Introduction to the special issue “The drowning swamp of Gračanica (Bosnia-Herzegovina)—a diversity hotspot from the middle Miocene in the Bugojno Basin”

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The middle Miocene was a key period in Earth’s history as climate changed from one of the warmest phases of the Cenozoic Era, the Miocene Climatic Optimum (MCO; ~ 16.8–14.7 Ma, Holbourn et al. 2014), to colder conditions, which resulted in the establishment of permanent ice sheets on Antarctica. This climate change had a profound impact on terrestrial ecosystems worldwide.

The fossils and sedimentary succession documented in the Gračanica coal mine in central Bosnia and Herzegovina provide an insight into the terrestrial and limnic fauna and flora and the palaeoenvironment at this site during the early middle Miocene, somewhere between 14.8 and 13.8 Ma, just around the fading MCO.

The Gračanica site is situated about 10 km SSE from the city of Bugojno (WGS84 coordinates: 43.997662° N, 17.518516° E) in central Bosnia and Herzegovina in the so-called Bugojno Basin (Fig. 1). This basin is one in a series of intra-montane Dinarides basins, which are filled with Neogene lacustrine deposits (Mandic et al. 2016b). These basins are the geological witnesses of the former Dinarides Lake System (DLS), which was a widespread and long-lived cluster of lakes that tectonically developed on the Dinarides-Anatolian Island. During the early and middle Miocene, the Dinarides-Anatolian Island was not only a major biogeographic barrier between the Paratethys and the proto-

Mediterranean Sea but also a part of an important migration corridor—the *Gomphotherium* land bridge—especially for terrestrial mammals on their way from Africa and/or Asia Minor to Europe (and reversely).

The investigation of the Dinarides Lake System dates back to the pioneering works of Neumayr (1869, 1880, 1883) and Brusina (1874, 1884, 1897, 1902), who recognised it as a unique evolutionary hotspot within the continental biota of southeastern Europe and described an immense number of previously unknown mollusc species. The mollusc fauna of the Bugojno Basin, and in particular of the Gračanica coal pit, was mentioned first by Katzer (1903, 1918), whereas its taxonomic content was enumerated first in the course of a geological exploration by Muftić and Behlilović (1966). The numerous mammal remains found in the coal series of the Gračanica mine were attributed to five proboscidean and suoid species by Malez and Slišković (1964, 1965, 1976).

Since the launch of the Austrian FWF scientific project “Mollusk Evolution of the Neogene Dinaride Lake System” in 2006, the Dinarides became the focus of numerous investigations mostly conducted by PhD students at the Universities of Utrecht, Zagreb and Graz, supervised by W. Krijgsman, L. Matenco, D. Pavelić, H. Hrvatović, M. Harzhauser and O. Mandic, among others. These studies provided an independent and integrative stratigraphic framework, as well as the palaeoenvironmental, depositional and tectonic insight to many of the larger Dinarides basins. Up to recent times, the following Miocene basins were investigated in detail (from SW to NE)—Pag (Jimenez-Moreno et al. 2009), Sinj (Jimenez-Moreno et al. 2008; Mandic et al. 2009; de Leeuw et al. 2010; Neubauer et al. 2011; Šegvić et al. 2014), Livno-Tomislavgrad (de Leeuw et al. 2011), Gacko (Mandic et al. 2011, Neubauer et al. 2013) and Sarajevo (Andrić et al. 2017; Sant et al. 2018). Furthermore, numerous investigations on the general aspects of the Dinarides late orogeny and palaeogeographic evolution (Mandic et al. 2012; de Leeuw et al. 2012; van Unen et al. 2019a, b) and the taxonomy,

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Fig. 1 **a** Geographic position of the Bugojno basin and the locality Gračanica in Bosnia and Herzegovina; **b** palaeogeographic map with Dinarides-Anatolian Island; **c** geological section of the outcropping deposits at the Gračanica coal mine with palaeoenvironmental interpretation

evolution and environmental significance of endemic Miocene limnic molluscs (Harzhauser and Mandić 2008, 2010; Harzhauser et al. 2012; Neubauer et al. 2013, 2014, 2015, 2016) were conducted. Despite such an intensive survey of the latest Dinarides evolution, the Bugojno Basin did not receive much attention, up to the present, due to its unclear stratigraphic position. A detailed survey of its mammal record, initiated to solve the latter dating problem, is now documented through this special issue.

This special issue presents the palaeontological results of the investigations of the fauna and flora found in the locality of Gračanica. Additional chapters dealing with the geology and depositional environment (Mandić et al. in prep.) and an integrative bio- and magnetostratigraphic dating of the

Gračanica section (Mandić et al. in prep.) as well as a mammalian faunal analysis (NN) are foreseen to be published soon in a subsequent issue of this journal.

The site Gračanica is a still active coal pit. The exploitation of the lignites started in 1938 as underground mining, but from 1977 on changed into an open-cast mining. However, traces of the former underground mining occasionally come to light in the quarry, when historic mining tunnels (Fig. 2d) are cut by the ongoing excavations.

The outcropping deposits in the Gračanica open cast mine is about 40 m in thickness (Fig. 1c); the lower half of this section (~ 20 m height; Fig. 1c, unit 1) contains rich intercalations of dark lignites, which are exploited by the mining company “Gračanica” (Fig. 2b).

Fig. 2 Impressions of the Gračanica coal mine and the lower, lignite-rich half (unit 1) of the Gračanica section. **a** Panoramic photo of the mine; **b** road sign board in Gračanica indicating the mine; **c** exemplary detail of the alternating sequence of dark lignites and light limestones; **d** collapsing

historic mining tunnel; **e** large proboscidean long bone in a lignite layer, showing the mellow preservation of bone tissue, with Charlene Gaillard (then JM) for scale; **f** panoramic photo showing how the vertical and lateral facies change. All photos by U. Göhlich in 2017

The site has long been known for its fossils of large mammals and molluscs, but in the course of this project and investigation, non-mammalian vertebrates, arthropods, siliceous microfossils and flora also contributed importantly to our understanding of this site.

As far as we know, all mammalian fossils as well as a fossil of a crocodilian (Vasilyan 2020, this issue) found in Gračanica come from the lignite-bearing lower half of the section (Fig. 1c, unit 1); it is interpreted as deriving from a swampy environment. The upper half of the section (~ 20 m height; Fig. 1c,

units 2 + 3) is made up of light-coloured, laminated marls, clays and silt-, sand-, and limestones (without any lignites) and represents an open lake environment with changing lake levels (Fig. 4e, f). These lake deposits yielded fossils of fishes, reptiles, amphibians, but also insects, a crab, algae cysts, diatoms and sponge spicules. The fossil molluscs, ostracods, a macroflorule and a rich pollen record were found throughout the complete geological succession (Fig. 1c). The entire section reflects a transgressive lacustrine succession and shows vertical and lateral facies changes (Mandic et al. 2016a); therefore, the ongoing mining continuously changes the aspect of the section (Figs. 2f, 4a, 4d).

