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# ‘X’ marks the spot! Sedimentological, geochemical and palaeontological investigations of Upper Cretaceous (Maastrichtian) vertebrate fossil localities from the Vălioara valley (Densuş-Ciula Formation, Haţeg Basin, Romania)

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ABSTRACT

At the beginning of the 20th century, the Croatian-Hungarian palaeontologist Ottokár Kadić discovered a rich Late Cretaceous vertebrate assemblage around Vălioara in the Haţeg Basin, including fossils of several dinosaurs and the lectotype of the eusuchian *Allodaposuchus*. These fossils were collected from seven main localities and have been housed in the collections of the Mining and Geological Survey of Hungary. However, the collection was mixed after World War II, and this unprovenanced material currently cannot be used for palaeoecological investigations. Nevertheless, the map marking the location of Kadić’s sites has been recently uncovered, showing the positions of the fossiliferous localities, which allows matching these with the historically collected specimens using geochemistry. Based on Kadić’s map, we georeferenced, relocated, and re-excavated these vertebrate-bearing outcrops, and documented their sedimentological context. Detailed stratigraphical investigations of the exposed successions indicate that this Vălioara material represents one of the oldest (earliest Maastrichtian) Late Cretaceous faunal assemblages known from the Haţeg Basin. The vertebrate remains collected during our new excavations around Vălioara represent turtles (*Kallokibotion*), crocodyliforms (*Allodaposuchus*, *Doratodon*, ‘*Theriosuchus*’, *Acynodon*), dinosaurs (*Zalmoxes*, *Telmatosaurus*, titanosaurs, theropods), and mammals. In order to determine potential geochemical differences among the sites, we selected several specimens with recorded stratigraphic position, measured their trace element compositions, and used these as independent proxies to assess the probable stratigraphic origin of the historical vertebrate fossils. Our detailed sedimentological, geochemical and palaeontological investigations around Vălioara contribute to a deeper understanding of the distribution, evolution and palaeoecology of the Haţeg vertebrate faunas during the latest Cretaceous.

## 1. Introduction

The Vertebrate Collection of the Mining and Geological Survey of Hungary (Magyar Bányászati és Földtani Szolgálat, abbreviated as MBFSZ) in Budapest houses hundreds of Upper Cretaceous continental vertebrate (mostly dinosaur) remains from Transylvania. This material was collected during the last decade of the 19th century and the first two decades of the 20th century by field geologists of the Royal Hungarian Geological Institute (the predecessor of the present-day MBFSZ; see below, Historical overview)

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mapping in the area of the Haţeg (in Hungarian: Hátszeg) Basin, in Hunedoara (Hunyad) County, western Romania (then part of Austria-Hungary). The vertebrate remains have been inventoried as more than 200 catalogue entries, most of which actually designate multiple specimens registered under common inventory numbers. Almost all of these remains were collected from several sites spread around the small village of Vălioara (Valiora), in the northwestern part of the Haţeg Basin. Transylvanian fossil vertebrate sites such as the nearby Sânpetru (Szentpéterfalva) are among the most important European uppermost Cretaceous dinosaur-bearing sites, and Vălioara, although mostly historically, was also considered a significant one.

The importance of this historical Vălioara fossil collection is emphasized by the fact that it includes type specimens such as the proposed lectotype of the basal eusuchian crocodyliform *Allodaposuchus precedens* Nopcsa, 1928 (Nopcsa, 1915, 1928; Buscalioni et al., 2001) and the possible holotype of the dwarf sauropod dinosaur *Magyarosaurus dacus* (Nopcsa, 1915) (Nopcsa, 1915; Huene, 1932), as well as several other scientifically important and frequently studied specimens (e.g. Huene, 1932; Weishampel et al., 1993, 2003; Buscalioni et al., 2001; Le Loeuff, 2005; Stein et al., 2010; Narváez et al., 2020). However, the exact location of the historical Vălioara sites yielding this important material remained unknown for more than a century.

The aim of the present study is to identify the positions, and determine the depositional environments, of the historical Kadić vertebrate sites based on available and, especially, newly acquired GIS, sedimentological, taphonomical, palaeontological and geochemical data concering the fossil-bearing horizons around Vălioara Valley. After discussing the historical and geological-palaeontological aspects of the wider Vălioara fossil locality, we provide new sedimentological and REE geochemical data for several bone-bearing successions from the surroundings of Vălioara, with special focus on those hosting the historical vertebrate sites discovered and excavated by Kadić. Finally, we determine the probable depositional environments of these successions with historical and new fossiliferous sites and their fauna, and discuss the significance of the newly amassed sedimentological, palaeontological, taphonomical, REE geochemical and palaeoecological data.

Institutional abbreviations used: **LPB [FGGUB]**, Laboratory of Palaeontology, Faculty of Geology and Geophysics, University of Bucharest, Romania; **MBFSZ**, Collection of the Mining and Geological Survey of Hungary, Budapest, Hungary; **NHM**, Natural History Museum, London, UK.

## 2. Historical overview

The Vălioara fossil vertebrate material housed in the MBFSZ collections was collected by the famous Croatian-Hungarian scientist Ottokár Kadić at the beginning of the 20th century. Kadić was employed at the Royal Hungarian Geological Institute from 1901 and a few years later, in 1909, he worked in Transylvania in the area near Runcu Mare (Nagyrunk), Hunedoara County, as part of the ongoing large-scale geological mapping of Hungary conducted by the institute (Böckh, 1903; Kadić, 2010). When he finished mapping in the Runcu Valley at the end of August 1909, he was assigned the task of his colleague Ferenc Schafarzik, who was mapping about 20 km to the southeast, at the western edge of the Haţeg Basin in the area around Vălioara and Densuş (Demsus). However, just as Kadić started to map in this newly appointed area, he discovered vertebrate remains (mostly dinosaurs) in Upper Cretaceous (Maastrichtian, at that time referred to as 'Danian' – e.g. Nopcsa, 1905) rocks in several sites in the surroundings of Vălioara (Lóczy, 1911; Kadić, 1911, 1916, 2010).

By that time Transylvanian dinosaur remains had been known from (and outside) the Haţeg Basin, including the famous locality of Sânpetru, first reported by the Royal Hungarian Geological Institute field geologist Gyula Halaváts (Halaváts, 1897). Almost simultaneously, but at a much larger scale, vertebrate remains were collected and described from Sânpetru by the legendary vertebrate palaeontologist Baron Ferenc Nopcsa (e.g. Nopcsa, 1900, 1902, 1905), following the initial discovery of such remains by Nopcsa's sister Ilona in 1895 (Weishampel and Jianu, 2011). Nopcsa (1905) had already mentioned the presence of dinosaur remains from around Vălioara and Densuş as well, thus Kadić's discoveries were not entirely unexpected. However, he found a large number of vertebrate fossils at several sites, and it took him the rest of the field season to excavate and collect these, whereas he failed to finish the geological mapping of the area. He planned to continue with both the mapping and with further excavations of the rich fossiliferous beds around Vălioara in the following years (Kadić, 1916). Although he never completed mapping the region, he kept prospecting for latest Cretaceous vertebrates here, and conducted systematic excavations for weeks in at least four subsequent seasons. According to the annual reports of the institute, Kadić excavated with his team of paid local workers in the Vălioara area in 1912, and then again especially in 1913, in 1914, and finally in 1915 (Kadić, 1916).

The Kadić material, several hundreds of specimens "*filling multiple cabinets*" (Kadić, 1916; here and in all following quotes, translated from Hungarian), was housed (and in part exhibited) in the Royal Hungarian Geological Institute. In his brief summary of the excavations, Kadić (1916) noted that he "*conducted the last excavations in the fall of 1915*", and that with these, he "*regarded his Vălioara research as accomplished*". After the end of World War I and the subsequent turmoils, vertebrate palaeontology research was practically halted in the Haţeg Basin for several decades, until the late 1970s, when Dan Grigorescu from the University of Bucharest started systematic excavations in the area (Grigorescu, 1983). From that moment, a large number of new sites and vertebrate localities have been discovered in the Haţeg Basin as well as in other parts of western Transylvania (see e.g. Codrea et al., 2010; Csiki-Sava et al., 2016), but all this time, the exact locations of the original Vălioara sites of Kadić remained unknown.

In his final excavation report, Kadić (1916) briefly described the geological background of the Vălioara area, and summarized his excavations and their outcome. In a few sentences he described each of the seven most productive sites (designated with Roman numerals I to VII), commenting on their lithology and on the preservation state of the remains they yielded. He also noted the presence of other nearby, less fossil-rich outcrops where he also found (mainly isolated) vertebrate remains, but no further details were given about these other occurrences. Unfortunately, his report did not provide maps or detailed guides to the exact locations of the fossiliferous sites; neither did he discuss the stratigraphic positions of the fossiliferous beds. He mentioned only the local names of the ravines where his excavation sites were located, sometimes complemented by hints about the approximate position of the sites within the specific outcrop, for example "*on the branching of the ravine (VI)*" (Kadić, 1916). These scarce details were hardly enough to identify his sites on the current topography, especially given the densely vegetated nature of the surroundings of Vălioara.

Beyond the brief overview of his field activities, Kadić did not intend to give a detailed account on the fossil localities or the material collected. Instead, Nopcsa, already the most competent researcher working on Transylvanian Cretaceous vertebrates, took up the study of the Vălioara material once it was collected, within the framework of his wider research on the Transylvanian dinosaurs and other vertebrates (Nopcsa, 1915).

It is worth stressing that, based on his record of cave research as well as on his activity as a curator, Kadić appears to have been precise, meticulous, and accustomed to systematic collecting methods; thus, it seems likely that he documented in his field notebooks vital information during (and about) the Vălioara excavations. Unfortunately, after his death in 1957, the largest part of his manuscripts and notes (filling an entire flat) was lost, thus his potential field documentations were most probably also destroyed.

Recently, however, after hearing our complaints about the lack of information regarding the original Kadić localities, Pál Pelikán (a late colleague at the MBFSZ) suggested that the map sheet of the Third Military Topographic Survey of the Habsburg Monarchy (mapped between 1869 and 1887), corresponding to the area where the Kadić excavations took place, should be checked in the Map Collection of the MBFSZ. He argued that there was a chance that the topographic map sheet used by Kadić during his fieldwork was available there, and might contain some information. The colleagues in the library of the MBFSZ gave access to the map collection, including the rather worn old map sheet depicting the Vălioara—Densuș area. There was no direct indication of the map sheet being used specifically by Kadić, but geological units have been partially coloured and marked in the northwestern parts of the Hațeg Basin, and some strike/dip symbols were also added among other notes. Most importantly, however, seven ‘X’ cross symbols with Roman numerals ranging from I to VII, as well as 16 additional black dots without numbers, have been marked on the map with ink in the surroundings of Vălioara (Fig. 1A). Remarkably, the spatial relationships of these crosses to each other as well as to the topography match the description of the seven most productive sites reported in the summary written by Kadić (1916), whereas the presence of the dots is in agreement with his note concerning the identification of other less important fossil occurrences. Moreover, as later turned out in the field, some of these ‘X’ marks and their locations could also be matched with the currently existing local names of the ravines (see below). This map made it possible to georeference the sites excavated by Kadić on modern maps and relocate them in the field (Fig.1).

### *2.1. The Kadić collection at the MBFSZ*

Almost all of the several hundred specimens collected by Kadić at Vălioara, including type specimens of *Allodaposuchus precedens* and *Magyarosaurus dacus*, lack information about their exact place of origin or stratigraphic provenance (except a very general ‘Danian’ designation), both in the inventory books and on their labels. Part of these specimens were inventoried in 1915—1916 or in the 1930s (those with inventory numbers starting with ‘Ob’, e.g. Ob.3131), whereas more than half of them got accession numbers only decades later, in the 1970s and 1980s (specimen numbers starting with ‘V’, e.g. V.13528). The information given in the catalogue and on the specimen labels is usually limited to their site of provenance - indicated only vaguely as ‘Valiora’ -, and to the collector, identified as Kadić (or even, in the case of the lately inventoried items, erroneously as ‘Nopcsa F.’). Moreover, inventory items with the ‘V’ numbers are mostly a mixture of dissociated specimens. Sometimes dozens of remains with different colours and preservation states, obviously originating from different sites/lithological units, and representing different taxa, were put together. A significant number of these specimens, especially the elongated ones, are broken and incomplete, but show traces of a characteristic collagenous animal glue on their breakage surfaces. In some cases, matching parts of the same skeletal element have been found mixed up among other specimens, and catalogued under different inventory numbers. This mixing might be the result of historical turmoils the institute went through, such as the Second World War.

Whatever happened to the fossils during the last hundred years, in the present, with a few notable exceptions, it is impossible to ascertain which specimen came from which of the 7 major and more numerous minor localities excavated by Kadić. Regardless of these shortcomings that hamper to a great extent the in-depth study and comprehensive exploitation of this important historical fossil vertebrate collection from the Hațeg Basin, several of its elements had been described, figured and/or discussed, subsequent to their excavation and accessioning into the Collection. As the Vălioara assemblage makes up the bulk of the MBFSZ collection of latest Cretaceous continental vertebrates, most of the studies using MBFSZ specimens indeed concern specimens collected by Kadić, although a few specimens originating from Sânpetru had also received some attention (e.g. Mlýnarski, 1966; Ősi and Főzy, 2007).

The first to study (at least part of) this collection was Nopcsa, in the framework of his vast research concerning the latest Cretaceous Transylvanian fossil vertebrates. Having first-hand knowledge about the Hațeg Basin geology (Nopcsa, 1905) and its vertebrates (e.g. Nopcsa, 1900, 1902), aware of the then ongoing excavation of these specimens, as well as having granted access to the material right after it was collected (Kadić, 1916), Nopcsa was definitively the best-suited to make the most of it in terms of scientific exploitation. However, it seems that unlike the cases of the fossil localities he himself excavated at Sânpetru for which he mentions at least occasionally sedimentary context, field association of different skeletal remains and/or taphonomic features (e.g. Nopcsa, 1900, 1904, 1914), he was either less aware or simply more careless about the same type of information easily available to him in the case of the Kadić collection. Consequently, Nopcsa employed only selected skeletal elements from Vălioara to complement the general osteological descriptions presented in his first synthetic overview of the latest Cretaceous dinosaur asssemblage from Hațeg (Nopcsa, 1915), including specimens used to erect a new taxon of titanosaurian sauropod, ‘*Titanosaurus*’ *dacus*, or to suggest the presence of large-bodied theropods in the fauna (see below). He also figured several skeletal elements from the Kadić collection, including associated skull and postcranial remains of a crocodyliform individual he referred to *Crocodilus affulevensis* (sic), a taxon previously described from uppermost Cretaceous deposits of southern France (Matheron, 1869). Later, he included ornithopod vertebral specimens from Vălioara in his monographic study (Nopcsa, 1925) describing the vertebral columns of the hadrosauroid ‘*Orthomerus*’ (now *Telmatosaurus*; Nopcsa, 1903; Weishampel et al., 1993) and of the rhabdodontid ‘*Rhabdodon*’ (now *Zalmoxes*; Weishampel et al., 2003). More importantly, he erected the new crocodyliform taxon *Allodaposuchus precedens* based on the remains from Vălioara previously referred to ‘*Crocodilus affulevensis*’ (Nopcsa, 1928).

After Nopcsa, there is an important gap in the study of the Kadić collection specimens, but such studies started to steadily emerge in the last decades of the 20th century. The type material of *Allodaposuchus precedens*, including its former lectotype, the first reasonably complete crocodyliform skull known from the uppermost Cretaceous of Europe, has been featured prominently in subsequent research (e.g. Buscalioni et al., 2001; Delfino et al., 2008b; Martin, 2010; Martin et al., 2016; Narváez et al., 2020). However, the most numerous publications involving specimens of the Kadić collection concern dinosaurs that are by far the best represented group.

Although the presence of theropods was assumed at Vălioara based on vertebral (Nopcsa, 1915) and cranial (Jianu and Weishampel, 1997) elements, these reports have been dismissed subsequently, as the caudal vertebrae show titanosaurian affinities (Z. Cs.-S. pers. obs.) whereas the cranial material is referable to rhabdodontids (Weishampel et al., 2003). Theropod remains are thus absent in the Vălioara material collected by Kadić.

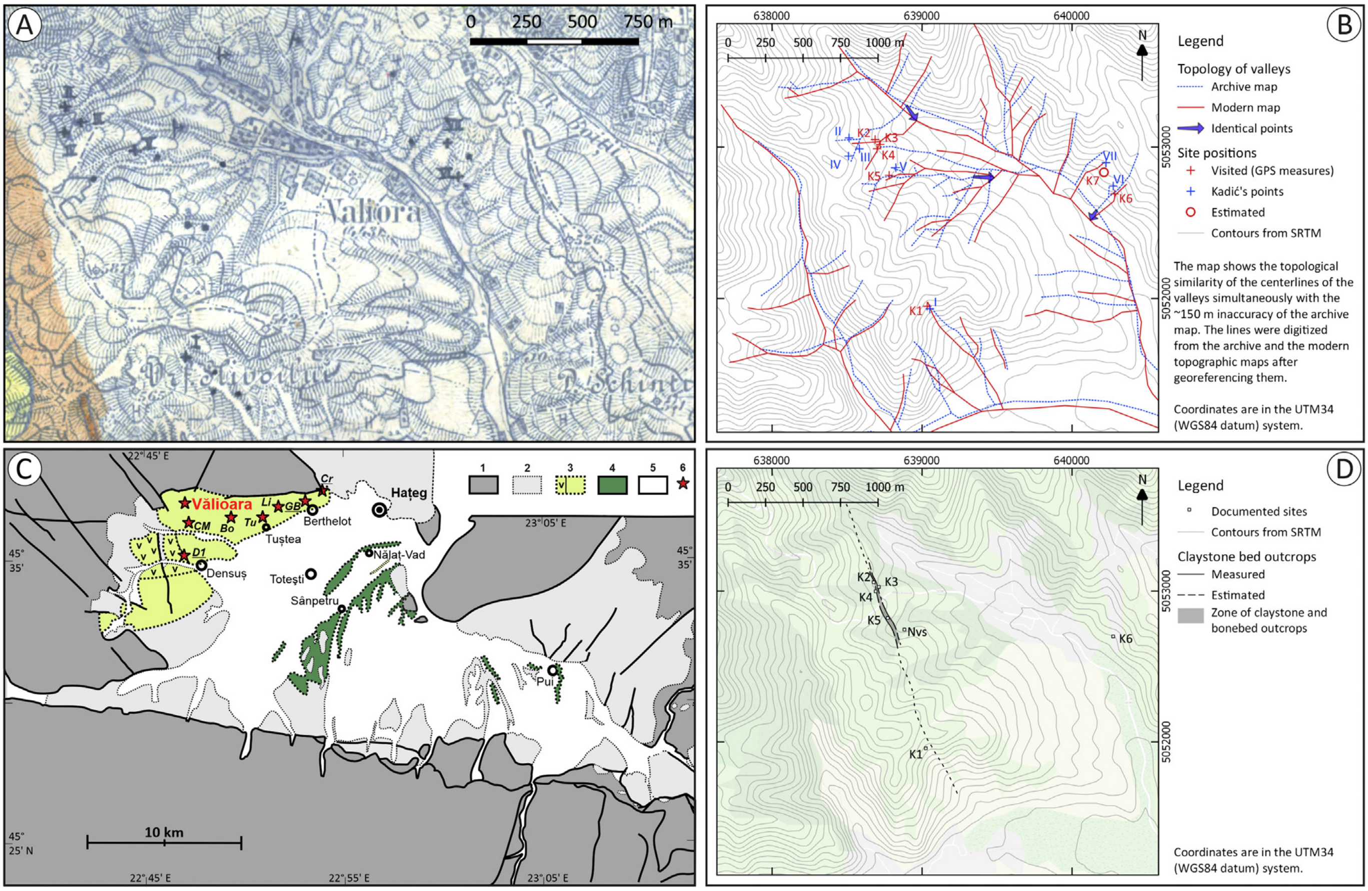


**Fig. 1.** Maps of the investigated area. A) A copy of the original map sheet of the Third Military Topographic Survey of the Habsburg Monarchy, showing the position of excavation sites I to VII of Kadić; B) Location of the outcrops marked by Kadić and revisited during our 2019 survey. The differences between the archive and the modern topographic maps are expressed using the digitized centerlines of the valleys, emphasizing the largely similar topology of the valley network. Contours are depicted using the SRTM data, to highlight the accuracy of the modern map. Note: the position of Kadić's site no. VII is considered traceable based on the topological similarity between the archive and the modern map, but this site was not found during the field work; C) Simplified geological map of the Haţeg Basin, with the location of the most important uppermost Cretaceous continental vertebrate localities (modified from Csiki-Sava et al., 2016); D) Map of the documented sites, with the measured claystone beds and their estimated general geometry (70° dip direction, 53° dip). Legend: 1 – crystalline basement; 2 - sedimentary cover of the Haţeg Basin, other than Maastrichtian continental beds; 3 - the Maastrichtian Densuş-Ciula Formation; v - dominantly volcano-sedimentary beds; 4 –the Maastrichtian Sînpetru Formation; 5 - Quaternary terraces and alluvia; 6 - main fossil sites. Abbreviations: Bo – Boiţa; CM – Ciula Mică; Cr – Crăguiş; D1 – Densuş; GB – General Berthelot; Li – Livezi; Nvs: New vertebrate site; Tu – Tuştea .

Ornithopod remains, on the other hand, make up a significant part of the Kadić collection. These were surveyed, described and (occasionally) figured in the most authoritative recent reviews of the two ornithopod genera currently known from the Haţeg Basin – the rhabdodontid *Zalmoxes* (Weishampel et al., 2003) and the hadrosauroid *Telmatosaurus* (Weishampel et al., 1993).

Finally, the largest number of publications concerns the sauropod remains collected by Kadić. Coincidently, these belong to the dinosaur group less well studied by Nopcsa himself, despite the fact that in his first review of the Transylvanian dinosaurs (Nopcsa, 1915) he gave a brief introductory description of a new sauropod taxon, the titanosaurian '*Titanosaurus*' *dacus*. The new taxon was based to a great extent on specimens from the Kadić collection, including here the only sauropod remains figured in this review. Later, to Nopcsa's personal invitation, Huene (1932) reviewed the entire Transylvanian sauropod material, including specimens collected by Kadić, and erected a new genus, *Magyarosaurus*, for it. He went on, and separated two distinct species (*M. dacus*, *M. transylvanicus*) within this genus, as well as recognized one more taxon, potentially referable to the same genus (?*M. hungaricus*). He also figured, for the first time, several important sauropod specimens from Vălioara. Again, Nopcsa's failure or oversight in recognizing the importance of the field data that would have been available from Kadić is worth mentioning. He (at that time, director of the Geological Institute) sent several sauropod specimens from the Vălioara collection to Huene for first-hand examination, but apparently did so with total disregard of their possible association, either within the same fossil locality, or even in the same skeleton (Kadić, 1916; Csiki and Grigorescu, 2006). Most intriguingly, in some cases such information (i.e., remains being associated and originating from one individual) is recorded even in the MBFSZ inventory book as historical entry, and thus was available to Nopcsa when he arranged the shipment of the specimens to Tübingen. Due to this information bias, Huene ended up referring Vălioara titanosaurian specimens that potentially belong to the same individual to different taxa, or simply remained unaware that further skeletal elements may be available for him to study in the case of some of the taxa he separated (e.g. Csiki and Grigorescu, 2006). More recently, sauropod skeletal elements from the Kadić material had been used to survey aspects of ontogenetic development and potential dwarfing in the Transylvanian sauropods (e.g. Jianu and Weishampel, 1999; Benton et al., 2010; Stein et al., 2010), to assess the range of body sizes represented in the sample, and its implications for the recognition of island dwarfism (e.g. Le Loeuff, 2005; Stein et al., 2010), as well as to understand local taxic diversity of titanosaurs (e.g. Csiki and Grigorescu, 2006; Csiki et al., 2007, 2011; Stein et al., 2010; Mannion et al., 2019a,b). Currently, Kadić's sauropod material is under re-study, in the framework of an ongoing general review of the Transylvanian titanosaurs (Mannion et al., 2019b; work in progress).

## 3. Geological background

The Haţeg Basin is an intermontane basin within the western part of the Southern Carpathians, in southwestern Transylvania, Romania. It was formed in the aftermath of the latest Cretaceous orogenetic events which shaped the present large-scale nappe structure of the Southern Carpathians (e.g. Săndulescu, 1984). The basin is filled with a spatially and temporally discontinuous sedimentary succession covering the Permian to Holocene time interval (e.g. Nopcsa, 1905; Laufer, 1925; Mamulea, 1953a,b; Stilla, 1985), including a thick pile of Upper Cretaceous deposits (Stilla, 1985; Pop, 1990; Grigorescu, 1992). Probably the most notorious part of this sedimentary succession is represented by the uppermost Cretaceous (Maastrichtian) continental deposits that yielded a rich assemblage of vertebrate remains, including dinosaurs and mammals, first studied by Nopcsa (1897, 1905, 1915, 1923a). These deposits were accumulated subsequent to the end-Cretaceous Second Getide nappe stacking and mountain building (Grigorescu, 1992; Willingshofer et al., 2001) that led to the uplift of the surrounding regions of mainly crystalline basement. This orogenetic event was followed by erosional denudation and transport of the resulting sediments into the Haţeg basinal area, which was newly created through post-orogenic collapse.

The post-collisional uppermost Cretaceous deposits are known to be exclusively continental (and dominantly alluvial) in the Haţeg Basin (see below). Correlative deposits have been mapped towards the west, as well as towards the north and north-east (e.g. Nopcsa, 1905; Grigorescu, 1992; Codrea et al., 2010; Csiki-Sava et al., 2016), showing that the entire region of the Southern Carpathians as well as large swaths of the surrounding areas have been emerged to coalesce and form the isolated Transylvanian landmass or the 'Haţeg Island' (Nopcsa, 1914, 1915; Weishampel et al., 1991; Benton et al., 2010; Csiki-Sava et al., 2015), one of the major emergent areas of the Late Cretaceous European Archipelago (Csiki-Sava et al., 2015).

Within the Haţeg Basin, post-collisional uppermost Cretaceous continental deposits are spread across the western and central-to-central-eastern parts (Fig. 1C), but the available outcrops are rather patchy and widely spaced, mainly covered by Quaternary deposits, and also heavily vegetated. This makes tight correlation between the different outcropping areas rather difficult, impeding the detailed understanding of the overall lithostratigraphic framework of the continental uppermost Cretaceous. Nevertheless, there is an emerging general agreement that these deposits can be ascribed to two major lithostratigraphic units – the Sînpetru Formation situated in the central parts of the basin, around Sânpetru village, and the Densuş-Ciula Formation that spreads across its western-northwestern areas, from Densuş and Ciula Mică in the west to Crăguiş in the east. The Vălioara area, place of the historical Kadić excavations, is situated in the northwestern corner of the Haţeg Basin, within the outcropping range of the Densuş-Ciula Formation.

