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Stage I – year 2021

Scientific report for stage I of MULTI-BRAIN PCE project: Natural history of an endemic insular radiation: the kogaionid multituberculates and their relevance for brain and sense evolution in Mammalia

STAGE I

Clarifying Late Cretaceous kogaionid spatial and temporal distribution; the beginning of morphologic and systematic study of relevant fossil material

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1. Stage I objectives and estimated results, according to the Achievement Plan

The main objectives of progress stage I of the MULTI-BRAIN project were represented by:
- field research activities in the areas of interest (the Upper Cretaceous continental and underlying marine deposits cropping out in the Alba Iulia – Sebeș area in the southwestern Transylvanian Basin; in the Hațeg Basin; and in the Rusca Montană Basin) in order to A) investigate the already known relevant fossiliferous successions and sites, and/or identify new such successions/sites; and to B) collect field data and observations, micropalaeontological, palynological, lithological samples for the analyses included in the achievement plan;
- preparation and analysis of the collected samples in search of A) micropaleontological content (foraminifera, microvertebrates); B) calcareous nannoplankton; C) palynological content and palynofacies; D) geochronometric data; taking into account the extension of investigations to any other type of analysis that will be considered of interest/relevant (mineralogical, petrografic, geochemical, etc.) is also possible;
- (preliminary) analysis and interpretation of the data obtained from the investigations performed;
- integrating the existing and newly-obtained data in order to obtain a (preliminary) picture of Late Cretaceous kogaionid spatial-temporal distribution in the Transylvanian realm;
- anatomical-morphological as well as systematic study, and description of key kogaionid specimens – stage I;
- dissemination of project research activities and obtained results, via A) scientific publications; B) conference presentations; C) public conferences.

Results predicted for stage I (2021) of the research project:
1. Field and laboratory primary geological, lithostratigraphical, sedimentological, palynological, micropalaeontological, palaeontological, geochronometrical datasets, and their preliminary interpretations
2. Monographic description of some crucial kogaionid specimens – as manuscripts in preparation
3. The preliminary version of an extended and up-to-date character-taxon matrix, necessary for performing a detailed phylogenetic analysis of kogaionids
4. Presence at international scientific conferences (at least 3 participations during 2021)
5. Two manuscripts ready for publication/submitted for publication in ISI ranked journals.

2. Activities performed during 2021 within the project (according to the în Achievement Plan), and obtained results

Introduction

The research activities performed during 2021 within the Multi-Brain project took place under the sign of, and were partly influenced by, the still ongoing COVID-19 pandemic. Accordingly, some of the planned activities had to be partly reconsidered, and their achievement was adapted to the existing conditions that were defined, above all, by reduced mobility possibilities; these adjustments also required, naturally, some budget recalibrations and reassignments for the current stage. The main activities impacted by these conditions were represented by the participations to international conferences and by the research stages of the research team members planned to take place abroad, as well as by visits of foreign collaborators (see below, activity details). Even under such unfavourable circumstances, foreseen among the contingency actions to be taken in order to mitigate and remedy potential difficulties that might appear during the project implementation, the target objectives were met, and the expected results achieved, mainly by flexibly adapting to the new conditions.

The main activities performed within the project during 2021 will be presented and detailed below, following the structure defined in its Achievement Plan (**PAP**).

Activity 1.1.–Field research activities and sampling in the areas of interest

According to the PAP, this main activity includes geological-palaeontological field prospecting, gathering field data and observation, as well as sample collecting for future processing and analysis, to be accompanied by small-scale excavations in the extraordinary instances when such excavations would be necessary.

The most important action of this Activity was represented by the field campaign organized for geological mapping, palaeontological prospecting, and collecting various samples (micropalaeontological, palynological, palaeontological, lithological, etc.). The campaign took place between the 10th and 20th of July, 2021 in the Hațeg Basin and the neighbouring regions, covering areas of interest where Upper Cretaceous marine and continental deposits crop out in the Hațeg, Rusca Montană, and (southwestern) Transylvanian basins, all regions known for the occurrence of kogaionid fossil sites (Csiki-Sava et al., 2016, 2017). The field campaign involved all research team members; additionally, these field activities were partly correlated, for some outcrops in the Hațeg Basin area, with activities performed by a team of

Fig. 1. The team of Romanian and Hungarian geologists and palaeontologists, Hațeg Basin (July 2021). To the right, the superviser of the Hungarian team, Gábor Botfalvai (Natural History Museum of Budapest, Departament of Palaeontology and Geology).

Hungarian geologist and palaeontologist colleagues (Fig. 1) who performed a more detailed sedimentological and palaeontological study, continuing a collaboration started two years ago, which produced scientific conference presentations and scientific papers, including results from the current project (see *Stage results*). A collaboration agreement signed in 2021 by the University of Bucharest and the Eötvös Loránd University of Budapest made this collaboration official for a 3-year interval which can be extended if necessary and, according to the agreement, the joint research results will be presented at various conferences and published in scientific journals, starting in 2022.

The main objective of these field activities consisted in field data collecting needed to moe thoroughly define and constrain the spatial and temporal distribution of kogaionid fossil remains (and, by extention, the distribution of the kogaionids across the Transylvanian landmass during the final Cretaceous). For this purpose, the field research targeted Upper Cretaceous deposits from the areas of interest, both the marine deposits underlying the continental ones, since they are more susceptible to offer reliable biostratigraphic information, as well as the fossil kogaionid-bearing continental deposits themselves. Only natural outcrops were explored; these included palaeontological site-bearing successions

identified in the perimeters of Vălioara, Ciula Mică, Boița, Livezi, Densuș, Pui, Totești, Unciuc, and Nălaț-Vad (Hațeg Basin), Nocea Valley, Pîrîul Scurt Valley, Ciotorog Valley, Lunca Cernii de Sus-Negoiu (Rusca Montană Basin), and Petrești-Sebeș (Transylvanian Basin). Synthetic lithologic logs of the investigated outcrops were drawn, with photos and GPS coordinates being also taken for each sampling point. Around 55 pelitic rock samples were collected for palynological and palaeontological analyses, including some micropalaeontological samples taken from marine sediments in order to obtain nannoplankton and foraminifera. Larger quantities of sediments susceptible of containing fossils were also collected from several sites within the investigated areas, in order to recover microvertebrate remains, including (hopefully) kogaionid multituberculates. Finally, igneous (andesite, tuff) and detritic rock samples were also collected from various sites of interest, for U-PB geochronometric dating. In all relevant cases, the sampling for various investigations was undertaken through coordinated efforts of the various team members, in order to facilitate the easiest and most precise correlation of the data derived from the diverse analyses planned.

For the investigated areas, the field activities of July 2021 were directed particularly towards a few specific objectives, whereas other directions of field investigation and sampling were of a more preliminary nature, aimed to evaluate the potential fossil content and usefulness of the respective successions for the project objectives; more detailed investigations in these latter areas are planned for the following stages of the project. The most important areas surveyed in 2021 included the Densuș-Ciula Mică-Vălioara area (in the Hațeg Basin), the Petrești-Sebeș area (in the Transylvanian Basin), and the Rusca Montană Basin, with the main reasons behind the selection of these specific areas is of interest being parlty different.

1.1.1. Densuș-Ciula Mică-Vălioara

The particular interest for this area of the western Hațeg Basin was supported by the particular lithostratigraphic position of the outcropping sedimentary successions within the framework of end-Cretaceous deposits of the Hațeg Basin (Csiki-Sava et al., 2016), by the co-occurrence (or close spatial occurrence) of vertebrate (including multituberculate)-bearing continental deposits and igneous rocks (the latter being more useful for U-Pb geochronometric dating methods), as well as by the co-occurrence (ore close spatial occurrence) of the fossil-bearing continental deposits and the underlying marine deposits. This geological setting offers multiple independent possibilities of constraining the age the fossil-bearing continental rocks, and, implicitly, that of the multituberculate occurrences from this area that hosts some of the oldest known kogaionid occurrences from the Hațeg Basin,

and, probably, from the entire Transylvanian realm. Additionally, recent investigations performed in collaboration with Hungarian colleagues (Botfalvai et al., 2021) showed that the deposits of this area are both fossil-rich and document important palaeoenvironmental changes, potentially significant for the more thorough understanding of the spatial and temporal distribution of the Transilvanian Late Cretaceous kogaionids.

Accordingly, a thorough prospection of the Vălioara area took place, during which several palynological samples were collected, associated with calcareous nannoplankton/ foraminifera samples for those parts of the local successions where marine deposits might also occur. A series of marine (Fig. 2a) and continental deposits crop out in the area of Ciula Mică, along the Geat Stream valley; prospecting identified a layer of volcanic tuff intercalated in these sedimentary successions (the continental or marine nature of these deposits will be established in the future), which opens the possibility of obtaining U-Pb geochronometric age data for that area, thus providing independent control for the K-Ar dates published from here previously (Bojar et al., 2011). Finally, close to Densuș, the volcanic successions cropping out in this area (Fig. 2b) in contact with Upper Cretaceous marine deposits were re-investigated and sampled for palynological and nannoplankton analyses; fossil leaves have also been identifies on this occasion, some of these being assigned to the palm species *Sabalites longirhachis* (Fig. 2c).

a b c

Fig. 2. Field images, Vălioara-Ciula Mică-Densuș area. A – succession of marine deposits at Ciula Mică; b. volcano-sedimentary deposits at Densuș; c. *Sabalites longirhachis* leaves, Densuș.

