## FLUVIAL GEOMORPHOSITES – INTERDISCIPLINARY AND APPLIED APPROACH

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#### Abstact

The term fluvial geomorphosites refers to the sites that result from the river bed dynamics and they are investigated by hydrogeomorphologic methods. The rocks and their evolution stage reflect and influence the duration of fluvial geomorphosites. That is why an important criterion for the selection would be the ratio of time and area of their genesis and existence. Most of fluvial geomorphosites have a short existence, because of the occurrence of flash floods. The interdisciplinary analysis of the fluvial and/or torrential river bed dynamics as well as the identification / selection of fluvial geomorphosites have in view: the river bed (geomorphology), the river drainage (hydrology) as well as the factors, which influence the river bed / fluvial landscape dynamics. The main elements which have to be followed in the interdisciplinary analysis of fluviatile or torrential riverbed dynamic in order to identify fluvial geomorphosites are: the riverbed relief (geomorphology; river discharge (hydrology) and generating; the factors that influence the river bed dynamic/ the fluviatile landscape.

Generally, the fluvial geomorphosites correspond to hydrogeomorphological landscapes in which singular/isolated forms/geosites or groups of geosites can be distinguished.

Case study: the Danube Gorges is a complex fluvial geomorphosite .

The study is partially integrated in the digital platform on geomorphosites. This e-learning device was initiated and developed by the University of Lausanne, Switzerland (Emmanuel Reynard, director, Luci Darbellay) in collaboration with five universities: University of Modena and Reggio Emilia, Italy (Paola Coratza), University of Savoie, France (Fabien Hobléa and Nathalie Cayla), University of Minho, Portugal (Paulo Pereira), University of Bucharest, Romania (Laura Comanescu and Florina Grecu), University of Paris IV – Sorbonne, France (Christian Giusti). The course, developed with the Learning Management System Moodle, is a completely free-access course. It is divided into four parts: (1) Generalities; (2) Methods; (3) Conservation and promotion; (4) Examples.

Keywords: fluvial geomorphosites, geomorphologic dynamic, Danube Gorges, e-learnig

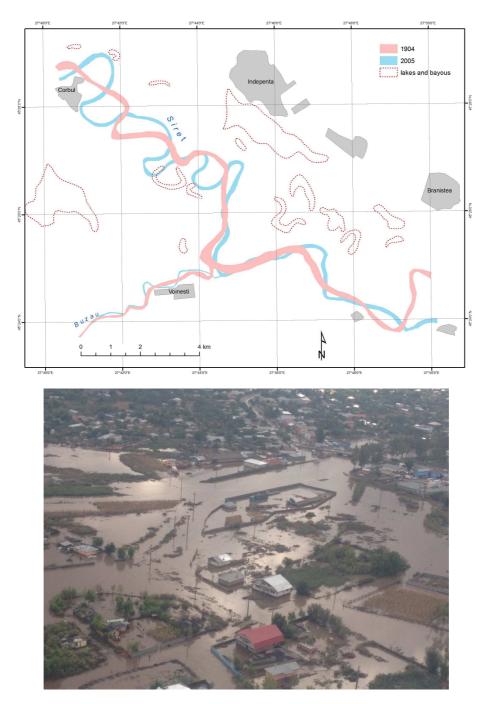
## 1. Concept, definition, scientific values

The concept of fluviatile geomorphosite, come out in the general context of defining geosites for their valuable forms of relief (Panizza, Piacente, 1993), represents the geomorphosite respectively the form of relief resulting from

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fluviatile processes and which generates a social interest (Panizza 2001). Etimologically, the fluviatile geomorphosites are those forms generated by rivers through phenomena of errosion, transport and accumulation, which have a particular scientific importance and value coming from social usage (cultural, ecologic, economic Panizza & Piacente, 1993; Reynard 2004), especially due to their spectacular and esthetic character (Wiederkehr *et al.*, 2010).

However, the content of the term is much more complex if taking into consideration the role of the terrestrial surface (relief) characteristics to which one might add the reduced length of the riverbed forms caused by the water dynamics with a maximum efficiency during floods. Therefore, there is a general incertitude for including these forms into the geosites category because of their reduced period of existence and so for considering them as disappeared geosites (Sellier, 2010). The rock and the evolutive stage of fluviatile forms are important factors if reffered to in a longer period of time (e.g. the gorges formed on limestones, the cut-off lobe hillocks as a stage in meanders evolution or some flood plains, terraces). In this way, the notion of geomorphosite reflects more correctly the genetic content of the sites resulted from the riverbed dynamics, and the investigation method is the hydrogeomorphologic one dominantly as it has been developed in the last decades (Kondolf & Piegay, 2003; Arnaud-Fassetta & Fort, 2004; Malavoi & Bravard, 2010; Ballais et al. 2011; Demers et al., 2014), in parallel with the researches on geosites. The high floods and the floods are a major factor of the hydrogeomorphologic dynamics which modifies the riverbed morphography and morphometry in horizontal and longitudinal profile. During the high flashfloods on the background of huge liquid and solid volumes transported by rivers, the errosion and accumulation processes intensify, generating important and generally rapid changes of both riverbeds and flood plains (Fig. 1).