### 3.1. *The Densuş-Ciula Formation*

This lithostratigraphic unit is characterized by a mixture of typical continental, alluvial deposits with volcanoclastic and volcano-sedimentary beds. Although the volcanoclastic material is widespread in the deposits of the unit, it occurs concentrated mainly in the westernmost and (supposedly) lowermost part of the Densuş-Ciula outcropping area, between Ştei, Densuş, Ciula Mică and Răchitova settlements (Fig. 1C). This volcano-sedimentary facies had been distinguished first as the Densuş Formation (Antonescu et al., 1983), but was afterwards referred to as the (informal) 'lower member' of the Densuş-Ciula Formation (Grigorescu, 1992). The contribution of the pyroclastic material diminishes towards the east, where it is restricted to reworked andesitic lithoclasts within conglomerates, respectively to altered volcanic ash identified in the matrix of some sandstones as well as in some finer-grained beds (e.g. Grigorescu, 1992). These more eastern successions, dominated by different types of alluvial deposits (see below), were separated as the Ciula Formation by Antonescu et al. (1983), but are currently recognized as the (informal) 'middle' and 'upper' members of the Densuş-Ciula Formation (Grigorescu, 1992). Historically, the distinction between the two upper subdivisions of the formation had been made based on the presence or absence of typically Mesozoic vertebrate remains, with the 'upper member' supposed to extend more or less continuously into the Paleocene. In recent years, however, dinosaur and other vertebrate remains typical of the latest Cretaceous assemblages known from the Sînpetru Formation and the 'middle member' of the Densuş-Ciula Formation had been reported from the upper part of this unit as well (Vasile et al., 2011a,b; Csiki-Sava et al., 2016). This suggests the shifting of the boundary between the two subunits farther to the east, east of Crăguiş, or possibly even a reconsideration of the classical three-fold subdivision of the formation. The presence of volcano-derived material within the succession of the Densuş-Ciula Formation testifies for ongoing volcanic activity towards the west, during the deposition of the 'lower member', respectively mostly preceding the accumulation of the 'middle' and 'upper' members.

The Maastrichian age of these deposits, first quoted as Danian (*sensu* latest Cretaceous) by Nopcsa (1905) and Laufer (1925), have been ascertained by Dincă et al. (1972). This age was subsequently upheld independently by palynological studies (Antonescu et al., 1983; Csiki et al., 2008), by their superposition on top of biostratigraphically dated Campanian marine beds (Grigorescu and Melinte, 2001; Melinte-Dobrinescu, 2010), and more recently by K–Ar radiometric ages (Bojar et al., 2011). Based on the strike and dip of the beds (see Supplementary I), the deposits of the Densuş-Ciula Formation appear to become younger towards the east. Accordingly, the uppermost Cretaceous continental beds cropping out in the neighborhood of Vălioara are considered to be lying close to the base of the Densuş-Ciula succession, in the basal part of the 'middle member', and are thus most probably of earliest to early Maastrichtian in age (Csiki-Sava et al., 2016). This age assessment is congruent with the 71.3 ± 1.6 Ma K–Ar radiometric age reported by Bojar et al. (2011) from a tuff layer situated slightly to the west, near Ciula Mică, and it is also concordant with the report of Maastrichtian palynological and gastropod assemblages from three different localities situated in the vicinity of our study area, one south of Ciula Mică, the other two on the eastern (left) side of the Vălioara Valley (Antonescu et al., 1983; Csiki et al., 2008).

The continental uppermost Cretaceous deposits of the 'middle member' of the Densuş-Ciula Formation – including those cropping out patchily, mainly within ravines, in the surroundings of Vălioara – were most recently reviewed by Csiki-Sava et al. (2016). These are represented by different alluvial deposits – reddish and grey-greenish conglomerates and sandstones that correspond to channel fills, alternating with variegated, red or grey-green siltstones and mudstones of floodplain origin, with very minor participation of coaly mudstones and thin coal seams known to be present mainly around Ciula Mică, a little to the west of the investigated area.

In the northern part of the Vălioara area, poorly sorted matrix-supported breccias are also recorded besides the more common lithotypes. These usually appear restricted to the lower part of the succession; their matrix is represented by reddish fine micaceous sands to mudstones, and the clasts are mainly metamorphic in origin, reminiscent of the crystalline basement rocks (phyllites, biotite-sericite schists, quartzites) cropping out a short distance to the north. The spatial proximity of these deposits to the northern crystalline basement border of the basin, as well their poorly sorted nature and clastofacies, suggests that they represent very proximal alluvial fan deposits (discussed below as talus breccia beds) developed at the foothills of the then recently uplifted and actively eroding basement units (e.g. Grigorescu and Csiki, 2002). On the other hand, the purplish grey, poorly sorted conglomerates and coarse sandstones featuring reworked and altered andesitic pebbles, a lithotype characteristic for the more eastern outcropping areas of the Densuș-Ciula Formation, such as those around Tuștea or General Berthelot (e.g. Grigorescu et al., 1994; Vasile et al., 2011a; Botfalvai et al., 2017), have not been reported so far from the surroundings of Vălioara.

### *3.2. Palaeontological record from the Densuș-Ciula Formation around the Vălioara locality*

The uppermost Cretaceous beds cropping out around Vălioara are among the most fossiliferous deposits of the Densuș-Ciula Formation. Subsequent to Kadić's work, a number of other important vertebrate localities have been identified in the area, including the rich microvertebrate bonebeds of Fântânele and Budurone (e.g. Grigorescu et al., 1999; Csiki et al., 2008; Vasile and Csiki, 2010). Furthermore, these deposits include the type localities of the endemic frog taxa *Hatzegobatrachus grigorescui* and *Paralatonia transylvanica* (Venczel and Csiki, 2003), respectively that of the giant azhdarchid pterosaur *Hatzegopteryx thambema* (Buffetaut et al., 2002).

These fossil sites cumulatively yielded a very diverse vertebrate fauna that includes lepisosteid and indeterminate osteichthyan fish (Grigorescu et al., 1999); several anurans (the alytids *Paralatonia transylvanica* and cf. *Bakonybatrachus*, the bombinatorid *Hatzegobatrachus grigorescui*, and a possible indeterminate pelobatid; Venczel and Csiki, 2003; Venczel et al., 2016); the albanerpetontid *Albanerpeton* (Grigorescu et al., 1999; Csiki et al., 2008; Vasile and Csiki, 2010); the basal testudinate *Kallokibotion bajazidi*, possibly associated with as yet indeterminate pleurodires (Vremir, 2004; Rabi et al., 2013); a morphological diversity of lizard remains that are unfortunately very poorly preserved and mainly taxonomically indeterminate (Csiki et al., 2008; Vasile and Csiki, 2010); the madtsoiid snake *Nidophis insularis* (Vasile et al., 2013a); diverse crocodyliforms, represented mainly by isolated teeth (*Allodaposuchus precedens*, *Sabresuchus* ('*Theriosuchus*') *sympiestodon*, *Acynodon*, *Doratodon*; Grigorescu et al., 1999; Martin et al., 2006, 2014: Vasile, 2008); the azhdarchid pterosaur *Hatzegopteryx thambema*, probably associated with a second large-sized taxon (Buffetaut et al., 2002; Vremir et al., 2018); dinosaurs, with titanosaurian sauropods (including *Magyarosaurus dacus*: Nopcsa, 1915), rhabdodontid (*Zalmoxes robustus*, *Z. shqiperorum*; Nopcsa, 1915; Weishampel et al., 2003) and hadrosauroid (*Telmatosaurus transsylvanicus*; Nopcsa, 1915; Weishampel et al., 1993) ornithopods, different small-sized non-avian theropods, known mainly based on isolated teeth (velociraptorine dromaeosaurids, *Richardoestesia*, *Euronychodon*; Vasile and Csiki, 2010), as well as indeterminate ornithurine birds (Wang et al., 2011); dinosaur eggshells (Csiki et al., 2008; Choi et al., 2020); and, finally, at least two different taxa of kogaionid multituberculate mammals (Csiki and Grigorescu, 2000, 2002). In addition to this vertebrate assemblage, palynological assemblages (Antonescu et al., 1983; Csiki et al., 2008), plant mesofossils (Lindfors et al., 2010), insect ichnofossils (Vasile et al., 2013b; Hermanová et al., 2017), as well as fragmentary terrestrial and freshwater gastropods (Antonescu et al., 1983; Pană et al., 2002) were also reported from the Vălioara area.

## 4. Bone-bearing horizons around Vălioara with special focus on the historical vertebrate sites discovered by Kadić

More than a hundred years after the excavations of Kadić, new reconnaissance fieldwork was devised and conducted around Vălioara village, in order to rediscover his former main vertebrate-bearing sites, as well as to survey their local successions in detail and to search for new potentially bone-bearing horizons. Besides its palaeontological significance, the aim of the new field survey was to understand the sedimentological conditions under which the specimens of the historical collection were preserved, as well as to identify the palaeoenvironmental conditions represented by the rocks in/around these sites, information that can then be used in subsequent palaeoecological investigations.

Relocating the historical sites was based primarily on the map used by Kadić and discovered in the map collection of the MBFSZ (Fig 1A). Based on the geo-referenced positions of the old fossil localities, two field surveys were carried out in the autumn of 2019 in the surroundings of Vălioara Valley. These were focused on the major ravines mentioned by Kadić (1916) as "*Pareu vartopilor*" (current toponym Pârâul Vârtopilor, from the Romanian term pârâu = creek), "*Pareu niagului*" (Pârâul Neagului), "*Pareu ogradilor*" (Pârâul Ogradiilor), and "*Pareu buduron*" (Pârâul Budurone), the locations of the seven most important vertebrate localities excavated by him (that is, mark 'X'-s I to VII). During our investigations, we employed an array of cartographical, sedimentological, palaeontological and geochemical methods in order to identify the historical sites of Kadić in the field and to collect all the available information about the palaeoenvironmental conditions under which the vertebrate remains were buried.

### *4.1. Locating Kadić's outcrops and sites using maps*

#### *4.1.1. Material and methods*

Maps were instrumental in re-locating the outcrops Kadić described briefly in 1916, more than one hundred years ago. At that time, the maps used in geological surveying were the 1:25000 topographic maps of the Third Military Topographic Survey of the Habsburg Monarchy (Balogh, 1994; Albert, 2019). Although these new maps were not available to the public, the geologists of the Royal Geological Institute of Hungary had access to them from 1880 onwards, and used them in the field (Pentelényi and Síkhegyi, 2012). These topographic maps were already compiled in the metric unit system, and besides slope hatches, they also depicted elevation contours with a 20 m interval (Jankó, 2018), making it possible to draw a geometrically accurate interpretation of the local stratigraphy.

The topography of the Haţeg Basin, as depicted on the map Kadić used, was surveyed in 1881-82 by officers of the Vienna Military Geographical Institute (Jankó, 2018). The mapping was extremely rapid, and was carried out as a plane table survey (Kretschmer, 1991). With this method the precise mapping of side valleys and especially of the smaller ravines is impractically time consuming, so the representation of smaller landforms was sometimes inaccurate. The estimated accuracy of these maps is within the maximum range of 200 m (Timár et al., 2010). Kadić drew a sketch of the observed geology and marked up the visited outcrops on the map sheet Coll. XXVII Sect. 23 SO (later renamed to 5769/4) depicting Vălioara village in its north-eastern corner (Fig. 1A). It can be georeferenced based on our knowledge of its projection and geodesic datum properties (Molnár and Timár, 2009).

There are newer topographic maps of the area available as well; these are the 1:25000 maps of the Gauss-Krüger system (zone 34) surveyed mainly in the 1960s and renewed several times later using aerial photogrammetry (Osaci-Costache, 2000). The map of the study area (sheet no. L34-94-B-a) is available online (Geomil, 2020).

Satellite photos of the area are freely available on Google Maps. The photos were taken by the Pleiades satellites of the French Space Agency (CNES) and Airbus, and have a relatively high (2.8 m) ground resolution (Gleyzes et al., 2012).

Due to the inaccuracies of the 19th century topographic survey and of the archive cartographic material itself, the outcrops and fossil localities marked on the unpublished map would certainly not fall to the right place after georeferencing, but there are other means as well to more precisely estimate the positions of the Kadić excavation sites. Based on his published description (Kadić, 1916) the geomorphological characteristics of the excavation sites can be reconstructed and identified on the actual maps and satellite photos. The topological positions of Kadić's mark 'X' points shown on his map can also serve as clues.

Our fieldwork in the fall of 2019 – using the georeferenced old topographic map annotated by Kadić, the new topographic maps, and Google satellite imagery – resulted in the localization of several vertebrate sites in the vicinity of Vălioara village (Table 1). To ascertain as much as possible that these newly localized places correspond at least roughly to the ones that Kadić has documented, the following criteria were examined:

1) Does the georeferenced location (latitude, longitude) of the sites on the manuscript map match the measured position of the visited outcrop?
2) Is the topological position of the site – relative to other map objects such as valleys and ridges – identical on the manuscript map and on the modern map?

To check for these criteria, we have built a GIS (Geographic Information System) using QGIS 3.4 to handle map visualization and database management. GIS methods to build a geodatabase of palaeontological sites and vertebrate discoveries were already used successfully previously (e.g. Birkenfeld et al., 2015; Ősi et al., 2019). The open source QGIS program was also mentioned as a useful tool in managing palaeontological geodatabases (Albert et al., 2018).

During the 2019 fieldwork we used handheld GPS for positioning, with a horizontal accuracy of 5–10 m. The georeferenced locations from the archive map were considered identical with the ones measured in the field (Table 1), if the horizontal difference between the coordinates was within two times the GPS accuracy. To analyse the topological relations between localities and local geomorphological features, the centre-lines of the valleys were digitized within QGIS both on the archive and the modern topographic maps. This produced an "archive" and a "modern" network of valleys. The "archive mark X" location points (i.e. vertebrate sites I to VII of Kadić) were also digitized from the manuscript map, while the "modern" excavation points identified by our team in 2019 (marked up as K sites; see Table 2) were positioned on the modern topographic map with their GPS-measured coordinates. Our topological analysis examined the relationships between the locality points and the line network of the valleys, respectively, for both the archive and the modern data. This relation was considered to be similar between the corresponding pair of "archive" and modern" points from the two data sets, if the points were on the same side of the line, and close to the same node(s) (i.e. forking and end of line points) of the line network, in both the archive and the modern topologies. For the GPS-measured coordinates, an uncertainty circle with a radius of the horizontal accuracy was taken into account during the analysis.

### 4.1.2. Results

The coordinates of the georeferenced sites from the archive map usually do not precisely match the ones identified and measured in the field at our excavation sites. The distance between the matching pairs of points varies between 25 and 200 m, and only in the case of our site K1 (corresponding to the one marked as I on the archive map) can we accept similarity in the coordinates (see Table 2, and Fig. 1B). Nevertheless, the topological analysis showed that the archive map and the modern one can be considered topologically similar in the neighbourhood of Vălioara. Topological similarity in this case means that the forking direction and the counts of the side valleys and gullies are the same on the two maps (Fig.1B). Only some minor side gullies are not represented on the modern map, but among the visited locations only site K6 was close to such a place.

**Table 1**
Records of the visited sites. Coordinates are in the UTM 34N system (WGS84 datum).

| | Name | Easting | Northing | Elevation | Horizontal accuracy [m] | Vertical accuracy [m] | Type |
|---|---|---|---|---|---|---|---|
| Pârâul Vârtopilor | K1 | 639034,3 | 5051949 | 467 | 10 | 6 | GPS |
| Pârâul Neagului | K2 | 638686,9 | 5053049,4 | 502 | 8 | 8 | GPS |
| | K3 | 638721,2 | 5053018 | 505 | 7 | 12 | GPS |
| | K4 | 638700 | 5052989,7 | 509 | 5 | 6 | GPS |
| Pârâul Ogradiilor | K5 | 638780,5 | 5052813,4 | 509 | 4 | 5 | GPS |
| | Nvs | 638891,9 | 5052736,2 | 496 | 10 | 5 | GPS |
| Pârâul Budurone | K6 | 640283,8 | 5052690,9 | 447 | 10 | 6 | GPS |

**Table 2**
Summary of the cartographic analysis.

| Name of ravines | Kadic's site | Visited site | Horizontal distance on the map between the two versions [m] | Horizontal accuracy of GPS measurement [m] | Topological position |
|---|---|---|---|---|---|
| Pârâul Vârtopilor | I | K1 | 24,3 | 10 | identical |
| Pârâul Neagului | II | K2 | 174 | 8 | identical |
| | III | K3 | 142,2 | 7 | identical |
| | IV | K4 | 196,8 | 5 | identical |
| Pârâul Ogradiilor | V | K5 | 67,9 | 10 | identical |
| Pârâul Budurone | VI | K6 | 52,4 | 5 | mainly similar[a] |
| | VII | – | – | – | traceable |

[a] Its relation to the main branch of the valley is identical, but a side gully was not present on the modern map.

Kadić added the 'X' points marking his excavation sites on a map which he considered to be the correct representations of the topography. If one assumes that he drew the points on their topologically accurate positions (i.e. he mapped correctly), then the points representing sites K1 to K6 measured by us are topologically identical or largely similar to the location points of excavation sites I, II, III, IV, V and VI, respectively, indicated on Kadić's map (Table 2). In the case of Kadić's site no. VII, its position is considered traceable based on the topological similarity between the archive and the modern map, just as in the case of the other localities. However, although we expected to find outcrops at the topologically traceable location, in the field we failed to do so, as this area is presently mainly levelled and heavily vegetated, even partly farmed.

Summarizing the above information, we managed to identify the locations of excavation sites I, II, III, IV, V and VI of Kadić marked on the manuscript map. In their current position, these sites are now referred to as K1, K2, K3, K4, K5 and K6, respectively (Fig. 2B). Most importantly, during the fieldwork a new vertebrate site (Nvs), situated close to K5, was also recorded and excavated. On the other hand, site VII of Kadić was not identified in the field.

### 4.2. Sedimentological description and interpretation of the successions exposed around the Kadić sites

After identifying the most probable locations of the vertebrate sites excavated by Kadić (1916), a comprehensive sedimentological and palaeontological prospecting has been conducted in the surroundings of these in order to survey the relocated former vertebrate-bearing successions as well as to discover new bone-bearing outcrops (Figs. 1-6). Previous palaeontological research in the Densuş-Ciula Formation focused mainly on the central-eastern parts of its outcropping area, due to better outcrop availability and the presence of several important and famous fossiliferous localities (e.g. Grigorescu et al., 1994; Grigorescu and Csiki, 2008; Csiki et al., 2010a; Vasile et al., 2011a, b; Csiki-Sava et al., 2016; Botfalvai et al., 2017, and Fig. 1C). Even though the neighbourhood of Vălioara was also prospected rather intensively during the recent decades, and with remarkable palaeontological results (e.g. Grigorescu et al., 1999; Csiki and Grigorescu, 2000; Buffetaut et al., 2002; Csiki et al., 2008; Vasile and Csiki, 2010), the activities so far focused mainly on the eastern side of the Vălioara Valley and the Vălioara-Boiţa interfluve, where outcrops are more easily available. Meanwhile, the sedimentary make-up of the uppermost Cretaceous continental successions exposed on the western side of Vălioara Valley, towards the interfluve with Geat Valley and with Ciula Mică locality – where most of the historical Kadić excavation sites are located –, remained severely understudied and thus relatively poorly known until our survey.

#### 4.2.1. Material and methods

During the 2019 fieldwork, deposits of the Densuş-Ciula Formation exposed around and mainly west of Vălioara Valley were the focus of our survey, with seven stratigraphic sections, each measuring 15–20 m in length, identified, logged, and studied in detail (Figs. 2-6). These sections correspond to the approximate locations identified for the original Kadić excavation sites. In order to distinguish between historical and actual sites, the historical vertebrate localities mentioned by Kadić will be marked with Roman numerals from I to VII as per his report (Kadić, 1916) and map notations, whereas the new excavation sites and sections surveyed by us in 2019 are referred to as K1 – K6 (see Fig. 1B and Table 2).

The UTM (zone 34) coordinates of these sections were measured with a 5–10 m horizontal accuracy. The sedimentary successions were examined and sampled in the field, and whenever present, fossils were removed for preparation and subsequent study. A total of 14 lithofacies were recognized using a classification based on grain size, bedding, fossil content, and sedimentary structures (Miall, 1985; Opluštil et al., 2005; Therrien, 2005; Roberts, 2007; Gao et al., 2020). The abbreviations of the different lithofacies and their descriptions are listed in Table 3.

Besides the sedimentological and stratigraphic analysis, geometric correlation of the documented stratigraphic sections was also attempted (Fig. 1D). At each site, bedding planes were measured wherever it was possible (Supplementary I). After the sedimentological analysis of the sections, originally horizontal planes (beds) were identified and selected. The bedding planes of these beds, forming planar surfaces in 3D, are suitable to trace the general dip and dip direction of a sequence of rock layers (e.g. Lisle, 2004). We used the JewelSuite™ geological modelling program to construct the intersection line of the bedding planes with the digital model of the surface. The latter is the freely available SRTM (Shuttle Radar Topography Mission) data which has 1 arc-second (~30 m) ground resolution (Farr et al., 2007).

The intersection of a 3D bedding plane and the topographic surface produces the trace line of the bed on the map. By selecting the originally horizontal beds at each site and constructing their trace lines on the map, we can analyse their geometric relations to each-other. The intersection lines – if they connect or plot very close to each other on the map – are good indicators of correlating strata (Fig. 1D). Also, the thickness of the stratigraphic sequence between two sites can be measured by projecting a perpendicular line from one of the sites to the plane of the other, distant site.

Besides our prospecting for macroscopically identifiable fossils in the surveyed sections, two samples, one taken near locality K2 (P2 – Fig. 3) and the other close to locality $N_{VS}$ (P1 – Fig. 5), were also collected for a preliminary assessment of potential palynological (i.e. particulate organic matter – POM) content and palynofacies analysis (Figs. 7-8). These samples were processed using standard palynological techniques (e.g. Batten, 1999). Approximately 50 g of sediment from each sample were treated with HCl (37%) to remove carbonates, and with HF (48%) to remove silicate minerals. Denser particles were separated from the organic residue using $ZnCl_2$ with a density of 2.0 g/cm$^3$. The residual matter was mounted on microscopic slides using glycerine jelly; the slides are stored in the collections of the Geology Department at the Alexandru Ioan Cuza, University, Iaşi, Romania.

As a proximal-to-distal trend is one of the principal controls on POM distribution, several distribution trends shown by different phytoclast types (e.g., Gorin and Steffen, 1991; Tyson, 1993, 1995; Mendonça Filho et al., 2011; Radmacher et al., 2020) have been used for a palaeoenvironmental assessment of the samples, including: 1. the high relative abundance of translucent phytoclasts (e.g., woody tissues, cuticles); in ancient deposits these are known to indicate strong terrestrial influence and/or influx, and thus this parameter mostly indicates proximal depositional conditions (i.e. fluvio-deltaic systems); 2. the high amount of lath-shaped, large opaque phytoclasts, which again suggests proximal facies deposits, as these result from short-term transport and thus support land proximity; 3. the high proportion of equidimensional, small and rounded opaque phytoclasts; these mainly suggest a distal depositional environment as they result from a lengthy transport.

#### 4.2.2. Sedimentological investigations in the 'Pareu vartopilor' (Pârâul Vârtopilor) side ravine of the Răchitova Valley, west of the Vălioara Valley (sites Kadić I and K1; see Fig. 1B and Table 2)

As Kadić (1916) mentioned, his site I, situated in the "*end section*" of '*Pareu vartopilor*' (Pârâul Vârtopilor) ravine, yielded many well-preserved, reddish-coloured vertebrate fossils. This left-side

**Table 3**

Lithofacies types defined around Vălioara Valley, with special focus on the investigated vertebrate site-bearing successions, based on Miall (1985), Roberts (2007), Opluštil et al. (2005), Therrien (2005), and Gao et al. (2020).

| Lithofacies identified around the Vălioara valley (sections of K1−K6) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Coarse-grained lithofacies | | | | | Fine-grained lithofacies | | | | |
| Facies code | Lithofacies | Sedimentary structures | Descriptions | Interpretation | Facies code | Lithofacies | Sedimentary structures | Descriptions | Interpretation |
| **Bt** | Matrix-supported breccia | Massive, structureless or normal grading, bottom boulders locally show indistinct imbiracion | *Colour:* Dark-gray to reddish-brown. *Matrix:* coarse sand to fine pebble; poorly sorted. *Clasts:* angular to subrounded, poorly sorted, pebble to cobble conglomerate, rarely boulder-sized metaclasts | Hyperconcentrated flood flows | **Fl** | Finely laminated mudstone | Laminated | *Colour*: greyish, brownish. Abundant to rare plant debrish, rare well preserved leaves and bone fossils. | **Water-logged, poorly drained floodplain sediments** |
| **Gm** | Massive conglomerate and sandstone | Erosive base, massive or crude stratification, | *Colour:* Light green to light grey. *Matrix:* fine to coarse-grained sand; poorly sorted. *Clasts:* typically cobble to pebble-size; poorly sorted; dominantly extraformational metamorphic pebbles, rare intraformational clayclasts and plant debris | Braided (minor) channel deposits | **Fm** | Massive mudstone and claystone | Massive, bioturbated | *Colour*: green, light-grey or bluish grey. Slightly carbonaceous plant debrish, fresh molluscs and bone fossils | |
| **Gcm** | Matrix-supported conglomerate | Trough and tabular cross-bedding; normal grading, lenticular unites with erosive base, coarse basal lags with gravel imbrication | *Colour*: Light green to light grey. *Matrix*: medium to coarse grained, poorly sorted sand. *Clasts*: moderately rounded, poorly sorted, pebble- to rarely cobble-sized, altered vulcanoclasts, metaclasts and red mudstone rip-up clasts. These facies alternate with cross-bedded sandstone facies | Channel and scour pool fill deposits | **Fmc** | Massive mudstone and claystone with high organic content | Massive | *Colour*: dark-gray to dark-brown. Abundant fresh water molluscs and carbonized plant material | |
| **Gcc** | Clast-supported conglomerate | Trough and tabular cross-bedding, occasionally massive and structureless | *Colour*: light grey. *Matrix*: medium to coarse grained, poorly sorted sand. *Clasts*: moderately rounded, moderately sorted, clast-supported, cobble- to rarely pebble-sized, altered vulcanoclasts, metaclasts and rip-up clasts derived from the underlaying sediments | Erosional lag deposits on surface; the largere grain size indicate higher depositional energy than the Gcm. | **Fr** | Mudstone and claystone | Vertical burrows and root traces | Colour: Dark-gray, light-grey or brownish grey. Fresh water molluscs | |
| | | | | | **C** | Coal, carbonaceous mud | Laminated or massive | Colour:black and dark grey. Carbonized plant material, fresh water molluscs | |
| **Se** | Sandstone with erosional scours and intraclasts | Massive, rarely cross-bedding, bioturbation burrows | *Colour*: light grey. *Grain size*: fine to medium-grained sand with granule sized rip-up clasts. | Channel-lag deposit | | | | | |
| **St** | Trough-shaped, cross-stratified sandstone | Cross-bedding, lenticular unit with erosive base | *Colour*: light green to light grey. *Grain size*: fine- to medium-grained sand, sometimes coarse-grained, poorly to moderately sorted | Channel and scour pool fill deposits | Pt | Mudstone and subordinate very fine-grained sandstone without calcrete concretions | Pedogenic features: sporadic burial-gley, root-mottles, tiny irregular root traces, vertical burrow fills | *Colour:* reddish (usually 2,5 YR 2.5/4). The mottles vary in colour (green, strong brown and gray). Absence of plant debris, rare fragmentary bones and teeth. | **Moderately- or well-drained floodplain sediments** |
| **Sl** | Fine-grained sandstone | Massive, low angle crossbeds | *Colour*: light green to light grey. *Grain size*: very fine- to fine-grained sand. Flat, non-erosive bases. | Sheet-splay deposit | **Ptc** | Mudstone with calcareous concentrations showing variable degree of development, from isolatedcalcrates to thick continuous layers | Pedogenic features: discontinuous calcrete horizons, | *Colour:* red to brown mudstone (usually 2,5 YR 2.5/4) with pale yellow carbonate nodules Absence of plant and vertebrate fossils. | |