1.1.2. Petrești-Sebeș

The outcrop from Petrești-Sebeș (Fig. 3) represented a main research objective during 2021, given that it comprises a long and apparently continuous succession from the marine deposits of the Bozeș Formation to the overlying continental deposits of the Sebeș Formation, a

succession that had been preliminarily dated previously as ranging from the Upper Campanian to the basal Maastrichtian (Csiki-Sava et al,, 2012; Vremir et al., 2014) and which have also revealed the presence of kogaionid multituberculate-bearing fossil sites during the past decade (Vremir et al., 2014, 2015). All local geological data indicate that this is a key succession for understanding the emergence of the Maastrichtian continental vertebrate faunas from the Transylvanian landmass, including that of its kogaionid multituberculate assemblages. Accordingly, the multi- and interdisciplinary study of this key succession represents an important target for the project, and was chosen as a major objective for the 2021 activities. A new micropalaeontological, palynological, and geochemical sampling session was undertaken in order to complete and extend the coverage of previous systematic samplings (see below, **1.3**), completed with sampling for U-Pb geochronometric dating (see below, **1.4**). Moreover, the study of the vertebrate-bearing fossil sites from this succession that yielded microvertebrate remains completes the panel of research activities aimed to a deeper and more detailed understanding of this succession (see below, **1.2**).

Fig. 3. The Upper Cretaceous succession from Petrești, during the sampling session of July 2021.

1.1.3. Rusca Montană Basin

The Rusca Montană Basin represents, alongside the Hațeg Basin and the Transylvanian Basin, one of the areas of Romania that functioned as a continental sedimentation area during the Late Cretaceous. Unlike the latter regions, more intensely surveyed previously for vertebrate remains, the Rusca Montană Basin is less well known both with respect to the extent of the uppermost Cretaceous continental deposits as well as to more precise constraints om the age and composition of the vertebrate faunas they contain. More intensive research in this area would likely yield important new information regarding multituberculate mammal palaeogeography and evolution, in correlation with a more precise dating of the fossiliferous deposits.

Fieldwork in the Rusca Montană area aimed at identifying new outcrops with vertebrate fossils (multituberculates included), but also at a more detailed investigation of already known sites, as well as at additional sampling for screen-washing, in order to identify mammal remains, but also other vertebrates helpful in reconstructing the palaeoecosystem the multituberculates were part of.

In order to identify new outcropping areas of potentially fossil-bearing continental deposits, geological prospecting took place in the central area of the basin, in the perimeter of Rusca Montană, and in the eastern part of the basin, in the area of Negoiu village.

The valleys of Negoiu Creek and its tributaries (Fărcădeana Cr., Mănăstirii Cr., Șterminosu Cr.) were explored in the eastern part of the basin, where most previously-described vertebrate remains from the Rusca Montană Basin were found (Vasile & Csiki, 2011; Codrea et al., 2012; Csiki-Sava et al., 2016). Silty layers, intercalated with sandstones and conglomerates (Fig. 4), yielded macrofaunal remains (turtle shell fragments, ornithopod postcrania); silty sediment samples (around 250 kg) had been collected for identification of microvertebrate remains. The collected lithic samples were processed by screen-washing, using 0.75 and 2 mm mesh sieves, the obtained concentrate being currently sorted under the binoculary.

Fig. 4. Continental silty deposits along Fărcădeana Creek (Negoiu village), sampled for microvertebrate remains and palynological analyses

The areas explored in the central part of the basin include the valleys of tributaries to Rusca Creek (Cătămaru, Ciocanul, Ciotorogu, Miclăușul creeks), but also those of tributaries to Loznișoara Creek (Nocea, Baia, Vameșul creeks), an area where coal mines functioned at the beginning of the XXth century (Dușa, 1970, 1974, 1987; Dușa & Bărilă, 1973), and where palaeobotanical remains, important for reconstructing the local palaeoenvironment, were found (for a recent review of the palaeofloristic material, see, for example, Popa et al., 2014; 2016). Vertebrate fossil-bearing sandstones and siltstones were found cropping out during

these explorations (Fig. 5). Around 200 kg of samples were collected from these deposits, for obtaining microvertebrate remains via screen-washing.

Besides prospecting for fossil vertebrate remains, samples were also collected for a more precise dating of the fossiliferous deposits, using pluridisciplinary methods.

Fig. 5. Fossil vertebrate remains, in the silty deposits from the central area of Rusca Montană Basin (Rusca Montană village).

The marine deposits identified during field exploration along the tributaries of Rusca Creek, represented by rhytmical, turbiditic marly and sandstone beds, were sampled for palynological, micropalaeontological, and nannofloral assemblages (Fig. 6). Such analyses are required for biostratigraphic dating of marine deposits underlying the vertebrate fossil-bearing continental deposits, and also for regional correlations with similar deposits from the Hațeg and Transylvanian basins, areas where such studies were recently made (Vremir et al., 2014; Țabără & Slimani, 2019), and also with coeval deposits from the Carpathian area.

Fig. 6. Marly marine deposits from the central area of the Rusca Basin (Rusca Montană village), sampled for palynologic and nannofloral analyses.

Other samples for biostratigraphic dating of the continental deposits, using palynologic analyses, were collected from deposits cropping out along the tributaries of Rusca and Loznișoara creeks, in the central part of the Rusca Montană Basin, but also from outcrops found along Negoiu Creek and its tributaries, in the eastern part of the basin. Layers that

already yielded vertebrate remainds, but also areas where palaeofloral assemblages were previously described, were the main targets of the sampling. In addition to their use in dating continental deposits, the palynological assemblages will also supply palaeoecological information that will be corroborated with the data derived from the faunal and floral fossil assemblages known from the area.

Fig. 7. Tuffitic sandstoned from the central part of the Rusca Montană Basin (Rusca Montană village), sampled for geochronometrical analyses.

The sedimentary deposits filling in the Rusca Montană Basin are crossed by igneous bodies, or esle interbedded with volcanic deposits that can be useful for constraining their stratigraphy through radiometric dating. For this end, samples were collected from tuffitic sandstones that alternate with the fossiliferous deposits (Fig. 7), and also from intrusive andesites that cross the Cretaceous sediments. The collected samples will be dated usind the U-Pb method at the University of Arizona laboratories, according to the activities planned within the project (see below, **1.4**). Although the igneous rocks from the area have been dated before (Kräunter et al., 1986; Strutinski et al., 1986), the improved technology and the employment of other, more precise, methodologies open the possibility to gather much more reliable and accurate absolute dates than those obtained more than 30 years ago.

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Outside the Upper Cretaceous continental fossiliferous deposits and underlying marine deposits, supplemental prospecting, field research, mapping and sampling activities (for palynology and nannoplankton) also targeted synchronous deposits accumulated in marine environments that existed quasi-contemporaneously with the advent and existence of the Transylvanian vertebrate faunas, marine environments that bordered the emergent land area (the so-called Transylvanian Landmass, or the Hațeg Island; e.g. Benton et al., 2010, Csiki-Sava et al., 2015). This secondary activity aims to obtain biostratigraphic (and, possibly, even geochronometric) age data, comparable to the ones derived from around and from inside the Transylvanian landmass, for better correlation between the two regions, and for a more precise temporal constraint on the emergence of the land and of the faunas it hosted. Upper

Cretaceous deposits, belonging to the Tarcău Nappe, were investigated in two areas of the Romanian Eastern Carpathians (the Pluton-Pipirig sector, and, respectively, Sucevița-Marginea). The purpose of the research in the Pluton-Pipirig area is to compare/correlate the Campanian – Maastrichtian palynomorph assemblages from this area to the assemblages of the same age identified in the Hațeg and Rusca Montană basins, and also to those from the SW Transylvanian Basin (Petrești-Sebeș area). Only Upper Cretaceous deposits, belonging to the Hangu Formation, are cropping out over extensive areas, represented by alternating shales, calcarenites, and sandstones (Fig. 8) accumulated in a marine environment (Grasu et al., 1988). Around 30 samples were collected from several geological sections identified along the Neamț river and its tributaries.

Fig. 8.The Hangu Formation, Pluton locality area (Tarcău Nappe).

Later, a second field trip to the Sucevița-Marginea area was made in October 2021, for geological and palaeontological prospecting, geological mapping, and sampling, in order to identify new outcrops with Upper Cretaceous fossiliferous deposits, susceptible of containing continental and marine palynomorph assemblages; such assemblages would allow reconstruction of the palaeoenvironmental evolution, as well as biostratigraphic dating of the studied deposits cropping out in the northern part of the Romanian Eastern Carpathians. The results obtained from the analysis of samples collected from this area will subsequently be correlated to the palynological data obtained from the Upper Cretaceous deposits of the Hațeg Basin, the Rusca Montană Basin, and the Petrești area, as well as with those obtained from the analysis of deposits assigned to the Hangu Formation from the Pluton – Pipirig area.

Fig. 9. The Hangu Formation (Upper Cretaceous) along the Sucevița River, represented by grey shales (left photo), intercalated with sandstones and calcarenites.

Only natural outcrops were explored, several of these being identified along the Sucevița River (Fig. 9) and its tributaries, between Marginea and Sucevița. During these activities:
- sedimentary successions previously identified as being of Coniacian – Maastrichtian (Late Cretaceous) age were identified;
- the geographic position (GPS coordinates) of each studied outcrop was recorded, the sedimentary successions were photographed, and synthetic lithologic logs were drawn;
- six (shale) samples were collected for laboratory preparation aimed at identifying Cretaceous fossil assemblages (palynomorphs, nannoplankton).

