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A mid-Miocene age for the Slanci Formation near Belgrade (Serbia), based on a record of the primitive antelope *Eotragus* cf. *clavatus* from Višnjica

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Abstract. In a borhole at Veliko Selo near Belgrade in the Miocene lacustrine sediments Slanci, which are locally known as the Slanačka Serija, a mammal tooth was found. The age of these deposits is under discussion. The fossil is here described and attributed with a query to the primitive antelope *Eotragus clavatus* (Gervais, 1850), which is suggestive of a Early Serravallian ("upper Badenian") or Early Middle Miocene age for these deposits, whereas an Aquitalian or Eggenburgian ("Egerian" or "Eggenburgian") (Early Miocene) age can be ruled out.

Key words: Miocene, Badenian, Serbia, Belgrade, Slanci Formation, Bovidae, *Eotragus*.

Апстракт. У језерским миоценским наслагама Вишњице код Београда, познатим у старијој литератури под називом "Сланачка серија" у истражној бушотини код Великог Села нађен је зуб фосилног сисара *Eotragus* cf. *clavatus* (Gervais, 1850). Налаз фосилних остатака *Eotragus*-а је од значаја за сагледавање развоја сисарске фауне у Европи. Такође, резултати истраживања изнети у овом раду представљају допринос познавању стратиграфије и палеогеографије миоцена околине Београда.

Кључне речи: Миоцен, Баден, Србија, Београд, Сланачка формација, Bovidae, *Eotragus*.

Introduction

The Danube Ključ area near Belgrade is situated on the borderline of the Balkan Mountains and the Pannonian lowlands on the south bank of the River Danube, comprising the villages of Grocka, Višnjica and Veliko Selo. Recent studies into the construction of a canalization basin near Višnjica–Veliko Selo have yielded new data on the geological structure of this area, as well as the first fossil mammal molar from Miocene lacustrine sediments (Slanačka serija, "formation" *sensu* Pavlović (1922). This tooth enables an age assignement for strata from which it was recovered.

Pavlović (1922) described a new lithostratigraphic unit ("formation" *sensu* Pavlović 1922) at Veliko Selo and Slanci, east of the city centre of Belgrade, where sandy clays and marly clays with floral imprints were found. He assumed a "First Mediterranean Age" (the old name for Aquitanian and Burdigalian age used localy) for these lacustrine sediments. These strata referred to in older literature as The Slanačka Serija (or Slanci Sequence; Pavlović 1922; Stevanović & Stangačilović 1954; Stevanović 1975, 1977), are the oldest Neogene sediments in the Belgrade area. The age of these deposits has, however, been the subject of a long debate.

The lacustrine sediments at Slanci were interpreted by Stevanović & Stangačilović (1954) as a sequence of lake deposits, including schistose, laminate clays, bituminous clays, platy marlstone and tuff. Those authors suggested a Burdigalian age because they considered that the sediments were stratigraphically older than Serravallian marine sediments nearby. The thickness of the Slanačka serija sediments was estimated to be in excess of 300 m. They are divided into a lower barren portion, lacking tuff, and an upper portion with fauna, including the last cephalopod to have lived in the area, *Aturia aturi* (Basterot, 1825). Stevanović (1977) again proposed a Burdigalian–Helvetian age.

Luković (1922), Krstić (1978) and Krstić *et al*. (1992) and suggested a Middle Miocene or Badenian age

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of the "Slanačka serija". On the basis of fauna collected from stratigrafically younger transgressive marine sediments, for example ostracods, foraminifera and fish teeth. According to F. Rögl (pers. comm. to KRSTIĆ 2007), the benthic species *Spiroplectinella carinata* (D'ORBIGNY) and planctonic Globigerinidae are present. The age of these younger strata deposited in the Danube Ključ area is estimated to be between 13.25 and 12.9 Ma.