 $\label{eq:Fig.1} \textit{Fig. 1.} \ \text{The Buzau-Siret confluence-a geosite with exceptional} \\ \text{vulnerability to flash floods}$ 

The researches made in the last two and three decades demonstrated the importance of such researches in the field of the natural hazards and risks. In this context, the actual studies are (and must be) concentrated on the interdisciplinary and applied approaches.

## 2. Additional values

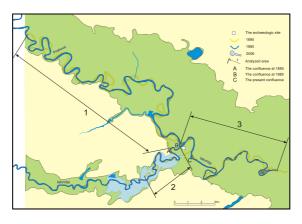
Regarding the social usage, this applies to sites with esthetic fluviatile landscapes, given either by vegetation or by rock (Wiederkehr et al., 2010). The esthetic attribute given by the vegetation and/or rock type imprint an ecological value to the hydrogeomorphosite which can be valued in tourism. The Danube Gorges, as a complex hydrogeomorphosite created by the river has also a significant ecological and economic/touristic value offered by its bio-geographic characteristics and its petrographic variety. The hydrogeomorphosites as well as some slope geomorphologic sites (landslides, surface erosion) have a great educational and didactic value, representing real field experiments with a strong dynamics. The cultural attribute is given by the possibility of cultural sites formation and development and less by the hydrogeomorphosite itself. The central fluvial islands on the Danube preserve ancient archaeological vestiges as along the major water courses an entire river-related civilization developed, as a proof being the archaeological sites (Dridu - Fig. 2). In this context, the archological sites in the riverbed and on the terasses gives more value tot those reliefs. Those elements can be considered fluvial geomorfosites.

## 3. Management

## 3.1. Identify, inventory and evaluation

The main elements which have to be followed in the interdisciplinary analysis of fluviatile or torrential riverbed dynamic in order to identify hydrogeomorphosites are:

- the riverbed relief (geomorphology): the riverbed and the flood plain, processes and forms of errosion (vertical and lateral), forms of accummulation (point bars, levees, central islands, alluvial fans), types of river beds, the width of the riverbed and of the flood plain; terrases; the slope in logitudinal profile; the horizontal profile (Grecu, Palmentola, 2003) (Fig. 2);
- river discharge (hydrology) and generating factors: liquid discharge, solid discharge, levels, flow velocity; characteristics of precipitations as the main source of river supply (quantity, duration and intensity, antecedent precipitations);



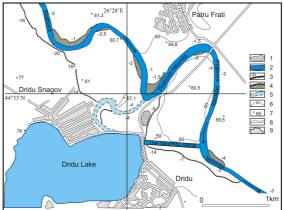




Fig. 2. Ialomița and Prahova floodplain morphodynamics in the subsidence area and Dridu archaeological site risk exposure. (Grecu *et al.*, 2009)

A. Floodplain morphodynamics in over 100 years; B. Geomorphologic map;

1 = Archeological site; 2 = river channel; 3 = cliff; 4 = bank; 5 = Abandoned channel; 6 = contour level; 7 = Elevation; 8 = Road; 9 = Settlement;

C. Location of the site within the inundation area in September 2005

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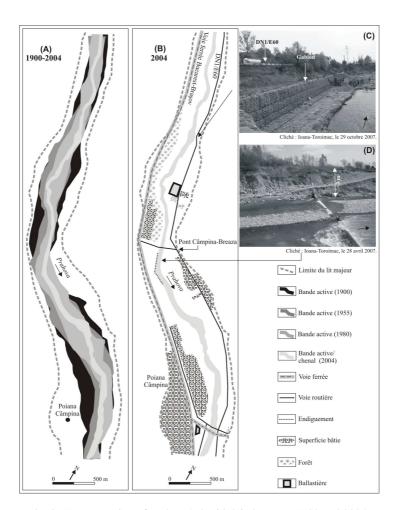


Fig. 3. (A) Narrowing of Prahova's braidplain between 1900 and 2004;
(B) Land-use of the Subcarpathians' bottom Prahova's valley in 2004;
(C) Gabion protection on the left bank of Prahova River;
(D) Prahova's channel incision in the Subcarpathians (Ioana-Toroimac *et al.*, 2010)

• the factors that influence the river bed dynamic/ the fluviatile landscape: natural (geologic, geomorphologic, hydroclimatic, biopedogeographic) and human (hydrotechnic planning, land use, the exploitation of riverbed sediments etc.).