Activity 1.2.–Sample preparation, processing, and analysis of the collected samples and palaeontologic specimens

According to the PAP, this main activity includes both A) the preparation of collected palaeontologic samples, processing (chemical treatment, screen-washing) the fossiliferous matrix, and inventorying of newly discovered fossil specimens, as well as B) the analysis and preliminary description of already existing and newly discovered specimens.

From the samples and fossil specimens collected during 2021, most of which represent microvertebrate-bearing sediment samples from the Hațeg and Rusca Montană basins (see **1.1**), the largest part are already being processed (inluding a multi-stage screen-washing activity needed to remove the fine sedimentary matrix); the resulting fraction will be sorted under binoculary during the following period (activity performed by Ștefan Vasile). Furthermore, given the stage I research priorities, as previously mentioned, our colleague proceeded to the screen-washing and sorting of the entire amount of fossiliferous matrix collected during previous years from the Petrești-Sebeș section, the microvertebrate

specimens recovered from this area being currently under detailed analysis and study with the aim of publishing them (Vasile et al., in preparation; Csiki-Sava et al. a, in preparation; see below, **1.8.-1.10.**).

In the framework of the collaboration set up to study the western part of the Hațeg Basin together with the Hungarian colleagues, much of the fossil material collected from this area was prepared and is undergoing post-preparation processing (conservation, inventorying, preliminary study) by the Hungarian partner, and it will be studied in collaboration starting with 2022 (see below, **1.9.-1.10.**).

Additionally to the microvertebrate-vertebrate material recovered, prepared, and/or studied in 2021, the field activities performed during stage I also allowed the identification of interesting and potentially important plant assemblages in the Hațeg and Rusca Montană basins (Fig. 2c). The plant macroremains discovered at Densuș, represented by *Sabalites longirhachis* leaf impressions, are already in conservation and under study (see **1.10.**); these occurrences are relevant to the project topic due to the palaeoenvironmental and palaeoclimatic information they offer, contributing to a more detailed image of the palaeoenvironments occupied by the kogaionid mammals, and of their palaeoecology.

Finally, the field studies also led to the identification and recovery of interesting invertebrate assemblages from two different locations, at Pui (Hațeg Basin) and Petrești (Transylvanian Basin). In the outcropping area near Pui (Hațeg Basin), from which numerous fossil vertebrate species have previously been described (for a recent synthesis, see Csiki-Sava et al., 2016, 2018), a Late Cretaceous gastropod assemblage was found (Fig. 10), which, alongside the spores-pollen assemblage we hope to recover from the same location (see **1.3.**), will supply important date needed for palaeoenvironmental interpretations, and, possibly, for a better dating of this palaeontological site.

Fig. 10. Fossil gastropod assemblage recovered from an Upper Cretaceous fossiliferous layer sampled for palynological assemblages at Pui (Hațeg Basin).

A relatively diverse assemblage of brackish-water mollusks (mainly gastropods) and corals (Fig. 11) was also identified and excavated from the top of the Bozeș Formation that

crops out in the Petrești – Sebeș section, while collecting new samples for palynological-micropalaeontological analyses during the summer of 2021 (see **1.3**,). Next to and correlated with the groups of organisms collected from this part of the succession that are more important for biostratigraphy and palaeoenvironmental reconstructions (see **1.3.**, **1.10.**), these invertebrate assemblages will also supply similar types of information. Such information will be needed for a better and more detailed understanding of the moment and the patterns of continentalisation of the Transylvanian landmass area, and of its colonization by the kogaionid multituberculate-bearing vertebrate assemblages.

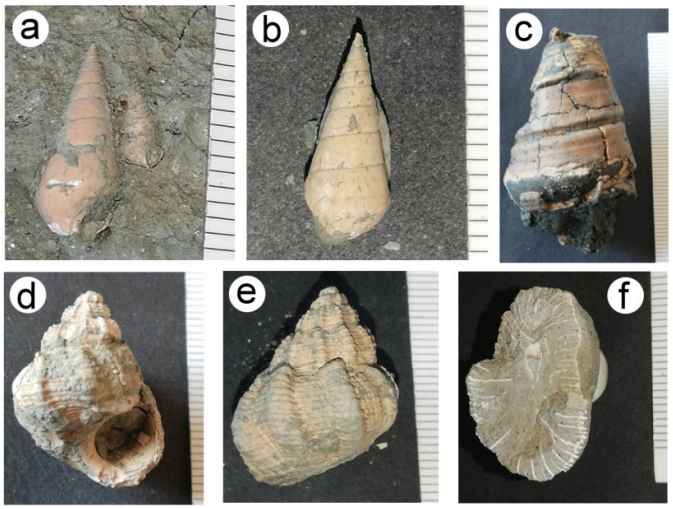


Fig. 10. Mollusk and coral assemblages from the top of the Bozeș Formation, Petrești section (scale in mm). a, b – Melanopsidae (brackish-water fauna); c – indetermined gastropod; d, e - *Barbotella maestrichtiensis*; f – coral.

Activity 1.3.–Palynological and micropalaeontological analyses

According to the PAP, this major activity includes two main directions of investigation: *A) Palynology*, starting with the preparation of palynological samples (chemical treatment, heavy liquid separation), followed by the mounting of praparates on slides for microscopic study, the microscopic study itself, the identification and photographing of the identified spores-pollen material, and concluded by writing reports on the identified palynological content and palynofacies; and, respectively, *B) Micropalaeontology* (calcareous nannoplankton, foraminifera), starting with micropalaeontological sample preparation (through chemical treatment), followed by the microscopic study of the preparates (slides, cells), by identification and photographing of the micropalaeontological material (calcareous nannoplankton, foraminifera), again concluded by writing reports on the micropalaeontological content and on its interpretation.

Fot the first research direction (*Palynology*), coordinated by Daniel Țabără, the year 2021 saw the collecting of a large number of samples from the areas of interest (see **1.1.**), followed by the processing of the largest part of these samples for obtaining spore-pollen preparates that currently are, or will be in the near future, under study for biostratigraphical

and palaeoenvironmental interpretations. These samples were prepared in the Palynology Laboratory at the Department of Geology ("Al. I. Cuza" University, Iași), according to a standard analytical procedure described in Botfalvai et al. (2021) and Țabără et al. (in review) (see **1.10.**). The most important results were obtained so far from the areas of Ciula Mică-Vălioara (some results already presented at conferences and even published – see **1.10.**, Botfalvai et al., 2021), Petrești-Sebeș (data partially presented at conferences and submitted for publication; **1.10.**), and the Romanian Eastern Carpathians.

Preliminary palynological analyses on samples from the base of the geological section from Vălioara (NW Hațeg Basin) produced an assemblage dominated by pollen assigned to the genus *Classopollis* (Fig. 12a-c), coming from an extinct family of halophyte gymnosperms typical to the Mesozoic Era (i.e. Cheirolepidiaceae), preffering coastal habitats, being adapted to dry climates and hypersaline soils (Michels et al., 2018). The same palynological assemblage also includes rare occurrences of freshwater algae (*Chomotriletes* sp.; Fig. 12d).The classical Densuș-Ciula Formation deposits from the same geological section yielded a palynological assemblage dominated by fern spores, and various pollen species coming from gymnosperms and, mostly angiosperms (Fig. 12e-m; Botfalvai et al., 2021).

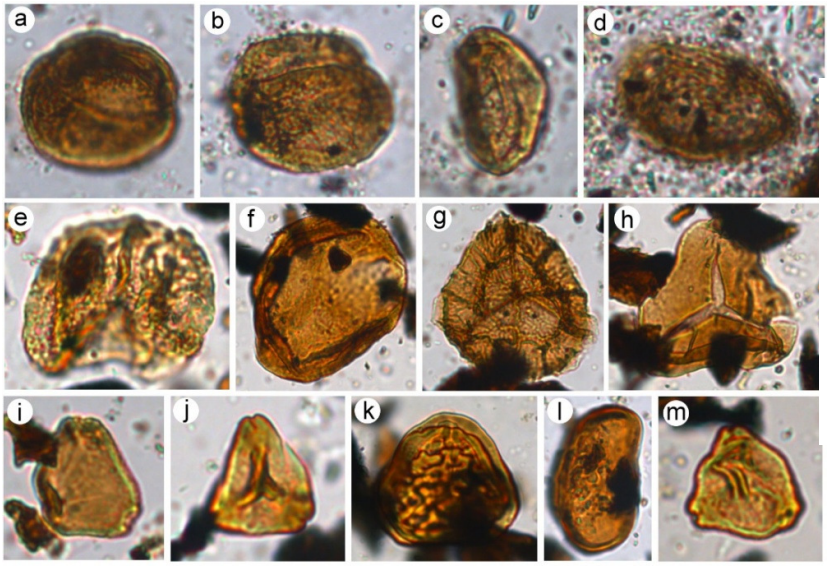


Fig. 12. Late Cretaceous palynological assemblage identified in the Vălioara section, Hațeg Basin. a–c - *Classopollis* sp.; d - *Chomotriletes* sp.; e – *Pinuspollenites* sp; f – *Araucariacites australis*; g – *Lusatisporites dettmanniae*; h – *Deltoidospora australis*; i – *Proteacidites parvus*; j –*Plicapollis serta*; k –*Polypodiaceoisporites* sp.; l –*Laevigatosporites ovatus*; m –*Myricipites bituitus*.

