 | M7 | Media | Total Calnistea (km) |
|---|---|---|---|---|---|---|---|---|---|
| Amplitude *A* (km) | 2,17 | 2,3 | 3,1 | 2,75 | 2,4 | 2,95 | 1,23 | 2,41 | |
| Lengh of onde $\lambda$ (km) | 2,75 | 1,7 | 2,5 | 3,5 | 3,25 | 1,8 | 2,7 | 2,6 | **18,2** |
| Lengh of talweg *L* ( km) | 4,61 | 6,77 | 7,64 | 6,28 | 7,3 | 6,67 | 5,5 | 6,39 | **44,7** |
| Index of meanders $I_m$ | 1,67 | 5,94 | 3,05 | 1,79 | 2,24 | 3,7 | 2,03 | 1,88 | **2,45** |

*M – meander*

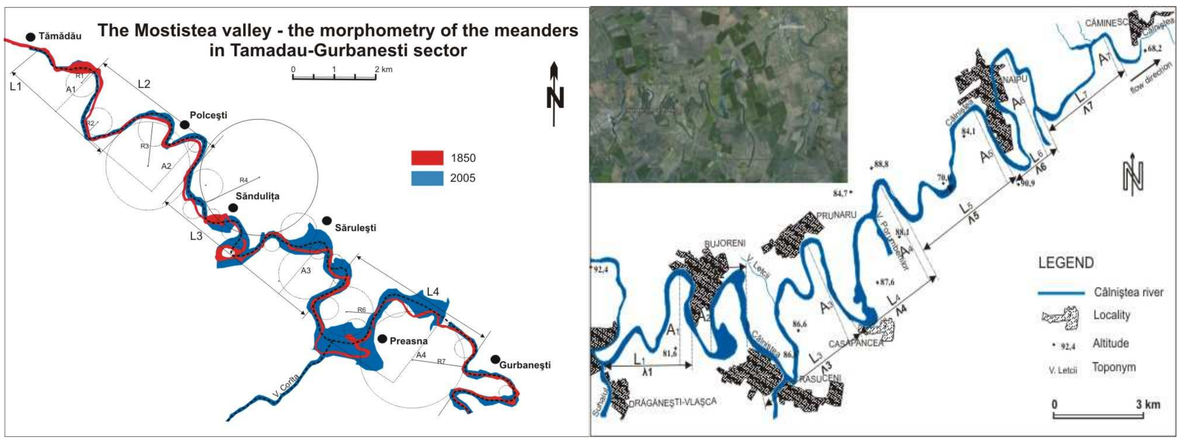



*Fig. 4*: **Morphometry of the meanders – Mostistea and Calnistea rivers**

## 4.2. Allochthonous rivers (Milcov)

The Curvature Carpathians region is the one with the most intense tectonic activity within Romania's teritory. In this area the Carpathian orogen comes in contact, on the outside, with three Precambrian stabil flatrocks: Moesic Platform in the south, the East European Platform and the Scythian Platyform in the north (Sandulescu, 1984). The tectonic mobility continually manifested since Badenian period causing the formation of Focsani Depression, in which there have been accumulated sedimentary rocks with a thickness of 13 km in its central part (Tarapoanca et. all., 2003).

At the Curvature Carpathians, the Milcov river records the same changes of the riverbed type on a length of only 41.7 km (Sacrieru, 2007, 2008). In this case the tectonic conditioning was the highest: up-lift movements on the upper sector corresponding to the Carpathian Orogen and subsidence movements on the lower sector superposed on the Focsani tectonic depression.

Siret river, the main collector of the region, developed its course along Peceneaga-Camena fault's extension, that is related to Dobrogea domain. Regarding its tributaries from the Curvature region (Trotus, Putna, Milcov, Ramnicu Sarat, Buzau), they most likely focused on secondary faults oriented to the NW-SE direction. This is demonstrated by Trotus river that clearly follows the fault with the same name.

Our analysis in this region stopped over Milcov River, characterized as being the smallest basin with its complete expansion from the Carpathian area until the subsidence plain (Sacrieru, 2008). It records the same changes of the river channel type (weaving, sinuous, meandering) on a length of only 41.7 km (Sacrieru, 2007). In the evolution of this river the tectonic conditioning was maximum: accretion movements on the lower course, corresponding to the Carpathian orogen and subsidence movements on the lower course, superposed over Focsani Depression.

