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New data on Maastrichtian fishes of the 'Haţeg Island'

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Abstract. Some discoveries from the continental deposits of the paleogeographic landmass named the 'Haţeg Island' complete the fossil record of the Maastrichtian fish fauna of Europe. Teeth belonging to the Lonchidiidae and three morphotypes of Teleostei indet. are reported herein, from the uppermost Cretaceous continental formations cropping out in the Haţeg and Transylvanian sedimentary basins of Romania. These fishes document a terrestrial realm, where various aquatic environments occurred ca. 70 Ma ago, immediately after the 'Laramian' (latest Cretaceous) tectonic pulse. It is important to note the presence of a brackish water shark, reported for the first time in the Maastrichtian deposits of Romania. This advance in research argues for a higher Cretaceous fish diversity in Transylvania than previously suggested. Therefore, the ecology of the ancient vertebrate communities is better documented with elements unknown so far.

Key words:
latest Cretaceous, vertebrates, Lonchidiidae, fish teeth, Romania.

Апстракт. Фосилни проналасци из континенталних наслага палеогеографског копна под именом „Hateg острво" употпуњују познавање рибље фосилне фауне мастрихта у Европи. У раду су приказани зуби из фамилије Lonchidiidae и три морфотипа Teleostei indet. из највиших делова кредних континенталних формација откривених у Hateg-у и трансилванијском седиментационом басену Румуније. Ови рибљи остаци указују на копнену средину са разноврсним воденим басенима пре око 70 милиона година, одмах након Ларамијске (каснокредне) тектонске фазе. Важно је напоменути проналазак бочатне ајкуле која је први пут документована у мастрихтским наслагама Румуније. Ово откриће указује на већи кредни диверзитет риба у Трансилванији него што се до сада сматрало. На овај начин пружа се бољи увид у екологију некадашњих заједница кичмењака са подацима који нису до сада били познати.

Кључне речи:
горња креда, кичмењаци, Lonchidiidae, рибљи зуби, Румунија.

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Introduction

During the latest Cretaceous (Maastrichtian), as a result of the 'Laramian' tectonic pulse, in the Occidental and Southern Carpathians of Romania thrusting nappes occurred, erecting the Western Transylvanids, the Getian and Supra-Getian nappes (Săndulescu, 1984). As a consequence, islands emerged in this region of the Tethys Ocean. Among them, the Eastern Tethyan 'Haţeg Island' is of great interest for geology and paleontology, mainly due to the peculiar vertebrate communities (Nopcsa, 1905, 1914, 1915, 1923; Codrea & Godefroit, 2008; Codrea et al., 2010a, 2010b, 2010c, 2012; Weishampel et al., 2010; Csiki-Sava et al., 2015, 2016, Solomon et al., 2020). This landmass has been estimated to cover a surface of around 80.000 km^2 (Benton et al., 2010); however, clear evidence documenting this paleogeographic pattern concerns is still meager, because one may suspect that at least a part of the once continental sedimentary deposits was eroded. Therefore nowadays, the related deposits are clearly noticeable only in a few sedimentary basins like Rusca Montană (Codrea et al., 2012, 2017a), Haţeg and the southwestern area of the Transylvanian one (Codrea & Dica, 2005, Solomon et al., 2020 and references therein), as well as in its western and northwestern sides, at Iara (Popescu-Voiteşti, 1936; Codrea et al., 2010c) and Someş–Odorhei (Nopcsa, 1905; Codrea & Godefroit, 2008). One may presume that similar deposits could also be present in the Zlatna sedimentary basin, but Maastrichtian vertebrate fossils have not been found in this area until now (Codrea & Dica, 2005). In fact, partly, the actual Apuseni Mts. had already emerged in Maastrichtian and were probably part of this 'island', perhaps including areas that are now parts of the basement of the Cenozoic Pannonian Basin. But the presumed related deposits were probably removed by subsequent erosion that could have restricted these latest Cretaceous deposits to small patches. Consequently, such terrestrial deposits were never crossed by drillings in the Romanian eastern margin of the Pannonian Basin or in its related sub-basins like Baia Mare, Şimleu, Vad–Borod, Beiuş, Zărand etc. (Paraschiv, 1975; Mutihac & Mutihac, 2010).