The section from Petrești-Sebeș was previously studied by Codrea et al. (2010), Vremir (2010), Csiki-Sava et al. (2012), and Vremir et al. (2014), and it exposes the contact between marine deposits (assigned to the Bozeș Formation) and the continental deposits assigned to the Sebeș Formation (see **1.1.**).

Up to now, a number of 18 palynological samples were analysed from this section (covering about 575 m of lithological thickness), most of these samples being collected systematically during previous field campaigns by interdisciplinary research teams that also included members from the project research team (for details, see Țabără et al. in review). A palynologic assemblage was only identified in the Bozeș Formation, the Sebeș Formation deposits being palynologically barren so far. The assemblage identified in the Bozeș Formation consists of 35 pteridophyte taxa, 6 gymnosperm pollen taxa, and 39 angiosperm taxa. Some taxa form this assemblage are presented in Fig. 13 (from Țabără et al. in review).

Based on palynological biomarkers identified in the analysed samples (e.g. *Trudopollis cuneolis, Klukisporites pseudoreticulatus*, and *Vadaszisporites sacali*), a Middle-Late Campanian age was assigned to the deposits of the Bozeș Formation cropping out at Petrești. The Middle Campanian palynological assemblage mainly includes spores from ferns that inhabited low altitude areas, of high humididy, and warm climate. The Upper Campanian reveals a mixed vegetation suggesting co-existence of plants typical to coastal areas, and of assemblages derived from higher-altitude areas, with colder and wetter environments (Țabără et al. in review).

The palynofacies analysis and interpretation of organic geochemistry data (Total Organic Carbon, Total Sulphur, Gas Cromatography – Mass Spectrometry GC-MS) (see below, **1.9.**) suggest that the lower and middle parts of the Bozeș Formation section cropping out at Petrești were deposited in a transitional environment of the sedimentary basin, and were subsequently transported down-slope into an external neritic – distal area of the same basin. The upper part of the Bozeș Formation cropping out at Petrești contains large coaly opaque phytoclasts, cuticle fragments coming from continental vegetation, suggestive of an internal-middle neritic palaeoenvironment (Țabără et al. in review).

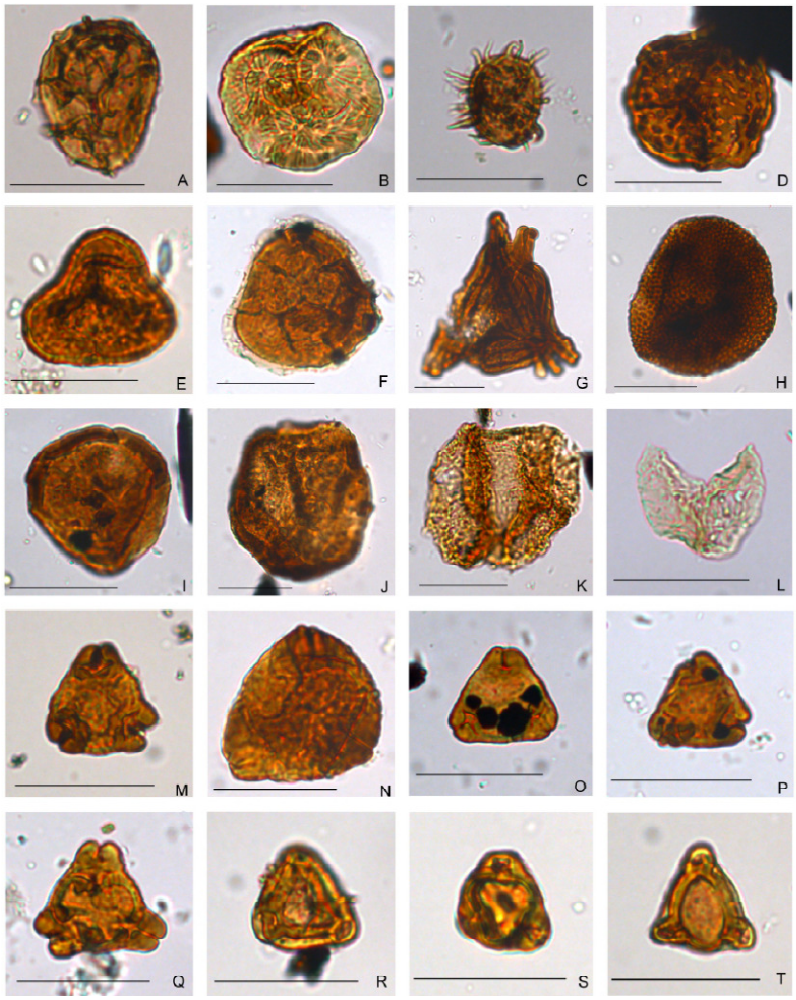


Fig. 13. Middle-Late Campanian continental palynomorph assemblage from the Petrești section (Bozeș Formation). A. *Lycopodiumsporites clavatoides*; B. *Asterisporites radiatus*; C. *Echinatisporis longechinus*; D. *Klukisporites pseudoreticulatus*; E. *Concavissimisporites* sp.; F. *Zlivisporites blanensis*; G. *Appendicisporites cristatus*; H. *Vadaszisporites sacali*; I. *Classopollis* sp.; J. *Araucariacites australis*; K. *Pinuspollenites* sp.; L. *Inaperturopollenites hiatus*; M. *Trudopollis spinulosus*; N. *Trudopollis fossulotrudens*; O. *Trudopollis nonperfectus,* with framboidal pyrite; P. *Trudopollis minimus,* with framboidal pyrite; Q. *Trudopollis cuneolis*; R. *Interporopollenites proporus*; S. *Interporopollenites endotriangulus*; T. *Interporopollenites klausii*.

Concerning the Romanian Eastern Carpathian area (Pluton-Pipirig sector), around 30 palynologic samples were collected from several geological sections identified along the valleys of Neamț River and its tributaries. The preliminary results listed below are included in Țabără et al. (in preparation; see **1.10.**). Palynological analyses performed on 15 samples revealed a conclusive palynological assemblage, represented by numerous marine phytoplankton and continental palynomorph species (Fig. 14). Dinoflagellates dominate the palynological assemblage (sometimes representing more than 70-80 % of the identified taxa), with the best represented genera being *Cerodinium, Isabelidinium*, and *Alterbidinium*. Some Maastrichtan continental palynomorphs (e.g. *Trudopollis* div. sp., various species of fern spores) identified in the Hangu Formation assemblage are shared with the assembages identified in western Romania (the Hațeg Basin and the southwestern Transylvanian Basin) (Țabără et al., in preparation).

The palynofacies of the Upper Cretaceous deposits of the Hangu Formation is dominated by continental organic matter (numerous coaly opaque phytoclast fragments, vegetal tissue and cuticles), the marine fraction (phytoplankton) being present in low amounts in the kerogen extracted from these rocks. This palynofacies information shows that the Upper Cretaceous deposits of the studied area were deposited in an internal-middle neritic area of the Moldavidic Basin (Țabără et al., in preparation). A similar sedimentary palaeoenvironmental interpretation is also supported by geochemical analyses (Total Organic Carbon, Total Sulphur, Gas Cromatography–Mass Spectrometry GC-MS) performed so far on 5 samples collected from the Pluton area. Another 8 shale samples are currently under geochemical analysis at the Natural Sciences Faculty, University of Silesia (Poland) (see **1.9.**) (Țabără et al., in preparation).

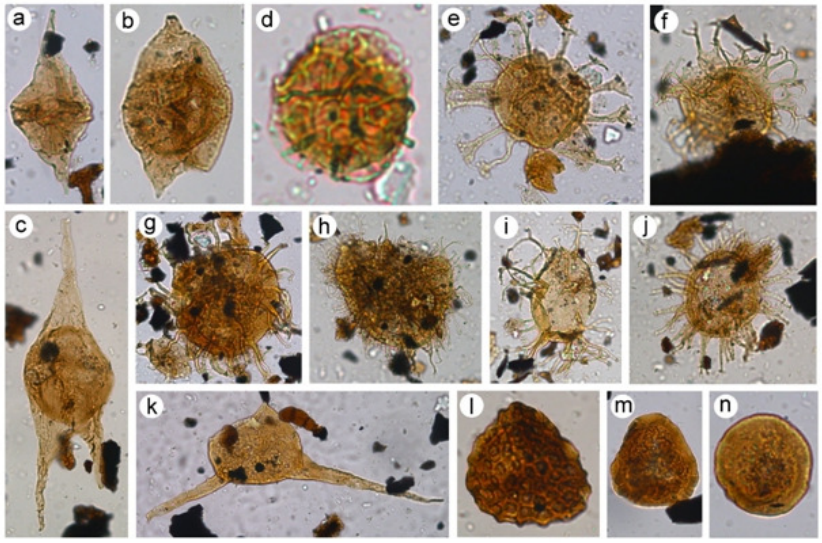


Fig. 14. Selected Late Campanian – Maastrichtian marine and continental palynomorphs from the Hangu Formation (Pluton-Pipirig area, Tarcău Nappe). a - *Alterbidinium acutulum*; b - *Isabelidinium cooksoniae*; c - *Cerodinium albertii*; d - *Cladopyxidium paucireticulatum*; e - *Hystrichosphaeridium tubiferum* subsp. *tubiferum*;f - *Spiniferites ramosus*; g - *Fibrocysta axialis*; h - *Areoligera senonensis*; i - *Achomosphaera ramulifera*; j - *Pervosphaeridium monasteriense*; k –*Odontochitina operculata*; l - *Klukisporites pseudoreticulatus*; m – *Polypodiaceoisporites* sp.; n – *Classopollis* sp. (from Țabără et al. in preparation)