Geological and palaeontological fieldwork at the Gračanica deposits was initiated more than a decade ago by O. Mandic (NHMW) in the frame of the Austrian FWF Project (P18519-B17) on the mollusc evolution in the Dinarides Lake System. The team including O. Mandic, M. Mandic, de Leeuw and W. Krijgsman (both University of Utrecht) logged two geological sections in the Gračanica quarry in 2008 and 2009 and conducted palaeomagnetic sampling and geophysical (magnetic susceptibility, natural gamma ray) logging throughout the sections. Furthermore, O. Mandic collected fossil molluscs during field seasons and visits in 2007–2009, 2016 and 2017; he took sediment samples throughout the entire section in 2009 for pollen and ostracod analyses. In 2016, the excursion of the RCMNS workshop “Lake-Basin-Evolution” in Zagreb/Croatia visited Gračanica (Mandic et al. 2016a, b). At that occasion, A. Pisera took samples for analyses of siliceous microfossils (diatoms, cysts of golden alga, green microalga, sponge spicules). Already in 2007, O. Mandic and a team of small mammal specialists (W. Wessels, H. de Bruijn (both University Utrecht), G. Daxner-Höck (NHMW), Z. Marković (NHM Belgrade)) had visited the Gračanica mine to conduct screen washings for small mammals, but the yield was very scanty. In 2017, a small joint digging crew from the Jurassica Museum in Porrentruy (Switzerland) (D. Vasilyan, R. Renaud, Ch. Gaillard) and the Museum of Natural History in Vienna (Austria) (O. Mandic, U. Göhlich) (Fig. 3) got permission to conduct a short digging campaign in the mine. In the frame of this campaign, mostly fossils from the upper half of the section were collected and further screen washing samples of about 70 kg were taken from five different marly layers intercalated between the lignites; unfortunately, they did not produce any further small mammal fossils, but only small molluscs and gyrogonites. The almost missing small mammal record as well as the missing or very bad preservation of bones (Fig. 2e) in general is probably a result of humid acid from the lignites, which affects and dissolves boney tissue, more so on tiny objects. In 2019, researchers from the Jurassica Museum in Porrentruy returned to the coal mine for a very short visit and collected a few more fossils.

Fossils, especially of fossil mammals, are known from this site since the beginning of the exploitation. Most of the large

Fig. 3 Impressions of the field and digging campaign in 2017. **a** Digging crew in 2017 (from left to right): Davit Vasilyan (JM), Ursula Göhlich (NHMW), Oleg Mandic (NHMW), Renaud Roch (JM) and Charlene Gaillard (then JM); **b** U. Göhlich splitting fine laminated marls and siltstones in the upper half of the Gračanica section; **c** D. Vasilyan, R. Roch and Ch. Gaillard documenting and packing fossils; **d** R. Roch splitting slabs in the upper half of the Gračanica section; **e** D. Vasilyan climbing on the limestone bed in the upper half of the lignite succession; **f** O. Mandic measuring magnetic susceptibility (with a SM-20 by Gf Instruments) in the upper part of the lignite-rich lower half of the section; **g** and **h** U. Göhlich taking screen washing samples of marls interlayered in the middle part of the lignite rich; **i** mine geologist Hamdija Puljarga and surveyor Branko Grabovac guiding Oleg Mandic in the coal pit; **j** and **k** hay piles (**j**) and cabbage fields (**k**) near Gračanica, typical for this region. All photos (except **f** and **i**) by U. Göhlich in 2017; photos **f** and **i** by Medina Mandic in 2009

mammal fossils were and are found by the miners as chance findings during the mining activities. Therefore, their exact finding positions within the section are unknown. However, the preservation of the mammalian fossils and the often still attached residue of sediment indicate that they all come from the lignite-rich lower half of the section. This is confirmed by the miners and by occasional findings of fossils during the research field seasons.

The age of the Gračanica deposits is early middle Miocene (late Langhian), but its exact dating is still ambiguous. Initially, a scanty small mammal fauna indicated correlation with the early to middle Miocene and the Mammal Neogene zones MN4–MN6 (Wessels et al. 2020, this issue). The large mammal fauna correlates best with the Neogene Mammal units MN5 and/or early MN6 (Aiglstorfer and Mayda 2020, this issue; Bastl et al. 2020, this issue; Becker and Tissier 2020, this issue; Becker et al. 2020, this issue; Coombs and Göhlich 2020, this issue; Göhlich 2020, this issue; Stefen 2020, this issue). Biostratigraphic and biochronological datings based on molluscs pointed to an absolute age of the deposits slightly younger than 15.0 Ma (Mandic et al. 2020, this issue) correlating MN5 (Hilgen et al. 2012). The youngest of all biostratigraphic datings for the Gračanica fauna is postulated to be between 14.0 and 13.7 Ma by van der Made (2020, this issue), based on the suid fauna, correlating MN6 (Hilgen et al. 2012). Correlation of the pollen palaeoclimate proxy with orbital parameters and insolation points to an age of the Gračanica section between 14.80 and 14.55 Ma (Jiménez-Moreno and Mandic 2020, this issue), correlating late MN5. Ongoing magnetostratigraphic analyses (Mandic et al. in prep) also suggest a date somewhere between 14.8 and 13.8 Ma, correlating with late MN5 or early MN6, respectively. The entire Gračanica section (ca. 40 m in height) is estimated to have been deposited during a time span of 200 kyr (Jiménez-Moreno and Mandic 2020, this issue).

A series of 19 articles in this special issue introduces taxonomic studies on all faunal and floral groups found in the fossil record so far; their analyses provide a picture of the then biocenoses and depositional palaeoenvironment and habitat at

the Gračanica site during a short period in the early middle Miocene.

In the frame of the present investigations, 29 mammalian taxa, a minimum of 6 ectothermic vertebrate taxa, 19 mollusc taxa, 15 arthropod taxa and more than 63 plant taxa are identified. Furthermore, a variety of siliceous microfossils (e.g. sponge spicules, diatoms and chrysophyte cysts) of at least 17 different species are documented. Most of the described vertebrate taxa are only sparsely represented by a few specimens. The Gračanica fauna is species-rich (specious), but poor in individuals. A complete faunal list is given below.

Gračanica is type locality for some newly established taxa: a new rhino species (*Plesiaceratherium balkanicum* n. sp.) (Becker and Tissier 2020, this issue) and four new species of molluscs (*Bania goehlichae* n. sp., *Prososthenia krijgsmani* n. sp., *Paradrobacia hrvatovici* n. sp. and *Illyricocongeria forcakovici* n. sp.) (Mandic et al. 2020, this issue) are described from this site.

The preservation of the mammalian fossils from Gračanica argues for their autochthonous origin. Some transport can be assumed only in the littoral lacustrine facies as indicated by the sedimentary structures (Fig. 4d) and the mollusc composition.

Large mammal fossils presented here are housed in the collections of the Natural History Museum Vienna (NHMW, Austria), in the Jurassica Museum, Porrentruy (JM, Switzerland) and minor also in the Bavarian State Collection of Paleontology and Geology in Munich (SNSM-BSPG, Germany). Small mammals are stored in the Natural History Museum in Belgrade (PMB). Furthermore, all molluscs and the gyrogonites are kept in the NHMW; the ectothermic vertebrates, the crab, the insects, and the macroflora are housed in the JM; the siliceous microfossils (sponges, diatoms and chrysophyte cysts) are stored in the Institute of Paleobiology, Polish Academy of Sciences, Warszawa; ostracods are repositied in the Croatian Geological Survey, Zagreb,

Faunal list of Gračanica	
VERTEBRATA	
MAMMALIA	
Eulipotyphla	
Soricidae indet.	
Insectivora indet.	
Rodentia	
Castoridae	<i>Steneofiber depereti</i>
Muridae	<i>Democricetodon mutilus</i>
	<i>Democricetodon gracilis</i>
Carnivora	
Amphicyonidae	<i>Amphicyon giganteus</i>
Ursidae	<i>Hemicyon goerlachensis</i>
	<i>Ursavus brevirohinus</i>
	gen. et sp. indet.
Mustelidae	<i>Percrocuta miocenica</i>
Percrocutidae	
Suoidae	
Suidae	<i>Bunolistriodon latidens</i>
	<i>Conohyus simorrensis</i>
	<i>Choeromorus lemuroides</i>
Ruminantia	
Tragulidae	<i>Dorcatherium vindebonense</i>
Palaeomerycidae	gen. et sp. indet.
Giraffidae	<i>Giraffokeryx</i> sp.
Bovidae	<i>?Tethyragus</i> sp.
	<i>Eotragus</i> ? <i>clavatus</i>
Rhinocerotidae	
Rhinocerotinae	<i>Brachypotherium brachypus</i>
	<i>Lartetotherium sansaniense</i>
	<i>Plesiaceratherium balkanicum</i> n.sp.
	<i>Hispanotherium</i> cf. <i>matritense</i>
Elasmotheriinae	
Chalicotheriidae	
Chalicotheriinae	<i>Anisodon</i> cf. <i>grande</i>
Equidae	
Anchitheriinae	<i>Anchitherium hippoides</i>
	<i>Anchitherium ezquerra</i>
Proboscidea	
Deinotheriidae	<i>Prodeinotherium bavaricum</i>
Gomphotheriidae	<i>Gomphotherium angustidens</i>
	cf. <i>Gomphotherium subtapiroideum</i>
	cf. <i>Protanancus</i> sp.

