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Spatial and temporal controls on historical channel responses – study of an atypical case: Someşu Mic River, Romania

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ABSTRACT: In this paper the spatial and temporal responses of the Someşu Mic River (Romania) to natural and anthropogenic controls over the past 150 years are analysed, based on a series of morphometric parameters extracted from five successive sets of topographic maps and one set of orthophotos. Prior to the intensive hydrotechnical interventions of the last four decades, the river was characterized by a complex alternation of different channel types, resulting in a mixture of alluvial and mixed sinuous – meandering – sinuous anabranched – meandering anabranched reaches, each a few hundred metres to a few kilometres long. The main cause for this spatial behaviour was the local geology. Its effects were intensified by a larger scale slope, slightly higher than along a longitudinal profile with normal concavity, as a consequence of the presence of a 400 m elevation knick-point located in the catchment area.

A generalized maintenance of river in the floodplain perimeter during the entire interval of study (centennial scale), with local planform adjustments and lack of median scale avulsion in lateral tilting areas and along the anabranched reaches, channel lengthening and meander development during hydrological stable periods and channel shortening and increasing of natural cutoffs during periods with higher incidence of floods (decadal scale), and the incapacity of local morphologic changes resulted from human interventions to completely counterbalance general trends (decadal scale), supports the idea of decreasing the amplitude and frequency of important floods, after the end of the Little Ice Age.

Channel metamorphosis by canalization, diminishing/elimination of overflows and medium-scale avulsions by changes in flow regimes (dams) and the presence of dykes in the floodplain perimeter, channel narrowing (43%) and incision (at least after 1945) downstream from dams, and probably because of in-channel gravel mining are the main anthropically induced changes along the Someşu Mic River. Even if human impact is important, both at the drainage basin scale and along the Someşu Mic River, it has only local impacts, subordinated to climate. The low level of human impact on this river could be the consequence of the higher general slope downstream from 400 m elevation knick-point, which probably forces the positioning of its effects under an important internal threshold of the fluvial system. This boundary condition defines Someşu Mic River as an atypical river. This study supports the idea that climate has a more important role in the post-Little Ice Age (LIA) rivers' behaviour than currently accepted. Copyright © 2011 John Wiley & Sons, Ltd.

KEYWORDS: Someşu Mic River; channel typology; historical behaviour; natural controls; human impact

Introduction

The historic behaviour of rivers has become an important subject of study for the scientific community, as river valleys are subjected to continuous and accelerated inhabitation and numerous hazards (floods, bank erosion, bed aggradation or degradation) are associated with river dynamics. Moreover, in the context of rapid global environment changes, river processes that operate at different time and space scales currently concern engineers, scientists and policy-makers (Macklin and Lewin, 1997; Goudie, 2006).

A general tendency of incision followed by channel narrowing and lateral stability is reported for many European rivers over the past *c.* 150 years (e.g. Liébault and Piégay, 2002; Rinaldi, 2003; Surian and Rinaldi, 2003; Wyżga, 2008). Two opposing views have emerged regarding the cause of this tendency: anthropogenic influence and/or natural cause (climatic changes associated with the end of the Little Ice Age and present-day warming) (Macklin and Lewin, 1997; Knighton, 1998). In supporting the anthropic causes of these changes, a series of authors (Gurnell, 1997; Surian, 1999; Winterbottom, 2000; Liébault and Piégay, 2001, 2002; Rinaldi, 2003; Surian and Rinaldi, 2003; Surian and Cisotto, 2007; Wyżga, 2008; Zawiejska and Wyżga, 2010) have shown that mutations in the type and distribution of riparian vegetation, land use change, gravel mining, local and large-scale hydrotechnical works have altered flow discharge, sediment supply and local stream power, thus leading to changes in channel behaviour and morphology. Further, some authors (e.g. Liébault and Piégay, 2002; Wyżga, 2008) have shown that there is no clear evidence (on decadal scale) for climate related changes in bankfull discharge, which is considered to be the most effective in channel morphological changes (the 'concept of dominant discharge' of Wolman and Miller, 1960) and thus climatic change is at most subordinate to the anthropogenic cause of channel dynamics (and associated morphologies) over this interval of time. Opposing this view, other authors (e.g. Rumsby and Macklin, 1996a, 1996b; Pisŭt, 2002; Starkel, 2002; Uribelarrea *et al.*, 2003; Rădoane *et al.*, 2010) have shown that climate change, and related changes of frequency and amplitude of floods, is the most important factor in the historic dynamics of river channels, and human interventions only modulate the modifications induced by climate changes. The warmer and drier period after the end of the Little Ice Age (1850, according to Lamb, 1995), with a more stable flow regime (e.g. Rumsby and Macklin, 1996a; Starkel, 2002) is responsible for the shift from aggradation, widening and braiding, dominant during the Little Ice Age, to channel incision, narrowing and general planform stability. Human impacts have accentuated this general trend, especially during the last decades.

In this paper we analyse the planform dynamics of the Someşu Mic River over the past *c.* 150 years, by using a combination of morphometric analysis on five series of topographic maps and one orthophoto, combined with sedimentologic and morphologic field observations. We aim to (1) identify the main controlling factors of the river's dynamics, (2) evaluate the natural mechanisms of change in time and space and (3) estimate the 'deterioration' degree of these natural mechanisms due to human interventions.

Regional Settings

The Someşu Mic River is located in northwest Romania, draining a surface of 3733 km^2, 80% of which is located in the Neogene Transylvanian Basin and 20% in the Apuseni Mountains. It is formed at the junction of Someşu Cald and Someşu Rece Rivers (presently in the Gilău Reservoir, Figure 1b). The river is 100 km long (or 175 km if considered together with the Someşu Cald River), predominantly sinuous, with short meandering reaches. Related to the general longitudinal profile (considered also from the Someşu Cald spring area), Someşu Mic River is located in the middle and the lower part of it, downstream from a 400 m elevation knick-point imposed by the resistance to erosion of the Gilău granite (Posea *et al.*, 1974) (Figure 1c). The upper sector of the investigated area (between the edge of the Transylvanian Basin and Cluj Napoca) consists of Eocene and Oligocene red clays, sandstones and limestone, disposed in monoclinal strata, disrupted locally by vertical tectonic movements along small-scale faults; while downstream from Cluj Napoca the bedrock consists of Miocene marls, volcanic tuffs, gypsum and salt, affected by diapiric movements associated to salt neotectonics (Ciupagea *et al.*, 1970; Krézsek and Bally, 2006) (Figure 1d).

The climate of the area is temperate continental. At Cluj Napoca meteorological station (Figure 1b), the mean annual temperature is 8·4 °C and the mean annual rainfall is 582 mm. The mountain area (23% of the drainage basin), with abundant precipitations (1150 mm/yr), high surface flow and important groundwater reserves, contributes more then 50% at the total discharge. In contrast, the main source of the suspended sediment load is in the middle and lower part of the drainage basin, as a consequence of increased susceptibility to erosion, induced by the presence of more friable rocks and less protective vegetation cover (Table I; Pandi, 1997).

The most important flood recorded by instrumental measurements is that of 12–14 May, 1970 (before the completion of the reservoirs in the upper drainage basin), when the peak discharge at Salatiu was 444 m^3/s (10–20 years return period) (Aniţan, 1974). Other important floods were recorded in 1855, 1884, 1888, 1913, 1932, 1940, 1958, 1962, 1964, 1975, 1981, 1991, 1995, 1997 and 2005 (Aniţan, 1974; Şerban, 2007). In a more general context, historic sources (Cernovodeanu and Binder, 1993; Dudaş, 1997) suggest a decrease of amplitude and frequency of floods after the end of the Little Ice Age (1850, after Lamb, 1995), both in Transylvania and entire Romania, a trend in conformity with evidences from other parts of Europe.

The Someşu Mic River valley is a well populated area, with three cities and 22 villages. The most extensive hydrotechnical interventions were done between 1959 and 1983 (Pop, 1996). Sixteen dams were constructed along the two tributaries (*i.e.* Beliş – Fântânele, Tarniţa and Gilău Lakes) and Someşu Mic River (Floreşti Reservoir) (Figure 1b). Estimations show that 84% of the discharge is retained in the artificial lakes, with an artificial redistribution throughout the year. A second important modification is the almost complete elimination of floods produced in the catchment area, especially after 1983, when Beliş – Fântânele Reservoir became functional. Sediment trapping behind the dams induces channel incision along the Someşu Mic River. Armencea *et al.* (1980) have mentioned an incision of 2·5 m downstream of Gilău Reservoir, after the first four years of its existence and Şerban (2007) have shown a generalized channel incision along the first 20 km after Gilău, attenuated downstream and then replaced by aggradation.

Direct interventions along the Someşu Mic River (bank stabilization, artificial meander cutoffs and dykes) were made within or adjacent to settlements, in areas susceptible to high rates of lateral erosion, avulsion or frequent floods. Between Gilău and Floreşti Reservoirs, the flow is diverted through an artificial channel, while the natural channel is partly abandoned. In Cluj Napoca the river is completely sewered, and dykes and bank stabilization works are present close to Sânnicoara. Downstream from Sânnicoara, the river has a more natural aspect, with a high alternation of sinuous and meandering reaches, and one anabranched reach (between Răscruci and Bonţida).

More than 30 gravel extraction points were identified in 2005, most of them located downstream from Apahida. No data are available on the volume of extracted gravel quantities in the last decades or on the impact of this activity on the Someşu Mic River morphology and its temporal behaviour. Studies along other Romanian rivers (e.g. Moldova, Siret; Rădoane and Rădoane, 2009) report at least a doubling of quantities of sediments extracted in the past 20 years, compared with the 1969–1981 interval. In these cases, the most evident effects are channel incision, of 1·5 m or even higher (3–4 m), and increase of suspended load.

Methods

Field observations (2005–2009), mainly qualitative, were focused on establishing the relation between active channel and the floodplain, morphological and sedimentological characteristics of the banks and the river bed, active processes along the river, direct human disturbances, and the nature of riparian vegetation. Field sheets by Rapp and Abbe (2003) were used as guidelines in this campaign. Estimation of river's bed grain size was made at eight positions along the river, and is based on the methodology of Wolman (1954).