The second research direction (*Micropalaentology*), coordinated by Ramona Bălc, included in 2021 the collecting of a large number of micropalaeontological samples from the areas of interest, as well as the preparation of numerous samples aiming for the recovery of their calcareous nannoplankton and, respectively, foraminiferal content; these samples come both from previous sampling campaigns performed before the start of the project, and (in smaller amount, for the moment) from our own samplings made during stage I. The main area of interest was represented by the Petrești section (66 nannoplankton samples, 28 foraminifera samples, collected from the same collecting points and during the same systematic sampling as the palynological samples analyzed from there, for more precise correlation of the resulting information), whereas only preliminary results are available so far from the Ciula

Mică-Vălioara area, and from the Romanian Eastern Carpathians. The preliminary data obtained from the Petrești succession were already presented at scientific conferences and a manuscript discussing these data is currently in the final stage of preparation for submission (Bălc et al., in preparation; see **1.10.**)

The technical procedures employed for recovering calcareous nannoplankton content follow the gravitational method described by Bown and Young (1998), as follows:

1. The entire outer surface of the sample was removed;
2. The sample was crushed, avoiding contamination by wrapping it in a paper towel;
3. The resulting sediment powder was put in a glass, and distilled water was added;
4. The suspention was stirred and left to disintegrate (for a few hours). Antiflocculant (sodium hexametaphosphate) was added to avoid sediment particles from clustering;
5. The suspension was stirred after a few hours and it was left to decante for 1-2 minutes;
6. The liquid separated on top of the crushed sample was decanted in a test tube and was left to sediment for 10-15 minutes;
7. The liquid was thrown out, and the sedimented fraction was used for slide preparation.

The micropalaeontological analyses were made in collaboration with colleagues from the Babeș-Bolyai University, Facultaty of Biology and Geology, Department of Geology (Raluca Bindiu-Haitonic, Szabolcs Kövecsi – see **1.9.**). The analytical method used for recovering small foraminifera employed the standard method (Armstrong and Brasier, 2005), as follows:

1. Drying (50˚C);
2. Soaking in distilled water;
3. Boiling;
4. Screen-washing on the 63 μm mesh size sieve;
5. Drying;
6. For the samples that were more difficult to disintegrate, treatment with 3% concentration hydrogen peroxide was used, after which the samples were screen-washed (63 μm mesh size sieve), and dried.

Each sample was dried and weighed before and after processing. Where possible (the samples were rich in small foraminifera), at least 250 foraminifera individuals were extracted from the resulting residue.

An optical microscope (Axiolab A) with a x1000 magnification degree was used for the microscopic analysis of the calcareous nannoplankton. Pictures of the identified species were taken using a computer-connected digital camera (AxioCam Erc5s), using the ZEN 3.4 (blue edition) software. Foraminifera were extracted manually, using an Optika SZM stereomicroscope with maximum 180 magnification. The separated foraminifera were stored

and sorted in micropalaeontological slides. The representative specimens were examined in detail and were imaged using a high-vacuum high-resolution scanning electron microscope (EmCrafts CUBE 2).

Qualitative and quantitative studies were made on the calcareous nannoplankton assemblage, in order to assess the age of the studied deposits and to reconstruct their depositional palaeoenvironment (Bălc et al., in preparation). To this end, at least 300 individuals were counted from each sample, with the data being subsequently used for statistical analyses, including Principal Component Analysis and Hierarchical Clustering Analysis, using PAST software, version 3.26b (Hammer et al., 2001). The Hierarchical Clustering Analysis (Q module) was made using Ward's algorythm (distance) and the Euclidian similarity index (connection). To check for cluster accuracy, for a better constraint of similarities and differences between the various samples/assemblages and for the identification of the main taxa, a Principal Component Analysis was employed, using a variance-covariance matrix (Hammer and Harper, 2006).

The calcareous nannoplankton taxa used for multivariate analysis were selected based on the abundance of species and taxonomic groups (higher than 2% in relative abundance), and samples containing less than 50 specimens were excluded from these analyses. Before the multivariate analysis of data, the data on relative abundance of species and groups (the obtained percentages) was submitted to arcsine transformation of the squared root (ASIN(SQRT(Data/100))).

The raw data offered by the small foraminifera assemblage were used to calculate the abundance and relative abundance of the major foraminifera groups represenetd (agglutinanted, bentonic calcareous, planktonic) as well as that of representative genera/species, to derive values of specific ecological indices (Fisher α, Shannon-Wiener – PAST software - Hammer et al., 2001), and for deducing palaeo-bathymetry (van der Zwaan et al., 1990; Murray, 2006).

The main results of these studies (Bălc et al., in preparation; see **1.10.**) can be synthesized as follows:

B1. Composition. diversity, and palaeoecology of the calcareous nannoplankton assemblage

The calcareous nannoplankton assemblage includes 135 species; the state of preservation is moderate-to-good, and the species abundance is high, only 5 of the 62 analysed samples containing relatively species-poor assemblages.

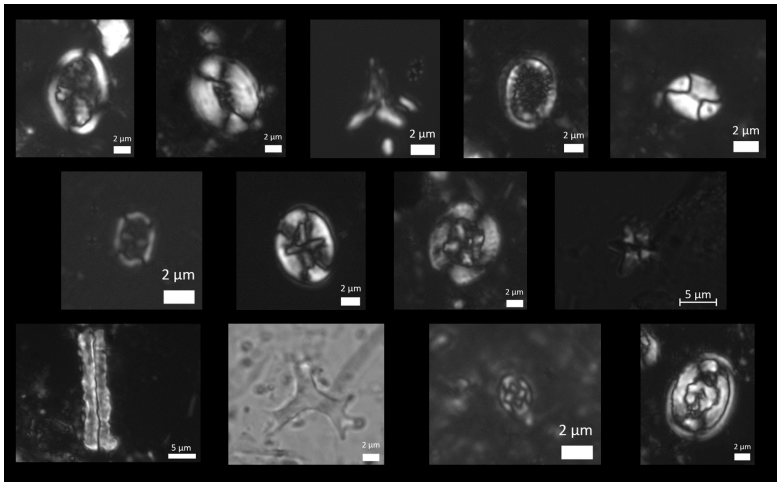


Fig. 15. Calcareous nannoplankton from the Petrești assemblage (details in Bălc et al., in preparation for publication).

The dominant species in the assemblage is *Watznaueria barnesiae*, followed by: *Prediscosphaera cretacea, Tranolithus orionatus*, *Eiffelithus eximius, Cribrosphaerella ehrenbergii, Retecapsa crenulata* and *Micula staurophora*. All of the above-mentioned species showed fluctuations along the profile, with more than one abundance peak. The other observed species were observed in much lower but constant numbers along the studied section, although some of these occured more rarely and discontinuously (Fig. 15).

Other features characterising the calcareous nannoplankton assemblage are: i) the absence or low presence of species typical for the Tethyan realm; ii) the presence within the assemblage of taxa sensitive to dissolution processes (e.g. *Biscutum constans, Discorhabdus ignotus*), and iii) the presence of the species *Russellia bukry* and *Russellia laswelli*, which registered a higher abundance at the base of the profile, their abundance decreasing towards the upper part.

Analysing the percentage of each species in the assemblage, surface water environmental conditions were also reconstructed. The data indicate warm, oligotrophic waters, of low productivity. Also, the presence of certain species in the calcareous nannoplankton assemblage allowed age assessment for the studied deposits (Bălc et al. in preparation).

B2. The composition, diversity, and palaeoecology of the small foraminifer assemblage

The small foraminifera assemblage shows an average-to-low degree of preservation and an abundance that varies along the studied section. The assemblage includes all three foraminifera groups (Bălc et al., in preparation). The bentonic forms (agglutinanted and calcareous bentonic) are the most abundant, reaching a maximum of 96.25% (Fig. 16). The planktonic foraminifera registered a maximum percentage of 49.69% (Fig. 17).

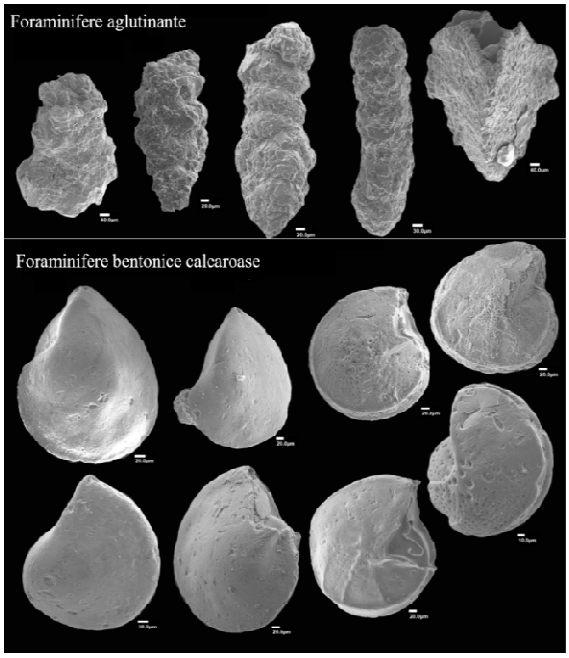
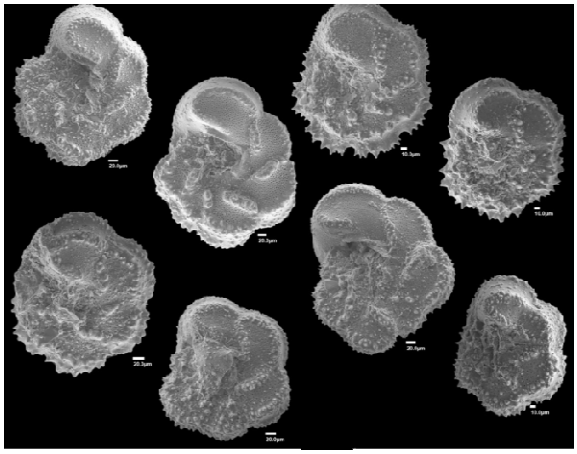


Fig. 16.Calcareous agglutinated and bentonic foraminifera from the small foraminifera assemblage from Petrești (details in Bălc et al., in preparation for publication).