(continued)

ECTOTHERMIC VERTEBRATA (non mammlia)	
AMPHIBIA	
Caudata	
Salamandridae	<i>Chelotriton</i> sp. (crocodile newt)
Anura	
Alytidae	<i>Latonia</i> sp. (painted frog)
PISCES	
Actinopterygii	
Cyprinidae	Barbini indet. (aff. <i>Barbus</i>)
Cyprinodontiformes	indet. (killifishes)
REPTILIA	
Eusuchia	
Alligatoroidea	<i>?Diplocynodon</i> sp.
Squamata	
Anguidae	Anguine sp. (osteoderm)
MOLLUSCA	
GASTROPODA	
Neritidae	<i>Theodoxus sinjanus</i>
Melanopsidae	<i>Melanopsis visianiana</i>
Hydrobiidae	<i>Bania goehlichae</i> nov. sp.
	<i>Bania</i> sp.
	<i>Cyclothyrella tryoniopsis</i>
	<i>Prososthenia krijgsmani</i> nov. sp.
Bithyniidae	<i>Bithynia</i> sp.
Lymnaeidae	gen. et sp. indet.
	<i>Ferrissia illyrica</i>
Planorbidae	<i>Planorbarius mantelli</i>
	<i>Gyraulus dalmaticus</i>
	<i>Gyraulus pulci</i>
	<i>Paradrobacia hrvatovici</i> nov. sp.
Helicidae	<i>Carychium nouleti</i>
Carychiidae	<i>Vertigo callosa</i>
Vertiginidae	<i>Vertigo diversidens</i>
	gen. et sp. indet.
Agriolimacidae	

(continued)	
BIVALVIA	
Dreissenidae	<i>Illyricocongeria forcakovici</i> nov. sp.
Sphaeriidae	<i>Pisidium bellardii</i>
ARTHROPODA	
CRUSTACEA	
Ostracoda	
Cyprididae	<i>Cypridopsis</i> cf. <i>biplanata</i> <i>?Eucypris</i> sp. <i>?Herpetocypris</i> sp. <i>Mediocypris</i> cf. <i>candonaeformis</i>
Candonidae;	<i>Candona</i> cf. <i>suevica</i> <i>Fabaeformiscandona</i> cf. <i>pokorny</i> <i>Fabaeformiscandona</i> sp.
Cyclocypridinae	<i>Cyclocypris</i> cf. <i>ovum</i>
Darwinulidae	<i>Darwinula stevensoni</i> <i>Vestalenula cylindrica</i>
Limnocytheridae	<i>Paralimnocythere rostrata</i>
Loxoconchidae	<i>Sagmatocythere</i> sp. (marine)
Brachyura	
Potamidae (freshwater crab)	<i>Potamon</i> sp.
INSECTA	
Diptera	
Bibionidae (March flies)	<i>Plecia</i> sp. <i>Bibio</i> sp.
PORIFERA	
sponge spicules (megascleres)	e.g. <i>Ochridaspongia</i> sp.
(7 morphotypes of sponge spicules)	<i>Ephydatia</i> sp.
Demospongiae	Potamolepidae indet.
PROTISTA	
Diatoms	
	<i>Staurosirella leptostauron</i> <i>Staurosirella pinnata</i> <i>Epithemia</i> sp. <i>Ellerbeckia</i> cf. <i>arenaria</i> <i>Fragilaria</i> sp.1 + sp. 2 <i>Encyonema</i> sp. <i>Eunotia</i> sp. Pennate species 1, indet. Pennate species 2, indet. Diatom indet.

(continued)	
Chrysophyta (golden algae)	chrysophyte cysts (8–11 morphotypes)
Chlorophyta (green algae)	e.g. <i>Botryococcus</i> sp. <i>Spirogyra</i> sp. (pollen) <i>Zygnema</i> sp. (pollen)
Charophyta Characeae	<i>Lychnothamnus duplicicarinatus</i> <i>Chara molassica notata</i>
FLORA	
MACROFLORA	
Pteridophyta Thelypteridaceae	<i>Pronephrium stiriaceum</i>
Gymnospermae Cupressaceae Taxodiaceae	<i>Glyptostrobus europaeus</i> fossil wood <15 cm diameter
Angiospermae Magnoliopsida Lauraceae Myricaceae Vitaceae incertae sedis	<i>Cinnamomum polymorphum</i> <i>Myrica</i> cf. <i>laevigata</i> <i>Vitis</i> cf. <i>globosa</i> „ <i>Rhamnus</i> “ <i>warthae</i> <i>Dicotylophyllum</i> sp. <i>Equisetum</i> sp.
Equisetaceae	
POLLEN > 63 pollen trees:	Taxodiaceae, <i>Sequoia</i> type, <i>Sciadopitys</i> , <i>Pinus</i> , <i>Cathaya</i> , <i>Cedrus</i> , <i>Picea</i> , <i>Quercus</i> evergreen, <i>Quercus deciduus</i> , <i>Fagus</i> , <i>Castanea-Castanopsis</i> , <i>Nyssa</i> , <i>Olea</i> , <i>Phillyrea</i> , <i>Fraxinus</i> , Cupressaceae, <i>Salix</i> , <i>Hedera</i> , Rubiaceae, <i>Microtropis fallax</i> , <i>Partenocissus</i> , <i>Cissus</i> , <i>Tilia</i> , <i>Rhus</i> , <i>Acer</i> , <i>Ulmus</i> , <i>Zelkova</i> , Sapotaceae, Cellastraceae, Hamamelidaceae, Hamamelidaceae, <i>Platanus</i> , <i>Liquidambar</i> , <i>Parrotia</i> , <i>Distylium</i> , <i>Mussaenda</i> type, <i>Carpinus</i> , <i>Carpinus</i> cf. <i>orientalis</i> , <i>Myrica</i> , <i>Juglans</i> , <i>Engelhardia</i> , <i>Platycarya</i> , <i>Carya</i> , <i>Pterocarya</i> , <i>Betula</i> , <i>Alnus</i> , <i>Ilex</i> , <i>Eucommia</i> , Poaceae, Rosaceae, <i>Scabiosa</i> , <i>Tricolporopollenites sibiricum</i> , <i>Plantago</i> , Malvaceae, Lamiaceae, Caryophyllaceae, Asteraceae, Amaranthaceae, Onagraceae, Apiaceae, <i>Typha</i> , <i>Myriophyllum</i> , Ranunculaceae, Cyperaceae
herbs & grasses and aquatics:	

Croatia; the pollen and algae are kept in the Department of Stratigraphy and Paleontology, University of Granada, Spain.