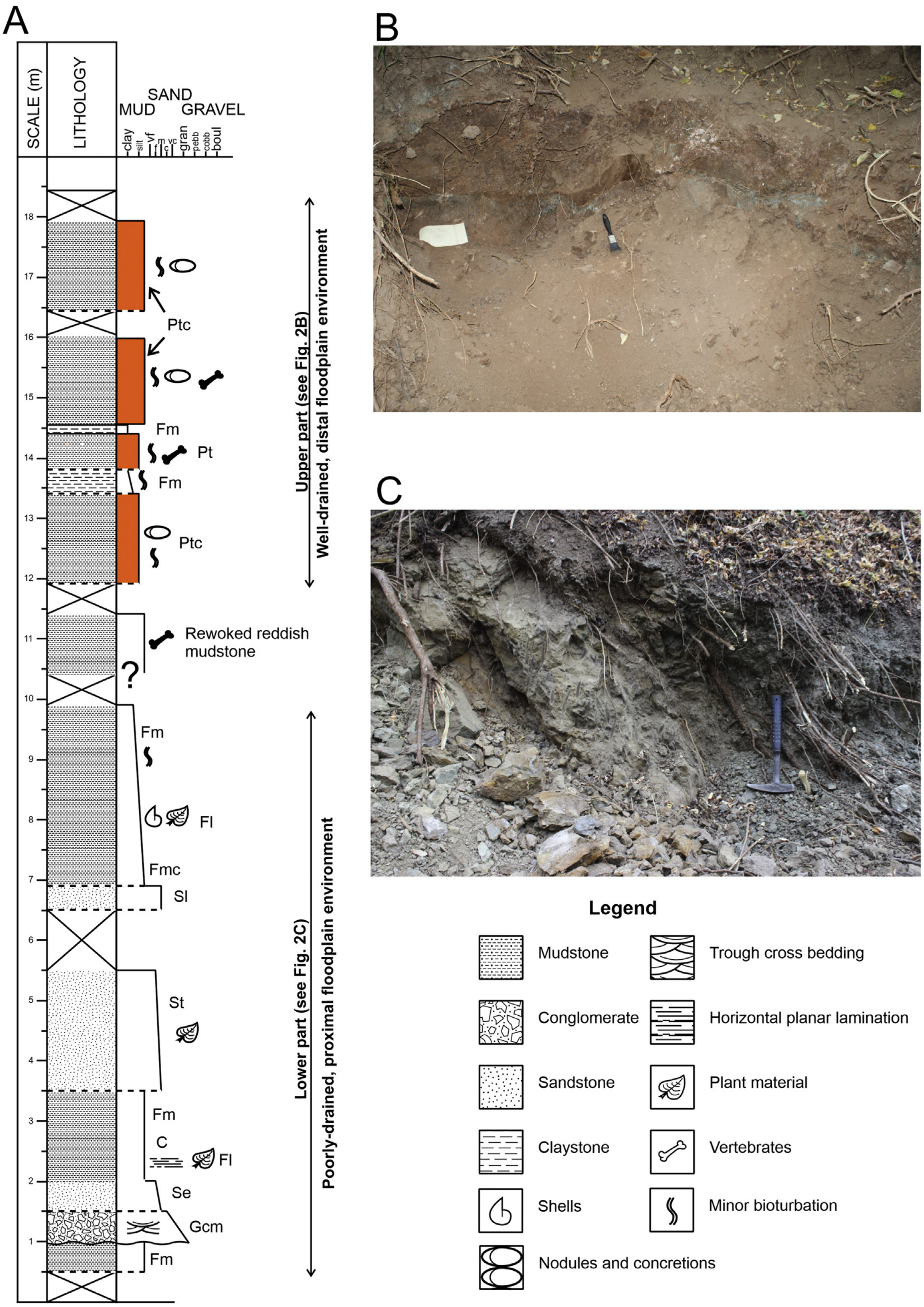


**Fig. 2.** A) Schematic stratigraphic section of site K1 in the Pârâul Vârtopilor ravine, showing main lithofacies and fossil content; B) photo of the bone-bearing layer at site K1; C) photo of the greyish-greenish rocks that are dominant in the lower part of the local section.

ravine of Răchitova Valley extends from Ciula Mică village to the north towards Vălioara, west of Vălioara Valley. The expression “end portion” must be interpreted as the up-hill end of the ravine, farther away upstream from Ciula Mică, as supported by the position of site I marked on the Kadić map as well as by our field observations (see below). To be noted, Kadić used this same terminology for all the ravines in his report. Kadić (1916) also noted that the bone-bearing horizon at site I was a reddish-coloured micaceous mudstone with carbonate nodules, which can be tentatively interpreted as a relatively well-drained paleosol with calcrete horizons.

During the fieldwork, detailed sedimentological mapping was conducted along Pârâul Vârtopilor. Our logging has shown that the exposed succession is dominated by greyish-greenish mudstone

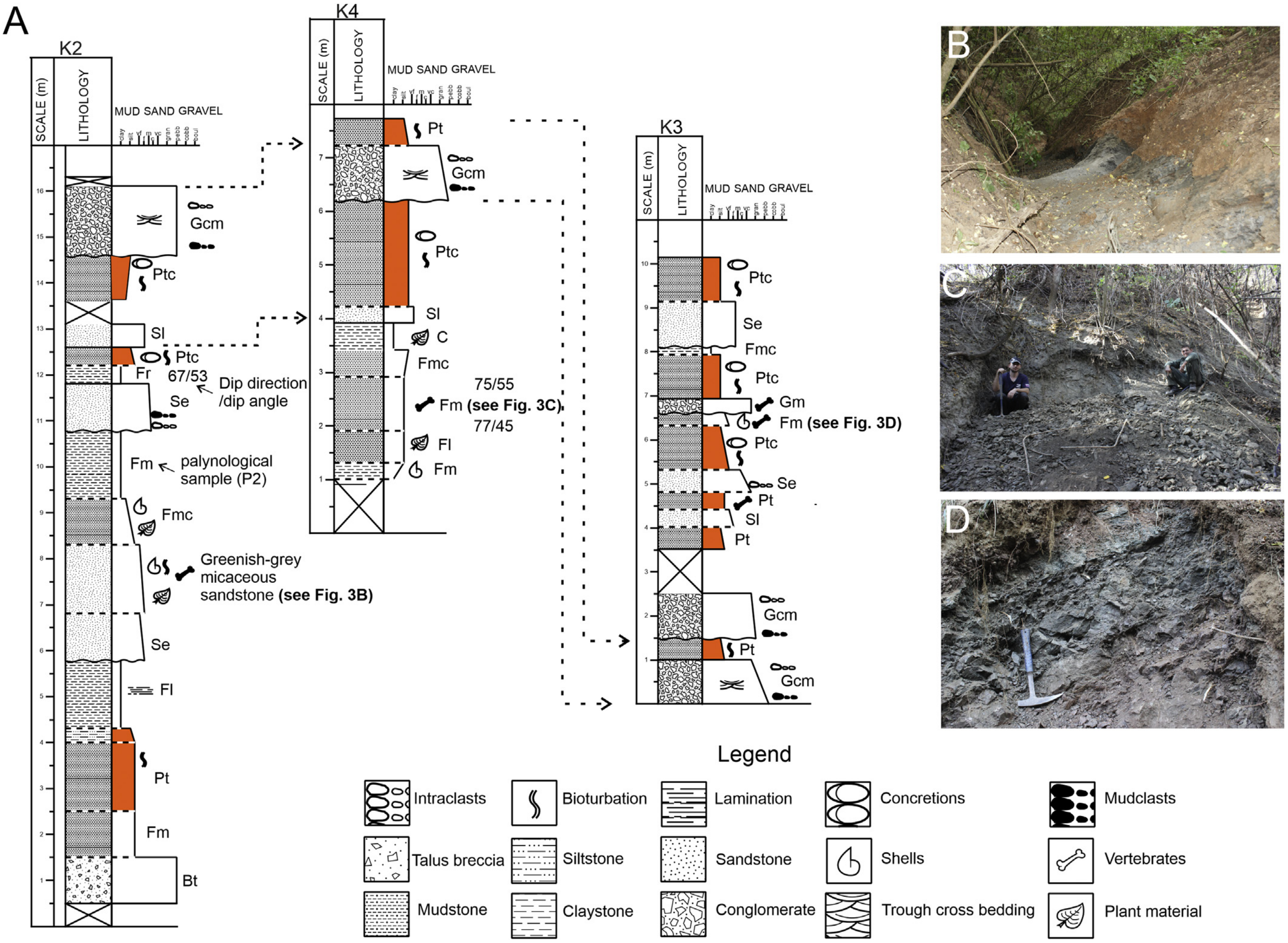


**Fig. 3.** Schematic stratigraphic section of sites K2, K4 and K3, located within the same continuous sedimentary sequence in the Pârâul Neagului ravine (A). Photos of the excavated fossiliferous horizons at site K2 (B), site K4 (C), and site K3 (D).

(Fm, Fl; see Table 3) interrupted by coal seams (C, Fmc) and conglomerates (Gcm), while reddish paleosols (Pt, Ptc) are only present at the top of the exposed succession (Fig. 2), near the upper end of the ravine. Since the bone-bearing horizon at site I was described by Kadić (1916) as a reddish mudstone, a lithotype only present at the top of the exposed section (Fig. 2B), this part of the succession (marked as K1 on Fig.1B) is considered as the probable location of the vertebrate site I of Kadić (1916). These reddish mudstones (Pt, Ptc) are moderately to well-developed paleosols with vertical root traces, carbonate nodules and sporadic burial-gley features indicating that pedogenesis took place on the better-drained, more elevated part of the floodplain. On the other hand, the presence of burial-gley features points to water-table fluctuations during or immediately after soil formation.

Several vertebrate fossils were collected from this upper, reddish paleosol-dominated (facies Pt, Ptc) part of the K1 succession, including remains of turtles, crocodyliforms and dinosaurs. These, just as all vertebrate remains collected during our 2019 surveys, are deposited at the Faculty of Geology and Geophysics, University of Bucharest (see Supplementary II). The newly collected *in situ* bones are red, but they are covered by a thin white crust, a state of preservation similar to that of numerous reddish bone specimens in the historical MBFSZ collection (e.g. MBFSZ V.13535; MBFSZ Ob.3088, MBFSZ Ob.4215; see Supplementary III). However, all of the newly collected fossils at K1 are small (less than 5 cm long) and poorly preserved, making it difficult if not impossible to compare their taphonomic features with those of visually similar specimens from the historical collection that consist exclusively of larger-sized remains. Additional to the *in situ* remains, two well-preserved rhabdodontid vertebrae (LPB [FGGUB] R.2701 and R.2702) were surface-collected near our excavation point at K1. Obviously these remains were eroded out from the surrounding *in situ* uppermost Cretaceous continental rocks. Furthermore, their light colour and the reddish sediment filling the bone cavities suggest they were buried and fossilized in an oxidative depositional environment, probably in a reddish paleosol but their exact source horizon could not have been identified.

Based on the available sedimentological (type of enclosing sediment), cartographical (Fig. 1B), and taphonomical (e.g. bone colour) evidence, we therefore suggest that the site I of Kadić (1916) was situated in the upper part of the Pârâul Vârtopilor ravine section (GPS coordinates: 45.6071 N; 22.7829 E). However, the exact stratigraphical horizon from which Kadić may have collected the reddish, large sized and well-preserved bones cannot be determined with certainty within this reddish paleosol-dominated upper part of the outcrop.

#### 4.2.3. *Sedimentological investigations in the* 'Pareu niagului' *(Pârâul Neagului) ravine, right-side tributary of the Vălioara Valley (Kadić II—IV and K2—K4)*

Kadić (1916) mentioned that three of his seven most important vertebrate sites (II, III and IV) were situated in a ravine he called '*Pareu niagului*' (current toponym — Pârâul Neagului). Our sedimentological and stratigraphical investigations suggest that these three sites are located within the same continuous sedimentary sequence (Fig. 3 and see below). Kadić (1916) gave a short description positioning these sites as follows: "*the most productive ravine around Vălioara was Pareu niagului, where we have excavated for several years in three important sites situated in the final part of this ravine, forking into two branches*". Kadić (1916) also mentioned that the bone-bearing rocks at all of these three vertebrate sites were represented by "*bluish-grey claystones and marls with plant fossils*", whereas the colour of the excavated bones was "*black*".

As our field observations have shown, diverse lithotypes of the Densuş-Ciula Formation are exposed in the Pârâul Neagului ravine, west of Vălioara village. Position of Site II was marked by Kadić (1916) on the northern branch of Pârâul Neagului, about 10 m upstream from the point where the ravine branches (Fig. 1A-B). Similar to the Pârâul Vârtopilor area, the beds at Pârâul Neagului are tilted towards ENE with a dip angle of about 40–50°. Accordingly, the oldest layers, represented by talus breccia beds (Bt) (reminiscent of those cropping out north of Vălioara, close to the border of the basin with the crystalline basement; see Geological Background) are exposed at the westernmost end of the northern branch, a few meters above topographically (but stratigraphically below) the presumed position of Kadić's site II. The talus breccia layers are covered by tens of meters of fluviatile deposits including dark-grey mudstones (Fmc, Fm, Fl), sandstones (Se), reddish coloured paleosols (Pt, Ptc), and claystones; the succession is topped by a 2 m thick conglomerate (Gcm). Altogether, these deposits indicate a dominantly wet, marshy palaeoenvironment within the proximal floodplain area. The topmost conglomerate bed (Gcm) represents a distinctive horizon since due to its resistance to erosion it can be tracked laterally for several meters in different outcrops, helping the correlation between the different vertebrate site-bearing sections (Fig. 3A).

Dark coloured claystone (Fl), mudstone (Fmc) and sandstone (Se, Sl) beds around the presumed position of Kadić's site II were carefully searched and locally excavated in order to check for the presence of vertebrate fossils, because these lithotypes were assumed to host the potentially bone-bearing horizon (Kadić, 1916). This search was indeed successful, as during our brief fieldwork a relatively rich and diverse vertebrate assemblage has been collected from a greenish-grey fine-grained micaceous sandstone horizon located 6–7 m below the marker-bed conglomerate (Fig. 3B; GPS coordinates:45.6171 N; 22.7788 E). The vertebrate material (remains of turtles, crocodyliforms and dinosaurs, including most significantly several associated-articulated tail vertebrae of a titanosaurian sauropod; see below and Supplementary II) discovered here is well-preserved, black-coloured, thus showing similar taphonomical conditions to those of the fossils reported by Kadić (1916) from the Pârâul Neagului localities.

A palynological sample was also collected from a dark grey, massive, bioturbated mudstone of the section hosting site K2 (see Fig. 3A). This sample (P2) has yielded a rather diverse and well-preserved palynological assemblage, consisting mainly of terrestrial plant-derived elements (with frequent polypodiacean spores), completed by sporadic freshwater algae spores. A total of 28 palynomorph taxa were identified, including sixteen ferns, one bryophyte, three gymnosperms, seven angiosperms, and one freshwater alga (Fig. 8 and Supplementary II).

Fern spores, including representatives of Polypodiaceae, Cyatheales, and ?Blechnaceae, are frequently observed elements of the assemblage (Fig. 8). From these, the most abundant specimens belong to *Polypodiaceoisporites verruspeciosus*, *P.* sp., *Deltoidospora minor* and *Laevigatosporites ovatus*, in addition to other spore taxa (e.g. *Appendicisporites tricornitatus*, *Biretisporites potoniaei*, *Cicatricosisporites dorogensis*, *Triplanosporites microsinuosus*). Gymnosperm pollen occurs in low diversity and abundance; the taxa identified include *Araucariacites australis*, *Classopollis* sp., and monosulcate pollen grains produced by cycads (*Cycadopites* sp.). Angiosperm taxa are represented mainly by specimens assigned to the *Normapolles* group (e.g. *Oculopollis praedicatus*, *Plicapollis serta*, *Trudopollis nonperfectus*), completed by Juglandaceae (*Subtriporopollenites anulatus*) and dicots of uncertain affinities (e.g. *Fraxinoipollenites* sp., *Triatriopollenites* sp.). One aquatic palynomorph, a freshwater alga (*Chomotriletes fragilis*), was also identified.

Sites III and IV were placed by Kadić in the southern branch of Pârâul Neagului, with site III situated closer to, and site IV farther upstream from, the branching point of the ravine (see Fig. 1A,B). Due to the interplay between local topography and the strike/dip of the beds, the rocks exposed at site K4 (corresponding in our estimates to site IV of Kadić; see Table 2) are stratigraphically somewhat lower than those from site K3 (corresponding to site III), and thus the description of the local sedimentary sequence starts with site K4 in order for it to follow the continuous sedimentary succession.

The sedimentary sequence exposed near site K4 more or less overlaps with the section logged at site K2, since in both cases the same greenish-grey, pebble-to rarely cobble-sized conglomerate beds (Gcm) appear at the top of the sections (Fig. 3A). However, the precise correlation of the finer-grained beds between the two sections is more problematic, since generally floodplain sediments deposited in a low-elevation floodplain can show high lateral heterogeneity (e.g. significantly different colours and grain-size), even on a small spatial scale. The bone-bearing, greenish-grey fine-grained micaceous sandstone bed of site K2 cannot be identified in the K4 section, either possibly due to such lateral facies changes, or else because it is situated stratigraphically somewhat

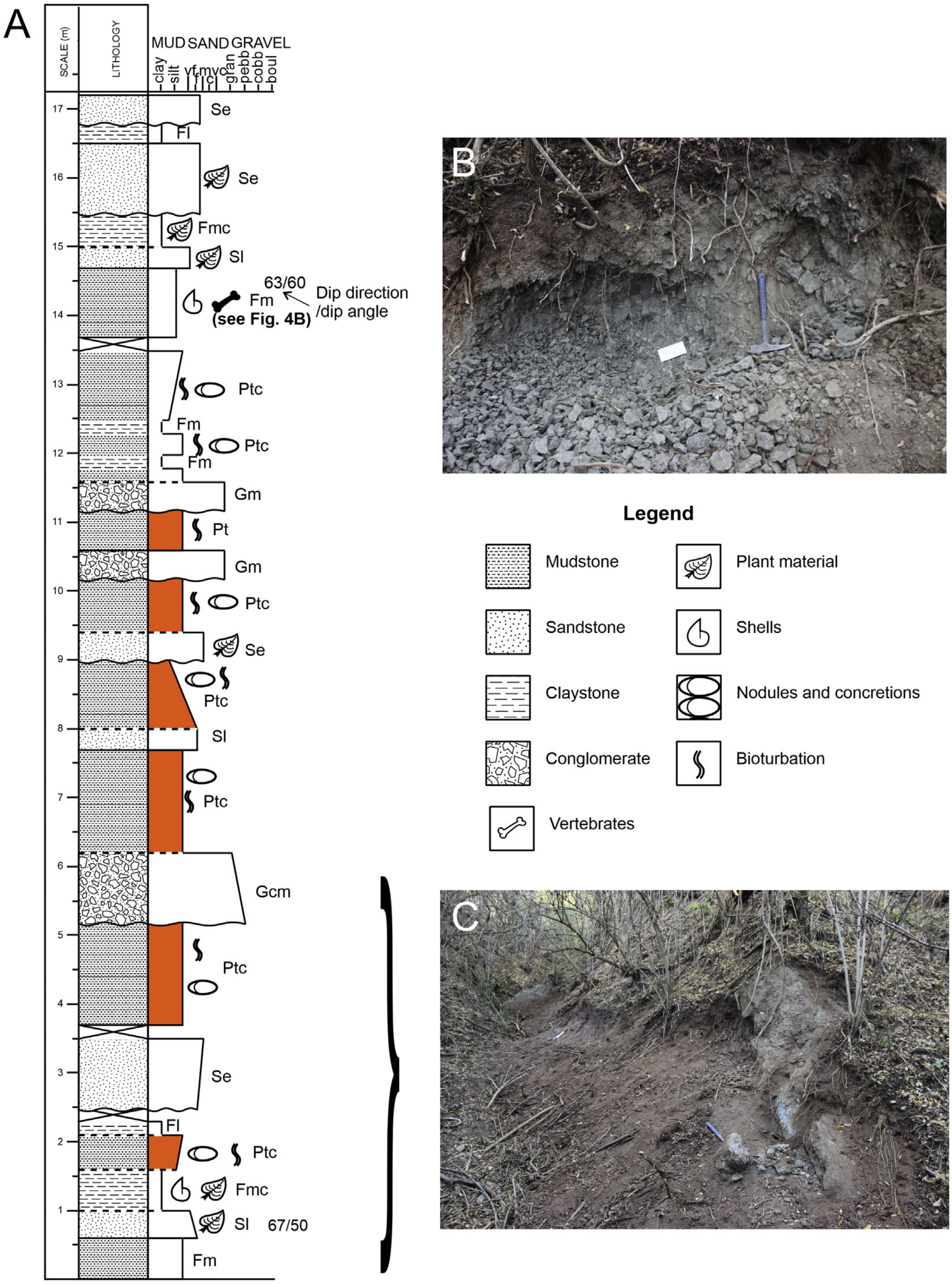


**Fig. 4.** A) Schematic stratigraphic section of site K5 in the Pârâul Ogradiilor ravine showing the main lithofacies and fossil content. Photos of the excavated horizon at site K5 (B) and the sediment types exposed in the lower part of the section (C).

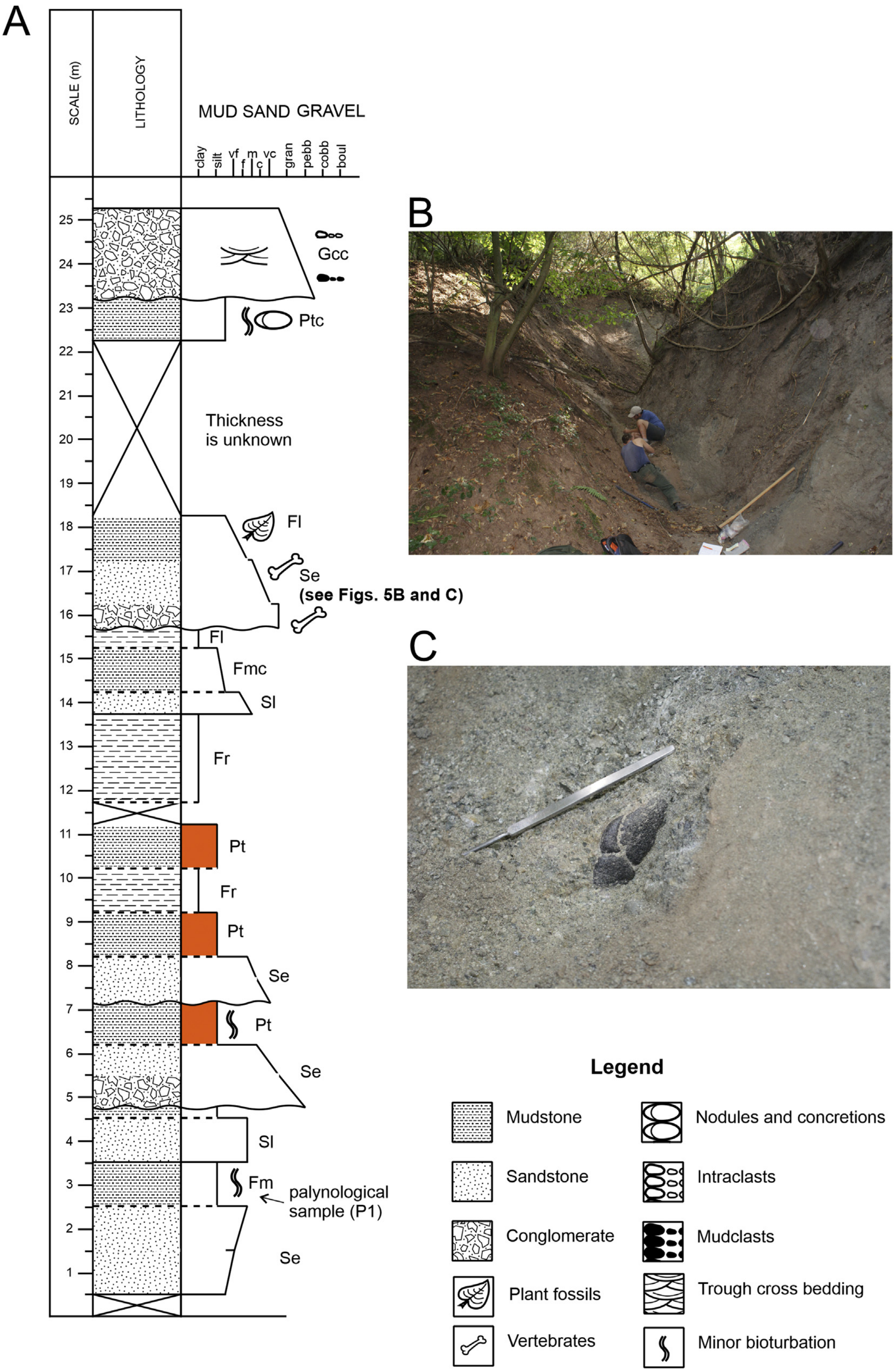


**Fig. 5.** A) Schematic stratigraphic section around the newly discovered vertebrate site (Nvs) in the Pârâul Ogradiilor ravine, approximately 100 m south of site K5. B) The excavation area of the Nvs. C) The main bone-bearing bed at site Nvs.

lower and does not crop out in the southern branch of the ravine. The sedimentary section around the presumed position of Kadić's site IV is dominated by grey mudstone and sandstone beds with a significant amount of plant debris, carbonized wood and coal seams (Fl, Fmc, C and Sl). A few poorly preserved vertebrate remains (e.g. rib fragments) were collected from a greyish mudstone horizon (Fm) situated 4–5 m below the conglomerate bed (GPS coordinates: 45.6166 N; 22.7790 E), but no significant concentration of vertebrate fossils was identified in the exposed succession (Fig. 3C).

The presumed position of Kadić's site III is approximately 10 m from the terminal branching of Pârâul Neagului (Fig. 1A-B), and its exposed section overlays the sections containing sites K2 and K4 within a continuous succession (Fig. 3A). The sedimentary sequence at K3 (that is, near the estimated location of site III of Kadić) is dominated by moderately to well-developed calcrete-bearing reddish paleosols (Ptc), while the water-logged sediment types (e.g. Fm, Fmc) are subordinate, indicating a more elevated floodplain position during deposition. The richest bone-bearing horizon (GPS coordinates: 45.6168 N; 22.7792 E) identified in the K3 section is a greyish-bluish mudstone (Fm) from which dozens of bone fragments were collected (Fig. 3D), associated with plant and gastropod remains. Furthermore, in the same succession one isolated bone fragment (LPB [FGGUB] R.2764) was found in a 40 cm thick conglomerate bed (Gm) that covers the main bone-bearing layer, and a few isolated vertebrate remains (LPB [FGGUB] R.2765 and M.1708) were collected from a lower reddish paleosol horizon (Pt) as well (see Supplementary II).