Terrestrial deposits related to this 'Haţeg Island' yielded particularly diverse assemblages of Maastrichtian vertebrates. The most iconic areas rich in fossil vertebrates are the Haţeg basin and the southwestern embayment of the Transylvanian basin, known as the Metaliferi sedimentary area (Codrea & Dica, 2005; Solomon et al., 2020) (Fig. 1). Numerous teeth and bones already processed were assigned to amphibians, lizards, dinosaurs, pterosaurs, crocodiles, turtles, birds and mammals (e.g., Nopcsa, 1905; Delfino et al., 2008; Codrea & Godefroit, 2008; Codrea et al., 2010a, 2010b, 2010c, 2012, 2013, 2014, 2017b; Vasile & Csiki, 2011; Ősi et al., 2014; Grellet-Tinner & Codrea, 2015; Csiki-Sava et al., 2015, 2016; Solomon et al., 2020). In other regions, the fossils are still scarce, but the outcrops of these areas were and still are less surveyed by paleontologists (e.g., Iara in Cluj County, where a single dinosaur bone was discovered; Codrea et al., 2010c, and related references).

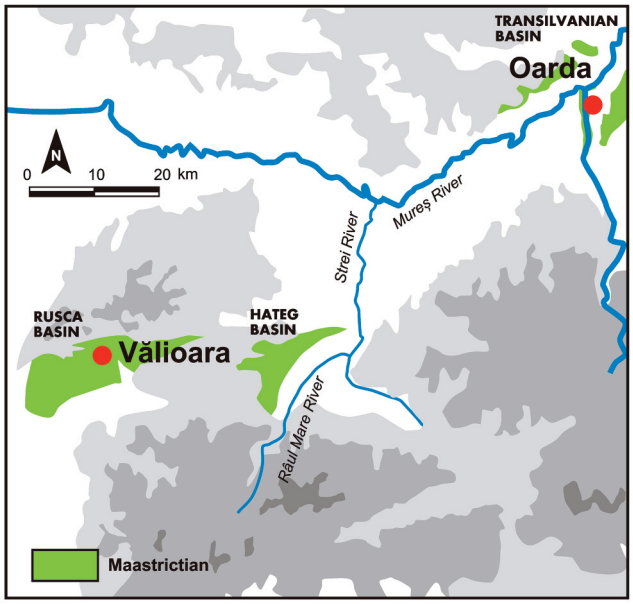

Fig. 1. *Geographical map of the vertebrate localities where the studied material originates from. After Grellet-Tinner et al. (2012), modified.*

Among these Maastrichtian vertebrates, the finds of fish remain in the territory of modern Romania are restricted to teeth and scales, due to specific hydro-taphonomy (Csiki et al., 2010). Teeth, due to their chemical composition and its resistance in such cases are the only remains found. Until now, there is not even a single location where fish skeletons could have been preserved. Consequently, only Lepisosteidae and some Characiformes remains

were illustrated and shortly discussed (e.g., Codrea et al., 2010a). Other reports only listed, but do not illustrate any representative of the recovered taxa and the referred remains. For that reason, any new find can be useful for reconstructing the Maastrichtian terrestrial environments.