The historical channel behaviour is based on five sets of topographical maps and one set of orthophotos (Table II). The maps were georeferenced or fitted to Stereo 70 projection, using geographical information system (GIS) software (ArcView 3.2). For the Austro-Hungarian maps (the Second

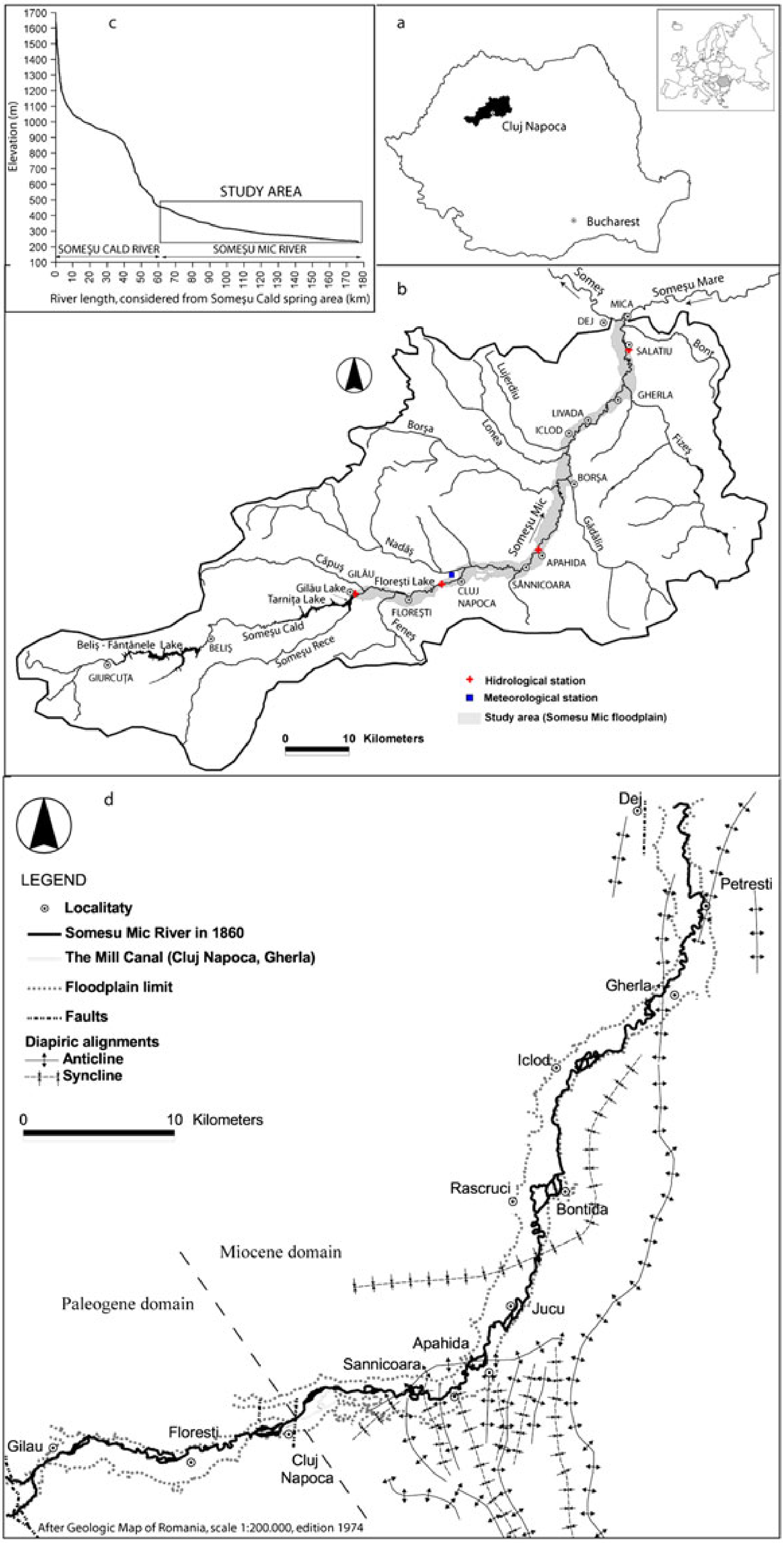

Figure 1. (a) Map of the Someşul Mic hydrographic basin, (b) position of study area in the general longitudinal profile, (c) detailed view of the study area, and (d) local geological conditions. This figure is available in colour online at wileyonlinelibrary.com/journal/espl

Table I. General data on the Someşu Mic River

Cross-section	Drainage basin area, A (km^2)	Mean altitude, a.s.l., H (m)	River length, L (km)	Mean yearly discharge, Q (m^3/s)	Suspended sediment load, Q_s (kg/s)	Suspended sediment yield, S_y (t/km^2 yr)
Gilău	863	1116	73	12.93	0.247	9.026
Cluj Napoca	1210	973	91	15.32	3.609	94.061
Apahida	1863	803	114	17.89	9.467	160.25
Salatiu	3595	604	169	22.56		

Table II. Summary of the cartographic supports used in this study

Map	Projection	Topographic survey	Edition	Scale	Map resolution	Reference year considered in this study
The Second Austro-Hungarian Military Survey (Institute of Military Geography, Vienna, Austria)	Cassini–Soldner projection, Zach-Oriani Ellipsoid	1859–1860	1869–1870	1:28 800	4 m/pixel	1860
The Third Austro-Hungarian Military Survey (Institute of Military Geography, Vienna, Austria)	Tg. Mureş stereo projection, Besel 1841 Ellipsoid	1869–1884	1890–1910	1:25 000	2 m/pixel	1884
Topographic maps (Romanian Military Topographic Service, Bucharest)	Gauss–Kruger projection, Pulkovo 1942 Ellipsoid	Field survey: 1908–1914 Aerophotos: 1956	1957	1:25 000	2 m/pixel	1956
Topographic plans (Institute of Geodesy, Photogrammetry, Cartography and Territorial Planning, Bucharest, Romania)	Stereo 70 projection, Krasovschi Ellipsoid	Aerophotos: 1968–1976 Field survey: 1970–1977	1971–1979	1:5000	0·4 m/pixel	1970
Topographic maps (Military Topographic Department, MApN, Romania)	Gauss–Kruger projection, Pulkovo 1942 Ellipsoid	1977	1978–1979	1:25 000	2 m/pixel	1977
Orthophotos (National Agency for Cadastre and Land Registration, Bucharest, Romania)	Stereo 70 projection, Krasovschi Ellipsoid	2005	—	1:5000	0·5 m/pixel	2005

and the Third Military Surveys), common points with the Stereo 70-projected maps (such as bridges, churches, road-crossings) were established and were used as anchors to re-project the Austro-Hungarian maps. The accuracy and precision of the re-projection was checked by comparison of the position of common points between successive sets of maps, and additionally, the overlapping of the railway (starting with the Third Military Survey); the differences between the maps, after re-projections and corrections, were less than 20 m.

For data analyses, the year(s) of field survey (Table II) was used, except for topographic maps edition 1957 (1:25 000) and topographic plans edition 1971–1979 (1:5000). In the first case, the maps were constructed by re-adjusting the land morphology from 1908 to 1914 after aerial photographs made in 1956. For this reason, the reference year is considered 1956. In the second case, the field measurements were performed before and after the historical flood recorded in May 1970, thus the maps reflect both the channel morphology before and after this event. But because some changes in the river morphology, between this set of maps and the next one (scale 1:25 000, edition 1977) are visible, the year 1970 was attributed as reference year.

Meander bend sinuosity, meander sinuosity, meander amplitude, meander wavelength, channel length, number of channels, number of channel cutoffs, and channel bankfull width were measured for all considered years. Using the methodology of Leopold and Wolman (1957), the meander bend and meander parameters were determined along the channel's central axis. For the other parameters, 303 equally (at 250 m) spaced lines were constructed first, perpendicular to the valley's centre axis, using the 1860 map as the reference map. This method, inspired from Rapp and Abbe (2003) and O'Connor *et al.* (2003), has the advantage to allow systematic analysis on the spatial and temporal channel changes. All parameters have been measured at the intersection points between these lines and the successive positions of the channel, as determined on the maps. Channel length was measured along its central axis, between two successive lines crossing the channels. Channel bankfull width was considered as the perpendicular line on the channel in the intersection point with the valley cross-section lines. Channel cutoffs have been mapped on successive maps based on morphological changes. The number of intersections between each profile and the active channels was used to determine anabranched reaches, which were considered as such if two conditions were met: the total number of channels was greater than two, and the width of the vegetated area between the channels exceeded the width of the channels (Nanson and Knighton, 1996). Additionally, channel bankfull slope for the 1970 reference year was constructed using elevations along the river, marked on maps.

Reach delimitation follows the methodology applied by Schumm *et al.* (1994) to the Mississippi River, where the main criteria were the morphometric characteristic of the channel in natural conditions. To compensate the lack of similar detailed information for the Someşu Mic River, the reach delimitation is based on a larger set of data, both quantitative and (especially) qualitative. Thus, reach limits were established taking into account the spatial succession of different channel types (sinuous, meandering or anabranched) for the 1860 reference year. Additional information consists of channel and floodplain characteristics (field survey), historical channel planform behaviour (successive sets of maps) and local geological conditions (obtained from geological maps, interpretation of floodplain morphology and *c.* 200 hydrotechnical and geotechnical cores located in the floodplain perimeter). The river was split into 42 reaches, each a few hundred metres to a few kilometres long. Figures 2a and 2b show the spatial configuration of the reaches in 1860, and their position in accordance with local geological conditions. Detailed morphometric parameters determined for the 1970 reference year, such as channel bankfull slope, channel bankfull width, channel length, meander sinuosity, number of channels, were used to generate new quantitative data at reach scale: single-thread/main channel sinuosity, channel bankfull slope (m/m), bankfull discharge (m^3/s), specific stream power (W/m^2), or the average number of channels for the anabranched reaches.

Results

Channel planform characteristics

Present day channel (Figure 3)
Channel width is 30–60 m (bankfull level), with higher values corresponding to local development of median and longitudinal