Summarizing these sedimentological observations, the sites K2, K3, and K4 are situated in a ca. 26 m thick continuous sedimentary sequence along the Pârâul Neagului ravine, with sites K2 and K4 being stratigraphically lower, whereas site K3 appears in the upper part of the section (Fig. 3A). The different sections cropping out in the ravine form a continuous succession, starting with a thick basal talus breccia horizon (Bt), which is followed by water-logged (e.g. Fm, Fl, Fmc), poorly drained floodplain deposits grading into well-drained floodplain deposits (e.g. Ptc), and finally capped by a thick channel conglomerate bed. Hence this succession provides a more detailed insight into the patterns of depositional environment changes in the basal part of the 'middle member' of the Densuş-Ciula Formation (see below). Since during our fieldwork several bone-bearing horizons with a lithology similar to that reported by Kadić (1916) were discovered in this succession, the exact positions of Kadić's bonebed(s) cannot be determined with certainty.

#### 4.2.4. *Sedimentological investigation in the* 'Pareu ogradilor' *(Pârâul Ogradiilor) ravine, right-side tributary of the Vălioara Valley (localities Kadić V, respectively K5 and Nvs)*

Kadić (1916) reportedly found a number of vertebrate fossils at several different places in the '*Pareu ogradilor*' (current toponym Pârâul Ogradiilor) ravine, southwest of Vălioara village, and he marked the richest bone accumulation of these as site V on his map (Fig. 1A). Unfortunately, very limited information is available about the fossil material collected here by Kadić, as he only indicated that the bone-bearing horizon also contained plant material. This information suggests reductive rather than oxidative sedimentological conditions for Kadić's site V.

According to our logging (Fig. 4), the lower part of the sedimentary succession exposed at Pârâul Ogradiilor is dominated by moderately developed, well-drained reddish paleosols (Ptc, Pt), interbedded with conglomerates (Gm, Gcm) and sandstone beds (Se, Sl). Towards the top of the section, the dark-coloured, water-logged sediment types (such as Fm, Fmc) become more dominant. The robust, approximately 1 m thick conglomerate bed (Gcm) located in the middle part of the section shows similarities in grain size (pebble to cobble size), colour (greenish-grey), structures (e.g. large-to small-scale trough cross-stratification) with conglomerate beds exposed in the Pârâul Neagului succession (near sections K2, K3 and K4), located a few hundred meters to the northwest. The section exposed at site K5 was expanded with clinometric measurements of strata in order to determine the stratigraphical relations between site K5 and other vertebrate sites around Vălioara Valley (Fig. 4A; Supplementary I). The recorded dips (approximately 50°) and dip directions (ENE) suggest that the measured claystone beds of section K5 are most probably correlatives of the claystone beds exposed at Pârâul Neagului nearby sites K2 and K4, indicating that sites K2, K4 and K5 are most likely situated within the same sedimentary succession (see below in the Discussions, and Fig. 1D).

During our field reconnaissance, no significant bone accumulation was found at the estimated position of Kadić's site V, although a few brownish-greyish bones and tooth fragments were discovered in a greenish mudstone horizon (Fm; see Fig. 4B). The bone-bearing bed is located in the upper part of the section characterized by water-logged sediment types that include plant and invertebrate fossils as well (GPS coordinates: 45.6150 N; 22.7800 E).

Nevertheless, while surveying the Pârâul Ogradiilor area, a new, relatively rich and diverse bone accumulation was discovered in a southern branch of the main ravine (marked as Nvs in Fig. 1B and Table 2; GPS coordinates: 45.6142 N; 22.7813 E), approximately 100 m south of the presumed position of the site V of Kadić (1916). This new bone-bearing horizon is situated in a sedimentary succession dominated by sandstones (Se, Sl) and greyish, blackish pelitic rocks (Fmc, Fm), while the reddish, well-drained paleosols are subordinate in this area (Fig. 5), indicating a proximal, more water-logged alluvial depositional environment. The 1.5 m thick bonebed is a channel-fill deposit that consists of microconglomerates at its base (Fig. 5C), overlain by fine sandstones, indicating a fining-upward unit (Se). Dozens of vertebrate fossils were collected from the basal part of this channel fill, where the sediment particle size ranges from granule to middle coarse sandstone. The fossil material excavated at site Nvs includes well-preserved, black-coloured bones representing turtles, crocodyliforms and different dinosaurs (*Telmatosaurus*, titanosaurians; see Supplementary II). The Pârâul Ogradiilor successions hosting sites Nvs and K5 have different stratigraphical positions: site Nvs is approximately 60 m higher in the stratigraphic column than site K5 based on the general dip and dip direction values of the strata measured at these locations (see Supplementary I and Fig. 1D).

A second palynological sample (P1) was collected upstream of site Nvs, along the left-branching main course of the ravine. Based on the dip of the beds, this sample was collected several meters below Nvs, from a hard, thinly laminated dark grey fine silty mudstone. Its analysis revealed an extremely meagre palynomorph assemblage, both poorly preserved and of low diversity (only a few hygrophytic fern spores such as *Deltoidospora toralis* or *D. minor* have been found, besides a small number of indeterminate spores: Supplementary II). The palynofacies of the sample is somewhat more instructive. Its particulate organic matter content is characterized by a predominance of equidimensional opaque phytoclasts (~95–98% of the total POM; Fig. 7A) belonging to the inertinite group; most often these have small dimensions (commonly <30 μm) and rounded shapes, suggesting prolonged transport. Translucent phytoclasts (e.g. cuticles, woody tissues) derived from continental vegetation are rare.

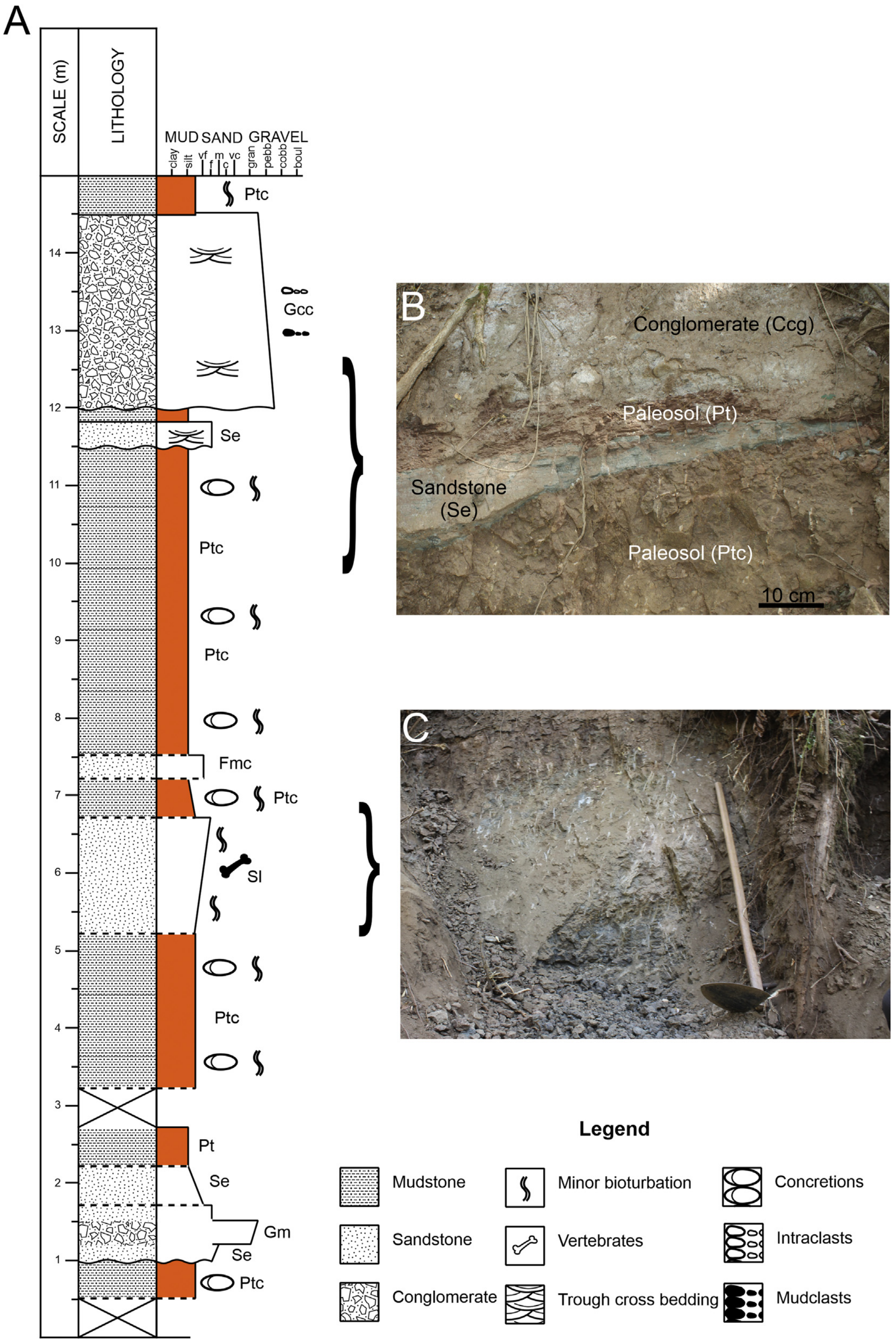


**Fig. 6.** A) Schematic stratigraphic section of site K6, in the Pârâul Budurone ravine, B) Thick conglomerate bed (Gcc) situated at the top of the section. C) Bone-bearing bed.

### *4.2.5. Sedimentological investigations in the* 'Pareu buduron' *(Pârâul Budurone) ravine, left-side tributary of the Vălioara Valley (localities Kadić VI and K6)*

According to Kadić (1916), he "*excavated two important bone accumulations located in the bifurcating ravine called Pareu buduron in the right side of the Vălioara Valley, below Vălioara village*". It is worth stressing here that, although Kadić specifically locates '*Pareu buduron*' on the right side of the valley, both the positions of his marks VI and VII (representing the two main bone accumulations) on the manuscript map, as well as further details he give in his brief report, show that his '*Pareu buduron*' location is actually on the left side of the valley. This usage of terms is consistent with the fact that Kadić, probably proceeding with his surveying upstream, unconventionally but regularly called the lower sections of the ravines 'startings' and their upper terminations, 'ends', which suggests that his 'right side' should also be interpreted as the customary left. This interpretation also concurs with the current local toponymy of the area (Pârâul Budurone) as verified in our conversations with local residents during the 2019 fieldwork. Moreover, this local toponym, as also highlighted by residents of Vălioara, is actually in use for the entire system of ravines on that particular hillside on which Kadić have marked his sites VI and VII.

This large areal coverage of the toponym Budurone is worth emphasizing, as there are at least two other important fossil occurrences to which the label Budurone was attached during the years. Grigorescu et al. (1999) reported a "Budurone microvertebrate fossil site" from Vălioara (named as such because at the time of its discovery, the locals identified the ravine within which it is located as Budurone ravine to one of the authors – Z.Cs.-S.). This microvertebrate bonebed (MvBB) was later described in detail by Csiki et al. (2008) and it is the type locality of the endemic alytid frog *Paralatonia transylvanica* (Venczel and Csiki, 2003). Our field survey showed that despite the name similarity, the Budurone MvBB is actually situated within a nearby, but different, parallel ravine, southeast of Kadić's '*Pareu buduron*' site. Furthermore, Budurone is also recorded as the locality that yielded an associated partial skeleton of a juvenile individual of the rhabdodontid ornithopod *Zalmoxes shqiperorum* reported in Weishampel et al. (2003; see also Csiki et al., 2010a; Brusatte et al., 2013a) – this locality appears to be located in a side-ravine nearby the one housing the Budurone MvBB, again distinct from the ravine hosting Kadić's '*Pareu buduron*' sites.

Kadić (1916) mentioned his site VI as being located "*on the branching of the ravine*", using the preposition '*on*' specifically (see below). Here, he collected black-coloured "*massive limb bones*" and "*exquisitely preserved large-sized vertebrae*" from a bluish sandstone bed (Kadić, 1916). The historical collection in the MBFSZ contains only a small number of titanosaurian bones that conform to Kadić's description. These remains included originally a string of eight associated large blackish caudal vertebrae (catalogued as MBFSZ Ob.3090), as well as associated fragmentary left and right femora (MBFSZ Ob.3103) and a corresponding right humerus (MBFSZ Ob.3104). These are significantly larger than most other titanosaurian remains from the Haţeg Basin (e.g. Le Loeuff, 2005; Csiki and Grigorescu, 2006; Csiki et al., 2007, 2011; Stein et al., 2010; Mannion et al., 2019b), and the MBFSZ inventory book clearly states that the limb bones belong to the same individual, though the same is not mentioned for the vertebrae. Since these remains are significantly larger than other bones in the collection, and they show a distinctive dark, almost black colour, it is safe to assume that Kadić (1916) referred to them as the black "thick limb bones" and "exquisitely preserved large-sized vertebrae" from his site VI.

The branching of the Pârâul Budurone ravine, as marked on the map (Fig. 1A) by his 'X' mark VI, can be easily identified even today, thus both the position and the fossil content of site VI is well supported based on Kadić's account and his map, corroborated with the presence of the above described unique set of large titanosaurian bones. However, the 'peninsula' bounded by the branching that was specifically indicated by Kadić as the bone-bearing site with the use of the preposition '*on*', though exposes a light grey sandstone bed, is topographically flat and currently heavily overgrown by vegetation. Thus, during our field survey at this ravine, we studied primarily an outcropping section exposed in the eastern (left-side) slope at the bifurcation of the ravine, just opposite of the branching point. This section is dominated by reddish paleosols (Ptc) and greenish, bluish or blackish sandstones (Se, Sl), while at the top of the section, a 2–3 m thick conglomerate bed (Gcc) is present (Fig. 6). The reddish paleosols (Ptc), characterized by the presence of several discontinuous calcrete horizons, as well as by that of slickensides and vertical to sub-horizontal finger-sized burrows, are suggestive of oxidizing conditions and a moderately to well-drained environment during pedogenesis; thus, they were formed on a more elevated part of the floodplain. The paleosol horizons are frequently covered by very fine-to fine-grained sandstone (Sl); these sandstone bodies have flat or gradational bases, and frequently grade into reddish paleosols towards their top. The fine grain size and the flat or gradational bases of these sandstones suggest a sheet splay origin, usually formed during periods of overbank flooding. The thick conglomerate bed (Gcc) situated at the top of the section shows very distinctive characters compared to the other conglomerates encountered around Vălioara Valley. This clast-supported conglomerate (Gcc) is more than 3 m thick, and the dominant pebble size is also larger, mostly cobble-sized, which reflects high discharge and higher energy of the depositional current than those suggested by the conglomerates recorded in the other studied sections. This cobble-to pebble-sized conglomerate incises the underlying well-developed reddish paleosol horizons, and its basal part is poorly imbricated. The clasts consist of altered volcanoclasts, diverse metaclasts, and rare red mudstone rip-up clasts derived from the underlying reddish paleosols, while the matrix is composed of coarse-grained sand and/or fine-grained gravel. Sedimentary structures include trough and tabular cross-bedding, and the basal conglomerate is fining upward into coarse sandstone. Although sedimentary structures and palaeocurrent direction cannot be observed in detail due to difficult accessibility and poor exposure, the relatively greater thickness, the dominant particle size, and the pronounced scale-trough cross-stratification of this channel fill suggest the action of distal gravelly-sandy braided streams. This facies type was described previously from several places in the middle part of the Densuş-Ciula Formation (e.g. Laufer, 1925; Grigorescu et al., 1994; Therrien, 2005; Vasile et al., 2011a; Botfalvai et al., 2017), but until this report its occurrences were restricted to more easterly parts of the 'middle member' outcropping area.

The overall features of the succession exposed at Kadić's Pârâul Budurone location VI suggest a more distal and more elevated floodplain position compared to that suggested by the depositional successions of the Pârâul Neagului (K2–K3–K4; Fig. 3) and Pârâul Ogradiilor (K5; Fig. 4) ravines, because the water-logged pelitic sediment types such as the greenish, greyish, blackish mudstone and claystone (Fm, Fmc, Fl) are completely absent (see Fig. 6).

Based on the information available in Kadić (1916), during our fieldwork we focused on the sandstone layers of the section exposed around the location of his Pârâul Budurone site, but only a single, highly abraded, brownish-greyish coloured limb bone fragment (LPB [FGGUB] R.2757) was collected here from a greenish/bluish sandstone bed (Sl; Fig. 6C) situated 5 m below the topping conglomerate horizon (GPS coordinates: 45.6136 N; 22.7992 E). The preservation state of this specimen is compatible neither with that reported by Kadić (1916) at his locality VI (let alone VII), nor with that of the set of large titanosaurian bones in the MBFSZ collection we assume to have been collected from Kadić's site VI.

As for the second '*Pareu buduron*' site (no. VII), Kadić (1916) described it as being situated "*in the middle of the main branch*" of the ravine, where "*a number of poorly preserved tiny bones were collected from red marl*". However, his description conflicts his map, on which, of the two branches of his '*Pareu buduron*' ravine, the eastern one seems to be longer and more pronounced. The western branch of the ravine (that indeed starts at the spur where site VI, discussed above, was supposedly located) quickly

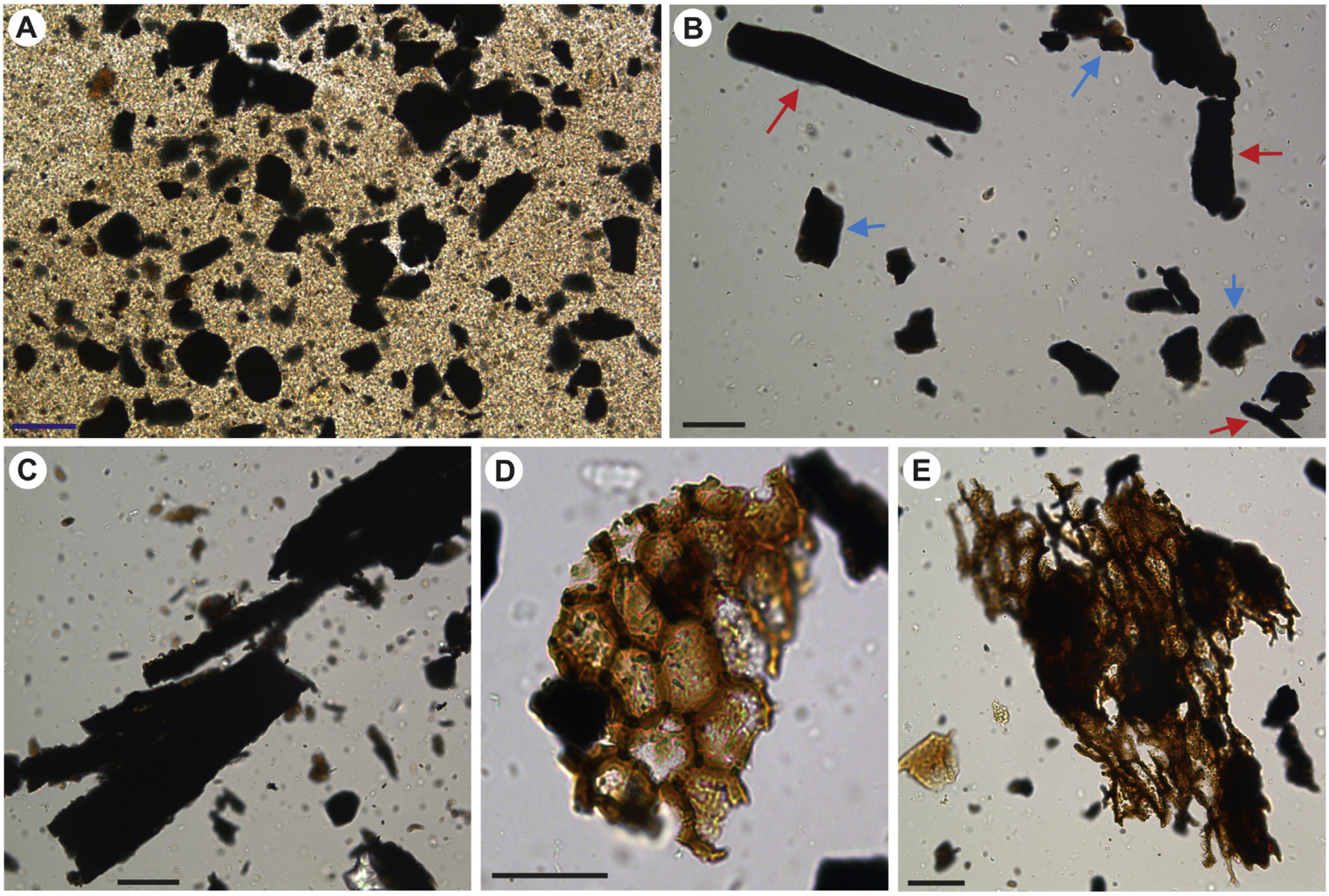


**Fig. 7.** Palynofacies components, including different types of phytoclasts, identified in samples collected in the surroundings of Vălioara Valley, in Pârâul Ogradiilor (sample P1; Fig. 5), respectively Pârâul Neagului (sample P2; Fig. 3), photographed under transmitted light (scale bar: 30 μm). A) Palynofacies dominated by small and rounded equidimensional opaque phytoclasts (sample P1); B) Lath-shaped opaque phytoclasts (red arrow) mixed with semi-opaque particles (blue arrows) of terrestrial origin (sample P2); C) Large lath-shaped opaque phytoclasts (sample P2); D) Cuticle (sample P2); E) Large-sized woody tissues (sample P2). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

widens and becomes less conspicuous, and turns into a shallow and wide (100 m) side-valley with flat floor. Yet, the map shows site VII in the middle of this western valley branch. The topographical features depicted on the historical map are still largely valid today, allowing us to retrace the potential location of site VII. However, during our survey this location was found to be agricultural land, completely covered by vegetation. It is still possible that at the time of Kadić's excavations a temporary creek cut deeper into the middle of this valley and exposed underlying uppermost Cretaceous bone-bearing rocks, but this was later refilled by farmers or by natural processes (e.g. landslide). Accordingly, no outcrop can be currently identified at (or nearby) Kadić's site VII.

### *4.3. Trace element geochemical investigations*

#### *4.3.1. Material and methods*

More than one hundred vertebrate fossils were collected during our field survey from the Pârâul Vârtopilor (K1), Pârâul Neagului (K2–K3–K4), Pârâul Ogradiilor (K5 and Nvs) and Pârâul Budurone (K6) sections in the surroundings of Vălioara Valley, of which 24 specimens were separated as samples for trace element analyses (see Table 4 and Supplementary III). In the cases of sites K1 and K3, bones representing different facies could be sampled, while for the other sites, sampling was restricted to only one bed per site due to specimen availability (Table 4). Furthermore, 27 bones were also sampled from the historical Vălioara collection of the MBFSZ in order to compare these with the *in situ* bones collected during the 2019 fieldwork. In the case of these historical specimens, the sites of origin are unknown; therefore, for the sake of our analysis artificial groupings were created based on their colour (see Table 5 and Supplementary III). This is justified because (1) Kadić (1916) paid special attention to the colour of the material collected from the various sites, and mainly this information is available to help potential site-specific separation of the fossils from his collection; and (2) the colour of fossil bones gives useful information about the oxidizing and pH conditions during fossilization, which represent important factors affecting rare earth element (REE) chemistry of pore fluids, and hence the REE content of the recrystallized bones. Three groups of specimens were separated based on their colour: the "*red group*" includes reddish and whitish coloured bones that indicate relatively oxidizing conditions during fossilization; the "*black group*" contains black and dark grey fossils resulting from fossilization under more reductive conditions; finally, the "*brown group*" is made up of brownish bones.

In selecting the historical specimens for geochemical sampling, we have also considered further points. As we noted above, the only material from the historical collection that can be linked with a great degree of certainty to one of the sites excavated by Kadić is

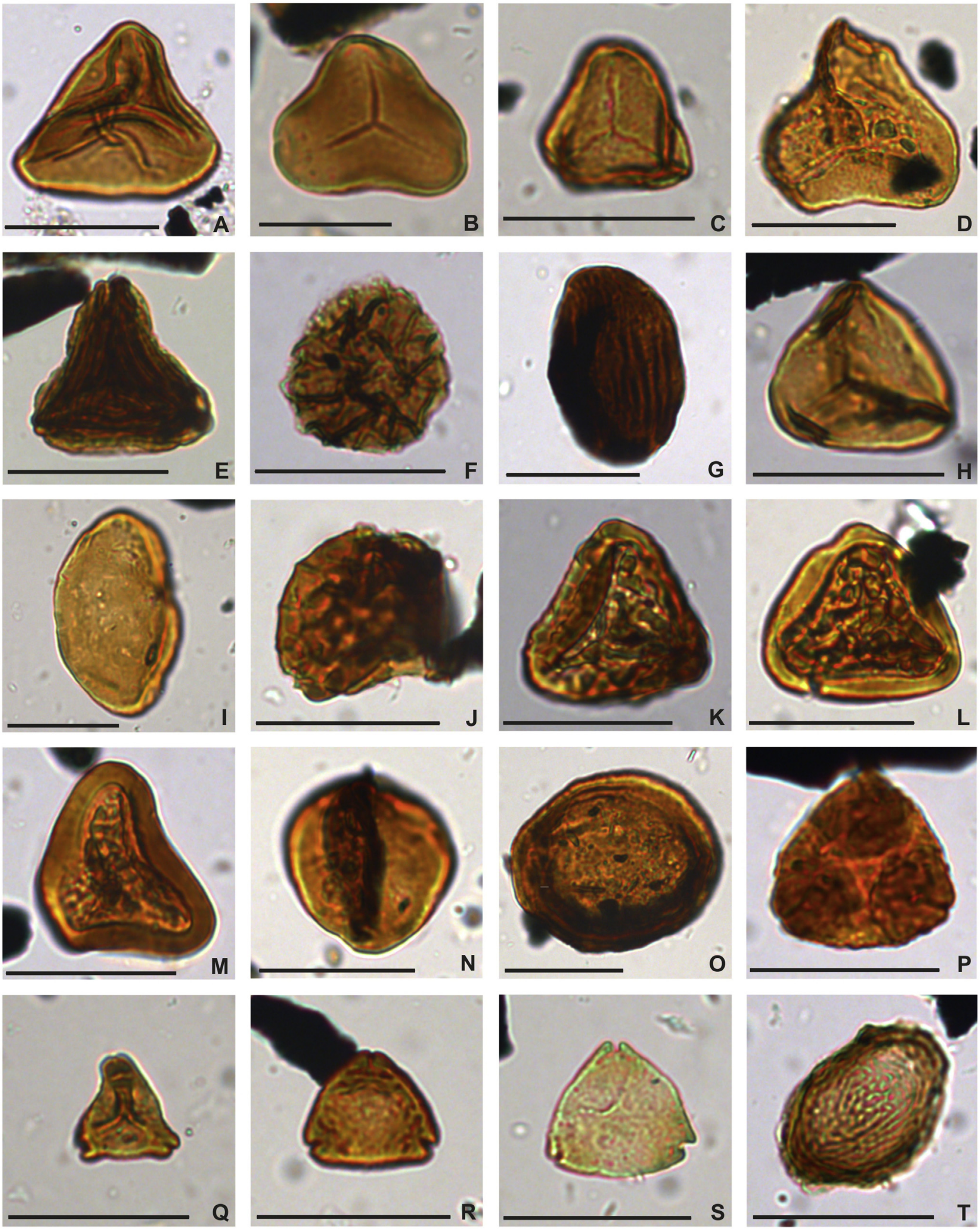


**Fig. 8.** Selected palynomorphs (cryptogam spores, gymnosperm and angiosperm pollen, and freshwater algae) identified in the samples from Vălioara Valley (scale bar: 30 μm). A) *Deltoidospora toralis* (sample P1); B) *Deltoidospora australis* (sample P2); C) *Deltoidospora minor* (sample P2); D) *Deltoidospora punctatus* (sample P2); E) *Appendicisporites tricornitatus* (sample P2); F) *Cicatricosisporites curvatus* (sample P2); G) *Cicatricosisporites dorogensis* (sample P2); H) *Biretisporites potoniaei* (sample P2); I) *Laevigatosporites major* (sample P2); J) *Lycopodiumsporites clavatoides* (sample P2); K) *Polypodiaceoisporites verruspeciosus* (sample P2); L, M) *Polypodiaceoisporites* sp. (sample P2); N) *Triplanosporites microsinuosus* (sample P2); O) *Classopollis* sp. (sample P2); P) *Oculopollis praedicatus* (sample P2); Q) *Plicapollis serta* (sample P2); R) *Trudopollis nonperfectus* (sample P2); S) *Triatriopollenites* sp. (sample P2); T) *Chomotriletes fragilis* (sample P2).