In spite of the taxa we add herein, the general Romanian evidence of Mesozoic fossil fish still remains surprisingly scarce (see Trif & Codrea, 2018 and references therein). The material studied herein has been collected from the Maastrichtian locality from the Haţeg Basin, Vălioara, as well as from the Metaliferi sedimentary area of the Transylvanian Basin, in the locality Oarda de Jos A. At Vălioara the sediment consists of greenish-gray clay that is part on the infill of a fluvial channel, while at Oarda A the sediment is represented by marls and white-gray clays from a fluvial oxbow channel that likely had a seasonal activity (Codrea et al., 2010a, Solomon et al., 2020). The locality Vălioara exposes the Densuş–Ciula Formation (Grigorescu & Anastasiu, 1990), while in the Metaliferi area, Oarda de Jos A exposes the Şard Formation (Codrea & Dica, 2005; Codrea et al., 2010a; Solomon et al., 2020).

Material and methods

The fossils refer exclusively to isolated teeth. The material is stored in the Babeş-Bolyai University, Paleontology-Stratigraphy Museum in Cluj-Napoca (abbreviated hereinafter, BBUPSM). The photographs were taken with a Nikon D7000 camera mounted on a Nikon SMZ 1000 binocular microscope. The SEM images have been produced with the support of the Royal Belgium Institute of Natural Sciences in Brussels (abbreviated, RBINS). In order to obtain the materials, the sediment was processed by screen-washing of sediment with 0.5 mm and 0.3 mm sieves. For the quantities of material processed see the comprehensive part in the Discussions section.

Systematic paleontology

Class Chondrichthyes Huxley, 1880
Subclass Elasmobranchii Bonaparte, 1838
Cohort Euselachii Hay, 1902
Order Hybodontiformes Maisey, 1975
Superfamily Hybodontoidea Owen, 1846
Family Lonchidiidae Herman, 1977

cf. *Lissodus* sp. *sensu* Brough, 1935
Fig. 2A–E

Material. One fragmentary tooth (BBUPSM V697).

Locality: Vălioara, Hunedoara County, Romania.

Geological age and formation: Maastrichtian, Densuş–Ciula Formation.

Description. The tooth is small. It reaches 3.4 mm in the mesio-distal direction and 1.8 mm labio-lingually. The specimen comprises a central, wide and low pyramidal cusp. A well-defined mesio-distal cutting edge is noticeable along the entire length of the crown from which smaller, secondary ridges diverge, but never reaching the edge of the crown. The central transverse ridge is better highlighted compared to the others. The labial margin of the tooth forms a well-defined apron. The labial face bears a central attrition, which is possibly caused by the adjoining tooth's lingual apron. The whole root is missing.

Remarks. The Hybodontoidea superfamily and the component families were subject of repeated reassessments. Several attempts have been made over the time to clarify issues related to its taxonomy (e.g., Duffin, 1985; Rees & Underwood, 2002; Dorka, 2003).

The Vălioara fragmentary tooth shares many similarities in its external morphology to those previously assigned to *Lissodus.* The genus is known at least from the Early Triassic until Maastrichtian (Cappetta, 2012), although some authors mention *Lissodus* occurring since Devonian (e.g., Ginter et al., 2002). A similar genus, *Lonchidion*, is sometimes considered as a junior synonym to *Lissodus* (Case & Schwimmer, 1988). However, Rees & Underwood (2002) and Cappetta (2012) considered it as a valid one. A single Maastrichtian species, *L. babulskii* Cappetta & Case, 1975 was initially assigned to *Lonchidion* but later Cappetta (2012) argued that *L. babulskii* does not correspond to the emended diagnosis of *Lonchidion* coined by Rees & Underwood (2002) and is closer in fact, to *Lissodus*. The Vălioara specimen resembles *L. babulskii* in general morphology, but it differs by the presence of secondary divergent