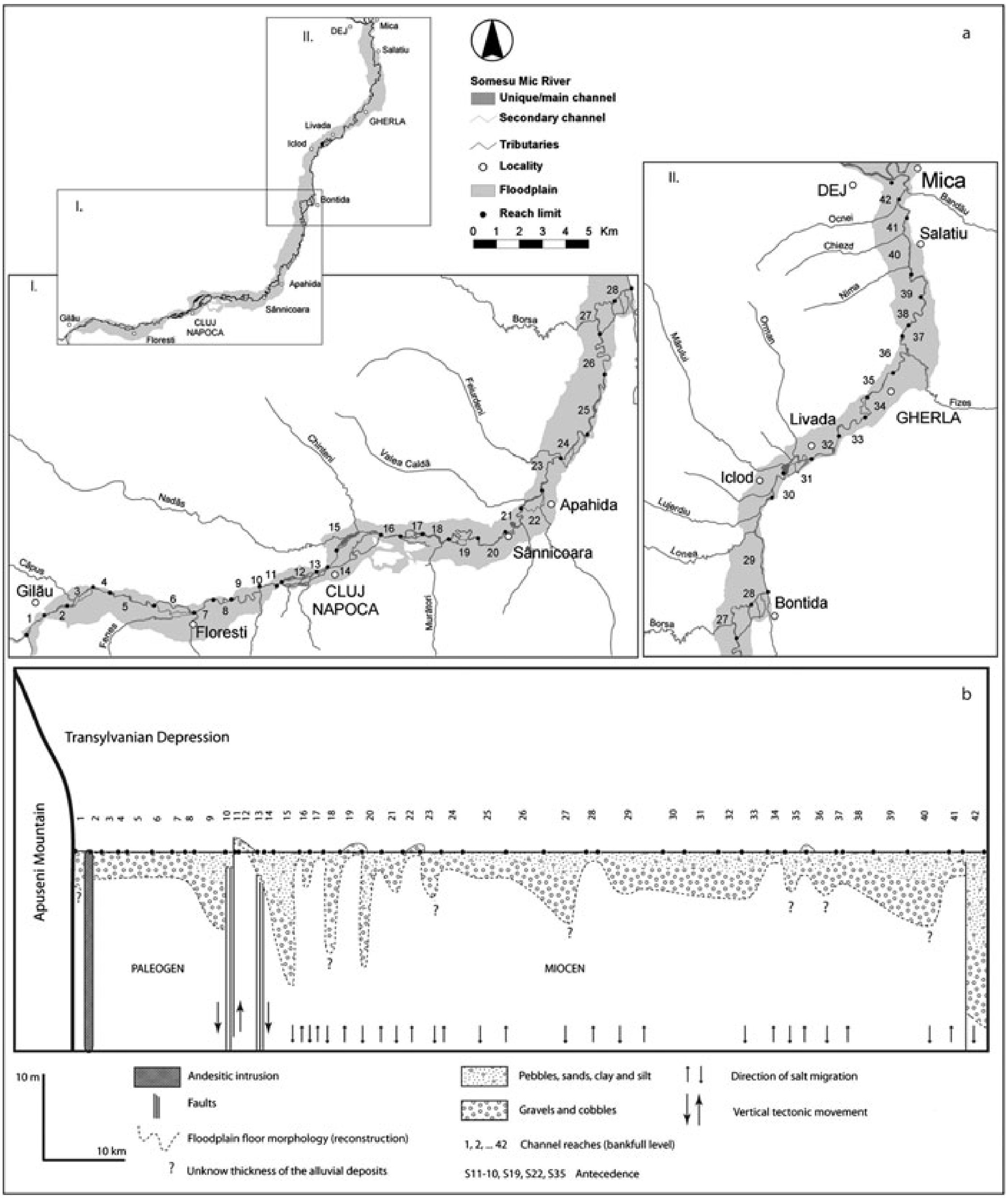

Figure 2. (a) Spatial planform position of the 42 channel reaches with different channel patterns for the 1860 reference year. (b) Spatial position along the longitudinal profile, related to floodplain surface and local geological conditions. The model of floodplain floor morphology and floodplain sedimentary structure was constructed based on geological maps of the area, field observations on floodplain morphology and interpretation of *c.* 200 hydrotechnical and geotechnical cores located in the floodplain.

Figure 3. Examples of channel morphology and sedimentology: (a) channel incised in Eocene clays, downstream from Gilău Dam, (b) steps imposed by Eocene limestone, downstream from Gilău, (c) steps imposed by Miocene volcanic tuffs, downstream from Cluj Napoca, (d) coarse gravel alluvial reach at Sânnicoara, (e) sinuous alluvial reach at Salatiu, with fine sediments in the river bed and banks, (f) coarse gravel meandering alluvial reach at Petreşti. This figure is available in colour online at wileyonlinelibrary.com/journal/espl

bars and islands. Bank elevation varies between 0·5–5 m, predominantly between 2–3 m. In the Palaeogene domain, upstream from Cluj Napoca, in the river bed clays, marls and limestone occur, with the exception of Floreşti meandering reach, which is an alluvial one. In the Miocene domain, between Cluj Napoca and Gherla, bedrock (marls and volcanic tuffs) and alluvial reaches are intercalated, with the predominance of the former. From Gherla to the confluence the river becomes alluvial. The occurrences of limestone and volcanic tuffs are associated with small steps of *c.* 0·1–1·5 m elevation, while clays and marls appear as continuous strata covered by a thin layer of alluvial sediments. Sediments are coarse, predominantly quartz, crystalline schist and granite (from the upper catchment area), with a downstream grain size decrease of D_{50} from 41 mm to 16 mm. Riparian vegetation is generally limited to the immediate vicinity of the river, fixed on its banks, with a width less than the channel width. Upstream from Cluj Napoca, tree species are dominant, while downstream shrubs and perennial herbs become predominant.

Channel morphology in natural conditions (before the large-scale hydrotechnical interventions)

General considerations. The single thread channel width and the multichannel reach width (Figure 4c), both evaluated for the 1860 reference year in 303 cross-sections, allow us to separate 10 anabranched reaches. They have an apparent random distribution, with no clear correspondence with the spatial distribution of the main tributaries junctions (Figure 4a), floodplain width (Figure 4b) or with the two geological domains (monoclinal Palaeogene strata versus Miocene strata affected by salt tectonic) (Figure 4e). The single-thread/main channel meander sinuosity indicates abrupt demarcations between reaches with low and high sinuosity values (Figure 4d), reflecting a high alternation of short sinuous (< 1·5) and meandering (> 1·5) reaches.

The spatial variation of channel sinuosity and spatial distribution of anabranched reaches (Figures 4c and 4d), indicate the existence of four channel types: sinuous, meandering, sinuous anabranching and meandering anabranching, with a

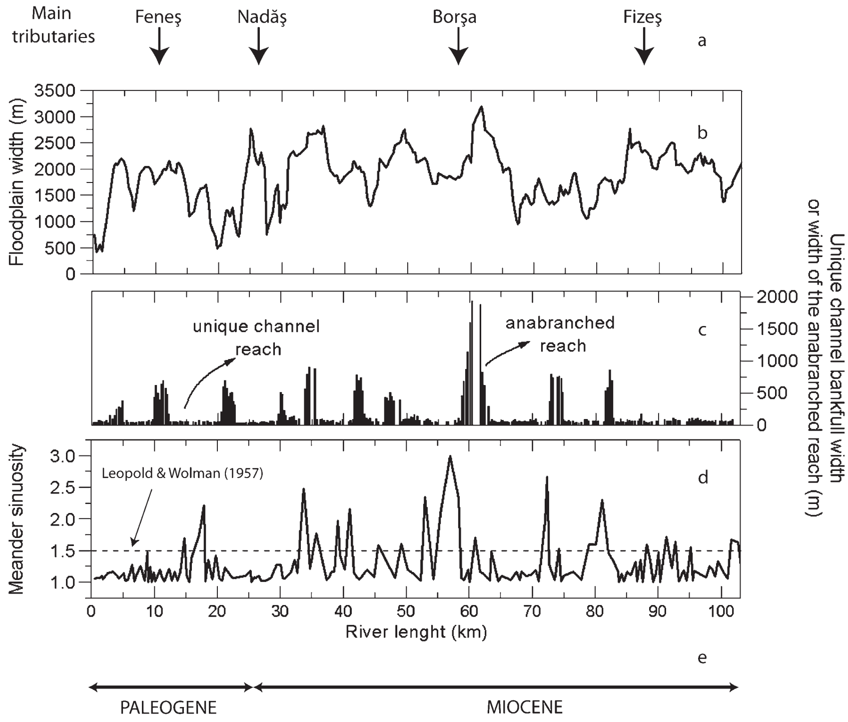

Figure 4. Planform morphometric measurements on channel typology for the 1860 reference year.

high rate of change in the longitudinal profile and with abrupt transitions between them. Field observations show that the four channel types can be both alluvial and mixed ones. Even if most of the anabranched reaches are mixed type, the cartographic evidences on the morphology of branches for the 1860 reference year and the planform evolution after this moment, the historical evidences of avulsions on the floodplain surface, and the presence of coarse gravels in the bed and banks of the river, recommend them for anabranches of type 3 (reaches 19, 22, 27, 31, 34) and type 6 (reaches: 3, 6, 12, 24, 28), from the Nanson and Knighton (1996) classification. However, because the cited classification is referring only to alluvial anabranches, attention must be paid to the similarities between the two. For example, the authors indicate that type 6 occurs in small, steep drainage basins in mountain areas, behind log jams and/or sediment accumulation. These conditions are not available along the sinuous anabranched reaches identified along the Someşu Mic River, which means that different genetic origin must be responsible for their existence. Meandering anabranches are fitting in the general description, except the occurrence of rock along the mixed ones.

Reach scale observations on channel typology (the 1970 reference year). Figure 5a shows the relation between the single-thread/main channel bankfull slope and sinuosity. At slope values lower than 0·0016 m/m, the sinuosity is extremely variable, with values between 1·0 and 2·7. Apparently, the straight, sinuous and meandering reaches are present in the same slope intervals, a relation that is not in accordance with the classical one established by Schumm and Khan (1972). As slope increases (maximum value 0·0065 m/m), only straight and sinuous reaches are present, most of them with a sinuosity in the range 1·05–1·2. The reaches in the Paleogene domain have bankfull slope values between 0·0025 and 0·0065 m/m, and those from the Miocene domain between 0·0001 and 0·0070 m/m (Figure 2), even if some exceptions are recorded in both cases. The anabranched reaches from the Paleogene domain have preferentially sinuous branches, and those developed in the Miocene domain are both sinuous and meandering (Figure 5a).

In Figure 5b, the relation between single-thread/main channel bankfull slope and specific stream power is shown, visualized for two distinct channel types identified along the river: alluvial and mixed type ones. For alluvial reaches, the relation between the two parameters has a classical trend, in accordance with the general laws of the hydraulic geometry: as slope increases, specific stream power will increase as well (Leopold and Maddock, 1953; Wolman and Miller, 1960; Schumm, 1977). The same can not be said about the mixed type reaches. The first observation is related to the four reaches (reaches 2, 3, 11 and 14) located in the upper part of the graph, at high slope values. They conserve their downstream spatial distribution, a trend that suggests an inverse relation between slope and specific stream power: as slope slowly decreases, stream power will increase (discharge increases proportionally with contributions from tributaries). This general trend and high slope values recommend the four reaches to a more bedrock like channel behaviour than an alluvial one. In order to distinguish them from the other mixed type reaches, we refer to them as 'bedrock' reaches.

The rest of the mixed type reaches are located between the two extremes. Their general trend reflects an alluvial channel behaviour, but at higher values of slope and specific stream power. They are more grouped in the vacinity of the alluvial domain, and more dispersed as they move towards the 'bedrock' channel types. Their intermediate position between the two situations could be interpreted as a reflection of the proportion between rock and alluvium in the channel cross-section: the reach will have a more alluvial behaviour as the rock proportion decreases and vice versa.