**Table 4**
REE concentration data from the geochemically sampled *in situ* vertebrate fossils from sites K1–K6 and Nvs, collected during the 2019 fieldwork.

| Sample | Inventory number LPB (FGGUB) | Site/ravines | Presumed site based on Kadić's map | Sediment | MREE/MREE* | LREE/HREE |
|---|---|---|---|---|---|---|
| NO3 | R.2701 | K1, Pârâul Vârtopilor | near site I | red coloured recent alluvium | 1,86 | 1,86 |
| NO5 | R.2759 | K1, Pârâul Vârtopilor | near site I | reddish paleosol | 1,91 | 0,96 |
| NO7 | R.2760 | K1, Pârâul Vârtopilor | near site I | reddish paleosol | 1,91 | 1,1 |
| NO8 | v.880 | K1, Pârâul Vârtopilor | near site I | reddish paleosol | 2,11 | 1,21 |
| NO16 | R.2672 | K2, Pârâul Neagului | near site II | greenish-grey micaceous fine-grained sandstone | 1,56 | 0,85 |
| NO17 | R.2763 | K2, Pârâul Neagului | near site II | greenish-grey micaceous fine-grained sandstone | 1,63 | 0,94 |
| NO19 | R.2709 | K2, Pârâul Neagului | near site II | greenish-grey micaceous fine-grained sandstone | 1,62 | 1,01 |
| NO27 | R.2761 | K2, Pârâul Neagului | near site II | greenish-grey micaceous fine-grained sandstone | 1,6 | 0,93 |
| NO68 | M.1708 | K3, Pârâul Neagului | near site III | reddish paleosol | 1,58 | 0,59 |
| NO69 | R.2765 | K3, Pârâul Neagului | near site III | reddish paleosol | 1,5 | 0,64 |
| NO95 | R.2764 | K3, Pârâul Neagului | near site III | conglomerate | 1,76 | 1,1 |
| NO90 | R.2721 | K3, Pârâul Neagului | near site III | greyish-bluish mudstone | 1,64 | 0,68 |
| NO83 | R.2729 | K3, Pârâul Neagului | near site III | greyish-bluish mudstone | 1,81 | 1,26 |
| NO70 | R.2730 | K3, Pârâul Neagului | near site III | greyish-bluish mudstone | 1,78 | 0,97 |
| NO79 | R.2734 | K3, Pârâul Neagului | near site III | greyish-bluish mudstone | 1,49 | 0,26 |
| NO65 | R.2738 | K4, Pârâul Neagului | near site IV | greyish mudstone | 1,76 | 1,17 |
| NO67 | R.2766 | K4, Pârâul Neagului | near site IV | greyish mudstone | 1,72 | 1,16 |
| NO100 | R.2740 | K5, Pârâul Ogradiilor | near site V | greenish mudstone | 1,62 | 0,83 |
| NO101 | R.2767 | K5, Pârâul Ogradiilor | near site V | greenish mudstone | 1,58 | 0,98 |
| NO96 | R.2757 | K6, Pârâul Budurone | near site VI | greenish/bluish sandstone bed | 1,74 | 1,93 |
| NO51 | R.2751 | Nvs, Pârâul Ogradiilor | new vertebrate site | greyish-bluish sandstone | 1,88 | 0,86 |
| NO61 | R.2747 | Nvs, Pârâul Ogradiilor | new vertebrate site | greyish-bluish sandstone | 1,86 | 0,66 |
| NO43 | R.2748 | Nvs, Pârâul Ogradiilor | new vertebrate site | greyish-bluish sandstone | 1,4 | 0,57 |
| NO42 | R.2768 | Nvs, Pârâul Ogradiilor | new vertebrate site | greyish-bluish sandstone | 1,92 | 0,52 |

Abbreviation: LREE = La, Pr, Ce, Nd; MREE = Eu, Gd, Tb, Dy; HREE = Er, Tm, Yb, Lu; MREE* = average LREE + HREE (see details in the text).

**Table 5**
REE concentration data in the geochemically sampled historical specimens from the MBFSZ collection, excavated by Kadić between 1909 and 1915.

| Sample | Inventory number | Colour | Anatomy | Group code | Note | MREE/MREE* | LREE/HREE |
|---|---|---|---|---|---|---|---|
| VA2 | V.13515 | white | rib | Red group | well-preserved rib fragment | 1,28 | 1,82 |
| VA3 | V.13507 | dark red | rib | Red group | abraded rib fragment | 1,74 | 1,72 |
| VA4 | V.13535 | red | limb bone | Red group | well-preserved limb bone | 1,37 | 2,03 |
| VA5 | V.12685/a | brown | tooth | Brown group | well-preserved tooth of *Allodaposuchus precedens* covered by the original enclosing (sandstone) sediments | 1,19 | 0,76 |
| VA6 | V.12685/a | brown | tooth | Brown group | well-preserved tooth of *Allodaposuchus precedens* covered by the original enclosing (sandstone) sediments | 1,26 | 0,73 |
| VA7 | V.12685/a | brown | bone fragment | Brown group | highly abraded bone-pebble covered by the original enclosing (sandstone) sediments | 0,97 | 0,41 |
| VA8 | V.13494 | dark brown | rib | Brown group | well preserved | 1,83 | 0,75 |
| VA9 | OB.4215 | dark red | limb bone | Red group | well-preserved limb bone | 1,73 | 1,17 |
| VA10 | OB.3088 | brown | limb bone | Brown group | well-preserved titanosaur femur ('*Magyarosaurus*') (subsample 2) | 1,65 | 1,36 |
| VA11 | OB.3089 | reddish brown | limb bone | Red group | well-preserved titanosaur hmerus ('*Magyarosaurus*') (subsample 2) | 1,45 | 1,31 |
| VA12 | V.13518 | brown | limb bone | Brown group | well-preserved but broken | 1,71 | 2,04 |
| VA13 | OB. 3103 | black | limb bone | Black group | large size, abraded titanosaur femur (subsample 1) | 1,73 | 1,58 |
| VA14 | OB. 3090 | black | vertebra | Black group | abraded titanosaur caudal vertebra (subsample 1) | 1,65 | 1,09 |
| VA15 | OB. 3090 | black | vertebra | Black group | abraded titanosaur caudal vertebra (subsample 1) | 1,71 | 1,2 |
| VA16 | V.13520 | white | vertebra | Red group | poorly preserved, highly abraded | 1,23 | 1,67 |
| VA17 | V.13529 | dark brown | limb bone | Brown group | weathered limb bone | 0,86 | 0,51 |
| VA18 | V.13533 | red | limb bone | Red group | abraded limb bone fragment | 1,42 | 1,7 |
| VA19 | V.13525 | white | rib | Red group | well-preserved rib fragment | 1,1 | 1,47 |
| VA20 | V.13510 | red | bone fragment | Red group | well-preserved but broken | 1,68 | 1,77 |
| VA21 | OB.3130 | black | limb bone | Black group | well-preserved limb bone | 1,74 | 2,39 |
| VA22 | OB.3282 | black | limb bone | Black group | well-preserved limb bone | 1,55 | 0,47 |
| VA23 | OB.3124 | black | limb bone | Black group | well-preserved limb bone | 1,98 | 1,12 |
| VA24 | OB.3129 | black | limb bone | Black group | well-preserved limb bone | 1,84 | 2,02 |
| VA25 | OB.5727 | brown | caudal vertebra | Brown group | abraded sauropod vertebra | 1,58 | 1,51 |
| VA26 | OB.5725 | brown | sacral-vertebra | Brown group | *Allodaposuchus precedens* (subsample 3) | 1,67 | 1,61 |
| VA27 | OB.3131 | brown | skull | Brown group | lectotype of *Allodaposuchus precedens* (subsample 3) | 1,48 | 1,71 |
| VA30 | OB.3091 | brown | vertebra | Brown group | potential holotype of *Magyarosaurus dacus* (subsample 2) | 1,63 | 1,37 |

Abbreviations as in Table 4. Note: since sites of origin are not known for these specimens, artificial groupings were created based on their colour, as indicated by their Group Code in the table (see details in the text).

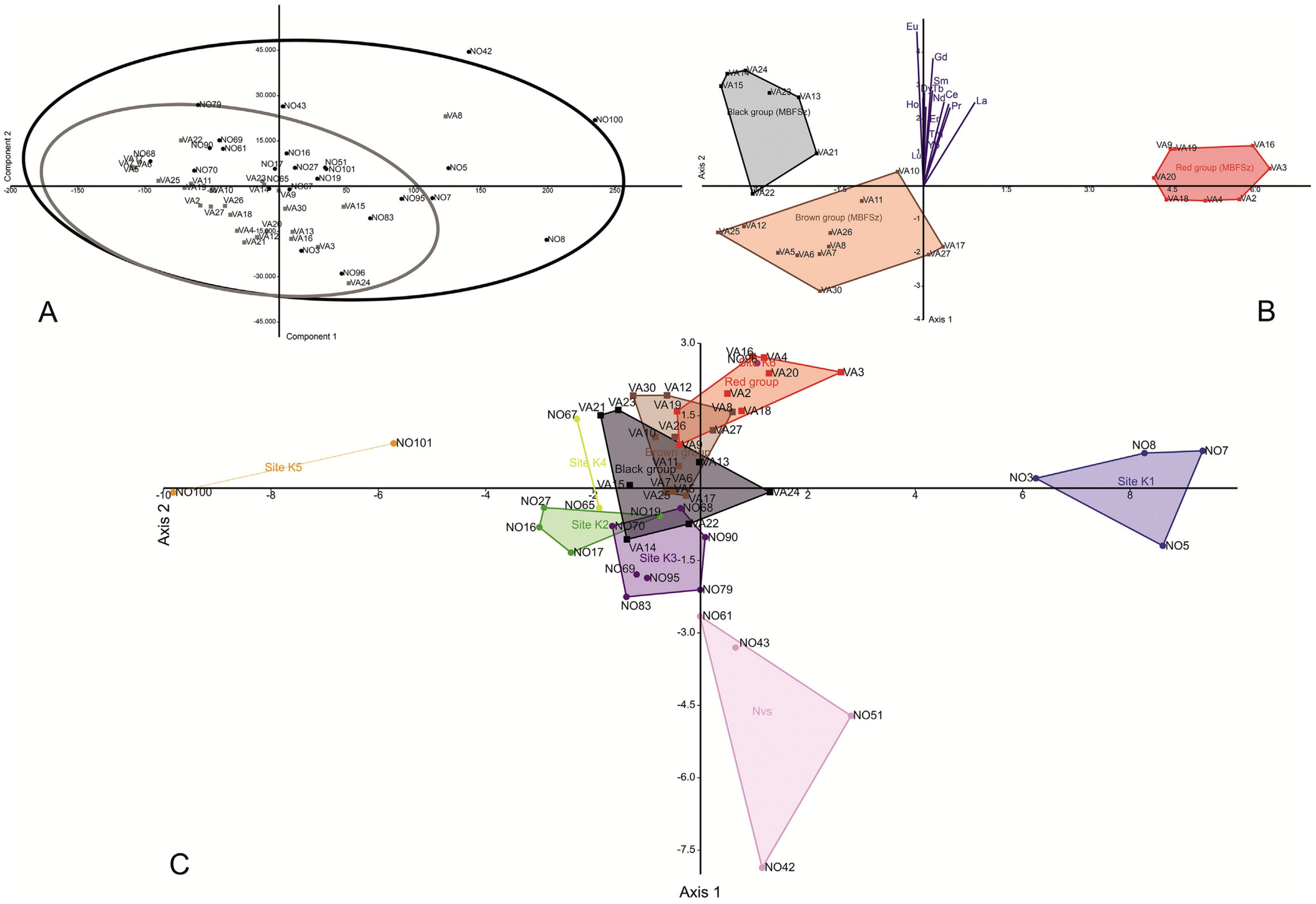


**Fig. 9.** Analysis of the rare earth element (REE) dataset using different multivariate exploratory methods. A) PCA plot along the PAAS normalized REE series. Black dots – newly collected specimens, grey squares – samples from the historical collections. The black 95% confidence ellipse of the new collection contains the complete confidence ellipse of the historical collection. B) LDA biplot based on the historical collection, broken down into the *a priori* defined colour-based groups (red, brown, black). The groups are marked with convex hulls. The REE as vectors show how important grouping factors are these. C) LDA plot of the entire sample; filled squares – samples from the historical collection (see fig. B), dots coloured according to the different new collection sites. The groups are marked with convex hulls. Note that samples from sites K1, K5 and Nvs are outliers, whereas the historical collection and our other sites (K2–K4, K6) are overlapping. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

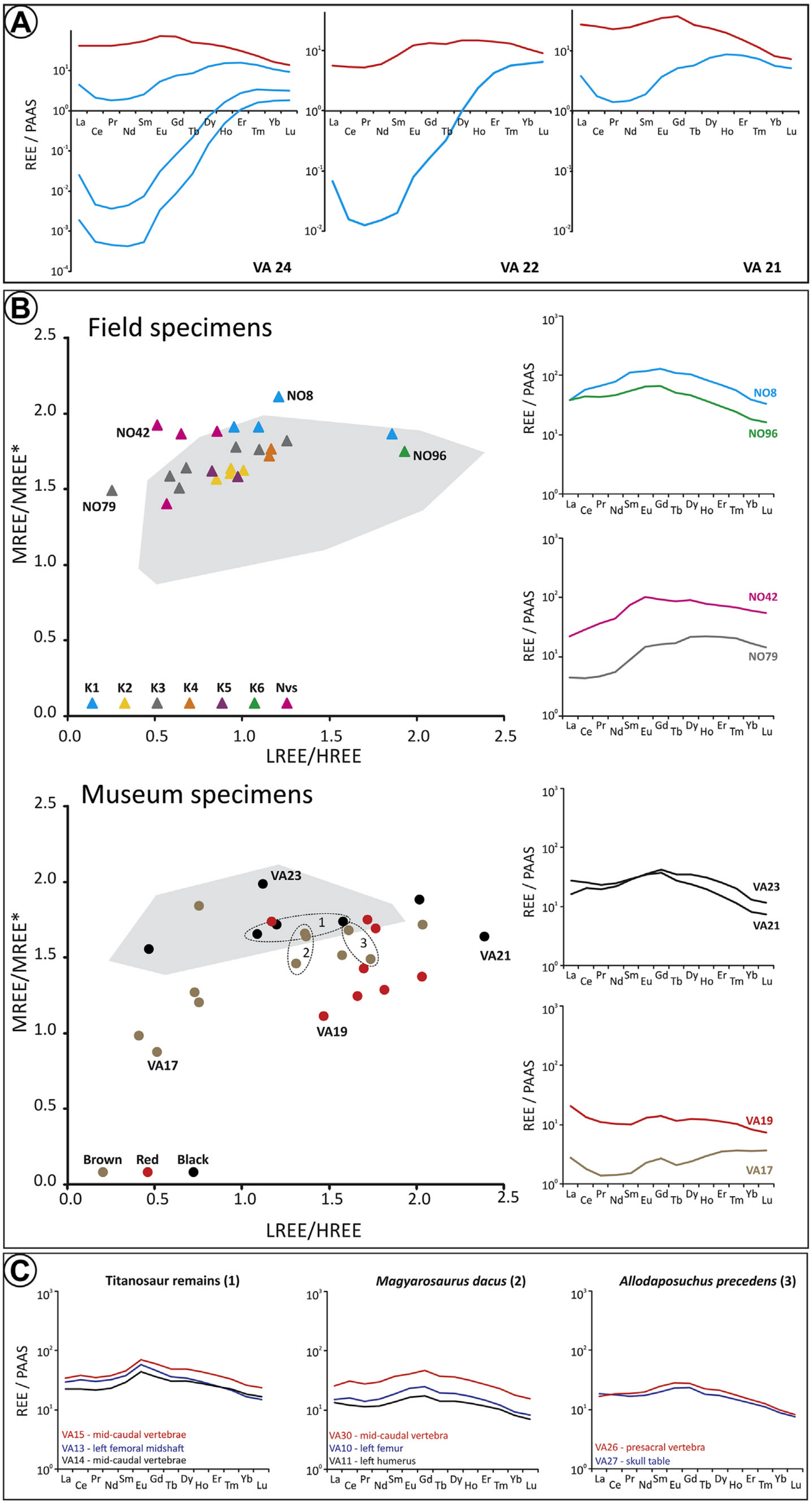


**Fig. 10.** REE geochemistry of the samples. A) PAAS normalized REE patterns of selected samples demonstrating fractionation along the REE series. Note that with a progressively more interior position of the analysing spot, the REE concentration decreases, whereas the degree of fractionation between LREE and HREE increases (i.e. more significant HREE enrichment). Only the most external, least fractionated (red) patterns are used in subsequent palaeoenvironmental or specimen provenance discussions. B) Non-fractionated REE

represented by a set of large-sized and black-colored associated titanosaurian remains (caudal vertebrae, fragmentary limb bones) that are reliably assumed to originate from site VI at Pârâul Budurone. Accordingly, we have chosen three different specimens from this set (sample VA13 – left femoral midshaft, MBFSZ Ob.3103; sample VA14 and VA15 – two mid-caudal vertebrae, both under accession number MBFSZ Ob.3090) to be included among the specimens sampled for REE analyses. This selection (subsample 1 – Table 5) was aimed particularly to check a hypothesis, that is, whether the geochemical signatures of these specimens, positively identified by Kadić as coming from one particular site, and by the MBFSZ registry book as coming from one individual, are closely comparable. A second special set of historical specimens selected for geochemical sampling (subsample 2 – Table 5) includes, first of all, the potential holotype mid-caudal vertebra of *Magyarosaurus dacus* (VA30; MBFSZ Ob.3091), together with two other titanosaurian appendicular elements, a left humerus (VA11; MBFSZ Ob.3089) and a left femur (VA10; MBFSZ Ob.3088). Based on their matching size, as well as their comparable taphonomical features and preservation state, these specimens may originate from one and the same site which, based on the brief account of Kadić (1916), could be tentatively identified as site I from Pârâul Vârtopilor. Furthermore, these elements are potentially conspecific, and possibly may even represent one single individual. This set was selected to check whether the specimens yield a coherent geochemical signal that would independently support their origin from the same locality. Finally, a third specifically selected subset of the historical sample (subsample 3 in Table 5) includes two skeletal elements of the eusuchian crocodyliform *Allodaposuchus precedens*, respectively VA27 (the former lectotype skull table; MBFSZ Ob.3131) and VA26 (a referred presacral vertebra, MBFSZ Ob.5725). Our geochemical sampling was designed to check whether these specimens may originate from the same site, as suggested by their comparable taphonomic features. This would be in accordance with Nopcsa (1914) who noted the discovery of several 'incomplete crocodilian skeletons' (most probably associated remains) at Vălioara.

Small chips of bone or minute tooth fragments were removed from the specimens selected for geochemical sampling (Tables 4–5). Special attention was taken to collect samples including the very external cortical layers of the elements, and wherever it was possible, the transition towards the more internal, often spongy, cancellous bone tissue. This allowed testing for REE gradients along an external-internal bone profile, and checking whether the obtained REE distributions were affected by fractionation along the REE series (see Trueman et al., 2011).

The samples were cut and embedded in epoxy resin, then polished for Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS). The ablation was carried out in He atmosphere using spot sizes of 100 μm in diameter. Each specimen was ablated between 1 and 4 times. The concentrations of several trace elements were determined by using a Perkin Elmer ELAN DRC II ICP-MS mass spectrometer at the University of Lausanne in Switzerland. The analytical list included $^{11}$B, $^{25}$Mg, $^{27}$Al, $^{29}$Si, $^{31}$P, $^{34}$S,$^{42}$Ca, $^{55}$Mn, $^{57}$Fe, $^{62}$Ni, $^{65}$Cu, $^{66}$Zn, $^{85}$Rb, $^{88}$Sr, $^{89}$Y, $^{91}$Zr, $^{137}$Ba, $^{139}$La, $^{140}$Ce, $^{141}$Pr, $^{143}$Nd, $^{147}$Sm, $^{151}$Eu, $^{157}$Gd, $^{159}$Tb, $^{163}$Dy, $^{165}$Ho, $^{166}$Er, $^{169}$Tm, $^{172}$Yb, $^{175}$Lu, $^{178}$Hf, $^{208}$Pb, $^{232}$Th and $^{238}$U. Standard reference material of NIST612 was used for external standardization (Pearce et al., 1997). As an internal standard, $^{42}$Ca was analysed, and CaO values of 54 and 50 wt% were used for enameloid, and for dentine and bone, respectively (e.g., Kocsis et al., 2014). The analytical reproducibility was generally better than ±5% SE. It must be mentioned at this point that a certain amount of variation in the CaO content exists between different parts of the fossilized vertebrate remains, and thus small deviations from the standard CaO values employed may be expected. Therefore, the obtained absolute values should be handled with precaution; nevertheless, the data allow relative comparison between samples and sites using element ratios or PAAS (Post-Archaean Australian Shale) normalized REE patterns (Supplementary IV). The REEs were subdivided into light, middle and heavy REE groups as follows, respectively: LREE (La, Pr, Ce, Nd), MREE (Eu, Gd, Tb, Dy), and HREE (Er, Tm, Yb, Lu). The value MREE* is defined by the average of LREE and HREE.

The PAST software was used for all statistical analyses (Fig. 9). Exploratory data analyses were carried out to find outlying variables or specimens. The variance and standard deviation for all variables were calculated both in the case of the specimens collected by Kadić and that of the new material (Supplementary III). The dataset was analysed using different multivariate exploratory methods such as principal component analysis (PCA) and linear discriminant analysis (LDA). LDA was used to test the strength of the *a priori* defined groups such as those based on the newly excavated localities as well as the colour groups from the Kadić collection. Site K6 was left out from the multivariate analyses because only one specimen was found in the Pârâul Budurone section. The variability at sites K4 and K5 may be also underestimated, since only 2 samples were studied from either of these. Accordingly, the K4 and K5 samples were retained in the study, but their reliability was considered with caution during data interpretation. Jackknife was not used because of the small sample size.

### 4.3.2. Results

The total REE contents measured range from 720 to 13471 ppm (mean = 5507 ppm; median = 5860 ppm) in the newly collected *in situ* vertebrate fossils, and from 11 to 27441 ppm (mean = 3148 ppm; median = 4094 ppm) within the samples from the MBFSZ historical collection (Supplementary IV).

Many samples display a high REE concentration gradient from the cortex of the bone towards the internal part, together with large changes in the REE distributions (Fig. 10). Similar observations have been reported previously, and such trends are explained by fractionation during REE uptake between LREE and HREE due to their different ionic radii (e.g., Trueman et al., 2011; Herwartz et al., 2013). This fractioning results in a gradual, relative HREE enrichment and LREE depletion towards the more internal parts of the bone (Fig. 10A). Obviously, these fractionated patterns are of no use in comparing different bones and sites for provenance study. In fact, the external, cortical part of the bones yielded REE patterns that are not fractionated and hence most closely reflect the REE distribution of early diagenetic fluids. Therefore, several analyses (44 out of 151), in which fractionation was evident or suspected, were eliminated from further discussions. The remaining *in situ* data range from one to four spots per sample that were averaged for each

ratios and selected REE patterns of newly collected and historical specimens. Grey shaded areas show the data spread of the other groups. LREE (La–Nd), MREE (Eu–Dy), HREE (Er–Lu) and MREE* = LREE + HREE. Important historical specimens – large black titanosaurian bones (subsample 1), *Magyarosaurus dacus* holotype and associated titanosaurian appendiculat elements (subsample 2), and *Allodaposuchus precedens* neotype and associated material (subsample 3) – are encircled. C) Matching REE patterns of the individual bones from special subsamples 1–3 suggest that these specimens probably originate from the same outcrop, and possibly even belong to the same individual. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

sample, and statistical analyses were performed on this mean dataset.

Principal component analyses on PAAS normalized REE data were performed in order to compare the newly collected bones with Kadić's material. The first two components explain more than 98% of the variance among the samples. PC1 (94.8%) appears with only positive precursor related mainly to the MREE, while PC2 relates to LREE (negative eigenvalues) and HREE (positive eigenvalues) (Fig. 9A and Supplement III). The variance of the newly collected material is higher than that found in the bones from the historical collection, but the 95% confidence ellipses of the two assemblages clearly overlap (Fig. 9A).

As noted above, the samples chosen from the MBFSZ collection were divided *a priori* into three groups based on their colour (see Table 5). The validity of these groups in terms of their REE content and distribution was tested with linear discriminant analyses (LDA) (Fig. 9B). The results separate the three groups, indicating that the colour and the REE content of the bones from the historical collection are strongly correlated, as 96.3% of these are correctly classified (Supplement III). Specimens from the "red group" differ from the other two groups ("black"and "brown") as they are enriched in LREE and Eu, whereas Eu and Gd are found to be important in differentiating specimens of the "black" and "brown" groups, respectively, based on the vectors of the biplot (Supplementary III).

To compare the Kadić material and the new Vălioara collection, the variance and the standard deviation along the PAAS normalized REE series were tested, checking whether these two subsamples behave in similar ways or display some significant differences. In both cases the curves show the same trends on the diagrams. In all elements except La, the Kadić specimens show lower variance and standard deviation compared to the new collection (Fig. 9A).

The PCA and LDA run on the entire sample gave similar results. The groups are valid in a very high percentage, as 92% of the specimens are correctly classified based on the confusion matrix of the LDA (Supplementary III).

The majority of the geochemical profiles obtained from the MBFSZ collection are largely similar to those from the newly collected specimens that were found in the Pârâul Neagului ravine (sites K2–K3–K4). As only 2 specimens were sampled from the Pârâul Ogradiilor locality (K5), the description of its variance remains highly questionable, but the REE content of these bones is somewhat similar to those of the bones from the Pârâul Neagului ravine. Vertebrate remains from Pârâul Vârtopilor (K1), collected from a red mudstone horizon, are similar to the bones of the "red group" from the MBFSZ collection, as both of these subgroups are relatively enriched in LREE compared to other specimens, but the newly collected material is also enriched in Pr and Nd, whereas the "red" samples from the Kadić collection are enriched mainly in La (Fig. 9C). On the LDA plot, these groups are on the positive side of LD1. The bones from the new vertebrate site (Nvs) found during 2019 are clearly different from all other sampled specimens, representing the only group in the first quartile on the LDA plot (Fig. 9C). The bones from this site are enriched in MREE, and not only in La but in Pr and Nd as well.

To better compare the newly excavated sites and the historical specimens, the data were plotted on a MREE/MREE* versus LREE/HREE diagram (Fig. 10). This allows identifying subtle differences among the PAAS normalized REE patterns. In the newly collected material, variation is mainly concentrated along the LREE/HREE values, with no significant change in the gradient of MREE enrichment. Meanwhile, many of the Kadić specimens have significantly lower MREE/MREE* values, especially the "red group" bones, and some tend to have higher LREE/HREE ratios driven by their HREE-depleted patterns.

