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# Danube valley geological structure, neotectonic activity and evolution during the Pliocene-Pleistocene time

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# THE LOWER DANUBE VALLEY. GEOLOGICAL STRUCTURE AND EVOLUTION DURING THE PLIOCENE-QUATERNARY

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**Abstract:** Stratigraphical and geophysical arguments are put forward, whereby that the beginning of sediments deposition by the Lower Danube and by its tributaries date back to the Upper Pliocene (2.6 Ma) and go up to and into the Lower Pleistocene. During the interval of 2.5-0.9 My, the Danube kept branching out gradually towards the east of the Dacian Basin. Concomitant, a number of intensely flooded low plains developed within the actual Romanian Plain as part of the Lower Danube Basin. Subsequently, during the Middle Pleistocene-Holocene, the Danube River cut the actual profile of the Valley. As a result, the higher relief of the Romanian Plain led to repeated down-cuttings of the 7 (8) stepped terraces. In the eastern half of the Lower Danube Valley, against the background of a mainly subsiding behaviour of the Platform, the upfinning sequences of the 7 terraces were progressively overlayed by the Aeolian Formation (up to 55 m thick). On the Black Sea continental shelf, within the Danube roughly 150 km long deep sea fan, there have been identified 8 seismic sequences, the first two with mass flow deposits, and the other six with alluvial channel fills. They have been ascribed, in accordance with their order of deposition, the indices S1...S8 (Winguth et al., 1997).The S1 sequence may be ascribed to the 800–700 ka interval, and the S2 sequence to the 640–530 ka interval. According to Wong *et al*. (1997), the approximate intervals of deposition of the last six alluvial sequences are: S3 between 480–400 ka, S4 between 400–320 ka, S5 between 320–190 ka, S6 between 190–75 ka, S7 between 75–25 ka and S8 during the last 25 ka.

**Keywords**: Romania, Danube, Pliocene, Quaternary, stratigraphy, paleogeography.

## 1. Introduction

In terms of length, the Danube River, ca 2857 km, occupies the second place in Europe after the Volga, ca 3688 km, but, because it connects ten countries and flows through four capitals: Vienna, Bratislava, Budapest and Belgrade, it ranks first from an economic and political point of view. From a geographical perspective, the Danube Basin Network is divided in three; the Upper between its springs (the Black Forest Mountains) and the Passau Passage; the Middle, between above-mentioned point and the watershed of the SW Carpathians (the Iron Gate Passage, Djerdap Gorge), and the Lower Basin which extends from the above-mentioned area to the Black Sea. The main feature of the Lower Danube Basin relief is a W-E decreasing elevation. So, on the eastern slope of the Southwestern Carpathians (Fig.1), the relief has moderate elevation values of elevations (currently around 700 m). Eastwards, the next radial-converging rim is formed of the Prebalkan, the Mироć and the Getic Tablelands, 700 - 300 m altitude. The last one, the Romanian Plain, with altitudes decreasing from west to east, includes three strips: a High Plain (300-160 m altitude), the Danube Valley: having till 7 terraces, 160-35 m high and a large Floodplain, 40 – 5 m a.s.l.

## 2. Material and Methods

The paper tackles the Stratigraphy and, relying on it, the Geological Evolution of the Lower Danube Basin during the Pliocene-Quaternary. In order to solve the first item, the outcrops existing in the Upper Miocene-Holocene formations on the eastern slope of the SW Carpathians, the Getic Tableland and the western third of the Romanian Plain were studied and sampled out between 1983 and 2000. Beside the two main dating criteria: mollusks biozones and the paleomagnetism of rocks, the fossil micro-mammalia have also been studied (Enciu, 2009). These three categories are major proofs, usually taken into account for dating continental deposits, which were used also to delimit the main four geological formations. Besides the outcrops, the cores of 87 continuous-coring mechanical wells, with depths of 250-375 m and 222 samples of rocks and 99 samples of macrofauna were looked into as well (Enciu, 2009).