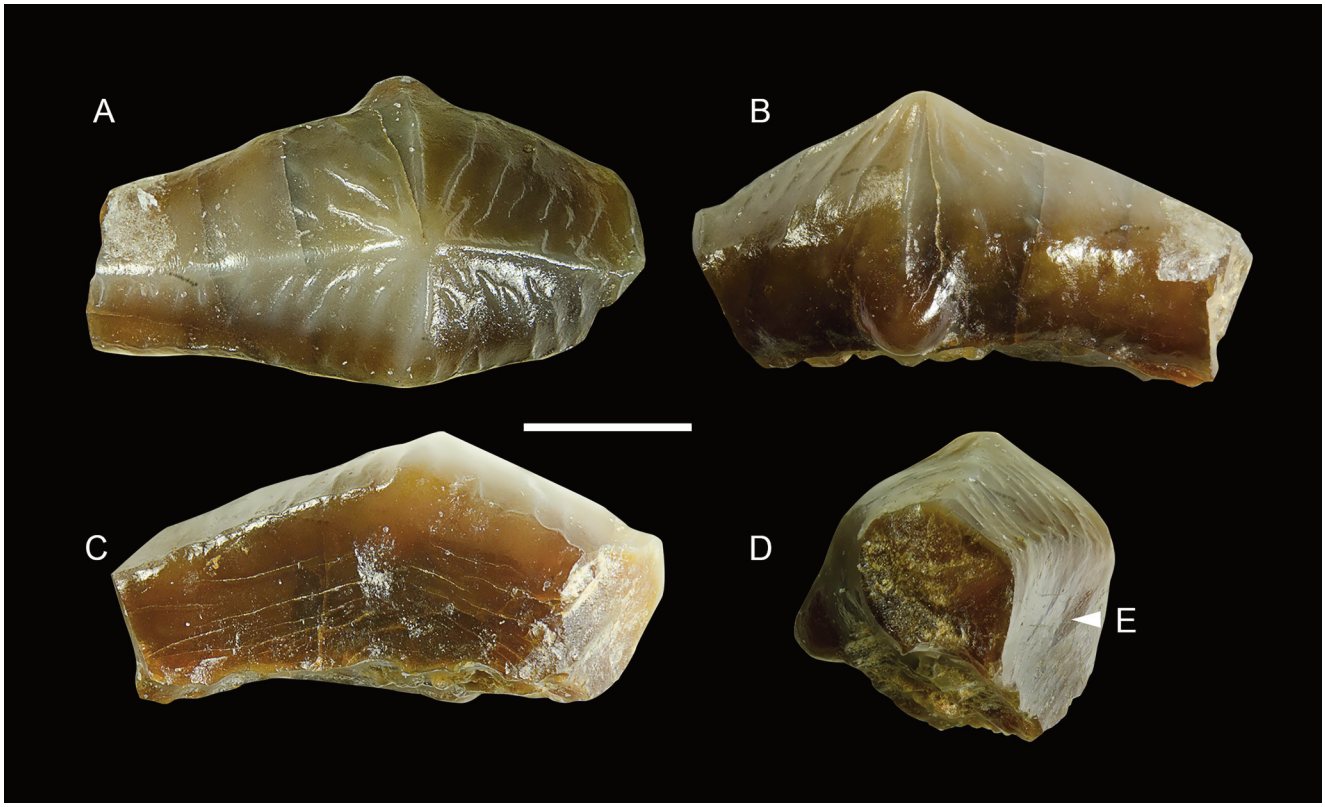

Fig. 2. *Lonchidiidae, cf. Lissodus sp., Maastrichtian, Vălioara, Haţeg: BBUPSM V697 in* ***A,*** *apical;* ***B,*** *labial;* ***C,*** *lingual and* ***D–E,*** *mesial views.* ***E,*** *the arrow indicates a central contact zone. Scale bar is 1 mm.*

ridges that are closer to those in the Jurassic species *L. leiodus* (Woodward, 1887).

Class Actinopterygii Klein, 1885

Actinopterygii indet., morphotype 1
Fig. 3A–B

Material. A single anterior tooth (BBUPSM V806).

Locality. Oarda de Jos A, Alba County, Romania.

Geological age and formation. Maastrichtian, Şard Formation.

Description. A very small tooth, with a height of 2.4 mm, a mesio-distal width of 0.9 mm and a maximal labio-lingual thickness of 1 mm is available for study. The upper part of the tooth crown is wide, while the lower portion narrows and is peduncle-like shaped, with a mesio-distal width restricted to only 0.55 mm.