### 4.3.3. Interpretation of the trace element analyses

The PCA analyses of normalized REE data show that the newly collected bone material has a higher variability in its REE distribution, although they still include all of the sampled Kadić specimens within their 95% confidence ellipses (Fig. 9A). This hints to a generally similar REE source and hence suggests origin of both primary sub-samples (new and historical) from the same region. However, the detailed LDA analyses reveal important differences (Fig. 9C), mainly based on the variance of REE composition between the new and the historical collections.

The newly collected, *in situ* samples exhibit a higher variance in their overall REE composition compared to the MBFSZ samples, indicating they were fossilized within a wider palaeoenvironmental range of the fluviatile system, whereas the samples from the historical collection appear to represent fewer facies types. Due to the marked differences in variability of REE distribution between the two collections, the detailed provenance analysis of the historical material as a function of the REE composition of the new collection did not produce unambiguous results, because only a few historical specimens exhibit significant similarities with bones from our newly excavated vertebrate sites (Figs. 9C and 10).

According to Trueman (1999), the HREE are preferentially mobilised as dissolved or colloidal complex, and thus they remain in solution and migrate with pore waters to river waters and runoff, whereas the LREE are preferentially retained within the weathering profile or are adsorped onto particle surfaces. Based on this model, bones that are recrystallized in well-drained soils will be relatively enriched in LREE, whereas bones that undergo recrystallization in water-saturated environments such as channel belts will be relatively enriched in HREE.

The vast majority of the fossil bones analysed from both the newly collected and the historical material are relatively enriched in MREE suggesting that recrystallization occurred in water-logged rather than in well-drained environments (e.g., Trueman, 1999; Metzger et al., 2004; Rogers et al., 2010). This assessment is consistent with the sedimentology of the sections exposed around Vălioara, which are dominated by greenish, bluish, sometimes dark-grey mudstone and claystone indicating a more water-saturated depositional environment (see above). Enrichment in LREE occurs frequently in bones that are fossilized in red-coloured, well-developed paleosols indicating an oxidizing and well-drained sedimentological condition, where the REE originate from the pore waters of the residual soil during bone recrystallization (Trueman, 1999; Metzger et al., 2004; Trueman et al., 2006; MacFadden et al., 2007; Rogers et al., 2010). Kadić (1916) mentioned only two main sites where the bone-bearing horizon was represented by red mudstone layers indicating oxidizing conditions during fossilization: site I, situated in the Pârâul Vârtopilor ravine, and site VII from the Pârâul Budurone ravine, from where many poorly preserved bones were collected. As discussed previously, site VII of Kadić is no longer accessible today. Only the surroundings of Kadić's site I could be investigated in detail during our 2019 fieldwork, and a few poorly preserved, small-sized vertebrate remains were collected *in situ* from a reddish paleosol horizon (Ptc) in the upstream section of the Pârâul Vârtopilor ravine. Four vertebrate remains (NO3; NO5; NO7; NO8; see Table 4 and Supplementary III) from this red mudstone were analysed for trace element composition. These bones, somewhat unexpectedly, exhibit REE patterns similar to bones that were collected from water-logged sediment types (Fl, Fm, Fmc), characterized by a relative depletion of LREE, coupled with enrichment of MREE (Fig. 10). This overlap indicates more complex patterns of water fluctuations (encompassing both water-saturated and -drained periods) during pedogenesis and the recrystallization of the bones. Such a complexity is also suggested by the presence of sporadic burial-gley features in the reddish mudstones, suggestive of water-table fluctuations during or immediately after soil formation (see above). Although the analysed samples from the Pârâul Vârtopilor ravine show unequivocal enrichment in MREEs, they differ slightly from samples from the other vertebrate sites by their relatively higher LREE content (Fig. 9C).

Eight red coloured bones (VA2-4, VA9, VA16, VA18-20; see Table 5 and Supplementary III) were sampled from the MBFSZ collection in order to determine (1) whether these bones collected by Kadić originate from the same bonebed as the ones excavated and investigated by us from the Pârâul Vârtopilor ravine, and (2) whether the bone colour shows significant correlation with its REE chemistry, and if so, what might be the implication(s) of such a correlation. All these historical red bones exhibit relative LREE enrichment compared to other sampled specimens (Fig. 9B), and form a more or less coherent datapoint population in terms of their MREE/MREEE* and LREE/HREE values (Fig. 10B). The linear discriminant analyses (LDA) confirmed that all of the reddish coloured bones are characterized by a relative LREE enrichment, and represent a clearly separated group compared to the black and brown coloured vertebrate remains (Fig. 9B). Based on these results, the reddish coloured bones were recrystallized under better drained and more oxidizing conditions, where LREE enrichment could take place during fossilization (e.g. Trueman, 1999; Trueman and Turros, 2002; Trueman et al., 2006; Rogers et al., 2010); that is, within a relatively well-developed paleosol horizon. Although the bone-bearing horizon excavated and sampled by us in the upper part of the Pârâul Vârtopilor ravine is a well-developed, reddish paleosol, the *in situ* bones collected here show a REE distribution (e.g. MREE/MREE*) which is significantly different from that recorded in the reddish bones of the MBFSZ collection (Fig. 9C). Therefore, the exact provenance of the reddish bones collected by Kadić cannot be determined at this time; nevertheless, it can be stated confidently that they are not originating directly from our site K1. It should be noted, however, that according to his account Kadić collected well-preserved, red coloured bones from only one site, which he named site I (Kadić, 1916), hence there is a high probability that most if not all of the well-preserved and reddish coloured bones from the historical MBFSZ collection came from the upper part of the Pârâul Vârtopilor ravine, near but not exactly from the same paleosol horizon (K1) excavated during our fieldwork.

Provenance analysis of the bones from the MBFSZ collection that are other than reddish in colour is highly problematic based on their REE composition. This is because the plots of the specimens sampled from the newly collected material from the Pârâul Neagului and Pârâul Ogradiilor ravines (the ones that include the presumed positions of sites II-III-IV and V of Kadić, 1916, respectively) are very similar to each other. Although minor differences can be observed among the measured data, all of these samples show MREE enrichment. Therefore, direct linkage of a given fossiliferous bed/outcrop to the MBFSZ material is difficult.

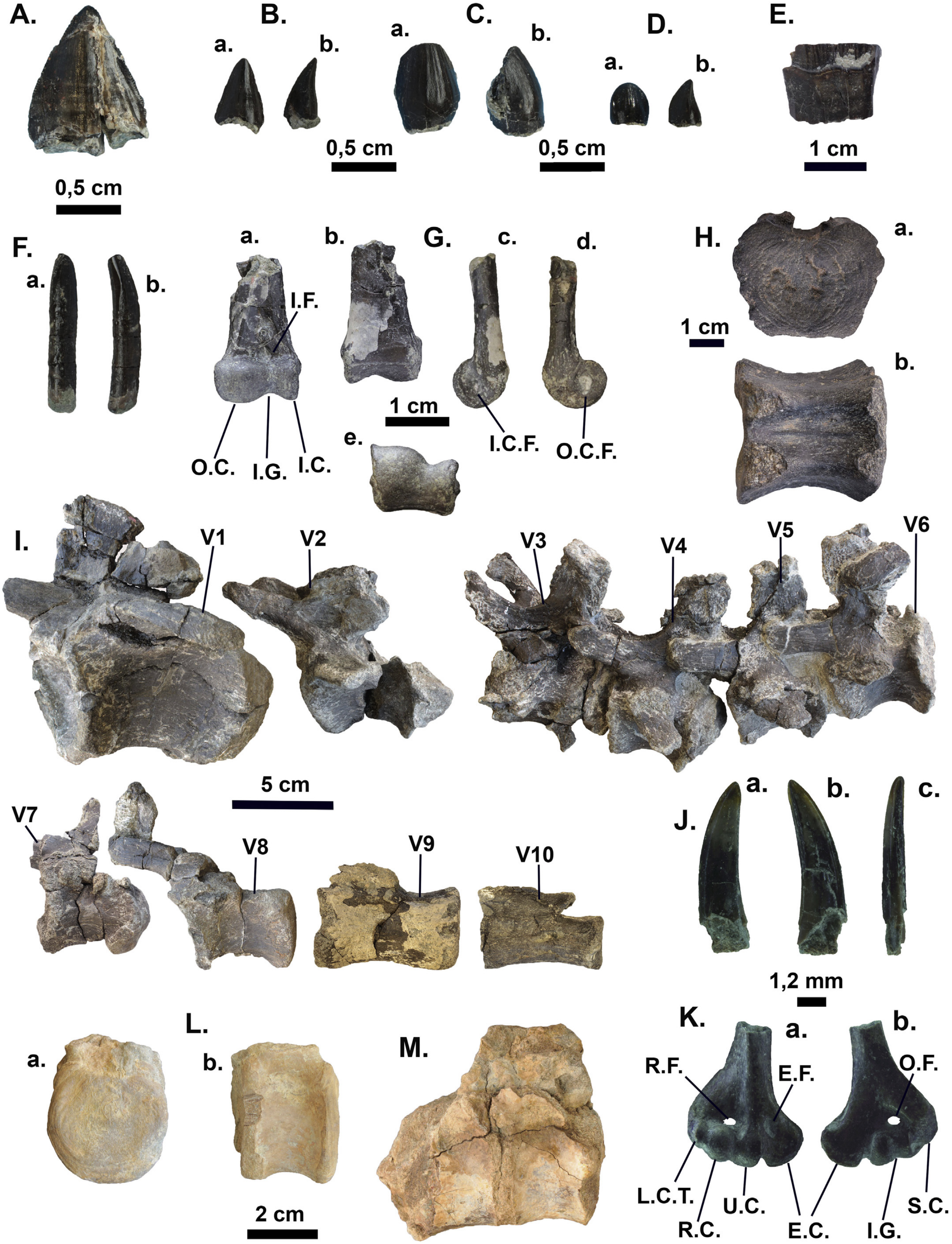
Furthermore, we have considered individually the three particular subsets we have selected specially from the historical collection (Budurone black titanosaurian bones, light coloured titanosaurian bones, and *Allodaposuchus* elements, respectively). Elements of the first subsample including the large sized, black coloured titanosaurian remains from the MBFSZ collection (sample VA13 - MBFSZ Ob.3103; VA14 and VA15 - MBFSZ Ob.3090) show very similar shale normalized REE patterns (Fig. 10C), and their datapoints plot in close proximity in the LRRE/HREE to MRRE/MRRE* space, somewhat removed from other specimens assigned together with these to the "black group" (Fig. 10B). Their REE signatures, besides the similarities in colour, size and preservation, would thus support previous suggestions that these elements most probably represent associated bones from the same skeleton, found in the same site. The same pattern can also be noticed for the light coloured titanosaurian bones of the second subsample (samples VA30, VA11 and VA10, corresponding to MBFSZ Ob.3091, MBFSZ Ob.3089 and MBFSZ Ob.3088, respectively; see Figs. 10B-C), that is, a matching REE enrichment patterns, and closely spaced datapoints plotted in the LRRE/HREE to MRRE/MRRE* graph. This geochemical similarity may also suggest that these bones probably represent associated titanosaurian material originating from one particular site. Such a conclusion is of great significance because the investigated material of the second subsample includes the potential holotype of *Magyarosaurus dacus* (MBFSZ Ob.3091), and thus our data supports possible skeletal association of the holotype material of this iconic sauropod taxon. In the case of the *Allodaposuchus* material from our third special subsample, the shale normalized REE patterns of the lectotype skull (sample VA27; MBFSZ Ob.3131) and referred sacral vertebra (sample VA26; MBFSZ Ob.5725) are also closely matching (Fig. 10C), again allowing similar interpretations concerning their origin – that they were excavated from the same site. As such, these elements are probably conspecific, as proposed initially by Nopcsa (1928) – an idea questioned subsequently by Buscalioni et al. (2001), but upheld recently by Narváez et al. (2020) on morphological grounds –, and may even originate from one individual.

Finally, the REE composition of the vertebrate remains from the new vertebrate site Nvs (located on the southern branch of the Pârâul Neagului ravine) differs significantly from that recorded in other specimens from both the newly collected and the historical material (Fig. 9C), indicating that this site indeed represents a new bone accumulation, unknown before our 2019 excavations.

To sum up, the newly excavated sites, identified based on Kadić's original map, yielded vertebrate remains that have largely similar REE distributions (typified by relatively high concentration of MREEs and relative depletion in LREE and HREE) to the black and brown bone samples from the MBFSZ collection. The trace element analyses do not contradict the assumption that the newly excavated beds are roughly/largely compatible with the localities Kadić sampled over a hundred years ago. Even though the precise location of some of his bonebeds remains unknown, we suggest that the close surroundings of these formerly excavated localities overlap with the places where we collected vertebrate fossils in the west-Vălioara Valley area (Pârâul Neagului and Pârâul Ogradiilor sections; see below).

### 4.4. Palaeontological significance of the newly collected material

During our fieldwork in 2019, vertebrate remains, most of them well-preserved, were collected from sites K1 – K6, as well as from Nvs (Fig. 11 and Supplementary II). The overall composition of the recovered assemblage – with turtles, crocodyliforms, dinosaurs and mammals – is reminiscent of those known from other vertebrate localities of the Densuş-Ciula Formation (e.g. Csiki-Sava et al., 2016). Nevertheless, several of the new occurrences are of palaeontological and/or palaeoecological significance, thus a brief account of the most important discoveries will be given here; a more detailed description and assessment of the material, pending complete preparation of the specimens, will be published elsewhere (work in progress).


A.
0,5 cm
B.
a.
b.
0,5 cm
C.
a.
b.
D.
a.
b.
0,5 cm
E.
1 cm
F.
a.
b.
G.
a.
b.
c.
d.
e.
I.F.
O.C.
I.G.
I.C.
1 cm
I.C.F.
O.C.F.
H.
a.
b.
1 cm
I.
V1
V2
V3
V4
V5
V6
5 cm
V7
V8
V9
V10
J.
a.
b.
c.
1,2 mm
K.
a.
b.
R.F.
E.F.
O.F.
L.C.T.
R.C.
U.C.
E.C.
I.G.
S.C.
L.
a.
b.
2 cm
M.

As usual in the uppermost Cretaceous continental deposits of the Haţeg Basin, turtle remains are among the most frequently encountered vertebrate fossils in the new collection. Although most of these are represented by small plate fragments, a relatively large and almost complete turtle shell (LPB [FGGUB] R.2710) was also collected from a dark-grey sandstone bed of the Pârâul Neagului ravine (K2 locality). The outer surface of this specimen (still under preparation, but with both the plastron and carapace preserved) shows an ornamentation pattern consisting of tiny and low vermiculations and tubercles reminiscent of *Kallokibotion* (Rabi et al., 2013; Pérez-García and Codrea, 2018), a common element of the local fauna. Similar *Kallokibotion*-like ornamentation can be observed on most of the turtle fragments collected in 2019 as well, although a few turtle plates (e.g. LPB [FGGUB] R.2707 and R.2709) show slightly different ornamentation with fine, closely spaced, parallel, longitudinal ridges, as well as wide and deep sulci. These may indicate that beside *Kallokibotion*, other (probably dortokid) turtle remains are also present in the material, but reaching such a conclusion definitvely requires the discovery of more, and better preserved, material.

Crocodyliforms are the most taxonomically diverse group in the assemblage, since at least four different taxa can be identified based on the isolated teeth recovered from different sites. These include *Allodaposuchus* (conical, longitudinally ribbed teeth; Fig. 11C), a *Theriosuchus*-like taxon (exemplified by a triangular, labio-lingually flattened tooth with non-serrated cutting edge; Fig. 11B), a *Doratodon*-like taxon (with labio-lingually flattened triangular teeth with serrations on the carinae; Fig. 11A), and *Acynodon* (represented by a slightly lingually curved tooth, with a strongly rounded tip and small longitudinal grooves along the cutting edges; Fig. 11D) (see Buscalioni et al., 1997, 2001; Martin et al., 2006, 2014; Delfino et al., 2008a, b; Csiki-Sava et al., 2016). All of these taxa had been reported previously from the Haţeg Basin (e.g. Nopcsa, 1915; Martin et al., 2006, 2010; Csiki-Sava et al., 2016).

The newly excavated dinosaurian material from Vălioara is dominated by different herbivores, with only one limb bone fragment identified as a paravian theropod (Fig. 11G). This specimen (LPB [FGGUB] R.2752), discovered at site Nvs in Pârâul Ogradiilor, represents the distal end of a right tibiotarsus. The distal end of the tibia is almost completely fused with the tarsals; only a faint line indicates the trace of the suture on the posterior face of the element. Only the distalmost end of the shaft is preserved; although slightly crushed, it was definitively antero-posteriorly compressed, with a flat posterior face. The distal articular end broadens slightly relative to the shaft; it is very weakly flattened anterior-posteriorly, almost quadrangular in distal view. The articular surface is formed of two anteriorly projected and unequally developed condyles; the lateral condyle is markedly larger and bulbous, anteriorly convex, whereas the medial one is narrower and anteriorly acute. The condyles are separated by a V-shaped intercondylar groove.

This bone shows certain similarities both with the isolated distal tibiotarsus NHM A4359 from the collections of the Natural History Museum in London, as well as with that of the aberrant dromaeosaurid *Balaur bondoc* (see Brusatte et al., 2013b). Tibiotarsus NHM A4359 had been referred previously to *Elopteryx nopcsai* (Andrews, 1913), and was later made the holotype of the presumed fossil owl *Heptasteornis andrewsi* (Harrison and Walker, 1975); it is now regarded as belonging to a small paravian theropod of unclear affinities, probably related to the dromaeosaurid *Balaur* (see review in Csiki et al., 2010b). The distal tibiotarsi of '*Heptasteornis*' and *Balaur* differ essentially in that the former is relatively more expanded latero-medially compared to its anteroposterior breadth (Brusatte et al., 2013b). In this respect, specimen LPB (FGGUB) R.2752 is more similar to *Balaur* than to NHM A4359; it differs, nevertheless, from *Balaur* in the absence of a relatively large lateral tubercle on the distal end of the articular end. The relatively smooth cortical surface of the new specimen also differentiates it from '*Heptasteornis*' and *Balaur*, both of which are characterized by a roughly sculptured external surface (Andrews, 1913; Brusatte et al., 2013b). This distal tibiotarsus records the presence of a small-sized derived theropod, probably related to *Balaur*-like paravians, in the newly collected faunal assemblage from Vălioara.

Among the herbivorous dinosaurs, titanosaurian sauropod remains are the most common fossils in the new collection. Besides one isolated tooth (Fig. 11F) and several fragmentary vertebrae (e.g. LPB [FGGUB] R.2725, R.2750), the most important specimen referable to this group is represented by a series of 10 associated (partly articulated) caudal vertebrae (V1 – V10 in Fig. 11I) with one chevron (LPB [FGGUB] R.2715). The procoelous nature of most vertebrae of the series (see below) and the anterior insertion of the neural arch on the centrum identify these securely as of titanosaurian affinities. The first preserved vertebra of the tail series (V1) is the largest, and has large and wide lateral processes that are strongly posteriorly projected; it is definitively an anterior caudal vertebra. The following vertebrae are smaller, with four of them found articulated; these have relatively smaller lateral processes, suggesting that they represent either the distalmost anterior or the anterior mid-caudal region (V3–V6). The last vertebra of the articulated series is distinctive in that it is not procoelous but amphiplatyan. The following vertebrae (V7–V8) are significantly smaller, more angular in cross-section, and procoelous again. Amphiplatyan middle and posterior caudal vertebrae are a plesiomorphic trait within Titanosauria (Salgado et al., 1997; Upchurch et al., 2004), but the presence of amphiplatyan mid-caudal vertebrae inserted within the procoelous series was reported to be autapomorphic for *Paludititan* described from Nălaţ-Vad in the Haţeg Basin (Csiki et al., 2010c), a taxon of somewhat younger age than the specimen reported here (Csiki-Sava et al., 2016). The last two vertebrae of the series (V9–V10) are strongly laterally compressed and have no lateral projections. Their centrum is mildly amphicoelous; the ventral longitudinal furrow is less well marked, and haemapophysal articular surfaces are no longer present. The preserved bases of the neural arches suggest that these were reduced, as well. Based on these features, these can be identified as distal caudal vertebrae, suggesting that the series as reconstructed from the available specimens is probably not continuous.

**Fig. 11.** Representative vertebrate fossils collected during the 2019 survey in the surroundings of Vălioara Valley. All specimen numbers are LPB (FGGUB); sites of origin indicated in parantheses. A) Isolated *Doratodon*-like tooth (v.880) in lingual view (K1); B) Isolated *Theriosuchus*-like anterior tooth (v.886) in a - lingual and b - mesial views (K2); C) Isolated *Allodaposuchus* sp. tooth (v.882) in a – labial and b - mesial views (K2); D) Isolated *Acynodon* sp. anterior tooth (v.885) in a - lingual and b - mesial views (K2); E) Isolated *Zalmoxes* sp. maxillary tooth (R.2747) in labial view (Nvs); F) Titanosauria indet., isolated tooth (R.2703) in a - lingual and b - mesial views (K1); G) Distal tibiotarsus of indeterminate paravian theropod (R.2752) in a - anterior, b - posterior, c - medial, d - lateral, and e – distal views (Nvs); H) Middle-distal caudal vertebral centrum of *Telmatosaurus* sp. (R.2749) in a - cranial and b - ventral views (Nvs); I) Partly articulated titanosaurian caudal vertebral series (R.2715) in left lateral view (K2); V1–V10 indicate approximate position of the individual vertebrae in the reconstructed (but not continuous) series; J) Kogaionid left lower incisor (i1; M.1707) in a - labial, b - lingual and c - occlusal views (K1); L) *Zalmoxes* sp. dorsal vertebra (R.2701) in a - cranial and b - lateral views (K1); M) *Zalmoxes* sp. sacrum fragment (R.2702) in lateral view (K1); K) Kogaionid distal right humerus (M.1708) in a - ventral and b - dorsal views (K3). Abbreviations: O.C.-outer condyle, I.C.-inner condyle, I.G.-intercondylar groove, I.F.-intercondylar fossa, I.C.F.-inner condylar fossa, O.C.F.-outer condylar fossa, R.C.-radial condyle, U.C.-ulnar condyle, E.C.-ectepicondyle, E.F.-ectepicondylar foramen, O.F.-olecranon fossa, L.C.T.-lateral capitular tail, R.F.-radial fossa, S.C.-supinator crest.

More detailed investigation of the affinities of this caudal series is forthcoming (work in progress). We only note here that of the two nominal titanosaurian genera known from the Haţeg Basin (*Magyarosaurus* and *Paludititan*), our new specimen LPB (FGGUB) R.2715 closely overlaps geographically and chronostratigraphically with the potential type material of *Magyarosaurus*, but it shows a condition previously considered autapomorphic for the younger *Paludititan* from the Sînpetru Formation. Whether this occurrence records the presence of *Paludititan*-type titanosaurians in the lower Densuş-Ciula Formation, or instead hints to closer phylogenetic relationships between *Paludititan* and *Magyarosaurus*, can only be definitively decided once the taxonomic and phylogenetic review of the entire Transylvanian titanosaurian material will be completed (Mannion et al., 2019b; work in progress).

Remains representing the rhabdodontid *Zalmoxes* sp. include a dorsal vertebral centrum (Fig. 11L) and a sacrum fragment consisting of two coossified centra (Fig. 11M), as well as isolated teeth (e.g. Fig. 11E). The teeth are easily identified as rhabdodontid due to their very characteristic morphology, with numerous subequal, slightly apically divergent ridges that cover the crown surface, and the presence of a discrete, well-defined cingulum that separates the crown from the root (Weishampel et al., 2003). The morphology of the dorsal and sacral vertebrae, both specimens recovered *ex-situ* from the Pârâul Vârtopilor section, is very similar. The centra are slightly amphicoelous, with a quasi-circular cross-section, and the articulate ends are slightly expanded relative to the middle of the centrum. In all their characteristics, these vertebrae are reminiscent of the dorsal and sacral vertebrae of *Zalmoxes* (Weishampel et al., 2003; Godefroit et al., 2009), and are thus here referred to as *Zalmoxes* sp.

The hadrosauroids are less well represented in the newly collected material. Only one specimen, a caudal vertebral centrum (LPB (FGGUB) R.2749; Fig. 11H) discovered in the Pârâul Ogradiilor section, can be definitively referred to this clade. It has a slightly dorso-ventrally flattened hexagonal shape in anterior view, a characteristic feature of vertebrae previously referred to *Telmatosaurus* (Nopcsa, 1925; Weishampel et al., 1993; Dalla Vecchia, 2009). The absence of transverse processes as well as the poorly developed neural arch (as suggested by the small and centrally positioned arch pedicels), together with the presence of the ventral longitudinal furrow, suggest that it originates either from the distalmost part of the middle section, or else from the distal (but not distalmost) part of the tail.

Multituberculate mammal remains were also collected. One of these (LPB [FGGUB] M.1707) is the coronal fragment of a left lower incisor (i1) found at Pârâul Vârtopilor (Fig. 11J): it is elongated, labio-lingually compressed, slightly curved and apically tapering. The dorsolingual edge is more angular than the dorsolabial and ventral edges. The tooth is enamel-covered but the enamel thickness is uneven, being thicker rostro-labially than it is dorsally and especially lingually. This specimen is reminiscent of the kogaionid i1s described previously from the Haţeg Basin, including specimen LPB [FGGUB] M.1635 referred to *Barbatodon transylvanicus* (Csiki et al., 2005; see also; Smith and Codrea, 2015), and most probably represents a kogaionid i1. The other mammalian fossil (LPB [FGGUB] M.1708) is a surface-collected distal end of a right humerus from the K3 site in the Pârâul Neagului ravine. The distal articular surface is expanded relative to the shaft, and presents a host of multituberculate characters such as the very large, spherical radial condyle, separated by a deep intercondylar groove from the ulnar condyle, and an entepicondyle that is larger than the ectepicondyle (e.g. Gambaryan and Kielan-Jaworowska, 1997). No multituberculate humeri had been described up to date from the Haţeg Basin; nevertheless, specimen LPB (FGGUB) M.1708 is very similar to the indeterminate multituberculate humerus UCMP 153039 reported by DeBey and Wilson (2017) from the uppermost Cretaceous of Montana.

## 5. Discussions

The sedimentary successions investigated in this study are situated in the northwestern part of the Haţeg Basin, in the vicinity of Vălioara Valley and close to the uplifted crystalline basement of the surrounding mountain ranges (Poiana Ruscă Mountains); they thus overlap with the mapped exposures of the Densuş-Ciula Formation (Fig. 1C). As discrete volcano-sedimentary beds were not detected, these successions belong to the 'middle member' of the Densuş-Ciula Formation (Grigorescu, 1992). Their general sedimentary make-up conforms indeed to that reported previously for the 'middle member', with a dominance of different siliciclastic beds of alluvial origin (Csiki-Sava et al., 2016), although some local differences were noted and will be discussed later. Overall, deposits of the middle part of the Densuş-Ciula Formation are interpreted to have been deposited within the confines of alluvial fan and braided river depositional systems (Csiki-Sava et al., 2016) fed by rivers that drained the metamorphic terrains of the Getic-Supragetic nappe pile bordering the basin to the north and north-west (Bojar et al., 2011).