We have analyzed the lithology, thickness and geometry of rock-bodies on differently-orientated sections through the wells, boundaries of sequences, well log responses a. o. for the four Pliocene-Quaternary formations.

trian, Slovak and Hungarian researchers for the Little Alföld region, i.e. that part of the median Danube catchment area extending between Vienna, Bratislava and Esztergom (Janacek, 1969; Haloużka, 1975; Pecsi et al., 1985, Scharek et al., 2000, Krstić et al., 2004). In the Quaternary series eight distinct terraces have been identified in the higher elevated areas, while in the prevailing sub-

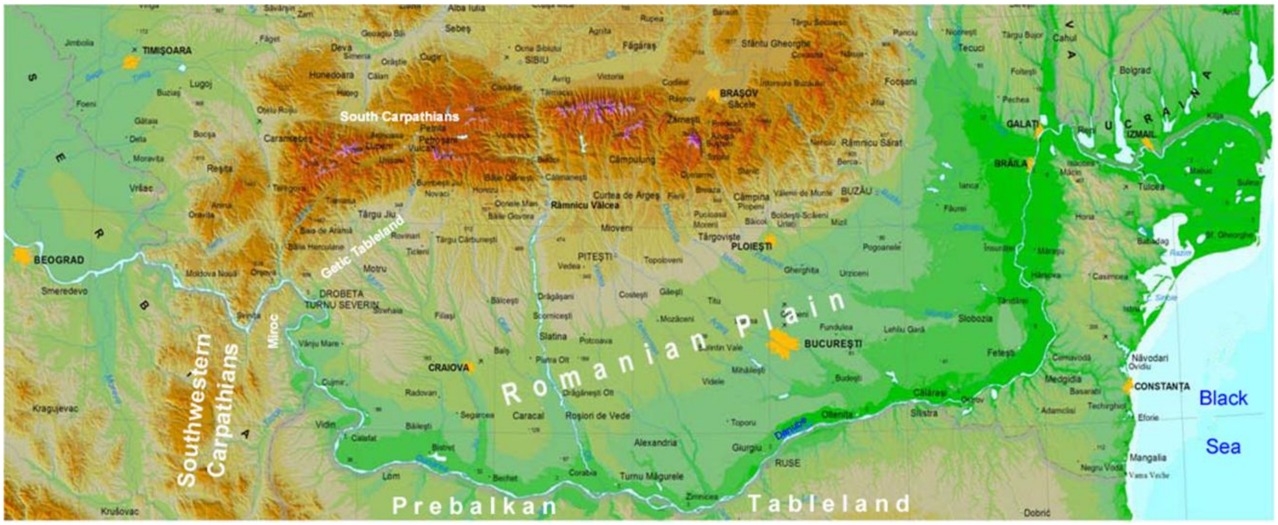


Fig.1 – Physic-Geographical Map of the Lower Danube Basin.

The second topic of this paper seams to harmonize geological hypotheses concerning the Lower Danube Valley modelling (cutting) during the Pliocene and the Quaternary. To this end, the author's own data have corroborated the information provided by the Serbian and Bulgarian researchers' papers about righthandside of the Danube Valley. Information on the mentioned side was published in the sheets of the Geological Map of Serbia on scale of 1:100 000. For the same purpose, the "Bregovo", "Vidin", "Lom" and "Kozlodui" sheets of the Geological Map of Bulgaria on the scale 1:100 000 were also used. The Geological Map of the lefthandside (Romanian area) was integrated with the righthandside ones, Bulgarian and Serbian, on the scale of 1 : 100 000 (Fig. 2).

### *A short review of previous studies about Pliocene-Quaternary formations in the Middle Danube Valley*

**1**. Since the 20th century, geologists have identified on their national territories (Vienna Basin, Little Alföld, Great Alföld a.o.) the remnants of the Danube Formation. It was firstly, defined in 1938 by Szadeczky-Kardoss in his geological monograph on a large area of the Pannonian Basin. Later on, the Danube Formation concept was used by Austrian...

siding areas it was the Danube Series with two complexes that was singled out.