This special issue comprises the following contributions:

Wessels et al. (2020) found small mammal remains in three outcrops of the open pit lignite mine Gračanica near Bugojno (Bosnia and Herzegovina). Despite the low number of specimens, two *Democricetodon* species, which differ in size, are identified. The co-occurrence of two *Democricetodon* species is

common in many late early and middle Miocene European small-mammal assemblages. The presence of both *D. mutilis* and *D. gracilis* allows a correlation to MN4–MN6 (*Palaeobiodiversity and Palaeoenvironments* 100(2) <https://doi.org/10.1007/s12549-018-0366-8>).

Stefen (2020) describes five castorid teeth from the early middle Miocene locality Gračanica in Bosnia and Herzegovina, probably originating from lower lacustrine lignite-rich deposits. These teeth from the upper jaw are similar in preservation, wear stage and size and may

Fig. 4 **a** Overview of the sedimentary succession in the Gračanica mine, showing a dark, lignite-bearing lower interval, overlain by the light limnic limestone and marl in the upper part of the outcrop; **b** tree log in the lowermost part of the section; **c** laminated dark, coaly layer with compacted, horizontally oriented mollusc shell fragments (white); **d** foresets in the upper, transitional part of the coal-bearing succession

showing progradation of the deltaic facies to the left; **e** synsedimentary slumping structure in the deeper water limnic facies of the Gračanica section (Fig. 1c, unit 2); **f** laminated marl in the upper half of the Gračanica section representing the deeper water limnic facies. All photos by U. Göhlich in 2017

represent one single individual. Due to their size and morphology (mainly state of hypsodonty and closing hypostria in P4), they are referred to *Stenefiber depereti*. Since a semiaquatic lifestyle is assumed for *Stenefiber*, it is most probable that the teeth are of autochthonous origin (*Palaeobiodiversity and Palaeoenvironments* 100(2) <https://doi.org/10.1007/s12549-018-0365-9>).

Bastl et al. (2020) investigate the fossil carnivores from Gračanica and detect the caniform families Amphicyonidae (*Amphicyon giganteus*), Ursidae (*Hemicyon goeriachensis*, *Ursavus brevirohinus*) and Mustelidae (indet.) and the feliform family Percrocutidae (*Percrocuta miocenica*). This fauna comprises omnivore, mesocarnivore and hypercarnivore taxa. Noteworthy is the lack of any Felidae, but this might be an effect of the general scantiness of carnivoran fossils in the site. The authors point to similarities of the Gračanica fauna with the carnivore faunas of the localities Prebreza (Serbia),

Mordoğan, Çandır, Paşalar and İnönü (all in Turkey), which are of comparable middle Miocene age. The occurrence of *H. goeriachensis* in Gračanica is the southernmost, while that of *P. miocenica* is the northernmost record in Europe; for *A. giganteus*, it is the first evidence outside of central Europe (except for Namibia). The coeval occurrence of *A. giganteus* and *H. goeriachensis* in the deposits of Gračanica suggests a possible assignment to MN6, even if MN5 cannot be ruled out (*Palaeobiodiversity and Palaeoenvironments* 100(2) <https://doi.org/10.1007/s12549-018-0353-0>).

Van der Made (2020) documents three taxa of suoids in Gračanica and discusses extensively their taxonomic problematics: the palaeochoerid *Choeromorus lemuroides* (previously *Taucanamo sansaniense*) and the suids *Bunolistriodon latidens* (Listriodontinae) and *Conohyus simorreensis* (Tetraconodontinae). These species are identified to belong to three

anagenetic lineages, known from Western Europe to Anatolia, which are described in detail. Based on these lineages, biostratigraphic correlations are proposed for an area extending from Western Europe to Anatolia. Based on the suoids, van der Made concludes the age of the fauna to be between 14.0 and 13.7 Ma, correlating MN6, which is the youngest of all proposed biostratigraphic datings for the Gračanica fauna (*Palaeobiodiversity and Palaeoenvironments* 100(2) <https://doi.org/10.1007/s12549-020-00420-9>).

Aiglstorfer and Mayda (2020) present the ruminant fauna from Gračanica. It comprises the tragulid *Dorcatherium vindebonense*, an undeterminable palaeomerycid (Palaeomerycidae gen. et sp. indet.), the bovids *?Tethytragus* sp. and *Eotragus ?clavatus* and the giraffe *Giraffokeryx* sp.; for the latter, it is the westernmost occurrence to date. They interpret the ruminant faunal assemblage to show Asian as well as European affinities and point to the role of the Balkan Peninsula as a migration corridor between the two continents (*Palaeobiodiversity and Palaeoenvironments* 100(2) <https://doi.org/10.1007/s12549-018-0354-z>).

Coombs and Göhlich (2020) identify the very few dental chalicotheres remains to represent most probably *Anisodon grande*, a chalicotheriine. Although no post-cranials are found in Gračanica, chalicotheriines are known to be characterised by their gorilla-like body plan with a strong disproportion of long forelimbs and shorter hindlimbs. Given the age designation of the fauna as MN5 or earliest MN6, the Gračanica chalicotheres is among one of the earliest known occurrences of this subfamily and of the genus *Anisodon* in Europe (*Palaeobiodiversity and Palaeoenvironments* 100(2) <https://doi.org/10.1007/s12549-018-0357-9>).

Becker et al. (2020) describe two species of anchitheres from the lignites of Gračanica: the medium-sized *Anchitherium hippoides* and the larger-sized *A. ezquerrae*. Both are recorded for the first time in southeastern Europe. Although the genus *Anchitherium* is broadly cosmopolitan, the record of *A. hippoides* was, so far, mostly restricted to Western and Central Europe, whereas *A. ezquerrae* was only known from the Iberian Peninsula (*Palaeobiodiversity and Palaeoenvironments* 100(2) <https://doi.org/10.1007/s12549-020-00419-2>).

Becker and Tissier (2020) confirm the co-occurrence of four rhino species in Gračanica, one of which is a new species: *Plesiaceratherium balkanicum* n. sp., *Lartetotherium sansaniense* and *Hispanotherium matritense* are three “small-sized”, brachyodont rhinoceroses (body mass less than 1 ton), whereas the heavy-weighted *Brachypotherium brachypus* reached more than 2 tons. This rhinocerotid assemblage is interpreted to inhabit a mesic woodland with diverse habitats from swampy forest to drier and more open environment (*Palaeobiodiversity and Palaeoenvironments* 100(2) <https://doi.org/10.1007/s12549-018-0352-1>).

Göhlich (2020) presents the early middle Miocene proboscidean fauna—deinotheres and gomphotheres—from Gračanica. Probably four taxa are documented in the site, exclusively represented by fossil teeth: the deinotheres *Prodeinotherium bavaricum* and the gomphotheres *Gomphotherium angustidens*, cf. *Gomphotherium subtapiroideum* and cf. *Protanancus* sp. The tentative systematic identification of some gomphothere taxa is due to the scantiness and fragmentary condition of the studied material and by the fact that several of the teeth represent milk teeth, which are more difficult to determine. The occurrence of *Protanancus* is noteworthy, because this taxon is extremely rarely documented in southeastern Europe so far; it is generally known from Africa and Asia (*Palaeobiodiversity and Palaeoenvironments* 100(2) <https://doi.org/10.1007/s12549-020-00436-1>).

