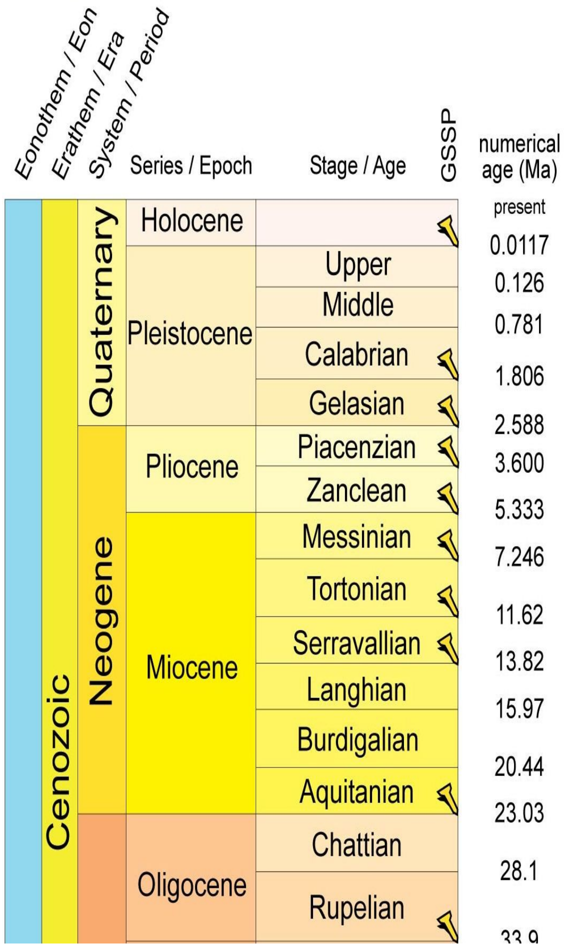
ONE DAY WORKSHOP

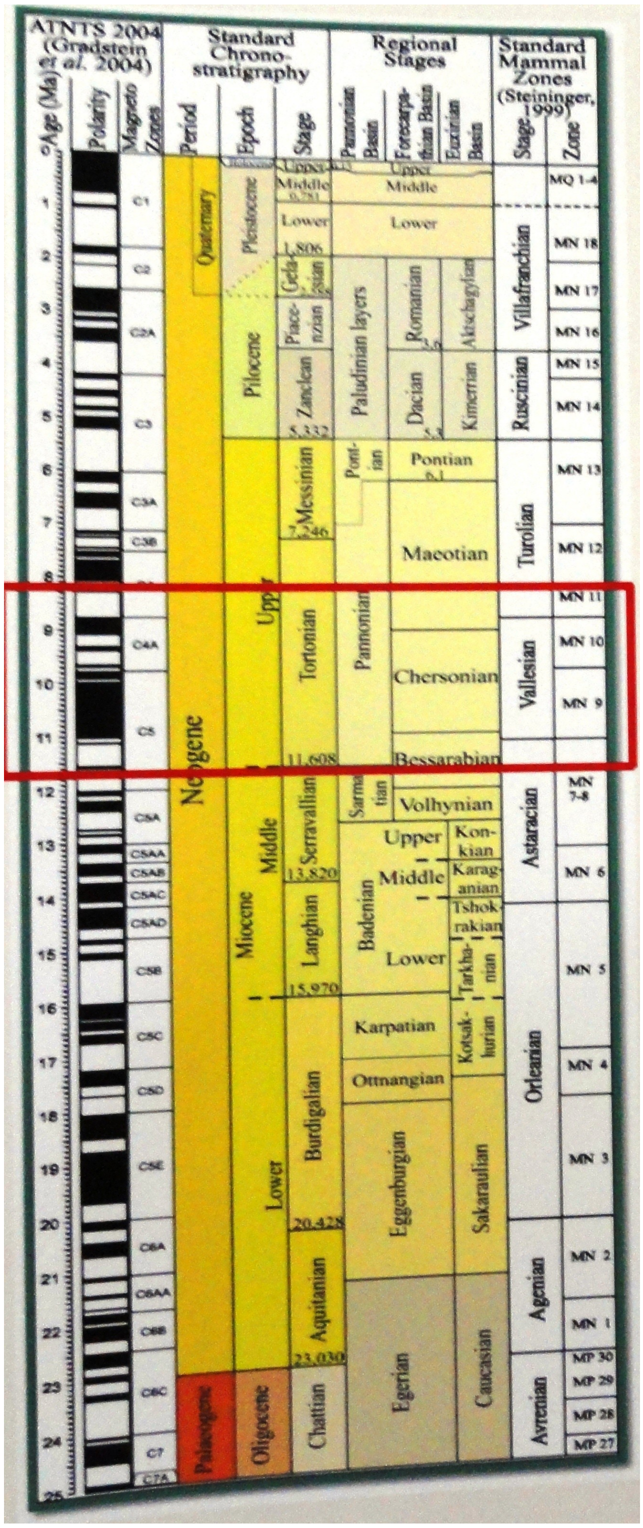
NEOGENE AND QUATERNARY STRATIGRAPHY
ACTUAL TERMINOLOGY AND NOMENCLATURE

Belgrade, September 20, 2013

Programme & Abstracts

SERBIAN GEOLOGICAL SOCIETY
Commission on Neogene
Commission on Quaternary
Stratigraphy, Paleontology and Tectonics Division





Segment of the ICS-IUGS International Chronostratigraphic Chart v2013/1 for the last 33.9 Ma
(source: http://www.stratigraphy.org/ICSchart/ChronostratChart2013-01.pdf)

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Edited by:
Ljupko Rundić
Tivadar Gaudenyi
Mladjen Jovanović

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NEOGENE AND QUATERNARY STRATIGRAPHY

ACTUAL TERMINOLOGY AND NOMENCLATURE

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SERBIAN GEOLOGICAL SOCIETY - Commission on Neogene
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SERBIAN GEOLOGICAL SOCIETY - Stratigraphy, Paleontology and Tectonics Division

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Preface

The workshop "Neogene and Quaternary Stratigraphy - Actual Terminology and Nomenclature" was initiated by the Commissions of Neogene and Quaternary within the Serbian Geological Society.

The last Serbian Geological Congress that held three years ago (2010) was a great platform for gaining collaboration between geoscientists from different institutions (universities, public enterprises and industry, different geological companies, etc.). Simultaneously, the Commission on Quaternary was established and the Commission on Neogene was reactivated. From that time, their main objective was to make a progress in research and encourage collaboration on national and international level.

The workshop is focused on the recent developments and changes in stratigraphy of the last 23 million years of Earth's history. In the last decades, the significant changes of the global and regional terminology and nomenclature of the Neogene and Quaternary were adopted. However, on national level geoscientist from different institutions and disciplines do not used a uniform terminology and nomenclature. Furthermore, very often they use an archaic terms. This approach caused a lot of misunderstanding, wrong interpretations and dissonances.

Therefore, the main goal of the workshop is to make an agreement and recommendation of which stratigraphical terminology and nomenclature to used on national level. In that sense, some suggestions and remarks of colleagues from abroad were deeply appreciated.

We hope that you will enjoy our workshop!

Editors

CONTENTS

Programme 6

Abstracts 7

Ljupko RUNDIĆ:
STRATIGRAPHY OF NEOGENE - STATUS AND PERSPECTIVES IN SERBIA 9

Oleg MANDIC, Arjan de LEEUW, Thomas A. NEUBAUER, Mathias HARZHAUSER, WoutKRIJGSMAN, Klaudia F. KUIPER, Hazim HRVATOVIĆ & Davor PAVELIĆ:
MIOCENE DINARIDE LAKE SYSTEM - STRATIGRAPHIC CONSTRAINS REVEAL ITS ENVIRONMENTAL AND BIOTIC EVOLUTION 12

Sejfudin VRABAC, Zijad FERHATBEGOVIĆ, Izudin ĐULOVIĆ & Azema JAHIĆ:
BIOSTRATIGRAPHIC CHARACTERISTICS OF THE BADENIAN AND SARMATIAN OF THE ROCK SALT DEPOSIT TETIMA NEAR TUZLA 15

Imre MAGYAR & Orsolya SZTANÓ:
THE LATE NEOGENE SEDIMENTATION AND STRATIGRAPHY IN THE PANNONIAN BASIN 18

Koraljka BAKRAČ & Jasenka SREMAC:
LATE PLIOCENE VEGETATION FROM THE DRAVA RIVER FLOOD-PLAIN (NORTHERN CROATIA) 21

Ivan DULIĆ, Vladislav GAJIĆ, Goran BOGIĆEVIĆ & Snežana MARJANOVIĆ:
LOWER MIOCENE IN THE BOREHOLES FROM THE SOUTH-EASTERN PART OF PANNONIAN BASIN: DIFFICULTIES IN DEFINING THE REGIONAL STAGES 24

Zoran MARKOVIĆ & Sanja ALABURIĆ:
NEOGENE MAMMALS OF SERBIA AND THEIR SIGNIFICANCE IN STRATIGRAPHY 26

Mlađen JOVANOVIĆ & Tivadar GAUDENYI:
CHANGES ON THE OFFICIAL QUATERNARY CHRONOSTRATIGRAPHICAL SCALE (ICS-IUGS) 28

Tivadar GAUDENYI & Mlađen JOVANOVIĆ:
MIS, TERMINATIONS, STAGES, STADIALS/INTERSTADIALS 31

Slobodan KNEŽEVIĆ & Meri GANIĆ:
INTRACARPATHIAN CONNECTION BETWEEN THE PANNONIAN AND DACIAN BASINS 34

Meri GANIĆ:
BRACKISH MIOCENE OF THE DACIAN BASIN IN EASTERN SERBIA – EXAMPLES, STATE AND CORRELATION POTENTIALS 36

Mlađen JOVANOVIĆ & Tivadar GAUDENYI:
STRATIGRAPHIC MODEL OF THE SERBIAN LOESS 38

Tivadar GAUDENYI, Mlađen JOVANOVIĆ & Draženko NENADIĆ:
ARCHAISMS IN THE SERBIAN QUATERNARY STRATIGRAPHY 41

Draženko NENADIĆ & Tivadar GAUDENYI:
STRATIGRAPHICAL POSITION OF PLEISTOCENE FLUVIAL POLYCYCLIC DEPOSITS OF SERBIA 44

Katarina BOGIĆEVIĆ:
LARGE MAMMALS AND QUATERNARY BIOCHRONOLOGY 47

Katarina BOGIĆEVIĆ & Draženko NENADIĆ:
QUATERNARY CONTINENTAL BIOCHRONOLOGY IN EUROPE BASED ON ARVICOLIDS 50

List of Authors 53

NEOGENE AND QUATERNARY STRATIGRAPHY
ACTUAL TERMINOLOGY AND NOMENCLATURE

Workshop Programme

Thursday, September 19, 2013
ARRIVAL AND ACCOMODATION FOR INVITED SPEAKERS AND GUESTS FROM ABROAD

Friday, September 20, 2013
9.00-9.15
OPENING CEREMONY

9.15-9.30
Ljupko RUNDIĆ:
STRATIGRAPHY OF NEOGENE - STATUS AND PERSPECTIVES IN SERBIA

9.30-10.00
Oleg MANDIC, Arjan de LEEUW, Thomas A. NEUBAUER, Mathias HARZHAUSER, Wout KRIJGSMAN, Klaudia F. KUIPER, Hazim HRVATOVIĆ & Davor PAVELIĆ:
MIOCENE DINARIDE LAKE SYSTEM - STRATIGRAPHIC CONSTRAINS REVEAL ITS ENVIRONMENTAL AND BIOTIC EVOLUTION

10.00-10.30
Sejfudin VRABAC, Zijad FERHATBEGOVIĆ, Izudin ĐULOVIĆ & Azema JAHIĆ:
BIOSTRATIGRAPHIC CHARACTERISTICS OF THE BADENIAN AND SARMATIAN OF THE ROCK SALT DEPOSIT TETIMA NEAR TUZLA

10.30-11.00
Imre MAGYAR & Orsolya SZTANÓ:
LATE NEOGENE SEDIMENTATION AND STRATIGRAPHY IN THE PANNONIAN BASIN

11.00-11.15
COFFEE BREAK

11.15-11.30
Koraljka BAKRAČ & Jasenka SREMAC:
LATE PLIOCENE VEGETATION FROM THE DRAVA RIVER FLOOD-PLAIN (NORTHERN CROATIA)

11.30-11.45
Ivan DULIĆ, Vladislav GAJIĆ, Goran BOGIĆEVIĆ & Snežana MARJANOVIĆ:
LOWER MIOCENE IN THE BOREHOLES FROM THE SOUTH-EASTERN PART OF PANNONIAN BASIN: DIFFICULTIES IN DEFINING THE REGIONAL STAGES

11.45-12.00
Zoran MARKOVIĆ & Sanja ALABURIĆ:
NEOGENE MAMMALS OF SERBIA AND THEIR SIGNIFICANCE IN STRATIGRAPHY

12.00-12.15
Mlađen JOVANOVIĆ & Tivadar GAUDENYI:
CHANGES ON THE OFFICIAL QUATERNARY CHRONOSTRATIGRAPHICAL SCALE (ICS-IUGS)

12.15-12.30
Tivadar GAUDENYI & Mlađen JOVANOVIĆ:
MIS, TERMINATIONS, STAGES, STADIALS/INTERSTADIALS

12.30-14.00
LUNCH

14.00-14.15
Slobodan KNEŽEVIĆ & Meri GANIĆ:
INTRACARPATHIAN CONNECTION BETWEEN THE PANNONIAN AND DACIAN BASINS

14.15-14.30
Meri GANIĆ:
BRACKISH MIOCENE OF THE DACIAN BASIN IN EASTERN SERBIA – EXAMPLES, STATE AND CORRELATION POTENTIALS

14.30-14.45
Mlađen JOVANOVIĆ & Tivadar GAUDENYI:
STRATIGRAPHIC MODEL OF THE SERBIAN LOESS

14.45 -15.00
Tivadar GAUDENYI, Mlađen JOVANOVIĆ & Draženko NENADIĆ:
ARCHAISMS IN THE SERBIAN QUATERNARY STRATIGRAPHY

15.00-15.15
Draženko NENADIĆ & Tivadar GAUDENYI:
STRATIGRAPHICAL POSITION OF PLEISTOCENE FLUVIAL POLYCYCLIC DEPOSITS OF SERBIA

15.15-15.30
Katarina BOGIĆEVIĆ:
LARGE MAMMALS AND QUATERNARY BIOCHRONOLOGY

15.30-15.45
Katarina BOGIĆEVIĆ & Draženko NENADIĆ:
QUATERNARY CONTINENTAL BIOCHRONOLOGY IN EUROPE BASED ON ARVICOLIDS

15.45-16.00
COFFEE BREAK

16.00-17.00
DISCUSSION AND CONCLUSIONS

ABSTRACTS

STRATIGRAPHY OF NEOGENE - STATUS AND PERSPECTIVES IN SERBIA

LJUPKO RUNDIĆ

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The researchers who dealing with the Neogene stratigraphy in Serbia, especially who coming from the small companies and non-university institutions, confronted a number of problems related to the (mis)understanding, usage of non-uniform nomenclature and archaic terminology which used in the written documents as well as presenting at conferences and meetings. This approach to the profession was resulted in the negative consequences (Mitrović & Rundić, 1998). However, all the turbulent social events and crises of the last twenty years were depressingly influenced to the stratigraphers of Serbia. We lost continuity and created a gap between the generations, the education of young people and their training is kept to a minimum, and the rate of unemployment has been steadily growing. Cooperation with foreign counterparts and reference laboratories has remained at quite low level. It has been continued almost to date, but there are visible steps forward. An additional problem (advantage) is the development of the Neogene in Serbia that is quite specific in relation to the all other countries in the region. In fact, until recently, in ex-Yugoslavia and Serbia & Montenegro, the Mediterranean and Paratethys Neogene were explored independently. From 2006, the geologists from Serbia are facing with the former Paratethys Sea: Central Paratethys (Pannonian Basin system, central-northern Serbia) and Eastern Paratethys (Dacian Basin, eastern Serbia).

Within the Neogene of the Mediterranean area (the general development of Neogene), there is almost a complete agreement to the stratigraphic division and the corresponding litho-, bio- and chronostratigraphic units. However, within the Pannonian Basin system a few different models are used for the explanation of spatial and temporal events during the Neogene (Magyar et al., 1999; Harzhauser & Mandic, 2008, Mandic et al., 2011). This primarily refers to the diverse lithostratigraphic units (e.g. formations, layers) and corresponding time's range (chronostratigraphy, presence or absence of certain regional stages or substages and spatial/temporal packages, depositional sequences and numerous transgressive-regressive cycles, etc.

For these reasons, integrated stratigraphic studies that are based on different criteria (lithostratigraphy, biostratigraphy, magnetostratigraphy, seismic & sequence stratigraphy, isotope stratigraphy, tectonostratigraphy, etc.) are present recently (Mandic et al., 2011; De Leeuw et al., 2013; Ter Borgh et al., 2013). During the last twenty years in some neighboring countries (Austria, Slovakia, Hungary, Romania) a new concept of study of Neogene was developed and it based on a coupled seismic – and sequence stratigraphy, tectonic and stratigraphic modeling. This concept was created in response to increasing demands from industry and the needs of the petroleum industry of individual countries. A modern, an integrated (inter-and multidisciplinary) approach of basin analysis and genesis of hydrocarbons and other natural resources led to the better understanding of the overall geodynamic evolution of the Pannonian Basin. Today, it is a basic methodological approach

And what are currently the biggest problems and dilemmas in the Neogene stratigraphy of Serbia? There are a few small groups of researchers that (almost independently of each other) work more or less with similar problems but there is poor communication between them. And there are a lot of open questions. First of all, the Lower Miocene is still a big unknown in terms of regional division into stages based on the model as set up in the Central Paratethys.