*The Danube Series Lower Complex*, going down to the depth of 200–300 m, includes deposits belonging to the Danube and to its tributaries (fine and medium-graded gravel). Considering its petrographic content, the Lower Complex was correlated with the first three terraces of the Danube in Austria: Laaerberg ($t_8$), Wienerberg ($t_7$) and Arsenal ($t_6$). It contains fresh water mollusks and has been ascribed to the Final Romanian (?) – Early Pleistocene (Szadeczky-Kardoss, 1938; Halouzka, 1975).

*The Danube Series Upper Complex* occurs within the last 130-150 m depth, in the middle of the depression. It contains alternating gravel and sands, occasionally with lenses of clay or peat coal. In terms of its petrographic content, this complex correlates with the deposits of the last five terraces of the Danube: Seyring $t_5$, Simmering $t_4$, Ganserndorf $t_3$, Stadt $t_2$ and Prater $t_1$.

**2.** Downstream, as a result of investigations into the margin of the Gerećse – Vishegrad Mountains (located to the SE), revealed only seven terrace levels were identified along the middle course of the Danube, ascribed to the time intervals of 2.4 – 2.2 Ma, 1.8 – 1.6 Ma, 1.1 – 0.85 Ma, 0.45 – 0.35 Ma, 0.25 – 0.17 Ma, and 0.10– 0.01 Ma (Fig. 1 in: Scharek et al., 2000).According to recent estimations (Ruszkiczay-Rüdiger, 2007, p 52), the onset of the incision of the Danube is ~ 0.90 Ma, consistently younger than the estimated ~ 2400 ka indicated by the previous scientists.

**3.** In the following, we shall sum up the morphogenetic model of the terraces lying along the Danube in the Southwestern Carpathians. The model was devised by Cvijić in 1908. According to that model, revised by the Rakic, 1977 and Rakić şi Simonović, 1997, one may distinguish in the Danube Gorge the following: the Dacian age of Valley floor at 260–320 m relative altitude (r.a.), the "Šip" terrace $t_7$ at 200–210 m r.a., the "Brza" terrace $t_6$ at 150–160 m r.a., the "Kljuć" terrace $t_5$ at 90–115 m r.a., the "Kosovića" terrace $t_4$ at 60–80 m r.a., the " Turnu" terrace $t_3$ at 30–50 m r.a., the