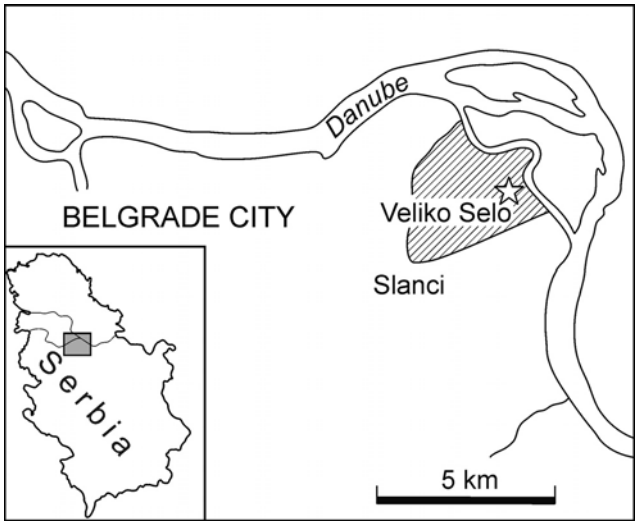

Fig. 1. In the vicinity of Belgrade on the banks of the River Danube, Višnjica, Veliko Selo and Slanci are located. The thickness of the deposits referred to as the "Slanačka serija" in the literature, is estimated to be 350 to 400 m (DOLIĆ 1977). The Slanci Formation is one unit of this series. In borehole VI-4i (indicated with asterisk) (GPS position data: 20°35'50'' E; 44°49'30'' N) at a depth of 8.8 m in the Slanci Formation, a specimen RGFKS31 was found.

Rich macrofloral remains from the village of Slanci were described by MILAKOVIĆ (1956, 1959) and MIHAJLOVIĆ (1978). These fossils, found in grey marls at a few localities in the village, include forms suggestive of a subtropical *Cinnamomum*, *Myrica*, *Engelhartia* and *Libocedrus* or a warm-temperate climate *Populus*, *Salix*, *Zelkova* and ferns. Species characteristic of drier and warm habitats include *Quercus*, *Pinus*, *Celtis* and *Eleagnus* or *Eucalyptus*, while *Metrosideros* and *Sapindos* are also represented. In general, these floral remains are typical of Mediterranean and steppe-savanna associations. Away from the lake, species abundant in a dry and warm climate occur (MIHAJLOVIĆ 1978).

OBRADOVIĆ (1979) described a sedimentary series of "Burdigalian–Helvetian" age and concluded that these were deposited in a shallow-water, lacustrine environment. The size of the lake and its marginal swamps was estimated to have been about ten square kilometres. The maximum depth was assessed to have been 150 m and preservation of organic material suggested anaerobic and stagnant conditions. The rich fossil flora shows that a humid climate existed in this area.

In the G-1 borehole in the village of Grocka, close to Veliko Selo and Slanci, the stratigraphically oldest lacustrine sediments are found at depths between 1300 and 1100 m (KNEŽEVIĆ *et al*. 1994). These are older than the overlying marine Paratethys sediments of Badenian age.

DOLIĆ (1997) described the strata of "Slanačka serija" as part of the "Lake group of the Danube Ključ". In strata exposed between the villages of Višnjica, Slanci and Veliko Selo, he recognised three formations which represent lacustrine sediments. From bottom to top these are (Fig. 2):

1) the Veliko Selo Formation, consisting of sandstone, conglomerate, tuff and tuffite, with an overal thickness between 150 and 200 m (not figured).

2) the Slanci Formation, with a coal horizon of 30 m thickness and lacustrine pelites with laminated shale, marlstone with tuff and tuffite some 50 to 70 m in thickness.

3) the Bučvar Formation, consisting of conglomerate, breccia, laminated shale and marlstone, with a thickness of 100 m.

DOLIĆ (1997) assumed the lake sediments to be of Aquitanian–Early Burdigalian ("Egerian–Eggenburgian" or Early Miocene) age. The contact between the "Lake group of the Danube Ključ" (Veliko Selo, Slanci and Bučvar formations *sensu* DOLIĆ) and the marine sediments of Badenian (Middle Miocene) age, he considered to be discordant.