The hydrogeomorphosites analysis, identification and sellection takes into account their scale (Giusti, Calvet, 2010). There is a strong relationship among the morphometric dimensions of the studied area, the characteristics of the major relief and the inventory of fluviale geosites, respectively their mapping (Regolini, 2012; Martin, 2013).

In broad terms the forms of torrential organisms would enter as well the fluviatile geosites category, if accepting the idea of fluviatile landscape in which the geomorphologic elements often appear scattered (Regolini, 2012). The temporal relation (persistence/ length; activ-inactiv processes/formes) of a site has to be a criterion of selection and evaluation for fluviatile geomorphosites. The reconstruction of disappeared fluviatile geomorphosites imposes the usage of some complex paleogeographic methods (Reynard *et al.*, 2011 a, b).

Generally, the fluviale geomorphosites create hydrogeomorphological ladscapes in which singular/isolated forms/geosites or groups of geosites individualize. In the case of complex fluviatile geomorphosites in which the water/river has the role of creating the site, geodiversity imposes itself through the occurrence of some singular geosites created by local favorability (petrographic, structural, climatic, ecologic, pedologic) factors (for example the Danube Gorges). The geodiversity index emphasizes the degree of complexity and the additional values of the fluviale geosites. It results from here the necessity of using the multicriterial method in obtaining the inventory and the evaluation of fluviale geomorphosites

## 3.2. Vulnerability and protection

The vulnerability of hydrogeomorphosites to natural and antropic hazards has in view both individual (central islands, meanders, waterfalls...) and complex geosites characterized through geodiversity (defilees, gorges, special bio-pedo-geographic areas from the river flood plain and terraces, etc.). Hazard type and also the degree of vunerability depend on the major relief form in which the valley/channel is incised. The most vulnerable are the hydrogeomorphosites from the quaternary alluvial or fluvio-lacustrine plains where the processes of lateral erosion and accumulation are active due to the reduced slope and to the geological layer formed by relatively low resistant rocks (loess, sands, gravels, etc.). An important role in the diminuation of the hydrogeomorphological processes/hazards is that of the vulnerability maps which are qualitative maps elaborated on the basis of some quantitative indices/paraeters. The criteria of the map elaboration result from the predominant type of hazard and their intensity depends on the scale of work (Grecu et al., 2013a)

The fluviatle geomorphosites protection is based on the vulnerability map to geomorphologic hazards of the (single) hydrogeomorphosite or of the territory in which complex hydrogeomorphosites are included. The intensity of vulnerability draws attention to the danger to which the geosite is exposed, especially when talking about medium, high and very high degrees of vulnerability. The protection includes legislative measures, prevention and

combat of hazard, protection from socio-economic activities and from hazards agression by inscribing into landscape conservation and recreation, at different and correspondent levels (national/regional, global; Joks Janssen and Luuk Knippenberg 2012). All these protection measures take into account the specific of the hydrogeomorphosites resulted from the intercausal interaction between water and land surface.

## 3.3. Valorisation

The valorisation methods and measures apply differentiated depending on the place of the fluvial geomorphosite in different categories, as follows:

- fluvial geomorphosites formed in soft rocks from plain units: meanders, cut-off lobe hillocks, point bars, islands; in this case, the valorisation is first of all scientific and educational; the use of field experiment and of the diachronic method allows the determination of the short-term or long-term dynamics and evolution of the fluvial geomorphosit;
- fluvial geomorphosites formed in hard rocks, specific to the mountain regions: waterfalls (*Fig. 4*), gorges, defilees etc.; the valorisation is touristic and it's made through panels and directions with scientific and touristic content;
- complex fluvial geomorphosites, characterized through geodiversity, especially ecological (humid areas, flora and fauna, vegetation); the valorisation is complex scientific, touristic, economical.



Fig. 4. Putna waterfall

# 4. Case study: The Danube Gorges-the complex fluviale geomorphosite/ hydrogeomorphosite

## 4.1. The area of study

The Danube Gorges are situated in the south-west on Romania (*Fig. 5*). The gorges formed here by the Danube are the most extended in Europe, measuring a length of 135 km. Our study area comprises about 115 000 hectares distributed within two counties: Caraş-Severin and Mehedinţi (the south-west national micro-region). The southern limit is the Danube itself, which builds the frontier between Romania and Serbia. The northern limit is drawn by the highest peaks of the nearby mountains.