The middle part of the Densuş-Ciula Formation ('middle member') was originally suggested to contain two main facies associations (Nopcsa, 1905) – one dominated by red-coloured siliciclastics, stretching from Crăguiş to Vălioara along the northern border of the basin, and one composed mainly of whitish-light grey siliciclastics, bordering the reddish deposits towards the south, between Haţeg and Boiţa, through Tuştea. More recent fieldwork has revealed that such a two-fold scheme of the 'middle member' represents an oversimplification (Csiki-Sava et al., 2016) as the two facies associations (red and whitish-light grey) actually interfinger in certain areas, and these are not spatially adjacent but most probably also overlapping chronostratigraphically, with the mass of the light grey facies being apparently somewhat younger. Furthermore, deposits of this member can be also divided into two markedly different parts along a west-east transect. Fine-grained deposits in the western part of this subunit, west of Boiţa (including most of the Vălioara Valley area) are characterized by the dominance of grey-green or grey-blueish siltstones and silty mudstones representing overbank deposits accumulated in poorly-drained floodplains (e.g. Csiki et al., 2008; Vasile, 2008, 2010; Vasile and Csiki, 2010), a view that is also upheld by our field survey in this area. Meanwhile, well-drained floodplain deposits consisting of massive, red-coloured silty micaceous mudstones with pedogenetic calcrete levels dominate in the eastern part of the 'middle member' outcropping area (Grigorescu and Csiki, 2008; Vasile et al., 2011a, b; Csiki-Sava et al., 2016; Botfalvai et al., 2017).

Vertebrate remains are widespread although not particularly common in the middle subunit of the Densuş-Ciula Formation (Csiki et al., 2010a; Csiki-Sava et al., 2016). However, with the notable exception of Vălioara locality (e.g. Kadić, 1916; Grigorescu et al., 1999; Vasile, 2008; Csiki et al., 2008, 2010a; and this study), most major vertebrate sites are located in the eastern part of this subunit (Fig. 1C). These include first of all the Tuştea-Oltoane vertebrate site, one of the most famous dinosaur localities in the Haţeg Basin, which has provided a rich and diverse assemblage of Late Cretaceous (Maastrichtian) continental vertebrates, including the most extensive dinosaur nesting site known from Central and Eastern Europe (e.g. Grigorescu et al., 2010; Botfalvai et al., 2017). The vertebrate fossils from Tuştea-Oltoane come from calcrete-bearing red to maroon-coloured paleosols suggesting a moderately to well-drained, more distal floodplain depositional environment. A dinosaur eggshell site near Livezi, farther to the east, was first reported by Grigorescu and Csiki (2008); since then, megaloolithid egg nests were also discovered here besides disperse eggshell fragments, together with a small number of macrovertebrate remains (turtles, titanosaurians) and microvertebrates (multituberculates) (Csiki-Sava et al., 2016). These were excavated mainly from calcrete-bearing red paleosol horizons belonging to the upper half of the Densuş-Ciula Formation ‘middle member’ (Grigorescu and Csiki, 2008; Grigorescu et al., 2010; Csiki-Sava et al., 2016; Flintașu et al., 2017); the exception is represented here by a very small microvertebrate assemblage screen-washed from a brownish-grey silty mudstone. Still farther to the east, vertebrate occurrences were reported at General Berthelot (formerly called Alsó-Farkadin or Fărcădinul de Jos; Vasile et al., 2011a; Csiki-Sava et al., 2016), as well as at Crăguiş (Zaharia, 2011; Vasile et al., 2011b; Csiki-Sava et al., 2016), in the easternmost part of the ‘middle member’ outcropping area, from where microvertebrates and eggshell material were recovered from dark red mudstone horizons representing both the ‘middle member’ and the ‘upper member’ of the Densuş-Ciula Formation (Vasile et al., 2011b; Csiki-Sava et al., 2016). The most recently discovered important vertebrate locality in the formation, Boița – lying geographically between Vălioara and Tuștea, and also belonging to the ‘middle member’ of the Densuş-Ciula Formation–, has yielded diverse vertebrate remains together with megaloolithid eggshell accummulations and nests (Csiki-Sava et al., 2018). Here, micro- and macrovertebrates were recovered mainly from dark greenish-grey silty mudstones from the basal part of the local succession, whereas megaloolithid remains occur in the upper part of the local succession, dominated by red siltstones interbedded with poorly consolidated light grey conglomerates and coarse sandstones. A somewhat similar situation is known to occur along the Geat Valley at Ciula Mică, where Vasile (2008) reported the presence of rare microvertebrate remains both from greyish-green and red siltstones-mudstones; here, however, the two fossiliferous beds are closely associated spatially.

The overall spatial and stratigraphical distribution of the depositional environments represented by these vertebrate sites (Fig. 12) suggests that investigation of the sedimentary successions cropping out around Vălioara Valley (and especially those on its righ side, in the Vălioara-Geat interfluve), and of their vertebrate assemblages, have great significance, as these appear to offer insight into a type of palaeoenvironment (more waterlogged, wetland-type floodplain) that is less well represented and less fossiliferous in other parts of the Densuş-Ciula Formation. Furthermore, this fossil-bearing lithotype is also relatively rarely encountered in the Haţeg Basin, overall (e.g. Grigorescu et al., 1999; Csiki et al., 2010a; Codrea and Solomon, 2012; Vasile and Panaitescu, 2012). In addition, based on the strike and dip of the beds in the investigated area (as well as across the entire outcropping area of the formation), the deposits of the Densuş-Ciula Formation appear to become younger towards the east (Laufer, 1925; Grigorescu, 1992; Csiki-Sava et al., 2016). Accordingly, the studied sections, especially those cropping out west of Vălioara Valley, are considered as lying close to the base of the middle part of the Densuş-Ciula succession, and thus the vertebrate remains originating from these local sections most probably represent some of the oldest vertebrate assemblages recorded in the formation. Indeed, aside from a partial skull element referred to as *Zalmoxes* sp. (LPB (FGGUB) R.2424) collected from deposits of the ‘lower member’ of the Densuş-Ciula Formation (Csiki-Sava et al., 2016), as well as the minor microvertebrate occurrences reported by Vasile (2008) from the Geat Valley north of Ciula Mică, the Vălioara vertebrate locality represents one the oldest bone accumulations from the entire Haţeg Basin. Furthermore, even at the local level of the Vălioara locality itself, from where several other vertebrate sites are currently on record (reviewed by Csiki et al., 2010a; Csiki-Sava et al., 2016; see also Geological Background above), most of the newly excavated sites, together with Kadić’s sites I to V, are probably slightly older (i.e., stratigraphically lower) than most other previously known vertebrate sites from this area, including Kadić’s localities VI and VII, as well as our locality K6 at Pârâul Budurone. These west-Vălioara sites, most probably lying stratigraphically somewhere between the vertebrate localities Densuș1 and Ciula Mică, and the classical microvertebrate fossil localities of Fântânele and Budurone (Grigorescu et al., 1999; Csiki et al., 2008; Vasile, 2008; Vasile and Csiki, 2010), respectively, would then belong either to tier 1/2 or to the basalmost part of tier 2 of the latest Cretaceous Transylvanian faunal assemblage succession, according to the biochronological scheme proposed by Csiki-Sava et al. (2016) (Fig. 12). As such, although direct correlation across southwestern Transylvania between the different outcropping areas with uppermost Cretaceous deposits and their vertebrate faunas is presently tenuous at best, the local assemblages derived from Kadić’s sites I to V as well as our sites K1–K5 and Nvs would rank among the earliest known vertebrate faunas of the Haţeg Island, dating most probably from the early-middle part of the early Maastrichtian (Fig.12; and see below).

### *5.1. Stratigraphic and sedimentological interpretation of the newly identified and historical vertebrate sites around Vălioara Valley*

Kadić (1916) mentioned seven important bone accumulations around Vălioara Valley, from which he collected a large number of diverse and well-preserved vertebrate fossils between 1909 and 1915. Using his unpublished map (Fig. 1B and Table 2), we managed to relocate the fossil-bearing outcrops described by him more than one hundred years ago (Kadić, 1916). During our fieldwork in 2019, seven stratigraphic sections (identified here as sites K1 to K6, and Nvs) were investigated along the ravines mentioned by Kadić (1916) as the locations of his vertebrate sites I through VI.

Our sedimentological investigations concluded that the uppermost Cretaceous sedimentary successions cropping out around Vălioara Valley are dominated by fine-grained floodplain deposits including grey-green or grey-blue siltstones and silty mudstones as well as red coloured calcrete-bearing paleosols, whereas the coarse-grained channel fill deposits such as conglomerates and sandstones are subordinate (Figs. 2-6). The sedimentary successions exposed in the Pârâul Vârtopilor and Pârâul Neagului ravines (hosting sites K1 to K4) located west of Vălioara are dominantly characterized by waterlogged, poorly–drained floodplain deposits; meanwhile, better drained, moderately to well-developed paleosols become more dominant east of the Vălioara Valley, in the Pârâul Budurone ravine (location of site K6). The sedimentary succession logged in Pârâul Ogradiilor (including site K5 and the new vertebrate site Nvs) seemingly represents a transitional phase between these two types of successions, as in this ravine the moderately to well-developed red calcrete-bearing paleosols are becoming better represented than at sites K1–K4 (Figs. 4 and 5).

These west-to-east changes in dominance from more waterlogged to better drained floodplain successions are consistent with previous interpretations according to which the western (older) part of the ‘middle member’ of the Densuş-Ciula Formation is dominated by proximal floodplain environments, whereas the eastern (younger) part of this subunit is characterized by more distal floodplain deposits (Vasile et al., 2011a). However, since only a very localized area surrounding the suspected locations of the Kadić vertebrate sites was mapped and sedimentologically investigated in our study, more detailed geological mapping would be needed to determinate the precise boundary (if any), as well as the

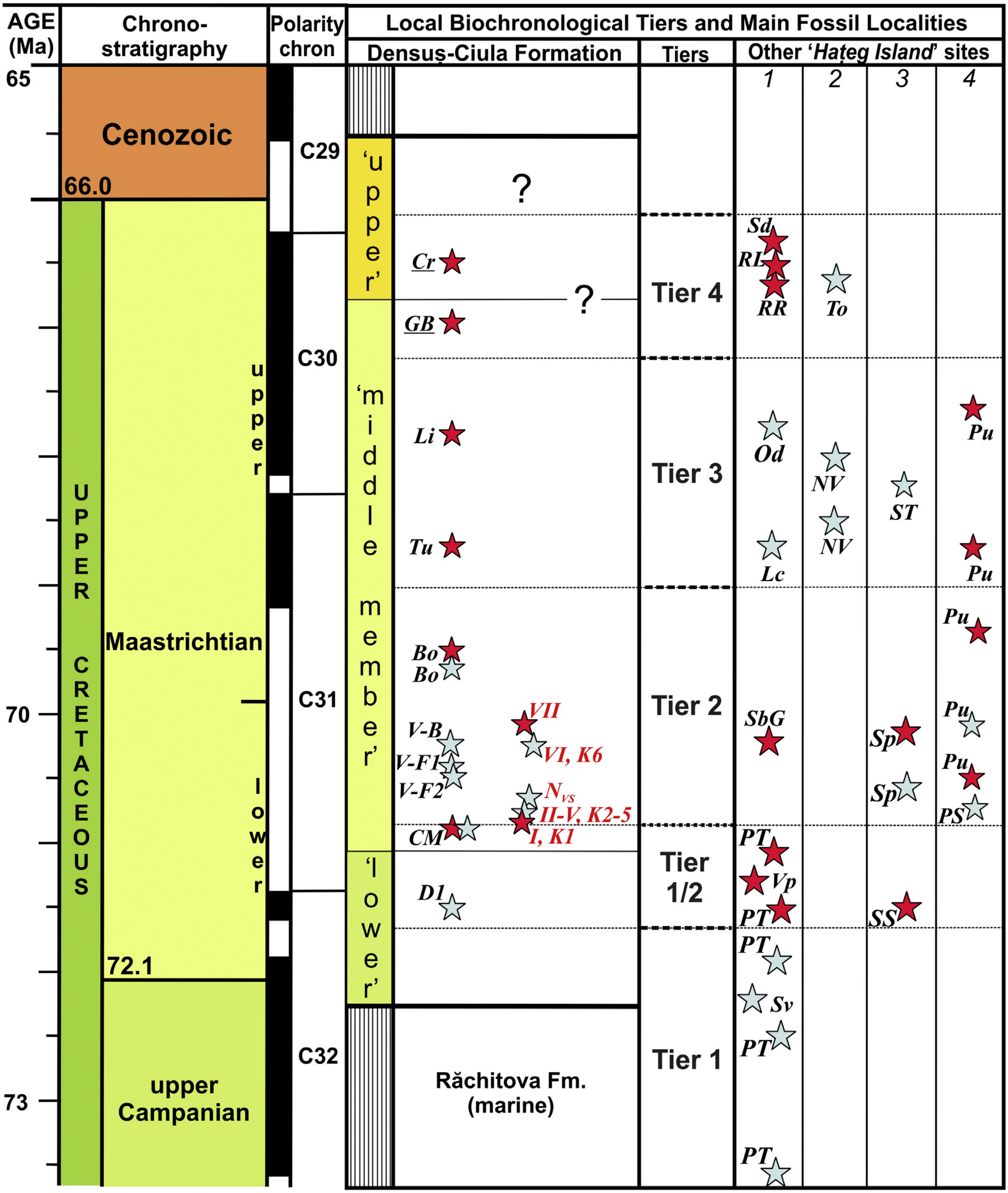


**Fig. 12.** Position of the west-Vălioara localities discussed in the present contribution (highlighted in red) within the four-tiered bio-chronostratigraphic distribution framework proposed by Csiki-Sava et al. (2016) for the latest Cretaceous Transylvanian continental vertebrate localities. Details for the Densuș-Ciula Formation include lithostratigraphic subdivisions, and distribution of formerly known (black, left side of column) and newly identified (red, right side of column) localities. For comparison, other important vertebrate localities from the Transylvanian landmass are also shown, grouped within the *1* – southwestern Transylvanian Basin, *2* – Râul Mare area, Hațeg Basin, *3* – Sibișel Valley, Sînpetru Formation stratotype section, Hațeg Basin, and *4* – Bărbat Valley, Pui, Hațeg Basin. Boundaries between the bio-chronostratigraphic tiers are placed only approximately, as are the positions of the different localities (see Csiki-Sava et al., 2016, for more details); '?' marks the presumptive position of the boundary between the 'middle' and the 'upper' members, as well as the supposed presence of the Paleogene within the 'upper member' of the Densuș-Ciula Formation, as was suggested previously (e.g., Grigorescu, 1992). Abbreviations: I–VII – Kadić's historical localities (Kadić, 1916, this paper; position of locality VII is estimated based on the general structural dip of the beds); Bo – vertebrate occurrences near Boița (see Csiki-Sava et al., 2018); K1–K6 – new vertebrate occurrences identified and excavated in 2019 in the immediate neighborhood of localities I-VI of Kadić; Nvs – new vertebrate locality identified in the Pârâul Ogradiilor area, west-Vălioara; for other locality abbreviations, see Csiki-Sava et al. (2016). Red stars mark localities discovered in dominantly red-coloured (oxidizing) deposits, grey-green stars, localities in blackish, grey or grey-green-coloured (reducing) deposits. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

detailed stratigraphical relationships, between the dominance of these two types of palaeoenvironments.

The sedimentary section of the Pârâul Neagului ravine (including sites K2–K3–K4) is the most significant one from a sedimentological point of view, because it contains the longest continuous succession logged by us, including both more waterlogged and pedogenetically not modified (e.g. Fm, Fl, Fmc), as well as well-drained (e.g. Pt, Ptc) floodplain deposits. As such, it provides a more detailed insight into the changing of the depositional environments in the lowermost ‘middle member’ of the Densuş-Ciula Formation. Overall, the dominance of the well-drained floodplain deposits increases upwards in this section (Fig. 3). The lower part of the local section overlying the talus breccia layers (Bt) and which includes sites K2 and K4 is dominated by greyish-green mudstones, claystones and sandstones containing coal seams, freshwater molluscs and disperse plant material (Fl, Fm, Fmc, Fr). Their presence suggests a relatively wet, proximal floodplain depositional environment, where the relatively high sedimentation rate and the prolonged saturation of the soil profile by groundwater prevented the evolution of more developed soil profiles (e.g. Bown and Kraus, 1987; Leckie et al., 1989; Kraus, 1999; Therrien, 2005; Retallack, 2008; Therrien et al., 2009). The calcrete-bearing red paleosols that become more dominant towards the upper part of the section (including site K3) indicate that the rate of sediment accumulation and/or sediment water saturation decreases up-section. The prevalence of red colour implies the abundance of ferric oxides and low organic content in these latter sedimentary rocks, pointing to oxidizing conditions and a moderately-to well-drained environment during pedogenesis, a conclusion also in accordance with the presence of vertical root-traces (e.g. Kraus, 1997, 1999; Davies-Vollum and Kraus, 2001; Therrien, 2005). The inferred better drainage of the soil, the reddish colour, and the presence of calcrete horizons all suggest that these red paleosols were formed on a more distal part of the floodplain (Bown and Kraus, 1987; Davies-Vollum and Kraus, 2001). Initially the sediment accumulation rate was probably somewhat higher, thus only less mature soils could develop. Later on, as the accumulation rate and/or the groundwater level dropped (as shown by development of calcrete horizons), well-matured paleosols developed in the upper part of the succession.

Overall, the recorded changes of floodplain deposition within a braided fluvial system can be interpreted as follows: the deposits from the lower part of the section formed near the main channel system, in areas characterized by higher sedimentation rates and relatively high water-table, resulting in more hidromorphic conditions. Meanwhile, the fine-grained reddish beds from the upper part of the succession point to floodplain positions farther away from the main riverbeds, characterized by a limited sediment input and well-drained conditions during pedogenesis (e.g. Miall, 1996; Therrien, 2005; Therrien et al., 2009; Botfalvai et al., 2017). A very similar sedimentological trend can be seen in the Pârâul Vârtopilor section that includes site K1 (Fig. 2). This similarity strongly suggests that the more pronounced dominance of the well-drained and well-developed paleosols upward in the sedimentary successions can be interpreted as a more generalised sedimentological shift that occurred in the local palaeoenvironment, and if this is so, such a trend may be used to enhance stratigraphic correlation between different vertebrate accumulations around Vălioara Valley.

The successions logged at the different sites were completed with clinometric measurements of strata. Basically such measurements are useful for stratigraphic and sedimentological interpretations but can also be employed to track relevant features (such as bedding planes) on the landscape surface. During our fieldwork, claystone beds with ENE dip direction and approximately 50° dip were observed both in Pârâul Neagului (close to sites K2 and K4) and in Pârâul Ogradiilor (near site K5). The average geometry of such beds is 70°/53° (dip direction/dip), calculated from five measurements (Supplementary I). The measured claystone beds are either positioned below or occur interlayered with the red paleosol layers, and usually contain vertebrate fossils (Figs. 3 and 5). Using these measurements, intersection lines of the bedding planes with the surface were constructed by means of geometry (e.g. Lisle, 2004) (Fig. 1D). With the trace-lines of the measured beds as boundaries, we compiled the map of the outcropping area of the bone-bearing claystone bed as a “zone of bonebed outcrops” (Fig. 1D). Geometrically this zone is about 10–15 m thick; the uncertainty concerning its thickness and position is estimated to be a few meters, due to the inherent errors of GPS positioning. Besides sites K2, K3 and K4, site K5 is also within the strike of this zone; furthermore, considering a 5° margin of error in the azimuth measurements, the relatively distant site K1 can also be a candidate to be correlated with this zone as it lies in its proximity as well (see Fig. 1D). Meanwhile, the newly identified site Nvs from the southern branch of Pârâul Ogradiilor is positioned stratigraphically ~60 m above this zone. Finally, although site K6 from Pârâul Budurone is located far from the reconstructed bonebed zone, on the eastern side of Vălioara Valley, it can be nevertheless positioned geometrically definitively well above this zone, maybe by as much as ~1055 m. Nevertheless, it should be emphasized that if there are faults between sites K6 and K2–K5, respectively, this vertical distance that was calculated solely on pure geometrical reasons obviously does not necessarily represent true stratigraphic thickness. Indeed, presence of faults in the study area can be suggested tentatively based on: 1) the tilted nature of the

**Table 6**
Summary of the identified positions for the historical Vălioara vertebrate sites excavated by Kadić.

| Based on | Description | Pârâul Vârtopilor | Pârâul Neagului | | | Pârâul Ogradiilor | Pârâul Budurone | |
|---|---|---|---|---|---|---|---|---|
| | | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 | Site 7 |
| Cartography and Geoinformatics | The position of the sites can be determined: | with high certainty | with high certainty | | | with high certainty | with high certainty | with little certainty |
| | Significant bone accumulation can or cannot be detected near the presumed position of the site | yes | yes | yes | yes | no | no | no |
| Sedimentology and taphonomy | Sediment type of the bone-bearing layer is or is not similar to that mentioned by Kadić (1916) | yes | yes | yes | yes | yes | yes | unknown |
| | Colour of the newly collected bones is or is not similar to that mentioned by Kadić (1916) | yes | yes | yes | yes | yes | no | unknown |
| Geochemistry | The REE composition of the *in situ* samples exhibits similarities with the MBFSZ collection | no | yes | yes | yes | no | no | unknown |

beds; 2) the presence of already mapped, approximately northwest-southeast trending faults that dissect the metamorphic basement to the north and also affect the crystalline/sedimentary boundary in the neighbourhood of Vălioara (e.g. Codarcea et al., 1968, Fig. 1C); and 3) the presence of deep valleys (such is the Vălioara Valley itself) cross-cutting the sedimentary cover and striking roughly in the same direction with the faults from the crystalline border.

Based on these evidences, we suggest that the sections mapped in the Pârâul Vârtopilor, Pârâul Neagului and Pârâul Ogradiilor ravines that were marked by Kadić on his map as hosting vertebrate localities represent parts of the same continuous, 10–15 m thick sedimentary succession (Fig. 1D). This conclusion is also supported by the fossil apatite REE analyses, since geochemically sampled bones from the Pârâul Neagului and Pârâul Ogradiilor ravines (including sites K2, K3, K4 and K5) yielded very similar REE distribution patterns suggesting that geochemical circumstances at these sites were similar during the geochemically 'vulnerable' period of early bone recrystallization (Figs. 9,10). Meanwhile, the outcrop sections hosting site Nvs at Pârâul Ogradiilor as well as those from Pârâul Budurone (VI, VII, K6), are situated in a stratigraphically higher position, overlying the succession that contains sites K2 to K5.

### 5.2. *Provenance analysis of Kadić's historical vertebrate material*

Finding the location of the vertebrate sites mentioned in Kadić's publication (Kadić, 1916) was possible only by discovering and using his manuscript map. However, once relocated, his map and the published brief descriptions of the outcrops were informative enough to organise a successful visit to the neighbourhood of Vălioara for a more detailed investigation of the area. Modern maps and satellite images gave the possibility to match these historic data with the terrain reality (Fig. 1). As a result, only one of these historical sites (marked as VII by Kadić) was not re-identified, partly because it was described rather vaguely, but also due to the dramatically changed terrain geomorphology and continuous vegetation cover at this location.

Trace elements (TE), and especially the REEs, are particularly well suited for provenance analyses in the case of fossil bones, because their REE content is obtained primarily from the burial environment, whose geochemistry is controlled by pore water chemistry (Trueman, 1999; Trueman and Tuross, 2002; Trueman et al., 2004, 2006; MacFadden et al., 2007; Kocsis et al., 2007, 2009; Suarez et al., 2010; Herwartz et al., 2011). Following up on such previous research, REE geochemical signatures were obtained from vertebrate remains discovered in the recently surveyed outcrops as well as from Kadić's material, in order to determine the provenance of the historical Kadić specimens. The REE analyses of the vertebrate material from Vălioara suggest that Kadić collected his fossils from roughly the same region where our 2019 excavations took place (see PCA analyses; Fig. 9A). Except for the reddish-coloured bones in the MBFSZ collection (see above), the bones from our newly excavated sites K1–K6 and from the Kadić material do not differ significantly in their REE composition, which indicate that: 1) they were recrystallized within similar palaeoenvironments, characterized by largely similar REE chemistry; and 2) no significant differences among the different outcrops were recorded based on the REE distribution of the fossils, thus separation of the MBFSZ collection specimens according to the old Kadić sites remains problematic. The overall similarities recorded in the palaeoenvironmental conditions during bone fossilization are not unexpected, because our detailed sedimentological and structural investigations pointed out that most of the historical Kadić sites (especially sites II, III, IV and V) together with our sites K2–K5, are located within the same 10–15 m thick sedimentary succession (see Fig. 1D), thus the sources of REE for the bones from the different sites were more or less the same during their fossilization.

Based on our geoinformatical, sedimentological and geochemical investigations, the results of our efforts to relocate the historical Kadić vertebrate sites can be summarized as follows (Table 6):

The site I of Kadić is located in the Pârâul Vârtopilor ravine; here, he collected well-preserved vertebrate remains from red-coloured mudstones. We found red-coloured mudstones only at the northern (upstream) end of this ravine, while the largest part of the local succession is dominated by greyish-greenish mudstone and sandstone. Thus, according to the sedimentological description given by Kadić (1916) about his site I bonebed, and in good agreement with his unpublished map, we suggest that this site must had been located at the northern end of Pârâul Vârtopilor, around the location of our newly identified K1 site that yielded remains of turtles, crocodyliforms, dinosaurs and mammals. However, the *in situ* remains from site K1 are small-sized, and their REE compositions differ somewhat from that of the reddish coloured bones from the MBFSZ collection (Fig. 9C), suggesting a slightly different provenance compared to the historical reddish-coloured bones. Despite these REE-related uncertainties, we suggest that the well-preserved, reddish-coloured bones from the MBFSZ collection most probably originate from site I of Pârâul Vârtopilor (but not specifically from bonebed K1), because only this site was mentioned as yielding reddish-coloured and well-preserved bone material from red mudstone deposits (Kadić, 1916). Sites II, III and IV 'X'-marked and described by Kadić were located in the Pârâul Neagului ravine west of Vălioara village. Based on our detailed sedimentological investigations, we suggest that each of these sites are located within the same continuous and relatively short sedimentary succession, and thus they can be considered as closely related vertebrate sites from palaeoecological and sedimentological points of view. A relatively rich vertebrate assemblage was discovered here in 2019 as well, and specimens sampled from this assemblage show similarities in their REE geochemistry and taphonomical features with some of the black and brown-coloured bones from the MBFSZ collection (Fig. 9C).

The potential position of site V of Kadić in the Pârâul Ogradiilor section can be determined only loosely based on geoinformatics and his unpublished map, as he did not gave enough lithology-related information concerning the former bonebed, and we were unable to find significant bone accumulations in this ravine at the approximate "X"-marked position. However, good structural-geological correlation between the different geoinformatics-based location points indicate that site V should be roughly in level with sites II, III and IV, lying within the same 10–15 thick sedimentary succession (Fig. 1D). Therefore bones from site V should originate from the same palaeoenvironment as are those from Pârâul Neagului. Indeed, the REE analyses of the newly excavated bones from the two ravines also suggest similar depositional environment for the two fossil assemblages (Fig. 10).

Limited, but still very useful information is available about Kadić's site VI. This vertebrate accumulation was located in the Pârâul Budurone ravine east of Vălioara, where well-preserved, large limb bones and vertebrae were collected from a bluish sandstone horizon (Kadić, 1916). Although outcrops in the Pârâul Budurone are relatively accessible and can be studied in a steep wall, no significant bone accumulation was detected here in 2019.