Thus, the ages proposed for the Slanačka serija vary between Egerian (some 24 to 20.5 Ma; ages according to STEININGER 1999) or Eggenburgian (20.5 to 18 Ma), Ottnangian (18 to 17.2 Ma), Karpathian (17.2 to 16.5 Ma) (all Early Miocene) and Badenian (16.5–13 Ma) or "Helvetian" (Middle Miocene). The antelope molar, found in a borehole core and described herein, permits a more precise indication of the age of the sediments in which yielded it.

Description of the section penetrated in borehole VI-4i

During the geological research for a construction of the future canalization interceptor, a molar was collected from the core of well VI-4i (Fig. 2). The core was drilled north of Veliko Selo on the elevated right bank of the River Danube at elevation 98 m, in the easterly side of the pit where this canalization interceptor is to be constructed.

The uppermost 1.7 m of the core comprise Quaternary colluvial deposits, while the reminder consists of Miocene sediments of the Slanci Formation. Between 1.7 to 2.7 m, occur clays with coal bands and a number amount of gypsum crystals, while between 2.7 to 8 m, there first are red clays on top with "rusty" siltstone clays with occasional gypsum crystals, and tuff and tuffite below. From 8 to 23.2 m, there are grey clays and

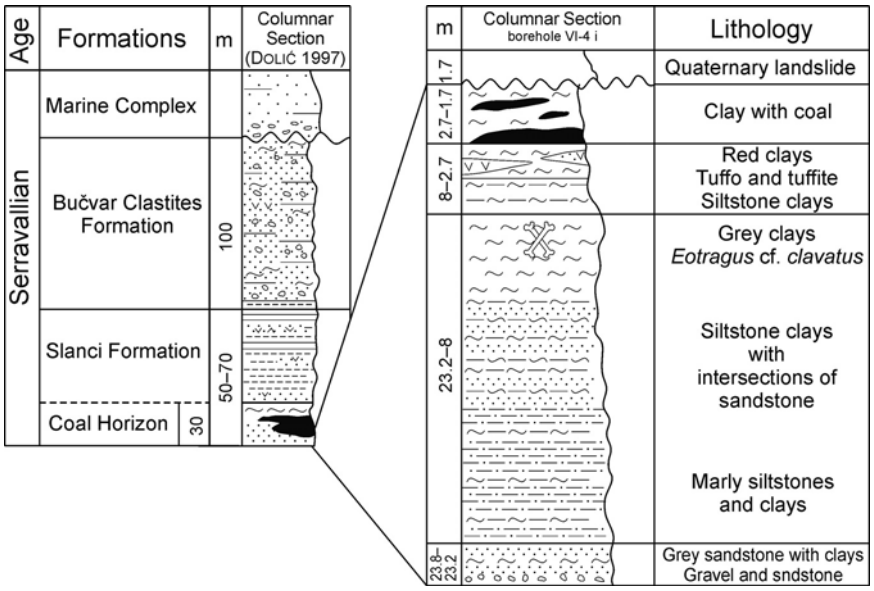

Fig. 2. Section penetrated in well VI-4i at Višnjica north of Veliko Selo on the elevated right bank of the River Danube (at 98 m) composed to a section of the formations of the Danube Ključ (according to Dolić, 1997). The position of *Eotragus* cf. *clavatus* is indicated.

yellowish silty clays with intercalations of sandstones of 2 to 3 cm in thickness. Gradually, to the lowest part of this section, sediments are represented by hard marly siltstone and clays. The molar was found at a depth of 8.8 m. In the lowermost portion of the core, at a depth of 23.8–23.2 m, there are grey siltstone sands with intersections of clays and a bed of sand with gravel.

Core lithology and correlation with other drillhole sections in the vicinity and sediments exposed suggests that the core covers the older portion of the Slanačka serija (see Fig. 1). The appearance of coal and coaly clays, as between 2.7 and 1.7 m, is characteristic of the lower part of the Slanci Formation in the eastern area of the Danube Ključ. The multicoloured sediments found at the base of the core probably represent the transition between the Slanci Formation and the underlying Veliko Selo Formation.