The lingual face is concave while the labial one is on the opposite, slightly convex. The apical margin of the tooth is sharp and straight. The tooth is symmetrical both in labial and lingual views. In the basal view, we can notice the pulp cavity, a relatively oval deep hollow. The base of the peduncle is perpendicular to the crown axis, forming a "buttress". The enamel exposes very small, elongated holes in the upper part of the crown, which form a reticulated surface.

Remarks. The morphology of the specimen BBUPSM V806 is similar to the Cenozoic Sparidae (see Cappetta, 1969, pl. XXI, figure 26–30; Bauzá-Rullán, 1981, pl. 1, figure 1–3; Schultz, 2013, pl 67, figure 2–5; Fricke et al., 2016, figure 6). The morphology is strikingly similar including the reticulated surface of the upper part of the tooth (Fig. 3D–G). The records of the Mesozoic Sparidae are uncertain. Sparidae indet. were reported indeed, from the Campanian of France (Buffetaut et al., 1996), and the Maastrichtian of the same country (Laurent et al., 1999; Laurent, 2003). However, later they were contested and it was suggested that the molariform teeth belong to the Paralbulinae (Blanco et al., 2017). The specimen is also similar to premaxillary

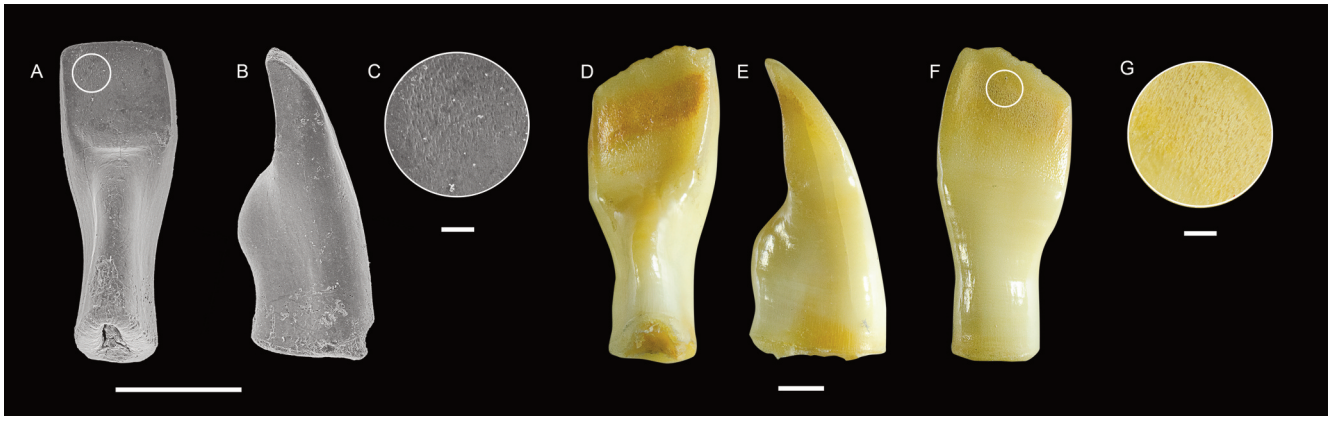

***Fig. 3**. Actinopterygii indet., morphotype 1, Oarda de Jos: BBUPSM V806 in **A,** lingual and **B,** distal views; **C,** detail of the surface (SEM images); Diplodus sargus, extant comparative material: in **D,** lingual, **E,** distal, **F,** labial views; **G,** detail of the surface. Scale bars are 1 mm for A, B, D, E and F and 0.2 mm for C and G.*

(incisor-shaped) teeth of pycnodont fishes (see Kriwet, 2001, figures 2 and 3; Sweetman et al., 2014, figure 10B). However, since these premaxillary teeth carry little diagnostic information for the pycnodonts, they are rarely figured so we cannot get a very clear image of their detailed morphology. We consider it more prudent to allocate this tooth only at the class level.