The used methodology is a more traditional so that the new results which arising from the new methods often missing (Rundić et al. 2013). These methods, as a rule, are relatively unfamiliar with our researchers (stable isotope, sequence stratigraphy, magnetostratigraphy, 40Ar/39Ar dating, etc.). The question of when, where and how the Lower Miocene lacustrine-continental regime was replaced by marine one (the well-known Badenian transgression) is still open, because there are several theories (i.e. Dolić, 1998; Krstić et al., 2003, 2012). Also, how big, and if there was a single "Serbian Lake" or it was a system of lakes? Are there more lacustrine phases in the Lower Miocene? Furthermore, there is a long-time question of the existence of Pontian Stage in Serbia. Pontian is a regional stage in the Eastern Paratethys and many now consider that it is not the Pontian s.str. that exists to the east of the Carpathian Mountains (Magyar et al., 1999; Piller et al., 2007). However, some authors have different opinion and they think that during the Pontian was existed a seaway via Serbia which was connected the basins on both sides of the Carpathians (Knežević & Ganić - this volume). There is also the question of stratigraphic range of the Pannonian Stage and a lot of disagreements among colleagues in Serbia and abroad are present (Papp, 1951; Stevanović & Papp, 1985; Ter Borgh et al., 2013). The precise radiometric age of the Neogene volcanic rocks and their correlation with standard biostratigraphic zones is a task that has not been done yet. Timing of major tectonic events and their biostratigraphic control still not yet at a satisfactory level. A particular problem is the lack of young staff who is seriously involved in the Neogene biostratigraphy and especially for studying the micro-and nannofossils (i.e. nannoplankton, foraminifera, dinoflagellate, diatoms, etc.). And last but not least, there is the problem of chronic deficiency of funding and small number of projects that investigate the Neogene.

For these reasons and the desire to engage in a common national and multilateral research of the Neogene of the Pannonian Basin and all over the Europe, during 2010 the Commission on Neogene of the Serbian Geological Society has re-launched and established. A few years ago, based on the initiative of the Serbian geologists who dealing with Neogene and colleagues from the Paleontological Institute of Vienna University, a new professional and scientific conference on Neogene of Central and Eastern Europe was established (the first such meeting took place on Fruska Gora, 2005 and the fifth one was in Varna, 2013). All who study the Neogene, through communication and contacts via our Commission and the mentioned workshop, it should be able to point out the main issues that concern them, to better analyze and through discussion they will find the best solution. What are the main objectives of the Commission? First of all, to jointly find the best solution for the above mentioned issues and problems. Personal example and cooperation should affect on young geologists in order to ensure that teamwork is the only solution. Such an approach and interdisciplinary researches should be supported by modern analytic methods (Harzhauser et al., 2004; Ganić et al., 2011; Paulissen et al., 2011; Rundić et al. 2011, 2012; Ter Borgh et al., 2013). After that it will be possible to expect the better results in the Neogene stratigraphy of Serbia. Besides, the members of Commission would have to be very actively involved in the activities of other professional bodies (e.g. the Commission for Stratigraphic Lexicon and Ethics, the Commission on Geological Maps, the Commission on Geological Heritage, etc.). Our basic idea is that all those directed in the professional sense on Neogene, should join to the Commission. Because, the time frame of about 20 Ma certainly provides a great perspective for studying, identification and explanation of natural phenomena and the timing of the geological processes.

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MIOCENE DINARIDE LAKE SYSTEM - STRATIGRAPHIC CONSTRAINS REVEAL ITS ENVIRONMENTAL AND BIOTIC EVOLUTION

OLEG MANDIC[1], ARJAN DE LEEUW[2], THOMAS A. NEUBAUER[1], MATHIAS HARZHAUSER[1], WOUT KRIJGSMAN[3], KLAUDIA F. KUIPER[4], HAZIM HRVATOVIĆ [5], DAVOR PAVELIĆ[6]

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During Early and Middle Miocene a series of long-living lakes occupied the intra-mountain basins of the Dinaric Alps in Southeastern Europe. So-called Dinaride Lake System (DLS) was settled on the western margin of the Dinaride–Anatolian Island landmass and represented the barrier between the Paratethys and the proto-Mediterranean seas (Krstić *et al*, 2003; Harzhauser & Mandic, 2008). Those up to 2000-m-thick sedimentary successions, dominated by fresh water limestones cover today parts of Croatia, Bosnia and Herzegovina, Montenegro, Serbia, Hungary and Slovenia. During its maximum extent, the DLS covered an area of c. 75,000 km^2.
Results from intensive investigation campaigns provided currently a deep-time window to DLS in constructing integrative Ar/Ar geochronologic and paleomagnetic age constrain for its key basins (De Leeuw *et al*, 2012). That allowed the stratigraphic correlations and a precise insight into the complex environmental history of that previously less-known region. In particular it was demonstrated that the lakes recorded a suite of climatic parameters. The captured fluctuations therein provide actually a high-resolution climate archive that considering its length allows not only establishing relations between the Miocene Climate Optimum (MCO) and its regional effects but also the weighting of the potential effect of Middle Miocene Climate Transition (MMCT) and regional geodynamics to its disintegration.
The regional stratigraphic scheme, integrating results from 14 basins, defined the DLS initiation at about 18 Ma and its end at about 14 Ma, with optimum development between 17 Ma and 15 Ma, correlating apparently well with the two-folded pattern of the MCO (De Leeuw *et al*, 2012). The younger part, characterized by a taxonomically rich mollusk record, coincided exactly with the Middle Miocene warming interval (Neubauer *et al*, 2011, 2013a, 2013b). Very detailed environmental analyses including studies on carbonate microfacies and coal petrology showed that the DLS was composed of alkaline, hard water lakes (Mandic *et al*, 2009, 2010). Stable isotope studies of mollusk shells demonstrated the pure freshwater composition of the lakes (Harzhauser *et al*, 2012). Finally, detailed palynological studies pointed out the interchange of warm-dry and cold-wet periods during generally warm, subtropical climate conditions (Jiménez-Moreno *et al*, 2008, 2009).
Apparent time correlation with the initial tectonic rifting of the Pannonian Basin pinpointed the geodynamics for the most important factor controlling the origin and geological history of these striking lakes (Mandic *et al*, 2012). Furthermore the lake deposition during the early and the middle DLS stages coincided largely with the highest Miocene concentration of greenhouse gases in Earth's atmosphere during the MCO. Consequently the immense coal deposits, mined in many lacustrine basins of Bosnia and Herzegovina and representing the crucial national energy resource can therefore be largely considered as product of that Miocene global warming event.
The late DLS stage is characterized in contrast by depositional hiatus or introduction of coarse clastic sedimentation. Yet, whereas in the northern DLS, thick successions of fluvial conglomerates are known from the Sarajevo Basin, such conglomerates are missing in the

southern DLS including the Livno−Tomislavgrad and Sinj Basins. There local debris flow deposits (sandstones and breccias) are recorded between ~15.2 and ~15.0 Ma in the Sinj Basin (De Leeuw *et al*, 2010) and between 14.8 and ~13.0 Ma in the Livno−Tomislavgrad Basin (De Leeuw *et al*, 2011). In all three basins the coarse clastic deposition coincide with the terminal phase of the main DLS depositional sequence indicating synsedimentary tectonics and relief building as a cause for the basinal inversion terminating the lacustrine deposition in the late Middle Miocene. The coincidence of the lakes' retreat with the global cooling interval of the MMCT is likely evident.

The mollusk record of the DLS includes about 200 species and represents the most prominent evolutionary hotspot in Europe during the Early and Middle Miocene (Harzhauser & Mandic, 2008, 2010). The taxonomic analyses proved that fauna as 98% endemic and traced the faunal immigration during its optimum development as practically non-existent. Hence, such outstandingly high diversity represents the combined effect of autochthonous evolution through speciation in a long-lived ecosystem and accumulation of inhered elements from previous phases. The significant environmental stress introducing the evolutionary pulses is marked by enhanced morphological variation reflecting the initiation of speciation through adaptation processes. The DLS mollusks show some striking morphological convergence to much better known fauna of the Late Miocene Lake Pannon. Our results now definitely excludes their coeval occurrence what makes this characterization still more striking. Adaptation to similar habitats under stable environmental conditions over hundred thousand or even millions of years can apparently lead the morphological adaptation in identical direction and result consequently in similar organism shapes also in not directly related lines. Finally the present investigation pinpointed the previously unknown faunistic gradient in the DLS dividing it into taxonomically richer and more evolutionary advanced southern part facing the less advanced and taxonomically poorer northern part. First our data could prove the coexistence of these regions earlier considered for being differently old. About the cause for that phenomenon such as water shed or climatic gradient can only be speculated before new data become available from subsequent investigations.

Two successive evolutionary faunas have been detected in the DLS successions, whereas the changeover between both coincides with the Early-Middle Miocene transition. The older fauna comprises the enigmatic clivunellid gastropods and a primitive dreissenid bivalve assemblage with *Mytilopsis kucici*. Subsequent to their extinction, peculiarly flattened, orbicular, and prominently large-sized species evolved within the *Mytilopsis drvarensis* clade. Within the younger phase, eye-catching events of morphological evolution were recorded for the gastropod lineages of the *Melanopsis* and *Prososthenia* members, lasting over more than 200 kyr. Correlating with palaeoenvironmental perturbations these were followed by extinction events reducing the species-rich faunal content to few pioneer species. This pattern clearly shows the accumulation mechanism behind the high species richness recorded in DLS. Similarly to Lake Pannon, the longevity of the single lakes was the crucial mechanism that facilitated accumulation of species, produced by iterative radiation and extinction events.

The paleogeographic distribution of widespread taxa implies that faunal exchange was strongly controlled by geographic distance. The fact that closer basins share larger percentages of the faunal content confirms that the DLS primarily consisted of largely isolated lacustrine environments getting only occasionally and locally into contact. Such events occurred preferably during humid climate periods when the regional lake levels increased, allowing easier faunal exchange. The hypothesis that the DLS shrank in its younger phase through southward marine transgression of the Central Paratethys onto the Dinaride Island has been largely disproved. According to present data, including both marine biostratigraphy and Ar/Ar dating of lake deposits, there were still at an age of 15 Ma coexisting lakes from the coastal Adriatic Sea area up to the Pannonian Basin. Still, most of the lakes disappeared already before the marine flooding of the Pannonian Basin at 14.8 Ma. The latter coincides with the start of tectonic activity in the area largely disrupting lake deposition. Finally, although the DLS was not coeval with Lake Pannon, the Late Miocene lacustrine sedimentation follows on DLS deposits in several basins such as Livno and Tomislavgrad, representing a possible niche for their few shared endemic genera (e.g. *Orygoceras*).

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BIOSTRATIGRAPHIC CHARACTERISTICS OF THE BADENIAN AND SARMATIAN OF THE ROCK SALT DEPOSIT TETIMA NEAR TUZLA

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During 2010 year it was done borehole B-71 on the salt deposit Tetima near Tuzla (northeastern Bosnia). Overlying sediments of salt were drilled without coring to a depth of 478 m.From these sediments were taken 98 samples. Higher roof of salt has been examined at every 10 m and samples in the near roof of salt were taken at intervals of 2-5 m. From each sample were taken 6 grams of sediment grain size over 0.15 mm for qualitative and quantitative analysis of foraminifera. Based on the association of foraminifera, overlying sediments of salt formation have been determined to the lower, middle and upper Badenian and lower Sarmatian, with appropriate local zones (Fig. 1).

Lower Badenian has been defined in the interval from 483.0 to 177.5 m. It is divided into two local zones. Older zone is *Ammonia viennensis* and *Nonion commune*, and younger zone is *Globigerinoides trilobus* and *Orbulina suturalis*.

Zone of *Ammonia viennensis* and *Nonion commune* has been determined in the interval 483-409 m. It is presented by a massive, sandy marls which are located in the immediate roof of salt formation.

Within this zone in the 31 samples were determined 23 species of foraminifera with dominant participation of *Ammonia viennensis* (d'ORBIGNY) (5356 individuals) and *Nonion commune* (d'ORBIGNY) (3389).With significantly fewer individuals are represented species: *Globigerinoides trilobus* (REUSS) (2148), *Orbulina suturalis* BRÖNNIMANN (1584), *Cycloforina contorta* (d'ORBIGNY) (360) and others. Local zone of *Globigerinoides trilobus* and *Orbulina suturalis* has been defined in the interval from 409.0 to 177.5 m. It was built from sheet to thinly stratified marls with layers of sandstone. In the 47 samples were determined 25 species of foraminifera. The largest number are *Globigerinoides trilobus* (REUSS) (6742) and *Orbulina suturalis* BRÖNNIMANN (6004). Other species are represented in the following number of individuals: *Globigerina bulloides* d'ORBIGNY (2356), *Bulimina elongata elongata* d' ORBIGNY (392) *Globoquadrina altispira* (CUSHMAN & JARVIS) (232), *Uvigerina macrocarinata* PAPP & TURNOVSKY) (136) etc. Middle Badenian has been defined in the interval from 177.5 to 153.0 m, and it is presented with zone *Pappina parkeri*. It is represented by sheet and thin-bedding marls with layers of sandstone. In this stratigraphic section 5 samples were taken and determined 8 species of foraminifera. The leading part has *Pappina parkeri* (KARRER) (160) followed by: *Bolivina dilatata maxima* CICHA & ZAPLETALOVA (104), *Orbulina suturalis* BRÖNNIMANN (64), *Globigerina bulloides* d'ORBIGNY (44), *Bulimina elongata elongata* d' ORBIGNY (36), etc. Upper Badenian has been defined at a depth of 153-45 m and it is presented by *Bolivina dilatata maxima* zone. Lithology composition is identical to middle Badenian.The analysis of 11 samples were determined 22 species of foraminifera. By numerical representation it is dominant *Bolivina dilatata maxima* CICHA & ZAPLETALOVA(164), followed by: *Uvigerina sp.* (152), *Globigerina bulloides* d'ORBIGNY (88), *Bulimina elongata elongata* d'ORBIGNY (72), *Orbulina suturalis* BRÖNNIMANN (52), etc.

Lower Sarmatian has been defined in the interval 45-0 m. It is presented with two local zones: older zone is *Elphidium hauerinum* and younger zone is *Porosononion granosum*. It was built from sheet to thinly stratified marls with layers of sandstone. From zone *Elphidium hauerinum* has been analyzed 2 samples and determined only two foraminiferal species: *Elphidium hauerinum* (d'ORBIGNY) (16) and *Porosononion granosum* (d'ORBIGNY) (4). This zone includes interval 45-28m. Zone *Porosononion granosum* has been defined in the interval 28-0 m. From this zone in two samples were determined *Porosononion granosum* (d□'ORBIGNY) (16) and *Elphidium* sp. (4).

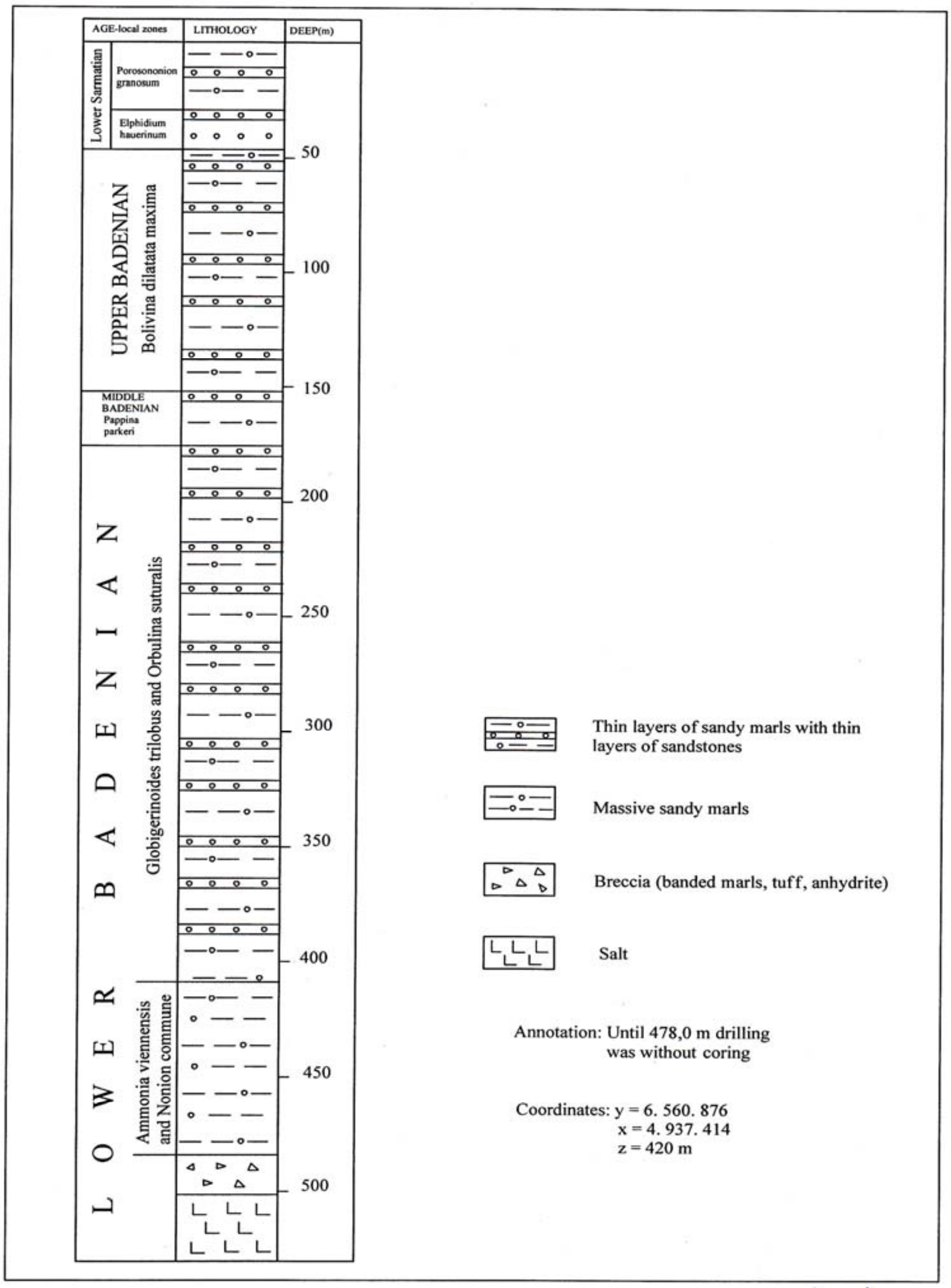

Fig. 1. Stratigraphic column of the Badenian and Sarmatian in the borehole B-71 of the rock salt deposite Tetima near Tuzla.