Palaeontology

Material and methods

The single molar from Višnjica, is kept in the collection of the Institute for Regional Geology and Paleontology, Faculty of Mining and Geology, University of Belgrade (RGF). It is here compared with *Eotragus* teeth from other localities, as housed at in the following collections: IPS, Institut de Paleontologia, Sabadell; IPUW, Institut für Paläontologie der Universität Wien; MHNT, Muséum d'Histoire Naturelle, Toulouse; MNHN, Muséum National d'Histoire Naturelle, Paris; NMB, Naturhistorisches Museum, Basel; SLJG, Steiermärkisches Landesmuseum Joanneum, Graz.

Measurements are taken as indicated by Van der Made (1989) and descriptive tooth morphology follows Van der Made (1996).

Description and comparison

The specimen preserves the buccal half of a right upper molar of selenodont morphology (Fig. 3). In the matrix sample contacting it, there is a root of another molar in front, suggesting it to be a second or third molar. The buccal wall extends much further posteriorly at the occlusal surface than at the base, which suggests that it is not a M^3, but rather a M^2. The selenodont morphology and its low crown show the tooth to have belonged to a ruminant, most probably a bovid or cervid. Although the crown is worn, it is visible that the tooth must have been fairly low, suggesting a Middle Miocene bovid or Miocene cervid, because younger members of these families tend to have higher crowns.

The buccal wall is relatively flat, as in early bovids. Early cervids, like *Procervulus*, *Dicroceros* and *Euprox* generally have a more strongly developed paraexocrista and the style in the centre is much more massive than at the base. In these characters, the tooth is closer to that in low-crowned early bovids, such as *Eotragus* and *Pseudoeotragus*. Of the protocone, only the protoendocrista can be seen. It is well developed, but at the occlusal level, it is not fused to the tetraprecrista or parapostcrista. In early cervids, the protopostcrista is better developed than the protoendocrista, whereas in later cervids the former crest tends to disappear and the latter becomes well developed. Even the earliest bovids have a well-developed protoendocrista and the protopostcrista is absent. The tetraprecrista and tetrapostcrista do not reach the buccal wall at the occlusal surface, leaving the posterior fossa open at both sides. Thus, the tooth represents an early bovid.

The tooth has a very low crown, much lower than in the Hypsodontinae (Köhler 1987), *Protragocerus*/*Miotragocerus* and also lower than a bovid from MN5 in Spain (Puente de Vallecas, Arroyo del Olivar, Valde-

moros, etc.; MORALES & SORIA 1985), which was referred to as *Protragoceros* or *Miotragoceros*. In addition, the latter forms generally are larger. *Tethytragus* (*Caprotragoides*) tends to be more hypsodont (AZANZA & MORALES 1994; VAN DER MADE & RIBOT 1999). Although *Tethytragus* from Pasalar, Çandir and La Grive are relatively low-crowned, they still are slightly higher than the molar from Višnjica. *Pseudoeotragus seegrabensis* has a M^2 that is slightly more high-crowned (VAN DER MADE 1989). *Eotragus* is a bovid having molars with the lowest crowns and thus is comparable in this respect to the molar from Višnjica.

In Europe, the *Eotragus artenensis* GINSBURG & HEINTZ, 1968 – *E. clavatus* (GERVAIS, 1850) (= *sansaniensis* (LARTET, 1851)) lineage is recognised, characterised by size increase, plus the very small *E. cristatus* (BIEDERMANN, 1873) (VAN DER MADE 1989). The M^2 from Višnjica has a length (DAPo = occlusal antero-posterior diameter) of 13.5 mm and a basal length (DAPb = basal antero-posterior) of 12.2 mm. In Fig. 3, the size increase in M^2 in the *E. artenensis* – *E. clavatus* lineage is shown. Additional measurements of other teeth show a similar picture (MAZO *et al*. 1998). The large sample from Sansan shows the range of variation. The molar from Višnjica is large compared to the M^2 of most samples, but is close to the mean value for specimens from Sansan.