The region corresponds to Almăj and Locva mountains, the two mountain systems that form the southern part of the Western Carpathians, called the Banat Mountains. Downstream, there are the Danube floodplain and the Mehedinți plateau. The western and eastern limits are two localities: Baziaş (at the Danube entrance on Romanian territory) and Drobeta Turnu-Severin, at the exit of the Danube from the gorges, respectively. They are part of the Natural Parc Porțile de Fier.

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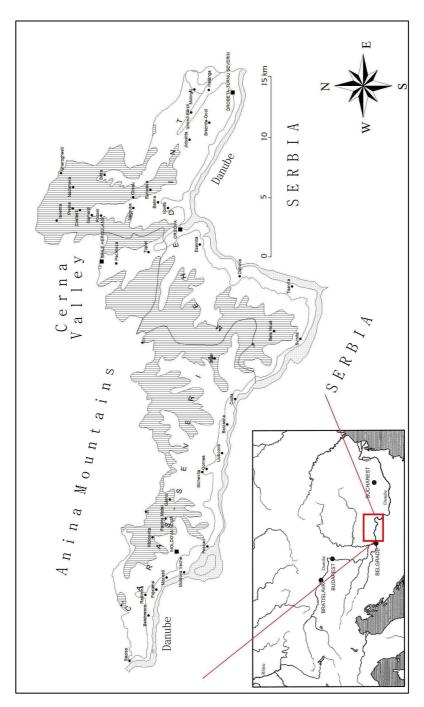


Fig.~5.~The~localization~of~Danube~Gorges~in~Romania. A very important region in the south-eastern Europe, from a geologic and geomorphologic perspective

# 4.2. The scientific and additional values. Hydro-geomorphologic approach (Grecu, Iosif 2014a)

The existence of calcareous, crystalline rocks or of soft sedimentary formations, in other words the variety of lithologic elements, corroborated with the presence of different tectonic faults have imprinted the specific general traits of the relief. In these circumstances, we can divide the Danube valley in several sectors, following their morpho-graphic characteristics.

- From Baziaş to Pescari, over a distance of 35 km there is a transition region, flanked by two large structural units, the crystalline of the Locva mountains on the left side of the Danube and the Dobrianske Planina and Komolske Planina mountains on the right side of the Danube (*Fig.* 7, section I). The morphologic evolution of the danubian valley in this sector is connected with the existence of a pre-quaternary bay of peri-carpathic type (the Moldova Nouă bay). In this sector, the valley has a maximum length of 1500 m. The low slope and the input of solid materials formed a series of islands which are now covered by the lake's waters. The only emerged island is Moldova Veche (of about 4 km long and with a maximum altitude of 103 m in Hunca mound).
- From Pescari to the confluence with Cameniţa river, the danubian valley exhibits very steep slopes that can reach 90° (Fig. 7, section II). Is the sector where the proper gorges of he Danube start. Over its 15 km length, the valley is cut in Jurassic and cretaceous limestones, in Sicheviţa and in crystalline schists and it form the first section of the gorges.
- Between Cameniţa and Greben, the Danube crosses the post-tectonic Liubcova or Sicheviţa depression (18 km length) built on the Miocene formations, where the valley presents an asymmetric profile (*Fig. 7*, section III). Next, there is the second section of the gorges, between Berzasca and Greben, sculpted in Jurassic limestones, cretaceous marls and marble-limestones, Permian conglomerates and sandstones.



Fig. 6. The Danube's geosite - entrance of the Danube in the Large Cazanes

The slopes are steep, with a height of 450 m and the valley has a length of 220 m. Here, there are suspended synclinals, subsequent, consequent and transversal valleys. The amplitude of the relief is high, a fact that determines the occurrence of landslides with consequences over human activities and ecosystem.