According to qualitative analysis of foraminifera it has been proved their the biggest variety in the lower Badenian especially in zone *Globigerinoides trilobus* and *Orbulina suturalis* with determination of 25 species.The poorest association of foraminifera has been defined in the lower Sarmatian with determination only two species. Based on quantitative analysis it has been proved wery different number of individuals of certain species of foraminfera in determined stratigraphic zones. Numerical representation of individuals has been increased in the lower Badenian and significant decreased in the middle and upper Badenian especially in lower Sarmatian. Maximum number of individuals of foraminifera in zone *Ammonia viennensis* and *Nonion commune is 664* and has been determined in the sample no.82 with a depth of 440m. This level is 43 m over salt formation. In zone *Globigerinoides trilobus* and *Orbulina suturalis* maximum number of foraminifera has been defined in the sample no.64 with a depth of 402 m with 1304 individuals. This sample represents fossil globigerina mud. In the Middle Badenian maximum number of foraminifera was determined in sample no. 19 with a depth of 170 m and it is 136 individuals.In the lower Sarmatian foraminifera have the lowest abundance. In the sample no. 3 with the depth of 33 m, which is in the zone *Elphidium hauerinum* have been noted 12 individuals. In the sample no. 1 with a depth of 13 m that is from the zone *Porosononion granosum* have been determined 16 individuals.

It is interesting that in the interval 478-390 m there is the greatest diversity and abundance of foraminifera and it can be explained by more favorable living conditions in the shallow part of sublitoral with normal salinity of the Central Paratethys. Reduced diversity and abundance of foraminifera in the younger part of the lower Badenian, middle and upper Badenian, as well as the lower Sarmatian, is result of flysch conditions of sedimentation, and fall salinity at the end of upper Badenian and especially in the Lower Sarmatian.

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LATE NEOGENE SEDIMENTATION AND STRATIGRAPHY IN THE PANNONIAN BASIN

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In the late Neogene (Late Miocene and Pliocene), the extensional Pannonian Basin trapped sediments from the surrounding Alpine-Carpathian-Dinarian source area. Thickness of the basin fill may reach 6 km in the largest depressions. The chronostratigraphic subdivision and correlation of this thick non-marine sediment pile and the usage of the regional Central Paratethyan stage system are contradictory and not uniform in the various countries. In order to establish a common language in stratigraphy, first the sedimentary processes and the geochronology have to be understood.

Sedimentation
Late Neogene sedimentation in the Pannonian Basin system took place in the large and brackish Lake Pannon and in adjacent deltaic and fluvial environments. Sediments arriving from the surrounding uplifted source area were partly accumulated on the flat-lying morphological shelf of the lake, whereas other portions of the sediment were passing through to the slope and transported by effective turbidity currents through leveed channels into the basin, and deposited on the deep basin floor as thick, extended turbidite lobes up to a distance of 30 km from the shelf edge. Therefore, the basin of the lake was filled by forward accretion of sediment packages. Successive positions of the shelf-margin are represented by a series of clinoforms in seismic profiles. The height of the clinoforms, and thus the minimum (undecompacted) paleo water depth is 200-600 m, and the width of the slope, as measured from the shelf-break down to the toe of slope, varies between 5 and 15 km. As a result, the lithological succession of the upper Neogene is quite uniform across the entire basin: deep lacustrine marls are overlain by turbidite-bearing layers, followed by fine-grained sediments of the slope, and, with a sharp lithological boundary, by sandy shallow lacustrine and various deltaic sediments. The shelf deposits usually display a cyclic architecture: 30-50 m thick coarsening upward units follow each other, representing individual delta progradations. Each unit consists of offshore shales, sandy deltaic lobes with distributary channel fills, crevasse splays, and organic-rich clays or lignite seams deposited in interdistributary marshes. The whole succession is capped by fluvial deposits (Sztanó et al. 2013).

Dating
Mammal biostratigraphy, radiometric dating from interbedded volcanics, and magnetic polarity profiles from boreholes and outcrops are the tools by which the Upper Neogene of the Pannonian Basin can be dated and correlated to the global geochronological scale (e.g. Magyar et Geary 2012; ter Borgh et al. 2013)..

Paleogeography
The most significant agent of the shelf growth was the sediment dispersal system of the paleo-Danube: about 2/3 of the basin's area was filled by sediment transport systems supplying sediments from the NW, from the Alps and Western Carpathians. After quickly filling the shallow Vienna Basin, the paleo-Danube started to build a morphological shelf into the deeper water of the Kisalföld/Danube sub-basin at about 10 Ma ago. The main control on shelf-margin growth was the regional subsidence of the basin, and the dominant direction of progradation was NW

to SE. Basement morphology only locally and moderately influenced the shelf advance. Progradation above the relatively uplifted but flooded (sublacustrine) basement highs, such as the Transdanubian Range, was especially fast as a consequence of low accommodation.

By 8.6 Ma, the northwestern part of the basin system had been turned into shelf areas and alluvial plains by the paleo-Danube and its tributaries, and a similar process took place in the northeastern part, where the paleo-Tisza system supplied sediments from the Northeastern and Eastern Carpathians. The two, almost perpendicularly striking systems coalesced, and formed a uniform shelf along the northern perimeter of the lake. The paleo-Danube system, however, remained the dominant agent, and it formed the youngest shelf margin of the Pannonian Basin in the southeastern corner of the basin system. This margin has an estimated age of about 4 Ma, and it lies 400 km to the southest of the oldest paleo-Danube shelf margin, in NE Serbia and W Romania. Additional local systems carried sediments from E to W along the eastern margin and S to N along the southern margin of the Pannonian Basin, respectively (Magyar et al. 2013).

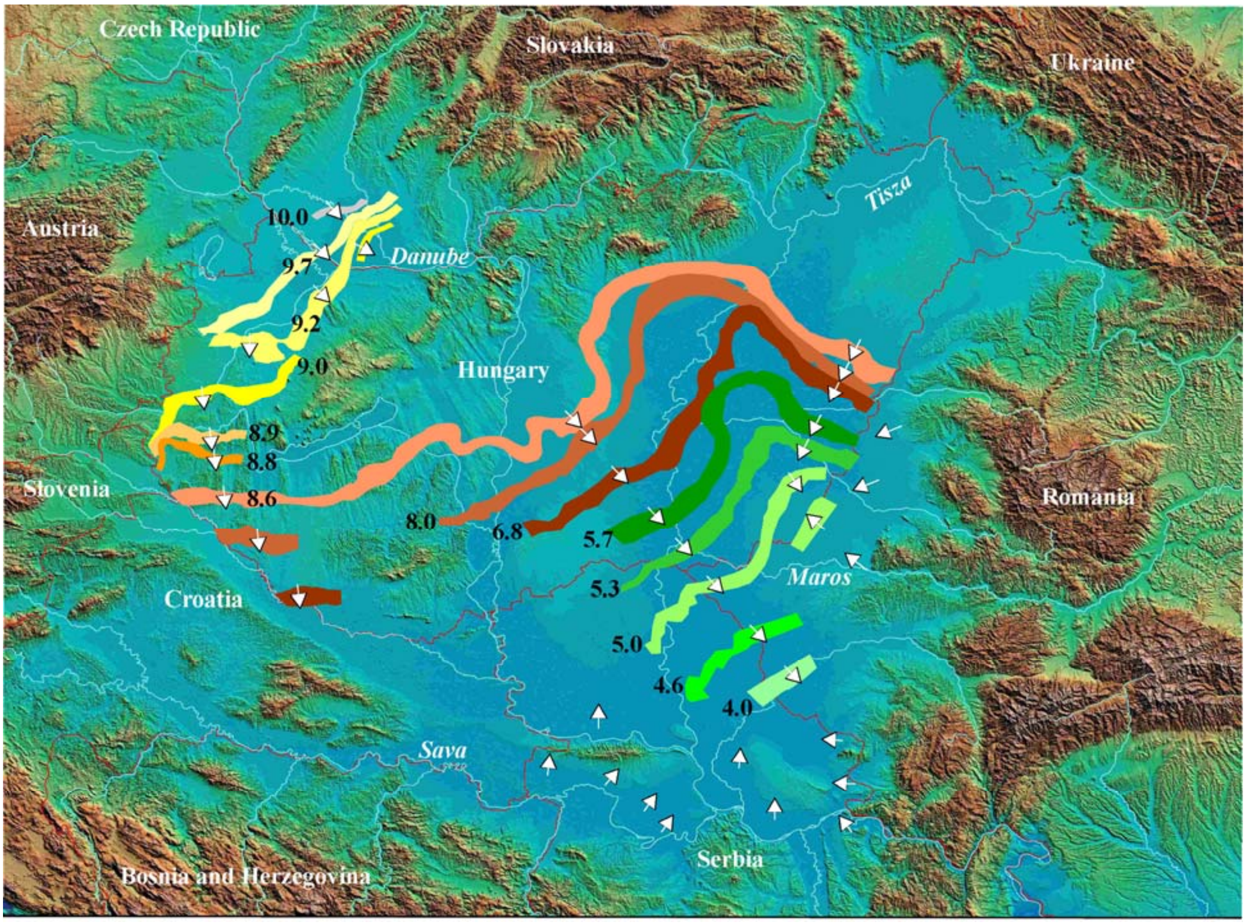

Fig. 1. Progradation of the paleo-Danube and paleo-Tisza shelf-margin slopes across the Pannonian Basin during Late Miocene and Early Pliocene times. Ribbons represent the width of the slope from the shelf-break to the toe of slope, adjacent black numbers indicate approximate age in million years. Where mapping was not possible due to scarcity of available *seismic profiles, only the dip directions as appeared on 2D profiles are indicated (white arrows).*

Stratigraphy

In spite of the recognition of extended clinoform successions, the shelf break is still commonly interpreted as a chronostratigraphic boundary, either between the Lower and Upper Pannonian, as in Hungary, or between the Lower and Upper Pontian, as in Slovenia, Croatia, and Serbia, or between the Pontian and Dacian, as in Romania. These interpretations are seemingly supported by the significant and usually sharp change in both lithology and fossil content across the shelf break. Shales with remains of deepwater animals, such as thin-shelled molluscs, are common below this boundary, whereas more sandy deltaic deposits with shallow water fauna occur above. The shelf break, however, cannot be considered a chronostratigraphic boundary, because the age difference along this lithological boundary across the entire Pannonian Basin, as discussed above, may amount 6 million years. Re-consideration of the meaning of the Pontian, Dacian and Romanian stages in the Pannonian Basin system is thus unavoidable.

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LATE PLIOCENE VEGETATION FROM THE DRAVA RIVER FLOOD-PLAIN (NORTHERN CROATIA)

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Pliocene deposits in the Drava River valley, near the town Virovitica in Northern Croatia contain plant megafossils and palynomorphs with characteristics of mixed mesophytic forest. Megafossils are scarce, but well preserved. Leaves and fructifications belong mostly to deciduous plants pollinated by wind. Collection includes one of the latest evidence of *Ginkgo* in Europe before the glaciation. Palynoflora partly coincides with megafossils, but shows wider variety of vegetation along the river basin. Arborescent and herbaceous components are both present and non-pollen grains are typical for fresh-water marshes within the flood-plain, in which all plant fossils were accumulated and preserved.
Pliocene clastic deposits with remnants of land flora in the Vicinity of Virovitica outcrop as erosional windows within the Pleistocene fine-grained loess and/or lacustrine-marsh silt and clay. They transgressive overly Pontian-Lower Pliocene Rhomboidea beds (Fig. 1) and were deposited during the 3rd depositional megacycle proposed by Saftić et al. (2003). During the basic geological mapping their age was interpreted as Late Pliocene – Early Pleistocene, due to the lack of fossils (Galović et al., 1981).

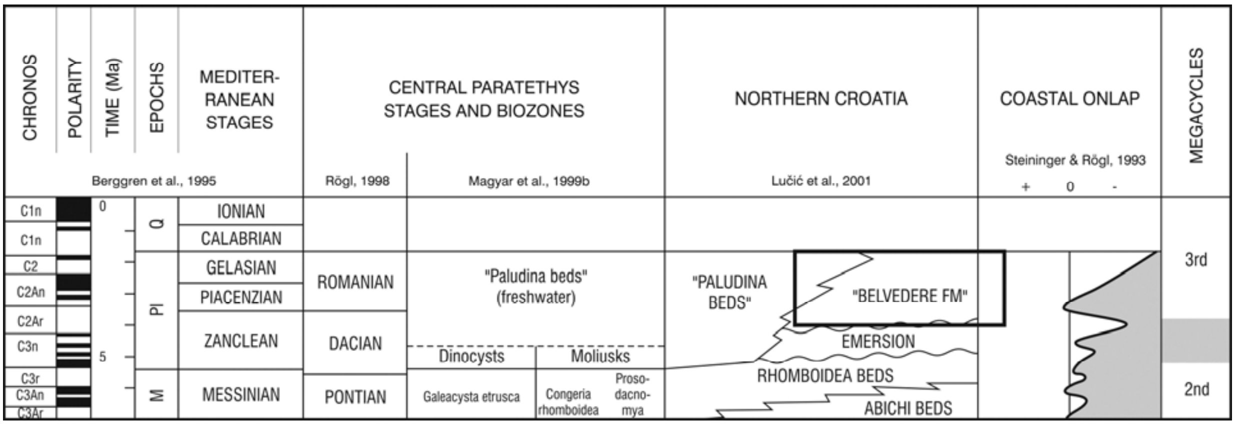

Fig. 1. Stratigraphy of Latest Miocene to Quaternary stages in Central and South-western Europe with local units in Northern Croatia published by Lučić et al. (2001) and megacycles proposed by Saftić et al. (2003) (modified after Popov et al., 2006; Janz & Vennemann, 2006). Position of clastic deposits with land flora is marked with a rectangle.

The best outcrops are present in quarries Rezovac, Cabuna and Bistrica south of the Drava River, between Virovitica and Podravska Slatina (Fig. 2).
Well preserved megaflora was found in siltose clays in the vicinity of Virovitica. Mrinjek et al. (2006) published a short list of collected samples, noticing that megaflora is well preserved, and dominated by maple leafs and hornbeam fructifications. During this research megaflora from the vicinity of Virovitica was studied in detail. Thirty-five specimens were found in siltose clays. Twenty-six taxa were determined. The most diverse are fagaceans and betulaceans, represented by leafs and fructifications. Dicotyledonous leaves are the most common, often medium to small sized. Toothed leaves predominate over simply ovate forms. Dycotiledones: *Parottia*, *Liquidambar*, *Quercus mediterranea*, *Q. kubinyi*, *Myrica lignitum* and *Zelkova* represent relics of the Miocene warm period. Beech (*Betula* sp.) and alder (*Alnus julianaeformis* (Sternberg) Kvacek & Holly) were introduced in this area during the Late Pliocene cooling.

Maple and hornbeam are known as colonizers of unconsolidated soils. Maple leaves belong to the fossil species *Acer integrrimum,* common in Europaean Neogene deposits. *Ginkgo adianthoides* (equivalent of the recent *G. biloba*) was generally common in disturbed streamside and levee environments during the Cretaceous, Paleogene and Neogene (Del Tredici, 2000; Royer et al., 2003,). Escaping the unfavourable conditions during the glaciation it disappeared from Europe ca. 2.5 Ma ago. Megaflora from the vicinity of Virovitica shows significant similarity with other Late Miocene and Pliocene floras from Europe.