Fig. 17. Planktonic foraminifera from the small foraminifera assemblages from Petrești (details in Bălc et al., in preparation for publication).



The most representative agglutinated foraminifera taxa in the assemblage are the tubular forms (*Nothia*, *Rhizammina*), the elongated forms (*Reophax*), and the rounded forms (*Haplophragmoides*, *Recurvoides*).

The bentonic calcareous foraminifera are represented by taxa belonging to Buliminidae (*Bolivina*, *Pseudouvigerina*, *Praebulimina*), Lagenidse (*Lenticulina*, *Nodosaria*), and Rotaliidae (*Cibicidoides*, *Eponides*, *Gyroidinoides*). From the planktonic foraminifera group, the most representative species belong to the genera: *Heterohelix*, *Globotruncana*, *Hedbergella*, *Rugoglobigerina*, and *Globotruncanella.*

The ratio the planctonic foraminifera present in the assemblage is a very important indicator for palaeo-depth reconstructions. Their percentages were inserted in the formula proposed by van der Zwaan et al. (1990) (D = e[3.58718+(0.03534*%P)], where D = depth in meters, %P = the percentage of planctonic foraminifera) for deducing palaeo-depths. The obtained bathymetric values range between 41 and 209 m and are thus characteristic for the shelf area (proximal shelf for the lower part of the studied section and distal shelf for the middle and upper part).

The presence of the genera *Heterohelix*, *Hedbergella*, *Rugoglobigerina*, *Globotruncanella*, and *Globotruncana* suggests the presence of warm waters and of mesotrophic environments in the water columns. The presence of epifaunal (*Lenticulina*, *Haplophragmoides*) and infaunal (*Reophax*, *Bolivina*, *Pseudouvigerina*, *Praebulimina*) taxa

on the sea bottom indicates mesotrophic environments for the lower part of the section, and eutrophic ones for the middle and upper parts.

The small foraminifer assemblage confirms the age indicated by the calcareous nannoplankton assemblage (Bălc et al. in preparation).

Activity 1.4.-U-Pb geochronometry analyses

According to the PAP, this major activity was planned to include sample preparation, zircon isolation and selection for U-Pb geochronometry study, as well as the start of U-Pb radiometric age measurement on zircons. Due to the partial reorganization of the activities and to the resulting changes in expenses which resulted from such a reorganizatio (in connection to the pandemic-driven conditions within which the project was implemented - see Introduction), we decided to redirect much of the funds not used for Traveling (online conferences, with implicitely lower costs) towards geochronometric analyses, preparing a higher number of samples for measurements than planned previously, and also launching phosphate geochronometric investigations (i.e., on vertebrate fossils), alongside those performed on samples of igneous and detritic rocks. As foreseen in the project proposal, the U-Pb geochronometric measurements using the LA-ICPMS (laser ablation inductively coupled mass spectrometry) method were made in specialized laboratories of the University of Arizona (UoA), being coordinated and supervised by Mihai Ducea; the employed measurement methodology, protocols, and standards, as well as the interpretation procedures used (or that will be used) in making these geochronometry analyses are presented in Stoica et al. (2016).

The same arguments used in selecting prioritary areas and topics for stage I, as previously described in detail in **1.1**., were also used to select the samples sent for analysis to UoA. While some of the samples used were collected before the start of the project, through personal efforts of members of the research team and of external collaborators (see 1.9.), other samples were collected during the field activities of 2021. Using already existing samples made an early start of the analytical activities possible and allowed to obtain preliminary gecohronometric data and information already during 2021, albeit the largest part of the samples analyzed during stage I were sent for geochronometric measurements only during the second half of the year. For the latter, result interpretation is still in progress, although we are planning to include at least part of these results (see below) in manuscripts that are currently being prepared for submission (e.g. Bălc et al., in preparation).

The U-Pb geochronometry samples analysed using the LA-ICPMS method included 2 fossil phosphate samples, 3 zircon samples derived from igneous rocks, and 6 zircon samples derived from detritic sedimentary rocks. Most analyzed samples were collected from the Petrești section, as part of the comprehensive multidisciplinary analysis effort oriented towards this section; they include phosphate samples (2), as well as most of the detritic zircon samples (5), all currently under interpretation aiming to obtain results publishable in the first trimester of 2022.

Besides those from Petrești, other samples analyzed in 2021 include one detritic zircon sample from the Rusca Montană Basin (under interpretation), as well as a series of igneous samples (volcanic tuffs, andesites) from the Hațeg Basin. From these latter, the analyses performed on the andesites collected previously from the Densuș area are currently being interpreted, whereas the measurements and interpretations on the tuff samples from the Ciula Mică and Unciuc areas are finalized; these were the object of a bachelor thesis defended at the University of Bucharest in July 2021, and will be prepared for publication during 2022 (see **1.10.**). Without going into details regarding these dates and results, given the existing plans for their publication, it can be said nevertheless that the geochronometric analysis of the tuff samples taken from Ciula Mică generally supports previous results obtained by Bojar et al. (2011) from the same area, but are more precise and, in part, correct the previoua age data. The dates and results obtained on the tuffs from Unciuc (studied for the first time using such a dating method) might shed new light on the litho- and chronostratigraphy of the deposits from that area, and might yield new interesting data concerning the geological evolution of the Hațeg Basin, as well as the Alpine igneous activity in the Carpathian area.

Activity 1.5.–The first preliminary syntheses for the spatial and temporal distribution of kogaionid occurrences

According to the PAP, this major activity aimed to reconstruct – in the current state of kowledge – the litho- and chronostratigraphic, as well as the palaeoenvironmental-palaeoecological framework of Late Cretaceous kogaionid evolution in the Transylvanian realm, based on a thorough synthesis of the previously known/published or unpublished litho- and biostratigraphic, geochronometric, sedimentologic information related to known kogaionid occurrences, using the (state-of-the-art) data that existed before the project implementation. This framework would represent a baseline to which the project results could be reported, thus allowing for an objective evaluation of the quality and quantity of new data and information acquired during the project.

This synthesis was made during 2021 by Zoltan Csiki-Sava and Ștefan Vasile, and it resulted in the inventory of a high number (27) of kogaionid occurrences across the Transylvanian realm (fig. 18), including the report of four new occurrences in the Hațeg Basin (Csiki-Sava et al., in review; see **1.10.**). The kogaionid remains from these new occurrences were briefly described, and new details on previously-known occurrences were also presented and discussed in the light of more recent discoveries and interpretations. This synthesis allowed the identification of novel spatial-temporal distribution models for the Transylvanian kogaionids (e.g., fig. 19), and these models have the potential to offer new clues related to the evolution of kogaionids, as well as their palaeoecological/palaeoenvironmental preferences and palaeobiology (Csiki-Sava et al., in review). These models are expected to be completed, updated, and/or verified and modified in the future as analyses, descriptions, and interpretations of other, already discovered or newly identified kogaionid remains and occurrences will become available.

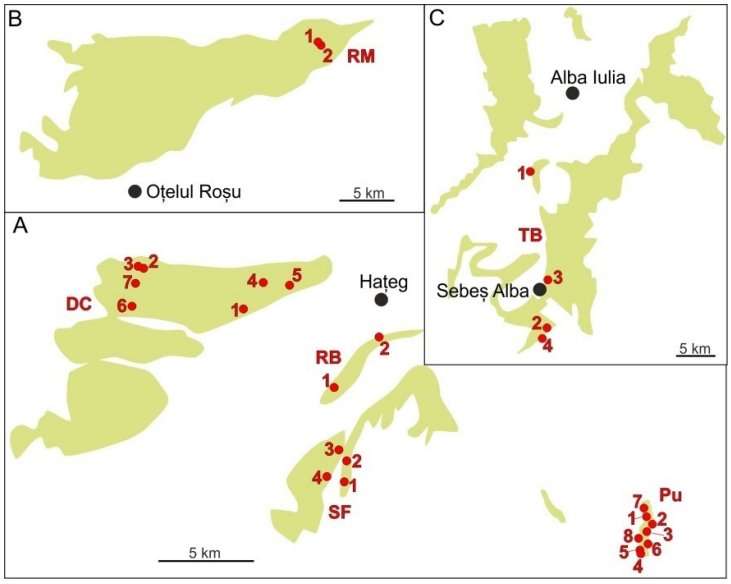


Fig. 17. Late Cretaceous kogaionid multituberculate occurrences in the Transylvanian realm (details in Csiki-Sava et al., in review).