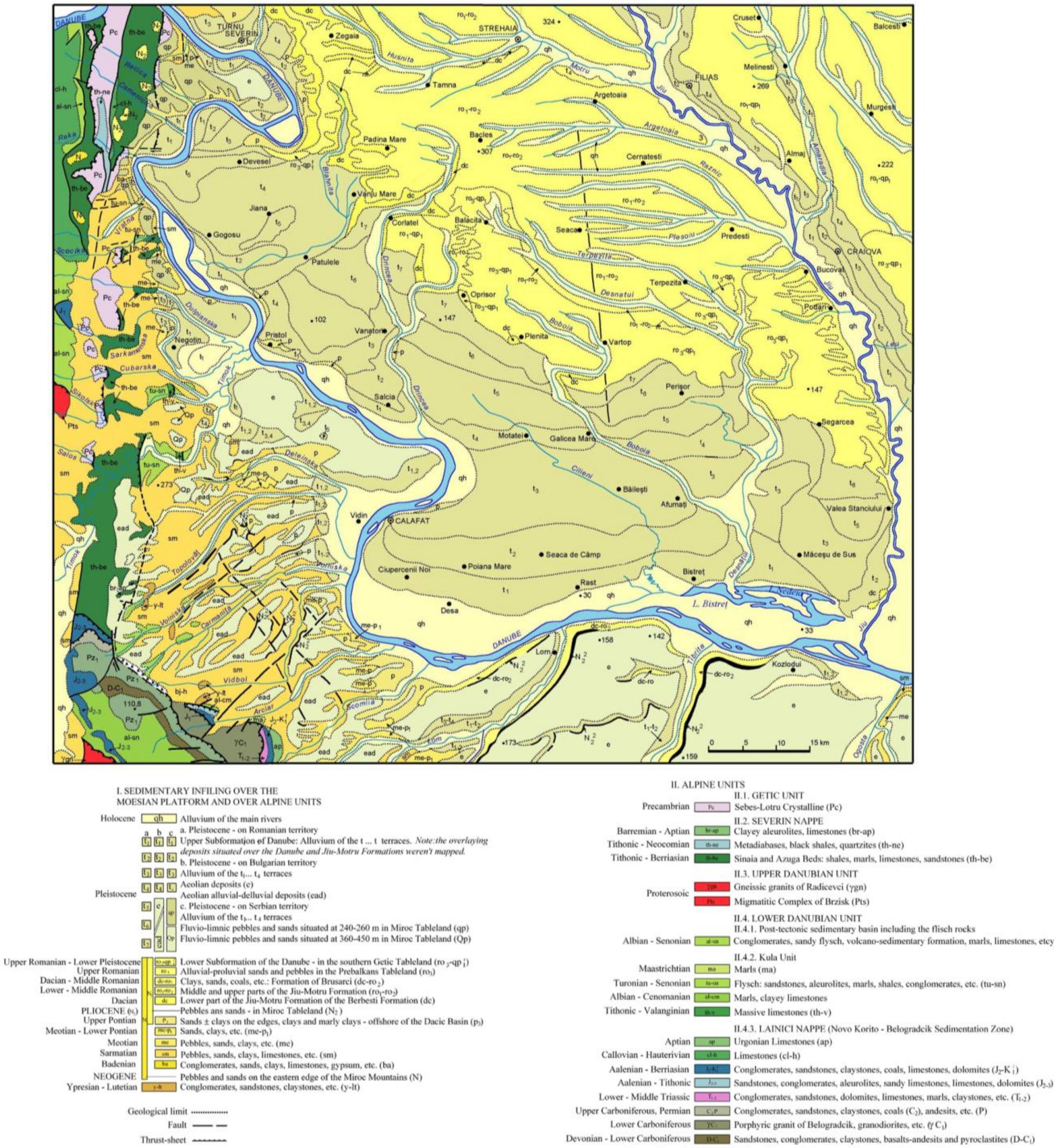


Fig. 2. Geological Map of the western third of the Lower Danube Basin.

″Kladovo” terrace $t_2$ at 10–20 m r.a., and the lower terrace ($t_1$) at 6–8 m r.a.

## 3. The Lower Danube Valley. Results and Discussion

### *3.1. The pre-Pliocene Structural Settings within the Lower Danube Valley*

The Lower Danube Valley ~ 400 km long and ~ 60 km mean width in the W-E and N-S directions, respectively, and the descending average altitude from 170 m in W (Drobeta Turnu Severin) to 20 m in E (Galati City). The Lower Danube Basin is overlying the SW Carpathians (including their Foredeep), the Moesian Platform and in the easternmost part, the North Dobrogea Burried Promontory and the Scythian Platform (Fig.3). The SW Carpathians, just like the whole Carpathian Chain, are allochthonous, coming from SSW, from the Tethysian area. During the Late Cretaceous-Tertiary, these mobile Carpathian units collided with the Moesian Platform's western boundary (Ratschbacher et al., 1993). Owing to the Carpathians' NNE progressive movement and to the corner effect at their contact with the rigid Moesian Platform, the history of the birth of the Lower Danube Valley is governed by the predominantly dextral shearing process along the S-N Poreč-Cerna-Jiu, Timok-Bâlta-Targu Jiu-Calimanesti and other strike-slip crustal faults (Kräuthner şi Krstić, 2002; Tarapoanca 2004). As a result, in the westernmost corner of the Lower Danube Basin, the Foredeep emerged during the Laramie tectonic event (Senonian).

Later on, during the Young Styric tectonic event (Badenian, ca 16 My), the strike-slip processes of the SW Carpathian nappes stack were reactivated. In their median part, over the weak portions, the Zagubica, Kucevo, Rakovo, Krivaco, Liubovca, Donji Milanovač, Bozovici, Orshova and other post-tectonic basins were formed. Usually, for this kind of mutual S-N movement, the magnitude of the SW Carpathians' uplift is in the order of a few hundreds of metres. Laterally, to the east, there is one shallow S-N Foredeep, followed to the east of the Lom Depression (no 2 in Fig.3) by an unequally, progressively, subsiding serie of panels of the Moesian Platform. This cratonic unit (MP) witnessed repeated extensions and warming during the Permian-Triassic, Lutetian, Burdigalian (basanites eruptions), Badenian a.o. (Tarapoanca, 2004).