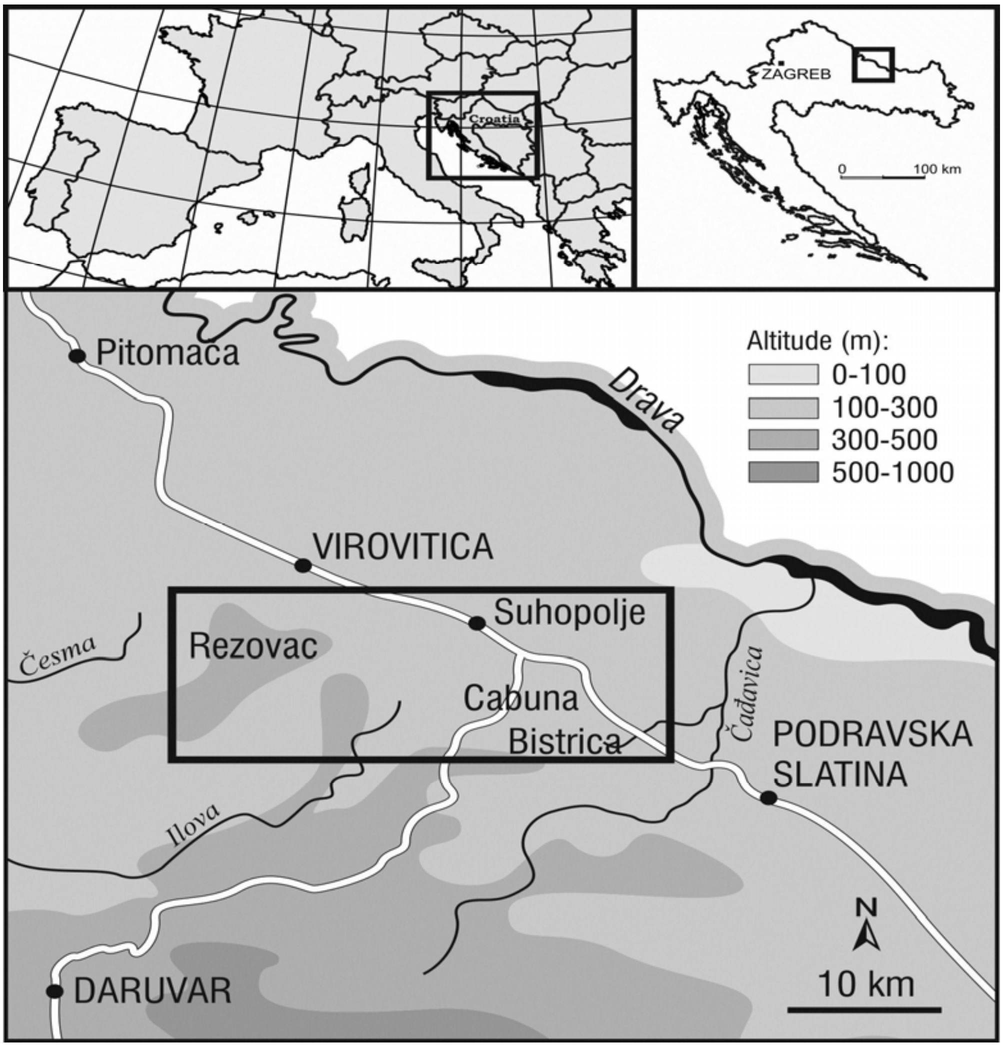

Fig.2. Map of the studied area with recent altitudinal belts (Atlas of Croatia, 1:100 000; 2002; modified).

Palynomorphs were extracted from the same clay samples from the vicinity of Cabuna, which contained the best preserved megafossils. Percentages of pollen taxa were calculated based on the complete pollen assemblage. Taxa have been grouped according to their ecological significance with respect to the Nix's (1982) classification: (1) *Cathaya*, an altitudinal conifer living today in Southern China; (2) Mesothermic (i.e. warm–temperate) elements (deciduous *Quercus, Carya, Pterocarya, Carpinus, Ulmus, Liquidambar, Myrica, Tilia* and *Fagus*) (3) *Pinus* and poorly preserved Pinaceae pollen grains; (4) microthermic (i.e. high-altitude) trees (*Abies* and *Picea*); (5) non-significant pollen grains (undetermined, poorly preserved pollen grains); (6) Mediterranean xerophytes (evergreen *Quercus*) and (7) herbs and shrubs (Asteraceae Asteroideae, Asteraceae Cichorioideae, Chenopodiaceae). There are no megathermic (i.e. tropical) elements, mega-mesothermic (i.e. subtropical) elements, Cupressaceae and steppe, while meso-microthermic (i.e. mid-altitude) trees (*Tsuga*) are sporadic. There are some non-pollen palynomorphs (NPP) that indicate the deposition within a flood-plain (freshwater marshes and oxbow lakes).
Megaflora from the Late Pliocene deposits of Drava river basin is well preserved, with no

fragmentation and/or size selection, which excludes long transportation and high water energy. The vegetation along the Drava river was organized in altitudinal belts. Considering the ecological needs of collected taxa, palaeovegetation from the vicinity of Virovitica dominantly belongs to a lower horizon of an evergreen and deciduous mixed forest, today growing above 700 m altitude. Within this vegetation the following arboreal taxa appear: *Quercus*, *Fagus*, *Carpinus* and *Acer*. Riparian vegetation of this horizon is composed of *Alnus*, *Carya*, *Ulmus* and *Liquidambar*. The shrub level was dominated by Asteraceae (Asteroideae and Cichorioideae) and Chenopodiaceae. Freshwater marshes and oxbow lakes contain algal remains, and ferns in marginal parts. *Myrica* is a component of a broad-leaved evergreen forest, present from coastal plains to 700 m, while *Betula, Fagus*, *Pinus, Cathaya* and *Tsuga* belonged to a mid-altitude deciduous and coniferous mixed forest. Finally, above 1800 m in altitude, a coniferous forest with *Abies* and *Picea* existed.

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LOWER MIOCENE IN THE BOREHOLES FROM THE SOUTH-EASTERN PART OF PANNONIAN BASIN: DIFFICULTIES IN DEFINING THE REGIONAL STAGES

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Lacustrine clastic and clastic-carbonate sediments of the Lower Miocene were ascertained by exploratory drilling on the territory of Serbia (Požarevac-Danube region, Morava trench, Kolubara basin) and the Northeastern Bosnia and Herzegovina (Semberia and Posavina regions). They were accumulated over the transgressive marine formations of Paleogene or older, Mesozoic and Paleozoic formations. Over the Lower Miocene sediments are typically developed Middle Miocene marine sediments. Thickness of the Lower Miocene varies from about 1500 m (area of Posavina in Bosnia and Herzegovina and Markovac depression in the Morava trench) to about 500 m (area of Drmno depression and other depressions in the Pozarevac Danube region).
Lower Miocene sediments are characterized by continuous change of colorful (gray-green, dark red, dark gray, gray-brown) heterogeneous clastic and carbonate sediments which includes: conglomerates, coarse and fine grain sandstones, silty marlstones, sandy marlstones and shales.
Micropaleontological studies in the Lower Miocene stated the relatively rich association of microflora (palynomorphs, freshwater algae Charophyta) and microfauna (foraminifers, ostracodes), based on which it was concluded that these sediments belong to Ottnangian and Karpatian, but does not exclude the possibility that older formations of the Lower Miocene were also developed.

The main problems with biostratigraphical parsing within the Lower Miocene are:
- Incomplete palynological associations, based on which it is not possible to precisely determine the boundary between Ottnangian and Karpatian, and in some cases it is not possible to implement any biostratigraphic parsing within the Lower Miocene, as is the case in wells from Semberia and Posavina area (Bosnia and Herzegovina). It is also important to point out that within the clastic-carbonate sequences are also separated palinological associations (Pantic, Secerov, Dulic, unpublished data), which indicate the development of younger Paleogene. Considering that in the Ottnangian-Karpatian sediments are often determined reworking of Cretaceous and Paleogene palynomorphs, precise phytostratigraphical interpretation is very difficult.
- In the Karpatian, and rarely in Ottnangian, the succession of freshwater (oligohaline), brackish (oligo-mesohaline) and pure marine (brachyhaline) sequences, which is indicated by associations of microfauna and calcareous nannoplankton (Gagić, 1990, 1994, Mihajlovic, 1997), was noted. Brackish sequences are characterized by the presence of representatives of the ostracod genera *Mediocypris* and *Potamocypris* and from the marine sequence it is determined relatively rich association of foraminifera: *Cibicides slovenicus* CICHA & ZAPLETALOVA, *Globigerina praebulloides* BLOW, *G. angustiumbilicata* BOLLI, *Globoquadrina langhiana* CITA & GELATI, *Semivulvulina* cf. *pectinata* (REUSS), etc.

These occurrences are particularly often found in the younger sediments of the Lower Miocene, which are developed in the Moravian trench and Požarevac-Danube region.
In the area of the Morava trench and Požarevac- Danube region, due to unchanging conditions of deposition (alternately succession of sandstones, siltstones, shales and marlstones) accurate separation of the Lower and Middle Miocene is more difficult, ie, the precise determination of biostratigraphical boundaries between the Karpatian and Lower Badenian. In such circumstances, considerable help in defining the boundary between the Lower and Middle Miocene provides seismogeological interpretation. On the seismic sections (Fig. 1), it is clear concordant relationship of the Lower Miocene and Lower Badenian sediments, as well as

clearly noticeable seismic horizon, which is interpreted as the boundary between the lower and middle Miocene.

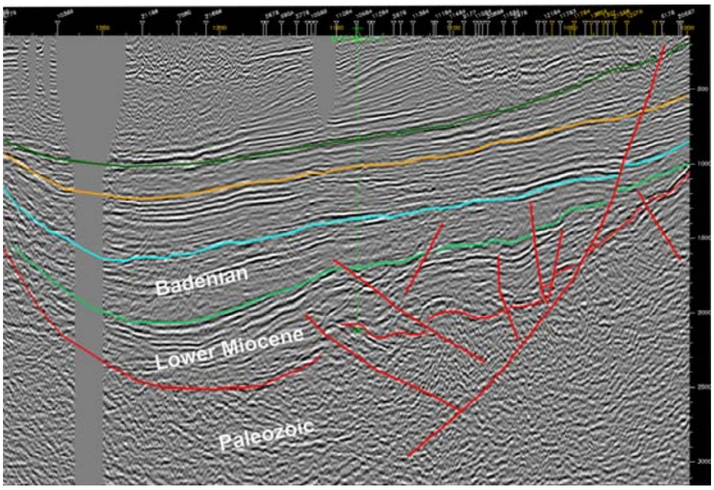

Fig. 1. Concordant relationship of the Lower Miocene and Lower Badenian sediments at Pozarevac Danube region

Unlike some areas of the Moravian trench and Pozarevac Danube region, in the Semberia and Posavina area in Northeastern Bosnia and Herzegovina, the boundary between the Karpatian and the Lower Badenian is clearly visible, on the basis of biostratigraphical and seismic data. In fact, there is a clear lithological boundaries, clear biostratigraphical boundary and most importantly, the seismic sections clearly show erosion-tectonic boundary between the Lower and Middle Miocene (Fig. 2).

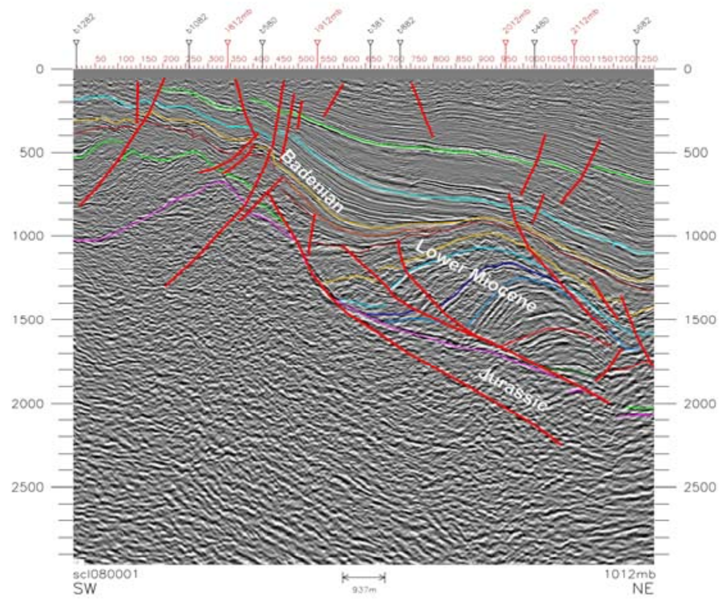

Fig. 2. Erosion-tectonic boundary between the Lower and Middle Miocene at Posavina area (Bosnia and Herzegovina)

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NEOGENE MAMMALS OF SERBIA AND THEIR SIGNIFICANCE IN STRATIGRAPHY

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Together with radioisotope and paleomagnetic studies of sediments in fossil beds, correlation of faunas is one of the main methods in determining the geological age of a fossil association. It is based on close matching of mammalian species or genera in one locality with the referent locality within the bioprovince (De Bruijn *et al.*, 1992) or block (Steininger *et al.*, 1996; Steininger, 1999). The similarity in composition of faunas in different localities is a consequence of same values of ecological factors at the time of their existence. The changes in ecological conditions cause either migrations of associations or adaptations to new situations. Adaptations cause evolutionary changes. Those forms that fail to adapt or migrate are bound to become extinct. In order to calculate correlations in an easier way, Mein (1975) has introduced a new unit to biostratigraphy – mammal zones for geological periods Paleogene (MP – abbreviation for *Mammals Paleogene*), Neogene (MN - *Mammals Neogene*) and Quaternary (MQ – *Mammals Quaternary*). The zones represent the series of fossil mammalian associations at individual localities, arranged in chronological sequences according to the evolutionary level (*stage-in-evolution*) and appearance or disappearance of specific taxa due to migration or extinction (De Bruijn *et al.*, 1992).

According to values of correlation with sites in central and southeastern Europe and Asia Minor, mammalian associations from sites in Serbia were placed in MN zones (Fig.1). The most complete associations are comprised of both large and small mammals. Presently there are only a few of them at the territory in Serbia. The individual records were only temporarily placed in MN zones according to morphological characteristics. Further field studies and possible increase in number of species recorded within the associations will evaluate the correctness of this decision.

Correlation was also used to determine influence of migration of mammalian faunas on composition of Miocene associations in Serbia. The main directions are West-East and East-West. They were recorded in all fossil sites in Serbia. This was particularly pronounced in composition of associations from Sibnica 1, Snegotin, Prebreza,Vračevići and Riđake. There are three assumed migratory phases, determining the composition of rodent fauna in Miocene of Serbia:

- The first phase (second half of Otnangian and first half of Carpathian), with species characteristic of extreme southeast of Europe and Anatolia,
- The second phase (beginning of second half of Badenian), with species characteristic for rodent associations of Central Europe,
- The third phase (end of Badenian, Sarmatian and beginning of Pannonian), with new influx of faunistic elements of southeastern Europe and Anatolia.