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- The Danube valley becomes larger immediately downstream because it enters in the Milanovac basin (after the name of the Serbian town situated here Donji Milanovac Fig. 7, section IV). In this depression developed on its right bank, the Danube takes a large curve and its valley attains 1800 in width. The valley is cut in rocks with different lithological structures Jurassic limestones, Permian clay and sandstone molasses, Triassic limestones. Here, we can find cuestas, structural surfaces, subsequent valleys.
- The most spectacular section of the Danube is comprised between the Iuti valley and the Orsova-Bahna depression (Fig. 7, section V). This sector is known under the name Cazane and encloses the most beautiful gorges on the entire course of the Danube. The Cazanes situated between Plavişeviţa and Ogradena are separated in two by the Dubova basin. Thus we can speak of two regions of the gorges, separated by a depression filled with the waters of the dam, forming a picturesque bay. The Large Cazanes (Fig. 6) are flanked by the Ciucaru Mare (318 m, on the Romanian bank) and Veliki Strbac (768 m, on the Serbian bank) mountain massifs; their length is of 3.8 km and the width does not surpass 200 m. The Ciucaru Mare, calcareous, presents a very steep slope towards the river (almost 90°) and its top is a plateau with calcareous microforms (dollines, uvales, suspended passages). If on the Serbian bank the cretaceous limestone is continuous from Veliki Strbac to Mali Strbac, on the Romanian bank the Miocene basin of Dubova with a mean altitude of 60 m interposes in the calcareous rock mass. This basin is not a large one: 2.3 km long and 1.2 km width. Downstream, between the chalks of Ciucaru Mic (313 m) and Mali Strbac, there are the Small Cazanes – gorges that continue the precedent general traits: steep and straight slopes.
- After these river gorges, the valley enlarges once again because of the presence of Orşova-Bahna basin, which is modeled in softer rocks (Fig. 7, section VI). At the confluence with Cerna valley, after the construction of the dam, a spectacular bay developed at the foot of the Orşova town. Before the construction of the dam, the Danube's valley presented here an island inhabited by Turkish (a true oriental corner), Ada Kaleh, formed mainly by the materials transported by Cerna river. The small slope of the bank allowed the construction of numerous summer houses, mainly in the last two decades.

• From Bahna to Turnu-Severin, the valley of the Danube becomes tight for the last time (*Fig.* 7 VII). We speak of a 9km section between Vârciorova and Gura Văii. The slopes are steep and well covered by forests. The Danube has dug the Sebeş crystalline and the autochthonous Severin cretaceous formations, specific for the Mehedinți Mountains and plateau. The slope of the walls varies between 3 and 30° (Grecu, Carablaisă *et al.*, 2012).

## 4.3. Valorisation, protection

The Danube's Gorges, created by the Danube in its pre-quaternary and quaternary evolution represents a hydro-geomorphosite given by the genetic elements and by the landscap of its longitudinal profile (*Fig. 7*). Within the Gorges, there are also variated geosites of different genesis but significant through their scientific, economic, touristic and patrimonial value. They are part of the Natural Park Porţile de Fier, and Iron Gate I Hydropower System (after 1971).

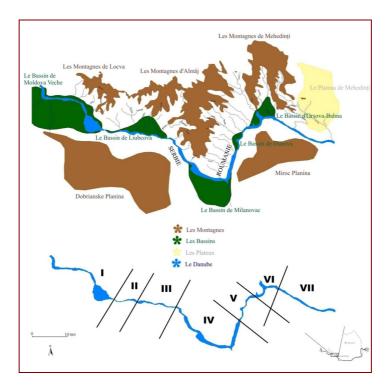


Fig. 7. The main relief units around the danubian valley (up). The seven valley sectors according to the description (down) (Iosif 2014)





Fig. 8. Landslides which affected the national road (left) and the slope protection works (right) in Liubotina – Danube Gorge





Fig. 9. The effect of flash floods from october 2014 in the riverbed of Eselnita. River within the Danube Gorge

The Iron Gate Reservoir is used for different purposes: production of electrical power, regularisatin of the Danube's flow, fisching, navigation, leisure, and habitat for aquatic birds.

In this sense, a few aspects to reflect on should be pointed out (Grecu, Iosif, 2014 a):

- Highlighting the most important geologic and hydro-geomorphologic elements. The geologic and geomorphologic patrimonies of this region are not at all highlighted as they should be. We will build a database with the most representative geosites of this region. This database can be used by the local authorities during the implementation of different development projects (Iosif, 2014).
- *Territorial landuse improvement*. A database for the improvement of territorial landuse should result from a more exhaustive inventory.
- *Geo-touristic capitalization*. An analysis of the geosites from a touristic point of view, considering the exposure to touristic fluxes.

• *The protection of hydro-geomorphologic patrimony*. Establishment of potential degradations of the geotop and the sustainable protection measures (*Fig. 8, 9*).

#### 5. Conclusions

Fluviatile geomorphosites should not be confounded with hydrologic geomorphosites. The specific of fluviatile geomorphosites consists in the interdependence relation between the river bed relief and the characteristics of water dynamics (*Fig. 4*). That is why most of the geosites do not resist in time; they can be reconstituted through paleogeographic methods (Reynard *et al.*, 2011b).

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