Reach 14 has a particular position in this picture. It has the maximum stream power value (103 W/m^2) recorded along the entire river, and in the field is located at the contact between the two geologic domains, superimposed on a short, but ample diapiric anticline, disposed along small-scale faults of the Paleogene domain (Figure 2b). Its position at the intersection of the two channel trends can be interpreted as a quantitative measure of an internal threshold of the river. A

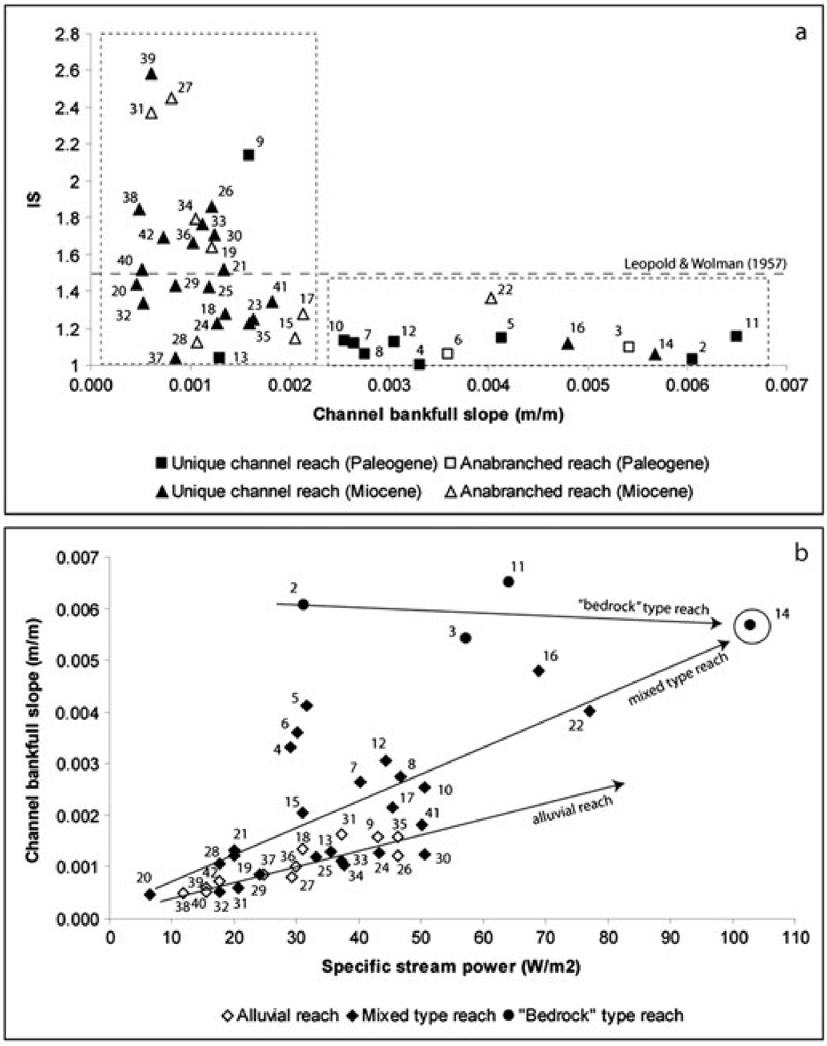

Figure 5. Relations established between (a) single-thread/main channel bankfull slope and sinuosity and (b) single-thread/main channel bankfull slope and specific stream power, evaluated in 42 reaches for the 1970 reference year.

higher rock proportion will determine 'bedrock' behaviour, and a smaller proportion will turn the channel to a more alluvial one. This relation is available both in the Paleogene and in the Miocene domains.

The specific stream power in relation to the nature of material from the river bed (Figure 6) shows that Eocene limestone and Miocene volcanic tuffs have the higher resistance to erosion, while gravels and sands the lower ones. Eocene marls and clays, followed by Miocene marls have intermediate positions. The slope registers a similar trend for Miocene rock, gravels and sands, but not for Paleogene rocks. Apparently, the Eocene clays induce higher channel slope than marls and limestone. However, at a closer look it is clear that these differences are introduced by reaches 2, 3 and 11, where other local controls are responsible for the additional slope values: initial slope of the floodplain floor and local tectonic uplifts.

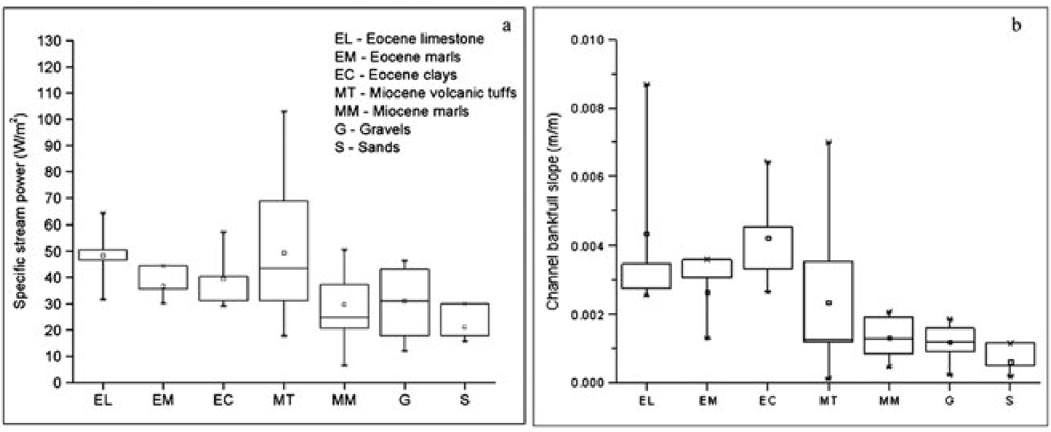

Figure 6. Relations established between (a) single-thread/main channel specific stream power and nature of materials from the river bed and (b) single-thread/main channel bankfull slope and nature of materials from the river bed, evaluated in 42 reaches for the 1970 reference year.

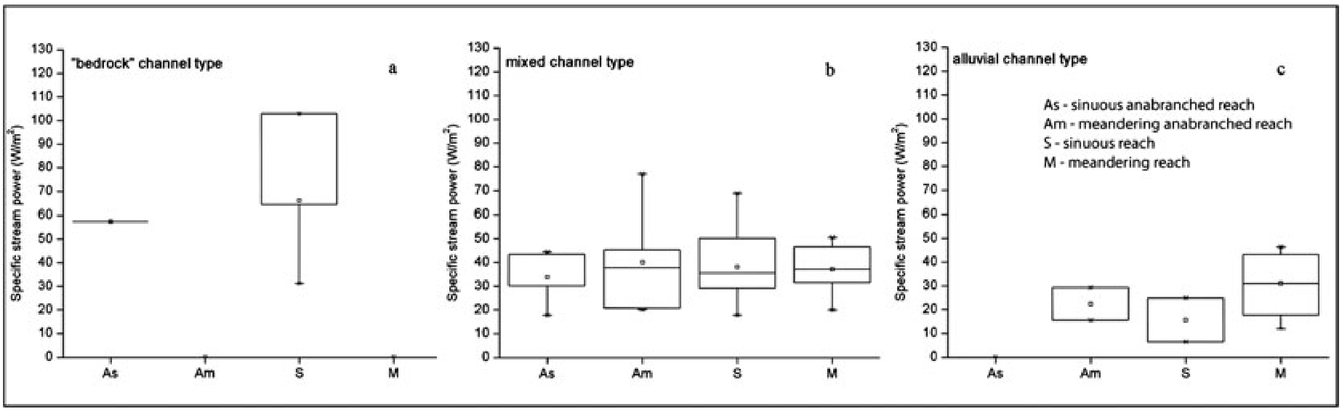

Figure 7. Relations established between single-thread/main channel specific stream power and (a) 'bedrock' channel type, (b) mixed channel type, (c) alluvial channel type, evaluated in 42 reaches for the 1970 reference year.

Figure 7 presents the specific stream power distribution for alluvial, mixed and 'bedrock' channels, referring to the four channel types identified along the river: sinuous, meandering, sinuous anabranch, meandering anabranch. The higher values are recorded for 'bedrock' channels, followed by mixed and alluvial ones. Referring to single-thread channels, it is observed that in the case of alluvial reaches, the sinuous ones register lower specific stream power values than the meandering ones, a relation in conformity with the Schumm and Khan (1972) experiment. The same relation also exists between sinuous and meandering mixed type reaches, even if it is less evident. In this case, the statistical deformation of the relation between the two channel types is introduced by the criteria used to define them: channel morphology in 1860. Such an example is reach 16, the most responsible one for this statistical deformation. This reach is recorded as sinuous, with high planform stability during the entire considered historical scale. But its high slope value and the local geological context indicate its position on a syncline, upstream from an anabranched reach fixed on a diapiric anticline (Figures 2a and 2b). According to Ouchi's experiments (1985), this tectonic context is associated with a couple of meandering–anabranching reaches. The same author suggests that if a sinuous reach is present where a meandering one should be, this indicates an advanced evolution stage of that particular reach. Considering this explanation, if reach 16 receives a theoretical meandering character, its specific stream power will naturally move into the limits associated with this channel type, and the normal relation between the sinuous and meandering channel is re-established.

In a synthetic form, specific stream power values indicate the following relations between single-thread channel types:

$$(S_r) > (M_m > S_m) > (M_a > S_a) \qquad (1)$$

where S represents sinuous reach, M meandering reach and r, m and a indicate 'bedrock', mixed and alluvial channel types.

A similar behaviour is recorded for anabranched reaches:

$$(\mathrm{As}_r) > (\mathrm{As}_m > \mathrm{Am}_m) > (\mathrm{Am}_a) \qquad (2)$$

where As represent sinuous anabranch and Am meandering anabranch.

For the next analysis, reaches were differentiated as sinuous, meandering, sinuous anabranched and meandering anabranched reaches and were plotted as single-thread/main channel bankfull slope versus single-thread/main channel bankfull discharge (Figure 8). The limits between sinuous, meandering and braiding domains were established by applying to our own data the two relations established by Leopold and Wolman (1957) and Ackers and Charlton (1971):

$$s = 0{\cdot}012 \;\; Q_{1\cdot5}^{-0\cdot44} \qquad (3)$$

$$s = 0{\cdot}0009 \;\; Q_{1\cdot5}^{-0\cdot21} \qquad (4)$$

where s represent the channel bankfull slope (in m/m) and $Q_{1.5}$ represent the channel bankfull discharge (in m^3/s).

The three energetic levels of 'bedrock', mixed and alluvial channels types, already seen in Figure 5b, are conserved here too. The alluvial reaches, even if they are sinuous, meandering or anabranched, are maintained between the limits calculated by Leopold and Wolman (1957) and Ackers and Charlton (1971). Referring to the mixed type reaches, parts of them are positioned between the two limits, but some of them are localized in the braiding level. These spatial distributions are apparent and reflect the effect of the rock, as the channel turns away from an alluvial behaviour. The same positioning in the braiding area is recorded for 'bedrock' reaches, which confirms the previous affirmation. The anabranching reaches are localized in the same areas as the sinuous and meandering ones, both for alluvial and mixed type channels (Figures 8a–8c).

Qualitative and quantitative comparisons with the Nanson and Knighton (1996) classification show that the meandering anabranched reaches recorded along the Someşu Mic River are characterized by higher specific stream power values and coarser materials in the bed and banks of the river, comparative with type 3 of the mentioned classification. On the contrary, sinuous anabranches are associated with lower specific stream power values than those indicated by the authors for type 6. For both cases, the other quantitative characteristics, *i.e.* lateral migration rate, vertical accretion rate and sinuosity, are maintained between the indicated limits. It appears that the three anabranching types (alluvial and mixed meandering anabranches, mixed sinuous anabranches) have a common domain of occurrence, which is not included in Nanson and Knighton (1996) classification (Figure 9). All these appreciations indicate that anabranched reaches inventoried along the Someşu Mic River are different from those identified by the authors, even the alluvial ones, not necessary through morphological or sedimentological characteristics but rather through their energetic levels of occurrence and genetic causes.