Actinopterygii indet., morphotype 2

Fig. 4A–E

Material. Two pharyngeal teeth (BBUPSM V803-804).

Locality. Oarda de Jos, Alba County, Romania.

Geological age and formation. Maastrichtian, Şard Formation.

Description. The teeth are strongly flattened and asymmetrical. Their sizes are similar to one another, 0.8 mm wide and 1 mm high. As the orientation of the tooth is unclear, we associate the concave side to the posterior orientation and the convex side to the anterior one. The general 'hook' shape suggests an affinity with the pharyngeal teeth found in many fish species.

Remarks. The morphology described is very similar to the morphotype 1 of the Teleostei indet. illustrated from the Santonian deposits of Hungary (Szabó & Ősi, 2017, figure 15a–b). Their interpretation of the morphology is similar, suggesting a pharyngeal position of the teeth.

***Fig. 4.** Actinopterygii indet., morphotype 2, Maastrichtian, Oarda de Jos, Transylvanian basin: BBUPSM V803, in **A,** labial, **B,** lingual and **C,** ?distal (B) views; BBUPSM V804, in **D,** labial and **E,** lingual views. Scale bars are 0.5 mm.*

Actinopterygii indet., morphotype 3
Fig. 5A–C

Material. One isolated tooth (BBUPSM V807).

Locality. Oarda de Jos, Alba County, Romania.

Geological age and formations. Maastrichtian, Șard Formation.

Description. The tooth is peculiar through its elongated, relatively narrow crown that forms a crest composed from an asymmetrical central cusp and three smaller cusps that progressively decrease in height, distally. In apical view, there can be observed another secondary cusp located in the anterior part of the tooth. It was worn down (as was the main cusp too) by the functional wear. On the lingual side a horizontal facet is present (Fig. 4M). This kind of surface has been described before (Gaudant & Smith, 2008) as a lingual cingulum.

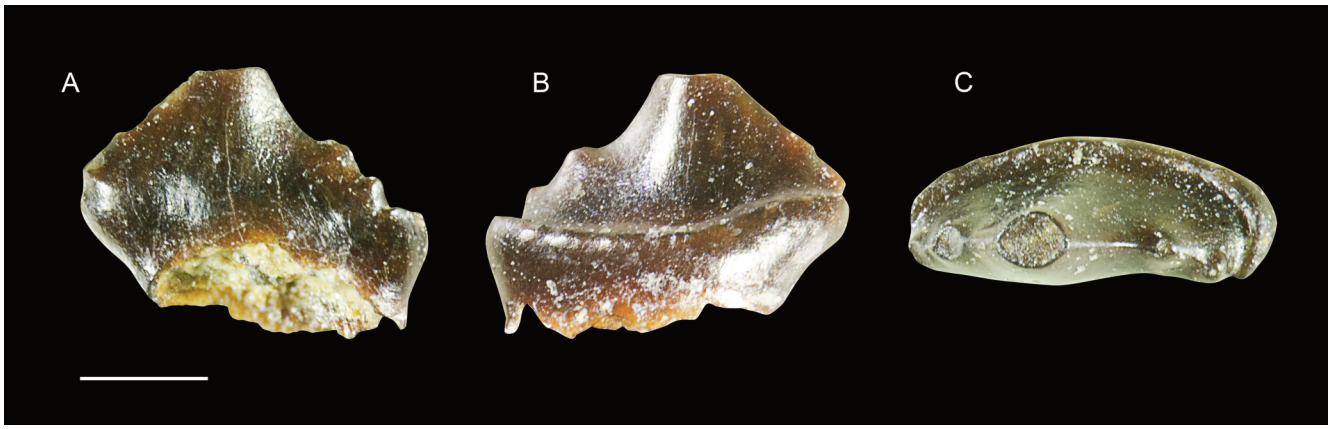

Fig. 5. *Actinopterygii indet., morphotype 3, Maastrichtian, Oarda de Jos, Transylvanian basin: BBUPSM V807, in A, labial;* ***B,*** *lingual and* ***C,*** *apical views. Scale bar is 1 mm.*