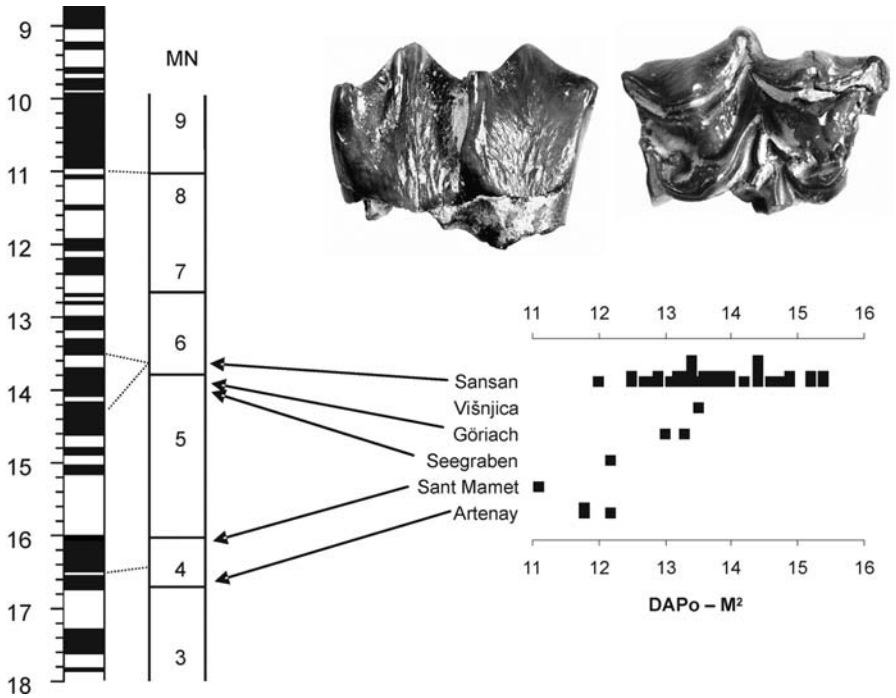

Fig. 3. Molar RGFKS31 of *Eotragus* cf. *clavatus* from Višnjica, buccal (left) and occlusal (right) view. The graph shows the DAPo or occlusal maximum length of M^2 of *Eotragus* from different European localities. In approximate stratigraphical order from old to young: Artenay (MNHN), Sant Mamet (IPS), Seegraben (SLJG), Göriach (SLJG, IPUW), Višnjica (RGF), Sansan (MNHN, MHNT, NMB). Correlations with to the MN proposed by VAN DER MADE (2005) (see discussion in text).

Discussion

Morphological features Višnjica molar best fit *Eotragus*. Accepting the range of variation as indicated by the Sansan sample, the specimen could be a particularly large individual of the small species *E. artenensis*. However, assuming that the small samples for Fig. 3 are probably close to the mean of populations which they represent, the tooth from Višnjica probably belongs to *Eotragus clavatus*. The use of open nomenclature reflects these uncertainties.

The *Eotragus* fossil and the age of the Slanačka serija

As mentioned above, the ages proposed for the Slanačka serija vary between Aquitanian or Early Burdigalian to Early Serravalien. The molar comes from the lower Slanci Formatioin, below the coal horizon.

As is apparent from the description and comparison, the age it indicates lies between the first and last occurrence of *Eotragus*, with a greater probability for a date close to Göriach and Sansan.

The oldest record of *Eotragus*, from Pakistan, is about 18 Ma old (SOLOUNIAS *et al*. 1995; GINSBURG *et al*. 2001). *Eotragus* is the oldest bovid in Europe and its first record is from Artenay (GINSBURG & HEINTZ 1968; GENTRY & HEIZMANN 1996; GENTRY *et al*. 1999) and the youngest probably from Manchones I. Artenay is a locality with *Democricetodon* but still without *Megacicetodon*, *Eumyarion*, *Deinotherium*, *Bunolistriodon* and *Dorcatherium*, and is early MN4 (MEIN 1975, 1977, 1990; DE BRUIJN *et al*. 1992) or zone B of the Aragonian (DAAMS *et al*. 1999b). Manchones I is placed in MN6 or zone G2 of the Aragonian (MEIN 1990; DE BRUIJN *et al*. 1992; DAAMS *et al*. 1999b). The age of Manchones I is estimated to be 13.25 Ma (DAAMS *et al*. 1999b).