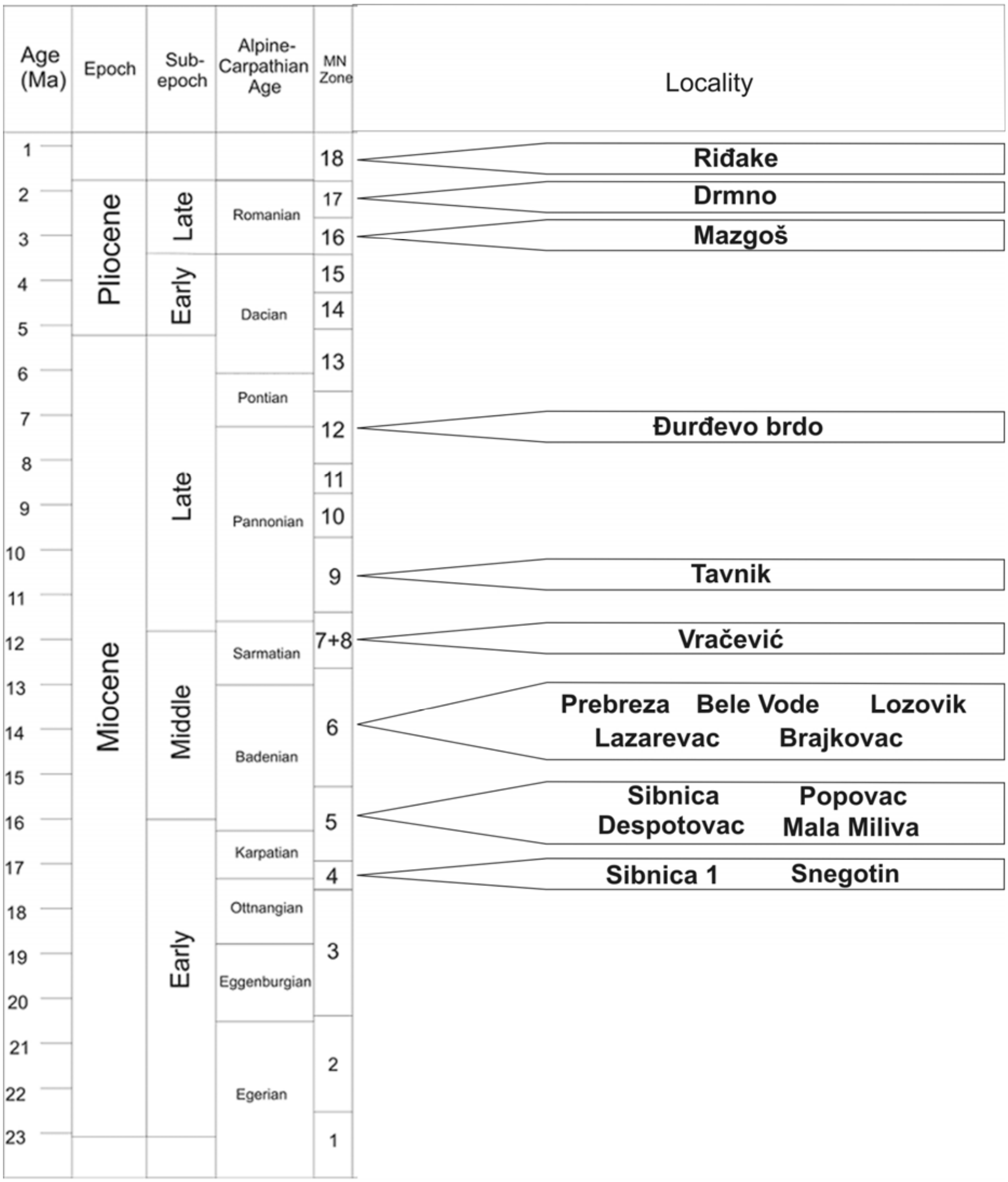

Fig. 1. Chronostratigraphic positions of the Neogene mammals localities in Serbia

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CHANGES ON THE OFFICIAL QUATERNARY CHRONOSTRATIGRAPHICAL SCALE (ICS-IUGS)

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The duration of the Pleistocene was according Penk and Brückner's (1909-1011) Alpine stratigraphic model being estimated at 660,000 years. It should be an early attempt at establishing a glacial-interglacial chronology, using the depth of weathering and the "intensity of erosion" in the northern Alpine region of Europe to estimate the duration of interglacial periods (Walker, 2005).
When in 1924 Eberl identified the traces of older ice ages, soon Milankovitch reconstructed the curves that records fluctuations of solar radiation for the last million years with the additional two glaciations (Eberl, 1930).
Until the 1970s the official lower boundary of the Quaternary and Pleistocene was pointed at ~1 Ma before present (Holmes, 1937, 1960; Kulp, 1961) (Figure 1). This concept based on Gignoux (1910) proposal of the "Calabrian" Stage for the "lowermost Pleistocene" ("Newer Pliocene") of Lyell (Ogg, 2004).
The new research results of climatic changes from the more precise investigations and newly established methodologies suggests the need to lowering the Quaternary and Pleistocene base (Figure 1).

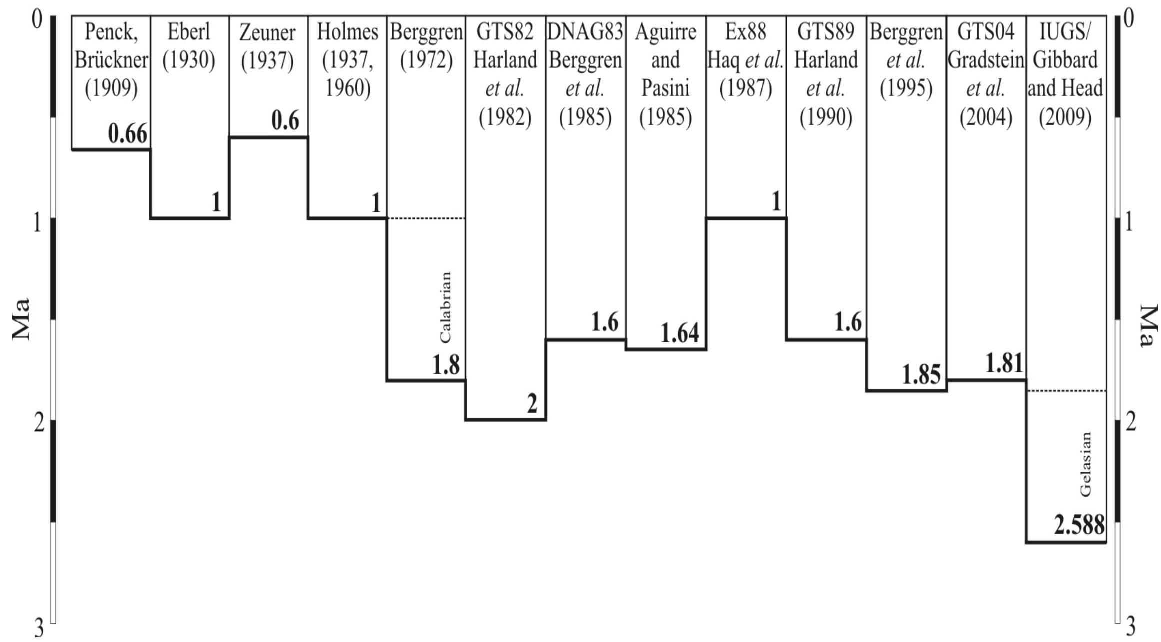

Figure 1. Overview of the time frame of the Quaternary (Gradstein, 2005, modified)

After the WWII in 1948 at the XVIII International Geological Congress (IGC) in London, an attempt was made to identify the Pleistocene base. The Vrica section in Calabria, southern Italy was finally selected, culminating in the ratification of the Plio-Pleistocene boundary, with an estimated age of 1.64 Ma (Aguirre and Pasini, 1985; Basett, 1985). Subsequently Hilgen (1991) calculated an astronomical calibrated age of 1.81 Ma for the boundary (Pillans and Naish,

2004). The draft proposal on the choice of a boundary stratotype for the the Pliocene-Pleistocene boundary was submitted and approved by the International Union for Quaternary Research (INQUA) Commission on Stratigraphy (also acting as the Subcommission on Quaternary Stratigraphy of the International Commission of Stratigraphy) at the XI INQUA Congress in Moscow (1982). The decision to assign the Global Stratotype Section and Point (GSSP) at Vrica in Sicily for the base of the Pleistocene near the top of Olduvai subchron was approved by the International Commission of Stratigraphy (ICS) in 1983, and this decision was "*isolated from other more or less related problems, such as...the status of the Quaternary within the the chonostratigraphic scale*" (Aguirre and Pasini, 1985) (after Ogg, 2004).
As part of attempt to standardize the geologic time scale, the International Commission on Stratigraphy (ICS) did away with the terms Tertiary and Quaternary, gave Paleogene and Neogene Period/System rank, and extended the Neogene to include the Pleistocene and Holocene (Berggren, 1998; Gradstein et al., 2004 and others). While this solution avoids the Tertiary/Quaternary boundary debate and provides a clear definition for scientific use, it overlooks a long history and tradition of usage.
The decision to abandoned the term Tertiary follows the historical trend that abandoned Primary and Secondary, and the scientific community has apparently accepted this change (Ogg, 2004; Aubry, 2005). The term Quaternary, however, has received overwhelming support to be retained as a formal chronostratigraphic unit.

System/ *Period*	Series/ *Epoch*	Subseries/ *Sub-epoch*	Stage/*Age*	MIS	Age (Ma)
QUATERNARY	Holocene			1	0.012
	Pleistocene	Upper/*Late*	Tarantian	2-5	0.126
		Middle	Ionian	6-19	0.781
		Lower/*Early*	Calabrian	20-63	1.806
			Gelasian	64-103	2.588

Table 2. Chronostratigraphical/*geochronological* subdivision of the Quaternary
(Gibbard et al., 2010, modified)

On 29th June 2009, the Executive Committee of the International Union for Geological Sciences (IUGS) approved, by majority vote, the 2nd June 2009 recommendation of the International Commission on Stratigraphy (ICS) that:
"1) the base of the Pleistocene Series/Epoch be lowered such that the Pleistocene includes the Gelasian Stage/Age and its base is defined by the Monte San Nicola GSSP, which also defines the base of the Gelasian;
2) the base of the Quaternary System/Period, and thus the Neogene–Quaternary boundary, be formally defined by the Monte San Nicola GSSP and thus be coincident with the bases of the Pleistocene and Gelasian, and
3) with these definitions, the Gelasian Stage/Age be transferred from the Pliocene Series/Epoch to the Pleistocene." (Riccardi, 2009)

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MIS, TERMINATIONS, STAGES, STADIALS/INTERSTADIALS

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Oxygen is one of the most significant keys to deciphering past climates. Oxygen comes in heavy and light varieties, or isotopes, which are useful for paleoclimate research. All oxygen atoms have 8 protons, but the nucleus might contain 8, 9, or 10 neutrons. "Light" oxygen-16, with 8 protons and 8 neutrons, is the most common isotope found in nature, followed by much lesser amounts of "heavy" oxygen-18, with 8 protons and 10 neutrons.
The ratio (relative amount) of these two types of oxygen in water changes with the climate. By determining how the ratio of heavy and light oxygen in marine sediments, ice cores, or fossils is different from a universally accepted standard, scientists can learn something about climate changes that have occurred in the past. The standard scientists use for comparison is based on the ratio of oxygen isotopes in ocean water at a depth of 200-500 meters.
Evaporation and condensation are the two processes that most influence the ratio of heavy oxygen to light oxygen in the oceans. Water molecules are made up of two hydrogen atoms and one oxygen atom. Water molecules containing light oxygen evaporate slightly more readily than water molecules containing a heavy oxygen atom. At the same time, water vapor molecules containing the heavy variety of oxygen condense more readily.
Ocean waters rich in heavy oxygen: During ice ages, cooler temperatures extend toward the equator, so the water vapor containing heavy oxygen rains out of the atmosphere at even lower latitudes than it does under milder conditions. The water vapor containing light oxygen moves toward the poles, eventually condenses, and falls onto the ice sheets where it stays. The water remaining in the ocean develops increasingly higher concentration of heavy oxygen compared to the universal standard, and the ice develops a higher concentration of light oxygen. Thus, high concentrations of heavy oxygen in the ocean tell scientists that light oxygen was trapped in the ice sheets. The exact oxygen ratios can show how much ice covered the Earth (www.briannica.com).
Ocean waters rich in light oxygen: Conversely, as temperatures rise, ice sheets melt, and freshwater runs into the ocean. Melting returns light oxygen to the water, and reduces the salinity of the oceans worldwide. Higher-than-standard global concentrations of light oxygen in ocean water indicate that global temperatures have warmed, resulting in less global ice cover and less saline waters. Because water vapor containing heavy oxygen condenses and falls as rain before water vapor containing light oxygen, higher-than-standard local concentrations of light oxygen indicate that the watersheds draining into the sea in that region experienced heavy rains, producing more diluted waters. Thus, scientists associate lower levels of heavy oxygen (again, compared to the standard) with fresher water, which on a global scale indicates warmer temperatures and melting, and on a local scale indicates heavier rainfall (www.britannica.com).
Paleoclimatologists use oxygen ratios from water trapped in glaciers as well as the oxygen absorbed in the shells of marine plants and animals to measure past temperatures and rainfall. In polar ice cores, the measurement is relatively simple: less heavy oxygen in the frozen water means that temperatures were cooler. Oxygen isotopes in ice cores taken from mountain tops closer to the equator are more difficult to measure since heavy oxygen tends to fall near the equator regardless of temperature. In shells, the measurement is far more complicated because the biological and chemical processes that form the shells skew the oxygen ratio in different ways depending on temperature.
The **marine isotope stages (MIS)**, their previous name was marine oxygen-isotope stages (MOIS), and also sometimes named oxygen isotope stages (OIS), however it was an evident

chronological differences between isotope stage recorded in the marine and continental deposits. MIS are alternating warm and cool periods in the Earth's paleoclimate, deduced from oxygen isotope data reflecting changes in temperature derived from data from deep sea core samples.

The **MIS timescale** was developed from the pioneering work of Cesare Emiliani in the 1950s, important advance came in 1967, when Nicholas Shackleton suggested that the fluctuations over time in the marine isotope ratios that had then become evident were caused not so much by changes in water temperature, as Emiliani thought, but mainly by changes in the volume of ice-sheets, which when they expanded took up the lighter oxygen-16 isotypes in preference to the heavier oxygen-18.

The cycles in the isotope ratio were found to correspond to terrestrial evidence of glacials and interglacials. A graph of the entire series of stages then revealed unsuspected advances and retreats of ice and also filled in the details of the stadials and interstadials. The marine isotopic records appear more complete and detailed than any terrestrial equivalents, and have enabled a timeline of glaciation for the Plio-Pleistocene to be identified.

Abrupt climate changes observed on the recently received continuous MIS records immediately attracted the attention of paleoclimatologists. Emiliani noted the characteristic "jagged" curve of the climate change (1966), which suggested that deglaciation occurred suddenly, during a period which did not exceed 10,000 years, as opposed to a gradual cooling process during glaciation. These sudden changes from completely glacial to completely interglacial conditions Broecker and van Donk (1970) called **termination**. In the past 620,000 years, seven terminations have been identified which comprise the six full glacial cycles (Broecker, 1984). They are marked with Roman numerals, starting from I, between the transition from MIS 6 to 5, to VII on the border between MIS 16 and 15. The "mid-point" period of the terminations is shown in Fig. 1. It has been observed that terminations III (MIS 8/9) and VI (MIS 14/13) are not terminations in the full sense of the word. Abrupt paleoclimatic changes, labeled by terminations I, II, IV, V and VII, form after a large amount of ice has been accumulated in the full glacial, which was not the case during MIS 14 and 8 (Raymo, 1997). On the SPECMAP timescale, terminations are closely related to the increase in summer insolation at φN65o, suggesting that global deglaciation occurs during thawing at high altitudes in the northern hemisphere (Broecker, 1984; Imbrie et al., 1993). The time interval between termination varies from 84,000 (terminations IV-V) to 120,000 (III-II) years, that is five-to six process cycles (Raymo, 1997).

In the international Quaternary English language climatostratigraphic nomenclature the term **stage has a dual use** while in the nomenclature in Serbian for this word we use terms “kat” (in plural “katovi”) and “stadijum” (in plural “stadijumi”).

“Kat” as a stratigraphic and chronostratigraphic unit have been used for much longer while the use of “stadijum” in professional Serbian literature is much more recent (Momčilović, 1974; Rundić, 2007).

The use of the “kat” is used with climatostratigraphic units with geographical
names, and if there are no geographical determinants the term “stadijum” is used. Examples of the use of “kat” are Holstein or Holstein “kat” (Holsteinian) in case of north-western stages (North West European Stages); Ipswich or Ipswich “kat” (Ipswichian) in case of British Isles floors (British Stages); Wisconsin or Wisconsin “kat” (Wisconsinan) if the subject are North American ”katovi” (North American Stages); Valdai or Valdai “kat” (Valdaian) and the Russian Plain “katovi” (Russian Plain Stages).

The term Gelasian is used as a geographical determinant, but when regional stratigraphic units are in question the correct use is: Italian Marine Stages or Italian Marine Super Stages, as it represents basic or standard “katovi” or stages ("Standard Stages") (Gaudenyi & Jovanović, 2012).

“Stadijum” or “stadijumi” used for OIS or MIS are primarily climatostratigraphic terms (Gibbard & van Kolfschoten, 2004). Based on changes in the δ18O oxygen isotope in deep-sea sediments the SPECMAP paleoclimatic model (Imbrie et al., 1984) was formed. Starting from the Holocene, the warm periods are marked by odd numbers and the cold phases with even numbers.

In the Quaternary setting the growth of stratigraphy recognised from short-duration, often highly characteristic events has led to attempts to use these features as a basis for correlation. This event stratigraphy (e.g Lowe et al., 1999), typically includes changes of sea level, climatic oscillations or rhythms and the like. These occurrences, often termed 'sub-Milankovitch events', may be preserved in a variety of environmental settings and thus offer important potential tools for high- to very high-resolution cross-correlation. Of particular importance are the so-called 'Heinrich Layers' which represent major iceberg-rafting events in the North Atlantic Ocean. These detritus bands can potentially provide important lithostratigraphical markers for intercore correlation in ocean sediments and the impact of their accompanying sudden coolings ('Heinrich Events') may be recognisable in certain sensitive terrestrial sequences (summary in Lowe & Walker 1997). The term stadial has been adopted for these short-lived cold phases, whilst the intervening warmer phases are referred to as interstadials in the ice-core sequences (cf. climatostratigraphy).

The American Code (1961) defines the fundamental units of the geologic-climate classification as follows:

A Glaciation is a climatic episode during which extensive glaciers developed, attained a maximum extent, and receded. A Stadial ('Stade') is a climatic episode, representing a subdivision of a glaciation, during which a secondary advance of glaciers took place. An Interstadial ('Interstade') is a climatic episode within a glaciation during which a secondary recession or standstill of glaciers took place.

An Interglacial ('Interglaciation') is an episode during which the climate was incompatible with the wide extent of glaciers that characterise a glaciation.

In Europe, following the work of Jessen & Milthers (1928), it is customary to use the terms interglacial and interstadial to define characteristic types of non-glacial climatic conditions indicated by vegetational changes; interglacial to describe a temperate period with a climatic optimum at least as warm as the present interglacial (Holocene, Flandrian) in the same region, and interstadial to describe a period that was either too short or too cold to allow the development of temperate deciduous forest or the equivalent of interglacial-type in the same region (West 1977).