Vasilyan (2020) studied the fauna of ectothermic vertebrates and provide preliminary results on fish, amphibian and reptile fauna from the Gračanica locality, Bugojno palaeolake. The aquatic and semiaquatic fauna comprise killifishes (Cyprinodontiformes indet.), a barb (Barbini indet. (aff. *Barbus*)), a crocodile newt (*Chelotriton* sp.), a painted frog (*Latonia* sp.) and a crocodile (Alligatoroidea indet., *?Diplocynodon*). The crocodile remains are confined to the lower, lignite-rich part of the section corresponding to the swamp deposit (unit 1). The fishes and amphibians come from the upper lacustrine unit 2. A *Barbus*-relative (Barbini indet. (aff. *Barbus*)) possibly represents one of the oldest fossil records of the group found in Europe. The crocodile newt (*Chelotriton* sp.) represents the first record of this group from the area. For the first time, fossil tadpoles of the genus *Latonia* are described, which moreover, are the first record of tadpole for both the family Discoglossidae and clade of discoglossoid frogs. The fossils, coming from the lacustrine interval, are referred to the deeper water facies. Taphonomic observations of the fossil remains suggest a relatively short phase of decay of the animal bodies and their (probably quick) sedimentation in the deeper parts of the lake, with poor oxygen content. The rich killifish material (ca. 90 skeletons), order Cyprinodontiformes, will be studied in more detail and published separately in the near future (*Palaeobiodiversity and Palaeoenvironments* 100(2) <https://doi.org/10.1007/s12549-019-00381-8>).

Xafis et al. (2020) investigate the palaeodietary preferences of large mammals present in Gračanica. A multiproxy approach by employing dental microwear and dental mesowear analysis provides new perspectives on the terrestrial palaeoecology of the Dinarides Lake System. The analysis of the herbivores reveals the presence of browsing, “dirty browsing” and mixed-feeding taxa, with seasonal fruit, or even grass intake; pure grazers are completely absent. Additionally, the analysis of the carnivores suggests the presence of hyaena- and cheetah-like hypercarnivores, as well as generalists. The palaeodietary traits of the fossil mammals

suggest a closed canopy-like environment, which is supported by the fossil plant assemblage. Palaeopalynological data confirms the omnipresence of fleshy fruit-bearing plants and herbaceous taxa, as well as grasses, which justifies the seasonal fruit browsing, the common “dirty browsing” and the occasional grazing behaviour visualised for some of the fossil mammals from Gračanica (*Palaeobiodiversity and Palaeoenvironments* 100(2) <https://doi.org/10.1007/s12549-020-00435-2>).

Butzmann et al. (2020) present a species-poor florule from the early middle Miocene lacustrine marls from the Gračanica coal mine. The florule comprises angiosperm leaves (Lauraceae, Myricaceae, “*Rhamnus*” *warthae*), *Glyptostrobus europaeus* twigs, a frond fragment of *Pronephrium stiriaceum* and a seed assignable to the Vitaceae. The composition of the florule is suggestive of a swampy lowland environment; climatic conditions were humid subtropical (Cfa climate). Lignite seams containing abundant fossil wood (including large logs) characterise the deposits underlying the marls; the interburden between the lignite has yielded abundant plant chaff, including shoot fragments of *Equisetum*, and the charophyte gyrogonites *Lychnothamnus duplicicarinatus* and *Chara molassica notata* (*Palaeobiodiversity and Palaeoenvironments* 100(2) <https://doi.org/10.1007/s12549-018-0356-x>).

Jiménez-Moreno and Mandić (2020) provide a palynological analysis throughout the sedimentary sequence in the Gračanica open cast mine, which detects significant changes in the environment and lake sedimentation during the late phase of the Miocene climatic optimum (MCO). Statistical analysis and sedimentary rates suggest that eccentricity- and precession-dominated orbital-scale variability is recorded in the studied core. The warmest conditions are registered at the base of the studied section that could be correlated with an eccentricity maximum at the end of the MCO. From then on, a cooling trend is recorded until the top of the sedimentary sequence, with coldest maxima, tentatively correlated with a minimum in eccentricity and insolation. Furthermore, observed changes in the vegetation and corresponding variations of the lake level are interpreted as smaller-scale cyclical climatic events (i.e. warm-dry vs. cold-humid) that possibly are related to precession cyclicity. The palynological study of the Gračanica section suggests that sedimentation in this Bugojno palaeolake basin lasted for about 200 kyr and was strongly conditioned by climate at the beginning of the middle Miocene climate transition. Correlation of the pollen palaeoclimate proxy with orbital parameters and insolation points to an age of the Gračanica section between 14.80 and 14.55 Ma (*Palaeobiodiversity and Palaeoenvironments* 100(2) <https://doi.org/10.1007/s12549-020-00416-5>).

Pisera et al. (2020) analyse the siliceous microfauna of the Bugojno palaeolake, consisting of predominantly sponge spicules (megasccleres) and subordinately of diatoms and

chrysophyte cysts. The sponge spicules represent 5–6 different taxa; the most common spicules are those of a fossil species of the extant genus *Ochridaspongia* (Malawispongiidae), whereas those referred to the genus *Ephydatia* (Spongillidae) and to the Potamolepidae are less common. The presence of *Ochridaspongia* is not only the first fossil occurrence of this sponge genus, but also suggests alkaline and oligotrophic conditions in the palaeolake. The diatoms are represented by 11 species (e.g. *Staurosirella leptostauron*, *S. pinnata*, *Epithemia* sp., *Ellerbeckia* sp. and *Encyonema* sp., *Fragilaria* sp. and *Eunotia* sp.), the most common of which indicate a shallowness of the palaeolake, with alkaline water high in mineral content and high pH and moderately to highly productive. Furthermore, 11 chrysophyte cyst morphotypes are identified. In one sample, the green alga *Botryococcus* sp. is common and suggests rather oligotrophic condition, indicating that conditions and nutrient levels were variable (*Palaeobiodiversity and Palaeoenvironments* 100(2) <https://doi.org/10.1007/s12549-019-00378-3>).

Mandić et al. (2020) investigated changes in the mollusc composition along the 40-m-long Gračanica section. The authors present a very first taxonomic documentation of a mollusc fauna from the Bugojno Basin, comprising 17 gastropod and 2 bivalve species, including limnic as well as terrestrial dwellers. New to science became dreissenid bivalve *Illyricocongeria forcakovici* nov. sp., and the hydrobiid gastropods *Prososthenia krijgsmani* nov. sp. and *Bania goehlichae* nov. sp. The palaeoecological analysis based on quantified samples showed distinct shifts in mollusc composition and abundance. Hence, the terrestrial snails were found restricted to the lower, coal-bearing interval of the section. Furthermore, the shallow limnic gastropod representatives like melanopsids, neritids and hydrobiids were abundant in deltaic and littoral settings, as indicated by the accompanied sedimentary features. Finally, the dreissenid bivalves were frequent in littoral and sublittoral environments. The Lake Bugojno fauna shows only a low to moderate level of similarity to other Miocene records in the Dinarides, probably reflecting its slightly younger stratigraphic position (*Palaeobiodiversity and Palaeoenvironments* 100(2) <https://doi.org/10.1007/s12549-020-00423-6>).

Harzhauser et al. (2020) introduced a new helcid species *Paradrobacia hrvatovici* n. sp. restricted in the Gračanica section to the coal-bearing depositional interval. This terrestrial pulmonate gastropod genus was up to now known by only three species that lived in the middle Miocene of Austria, the late Miocene of Greece and the Pliocene of Germany. Consistent with the new record from Gračanica, all latter species were found in lignites or lignite-bearing marls, which is why the genus is interpreted as an indicator of moist woodland environments (*Palaeobiodiversity and Palaeoenvironments* 100(2) <https://doi.org/10.1007/s12549-018-0344-1>).