The ages of MN units are still under discussion, especially the MN3-4 and MN6-7 transitions. Higher ages for MN units are suggested by DAXNER-HÖCK *et*

al. (1998), and REICHENBACHER *et al*. (1998), STEININGER (1999) while younger dates were by KRIJGSMAN *et al*. (1994, 2003), DAAMS *et al*. (1999a, b), AGUSTÍ *et al*. (2001), LARRASOAÑA *et al*. (2006), MONTES *et al*. (2006); see also RÖGL (1999), VAN DER MADE (1996, 2005). The estimated age of the MN 3-4 transition varies between 18 and 16.6 Ma and that of the MN 6-7 transition between 12.5 and 13 Ma. The total range (18 to 12.5 Ma) represents the possible age of the molar from Višnjica. An Egerian or Eggenburgian age can thus be discounted for the deposits which yielded it.

The more likely age of this molar ranges between Göriach and Sansan and possibly also Manchones I. Göriach was placed in MN6 (MEIN 1975, 1977, 1990; DE BRUIJN *et al*. 1992), but its more likely age is very late in MN5, close to the MN5-6 transition, and time equivalent to zone E of the Aragonian (VAN DER MADE 1998; VAN DER MADE & RIBOT 1999; DAXNER-HÖCK *et al*. 2004;). The age of the MN5-6 transition has been estimated to be about 15.1 Ma (REICHENBACHER *et al*. 1998) and 13.75 Ma (DAAMS *et al*. 1999a/b). The age of Sansan is under discussion as well, since its palaeomagnetism has been interpreted in different ways indicating ages of about 15 and 13.6 Ma (SEN, 1997, DAAMS *et al*. 1999a/b). As stated above, the age of Manchones I is estimated to be 13.25 Ma. The more likely age for deposits at Višnjica thus is around 15.1–13.25 Ma. This is more in line with the younger age estimates, which places the Slanačka serija Slanci Sequence in the Middle Miocene.

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Резиме

Средњомиоценска старост "Сланачке Серије" (околина Београда, Србија) на основу фосилних остатака примитивне антилопе *Eotragus* cf. *clavatus* из Вишњице

У непосредној околине Београда налазе се седименти Миоценске старости познати у старијој литератури као седименти "Сланачке Серије". Ови језерски седименти, представљени глинцима и лапоцима, са појавом угља, туфа и туфита, истраживани су више пута у прошлости (PAVLOVIĆ 1922; LUKOVIĆ 1922; STEVANOVIĆ & STANGAČILOVIĆ 1954; MILAKOVIĆ 1956, 1959; OBRADOVIĆ 1970; STEVANOVIĆ 1975, 1977; MIHAJLOVIĆ 1978; KRSTIĆ 1978, 1988, 1992; KNEŽEVIĆ 1994; DOLIĆ 1997). Током ранијих истраживања пронађени су остаци флоре и фауне. Сама старост језерских седимената Сланачке формације одређена је на основу суперпозиције и млађих седимената који су таложени у маринској трансгресији која се десила током Бадена (KRSTIĆ 1992). Старост маринских седимената је одређена на основу фауне.

Током истраживања која су обављена приликом копања канализационог колектора у Сланцима, у бушотини VI-4i, пронађени су остаци фосилног сисара који припада еволутивном низу *Eotragus artenensis* GINSBURG & HEINTZ, 1968 — *E. clavatus* (GERVAIS, 1850) (= *sansaniensis* (LARTET, 1851)). На основу палеонтолошке анализе остаци горњег десног молара одређени су као *Eotragus* cf. *clavatus* (GERVAIS, 1850). Поређењем са другим остацима ове линије фосилних бовида, који су пронађени у мноштву европских локалитета, показало се да би наш примерак одговарао врастама које су егзистирале током транзиције NM5 у MN6 јединицу. Одређен је могући интервал, изражен у апсолутној старости, између 15.1 и 13.25 милиона година (сл. 3).

Присуство фосилног материјала који је прикупљен током ранијих истраживања није био довољан да би се одредила тачна старост Сланачке формације. Наласком остататака примитиве антелопе из рода *Eotragus,* може се закључити да је старост седимената Сланачке формације мања него што су то предпостављали неки аутори.