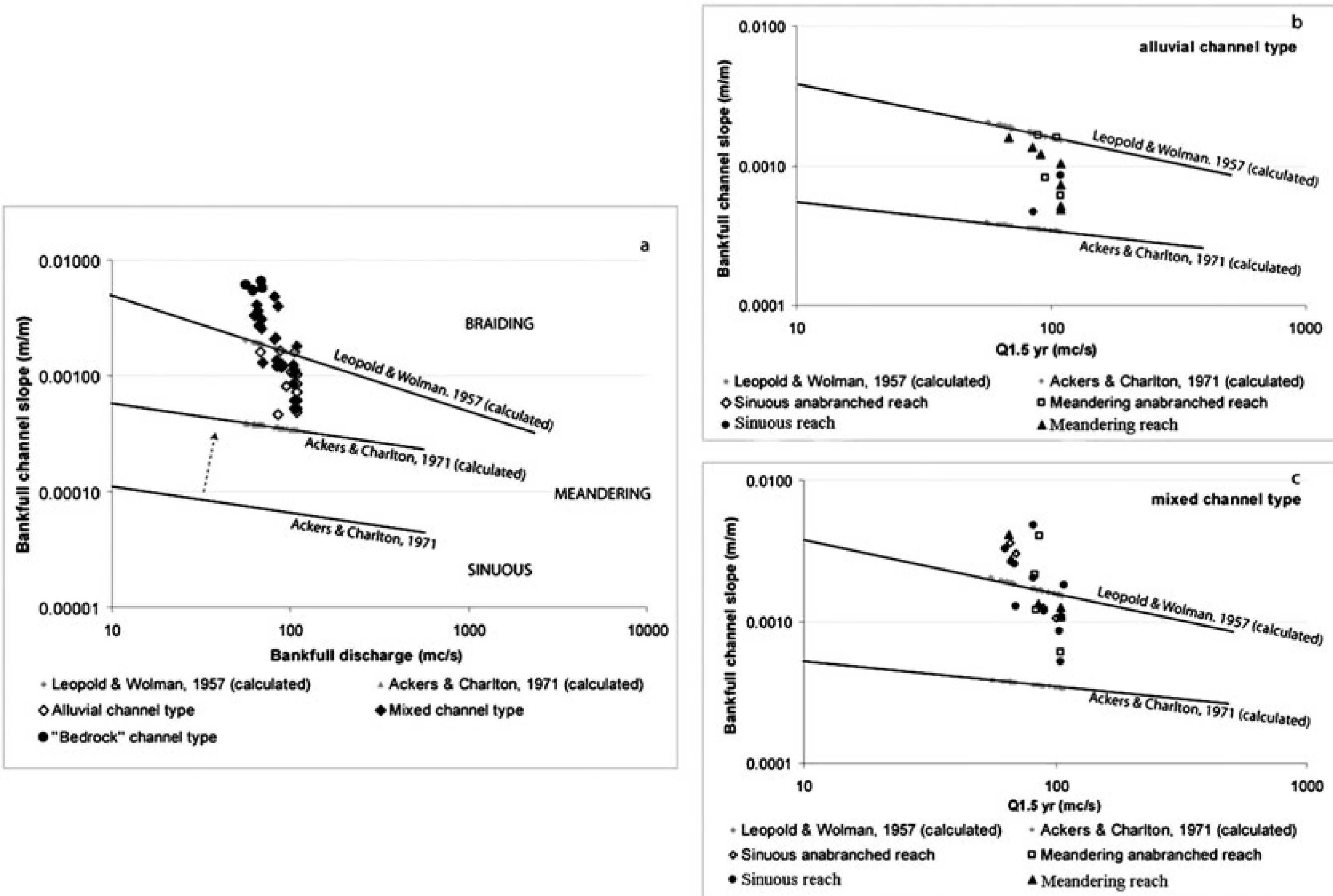

Figure 8. Relations established between single-thread/main channel bankfull slope and bankfull discharge (a) for all 42 reaches, (b) for alluvial channel types, (c) for mixed channel types, for the 1970 reference year.

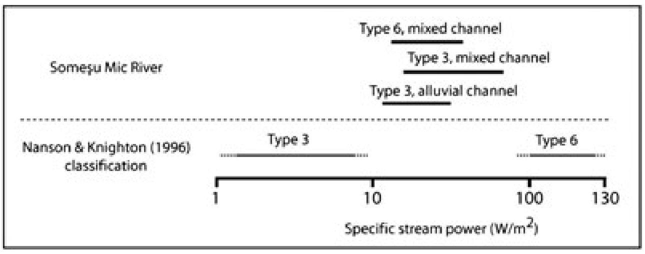

Figure 9. Domains of occurrence for anabranching reaches identified along the Someşu Mic River (the 1970 reference year) in comparison with Nanson and Knighton (1996) classification of anabranched channels.

Temporal behaviour

Rates of change – general pattern

The temporal variability of the total or average values of seven morphometric parameters of the single-thread/main channel are presented in Figure 10. The total length of channel (Figure 10a) variation between successive reference years is a first measure of the channel planform behaviour in the last 145 years. The most impressive change is recorded between 1860 and 1884, when the river length increased by 7·4 km. The next 72 years are marked by a decrease of almost 4 km, which was followed by an abrupt but not very important increase (1·7 km), until 1970. Between 1970 and 1977, the river decreased once again, with 3·2 km, a tendency continued with a lower rate during the last 24 years (< 0·5 km). The average meander sinuosity (Figure 10b) has a similar behaviour with the river length between 1860 and 1977. For the last 28 years, it recorded an important increase, which annulated the sharp decrease registered between 1970 and 1977. The pattern of the average meander bend sinuosity is different than that of meander sinuosity. After an abrupt increase between 1860 and 1884 (Figure 10c), it has a constant value for the next 72 years, followed by a rapid return (between 1956 and 1970) to the previous low value, and an ample increase after 1977. The average meander wavelength (Figure 10d), after a sharp increase of 138 m in the first 28 years and a slight decrease of 40 m in the next 72 years, rapidly decreased another 52 m in only 14 years. This late decrease was attenuated by an increase of 47 m during the last 35 years. Between 1860 and 1884, the average meander amplitude (Figure 10e) has the same signal as the previous parameters between 1860 and 1956. Afterwards, the decrease continued, more abrupt between 1970 and 1977. Between 1977 and 2005 the parameter increased, attaining an intermediate value between those recorded in 1884 (220 m) and 1956 (184 m). The temporal distribution of number of cutoffs (Figure 10f), natural (nick or chute cutoffs) as well as artificial ones, has a completely different trend from those presented before. It registers minimum values (five cutoffs) in the

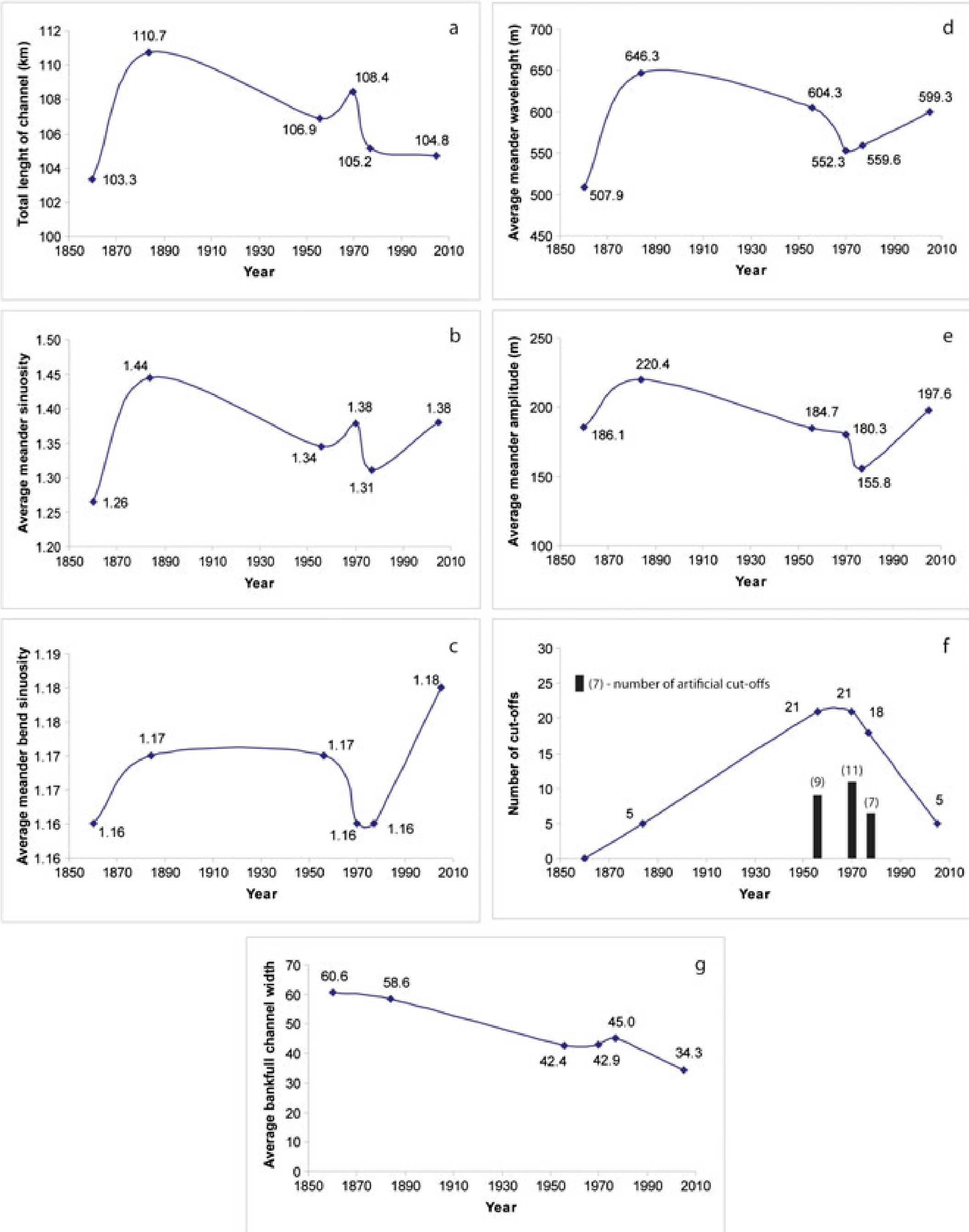

Figure 10. Temporal variability of (a) total length of channel, (b) average meander sinuosity, (c) average meander bend sinuosity, (d) average meander wavelength, (e) average meander amplitude, (f) number of cutoffs, (g) average bankfull channel width, between 1860 and 2005. This figure is available in colour online at wileyonlinelibrary.com/journal/espl

first 28 years and the last 27 years, and high values (18–21 cutoffs) between 1884–1956, 1965–1970 and 1970–1977. The last considered morphometric parameter is the average channel bankfull width (Figure 10g), which also has a particular trend: a general decrease from 60 m to 35 m (47%), with the most important decrease between 1884 and 1956.

Rates of change at reach scale level

The spatial distribution of single-thread/main channel planform responses is summarized in Figures 11 and 12, where river length and channel bankfull width variations are presented as differences between two consecutive reference years.

Channel length differences between 1860–1884 and 1884–1956 are of opposite sign, increasing in the first 28 years and decreasing in the next 72 years and vice versa (Figure 11a). In the next interval (1956–1970), this parameter has lower amplitudes of change, a reflection of either a general planform stability or the short interval between the two reference years (Figure 11a). Between 1970 and 1977, the first 30 km (reaches 1–16) are characterized by stability, and only the next 80 km present a higher variability. In the last case, variations tend to be similar with those from 1860 to 1884, but less impressive, except reach 26, which was strongly straightened (Figure 11b). For the last 28 years (1977–2005), the river continued to be stable in the first 30 km and more variable downstream. The main changes consist in an important shortening of reach 6 and a switch of length variations in the opposite sense, similar to the one between 1956 and 1970 (Figure 11b).