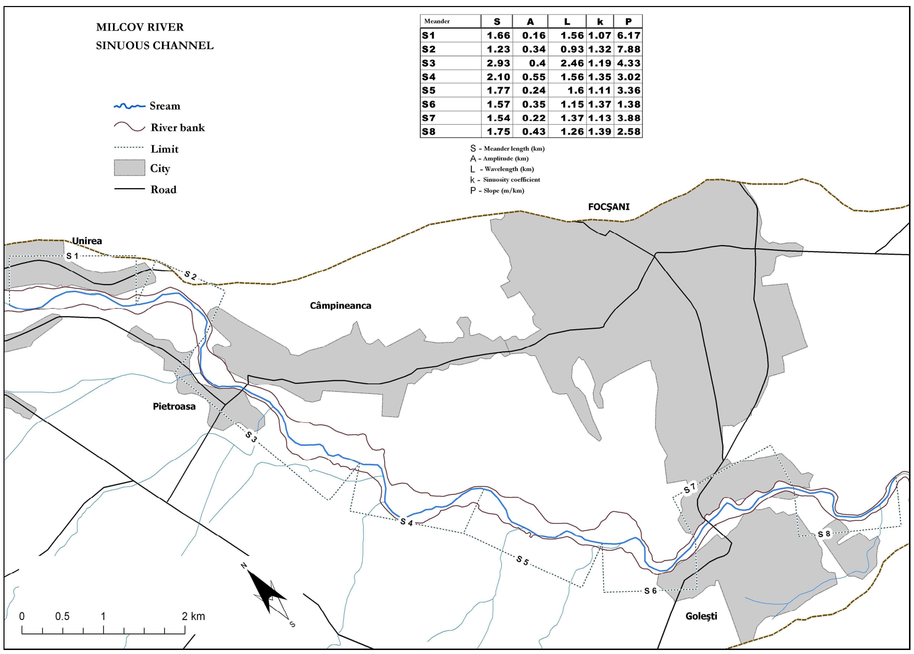
In the Medium and Superior Pleistocene the rising of the current basin, with about 250 m average, favored the formation of a system of 11 terraces, since Riss, with a deepening rate between 0.3-1.5 mm/yr (Necea, 2010).

Milcov's lower course, pertain to The Romanian Plane, was formed exclusively in the Superior

Holocene through multiple divagations. The braided river channel is typical for the alluvial cone that provides an important volume of alluvium transported from upper and medium sectors. The sinuous river channel is only a transition sector between the meandering and braided ones. In our case it overlaps a region of current vertical movements of descent of 2-3 mm / yr (Van der Hoeven et al., 2005).

The sinuous river channel (sinuous channel) is characterized by a coefficient of sinuosity with values ranging between 1.2 and 1.5. It's a sector developed on the direction NNW – SSE, on a length of 11.6 km, between Pietroasa and Goleşti (fig. 4). The average slope is 3.2 m / km. The presence of lateral river islands with heights up to 1 m above the talweg, may determine us to include this sector to the sinuous with alternate bars subtype. In this sector there is a clear relationship between slope and volume, respectively the granulometry of the riverbed deposits.

In this area, the riverbed is sunk in fine plain deposits: gravels, sands and loess deposits of Superior Pleistocene - Holocene age. The banks have the greatest heights of the entire plain sector, between 6 and 12 m (Pietroasa, Goleşti) (fig. 5). The riverbed width sometimes exceeds 500 m and there can be identified two levels at 0.5 and 2-4 m (Ielenicz, 1988).




| Meander | S | A | L | k | P |
|---|---|---|---|---|---|
| S1 | 1.66 | 0.16 | 1.56 | 1.07 | 6.17 |
| S2 | 1.23 | 0.34 | 0.93 | 1.32 | 7.88 |
| S3 | 2.93 | 0.4 | 2.46 | 1.19 | 4.33 |
| S4 | 2.10 | 0.55 | 1.56 | 1.35 | 3.02 |
| S5 | 1.77 | 0.24 | 1.6 | 1.11 | 3.36 |
| S6 | 1.57 | 0.35 | 1.15 | 1.37 | 1.38 |
| S7 | 1.54 | 0.22 | 1.37 | 1.13 | 3.88 |
| S8 | 1.75 | 0.43 | 1.26 | 1.39 | 2.58 |

*Fig. 5*: **Milcovul riverbed between Pietroasa-Golesti. Sinuous channel**

The meandering channel has values of the sinuosity coefficient of over 1.5. The maximum value, of 3.13, was determined for complex meanders. This meandering sector starts to the East of Goleşti locality and ends at the discharge in Putna (Răstoaca) (Fig. 6). The meandering channel matches the subsidence sector. Compared with the general level of the plain, the riverbed deepened with 6-8 m during the Holocene. The general direction of the meandering course is West – East, on a sinuous length of 18.7 km.