Hajek-Tadesse (2020) investigated ostracod contents in sieving residues of 13 sediment bulk-samples regularly

distributed along the 40-m-thick succession of the coal-mine Gračanica. The coal-bearing lower part of the succession allowed detection of 11 species. In contrast, the upper, marl-dominated part of the section did not allow determinations at the species level, because of a high-degree of fragmentation of ostracod shells. Furthermore, the topmost sample from a sandy layer was barren of fossils. In the samples of the lowermost third of the section, the pioneering species, such as *Fabaeformiscandona* cf. *pokorny* and *Vestalenula cylindrica*, show increased abundances and indicate a very shallow, temporary environment, with low water energy, partially of palustrine type, with possible seasonally fluctuating water salinities, within a warm subtropical climate. The transitional interval from the coal- to the marl-dominated part of the section shows dominant *Cypridopsis* cf. *biplanata* indicating a well-oxygenated body of shallow, richly vegetated, open water. Finally, the upper part of the section is composed of different but not closely detectable candonid genera indicating a deeper and stable open lake environment (*Palaeobiodiversity and Palaeoenvironments* 100(2) <https://doi.org/10.1007/s12549-019-00403-5>).

Hyžný (2020) presents a single specimen of a freshwater crab (decapod) from the limnic sediments of the former Lake Bugojno, found in the late Langhian site of Gračanica. The freshwater brachyuran is identified as *Potamon* sp. The Gračanica specimen is supposed to be the oldest *Potamon* occurrence from southern Europe. The articulated female individual with preserved pereopods suggests no postmortem transport and indicates the autochthonous deposition in the riparian zone of the lake. Peculiar preservation of cuticular disks confirms that these structures have preservation potential. If found isolated, these disks may confirm the presence of decapods in studied assemblages and can be considered an additional tool for identification of otherwise rare freshwater crab fossils (*Palaeobiodiversity and Palaeoenvironments* 100(2) <https://doi.org/10.1007/s12549-019-00374-7>).

Wedmann and Skartveit (2020) describe two fossil March flies (Insecta, Diptera, Bibionidae) from the open lake deposits of the early middle Miocene Gračanica mine near Bugojno. These two fossils represent the first insects documented from the Dinarides Lake System. They are identified as *Plecia* sp. and *Bibio* sp. The specimens seem not to be conspecific with any known fossil bibionids, but the incomplete preservation does not allow descriptions of new species. The habitus and colouration of the *Bibio* specimen are very similar to those of the recent species *Bibio hortulanus*. The presence of the genus *Plecia* is considered to indicate a warm climate, while *Bibio* points more to a temperate climate (*Palaeobiodiversity and Palaeoenvironments* 100(2) <https://doi.org/10.1007/s12549-018-00369-w>).

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References

- Aiglstorfer, M., & Mayda, S. (2020). Ruminantia from the middle Miocene of the Gračanica coalmine (Bugojno Basin, Bosnia-Herzegovina). In U.B. Göhlich & O. Mandic (Eds.) *The drowning swamp of Gračanica (Bosnia-Herzegovina) – a diversity hotspot from the middle Miocene in the Bugojno Basin. Palaeobiodiversity and Palaeoenvironments*, 100(2). <https://doi.org/10.1007/s12549-018-0354-z>. [this issue]
- Andrić, N., Sant, K., Matenco, L., Mandic, O., Pavelić, D., Tomljenović, B., Demir, V., & Hrvatović, H. (2017). The link between tectonics and sedimentation in asymmetric extensional basins: inferences from the study of the Sarajevo-Zenica Basin. *Marine and Petroleum Geology*, 83, 305–332.
- Bastl, K., Nagel, D., Morlo, M., & Göhlich, U.B. (2020). The Carnivora (Mammalia) from the middle Miocene locality of Gračanica (Bugojno Basin, Gornji Vakuf, Bosnia and Herzegovina). In U.B. Göhlich & O. Mandic (Eds.) *The drowning swamp of Gračanica (Bosnia-Herzegovina) – a diversity hotspot from the middle Miocene in the Bugojno Basin. Palaeobiodiversity and Palaeoenvironments* 100(2). <https://doi.org/10.1007/s12549-018-0353-0>. [this issue]
- Becker, D. & Tissier, J. (2020). Rhinocerotidae from the early middle Miocene locality Gračanica (Bugojno Basin, Bosnia-Herzegovina). In U.B. Göhlich & O. Mandic (Eds.) *The drowning swamp of Gračanica (Bosnia-Herzegovina) – a diversity hotspot from the middle Miocene in the Bugojno Basin. Palaeobiodiversity and Palaeoenvironments*, 100(2). <https://doi.org/10.1007/s12549-018-0352-1>. [this issue]
- Becker, D., Tissier, J., Vasilyan, D., & Göhlich, U.B. (2020). Anchitheriinae (Perissodactyla, Equidae) from the early middle Miocene locality Gračanica (Bugojno Basin, Bosnia-Herzegovina). In U.B. Göhlich & O. Mandic (Eds.) *The drowning swamp of Gračanica (Bosnia-Herzegovina) – a diversity hotspot from the middle Miocene in the Bugojno Basin. Palaeobiodiversity and Palaeoenvironments* 100(2). <https://doi.org/10.1007/s12549-020-00419-2>. [this issue]
- Brusina, S. (1874). Fossile Binnen-Mollusken aus Dalmatien, Kroatien und Slavonien nebst einem Anhang. 138 pp., Agram: Actienbuchdruckerei.
- Brusina, S. (1884). Die Neritodonta Dalmatiens und Slavoniens nebst allerlei malakologischen Bemerkungen. *Jahrbücher der Deutschen Malakozoologischen Gesellschaft*, 11, 17–120.
- Brusina, S. (1897). Gragja za neogensku malakološku faunu Dalmacije, Hrvatske i Slavonije uz neke vrste iz Bosne i Hercegovine i Srbije. *Djela Jugoslavenske akademije znanosti i umjetnosti*, 18, 1–43.
- Brusina, S. (1902). Iconographia molluscorum fossilium in tellure tertiariorum Hungariae, Croatiae, Slavoniae, Dalmatiae, Bosniae, Hercegovinae, Serbiae et Bulgariae inventorum. Atlas. - 30 pls., Zagrabiae.