Changes of channel bankfull width between 1860–1884 and 1884–1956 are also of opposing sign, as channel reaches with a general widening during the first 28 years recorded a narrowing in the following interval, and vice-versa (Figure 12a). Except for

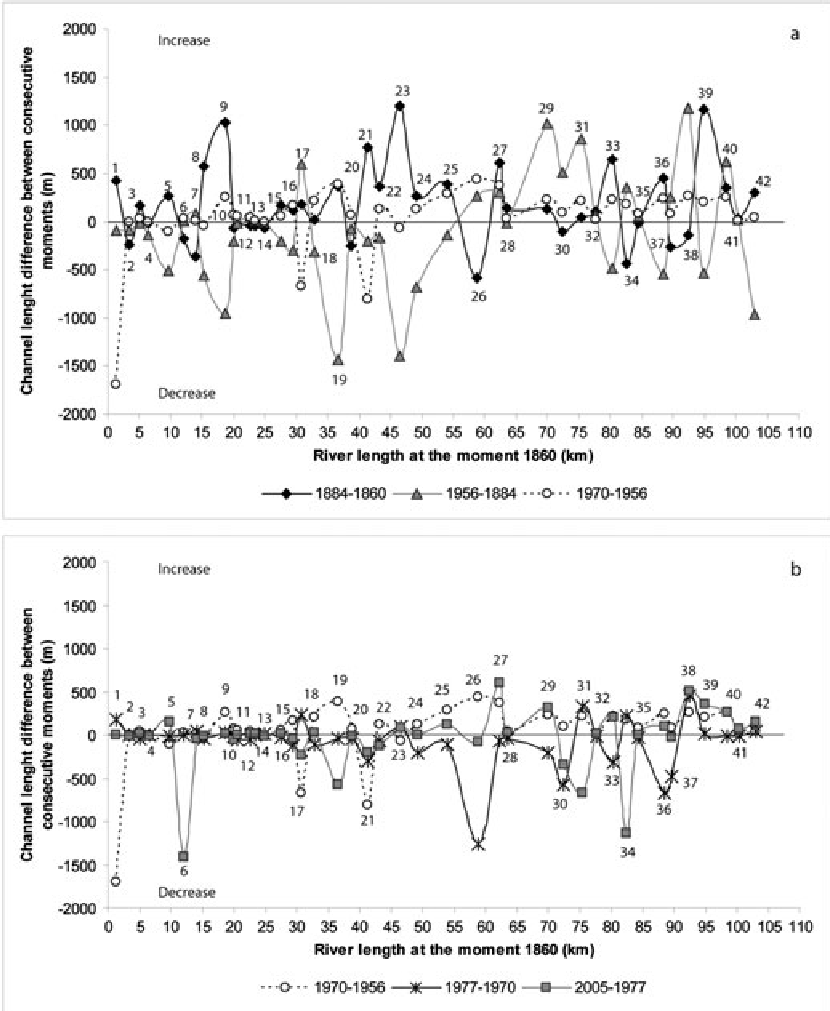

Figure 11. Temporal variability of channel length difference between consecutive reference years, evaluated in 42 reaches: (a) 1860–1970 interval, (b) 1956–2005 interval.

these spatial cyclical responses, no other general trends are observed. The next interval of time (1956–1970) registers an important channel bankfull widening along the reaches located in the first 15 km (reaches 1–7). Starting with reach 8, a return to the natural trend notified earlier is observed. For this time, the responses are in the same direction as between 1860 and 1886, sometimes with comparative amplitudes (reaches 20, 28), but usually with smaller values (Figure 12a). Intervals 1970–1977 and 1977–2005 show some different patterns than before (Figure 12b). Meaningful changes are recorded along the first *c.* 40 km, with the most important one along the reaches 1–6: a channel narrowing of *c.* 60–80 m between 1970 and 1977, which compensates the widening registered in the previous 14 years, followed by another widening trend in the next 28 years, but at this time at a smaller rate. The second modification is recorded along the reaches 15–21, which became more stabilized for the rest of the time, while their previous dynamic behaviour seems to be transferred to reaches 22–25. Downstream from there, the reaches continues to be grouped as before. The general trends are a small-scale widening between 1970 and 1977, which continues the trend from 1956 to 1970, and a narrowing after 1977.

Figure 13 shows the temporal behaviour of anabranched reaches (identified for the 1860 reference year) through the average number of their branches. The most impressive aspect is related to four sharp decreases to value ‘one’, which indicate the installation of a single-thread channel type. Their temporal distributions are apparent, as they are induced by the intervals between the successive maps, the main sources of evidence on their transformations. These results reflect the hydrotechnical interventions, most of them concentrated between 1956 and the few years after 1977. After these interventions only one anabranch remained functional (Bonțida–Răscruci).

Discussions

Channel planform characteristics

Causes of different channel types

The anabranched reaches imposed in the past specific wetland landscapes, developed generally on relative small surfaces of only a few hectares. Previous studies suggested that tributaries (Buz, 1972) or diapiric alignments (Pop, 1966) are responsible for their occurrence. However, the positions of the main confluences along the river, both upstream and downstream from the anabranched reaches, and even between their limits (Figures 4a and 4c), and the absence of important morphological and sedimentological changes of the main channel near the junctions, both in present and historical times, suggest that the tributaries were not responsible for river anabranching. We thus favour the opinion that the diapiric alignments imposed changes in the channel’s slope and, as a result, natural conditions for repeated lateral avulsions.

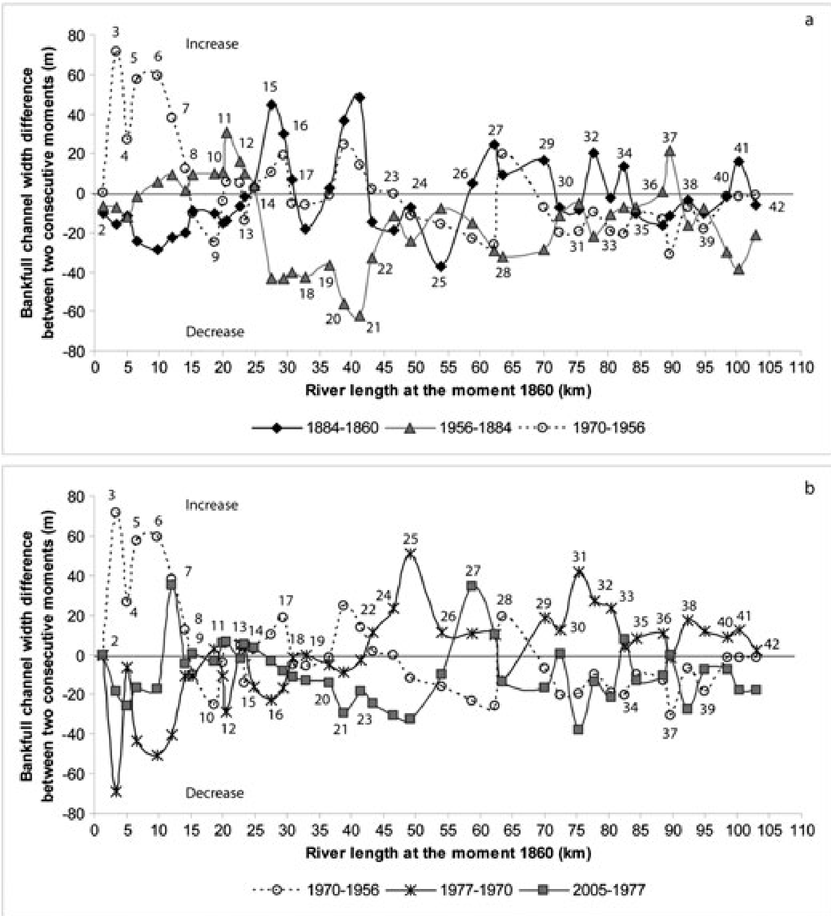

Figure 12. Temporal variability of channel bankfull width difference between consecutive reference years,, evaluated in 42 reaches: (a) 1860–1970 interval, (b) 1956–2005 interval.

Downstream from Cluj Napoca, the spatial disposure of meandering and anabranched reaches along the river reflects the models of channel planform responses of a mixed load meandering river as responses to slow active tectonic movements, proposed by Ouchi (1985). Thus, when the river crosses a diapiric anticline, an anabranched reach develops upstream, behind the natural dam imposed by the anticline's flank, while meandering occurs downstream from the anticline, on higher slope conditions. When the river crosses a syncline, the position of these two channel types is inverted, as meandering occurs on the syncline's flank, and the anabranched reach will develop in the area with maximum inflexion. The experiments by Ouchi (1985) show that in time, as the natural dam retreats, the anabranched reach will tend to reduce its dimensions, while downstream, the meander cutoffs will induce a more sinuous course. This behaviour could explain in part the occurrence of sinuous reaches in our study area.

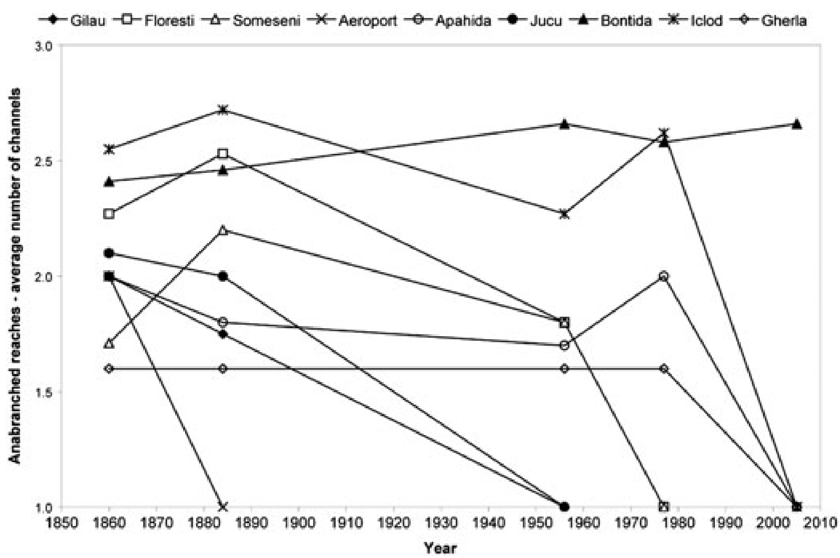

Figure 13. Temporal dynamic of anabranched reaches between 1860 and 2005.

Next, sinuous reaches, 5 to 30 km long, disposed at the floodplain's edge, occur downstream from Apahida. As Figure 1d shows, starting from here, synclines are mostly disposed parallel to the floodplain orientation. This local geological context allows us to presume the lateral tilting of the valley floor. The experiment of Peakall (1996), cited by Schumm *et al.* (2000), on the effect of lateral tilt on a stable channel, shows a shift of the channel downwards on the lateral slope, which could explain the lateral position of the Someşu Mic River in these areas. Considering the discussions of Schumm *et al.* (2000) on the styles of lateral channel migration as a response to lateral tilting, the third mentioned style ('combing'), which presume 'a slow migration by a preferential down slope erosion and/or meander cutoff on one side of the river', seems to explain this morphology.