Starting with the Sarmatian, to east of Intramoesian Fault (fig.3), the main four panels existing in the basement of the Lower Danube Basin were involved in one uneqally SE-NW subsidence, more intense near the Curvature Carpathians Arc as the result of flexural loading (Bertotti et al. 2003). In eastern half of Romanian Plain, some of the paleohydrographic consequences are: the W-E elongation of the Danube Course (Upper Romanian-Lower Pleistocene), the progressive bending of the Danube River from SSE to NNW (between Silistra and Galati) and subsequent flowing in to the Black Sea along the boundary between the North Dobrogea Orogene and the Scythian Platform at the begining of the Middle Pleistocene (Wong et al., 1997).

### *3.2. The Lower Danube Valley during the last sedimentary cycle*

In the western corner of the Lower Danube Valley, the last accretion of mountain slices was therefore most probably Late Badenian, 15-13 Ma to Sarmatian, 13-11 Ma (Sanders, 1999). As a reflex, on the eastern flank of the SW Carpathians, a pile of alluvial fans (few decameters thick), continuing with mini-deltas (sandy) deposits, had been accumulated (Krstić et al., 1997).Then, during the Meotian, the lithofacies was changing from deltas to offshore sandy deposits. The complete infilling of the westernmost part of Dacian Basin is reported to ca 5.5 Ma, with the sands near the edges grades the commonly marly Pontian offshore. The W-E sequential analysis across the margin of Carpathians and its Fore-deep provides constraints both on the last stages of basin filling and on the onset of fluviatile sedimentation related to the development of the paleo-Danube starting with Pontian (Tarapoanca, 2004, fig.3.12).

Starting with the Early Dacian (5,3 Ma.), the communication between the Pannonian and the Dacian basins was reduced to a system of channels and straights along of the post-tectonic Liubcova, Donji Milanovač and Orshova basins. The Dacian Basin became a gulf of the Black Sea. In its westernmost corner, the Lom, the Timok, the Danube and other radial-converging rivers built the sandy, the Berbesti Formation, littoral-lacustrine (Lower Dacian). Then, during the Upper Dacian-Middle Romanian, the Constructive Deltaic Phase was succeded by the Upper Delta Plain and the Floodplain environments (the Jiu Motru Forma-tion):

100-350 m of parasequences with sands, silts, clays, gley paleosoils or 2-9 coal seams.

### 3.3. Danube Formation in the Lower Danube Valley

Around 2.5 Ma. BP, genetically associated to the general cooling of the northern hemisphere and implicitly to the lowering of the Dacian Basin, starting from the western third, the Danube River and its tributaries extended step by step to the central sector and to the east, towards the Black Sea. Besides, the development of the Danube's fluviatile Network was made possible being stimulated by the last uprising of the Southwestern Carpathians and of the associated Foredeep, genetically connected with the Wallachian compressive event of Upper Romanian age.

**a.** In the ***Miroć Tableland,*** three sections belonging to a 20 – 60 m-thick formation of gravel and sands with *Mammuthus meridionalis* have been preserved within a ca. 7 km-long strip occurring at +240– +260 m a.a.. On the Geological Map of Serbia, those deposits have been ascribed to the Pliocene and to the ″Sip" terrace of the Danube (200–210 m r.a.). By taking into account the elevation, lithology and age, they can be correlated with the Lower Danube Formation. Using the Serbian Geological Map 1 : 100 000 (Antonijevic 1975; Bogdanovic et al. 1978a, 1978b a.o), we assigned the small mapped surfaces with Pliocene coarse alluvium ($N_2$) to the Lower Member of the Danube Formation; the Fluviatile-Lacustrine (Qp), the Fluviatile (qp) and the $t_4…t_1$ terrace deposits to the Upper Member (Fig.2, Legend).