Finally, analyses of the special subsets from the historical collection have also yielded some interesting results. First, the remarkably similar REE composition of the large black titanosaurian remains (subsample 1 - MBFSZ Ob.3103, MBFSZ Ob.3090; Table 5) supports Kadić's (1916) account of these specimens being excavated from the same place (site VI on Pârâul Budurone), while also substantiates the information recorded in the registry book which states that these remains came not only from the same site, but probably also from the same individual. Similarly, the uniformity and morphospatial separatedness of the light-colored titanosaurian specimens (subsample 2, including the potential *Magyarosaurus dacus* holotype caudal MBFSZ Ob.3091 alongside two appendicular elements, MBFSZ Ob.3089 and MBFSZ Ob.3088; Table 5) supports the preliminary assessment according to which these remains may originate from the same site (and thus possibly belong to the same taxon, or even to the same individual). Although their REE signature does not match that of the new specimens derived from site K1, our geostructural and sedimentological investigations suggest that their origin could be traced back to site I of Kadić in the Pârâul Vârtopilor section.

### *5.3. Palaeontological and palaeoecological significance*

#### *5.3.1. Chronostratigraphical and biochronological position of the vertebrates from Vălioara Valley*

By the time Kadić (1916) gave his short report on his excavations around Vălioara, and Nopcsa (1915) made a preliminary overview of the material collected here in his first review of the Transylvanian dinosaurs, vertebrate remains have been reported to occur in several localities across, and outside, the Haţeg Basin (e.g., Halaváts, 1897; Nopcsa, 1905, 1914). Nevertheless, once Kadić's excavations have been completed, Vălioara became the second most important uppermost Cretaceous vertebrate locality in the entire Transyvanian region after Sânpetru, in terms of fossil abundance and taxic diversity.

While first assessing the material from Vălioara, Nopcsa recognized the roughly same (macro)vertebrate assemblage in Kadić's collection as the one he himself excavated at Sânpetru (Nopcsa, 1914, 1915), suggesting the presence of a homogenous, rather low-diversity fauna across the entire Transylvanian region. According to his 1915 overview (Nopcsa, 1915, completed and updated subsequently in Nopcsa, 1923a), this fauna included: the crocodyliform *Allodaposuchus precedens* (first referred to as *Crocodylus affulevensis*); the titanosaurian sauropod *Titanosaurus dacus* (renamed as *Magyarosaurus dacus* by Huene, 1932); the theropod *Megalosaurus* sp. (a record actually based on titanosaurian caudal vertebrae); the ankylosaur *Struthiosaurus transilvanicus*; and two ornithopods, the basal taxon *Rhabdodon priscum* (a rhabdodontid now referred to as *Zalmoxes robustus*; Weishampel et al., 2003) and the hadrosauroid *Orthomerus transsylvanicus* (now referred to as *Telmatosaurus transylvanicus*, a taxon erected by Nopcsa much earlier; Nopcsa, 1903; Weishampel et al., 1993), a list to which he later added the basal turtle *Kallokibotion bajazidi* (Nopcsa, 1923a,b) as well. Redescription and reinterpretation of the titanosaurian skeletal remains from Transylvania by Huene (1932) has divided the available material into three supposedly closely related taxa, *M. dacus*, *M. transylvanicus* and ?*M. hungaricus*, with specimens from Vălioara being referred to each of the three species. Although the validity of these species is contentious, and the three are sometimes considered to be probably synonymous (see McIntosh, 1990; Le Loeuff, 1993; Upchurch et al., 2004), more than one titanosaurian taxon appears to be represented in the Vălioara assemblage excavated by Kadić (Csiki and Grigorescu, 2006; Stein et al., 2010; work in progress). More recent discoveries have significantly expanded the fossil record known around Vălioara with a large number of non-dinosaurian vertebrate taxa including fish, amphibians, lizards, snakes, diverse crocodyliforms, pterosaurs, and mammals alongside birds and an array of small non-avian theropod dinosaurs, and completing this fossil record with invertebrates and plants as well (see review in sub-section *Palaeontological record from the Densuş-Ciula Formation …*, above).

Most of these recent faunal additions originate, however, from several microvertebrate fossil bonebeds (MvBBs) discovered on the eastern (left) side of Vălioara Valley (e.g. Grigorescu et al., 1999; Csiki et al., 2008; Vasile, 2008; Vasile and Csiki, 2010). As outlined previously, based on the general dip and strike of the beds in the Vălioara area, these sites should be somewhat younger (i.e., stratigraphically higher; see Fig. 12) than the majority of the fossil sites discussed in our report, with the exception of sites VI-VII of Kadić (1916) as well as our site K6.

Further information concerning the age of these west-Vălioara deposits comes from palynology (Fig. 8 and Supplementary II). Although sample P1 from Pârâul Ogradiilor did not yield biostratigraphically significant data, the assemblage identified in sample P2 (collected near site K2 în Pârâul Neagului) may offer more telling insights; these should be, however, treated with caution for the moment, given the preliminary, prospective nature of our sampling. Among the taxa found in sample P2 (see Supplementary II), there are several *Normapolles* group taxa (early angiosperms) that have been successfully used to date Upper Cretaceous terrestrial successions (e.g. Antonescu, 1973; Portnyagina, 1981; Antonescu et al., 1983; Van Itterbeeck et al., 2005; Polette and Batten, 2017; Peyrot et al., 2020).

One of these biostratigraphically significant terrestrial palynomorphs is *Oculopollis praedicatus* (Fig. 8P), which is known to range from the Santonian to the Campanian (Pavlishina et al., 2004; Polette and Batten, 2017). It is conceivable, although yet to be demostrated convincingly, that *O. praedicatus* (previously assigned to *Semioculopollis praedicatus*) may have persisted into the latest Cretaceous (Maastrichtian) in the Transylvanian area, including the Haţeg Basin. This is because the taxon was already reported previously south of Ciula Mică by Antonescu et al. (1983), presumably from basal deposits of the 'middle member' of the Densuş-Ciula Formation, and more importantly by Bojar et al. (2005) from the terminal part of the Sibişel succession of the Sînpetru Formation, which has been dated as mid-Maastrichtian using magnetostratigraphy (Panaiotu and Panaiotu, 2010; Csiki-Sava et al., 2016).

Two other *Normapolles* group taxa with biostratigraphic significance, *Plicapollis serta* and *Trudopollis nonperfectus* (Figs. 8Q-R), also occur in the studied sample. According to Góczán and Siegl-Farkas (1990), *Plicapollis serta* marks the upper Santonian in Hungary, but it documents a late Campanian—Maastrichtian age in Spain (Peyrot et al., 2013) or in the Altai Region (Lebedeva et al., 2019). *Plicapollis serta* (previously assigned to *Plicapollis* sp. in Csiki et al., 2008: Plate II, Fig. 7) was already reported from the Maastrichtian of the Budurone MvBB, situated close to our locality K6, but also from the Nălaţ-Vad — Toteşti area along the Râul Mare Valley, from deposits dated to around the early/late Maastrichtian boundary (Van Itterbeeck et al., 2005). Finally, *Trudopollis nonperfectus*, which range from the Santonian to the Campanian (Polette and Batten, 2017), also occurs in Santonian—Campanian marine deposits (Răchitova Formation; see Fig. 12) of the Haţeg Basin (Ţabără and Slimani, 2019), and now it appears that its range can be extended into the early Maastrichtian.

According to Portnyagina (1981), various species of *Trudopollis, Plicapollis* and *Subtriporopollenites* prevail in Maastrichtian assemblages from the Skale zone of the Eastern Carpathians, but are less common in older deposits. Our angiosperm assemblage identified in sample P2 consists mainly of specimens assigned to *Trudopollis* and *Plicapollis*, allowing a good correlation with the Maastrichtian assemblages from the Skale area, and independently supports a Maastrichtian age of the deposits around site K2.

To conclude, the vertebrates recovered from sites K2—K5, together with those reported by Nopcsa and subsequent researchers from the largest part of the Kadić material (with the clear exception of the large titanosaurian remains from Pârâul Budurone, excavated from site VI) make up a somewhat (albeit only very slightly) older vertebrate assemblage than that derived from the different Vălioara MvBBs included by Csiki-Sava et al. (2016) into their Tier 2 category. The proximity of sites I–V, respectively K1–K5 and Nvs, to Ciula Mică suggests that these could be more closely comparable in stratigraphic position to the sites reported by Vasile (2010) from the Geat Valley, and thus their composite vertebrate assemblage may actually represents transitional faunal evolution stage Tier 1/2, or, at the very least, it is the oldest known Tier 2 assemblage in the Densuș-Ciula Formation. Furthermore, since site K1 (together with Kadić's site I) appears to be slightly older than the bonebed section corresponding to sites K2–K5, whereas site Nvs is somewhat younger than this bonebed section (Figs. 1D, 12), their succession may document (especially once better explored and excavated) the gradual emergence of Tier 2 faunas in the area.

Finally, it should be emphasized that only very sparse and not very well preserved fossil remains were reported from more westerly (and thus somewhat older) deposits of the Densuș-Ciula Formation. These originate from a small number of localities from near Ciula Mică and Densuș. At Ciula Mică, fossil-poor microvertebrate localities were described by Vasile (2010) from deposits assigned to the 'middle member' along the Pârâul Geat (Geat Valley), with remains of the ziphosuchian crocodyliform *Doratodon* and possible dromaeosaurid theropods, together with *Pseudogeckoolithus* eggshells referable to indeterminate maniraptorans (Choi et al., 2020). From Densuș, only one report of associated cranial remains of a small-sized rhabdodontid is available from the deposits of the 'lower member' (Csiki-Sava et al., 2016). Although Schafarzik (1909) noted the discovery of teeth in this area, the whereabouts and thus identity of these teeth remains unknown.

Based on the regional dip of the beds, both of these areas host somewhat older, Tier 1/2 localities (Csiki-Sava et al., 2016; Fig. 12). Accordingly, the west-Vălioara assemblages from the Geat-Vălioara interfluve (derived from sites I–V, respectively K1–K5 and Nvs) represent the oldest relatively diversified ones from the entire Densuș-Ciula Formation. Furthermore, based on the tentative correlation of the uppermost Cretaceous vertebrate localities from the Transylvanian region overall (Csiki-Sava et al., 2016), these west-Vălioara localities rank among the oldest ones known from the entire Hațeg Basin area, where they may be matched only by the Pui-Swamp locality from the 'Pui beds' cropping out along the Bărbat River farther to the east, as well as by some of the more basal vertebrate localities from the classical Sibișel Valley section at Sânpetru. Similarly, at the wider spatial scale of the 'Hațeg Island', only a few localities of roughly comparable age are known from the Rusca Montană Basin (Nocea), and from the Transylvanian Basin (Vurpăr, Petrești, maybe Sebeș-Glod), respectively (Csiki-Sava et al., 2016).

### 5.3.2. Palaeoecological implications

As discussed above, the fossiliferous sites spread around Vălioara are remarkable in that they occur mainly in deposits suggestive of water-logged, poorly drained floodplain environments, in contrast with sites situated more to the east (and, in the same time, stratigraphically higher) within the Densuș-Ciula Formation (Fig. 12). Our sedimentological survey also showed that such water-logged environments are generally better represented in the west-Vălioara area, compared to more eastern areas, pointing to a wider development of such wetland-type palaeoenvironments in the lowermost part of the 'middle member' of the Densuș-Ciula Formation, whereas pedogenetically modified, well-drained floodplain deposits occur more commonly in the middle-upper part of the subunit.

These sedimentological observations are also independently supported by palynological analyses. The more productive sample P2 was collected near the site K2 bonebed that was interpreted as a waterlogged environment based on sedimentology. On its turn, this sample is characterized by a palynofacies dominated by a mixture of lath-shaped, often large opaque phytoclasts (on average representing ~ 45–50% of the assemblage; Fig. 7B-C) and semi-opaque particles of terrestrial origin, respectively. These latter, on their turn, include both cuticles (epidermal leaf tissues; Fig. 7D) and large translucent biostructured phytoclasts (woody tissues; Fig. 7E). Palynomorphs, although present, are rather rare (1–2% of the total POM) and include exclusively continental taxa. The sedimentary organic matter recorded in sample P2 includes thus a large proportion of continental material and exhibits a clear proximal signature with the constant presence of lath-shaped opaque phytoclasts, as well as of the various large translucent phytoclasts (cuticles, woody tissues). All these features suggest a definitively land-bound, continental setting (Tyson, 1995; Radmacher et al., 2020).

The palynological assemblage itself is dominated by fern spores such as *Polypodiaceoisporites, Deltoidospora* and *Laevigatosporites*. According to Abbink et al. (2004) and Wang et al. (2005), the ecology of these Mesozoic ferns - the Cyatheaceae and the Polypodiaceae - confirms that they grew in moist lowland (fluvial and/or coastal) habitats, under rather warm climatic conditions. Their dominance, together with the presence of rare phytoplankton specimens referable to the freshwater alga *Chomotriletes*, is suggestive of perennially to temporarely wet, low-elevation fluvio-deltaic systems such as wetlands, ponds or temporary lakes (Duringer and Doubinger, 1985; Tyson, 1995). The presence of comparable palaeoenvironmental settings was already noted, using similar arguments, by Van Itterbeeck et al. (2005) for the Maastrichtian succession from the Nălaț-Vad area, in the central part of the Hațeg Basin. Our identification of lowland fluvial and/or costal wetland palaeoenvironments in the west-Vălioara area is also concordant with the previous report of Antonescu et al. (1983) who noted the presence of spores referable to the free-floating freshwater fern *Azolla* in a palynological sample from the neighborhood of Ciula Mică, in the proximity of our study area. Rare occurrences of pollen types from plants that grew at higher altitudes and require cooler but still wet conditions (e.g. *Araucariacites, Trudopollis*; Bowman et al., 2014; Daly and Jolley, 2015) were also identified in the sample P2 assemblage; these suggest the nearby presence of vegetated highland areas.

Still in the same general area but slightly to the east (and thus higher in the section; see Fig. 12), a palynological assemblage was also reported from the Budurone MvBB (Csiki et al., 2008). Its composition is reminiscent of our sample P2 in the absolute abundance of fern spores (mainly *Polypodiaceoisporites* and *Laevigatosporites*), as well as in that the Normapolles-group pollen is dominated by different species of *Trudopollis* and *Plicapollis*. This Budurone assemblage lacks, however, any signs of freshwater ferns and phytoplankton, suggesting a more temporary and less extensively waterlogged palaeoenvironment, interpreted by Csiki et al. (2008) as a small swamp or a shallow, marshy pond developed within a poorly drained floodplain. Admittedly, the currently available palynological sample size discussed here is small (with one sample from Ciula Mică, as well as one each from west-Vălioara and east-Vălioara, respectively), but if it is to be taken at face value, it suggests a transition from more water-logged and perennial to less water-logged and more temporary floodplain environments up-section in the basal part of the 'middle member' of the Densuș-Ciula Formation. Such a transition, if upheld by future studies, would presage the already noted changes from a dominance of wetter, less well drained floodplain palaeoenvironments to that of well-drained ones, going further up-section within the Densuș-Ciula Formation (e.g. Vasile et al., 2011a; this paper).

Our second palynological sample (P1, collected near site Nvs) is even more intriguing to interpret. As noted above, sample P1 derives from the western, upstream end of the Pârâul Ogradiilor section, corresponding to the basal part of the local succession, taking into account the dip of the beds (Fig. 5). It is poorly fossiliferous, with very few and poorly preserved palynomorphs, whereas its POM content is dominated by small, rounded opaque phytoclasts. According to Tyson (1993), Mendonça Filho et al. (2011) and Radmacher et al. (2020), the abundance of such phytoclasts indicates a sedimentary setting that is located farther away from a continental source area, with longer-distance transport of the plant material resulting in more advanced fragmentation and good sorting, both of which are typical for distal basinal environments (Tyson, 1993, 1995). Further detailed palynological sampling in this area is sorely needed to better understand the significance of this sample; we only note here that a roughly similar palynofacies has been described previously from the neighborhood of Densuș (situated somewhat to the southwest from our study area) by Țabără and Slimani (2019), from marine deposits assigned to the Upper Member of the Răchitova Formation.

Considering the important palaeoenvironmental shift outlined above within the Densuș-Ciula Formation from more water-logged to progressively better-drained conditions up-section, as supported by both sedimentology and palynology, the constancy in faunal composition throughout its succession is remarkable, at least at a higher taxonomic level. (It is worth emphasizing here that - depending on the taxa concerned — more or less comprehensive above-species clades represent the level where meaningful and coherent faunal comparisons can be made, given that in most clades, species- or sometimes even genus-level distinction of the taxa represented is not yet possible). The core composition of the local faunas assembled at the Tier 1/2 — Tier 2 transition, including kallokibotionine and dortokid turtles, ziphosuchian, atoposaurid and basal eusuchian (allodaposuchid, hylaeochampsid) crocodyliforms, rhabdododontid, hadrosauroid, titanosaurian and paravian dinosaurs, and kogaionid multituberculates, as witnessed by the fossil content of the different Ciula Mică and west-Vălioara sites (e.g., Vasile, 2010; Csiki-Sava et al., 2016; and this paper) remains the same up to the youngest sites of the formation, known from General Berthelot and Crăguiș (see Vasile et al., 2011a, b; Csiki-Sava et al., 2016). Faunal differences recorded between localities and sites located at different levels of the formation are attributable more probably to differences in degree of surveying, quality of exposures and/or excavation methods used rather than to real clade-level differences in the composition of the local faunas themselves, as suggested by the recently ‘re-discovered’ Boița locality (Csiki-Sava et al., 2018).

Even with these caveats in mind, at the current level of knowledge some minor faunal differences may be noticed between the older and younger Densuș-Ciula assemblages. *Acynodon*-like teeth have been reported to be present in several microvertebrate bonebeds in the east-Vălioara area (Martin et al., 2006; Vasile, 2008), being even somewhat common at Fântânele MvBB (Vasile and Csiki, 2010), and now this morphotype was also recovered from our site K2 — all these occurrences come from dark grey and fine-grained, poorly drained floodplain deposits. Teeth of *Acynodon* become, however, very rare in younger sites within the Densuș-Ciula Formation, where better-drained floodplain deposits dominate (Vasile and Csiki, 2010; Csiki-Sava et al., 2016). Other than the Densuș-Ciula Formation, *Acynodon* has also been reported from lower Maastrichtian (Tier 1/2 to Tier 2) localities from Pui (Pui Swamp, Pui Gater, Pui Depozit; Codrea and Solomon, 2012; Vasile and Panaitescu, 2012; Solomon and Codrea, 2015; Csiki-Sava et al., 2016) and Sânpetru (Scoabă; Csiki-Sava et al., 2016), but are currently unknown from younger sites both at Pui and Sânpetru, as well in at the younger Nălaț-Vad or Totești localities, along the Râul Mare River (see Csiki-Sava et al., 2016, Fig. 12). Furthermore, at least at Pui, *Acynodon* teeth were recovered exclusively from dark grey channel fill or oxbow lake/swamp deposits. In the Transylvanian Basin, *Acynodon*-like teeth had been reported from a T1/2 site from Petrești (Vremir et al., 2015), as well as from the Tier 3 site of Oarda de Jos A (Jipa, 2012), in both cases from fine-grained dark grey poorly drained floodplain deposits. The quasi-restriction of *Acynodon* remains to such poorly drained facies deposits is in accordance with the proposed dominantly aquatic lifestyle of the taxon (e.g., Martin et al., 2006), and suggests that habitat preference might have played a role in its restricted distribution pattern seen in the Densuș-Ciula Formation.

It is also interesting to note that relatively large-sized titanosaurs (as exemplified by the black Budurone specimen excavated by Kadić from his site VI) appear to be absent from the transitional T1/2 and basalmost T2 Densuș-Ciula assemblages (contrary to the suggestion of Csiki-Sava et al., 2016). All titanosaurian specimens currently known from west of the Vălioara Valley (including those from the MBFSZ collection, with the holotype of *Magyarosaurus*, and from our recent collecting) represent small-to medium-sized individuals. Further up-section in the Densuș-Ciula Formation, medium- and large-sized titanosaurian individuals (the known specimens are too fragmentary to decide whether they represent distinct taxa or not) co-occur, as it was reported for example for the Tuștea locality by Csiki-Sava et al. (2012). The same pattern seems to hold for other areas of the Transylvanian landmass as well. At Sânpetru, titanosaurian specimens known from the basalmost part of the section (Scoabă site, Tier 1/2) represent exclusively small-medium sized individuals, whereas larger specimens (possibly new taxa; Csiki and Grigorescu, 2006; work in progress) are documented in younger beds, where they are largely contemporaneous with small-medium sized taxa. Finally, most titanosaurian remains known in the southwestern Transylvanian Basin belong to small-medium sized individuals (e.g., Codrea et al., 2010), whereas large-sized titanosaurs make their appearance in the uppermost part of the local section (the Tier 4 locality of Râpa Roșie — Sebeș; Csiki and Vremir, 2011). It may well be that large-sized taxa appear somewhat later than dwarfed ones such as *Magyarosaurus* due to subsequent immigration from outside the Transylvanian Landmass, although this issue can be settled more conclusively only with the forthcoming taxonomic-systematic revision of the entire titanosaurian material from the Transylvanian area (Mannion et al., 2019b; work in progress).

## 6. Conclusions

Upper Cretaceous continental vertebrate sites in Romania are among the most important localities of this age in Europe. Some of these sites, particularly the ones in the Haţeg Basin, have been studied for more than a hundred years. At the beginning of the 20th century, hundreds of vertebrate remains have been collected around Vălioara (situated in the western edge of the Haţeg Basin) by Ottokár Kadić, and this material was placed into the collections of the predecessor of the Mining and Geological Survey of Hungary (MBFSZ) in Budapest. The Vălioara material was first studied by the legendary vertebrate palaeontologist Ferenc Nopcsa, who identified several taxa from this historical collection which includes the lectotype of the basal eusuchian crocodyliform *Allodaposuchus precedens* Nopcsa, 1928 and the possible type of the dwarf titanosaurian sauropod *Magyarosaurus dacus* (Nopcsa, 1915) besides other scientifically important and frequently restudied specimens. In 1916, in a short report, Kadić summarized his research at Vălioara, and described the seven most productive excavation sites (identified with Roman numerals from I to VII) very briefly. However, this report did not provide maps or geological sections, neither did he gave detailed guides to the exact locations of the sites or to the stratigraphical positions of the fossiliferous beds, and thus for decades the exact locations of these historical Vălioara sites remained unknown. However, more than a hundred years after his excavations, the original map used by Kadić, rediscovered in the Map Collection of the MBFSZ, turned out to include precisely such information. This map made it possible to transfer and georeference the sites excavated by Kadić on modern maps, then to relocate and survey the local successions hosting the historical sites of Kadić in the field. Based on the georeferenced positions of the old fossil localities, two field surveys were carried out in 2019 to collect all the available information about the palaeoenvironmental conditions under which the vertebrate remains from these sites were buried. Our detailed GIS, sedimentological, taphonomical, palaeontological and geochemical analysis led to the following results:

1. Based on the rediscovered map of Kadić and his published brief descriptions, the locations of most of his vertebrate sites could be reconstructed and identified on present-day maps and satellite photos. The remarkable topological similarity between Kadić's map and the recent ones, as indicated by the overlapping patterns of ravine forking directions as well as counts of side valleys and gullies, ascertains that the positions of the sections surveyed in 2019 by us largely correspond to those of the localities where Kadić made his excavations more than one hundred years ago (Fig. 1).
2. During our fieldwork, several stratigraphic sections were logged and investigated along the ravines mentioned by Kadić (1916) as the locations of his vertebrate sites, and significant new bone accumulations were detected. Our stratigraphical and sedimentological investigations pointed out that the uppermost Cretaceous sedimentary successions near these fossiliferous sites of the Vălioara Valley are dominated by fine-grained, waterlogged, poorly—drained floodplains deposits, and better-drained, moderately to well-developed paleosols become more common only towards the upper part of the local succession.
3. As emphasized by our investigations, the overall spatial and stratigraphical distribution of the depositional environments and fossiliferous localities within the Densuș-Ciula Formation suggests that the sedimentary successions cropping out around (and especially west of) Vălioara Valley, and their vertebrate assemblages offer valuable insights into a type of palaeoenvironment (more waterlogged, wetland-type floodplains) that is less well represented and less fossiliferous in other parts of the unit.
4. The detailed stratigraphical investigation of the exposed sedimentary successions (including the strike and dip of the beds) indicates that apart from a few isolated vertebrate remains reported previously, this west-Vălioara vertebrate material represents one the oldest faunal assemblages from the entire Haţeg Basin.
5. During our fieldwork in 2019, many well-preserved vertebrate remains were collected from the relocated fossiliferous sections. This newly excavated vertebrate assemblage shows a taxonomical composition that is largely similar to that known from other sites of the Densuș-Ciula Formation; however, our fieldwork has succeeded to significantly expand the local faunal list that was based on the Kadić collection, by adding several new taxa, including turtles, crocodyliforms, dinosaurs, and mammals.
6. The rare earth element (REE) geochemical compositions of vertebrate remains from both the new and the historical Vălioara collections were investigated in order to determine the provenance of the latter. Our REE analyses suggest that Kadić collected his fossils from roughly the same region as where our excavations were conducted in 2019, as the PCA analyses of the normalized REE data shows that both assemblages exhibit similar REE composition. For the moment, precise pinpointing of the location of his excavation sites and their correspondence with the newly excavated fossiliferous localities remains elusive due to largely overlapping REE distributions within the sample. However, at least in some instances the geochemical data suggest that the newly identified fossiliferous levels do not coincide exactly with those reported by Kadić, and do represent entirely new vertebrate occurrences.
7. As an important outcome, our research also yielded new information on two iconic Transylvanian fossil taxa, the titanosaurian *Magyarosaurus dacus* and the basal eusuchian *Allodaposuchus precedens.* In the case of *Magyarosaurus*, its potential type locality can be placed with confidence in the upper, reddish paleosol-bearing section of the Pârâul Vârtopilor ravine, although precise pinpointing of its *stratum typicum* proves to be as yet elusive. Furthermore, our taphonomic assessments and REE analyses suggest association of several titanosaurian appendicular elements with the potential holotype middle caudal vertebra within the same site (site I of Kadić). As for *Allodaposuchus*, the location of the site yielding its former lectotype (skull table MBFSZ Ob.3131) cannot be currently identified with certainty based on our REE provenance analyses, although the specimen most probable came from one of the sites excavated by Kadić in the Pârâul Neagului or Pârâul Ogradiilor ravines. However, these same analyses support potential skeletal association between this partial skull and referred postcranial elements, in accordance with the suggestion put forth by Nopcsa (1928). Finally, field (and probably skeletal) association is also upheld for the very large black-coloured titanosaurian specimens from the MBFSZ which with great certainty were excavated by Kadić from his site VI located along Pârâul Budurone.
8. Our sedimentological, stratigraphical, palaeontological-palynological and geochemical investigations contribute greatly to the knowledge concerning the palaeoenvironments and faunal compositions represented in the basalmost part of the continental uppermost Cretaceous from the Haţeg Basin, and through these, to a better understanding of the palaeoecological setting and regional evolution of the Haţeg vertebrate fauna near the end of the Cretaceous. In this respect, the most important contribution is represented by the identification of previously largely unnoticed sedimentological-palaeoambiental changes that took place during the deposition of the middle part of the Densuș-Ciula Formation, implying a shift over time from more waterlogged, wetland-type environments to drier, well-drained floodplain-dominated environments.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cretres.2021.104781.