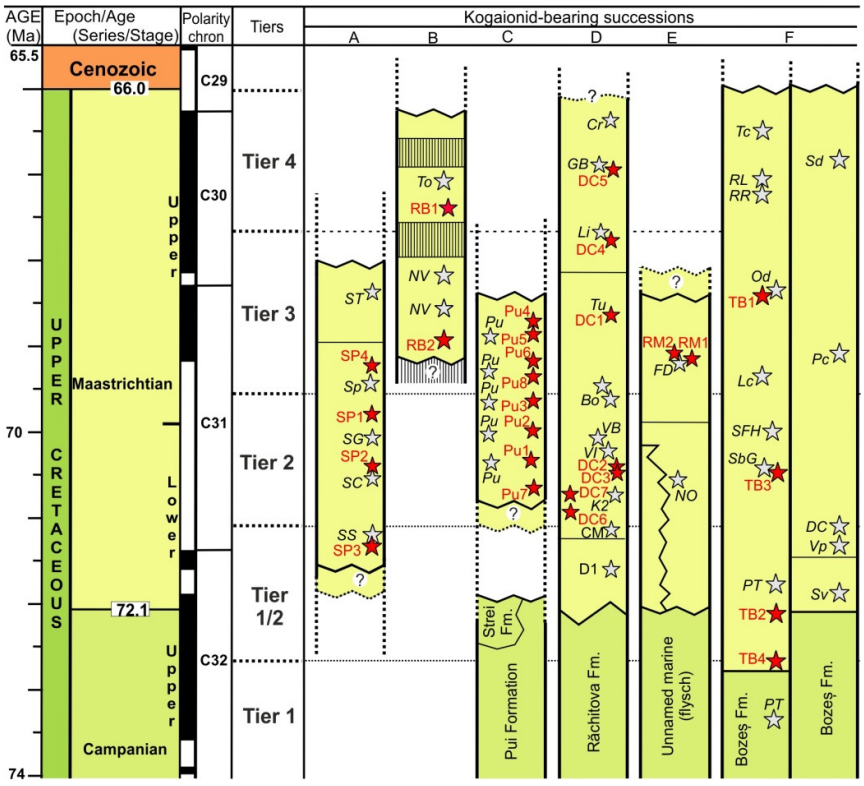


Fig. 18. Late Cretaceous kogaionid multituberculate litho- and chronostratigraphic distribution in the Transilvanian realm, revised and updated (details in Csiki-Sava et al., in review)

Activity 1.6.–The study of new key Late Cretaceous kogaionid specimens – stage 1

According to the PAP, this main activity was aimed at the morphological-anatomical description of selected kogaionid specimens that either have a high degree of preservation and/or are important/relevant for other reasons, as well as at the coding of these specimens/taxa in the character-taxon matrix that is under preparation (see **1.7.**). In this context, the activities performed (mostly by Zoltan Csiki-Sava) included:

- the description of osteologic material (represented almost exclusively by isolated dental remains) coming from kogaionid-bearing fossiliferous sites that are newly reported in the spatial-temporal distribution synthesis made by Csiki-Sava et al. (in review). The isolated teeth coming from 3 of these 4 new occurrences (of which only one yielded more than one specimen) were described in detail, compared, discussed, and figured in the above-mentioned manuscript, in order to complete the existing information related to the fossil record of Late Cretaceous Transylvanian kogaionids. The more complete dental, gnathic, and cranial associated remains from the fourth site will be described in detail later, given the importance of this specimen.

- the description of new, previously unreported dental elements belonging to formerly described specimens (e.g., specimen LPB (FGGUB) M.1635, assigned to the taxon

Barbatodon transylvanicus), as well as new data, measurements, and observations on already known specimens; these data shed a new light on some previous interpretations/ identifications (see Csiki-Sava et al., in review).

- the description of an important and relatively rich assemblage of isolated kogaionid teeth, recovered from the basal part of the vertebrate-bearing fossiliferous succession from the Petreşti-Sebeş section. The presence of these multituberculate remains in a microvertebrate bonebed site was so far announced only preliminarly, at conferences or in general faual review publications (e.g., Vremir et al., 2015; Csiki-Sava et al., 2016), without including a detailed description, relevant comparisons, and interpretation of these fossils. Additionally, the chronostratigraphic position of this microvertebrate occurrence underlines the importance of the kogaionids from the assemblage for understanding the evolution and morphological transformations within the group. At this point (the end of stage I), the description of the kogaionid faunule from this fossiliferous site is currently in progress in the form of a manuscript in preparation (see also **1.8.**, **1.10.**), with the target of submitting this manuscript (Csiki-Sava et al., in preparation a) for publication in the first half of 2022. And, finally, the most important components of the Activity,

- the detailed description of a multituberculate individual that was also recovered from the Petreşti succession, and was reported preliminarily in previous publications (Csiki-Sava et al., 2012; Vremir et al., 2014, 2015). Since it concerns an individual represented by associated skeletal and dental remains, the description and analysis of this specimen will add important new information to the current knowledge on the Late Cretaceous kogaionids of the Transylvanian landmass, with major implications for understanding the evolutionary history of the group. At this point (the end of stage I), the description of this kogaionid individual is in progress, in the form of a manuscript in preparation (Csiki-Sava et al., in preparation b; also see **1.8.**, **1.10.**), the aim being to submit the manuscript for publication in the first half of 2022.

- starting, at the end of 2021, the monographic analysis of a multituberculate individual from the Haţeg Basin, briefly described previously, but which will now receive a more detailed and more complex treatment. It is estimated that this work will be completed towards the end of the second trimester of 2022.

It is worth mentioning in this context the acquisition from the stage I funds of the Multi-Brain project of a performant stereo-microscope, needed for a detailed analysis of the studied specimens that are generally of small size.

Activity 1.7.–Start of the construction of an extended character-taxon matrix (MCT) for phylogenetic analysis

According to the PAP, this main activity involves adapting and merging MCTs employed in different previous phylogenetic analyses applied to multituberculates/allotherians, completing this composite MCT by adding new taxa and characters, as well as re-checking previous codings, based on new specimens / more detailed publications / recent systematic and anatomic re-interpretations. In this regard, two recently-used MCTs employed particularly for kogaionids (Csiki-Sava et al., 2018; Smith et al., 2021) were selected, were started to be integrated, and their codings re-checked. Additionally, these anterior codings will be completed, given the new informations accumulated on previously published specimens/taxa. The ongoing monographic description of kogaionid individuals from Petrești and the Hațeg Basin also represents an opportunity to insert these individuals, in one case for the first time, in such a composite MCT, in order to analyze their phylogenetic position and relations. As the studies mentioned at **1.6.** will advance and be completed, the completion of the MCT will also advance, as envisaged in **1.7.**, and the latter will be completed progressively in parallel with the description of new kogaionid and other multituberculate individuals/taxa (also see **1.9.**).

A new approach that will be tested while this activity is completed is represented by an attempt to code not taxa, but operational taxonomic units (OTU) represented by individuals, an approach made possible by the discovery of a significant number of kogaionid specimens represented by partial skeletons containing associated dental, gnathic, cranial, and, sometimes, postcranial remains (see Csiki-Sava et al., in review). This approach has the potential of revealing taxonomically significant differences between individuals previously assigned to the same taxon, or, alternatively, the existence of potential intraspecific individual differences within the sample referred/referable to the same species.

Activity 1.8.- CT-scan and SEM imagery – stage 1

According to the PAP, this main activity implies the CT (computerized tomography) scanning of relevant specimens (kogaionid skulls), the acquisition of the first CT-scan and SEM (scanning electron microscope) image sets, as well as the processing of scanned data and preliminary preparation of the first sets of acquired digital images. Since all these data will represent important (even essential) components of future publications, no detailed information will be given on the results obtained so far, but only a description of the progress made and of the status reached by the end of 2021, at the end of stage I.

Part of the acquisition activities have already been performed before the project started, but the acquired datasets were not yet processed and used, whereas other datasets acquired by modern imagery (CT-scan, SEM) were accumulated during this year. Most of these advanced imagery acquisition activities were performed at external institutions with which connections were established through our external collaborators (University of Edinburgh; the American Museum of Natural Sciences, New York), whereas part of the SEM imagery was acquired with the assistance of colleagues from the Babeș-Bolyai University, Cluj-Napoca and the direct involvement of team members (Ramona Bălc, Ștefan Vasile). Currently, these datasets are being collected and archived for secure storage (including on external hard drives with multiple back-up options), both within the project and at external collaborators (see **1.9.**).

Additionally, with support from external colleagues-collaborators, the digital reconstruction (rendering and segmentation) based on CT-scan datasets was also started for specimens that are already under study or will enter study this year (see 1.6.). This activity is essential for the detailed and exhaustive description of the most important key specimens, respectively of those represented by cranial/gnathic material for which different details of the internal or even external morphology remain hidden either for morphological/anatomical easons or else due to objective limitations of the preparation. The information obtained from such segmentation activities of the CT-scan data is already successfully used in ongoing studies (see **1.6.**), and once the description for other specimens will proceed during stages II and III, these new specimens will also be, in parallel, scanned/reconstructed/segmented.

Beside the basic external and internal cranio-dental morphology data and details, useful in describing the respective specimens, obtained through CT-scan imagery, important information related to the internal cranial structures is also being accumulated in the same time; such inormation will be essential for the objectives planned for the third year of the project.