Why in the Paleogene domain, where salt tectonics is not present, is a comparable channel planform behaviour recorded? Between Gilău and Cluj Napoca, we identified three anabranched reaches: 3, 6 and 12. The morphometric relations established between these and the upstream and downstream neighbouring ones show that anabranching is a transitory stage between higher and lower energetic reaches. These relations suggest that the anabranches are areas where the in-excess energy introduced by the upper reaches (higher slope induced by initial slope of the floodplain floor – reach 2, occurrence of limestone in the river's bed – reach 5, or tectonic uplift – reach 11) are consumed. When considering downstream restrictive conditions, they are certificated by the positions of sharp transitions to sinuous channels, which are stable over the entire considered historical scale. At these transitions the proportion of slope changes are higher than those registered at the transition to anabranching reaches. Probably, these important slope reductions (reaches 4 and 7: Eocene clay, reach 13: low tectonic uplift rate) play the role of local base levels for the secondary branches of the upper anabranching reaches.

Causes of different types of anabranching

In the Eocene domain, only sinuous anabranches are present, while in the Miocene domain the meandering anabranches are dominant. Moreover, the sinuous anabranches are present only for the mixed channel types, while the meandering ones can be either alluvial or mixed. In the case of mixed type reaches, the sinuous anabranches are characterized by high slope values (e.g., those developed in the Palaeogene domain), or by low slope values – even lower than those of meandering anabranches – in the Miocene domain. Also, slope values of the meandering anabranches are higher than those of the sinuous anabranches. From these considerations it can be concluded that the slope itself is not responsible for their differentiation along the river. Such a behaviour could be better explained by the rock–alluvium proportion in the channel cross-section. Therefore, a higher rock proportion in the river banks will not favour the lateral movement, even if the slope could permit this. In these situations, the in-excess energy will be consumed by vertical incision and the branches will be sinuous. The opposite situation is when the banks are non-cohesive and the in-excess energy introduced by local geological conditions will be consumed through lateral migration. Comparatively, the alluvial meandering anabranches are present at even lower energetic values than those of the mixed meandering ones.

Channel typology

Figure 14 shows a synthesis of the relations established between the 42 reaches, as reflected by quantitative relations between the main morphometric parameters. A few general patterns can be highlighted: (a) decreases of slope and specific stream power in the downstream direction and from 'bedrock' to mixed and alluvial reaches; (b) normal relation between slope and single-thread channel planform behaviour, even if the alluvial and mixed types evolves at different energetic levels; (c) a good memory of the initial planform configurations, even if the historical planform configuration indicates different channel types (e.g., projection of reach 16 in the field of the initial channel type); (d) superposition of anabranching reaches on the sinuous–meandering ranges; (e) for the mixed type reaches, the rock–alluvium proportion in the channel cross-section seems to be the main control for the channel type (a higher proportion of rock will impose sinuous or sinuous anabranching reaches and an increase of alluvium will favour lateral meandering along the single-thread channel reaches as well as the anabranching ones).

A measure of how channel types identified along the Someşu Mic River are reported to classical alluvial channel types classifications (Leopold and Wolman, 1957; Schumm and Khan, 1972; Schumm, 1977; Brice, 1982; Church, 1983) is offered by the positions of Leopold and Wolman (1957) and Ackers and Charlton (1971) limits, calculated for our data (42 reaches) (Figure 8). The limit calculated according to Leopold and Wolman (1957) reproduces the known one. Not the same result was obtained for the Ackers and Charlton (1971) limit,

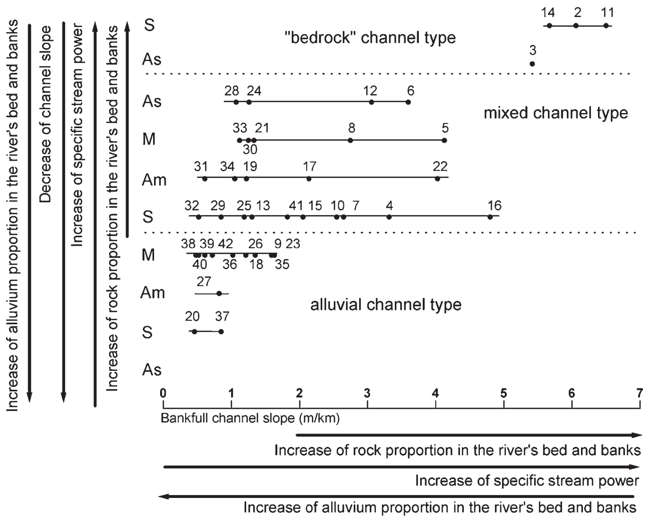

Figure 14. Spatial relations established between different channel types along the Someşu Mic River.

ours being parallel with that of these authors, but shifted to higher slope values. From here three questions arise: Is the rock from the bed and banks of the river responsible for the shift of the limit calculated according to Ackers and Charlton (1971)? If so, why doesn't the Leopold and Wolman (1957) calculated limit register a similar behaviour? Or, is the Someşu Mic River an atypical river, where some drainage basin scale controls impose higher energetic levels, for both alluvial and mixed type reaches?

Answers to these questions are offered by the behaviour of alluvial sinuous reaches and anabranched reaches. Referring to alluvial reaches, not only the meandering ones are positioned above the Ackers and Charlton (1971) calculated limit, but also the sinuous ones (Figure 8b). As the values of sinuous reaches are arbitrary distributed between the two limits, two explanations are possible: their domain of manifestation is shifted to a higher energetic level (as a boundary condition) and/or they reflect the advanced stage of a previous meandering reach, as was reported for reach 16. In the case of anabranched reaches, the values of the main channel specific stream power indicates higher energetic conditions for the occurrence of type 3 meandering anabranches, and lower energetic condition for type 6 sinuous anabranches than those indicated by Nanson and Knighton (1996) classification, a pattern in which the alluvial meandering anabranches are included, too. This last observation reinforces the third question, on the existence of a regional control, which imposes a superior energetic level along the entire river.

A possible cause of this could be the general slope of the river, downstream from the main knick-point of the general longitudinal profile (considered from the Someşu Cald spring area) (Figure 1c). Mathematical analyses of the general longitudinal profile (Feier, 2010) indicates the presence of a slightly accentuated slope along the median and inferior parts of it, including our study area. This increase was interpreted as a response to slope modification along the 400 m high knick-point (induced by different rock resistance to erosion), in order to maintain a general dynamic equilibrium along the entire longitudinal profile. Because the river has planform configurations maintained in the sinuous and meandering domain, only the Ackers and Charlton (1971) limit is affected by this discrete slope addition, while the limit between meandering and braiding remains out of this influence.

Temporal behaviour

Channel planform changes

The total length of channel and the average values of the main morphometric parameters of meanders register a general increasing trend between 1860 and 1884, followed by a decrease between 1884 and 1956. This direct relation is well known, and implies an increase of river length as it will meander, and a shortening of it as the meander bends between cutoff. Some studies on historical channel behaviour (e.g. Rumsby and Macklin, 1996a; Starkel, 2002; Uribelarrea *et al.*, 2003) suggest an association between more humid periods (with higher incidence of important floods) and channel strengthening, and less humid periods and channel planform development, both at centennial and decadal scale. Many studies accentuate the human control on this direct relation, especially during the last 150 years (e.g. Liébault and Piégay, 2002; Wyżga, 2008), while others (e.g. Hooke, 1996, 2006, 2007; Knighton, 1998) discuss on the complex relation between the two controlling factors and non-linear channel adjustments.

The temporal distribution of natural cutoffs along the Someşu Mic River (Figure 10f) and of important floods reported in the area during the last 150 years (see General settings) supports an association between channel planform dynamic and cyclical changes in river discharge (incidence of floods) at decadal scale. For example, the number of cutoffs strongly increased between 1884 and 1956, as did the number of important floods. Comparison of single-thread/main channel planform positions between the two reference years indicates at least 12 natural cutoffs, the highest number registered between two consecutive reference years. Therefore, it is asserted that the first 28 years of this period were characterized by more stable climatic conditions, with fewer important floods and favourable conditions for lateral meandering. In contrast, the following period has recorded an increased incidence of high discharges, which determined the local channel shortenings by meander chute cutoffs. This observation is in accordance with Probst and Tardy (1987), who indicate that during the first 50 years of the twentieth century, in central Europe (including Romania) a more humid period was recorded, around 1910–1920 and 1925–1945.

The next period (1956–1970) has some contrasting trends. The first large-scale hydrotechnical interventions were initiated in this period, both at catchment scale (dam construction), and along the river. A quantitative measure of the amplitude of direct human interventions along the river is given by the number of artificial cutoffs, recognized on maps: nine for the 1956 reference year, between Sânnicoara and Gherla, and 11 for the 1970 reference year, between Gilău and Apahida (Figure 10f). Also, the most important historical flood in the area, produced in May 1970, occured at the end of this interval of time. The increase of total channel length and average meander sinuosity in this interval (Figures 10a and 10b) suggests a stable period, with channel lateral migration. But the superimposed decrease of average values of meander amplitude, meander wavelength and meander bend sinuosity (more abrupt for the last two parameters), correlated with the high number of cutoffs, natural and artificial (Figures 10c–10f), indicates a different pattern, with important spatial responses concentrated along the most dynamic reaches. Channel length differences between the two considered reference years (Figure 11a) show that the most ample channel shortenings were recorded along reaches 17 and 21. But these two particular cases are not ample enough to generate the observed trends. The answer could be the more discrete spatial responses, at the scale of isolated meander bend scale, which occurred in the last part of the interval. They could be either human induced (artificial cutoffs), or natural cutoffs produced during the 1970 flood. These small-scale spatial responses were able to modify the meanders spatial expansions, but they are not sufficiently strong to cancel the increasing trend of channel length and sinuosity started during the previous interval of time.

Between 1970 and 1977 no important floods occurred, while hydrotechnical interventions reached their maximum extension, both at catchment scale (Beliş–Fântânele Reservoir was non-functional at that moment), and along the river. The main planform morphometric parameters register a general decrease or maintain similar values with the precedent ones (Figure 10); and the high number of cutoffs suggests three possible causes for this: natural cutoffs during the 1970 flood, isolated neck cutoffs of some advanced meander bends and artificial cutoffs (seven cutoffs – Figure 10f, with five concentrated along reaches 34 and 35, in the perimeter of Gherla city). The spatial variation of channel length difference between 1970 and 1977 indicate a high stability along the first 30 km (Figure 11b), which corresponds with the river segment between Gilău and Sânnicoara, with extensive hydrotechnical interventions. This artificially induced stability is compensated downstream by a more dynamic planform behaviour, with a general decrease trend to which also local artificial cutoffs contributed. An additional measure of artificial cutoffs during this interval of time is given by the average meander amplitude, which attains its minimum value.