Remarks. The discussed tooth has a vague resemblance with some Characiformes teeth. The presence of Characiformes in Maastrichtian has been reported for the first time in Romania and in Europe in 1985, when an isolated tooth from Pui was identified by H. Cappetta as belonging to Characidae indet. (in Grigorescu et al., 1985). Only a few other reports mentioned or illustrated this taxon from Romania, but they are all lacking of a detailed discussion (Csiki et al., 2008; Grigorescu et al., 2010; Codrea et al., 2013). Moreover, the original material from 1985 was subsequently lost (Grigorescu et al., 2010, p. 146). The poor state of preservation does not allow us the taxonomic allocation even at the level of order. We only notice the similarity with Characiformes but we refrain from more precise identification.

Discussions

After some additional field missions, we are now able to document new fish taxa, based on some isolated teeth as follows. Now, we are able to document the presence of Lonchidiidae in the Hațeg Basin based on the first find of a shark in the Maastrichtian deposits of Romania. Additional undetermined teleost fishes are also reported and illustrated. These data indicate a fish diversity richer than it has already been known. Even if we take into consideration the material exposed herein, the overall fish diversity in the 'Hațeg Island' still remains extremely scarce. We need to emphasize the scarcity of Maastrichtian fish remains (other than Lepisosteidae) in this area. From the locality Oarda de Jos A, were processed more than 2.8 tons of sediment (Codrea et al., 2017a) and in addition to several hundreds of remains of teeth and scales of Lepisosteidae only the above-described specimens were found. Several other hundreds of kilograms were further processed in the next years. In addition, from the other localities with Maastrichtian continental deposits, large quantities of sediment

have been processed too (1000 kgs in Codrea et al., 2012; 150 kgs in Codrea & Solomon, 2012; 900 kgs in Csiki-Sava et al., 2016; 750 kgs in Codrea et al., 2017b) but no other remains a part of the Lepisosteidae and Characiformes were reported.

Compared to the Hungarian Santonian fauna (Szabó & Ősi, 2017), or to the Maastrichtian faunas of France (Blanco et al., 2017) and Spain (Berreteaga et al., 2011), the Romanian fish fauna of similar geological ages seems to be less diverse by the present knowledge. This scarcity makes it difficult to establish clear trophic relationships between fishes. The abundance of gar fishes from the family Lepisosteidae (Csiki et al., 2008; Grigorescu et al., 2010; Codrea et al., 2013) makes their autochthonous status probable, with a possible secondary relationship to a nearby marine environment (e.g., the extant species of *Atractosteus* are known to visit full marine waters according to Nelson et al., 2016).

Although, at a first glance, the presence of the Lonchidiidae shark tooth might raise questions about the ancient physiography of the so-called 'Haţeg Island', it should be noted that many genera from the Hybodontoidea including *Lissodus* have been related to a brackish, fluvio-marine environment, such as the deltaic domains, or the estuarine and even freshwater environments (Bender & Hancox, 2004; Rees & Underwood, 2006, 2008). Therefore, the presence of this shark in Vălioara is not surprising, considering the euryhaline living environment characteristic of this family.

The habitat and trophic relations of the other fish elements are unknown. One possibility is that the Lonchidiidae and other components of this paleocommunity are anadromous fishes that went upstream into freshwater rivers and the related lakes when their flow increased seasonally or occasionally. This could account for the rarity of this kind of remains. Another possibility might be that they were pray for various larger vertebrate taxa, like piscivorous birds or pterosaurs. Apart from this report, only one other representative of the Lonchidiidae, *Lissodus* sp. has been found in Romania in the Middle Triassic (Anisian) of Lugaşu de Sus in littoral, shallow marine environments (Posmoşanu, 2015).