In North America, mainly in the USA, the term interglaciation is occasionally used for interglacial (cf. American Code 1961). Likewise, the terms stade and interstade may be used instead of stadial and interstadial, respectively (cf. American Code 1961) (Gibbard & van Kolfschoten, 2004).

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INTRACARPATHIAN CONNECTION BETWEEN THE PANNONIAN AND DACIAN BASINS

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The mountain range of the Carpathians had a natural barrier formed through the Neogene, which separated large sedimentary areas of the western Pannonian basin from the eastern Dacian basin. During the existence of the complex epicontinental sea Parathetys in the Lower and Middle Miocene, the link between the eastern and central Parathetys was the Intracarpathian straits. The connection was broken early in the Upper Miocene or at the Middle/Upper Miocene boundary by the Carpathians uplifting. The isolated Pannonian Sea transformed into the brackish lake Pannon (Magar et al., 1999) in which developed endemic fauna, referred to in literature as the caspibrackish fauna. The present-time territory of Serbia with its Upper Miocene deposits is the key area for interpretation of the Middle and Upper Miocene geodynamic processes in the East/Central Paratethys, because it included south-Carpathians, southeastern Pannonian Basin and western margin of the Dacian Basin.

Largely peripheral through most of the Miocene and in the Pliocene and a foreland in the eastern Paratethys, the Dacian Basin had the deep Black Sea basin in its centre (Bartol et al., 2012). During the late Miocene 'salinity crisis', sea level in the eastern Mediterranean was considerably lower, but so it was also in the Black Sea aquatorium that had periodical communication with the eastern Mediterranean Sea. The Black Sea water body communicated with the eastern Mediterranean through the Scythian strait, along or across Dobrogea barrier (Bartol et al., 2012). The isolated lake Pannon surrounded by mountain ranges of the Carpathians, Alps and Dinarides, must have had a larger surface area than the basins of the eastern Paratethys or the Mediterranean Sea.

The link forming between the lake Pannon and the Dacian Sea in the Upper Miocene was a dramatic and important event in the evolution of the Central and Eastern Europe. It opened through the Carpathians a water-course of communication and migration of fauna between the basins of the Central and Eastern Paratethys. Sediments deposited on the either side of the Carpathians, those in Serbia determined as Pontian beds. Biostratigraphical boundary of the Pontian and the underlying Maeotian is sharp and distinct, according to (Stevanović, 1951), whereas the boundary with the older Pannonian in the Pannonian basin is gradual and indistinct in places.

A likely guideline for reconstruction of the process of communication between the lake Pannon and the Eastern Paratethys is the hypsometric record of synchronous Pontian beds, as well as the analysis of faunal assemblages. Outcrop areas of Pontian rocks in Serbia, formed in the Pannonian basin, are found at elevations over 150 metres, up to 250 metres, and rarely at 250 metres in western Serbia. Pontian beds of eastern Serbia from the Dacian basin are recognized at the highest altitudes between 80 and 100 metres, or rarely 150 metres (Fig. 1). These elevations of Pontian deposits in Serbia and the level difference of synchronous rocks between the Pannonian basin west of the Carpathians and on the periphery of Dacian basin east of the Carpathian resulted from two controlling factors: (a) initial topographic status of the two separated water bodies before the communication in the Pontian and (b) differential movement of the basement in the Pliocene and the Quaternary, or a relative uplift of most of the Pannonian basin and further subsidence of the Dacian floor and the Black Sea basin.

The new break-through the Carpathians in the late Miocene was preceded by an endogenic process, radial tectonic movement, and its resultant faults that cut across the mountain range. The new corridor did not use the old straits from the Middle Miocene with the fragmentary preserved deposits in the isolated areas at Donji Milanovac and the village Slatina near Bor. It opened in a new place, according to (Stevanović, 1951, 1987), where the Djerdap Gorge is at present. The Latin name for the Djerdap (*Porta ferrum*, or Iron Gate), where the new corridor formed to connect aquatoria of the lake Pannon and the eastern Paratethys, was given to a Pontian substage – the Portaferrian. Formation of the new waterway was a complex geodynamic process. One or possibly more water-courses developed along the faults from the western periphery of the Carpathians to the Dacian basin. The stream or streams formed a river that transported water from the lake Pannon into the Dacian Sea, very likely over one large or a number of small waterfalls to cover the difference in surface elevation. Geomorphologically, the situation is comparable to the present-day connection of the North-American Great Lakes. Here the more elevated Lake Erie outlet flows over the Niagara Escarpment, the known Niagara Falls, into the less elevated Lake Ontario. The river and fall connection transformed through geologic time into a true lake strait.

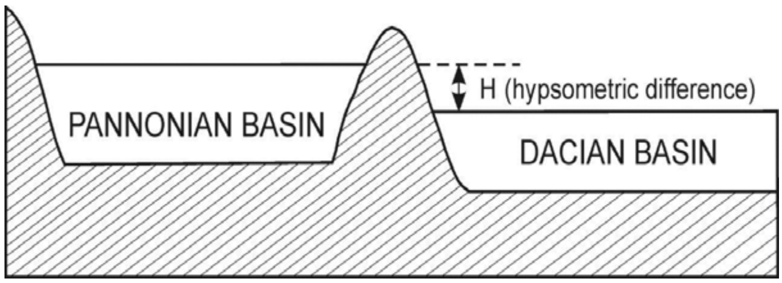

Fig. 1: Proposed hypsometric differences between Pannonian and Dacian Basin

Similar examples of the interconnection of large sedimentary basins in different topographic positions may be found in the geological record of the Mediterranean Sea. Its link with the Atlantic Ocean in the Pliocene was the present area of Gibraltar. The Ocean level was then higher than the surface of the Mediterranean Sea; the communication began over a huge waterfall. Thousands of years elapsed before the Mediterranean Sea level equalled the surface of the adjoining ocean. A geographically nearer example is the communication of the Mediterranean and the Black Sea in the early Holocene, when tectonic events and subsequent exogenic processes formed a corridor in the present Bosporus area. The extensive Black Sea basin included a large cryptodepression with its deepest part accommodating a freshwater lake. With the global rise of sea level resulting from the melting of ice sheets in the early Holocene, the Mediterranean Sea level exceeded the elevation of the isolated cryptodepression in the Black Sea basin. Communication of the water bodies established across Bosporus was a seaway over an immense waterfall until levels in the two aquatoria equated and the present-day Bosporus strait was formed.
After the Pannonian and Dacian basins have been linked by the Đerdap waterway, endemic caspibrackish fauna migrated from the elevated lake Pannon to the eastern Paratethys. Many fossil faunal species occur in both depositional environments. Some species in the Serbian part of the Dacian basin, however, are lacking (Stevanović, 1951) in the Pontian west of the Carpathians. This may imply the adaptation of caspibrackish fauna originally from the lake Pannon and its development when the bionomic conditions became favourable. New species of kaspibrackish fauna developed in the changed environment, which could not migrate through the Đerdap strait, and are lacking in the Pontian west of the Carpathians.
The above facts lead to the conclusion that the formation of the Đerdap waterway was complex and that the course of water and fauna migration run mainly from the lake Pannon to the Dacian-Black Sea basin.

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BRACKISH MIOCENE OF THE DACIAN BASIN IN EASTERN SERBIA – EXAMPLES, STATE AND CORRELATION POTENTIALS

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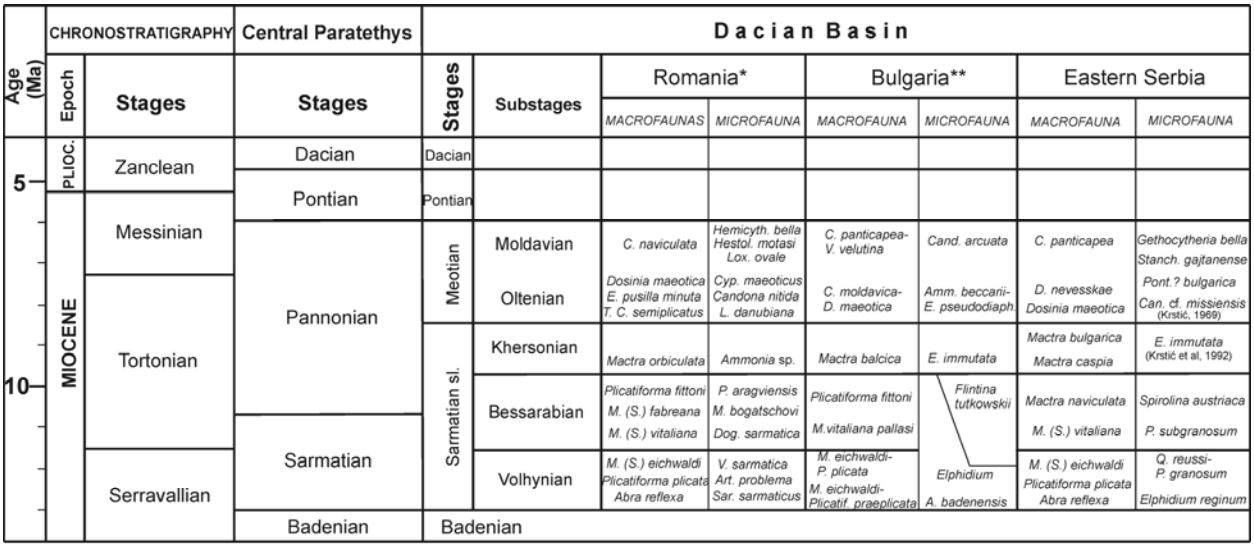
The Dacian basin in the Eastern Serbia extends NNE-SSW direction, from Kladovo in the North up to Veliki Izvor, i.e. Vrska čuka in the South. In geomorphological terms this area belongs to Eastern Carpathian foreland or Western margin of Dacian basin. Brackish Miocene is, in this area, distinguished by formations of Sarmatian and Meotian stages and it extends to the north of Zaječar.

During Sarmatian and Meotian ages, sedimentation occurred in the area of former shelf, so that terrigenous deposits and carbonates dominate. Altered bionomic conditions as the result of salinity drop due to the isolation of Paratethys at that time had an effect on the structure of fauna in this area as well, where euryhaline forms with large number of individuals in associations dominate.

The oldest Sarmatian sediments are characterized by clays and sandy clays (Džodžo-Tomić, 1963, 1970), siltstones, and in higher layers there are sands, gravels and limestone of Volhynian Substage, where molluscs corresponding to zones: *Abra reflexa*, *Plicatiforma plicata* and *Mactra (Sarmatimactra) eichwaldi* could be found (Ganić, 2005). Biostratigraphic divisions of the Volhynian were also made on the basis of Foraminiferal associations, where two zones distinguished: older *Elphidium reginum* and younger *Porosononion granosum/Quinqueloculina reussi* (Ganić, 2005), (Fig. 1). Formations of this age may be followed at several locations in the area of Štubičko-Timočka valley and eastern of this structure, for example in the area of Jabukovac, Šipikovo, Braćevac, Tamnič, Rogljevo, Jelašnica etc.



*(Papaianopol, Marinescu, 1994)
**(Kojumdgieva et al. 1989)

Fig. 1. The Correlation chart of Dacian Basin in Eastern Serbia with neighbouring areas

The Bessarabian Substage is in lower part distinguished by clayely sand and varved sandy clay sediments and in upper parts by different types of limestone and sandstone. Older layer is distinguished by zone of the molluscs association with *Mactra (Sarmatimactra) vitaliana*, and younger, calcareous, oo-intra-sparite, correspond the zone with *Mactra naviculata* (Ganić,2005). Foraminiferal associations consist of forms that have better adapted to brackish sea regime, so that two taxon range zones can be distinguished: the older one with *Porosononion subgranosum* and younger zone with *Spirolina austriaca* (Ganić, 2005), (Fig. 1). Bessarabian sediments were established in the vicinity of Zlokuće, Rajac, Crnomasnica, Braćevac, Kovilovo, Jasenica, Čubra and Negotin.

Khersonian sediments in Eastern Serbia are small distribution which is the result of regressive movements. Mainly there are poorly sorted clastic sediments (gravelly sands and silty-sandy gravels, argillaceous siltstones). At the same time, there are also calcarenite and calcrudite limestone. The brackishness of the sea has affected the existence of euryhaline type fauna, whose populations had a small number of genera and species but a large number of individuals (Stevanović, Paramonova, 1983). The Macrofaunistic association corresponds to older Khersonian and it is distinguished by the zone containing *Mactra bulgarica* and *M. caspia*, (Ganić,2005), and zonal ostracod species is *Euxinocythere immutata* (Krstić *et al*, 1992) (Fig. 1). Khersonian formations are established near Mihajlovac, Dušanovac, Mokranje and Bukovo.

Meotian Stage (Upper Miocene) in Eastern Serbia is transgressive over the Khersonian or Bessarabian sediments, where also angular discordance exists (Stevanović, 1977, 1980). Meotian formations are distinguished by gravels, sands and clays, and partially there are also interbeds of limestone. Based on macrofauna, two zones (Ganić,2005), can be distinguished: older zone containing *Dosinia maeotica* and *Dreissenomya nevesskae* and younger zone containing *Congeria panticapea bulgarica* (Ganić, 2005). By analyzing microfaunistic associations of ostracods, 4 biostratigraphical zones were separated (Krstić, 1969): 1. zone *Candona* aff. *missiensis*, 2. zone *Pontioniella*? *bulgarica*, 3. zone *Stanchevia gajtenense* i 4. zone *Getocytheria bella* (Fig. 1). Meotian sediments were established near Podvrška, Badnjevo, Bukovo, Mihajlovac etc.

This stratigraphic division of Sarmatian and Meotian sediments of the western margin of Dacian basin in Eastern Serbia (Fig. 1) represents the framework for correlation with synchronic units of Eastern Paratethys (Dacian basin in Romania and Bulgaria), Central Paratethys (Pannonian basin) and the relation to the global stratigraphic division (Stioca *et al*. 2013).

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STRATIGRAPHICAL MODEL OF THE SERBIAN LOESS

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The results of multidisciplinary investigations of loess-paleosol sequences (LPSS) in the Vojvodina region over the last several years have improved knowledge and understanding of the their chronostratigraphy. LPSS preserved in northern part of Serbia are exceptionally complete and as such represent one of the most detailed terrestrial climatic records available. Marković *et al*. (2003, 2006, 2012) designated the loess-paleosol units names in North Serbia following the Chinese loess-stratigraphic system (e.g. Liu, 1985; Kukla, 1987; Kukla and An, 1989), but inserting prefix "SL" referring to the Stari Slankamen site as the standard type section. Due to incompleteness of the youngest part of Stari Slankamen section, the prefix "V" is now used (Marković *et al*., 2008, 2013).
Stratigraphy of LPSS in North Serbia is resolved using several independent aproaches.
Although stratigraphy of Last Glacial LPSS from Vojvodina is resolved by absolute dating (Fuchs et al., 2008; Markovic et al., 2008), for older horizon there is still no agreeable dating. That emphasize importance of MS correlation (Buggle et al., 2008; Markovic et al, 2012, 2013).

Loess stratigraphy		MIS
Serbian loess	China	
V-S0	S0	1
V-L1	L1	2, 3, 4
V-S1	S1	5
V-L2	L2	6
V-S2	S2	7
V-L3	L3	8
V-S3	S3	9
V-L4	L4	10
V-S4	S4	11
V-L5	L5	12
V-S5	S5	13, 14, 15
V-L6	L6	1
V-S6	S6	17
V-L7	L7	18
V-S7	S7	19
V-L8	L8	20
V-S8	S8	21
V-L9	L9	22
V-S9	S9	23, 24, 25
V-L10	L10	26
Basal complex V-S10-?	S10-?	27-?

Table 1. Relationship between Serbian (Marković et al., 2012) and Chinese (Kukla, 1987; Kukla & An., 1987) loess-paleosol units and Marine Oxygen isotope subdivision (Imbrie et al., 1984) (after Marković et al., 2012)

The first thermoluminiscence dating provided by Singhvi *et al*. (1989) and Butrym *et al*. (1991) are significantly revides by recent application of TL and IRSL. These techniques have been widely applied on the last glacial/interglacial loess sequences in Vojvodina (Antoine *et al*., 2009; Bokhorst *et al*., 2009; Fuchs *et al*., 2008; Marković *et al*., 2008).
Amino acid racemisation (AAR) relative geochronology has been successfully applied to define up to last 5 glacial-interglacial cycles (Marković *et al*., 2005, 2006, 2011).
On the Stari Slankamen section, paleomagnetic Brunhes-Matuyama boundary (MBB) between Lower and Middle Pleistocne is detected. The results of the paleomagnetic investigations on the site are confirmed and precisely positioned (Hambach *et al*., 2009; Jovanović *et al*., 2010; Marković *et al*., 2011). Presence of reversed polarity is shown in lower part of the lowest loess layer V-L9. The lowermost 1 m of section, within the basal pedocomplex, exhibits an interval of normal polarity, potentially indicating the Jaramillo Subchron. Time lag between detected and expected MBB postition is result of complex lock-in processes (e.g. Spassov *et al*., 2003; Liu *et al*., 2008). However, according to paleointensity results, MBB reversal occurs during formation of V-S7 paleosol, which is equivavelnt of MIS 19. Such postition is equvivalent to MBB in Chinese loess (Zhou and Shackleton, 1999; Tauxe *et al*., 1996).
Detailed subdivision of the Brunhes Chron age LPSS in Vojvodina is based on the magnetic susceptibility (MS) record. The distinct and characteristic MS signal at many investigated loess sites in Vojvodina, resembles the typical pattern of the enviromagnetic records determined from other Eurasian loess sites. As proxy of paleoclimatic trends rock magnetic data allow to extend correlation to marine isotope record and Antartica ice cores also (Antoine *et al* ., 2009; Buggle *et al*., 2009; Fuchs *et al*., 2008; Hambach *et al.,* 2008; Marković *et al.,* 2005, 2008, 2009, 2011, 2012)

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ARCHAISMS IN THE SERBIAN QUATERNARY STRATIGRAPHY

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In the recent year two main concepts in the Serbian stratigraphy should be placed to the history of the stratigraphical research: the globally rejected use of the Alpine morphostratigraphical model as chronostratigraphical model and the Eopleistocene stratigraphical unit for the Serbian Lower Pleistocene sequences.