- Butzmann, R., Göhlich, U.B., Bassler, B., & Krings, M. (2020). Macroflora and charophyte gyrogonites from the middle Miocene Gračanica deposits in central Bosnia and Herzegovina. In U.B. Göhlich & O. Mandic (Eds.) *The drowning swamp of Gračanica (Bosnia-Herzegovina) - a diversity hotspot from the middle Miocene in the Bugojno Basin. Palaeobiodiversity and Palaeoenvironments*, 100(2). <https://doi.org/10.1007/s12549-018-0356-x> [this issue]
- Coombs, M.M. & Göhlich, U.B. (2020). *Anisodon* (Perissodactyla, Chalicotheriinae) from the middle Miocene locality Gračanica (Bugojno Basin, Gornji Vakuf, Bosnia and Herzegovina). In U.B. Göhlich & O. Mandic (Eds.) *The drowning swamp of Gračanica (Bosnia-Herzegovina) - a diversity hotspot from the middle Miocene in the Bugojno Basin. Palaeobiodiversity and Palaeoenvironments*, 100(2). <https://doi.org/10.1007/s12549-018-0357-9>. [this issue]
- Göhlich, U.B. (2020). The proboscidean fauna (Mammalia) from the middle Miocene lignites of Gračanica near Bugojno (Bosnia-Herzegovina). In U.B. Göhlich & O. Mandic (Eds.) *The drowning swamp of Gračanica (Bosnia-Herzegovina) - a diversity hotspot from the middle Miocene in the Bugojno Basin. Palaeobiodiversity and Palaeoenvironments*, 100(2). <https://doi.org/10.1007/s12549-020-00436-1>. [this issue]
- Hajek-Tadesse, V. (2020). Ostracods and the middle Miocene evolution of the Bugojno Basin (Bosnia and Herzegovina). In U.B. Göhlich & O. Mandic (Eds.) *The drowning swamp of Gračanica (Bosnia-Herzegovina) - a diversity hotspot from the middle Miocene in the Bugojno Basin. Palaeobiodiversity and Palaeoenvironments*, 100(2). <https://doi.org/10.1007/s12549-019-00403-5> [this issue]
- Harzhauser, M., & Mandic, O. (2008). Neogene lake systems of Central and South-Eastern Europe: faunal diversity, gradients and interrelations. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 260(3–4), 417–434.
- Harzhauser, M., & Mandic, O. (2010). Neogene dreissenids in Central Europe: evolutionary shifts and diversity changes. In G. van der Veld, S. Rajagopal, & A. bij de Vaate, (Eds.) *The Zebra Mussel in Europe*. 11–28, 426–478. Leiden: Backhuys Publishers.
- Harzhauser, M., Mandic, O., Latal, C., & Kern, A. (2012). Stable isotope composition of the Miocene Dinaride Lake System deduced from its endemic mollusc fauna. *Hydrobiologia*, 682(1), 27–46.
- Harzhauser, M., Mandic, O., Nordsieck, H., & Neubauer, T. A. (2020). A new Helicidae (Gastropoda) from the middle Miocene of Bosnia and Herzegovina, with a revision of the genus *Paradrobacia*. In U.B. Göhlich & O. Mandic (Eds.) *The drowning swamp of Gračanica (Bosnia-Herzegovina) - a diversity hotspot from the middle Miocene in the Bugojno Basin. Palaeobiodiversity and Palaeoenvironments*, 100(2). <https://doi.org/10.1007/s12549-018-0344-1>. [this issue]
- Hilgen, F. J., Lourens, L. J., & Van Dam, J. A. (2012). The Neogene Period. In F. M. Gradstein, J. G. Ogg, M. Schmitz, & G. Ogg (Eds.), *A Geologic Time Scale 2012* (pp. 923–978). Amsterdam: Elsevier.
- Holbourn, A., Kuhnt, W., Lyle, M., Schneider, L., Romero, O., & Andersen, N. (2014). Middle Miocene climate cooling linked to intensification of eastern equatorial Pacific upwelling. *Geology*, 42(1), 19–22.
- Hyžný, M. (2020). A freshwater crab *Potamon* (Brachyura: Potamidae) from the middle Miocene Lake Bugojno (Gračanica, Bosnia and Herzegovina), with notes on potamid taphonomy. In U.B. Göhlich & O. Mandic (Eds.) *The drowning swamp of Gračanica (Bosnia-Herzegovina) - a diversity hotspot from the middle Miocene in the Bugojno Basin. Palaeobiodiversity and Palaeoenvironments*, 100(2). <https://doi.org/10.1007/s12549-019-00374-7>. [this issue]
- Jiménez-Moreno, G., Mandic, O., Harzhauser, M., Pavelić, D., & Vranjković, A. (2008). Vegetation and climate dynamics during the early Middle Miocene from Lake Sinj (Dinaride Lake System, SE Croatia). *Review of Palaeobotany and Palynology*, 152, 270–278.
- Jimenez-Moreno, G., Leeuw, A. de, Mandic, O., Harzhauser, M., Pavelić, D., Krijgsman, W., & Vranjkovic, A. (2009). Integrated stratigraphy of the early Miocene lacustrine deposits of Pag Island (SW Croatia): palaeovegetation and environmental changes in the Dinaride Lake System. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 280(1–2), 193–206.
- Jiménez-Moreno, G. & Mandic, O. (2020). Middle Miocene climatic oscillations controlled by orbital-scale changes triggered environmental and vegetation variability in the Dinarides Lake System (Bugojno Basin, Bosnia and Herzegovina). In U.B. Göhlich & O. Mandic (Eds.) *The drowning swamp of Gračanica (Bosnia-Herzegovina) - a diversity hotspot from the middle Miocene in the Bugojno Basin. Palaeobiodiversity and Palaeoenvironments*, 100(2). <https://doi.org/10.1007/s12549-020-00416-5> [this issue]
- Katzer, F. (1903). *Geologischer Führer durch Bosnien und die Herzegovina*. 280 pp. Sarajevo: Landesdruckerei.
- Katzer, F. (1918). *Die fossilen Kohlen Bosniens und der Herzegovina*. Erster Band. 403 pp. Wien: Selbstverlag.
- Leeuw, A. de, Mandic, O., Vranjković, A., Pavelić, D., Harzhauser, M., Krijgsman, W., & Kuiper, K. F. (2010). Chronology and integrated stratigraphy of the Miocene Sinj Basin (Dinaride Lake System, Croatia). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 292, 155–167.
- Leeuw, A. de, Mandic, O., Krijgsman, W., Kuiper, K., & Hrvatović, H. (2011). A chronostratigraphy for the Dinaride Lake System deposits of the Livno-Tomislavgrad Basin: the rise and fall of a long-lived lacustrine environment in an intra-montane setting. *Stratigraphy*, 8(1), 29–43.
- Leeuw, A. de, Mandic, O., Krijgsman, W., Kuiper, K., & Hrvatović, H. (2012). Paleomagnetic and geochronologic constraints on the geodynamic evolution of the Central Dinarides. *Tectonophysics*, 530–531, 286–298.
- Malez, M., & Slišković, T. (1964). Neue Fundorte Tertiärer Wirbeltiere in Bosnien und Herzegovina. *Bulletin Scientifique*, 9(1–2), 3–5.
- Malez, M. & Slišković, T. (1965). O novim nalazima vrste *Dinotherium bavaricum* v. Meyer u ugljenokopu Repovica kod Konjica. *Glasnik zemaljskog muzeja BiH, Prirodne nauke*, 3–4, 7–23, Sarajevo.
- Malez, M., & Slišković, T. (1976). Starost nekih nalaza ugljena u tercijaru Bosne i Hercegovine na osnovi nalaza vertebata. *Geološki glasnik Sarajevo*, 21, 39–56.
- Mandic, O., Pavelić, D., Harzhauser, M., Zupanic, J., Reischenbacher, D., Sachsenhofer, R. F., Tadej, N., & Vranjkovic, A. (2009). Depositional history of the Miocene Lake Sinj (Dinaride Lake System, Croatia): a long-lived hard-water lake in a pull-apart tectonic setting. *Journal of Paleolimnology*, 41, 431–452.
- Mandic, O., de Leeuw, A., Vukovic, B., Krijgsman, W., Harzhauser, M., & Kuiper, K.F. (2011). Palaeoenvironmental evolution of Lake Gacko (NE Bosnia and Herzegovina): impact of the Middle Miocene Climatic Optimum on the Dinaride Lake System. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 299(3–4) 475–492.
- Mandic, O., De Leeuw, A., Bulić, J., Kuiper, K., Krijgsman, W., & Jurišić-Polšak, Z. (2012). Paleogeographic evolution of the Southern Pannonian Basin: 40Ar/39Ar age constraints on the Miocene continental series of northern Croatia. *International Journal of Earth Sciences*, 101, 1033–1046.
- Mandic, O., Göhlich, U. B., Krijgsman, W., De Leeuw, A., & Hrvatović, H. (2016a). Lake Bugojno – three lacustrine cycles. In O. Mandic, D. Pavelić, M. Kovačić, K. Sant, N. Andrić, & H. Hrvatović (Eds.) *Field trip guide-book. Lake-basin–evolution. RCMNS Interim Colloquium 2016 & Croatian Geological Society Limnogeology Workshop* (pp. 19–24).
- Mandic, O., Pavelić, D., Kovačić, M., Sant, K., Andrić, N., & Hrvatović, H. (2016b). *Field trip guide-book. Lake-basin–evolution. RCMNS Interim Colloquium 2016 & Croatian Geological Society Limnogeology Workshop*. Zagreb: Croatian Geological Society.
- Mandic, O., Harzhauser, M., & Neubauer, T.A. (2020). Taxonomy, paleoecology and stratigraphy of the middle Miocene mollusk fauna