**b.** On the same right bank, in the Timok-Ogosta interstream of the **Prebalkan Tableland**, an erosive - accumulative formation, mainly built by the Danube righthand tributaries ($N_2^2$ in Fig. 2) was identified (Filipov et al., 1992; Nikolov and Filipov, 1996). It consists of a 0.5 - 20 m-thick beds of gravels and sands. Still in the Prebalkan Tableland, yet farther east, in the basins of the Vit, Osam and Iantra rivers, relics of a hydrographical network dating from the Pliocene, can be found at a height

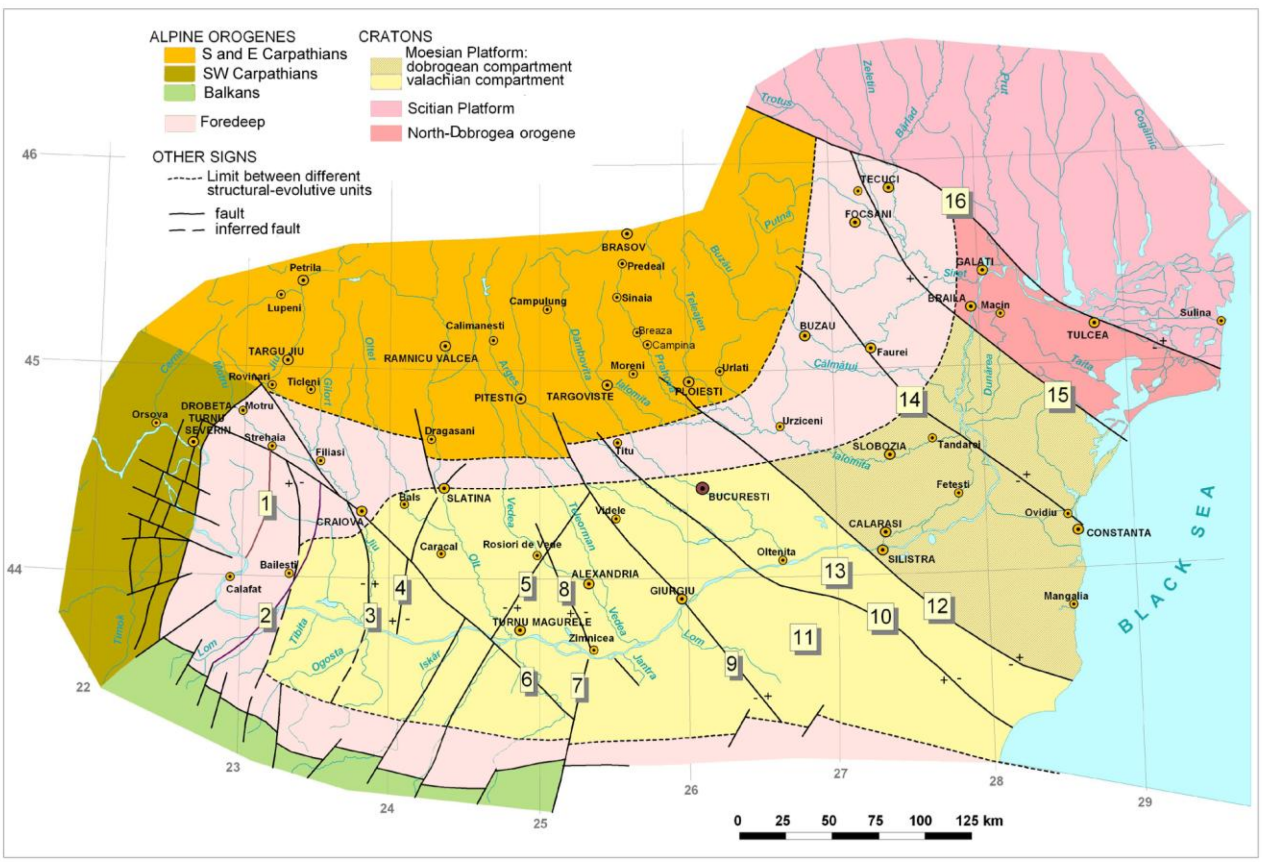

Fig. 3. The main structural elements of the Lower Danube Basin. 1 Strehaia-Vidin uplift; 2 Lom depression; 3 Jiu fault; 4 Campeni fault; 5 Lita fault ;6 Osam fault; 7 „Basalts' fault ; 8. Calmatui fault (Enciu et al., 2001) ; 9 Kubrat-Vetrino fault (Shanov, 2007); 10.Balchik-Dulovo fault (Shanov, 2007); 11. Ludogorie uplift; 12. Intramoesian fault; 13. Tutrakan depression (Shanov, 2007); 14. Capidava-Ovidiu fault; 15. Peceneaga-Camena fault; 16. Trotus-Sfantu Gheorghe fault.