Penck & Brückner´s morphostratigraphical model of the Alps (1909-1986)
In the Alpine region the term "glaciation" in a climatostratigraphic sense refers to a period during which the glaciers reached down into the foothills. Periods during which this was not the case showed refereed to a "cold stage" (Ehlers, 1996).
The classic Alpine stratigraphy is largely a morphostratigraphy. The so-called glacial series consist of a sequence of tongue basins with drumlins, moraine belts and gravel spreads. The term "glacial series" coined Penck & Brückner (1901-1909). Peck and his student Brückner laid emphasis on demonstrating the direct connection between gravel spraeds, terraces and moraines of the same age. In the northern foothills of the Alps comprehensive morphological sequences of this type were initially found only for three glaciations; for the fourth this evidence was produced much later through investigations in Upper Austria (Weinberger, 1950; Kohl, 1958). Rögner (1979), however considers that he has detected intercalated melteater deposits and morainic material of fifth glaciation, no such complete landform assemblages have been preserved.
The morphostratigraphic method was developed in the northern Alpine foothills; it is there where it is best applied. In the southern and French margin of the western Alps, it is much difficult to use this method. These restrictions also apply to central Switzerland, where the Jurassic mountains barred free outflow of glaciers and meltwaters (Ehlers, 1996).
Since the time when Penck & Brückner (1901-1909) published their classical account of the Alpine "Ice Ages" their division of the Pleistocene into four cold stages stages with interwarming warm stages has become a model that has applied globally into nurmeous local stratigraphies as for the Serbian terrestrial sequences. Some followers even went as far as classifying the deposits of the Middle Danube Basin or other regions with the Alpine stratigraphical nomenclature. A uniformity of names, however only makes sense where the deposits can be reliably demonstrated to the same age. Penck & Brückner´s (1901-1909) system has been understood as a chronostratigraphical subdivision, but actually it is based upon morphostratigraphical correlations that are not easily transferred into different regions (Ehlers, 1996).
Although being an internationally recognised Quaternary stratigraphical framework, the original stratigraphic subdivision into Günz, Minder, Riss and Würm no longer corresponds with the result of deep-sea stratigraphy and other recent discoveries of the international Quateranry research. Even in the Alpine region, the results of recent research can only be fitted into this old system with great difficulties. These major problems became evident within the framewor of the ICGP Project 24 "Quaternary Glaciations in the Northern Hemisphere". As a result, one of the conclusions in the final report was: "In the Alpine region the classic nomenclature of Penck & Brückner must be abandoned" (Šibrava, 1986; Ehlers, 1996).

Eopleistocene of Serbia (1972-2010)
With the decision of the 18th IGC (held in London, 1948) to the lower Quateranry bourndary by addind the Calabrian Stage (in case of marine deposits) and Villafranchian Stage (in case of

terrestrial deposits) to the Lower Pleistocene (King and Oakley, 1950), from the 1970s it became evident that the lower boundary of the Pleistocene/Quaternary was numerically estblished at 1.8-1.6 Ma (e.g. Breggren, 1972; Haq et al., 1977). The Eopleistocene was introduced in 1972 from the former USSR scheme to denomite the oldest Quaternary fluvio lacustrine sequences which were older than 0.8 Ma and lie under the Tiraspolian beds which are equivalent to the “Mindel Glaciation” (after Rakić, 1975). This the nearly million year old gap was named with the new stage called Eopleistocene. This was one of the main reasons why the term Eopleistocene was implemented into the Serbian Quaternary stratigraphical terminology in 1972 and it was used in a semi-official way until 2010 (Gaudenyi et al., in press).

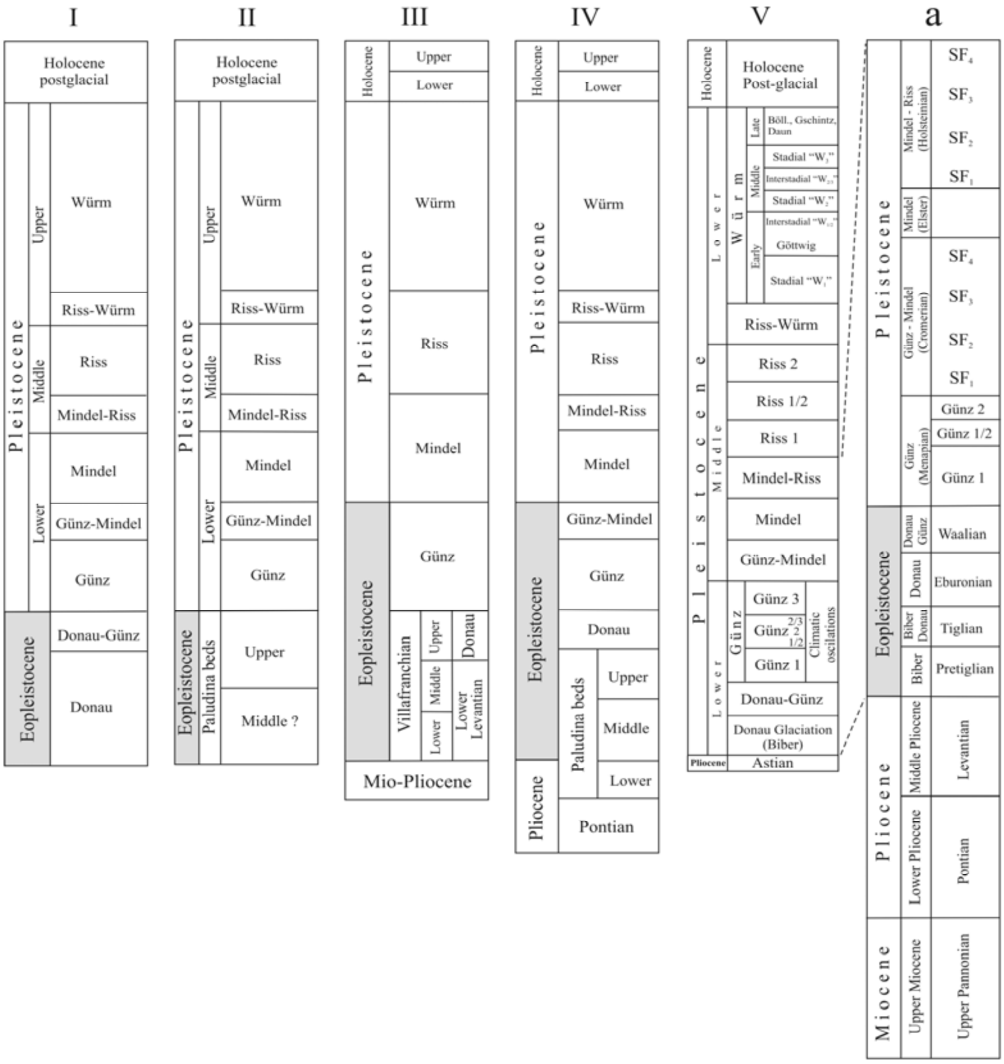

Table 1. The concept of the Quaternary stratigraphical scheme used in the 1970s and 1980s in Serbia (and Yugoslavia) The Global cronostratigraphical classification and the Italian Marine Stages were taken from the Cohen and Gibbard (2011) chart; the scheme for terrestrial deposits of Marković-Marjanović (1972) from is from Rakić (1976)., the Alpine glaciation model units are: G (Günz), GM (Günz-Mindel), M (Mindel), MR (Mindel-Riss), R (Riss), RW (Riss-Würm), W (Würm); the scheme for fluvial deposits (version A) is after Rakić (1975); the scheme for fluvial deposits (version B) is after Marković-Marjanović (1979).

In 2009, with the official ratification of the ICS (IUGS) of the lowering of the Neogene/Quaternary, i.e. Pliocene/Pleistocene boundary to 2.58 Ma, so anyway the use of the Eopleisteocene in the Serbian stratigraphical terminology lost its meaning.

The use of the term Eopleistocene in the Serbian stratigraphical scheme cannot be accepted in the sense of modern straigraphical principles, because the mixing of the discriminatory concepts of the Alpine morphostratigraphical model with regional (exUSSR) climatostratigrphical and/or biostratigraphical units was obvious. As a term, Eoplesitocene also caused a number of unclear and undefined problems/misunderstandings with regard to relations: Eopleistocene-Pleistocene, Eopleistocene-Lower Pleistocene (Table 1.), Eopleistocene-Alpine morphostratigraphical stages. With the developments and changes in the Quaternary stratigraphy, the Serbian Eopleistocene should be interpreted and replaced with (upper part of) Lower Pleistocene, because the base of the Eoplesitocene been identified at nearly 1.8 Ma and the Lower/Middle Pleistocene (Brunhes-Matuyama) boundary does not corresponds with the Eopleistocene-Neopleistocene boundary (Gaudenyi et al., in press).

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STRATIGRAPHICAL POSITION OF PLEISTOCENE FLUVIAL POLYCYCLIC DEPOSITS OF SERBIA

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Clastic deposits of the polycyclic fluvial phase of sedimentation have significant distribution in the areas of the Serbian part of the Pannonian basin, especially in the riparian area of the Danube and Sava. These sediments are almost everywhere overlain by younger Pleistocene or Holocene deposits, and their thickness varies from 20-30 meters in the periphereal parts, to more than 100 meters in the depressions of Vojvodina's part of the Pannonian Basin. The names *Corbicula fluminalis* beds (slojevi sa *Corbicula fluminalis*) and Makiš deposits (Makiški slojevi) come from the presence of molluscs identified for the first time by Laskarev (1926).
Some of these deposits do not contain *Corbicula fluminalis,* although it is evident that they have the same lithological and other characteristics (Laskarev, 1952). Basically the Pleistocene *Corbicula* was identified in three main areas: the area of the Sava and Danube riparian in the vicinity of Belgrade, Zrenjanin and between Brza Palanka and Golubac .
Lithologically, polycyclic fluvial sediment are made of cyclical alternation of typical riverbed deposits (sands, gravels) with sediments of flood phase (silts and clays) that could be observed in many places. In some cycles flood deposits are missing and regular multi-phase gradation of material has been formed, with coarser material in the lower, and finer in the upper parts. Beside *Corbicula fluminalis* (MÜLLER) the commonest fossil mollusks in these deposits are: *Fagotia acicularis* (FÉRRUSAC), *Fagotia esperi* (FÉRRUSAC), *Lithoglyphus naticoides* (PFEIFFER), *L. fuscus* (PFEIFFER), *Amphimelania holandri* (FÉRRUSAC), *Theodoxus transversalis* (PFEIFFER), *T. danubialis* (PFEIFFER), *Bithynia tentaculata* (LINNAEUS), *Viviparus boeckhi* (HALAVATS), , *Unio crassus* (PHILIPSSON), *Pisidium amnicum* (MÜLLER), etc (Nenadić, 2003; Nenadić *et al.*, 2009).
In the area of Srem these sediments are mainly deposited over the bog-terrestrial deposits of Pliocene and older Pleistocene, and only in the small part, in the area of the confluence of the Danube and Sava, they are underlain by Miocene deposits (Knežević *et al.,* 1998; Nenadić, 2003). These deposits are widely spread, forming riparian areas on the right side of the Sava, lower parts of the Kolubara and Tamnava valleys, and further to the south (Stejić, 1997; Stejić & Rakić, 1998). In the territory of the southern Banat these deposits (Rakić, 1985) lie over different levels of the Pontian or Paludina Beds (Beds with *Viviparus vukotinovici*), the equivalent of lower part of the Upper Pliocene. Similar deposits (Rakić, 1977) make the highest terrace floors in the valleys of the Zapadna and Južna Morava and Nišava, the Azanja fossil valley, Dunavski ključ etc. After this author, fluvial polycyclic sediments of Vojvodina can be correlated with gravels of the high terrace floors of the Donau (150-160 m), Günz (90-110 m) and Mindel glaciation (50-60 m).
Earlier authors (*e.g.* Laskarev, 1938; Stevanović, 1977) used the presence of the fossil assemblage of mollusks *Corbicula fluminalis* (MÜLLER) and *Viviparus diluvianus* (KUNTH.) to determine the age as Middle Pleistocene - Mindel, Mindel/Riss (after the Pleistocene subdivision for the Alps). The results concerning on the stratigraphy from core analysis in the 1990-s suggests that the Pleistocene *Corbicula* species of the Sava riparian belongs to the temperate stages (equivalent to the interglacials) of Early and Middle Pleistocene age (Nenadić *et al.*, 2010). The results also support the conclusions of the analysis of the Hungarian sites by Krolopp (2003).
In the studies of the Quaternary deposits between Brza Palanka and Golubac (Rakić & Simović, 1997), the sediments of the Sip terrace contains the associations of fauna with *Corbicula apsheronica,* "the older part of polycyclic deposits can be best fitted with Romanian, actually with Lower Levantian beds of Romania". In the Lower Levantian terminating with Mindel,

polycyclic river sediments are represented in the lower part by beds with *Unio dawilai* and in upper parts by *Viviparus boeckhi* and *Corbicula fluminalis* (Rakić & Simović, 1997). Basically the idea of subdivision of Rakić & Simović (1997) is that the lower part of policyclic sediments is synchronous with the Middle Paludina beds with the *Corbicula apsheronica* fauna, while the younger parts with more silt and clay were of "Mindel" age; however the authors' reason for definition of several *Corbicula*species has not been properly justified.

On the basis of the recent studies and the revision of the guide species, such as *Corbicula fluminalis* (MÜLLER), *Viviparus boeckhi* (HALAVATS) and *Fagotia esperi* (FÉRRUSAC), the polycyclic fluvial deposits that contain the mentioned species are dated as the Lower Pleistocene (Nenadić *at al*., 2009). In the area of the Belgrade Posavina the guide fossils presently used for determining age (Early Pleistocene) are *Viviparus boeckhi* (HALAVATS) and *Fagotia esperi* (FÉRRUSAC), in the older coarse-clastic beds and *Corbicula fluminalis* (O.F.MÜLLER) in the younger gravelly sands. However, in the deposits of Hungary, *Corbicula fluminalis* was found in the Lower Quaternary deposits in the *Viviparus boeckhi* Horizon (*e.g.* Halaváts, 1888).

The results concerning on the stratigraphy from core analysis in the 1990-s and comparison of the other European records, the malacological revision suggests that the taxonomy of the Pleistocene *Corbicula* species is not solved the *Viviparus diluvianus* from Serbia should be identified as *Viviparus boeckhi* (HALAVATS). The Serbian Pleistocene *Corbicula* beds belongs to the temperate stages (equivalent to the interglacials) of Early and Middle Pleistocene age. The results also support the conclusions of the analysis of the Hungarian sites by Krolopp (e.g. Krolopp 2003).

The results of the investigations shows that the Pleistocene *Corbicula* beds basically represents the litho-climatostratigraphical unit(s) which were identified according to the index fossils of fluvial *Corbicula* molluscs and it corresponds to the Pleistocene warm/temperate stages of the upper part of Lower Pleistocene and Middle Pleistocene. The lowermost subunit of the Pleistocene *Corbicula* beds identified as *Viviparus boechki* Horizon (after Halaváts, 1888) (Gaudenyi et al., 2013).

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LARGE MAMMALS AND QUATERNARY BIOCHRONOLOGY

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The mammal fossil record is not characterised by a continous and gradual evolution (as it could be expected), but is interrupted with sudden, abrupt changes: extinctions, rapid evolution, appearance of new adaptations, migrations. Such abrupt changes were earlier interpreted as a consequence of gaps in fossil record, but more recently it has become evident that they represent real revolutions, faunal (or "dispersal") events of continental scope. The concept of "dispersal events" as short periods of rapid intercontinental migrations and faunal replacements was first introduced by Repenning (1967).

In Lindsay et al. (1980) three dispersal mammalian events were recognized in the Pliocene and Early Pleistocene of Asia and Europe, dated respectively at about 3.4, 2.6 and 1.9 MYA (=millions of years ago). The fourth event was a revolutionary one, with the extinction of archaic Pliocene elements in fauna and the emergence of a new assemblage of modern appearance. This event is called the "end-Villafranchian event" (Azzaroli, 1983).