However, hybodont sharks are mentioned also in Southern Carpathians, in the Reşiţa-Moldova Nouă sedimentary area (Mutihac & Ionesi, 1974), in Anina area (Dica & Codrea, 2006). They referred to *Hybodus* sp., based on five isolated teeth (BBUPSM V 416 – V 420), found in the Steierdorf Formation, Uteriş Member (Pliensbachian), in bituminous shales. These sharks inhabited the waters of an intramountain sedimentary basin that occurred in the area, during the Pliensbachian-Toarcian crisis (Dera et al., 2011, 2016).

In the context of this geological find – continental freshwater sedimentary deposits – the Characiformes also seem to be an autochthonous taxon, as the large majority of the extant Characiformes fossils are confined to fresh waters (Nelson et al., 2016). Previously considered to be carnivorous fishes (Grigorescu et al., 2010), we appreciate that for instance there is no direct evidence of the diet of the latest Cretaceous Characiformes from Romania. Indeed, many of the Characiformes are carnivorous (Nelson et al., 2016), but there are also some of them with a diet based in dominance on algae, that also have sharp multicuspidate teeth (e.g., *Hyphessobrycon copelandi*, *H. piorskii* or *Ctenobrycon hauxwellianus* and *C. oliverai*; Benine et al., 2010; Ramírez et al., 2015; Guimarães et al., 2018).

Conclusions

For the Maastrichtian 'Haţeg Island' based on various fish dweller taxa, we reconstruct a terrestrial area with diverse aquatic environments. Some of the fishes were possibly anadromous taxa coming from brackish environments or even from the open marine realm. The presence of the hybodont shark in the deposits of the Densuş-Ciula Formation could not be accidental. We may think about its vicinity with the Tethys Sea margin, as far we know that in Rusca Montană basin there were mangrove plant communities (Petrescu & Duşa, 1970, 1980, 1982) and palms on swampy terrains (Popa et al., 2014, 2016) similar to an island flora. It is less probable that this shark will be recorded in the sediments of the Sânpetru Formation or in the ones from Pui, in the so-called 'Bărbat Beds' (Therrien, 2005), both being considered as having once much more inland positions.

Acknowledgements

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Резиме

Нови подаци о мастрихтским рибама „Haţeg" острва

Острво „Haţeg" у некадашњем источном Тетису је од великог интереса за геологију и палеонтологију због очуваних необичних заједница кичмењака. Процењује се да је ова копнена маса покривала површину од око 80.000 km^2. Овде су пронађени бројни остаци зуба и костију за које је утврђено да припадају водоземцима, гуштерима, диносаурима, птеросаурима, крокодилима, корњачама, птицама и сисарима. Насупрот овим таксонима, остаци риба су изненађујуће ретки. Проучавани палеонтолошки материјал је прикупљен на мастрихтским локалитетима Vălioara у „Haţeg" басену и Oarda de Jos A који се налази у трансилванијском басену. На локалитету Vălioara, мастрихтски седименти Densuş-Ciula формације представљени су зеленкасто-сивим глинама које представљају испуну флувијалног канала, док су на локалитету Oarda de Jos A наслаге изграђене од лапораца и белосивих глина које потичу из некадашњег канала који је вероватно био само сезонски активан и саставни су део Şard формације.

По први пут је у „Haţeg" басену документовано присуство зуба из фамилије Lonchidiidae што представља први проналазак бракичних ајкула у мастрихтским наслагама Румуније. Ова фамилија је карактеристична за бочатно, флувио-маринско окружење као што су делте и естуари, па чак и слатководне средине, и представља еврихалинску врсту. Такође, документовани су и приказани остаци неутврђених кошљориба. Ови подаци указују на богатију рибљу разноврсност него што се то до сада сматрало. У поређењу са мађарском сантонском фауном, или са фауном из мастрихта Француске и Шпаније, румунска рибља фауна показује мању разноликост.

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