of +190–+200 m. According to Bulgarian researchers, during the Middle Romanian, Danube' righthandside tributaries dissected a roughly 90 m-deep escarpment (Doncev et al.,1985). Subsequently, an ″old abrasive-accumulative horizon" would accumulate on the surface of the escarpment base at roughly 110–100 m r. a. That 7–8 m-thick horizon consists of gravel and sands with *Zygolophodon borsoni, Anancus arvernensis* and *Mammuthus meridionalis* ascribed to the $MN_{17}$ biozone, interval 2.60 – 0.99 Ma, Upper Romanian – Early Pleistocene (Evlogiev *et al*., 1995). In our opinion, this can be reported to the Lower Member of the Danube Formation. Between 0.99 – 0.80 Ma, namely at the end of Early Pleistocene, a formation consisting of mixed clays and gravel accumulated, including relics of cold weather mammalians (*Mammuthus meridionalis, Cervus elaphus* Linne and *Capreolus capreolus* Gray.). The six terraces were shaped during the Middle-Upper Pleistocene (assigned in our opinion to the Upper Member of the Danube Formation).

## c. High Plains as part of the Romanian Plain

On the lefthandside of the Danube Valley, the Danube Formation has two members. ***The Lower Member***, Upper Romanian-Lower Pleistocene (**$ro_3$-$qp_1^1$**), is made up of a flat alluvial fan (Balacița High Plain) that continues to the east with braided streams deposits (Salcuța, Romanati Plains) and with buried, stacked up-fining coarse sequences (Bucharest Plain, a subunit situated in the central part of the Romanian Plain). Using the remnants of the macromammalia found in the elapsed one century within 34 quarries of pebbles and sands (*Anancus arvernensis* Croiset et Jobert, *Mammuthus planifrons* Falconer, *Mammuthus meridionalis* Nesti, *Dicerorhinus etruscus* Falconer) and of the micromammalia (*Mimomys cf. livenzovicus* Alexandrova, *Mimomys pliocaenicus* F.Major, *Mimomys coelodus* Kretzoi , *Kislandia rex* Kormos, *Borsodia langurodontoides* etc), it appears that this prograding process took place during a long interval of time, around one million and a half years, from 2.5 to 1.0 Ma.BP.

The environment of the braided river-type developed against the background of a climate transitional from humid and warm to rather cool. The cumulated surface of the Lower Member of the Danube Formation was around 52 600 $km^2$. In the outcroppings, on the southernmost edge of the High Plains, an increasing W-E elongated strip (5-20 km wide and over 75 km long) is preserved, representing the lateral north remainder of the Lower Member of the Danube Formation. On the northern rim of this W-E prograding band, approximately on the parallel of Craiova City, debris flow deposits (ca 10-15 m thick of clayey-pebbley sheet) were identified.

## d. The Lower Danube Valley

Starting with the second part of the Lower Pleistocene, the Danube began cutting the present profile of its valley. As a result, just the median part of the Lower Member of the Danube Formation was self-evacuated in the Middle-Upper Pleistocene, when the Danube deposited the frontal load in the Black Sea (Wong et al., 1997).Through moulding, the higher relief of the Oltenia Plain ensured repeated down-cutting of the seven stepped terraces. Subsequently, the Danube River deepened in the Dacian-Lower Pleistocene pile, between 160 m deep in the western part of the Lower Danube Valley (Drobeta Turnu Severin City) and 65 m in the central part (Turnu Magurele City). As a result, the higher relief of the Romanian Plain underwent the repeated down-cuttings of the stairway-like seven terraces and the floodplain (Upper Member of the Danube Formation).