On the basis of these "dispersal events" and succession of mammal faunas three biochronologic units (mammal ages) in Quaternary were distinguished – Villafranchian, Galerian and Aurelian. Mammal ages (MA) have been further subdivided into faunal units (FU). High rank biochronological units (mammal ages) are useful tools for correlations, while lower rank biochronological units (faunal units) have a more restricted, regional correlative significance (Rook & Martínez-Navarro, 2010).

Mammal ages were first based on Italian fossil record and was established by Azzaroli et al. (1988), but later they were applied in other parts of Europe. In Russia V. I. Gromov already in 1948. recognized six mammal assemblages of Pleistocene fauna: Khaprovian, Psekupsian, Tamanian, Tiraspolian, Khazarian and Upper Palaeolithic. These assemblages were characterized by the presence of different mammoth species. The recent revision of them and correlation with biochronological zonation of Southern Europe has been made by Vangengeim (2010).

Villafranchian MA (Mammal Age). The term "Villafranchian" was proposed by Pareto (1865) as a continental stage referring to fluvial and lacustrine sediments in the surroundings of Villafranca d'Asti (Piedmont) with remains of mammal fauna. Gignoux (1916) proposed a correlation of this stage with marine Calabrian (late Pliocene). Thereafter, the term has been used rather loosely and ambiguously, for the continental formations and for a biochronological unit. The Villafranchian has recently been subdivided into Early, Middle and Late (Gliozzi *et al.* 1997) with eight Faunal Units (F.U.) (number of faunal units varies in different authors).

Early Villafranchian. The beginning of Villafranchian is defined with the first appearance of a primitive bovid of the genus of *Leptobos* in Italy (so-called "*Leptobos* event"; Azzaroli et al. 1988), large cervids and felids. This event took place approximately 3.5 MYA, and the whole Early Villafranchian belongs to Late Pliocene. The fauna of the Early Villlafranchian still retains typical forest elements (*Mammuthus*, *Tapirus*). The Early Villafranchian is also characterized in Eastern Europe (Romania, Bulgaria) by the appearance of a primitive form of the elephant - *Mammuthus rumanus*, the ancestor of *M. meridionalis* (Lister & van den Essen, 2003, Markov & Spassov, 2003).

Middle Villafranchian. The beginning of the Middle Villafranchian actually coincides with the Gauss/Matuyama magnetic transgression and the onset of Quaternary (Pleistocene). The boundary between Early and Middle Villafranchian is defined with the common appearance in fossil record of species *Mammuthus meridionalis* (*M. rumanus*, after Lister & van Essen, 2003) and *Equus* (a real horse with one finger – *Equus* cf. *livenzovensis*) (so-called "elephant-*Equus* event"; Azzaroli, 1977). "Elephant-*Equus*" dispersal event (dated about 2.6 MYA by Lindsay et al., 1980) marks the extinction of a warm forest assemblage from the last period (*Zygolophodon borsoni*, *Tapirus arvernensis, Sus minor* and *Ursus minimus*) and its replacement with a fauna indicative of a more open environment (a primitive elephant (*Mammuthus meridionalis/rumanus*), gazelle (*Gazella borbonica*) and a monodactyl equid (*Equus* cf. *livenzovensis*)) (Azzaroli, 1983). This faunal turnover is connected with climate worsening.

Recently, there is an opinion that the term "elephant-*Equus* event", although widely accepted, should be avoided, because both *Equus* and modern elephants (from the genus *Mammuthus*) could be found in some Early Villafranchian sites (Rook & Martínez-Navarro, 2010).

Late Villafranchian. There is no sharp transition between Middle and Late Villafranchian Faunas. The boundary between them is represented with the first appearance of the species *Canis etruscus* (Etrurian wolf). Martínez-Navarro (2010) has suggested that the term "Wolf-event" (Azzaroli, 1983) for the dispersal event in the beginning of the Late Villafranchian should be substituted with "*Pachycrocuta brevirostris*-event", because this is the most widespread carnivore of that time, and besides, *Canis etruscus* actually appeared already in the Middle Villafranchian (Costa San Giacomo) and *Canis* sp. even in the Early Villafranchian (Vialette). Mammal fauna of that period includes also *Leptobos etruscus* (which replaces earlier *L. stenometopon*), *Sus strozzii, Pachycrocuta brevirostris* (large hyaena) (Torre, 1967).

The "end-Villafranchian" event took place 1.0-0.9 MYA. That was an event of profound importance, because more than one half of the late Villafranchian fauna disappeared without descent. Few species survived but only for a short time in the Early Middle Pleistocene.

The result of this faunal turnover was a mammal assemblage of rather modern appearance.

Galerian MA. Ambrosetti et al. (1972) introduced the term Galerian for early Middle Pleistocene faunas; the name was derived from the locality Ponte Galeria in the Tiber delta west of Rome. The beginning of this age is marked by the appearance of *Praemegaceros verticornis* (Gliozzi *et al.* 1997).

Galerian spans a much shorter time than the Villafranchian and is faunistically much more uniform. The mammal fauna typical for this period includes: *Praemegaceros verticornis*, *Megaceros solilhacus, M. savini, Cervus elaphus acoronatus, Cervus elaphoides, Cervalces latifrons, Bison schoetensacki, Equus süssenbornensis, E. altidens, Ursus deningeri* (Azzaroli, 1983).

Aurelian MA. In Italy, the beginning of Aurelian mammal age (after Via Aurelia, NE of Rome) is indicated by the first occurrence of *Megaloceros giganteus*, *Ursus spelaeus* and *Canis lupus* and is correlated with MIS 9 – appoximately 0.3 MYA (Gliozzi et al. 1997). This Mammal Age sees the appearance of the taxa that represent the core of the resent day mammal fauna.

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QUATERNARY CONTINENTAL BIOCHRONOLOGY IN EUROPE BASED ON ARVICOLIDS

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Introduction

Voles and lemmings (Arvicolidae, Rodentia) are among those groups that have the utmost importance for biostratigraphy and biochronology. Their rapid evolution and radiation, as well as abundant fossil record, make them ideal leading fossils.

M. Kretzoi (1941) first invented biochronologic division of Quaternary, according to rodent faunas in Hungary. He proposed two biochronologic units: Villanyium (-ian) and Biharium (-ian). Later, the term Toringian was introduced (Fejfar & Heinrich, 1981) for the youngest biochronologic unit which comes after Biharian.

During the last several decades the European Neogene and Quaternary mammal chronology has been successfully developed. In 1980s and 1990s a biostratigraphic framework of the European Late Cenozoic based on Neogene arvicolid rodents was established (Fejfar & Heinrich, 1981, 1983, 1986, 1990). The Late Neogene of Europe was then subdivided into rodent superzones characterized by concurrent ranges of arvicolid genera. This scale is most widespread for the Plio-Pleistocene of Europe and the former Soviet Union. The complete scale, with small mammal biozones, is proposed by Fejfar and Heinrich (1990).

Vangengeim et al. (2001) proposed a scheme of small mammal (vole) zones for Eastern Europe (MQR zones). The zones are based on the appearance of new forms in the *Borsodia-Prolagurus-Lagurus*, *Mimomys-Arvicola* and *Allophaiomys-Microtus (Stenocranius)* evolutionary lineages. Eleven zones are distinguished and correlated with mammal assemblages introduced by Gromov (1948).

Villanyian (*Borsodia-Villanyia* Superzone). It is first defined by Kretzoi (1941) as the temporal interval of the concurrent ranges of the genera *Borsodia* and *Villanyia*. The lower boundary is defined as FAD of *Borsodia*. The appearance of *Microtus (Allophaiomys)* marks the close of the Villanyian and the onset of the Biharian.

The fauna contains pronouncedly grassland forms with North American immigrants via the Bering-Straits and Siberia that have replaced the southern forms. Murids, glirids, petauristids and other typical forest forms disappeared and were replaced abruptly with an arvicolid-cricetid assemblage.

Villanyian includes three Neogene mammal zones (after Mein, 1975): MN16a (*Mimomys hassiacus-M.stehlini*), 16b (*M.polonicus*) and 17 (*M.pliocaenicus*) (part of MN 16b and the whole MN 17 are included in Quaternary in new stratigraphic subdivision – Gibbard & Head, 2009).

Biharian (*Microtus-Mimomys* Superzone). Defined by Kretzoi (1941); the temporal interval of the concurrent ranges of the genera *Microtus* and *Mimomys*. The beginning coincides with FAD of *Microtus (Allophaiomys*). At the upper boundary *Mimomys savini* is substituted by *Arvicola*.

This period is characterized by the apperance of essential members our extant fauna (or their direct ancestors), followed by the extinctions of the remaining primitive groups.

The first biozone is characterized by the concurrent existence of *M. pusillus* and *M. savini*, while in the second *M. pusillus* disappeared but *M. savini* remains.

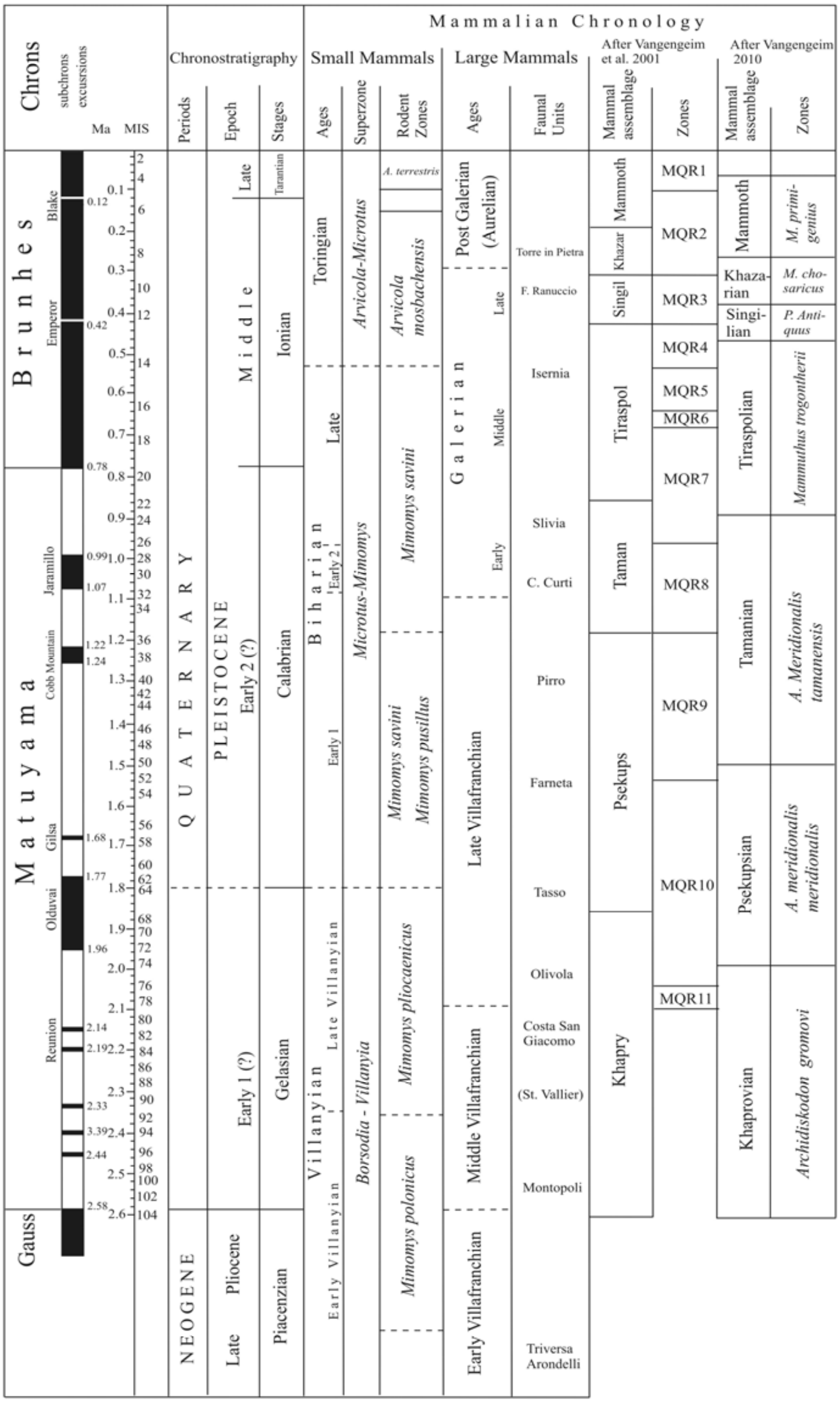

Fig. 1. Integrated stratigraphic scheme for the Quaternary large and small mammals of Europe.

Toringian (*Arvicola-Microtus* Superzone). Defined by Fejfar & Heinrich (1981); the temporal interval of the concurrent ranges of the genera *Arvicola* and *Microtus*. The beginning of the Toringian is marked by the replacement of *Mimomys savini* (form with rooted molars) by its presumed descendent, a rootless form *Arvicola mosbachensis (=cantiana*). This superzone includes two zones – earlier, *A. mosbachensis* and later – *A. terrestris*.

Correlation with large mammal-based biochronology. Correlation between small and large mammal units presents some difficulties, because many localities have no valid documentation of mammal of both classes of size, but many attempts have been made to connect those scales.

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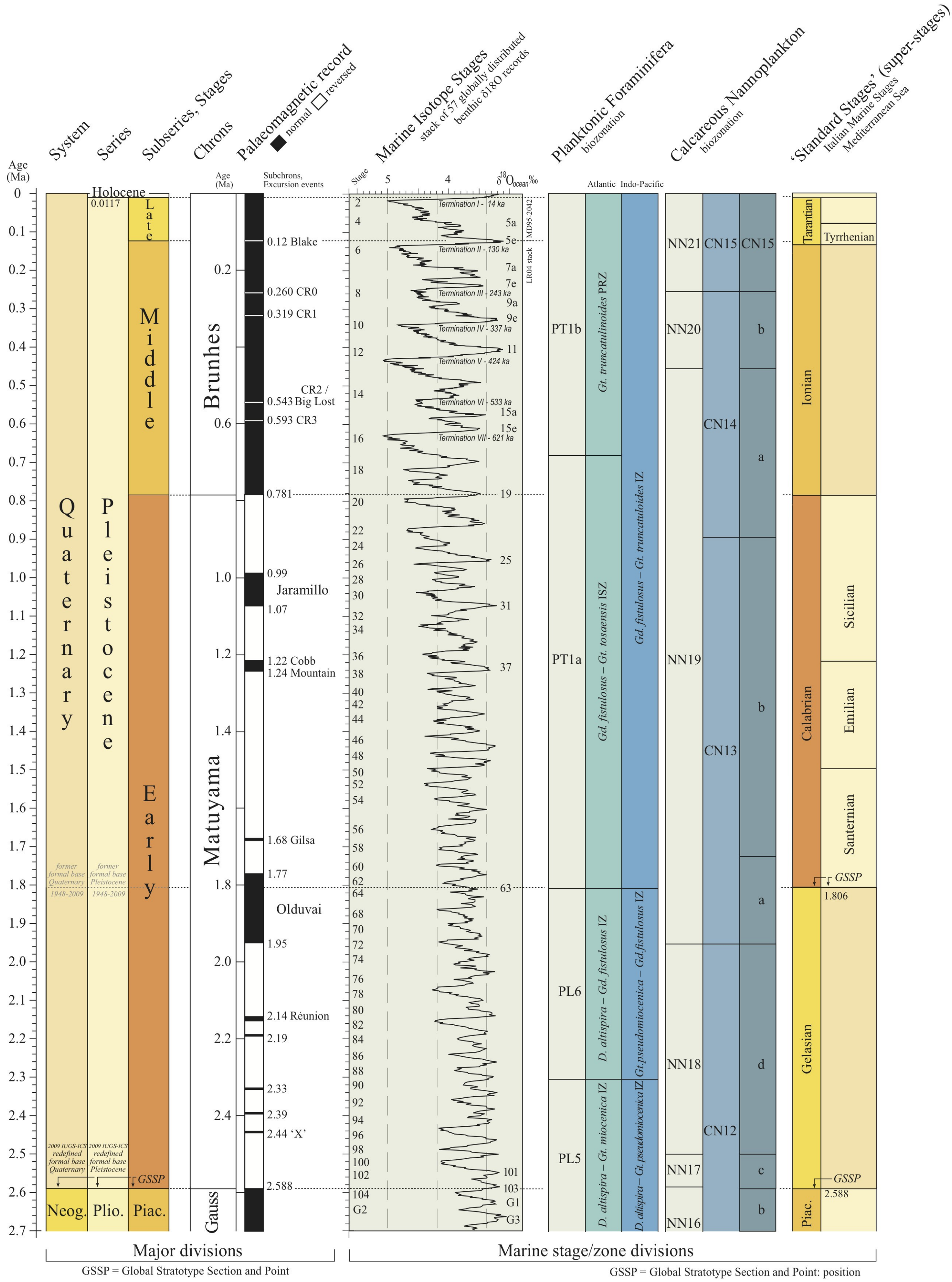

Major divisions and Marine stage/zone divisions of the Global chronostratigraphical correlation table for the last 2.7 million years v2011
Extracted segment from: Cohen K.M. & Gibbard, P. 2011 Global chronostratigraphical correlation table for the last 2.7 million years. Subcommission on Quaternary Stratigraphy (International Commission on Stratigraphy), Cambridge, England.
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