- from the Gračanica coal pit near Bugojno in Bosnia and Herzegovina. In U.B. Göhlich & O. Mandic (Eds.) *The drowning swamp of Gračanica (Bosnia-Herzegovina) – a diversity hotspot from the middle Miocene in the Bugojno Basin. Palaeobiodiversity and Palaeoenvironments*, 100(2). <https://doi.org/10.1007/s12549-020-00423-6>. [this issue]
- Muftić, M. & Behlilović, S. (1966). Prikaz geološkog poznavanja ugljenonosnih naslaga Gračanice kod Bugojna. *Geološki glasnik Sarajevo*, 11, 303–312.
- Neubauer, T. A., Mandic, O., & Harzhauser, M. (2011). Middle Miocene freshwater mollusks from Lake Sinj (Dinaride Lake System, SE Croatia; Langhian). *Archiv für Molluskenkunde*, 140(2), 201–237.
- Neubauer, T. A., Mandic, O., Harzhauser, M., & Hrvatovic, H. (2013). A new Miocene lacustrine mollusc fauna of the Dinaride Lake System and its palaeobiogeographic, palaeoecologic, and taxonomic implications. *Palaeontology*, 56(1), 129–156.
- Neubauer, T. A., Mandic, O., & Harzhauser, M. (2014). A new melanopsid species from the Middle Miocene Kupres Basin (Bosnia and Herzegovina). *The Nautilus*, 128(2), 51–54.
- Neubauer, T. A., Mandic, O., & Harzhauser, M. (2015). The freshwater mollusk fauna of the Middle Miocene Lake Drniš (Dinaride Lake System, Croatia): a taxonomic and systematic revision. *Austrian Journal of Earth Sciences*, 108(2), 15–67.
- Neubauer, T. A., Mandic, O., & Harzhauser, M. (2016). The early middle Miocene lacustrine gastropod fauna of Džepi, Bosnia and Herzegovina (Dinaride Lake System): high endemism in a small space. *Bulletin of Geosciences*, 91(2), 271–296.
- Neumayr, M. (1869). II. Beiträge zur Kenntniss (sic!) fossiler Binnenfaunen. *Jahrbuch der kaiserlich-königlichen geologischen Reichsanstalt*, 19, 355–382.
- Neumayr, M. (1880). Tertiäre Binnenmollusken aus Bosnien und der Hercegovina. *Jahrbuch der kaiserlich-königlichen Geologischen Reichsanstalt*, 30, 463–492.
- Neumayr, M. (1883). Zur Morphologie des Bivalvenschlosses. *Sitzungsberichte der kaiserlich-königlichen Akademie der Wissenschaften, Wien*, 88, 385–419.
- Pisera, A. Siver, P.A., & Mandic, O. (2020). Miocene siliceous microfossils from the open cast coal mine Gračanica (Bugojno paleolake, Bosnia and Herzegovina) and their significance: a preliminary report. In U.B. Göhlich & O. Mandic (Eds.) *The drowning swamp of Gračanica (Bosnia-Herzegovina) – a diversity hotspot from the middle Miocene in the Bugojno Basin. Palaeobiodiversity and Palaeoenvironments*, 100(2). <https://doi.org/10.1007/s12549-019-00378-3> [this issue]
- Sant, K., Andrić, N., Mandic, O., Demir, V., Pavelić, D., Rundić, L., Hrvatović, H., Matenco, L., & Krijgsman, W. (2018). Magneto-biostratigraphy and palaeoenvironments of the Miocene freshwater sediments of the Sarajevo-Zenica Basin. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 506, 48–69.
- Šegvić, B., Mileusnić, M., Aljinović, D., Vranjković, A., Mandic, O., Pavelić, D., Dragičević, I., & Mählmann, R. F. (2014). The provenance and diagenesis of tuffs from the Dinaride Lake System (Miocene, Southern Croatia). *European Journal of Mineralogy*, 26(1), 83–101.
- Stefen, C. (2020). The castorids (Mammalia, Castoridae) from the (early) middle Miocene of Gračanica (Bosnia-Herzegovina). In U.B. Göhlich & O. Mandic (Eds.) *The drowning swamp of Gračanica (Bosnia-Herzegovina) – a diversity hotspot from the middle Miocene in the Bugojno Basin. Palaeobiodiversity and Palaeoenvironments*, 100(2). <https://doi.org/10.1007/s12549-018-0365-9>. [this issue]
- Made, J. van der (2020). The Suoidea from the Middle Miocene of Gračanica (Bugojno Basin, Bosnia and Herzegovina) - evolution, taxonomy & biostratigraphy. In U.B. Göhlich & O. Mandic (Eds.) *The drowning swamp of Gračanica (Bosnia-Herzegovina) – a diversity hotspot from the middle Miocene in the Bugojno Basin. Palaeobiodiversity and Palaeoenvironments*, 100(2). <https://doi.org/10.1007/s12549-020-00420-9>. [this issue]
- Unen, M. van, Matenco, L., Nader, F. H., Darnault, R., Mandic, O., & Demir, V. (2019a). Kinematics of foreland-vergent crustal accretion: inferences from the Dinarides evolution. *Tectonics*, 38, 49–76.
- Unen, M. van, Matenco, L., Demir, V., Nader, F. H., Darnault, R., & Mandic, O. (2019b). Transfer of deformation during indentation: Inferences from the postmiddle Miocene evolution of the Dinarides. *Global and Planetary Change*, 182, 103027.
- Vasilyan, D. (2020). Fish, amphibian and reptilian assemblage from the middle Miocene locality Gračanica – Bugojno palaeolake, Bosnia and Herzegovina. In U.B. Göhlich & O. Mandic (Eds.) *The drowning swamp of Gračanica (Bosnia-Herzegovina) – a diversity hotspot from the middle Miocene in the Bugojno Basin. Palaeobiodiversity and Palaeoenvironments*, 100(2). <https://doi.org/10.1007/s12549-019-00381-8>. [this issue]
- Wedmann, S. & Skartveit, J. (2020). First record of march flies (Insecta: Diptera: Bibionidae) from the Miocene Gračanica mine (Bugojno, Bosnia-Herzegovina). In U.B. Göhlich & O. Mandic (Eds.) *The drowning swamp of Gračanica (Bosnia-Herzegovina) – a diversity hotspot from the middle Miocene in the Bugojno Basin. Palaeobiodiversity and Palaeoenvironments*, 100(2). <https://doi.org/10.1007/s12549-018-00369-w>. [this issue]
- Wessels, W., Bruijn, H. de, Marković, Z., & Milivojević, M. (2020). Small mammals from the opencast lignite mine Gračanica (Bugojno), Bosnia and Herzegovina. In U.B. Göhlich & O. Mandic (Eds.) *The drowning swamp of Gračanica (Bosnia-Herzegovina) – a diversity hotspot from the middle Miocene in the Bugojno Basin. Palaeobiodiversity and Palaeoenvironments*, 100(2). <https://doi.org/10.1007/s12549-018-0366-8>. [this issue]
- Xafis, A., Saarinen, J., Bastl, K., Nagel, D., & Grimsson, F. (2020). Palaeodietary traits of large mammals from the middle Miocene of Gračanica (Bugojno Basin, Bosnia-Herzegovina). In U.B. Göhlich & O. Mandic (Eds.) *The drowning swamp of Gračanica (Bosnia-Herzegovina) – a diversity hotspot from the middle Miocene in the Bugojno Basin. Palaeobiodiversity and Palaeoenvironments*, 100(2). <https://doi.org/10.1007/s12549-020-00435-2> [this issue]

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