The Recent Crustal Displacements Map indicates that structural units in the Romanian Plain basement located eastward of Intramoesian fault valley have been subject mostly to sinking movements. The sinking rates amount to about 0.5 mm/year between the Intramoesian and the Capidava – Ovidiu faults and up to 1–3 mm/year, between Capidava – Ovidiu and Sf. Gheorghe – Galați Faults (Enciu, 2009). As a result of the bedrock subsidence, the first 80–100 m depth-interval includes till 6-8 mature alluvial sequences (rounded gravel, sands with gravel, yellow and speckled clays) alternating ephemeral lacustrine sequences (bitumen clays, peat clays, carbonate clays) of Middle-Late Pleistocene age.

On the Black Sea continental shelf, within the Danube roughly 150 km long deep sea fan, there have been identified 8 seismic sequences (the first two with mass flow deposits, and the other six with alluvial channel fills, levee deposits, overbank sediments and mass slide deposits along canyon paths). They have been ascribed, in accordance with their order of deposition, the indices S1...S8. By correspondence with the Dniestr (Nistru) terraces dating scheme (Musinschi, 1999), the S1 sequence may be ascribed to the 800–700 ka interval, and the S2 sequence to the 640–530 ka interval. By using the preliminary relative sea level curve (Winguth et al., 1997), the approximate intervals of deposition of the last six alluvial sequences are: S3 between 480–400 ka, S4 between 400–320 ka, S5 between 320–190 ka, S6 between 190–75 ka, S7 between 75–25 ka and S8 during the last 25 ka (Wong *et al*. (1997). Returning to the Lower Danube Valley's terraces, one should note the very poorly constrained ages of the Lower Danube Terraces. Supposedly, they are ascribed to the Middle and Upper Pleistocene (Enciu, 2009).

## 4. Conclusions

1.The acceleration of the dextral wrenching of the Carpathian units along the contact with the western edge of the Moesian Platform during the Middle Miocene (Badenian) tectogenetic phase favoured the emergence of Rakovo, Kucevo, Liubovca, Donji Milanovać and Orshova post-tectonic basins within the SW Carpatians and implicitly the connection of the waters of the Pannonian and the Dacian basins through a W-E segmented line of straights and channels, the forerunner of the present Iron Gate Passageway.

2.On the eastern slope of the SW Carpathian ridge, mainly coarse siliciclastic formations were accumulated during the Upper Badenian-Meotian interval and large deltas with dominant prograding seismic facies started developing on the Meotian-Pontian boundary.

3.A sequence analysis of the contact between the SW Carpathian orogene and the Moesian Platform added constraints on the onset of fluviatile sedimentation related to the development of a paleo-Danube. A very dense network of the continuous mechanical corring wells for Lower Pliocene seams of coals (300-400 m deep) made in the westernmost corner of the Lower Danube Valley identified the Gilbert delta of the paleo-Danube Lower Dacian (5.3- 4.6 Ma), containing ca 40 km long and up to 160 m thick monotonous sands.

4. During the Upper Dacian-Middle Romanian, within the western third of the Dacian Basin, the Constructive Deltaic Phase was succeeded by the Upper Delta Plain and Floodplain environments (the Jiu Motru Formation; main mud-filled area of to 300 m parasequences with sands, silts, clays, gley paleosoils or 2-9 coal seams).

5.Climate-controlled changes in the hydrological regime of the Danube Lower Basin induced alternation of erosion and sedimentation cycles.As the result, during the Upper Romanian-Lower Pleistocene, Danube modelled one extensive plain of repeated flooding and have been contributed decisively to the Dacian Basin' infilling (Lower Member of Danube formation). Subsequently, the Danube River deepened in the Dacian-Lower Pleistocene pile, between 160 m deep in the western part of the Lower Danube Valley (Drobeta Turnu Severin City) and 65 m in the central part (Turnu Magurele City). As a result, the higher relief of the Romanian Plain underwent the repeated downcuttings of the stairway-like seven terraces and the floodplain (Upper Member of the Danube Formation). The presented hypothesis about the Lower Danube Valley' evolution is in accordance with the Seismostratigraphy results made on the Black Sea continental shelf along the Danube deep fan.

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