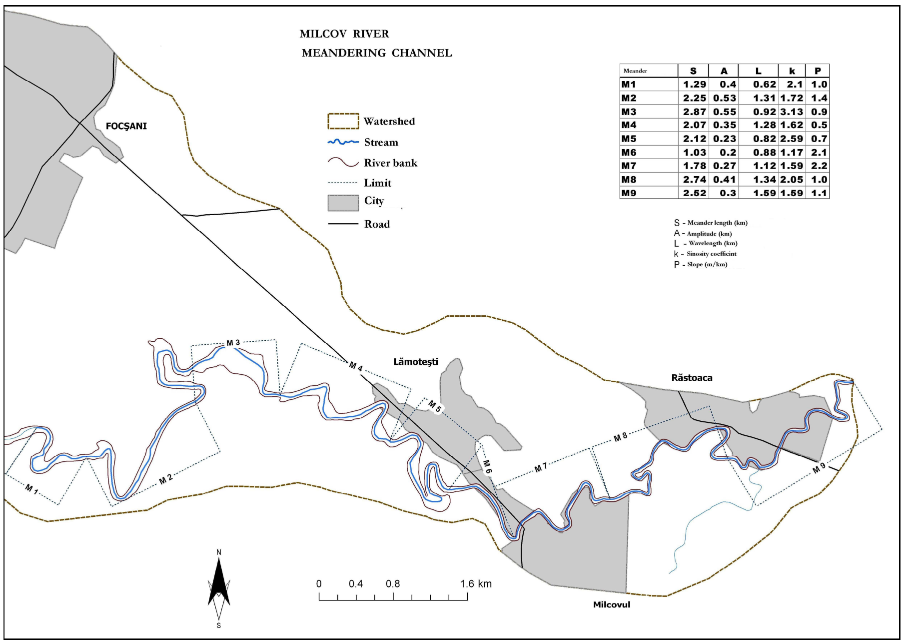
Given the 8.8 km length in straight line, it comes out a 2.1 average coefficient of sinuosity. The average slope has the lowest value, 0.65 m / km. Although meanders delineation is made from the general direction of the river, there is a high degree of subjectivity in determining the meanders ends. When the river comes back on the general direction of flow (in our case West - East), it can be defined the limit of the meander. In the case of complex meanders, the morphometric calculations can be made both on the entire meander, and on loops of meanders.

## 5. Conclusions

In order to understand the presend-day characteristics of the meandered riverbeds, measurements have been taken on 6 watercourses of different orders: Siret, Ialomita, Arges, Mostistea, Calnistea, Milcov. Meandered sectors have been delineated, having variable lengths between 15-25 km, on which the main morphometrcial parameters have been computed: bend radius, meander wave length and meander amplitude. All measurements have been done on meander bends.

The obtained values for the correlation between the length and amplitude of the meanders show that, selected on tectonic criteria, there is no big difference between the characteristics of meanders in large allochthonous rivers and small autochthonous rivers. The best correlation is achieved at Siret River in the subsidence area; it is a river with a large basin (S = 42 274 km$^2$) and high annual average flows (in comparison with those of local rivers) (fig. 7).

Analyzing the coefficient of sinuosity and meandering in various regions of the Romanian Plain with active neotectonic particularities, it can be observed that there are no big differences. It follows that the meandering process is extremely complex depending on the local characteristics of the causal variables, neotectonics being one of these variables.




| Meander | S | A | L | k | P |
|---|---|---|---|---|---|
| M1 | 1.29 | 0.4 | 0.62 | 2.1 | 1.0 |
| M2 | 2.25 | 0.53 | 1.31 | 1.72 | 1.4 |
| M3 | 2.87 | 0.55 | 0.92 | 3.13 | 0.9 |
| M4 | 2.07 | 0.35 | 1.28 | 1.62 | 0.5 |
| M5 | 2.12 | 0.23 | 0.82 | 2.59 | 0.7 |
| M6 | 1.03 | 0.2 | 0.88 | 1.17 | 2.1 |
| M7 | 1.78 | 0.27 | 1.12 | 1.59 | 2.2 |
| M8 | 2.74 | 0.41 | 1.34 | 2.05 | 1.0 |
| M9 | 2.52 | 0.3 | 1.59 | 1.59 | 1.1 |

S - Meander length (km)
A - Amplitude (km)
L - Wavelength (km)
k - Sinosity coefficint
P - Slope (m/km)

*Fig. 6*: **Milcov riverbed between Golesti-Rastoaca. Meandering channel sector**

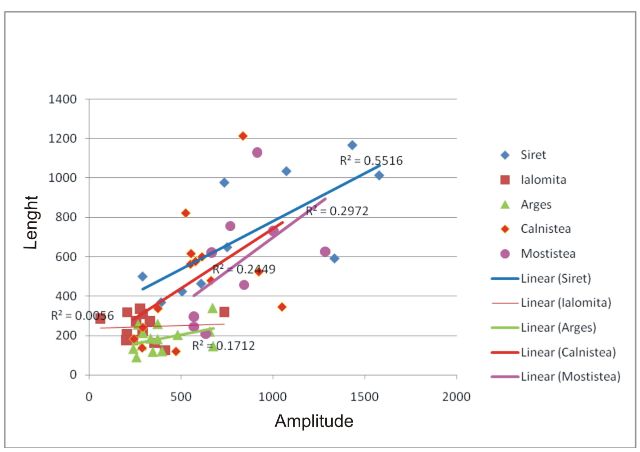



*Fig. 7* : **Corellation between the lenght and amplitude of the meanders**
Siret – $R^2$=0.551, r = 0,74; Mostistea – $R^2$=0.297, r = 0,54; Arges – $R^2$=0.171, r = 0,41; Ialomita - $R^2$=0.111, r =0,33; Calnistea – $R^2$=0.244, r = 0, 156

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