Over the past 28 years (1977–2005), all considered meander parameters registered positive trends, even maximum values at historical scale (Figure 10c). Only the river total length maintained its value at the level of 1977. The hydrotechnical works continued until 1983, mostly concentrating on dam constructions. In this interval, the river is characterized by high planform stability between Gilău and Sânnicoara, and by a more dynamic character between Sânnicoara, and Dej–Mica (Figure 11b). Opposite to the previous interval, the low number of cutoffs indicates now that the most important planform mechanism is meandering. As meander bend sinuosity has the most impressive increase, it means that the main changes are produced at this scale. This is confirmed by the actual planform configuration, where large isolated meander bends can be recognized along some historical sinuous reaches (reaches 25 and 29). It should be stressed that even if lateral migration (translated in channel length differences between consecutive reference years) has a positive trend, with expansions also along some sinuous reaches, the river length does not follow this trend.

The last observation on channel planform behaviour is related to the general amplitude of changes. The maximum amplitude of changes occurred between 1860 and 1884, as suggested by temporal variations of total length of channel, average meander sinuosity and average. Variations from the following interval of time, whether they are in the same direction or not, are maintained between these limits. Some exceptions, with no important effects on the general trends, are recorded for the average meander amplitude and the average meander bend sinuosity. The two parameters have a similar signal, except for the 1977 reference year, when the average meander amplitude decreased comparing with the 1860 reference year. As was already mentioned, this situation could be determined by the continuing artificial cutoffs programme, between 1970 and 1977. In the case of the average meander bent sinuosity, the maximum value is recorded for the 2005 reference year, and is considered to reflect the increasing importance of isolated meander bends in channel spatial adjustments during the last decades, probably caused or accentuated by the existence of artificially induced channel stability along the first 30 km.

Channel vertical behaviour

The average values of channel bankfull width suggest a general decrease in the last 145 years (Figure 10g), more accentuated between two intervals: 1884–1956 and 1977–2005. Moreover, field evidences show that the incision is an active process, especially along the first half of the river. Previous studies on Romanian river bed temporal evolution (Diaconu *et al*., 1962; Rădoane and Rădoane, 2005; Şerban, 2007; Rădoane *et al*., 2010), suggests a historical incision trend. Diaconu *et al*. (1962) indicated a generalized degradation along the Someşu Mic River (Apahida hydrological station) between at least 1945 and 1956. Rădoane *et al*. (2010) demonstrates that between 1956 and 2007 degradation was the most important process along the rivers located in the northeast and eastern parts of Romania. Şerban (2007) shows that between 1982 and 1995 the Someşu Mic River (the first 20 km) was characterized by vertical incision. Combining the information from these studies, it results that a general incision trend associated with channel narrowing was active from at least 1945. This finding suggests that the river responses are possibly conditioned by regional scale controls, with impact on decadal or even centennial time scale.

In this general context, it is not easy to understand the spatial variability of channel bankfull width or differences between consecutive reference years, especially if data on bars position and dynamics, gravel mining, riparian vegetation, nature of banks, are only general and qualitative. With this restriction, our observations are oriented only towards deviations from the natural trends (opposed signs between consecutive intervals, Figures 12a and 12b), recorded during the intervals of time when important hydrotechnical constructions were done. The first massive work was the construction of Gilău dam, started after 1959. This corresponds in our data with the large channel widening along the first 10 km of the river, recorded between 1956 and 1970, as a reflection of large quantities of sediment supplied to the channel, which diminished its transport capacity and induced aggradation and widening. In contrast, the narrowing (and incision) of the same segment between 1970 and 1977 can be a reflection of the functioning of the Gilău Reservoir, as sediments started to be trapped behind the dam and the flow became more aggressive. A few years after, the Floreşti Reservoir and the artificial channel which makes the junction with the Gilău Reservoir were constructed. These interventions are the main causes of channel abandonment between the two lakes (changes became less important than those registered between 1956 and 1970) and channel widening downstream of the Floreşti Reservoir (caused by the lake construction, reach 7 records the maximum amplitude of widening between 1977 and 2005, Figure 12b). The last significant change, recorded over the past 28 years, is the decrease of channel bankfull width between Cluj Napoca and Sânnicoara, interpreted as a consequence of the artificial straightening of the river, responsible for local slope and stream power increase.

The five examples of channel bankfull width responses to hydrotechnical interventions emphasize the local role of hydrotechnical works and also the rapid downstream capacity of the channel to return to a more natural behaviour. Thus, the channel bankfull width decrease after 1977 can be seen as a returning to the natural trend after the end of the most ample human interventions along it, accentuated after 1983 by artificially induced flow regime.

Anthropogenic versus natural controls on channel spatial and temporal responses

Local geology was identified to be the main cause for the high rate of alternation of different channel types along the river, at least before the large-scale canalization works from the last four decades (Figures 1b, 2a and 2b). Another important finding was that the four channel types (sinuous, meandering, sinuous anabranching, meandering anabranching), even if they are alluvial or mixed types, are grouped at a superior level of energy, comparing with the ones indicated by classical classifications of alluvial channels (Figures 8 and 9). A possible cause for this behaviour was interpreted to be the slightly higher general slope, downstream from a 400 m high knick-point in the graded profile (Figure 1c), which is responsible for a higher initial incision of the river in the floodplain sediments and, therefore, an accentuation of the local structural and tectonic effects of river spatial behaviour (Figures 5–7). These two natural controls act as boundary conditions for river evolution at historical scale.

In this context, the main anthropically induced processes along the Someşu Mic River, during the last 150 years, are (1) channel metamorphosis by canalization; (2) transformation of many meandering and anabranching reaches into sinuous ones (Figures 10f, 11 and 13); (3) diminishing and/or elimination of overflows and medium-scale avulsions, by changes occurred in flow regimes (dams) and the presence of dykes in the floodplain perimeter (Figure 13); (4) incision and narrowing of channel downstream from dams or along straightened reaches, and probably also due to in-channel gravel mining (Figures 10g and 12). Similar changes have been reported also for numerous European rivers in the UK (e.g. Gurnell, 1997; Winterbottom, 2000), France (e.g. Bravard *et al.*, 1997; Liébault and Piégay, 2001, 2002; Arnaud-Fassetta, 2003), Italy (e.g. Surian, 1999; Rinaldi, 2003; Surian and Rinaldi, 2003; Simon and Rinaldi, 2006; Surian and Cisotto, 2007; Comitti *et al.*, 2011), Spain (e.g. Uribelarrea *et al.*, 2003; Hooke, 2006; Martín-Vide *et al.*, 2010), Poland (e.g. Wyżga, 2008; Zawiejska and Wyżga, 2010), etc., comparison which supports the idea that the Someşu Mic River is highly modified by human interventions, especially in the second part of the twentieth century. From this perspective, the generalized decreasing trend of channel width (Figure 10g) could be taken as a quantitative measure of the human induced transformation starting with the end of the nineteenth century.

However, as mentioned a few times earlier, some of our results do not entirely support this interpretation, as they better reflect the sensibility of the Someşu Mic River to post-Little Ice Age decadal and centennial climatic changes: (1) channel lengthening and meander development during hydrological stable periods and channel shortening and increasing of natural cutoffs during periods with higher incidence of floods (decadal scale) (Figures 10a, 10b, 10d, 10e, 10f and 11); (2) the incapacity of local morphologic changes resulted from human interventions (channel straightening, incision or widening) to completely counterbalance the general trends (Figures 11 and 12), even during the period of intensive hydrotechnical works (decadal scale); (3) a generalized maintenance of the river in the floodplain perimeter during the entire interval of study (centennial scale), with local planform adjustments and lack of median-scale avulsion in lateral tilting areas and along the anabranched reaches, behaviour which supports the idea of decreasing of amplitude and frequency of important floods, after the end of the Little Ice Age.

From this viewpoint, the reduced amplitude of planform changes after 1884 and the general narrowing tendency (Figure 10) is interpreted as the result of the general climatic and hydrologic stabilization following the end of the Little Ice Age, in accordance with Rumsby and Macklin (1996a) and Starkel (2002). Also, the strong channel planform changes between 1860 and 1884 (Figures 10a–10e) can be attributed to the transition time from Little Ice Age to the new climatic and hydrological condition, as also suggested by Rumsby and Macklin (1996a, 1996b). This relatively short phase (years to decades) will correspond to the period of riparian vegetation stabilization after the previous period of intense flooding (Liébault and Piégay, 2001), a stabilization that is determined by natural conditions (vegetation changes lagging climatic changes by a few decades – Knox, 1983), rather than human induced reforestation (this phenomenon is not reported in this area). Therefore, we suppose that during bank re-vegetation and reduced incidence of flooding, the lateral migration of the channels is more noticeable, as (1) the banks lack any protective vegetation and (2) floods will not lead to meander cutoff. Further, this combination of reduced vegetation and lower incidence of floods can also explain the reduced rate of channel narrowing, which will accelerate in the next interval (post-1884), once the riparian vegetation is stabilized and banks are more protected. However, it must be noted that the reference years used in this study, induced by the time of mapping, do not necessarily capture the 20–30 year long cycles of climatic and hydrologic variability suggested by several authors (Probst and Tardy, 1987; Rumsby and Macklin, 1996b; Kern *et al.*, 2009). We consider that our data mostly capture the strongest climatic signal in these cycles, e.g. the period of reduced floods frequency between 1863 and 1875 (a dry period, followed by a more humid one between 1876 and 1882), and that of enhanced flood frequency between 1911 and 1941 (recorded before the European drought of 1942 to 1956).

Following these ideas, before 1983, even if there are clear evidences of high direct and indirect human pressure on the Someşu Mic River, climate (with influence on amplitude and frequency of floods) seems to be the main controlling factor, while the anthropogenic control is subordinated to it. Since 1983, the hydrological stable period, induced mainly by the Beliş–Fântânele Reservoir, favoured local scale lateral planform activity along the Someşu Mic River, preferentially downstream from Apahida, and channel narrowing and incision, at least along the first tens of kilometres of the river. Because these processes are not capable of counteracting the general tendencies of the main channel's morphometric parameters, it results in the anthropogenic impact being subordinated to climate, even if now it is more accentuated and seems to surpass in a large measure the role of local geological controls. The precedence of climate as controlling factor can be also a consequence of the existence of a higher general slope (Figure 1c), which probably force the positioning of human impact under an important internal threshold of the fluvial system, and makes more visible the effects of natural controls. Confirmation of this model needs additional data and also more detailed analyses on mechanisms of spatial and temporal river reactions to natural and anthropogenic controls, acting both at drainage basin and local level.

Conclusions

This paper presents the first results on the study of the historical evolution of the Someşu Mic River, Romania, based mainly on successive sets of cartographic maps and field survey data. The Someşu Mic River is an atypical example of historical channel evolution. Its particularities are given by local geological conditions and a slightly higher general slope, imposed by a 400 m high knick-point located upstream from the study area. Spatial and temporal behaviour of the channel's main morphometric parameters suggests that these two natural controls, acting as boundary conditions at historical scale, are responsible for a better separation of natural and anthropogenic ones on the river behaviour. Climate, with its centennial and decadal variations, seems to be the main controlling factor, while human impact is subordinated to it. The similarity between the historic behaviour of this river with many other rivers from Europe, consisting in a tendency of narrowing and incision and higher planform stability during the last 150 years, could suggest that the role of climate in river spatial and temporal changes at a regional scale is more important than presently accepted. Further studies are necessary, where the role of each controlling factor must be analysed in more detail and over a longer time period.

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