It should be mentioned here that the successful implementation of this project component is supported by the second important equipment acquisition made within the project, namely that of a computer with high computing and representation capacity (workstation), purchased in order to run the required special software in optimal conditions; with this equipment, the processing of the CT scanning data (usually represented several Gb of raw data in unprocessed state, for each specimen) is achievable at reasonable speed and accuracy, as is the successful manipulation of the reconstructed and segmented 3D images.

On the other hand, due to delays that intervened in the acquisition activities of the projects, a second purchase foreseeen for this major activity, namely that of specialized software

required to manipulate the acquired CT-scan images, could not be made in time, and was delayed as acquisition/expense for the second year of the project, and the funds set aside for this purpose were redirected towards obtaining a higher number of geochronometric analyses in 2021. The absence of this software was compensated at this moment through collaboration with external collaborators that are involved in the respective studies, and contributed by performing these rendering/segmentation activities (see below, **1.9.**).

Activity 1.9.–Scientific cooperation activities

According to the PAP, this main activity implies working visits, research stages in national and foreign institutions, as well as the organization of a workshop including the research team and external collaborators. As it was already mentioned in the PAP, these activities were going to take place 'if required and the conditions allow them', referring directly to the impredictible circumstances that may appear du to the evolution of the COVID-19 pandemic. Indeed, many such activities, althogh clearly useful for achieving the project objectives, had to be adapted to conditions specific to the pandemic. Collaboration with foreign co-workers was entirely moved to the virtual medium, with occasional contacts via digital means of communication (Skype, Zoom, Google Meet), with even those activities restricted to the national territory being partially resized. Nevertheless, even under such inproper conditions, the obtained results and the opportunities identified and exploited/planned for the future are numerous.

Regarding the collaboration and scientific mobility inside Romania, involving both members of the research team as well as other institutions, the moments of relative pandemic relaxation allowed some essential activities to take place, thus contributing to the achievement of the results that can now be accounted for in the project (see **1.10.**). They include, first of all, the field activities that took place, which allowed direct contacts between members of the research team, as well as with some external collaborators (see **1.1.**), contacts that are useful for a better planning of future steps in the research activity. Furthermore, the other mobility activities performed were also instrumental in reaching the objectives and results reported here.

At the beginning of the year (April-May), Ștefan Vasile traveled to Cluj-Napoca, to work in the collections of the Transylvanian Museum Society, where many of the vertebrate fossils recovered from the Petrești section are stored (a main objective of study for stage I). This allowed direct access to the collections, and even offered the possibility of temporary loan of these fossil collections, enabling their investigation in the more favourable conditions

availabe at the University of Bucharest – thus creating optimal conditions for studying these fossils. Also, meetings between various members of the research team, taking place in the autumn of 2021, allowed a more efficient collaboration, including comparisons, correlations, and synthesis of the obtained data, which represented a substantial contribution to the relatively advanced (in our opinion, of course) state in which publication and result dissemination activities are at this point. Finally, the possibility for Ștefan Vasile to travel to Cluj-Napoca in the autumn of 2021, to benefit from no-cost access to the SEM facilities of the Babeș-Bolyai University, access intermediated by colleagues in this institution (to whom we extend our gratitude), was an important positive element in the current phases of writing the two manuscripts dedicated to the microvertebrate assemblages known from the Petrești-Sebeș section (see **1.2.**, **1.5.**, **1.10.**).

On the other hand, even under the conditions of dominantly virtual contacts with external collaborators of the project (either those already considered and mentioned while applying the project proposal, or else colleagues who were contacted only during project implementation, once new ideas, potential lines of investigation, or opportunities appeared), these contacts proved to be extremely useful, lucrative, efficient, and show good potential for future collaboration. A few of the most important such collaborations will be listed, in brief, without excessive details (also see **1.10.**):

- the already-mentioned collaboration (**1.1.**) with geologists and palaeontologists from Hungary (G. Botfalvai, J. Magyar,A. Osi, G. Albert, etc.), that was made official in 2021, for detailed mapping, geological, palaeontological, sedimentological, and taphonomical study of the Upper Cretaceous deposits from western Hațeg Basin. This collaboration already produced results in 2021, by publication of a first common paper, attending a significant number of conferences, participation to a partially-correlated field campaign, and the start of a stage of doctoral formation at the Eötvös Loránd University from Budapest for one of the participants at these activities (J. Magyar), within which the principal investigator (Z. Csiki-Sava) is also co-supervisor. The material resulted from the field research will be published/communicated in the future.

- the collaboration, also mentioned before, with micropalaeontologists from the Babeș-Bolyai University (R. Bindiu-Haitonic, Sz.-A. Kövecsi), who contribute to the study of the foraminiferal assemblages derived from the marine successions of interest for the project. The results of this collaboration include one conference presentation, one manuscript nearing completion, as well as others in preparation/planned.

- the collaboration, already started before the start of the project (e.g., Țabără & Slimani, 2019), but which will now (also) be supported from project funds, with H. Slimani from the Mohammed V University in Rabat, Laboratory of Geo-Biodiversity and Natural Heritage, Morocco, a good specialist in identifying and interpreting Late Cretaceous – Palaeocene marine palynomorphs from North Africa and Central Europe. This collaboration enables a good and efficient interpretation of the Upper Cretaceous marine microflora from the areas studied in the present research project, his implication becoming essential should ellements of marine phytoplankton (dinoflagellates) appear in the recovered assemblages, such being the case for the successions from the Romanian Eastern Carpathians and (apparently) for some in the Hațeg Basin as well.
- the new collaboration with M. Fabiańska from the Silesia University in Katowice, Natural Sciences Faculty, Sosnowiec, Poland, specialized in organic geochemistry. This cooperation was initiated when, during the multidisciplinary study of the Petrești succession, we decided to extend the array of investigations, using as first contact opportunity an Erasmus activity that involved a student of Daniel Țabără. Following this collaboration, the geochemical analyses (TOC, TC, GC-MS for n-alkans, sterans and hopans) for some of the samples collected from the field this year (the Petrești-Sebeș section, the Hațeg Basin, the Pluton-Pipirig area) were made in the laboratories of the Natural Sciences Faculty from Sosnowiec. The first results and their palaeoenvironmental interpretations based on the geochemical parameters obtained for the Upper Cretaceous deposits (Bozeș Formation) from the Petrești-Sebeș section are submitted for publication (see **1.10.**). Other 8 shale samples from the Pluton-Pipirig area are currently under analysis at the Silesia University, being part of other planned studies/publications.
- collaboration with S.L. Brusatte from the University of Edinburgh (UoE), Scotland, one that already has a lengthy history (e.g., Vremir et al., 2014; Csiki-Sava et al., 2015, 2016, 2018, in review), was planned from the project proposal stage. This collaboration is presently diversified and extended, by initiating at least two distinct lines of cooperation with UoE post-doctoral researchers: thus, O. Bertrand will take part in the analysis and description of an important kogaionid specimen from the Hațeg Basin (see **1.6.**), and she is already involved in the reconstruction and segmentation of CT scanning data of the specimen, and this collaboration will also extend onto other objectives foreseen for project stages II and III; and collaboration with G. Funston will involve creating a new, innovative, type of analysis, now to be applied to multituberculates for the first time, which includes a new combination of

osteohistological and geochemical approaches for identifying palaeoecological-palaeobiological parameters.

- the collaboration, also foreseen in the project proposal and having a lengthy history with noteworthy results (e.g., Csiki-Sava et al., 2018, in review), with J. Meng and M.A. Norell from the American Museum of Natural History, was and remains instrumental for the pro-bono acquisition of most of the CT (and, partly, SEM) imagery, as well as for access to specimens for comparisons. This collaboration is now extended by including the post-doctoral researcher F.-Y. Mao (also from the Institute of Vertebrate Palaeontology and Palaeoanthropology of Beijing, China), together with whom we will describe and interpret the kogaionid individual from Petrești (see **1.6.**) – a collaboration that already started through teamwork reconstruction, segmenting, and study of the CTscan, and integration of these data during the preparation of the manuscript. This collaboration is foreseen to extend for the future years, covering other objectives/thematics of the project that represent research topics of common interest.

- the newly started collaboration with I. Seghedi from the Institute of Geodynamics, Bucharest, together with whom we will study the bodies of igneous rocks of the Hațeg Basin that represented the objective of geochronometric analyses performed in 2021; some of the samples analyzed in 2021 were collected by our collaborator.

Activity 1.10.–Results dissemination – stage 1

According to the PAP, this main activity implies participation to national conferences with international attendance, and to international conferences, preparing manuscripts on the basis of the data acquired in stage 1, as well as giving public presentations related to the thematics of the project. Below, we will give a detailed account on the dissemination activities and the resulting deliverables.

Conference participation

As already mentioned in the Introduction, participating in conferences was also influenced by the pandemic conditions, as all such activities aimed for 2021 were transformed into online, virtual events. This modification required reassignment of pre-calculated funds, but not that of the actual activities, as deliverables. Thus, the members of the Multi-Brain project research team attended in 2021 the following conferences, in thematics directly related to the objectives and the activities of the project (the names of the research team members in **bold**; those of the important external collaborators, in *italics*):

The 22nd Conference of Mining, Metallurgy, and Geology (22. Bányászati-Kohászati-Földtani Konferencia), Cluj-Napoca (7-8 May):

A „kincses térkép" – lelőhelyek, dinoszauruszok és ősemlősök nyomában a Hátszegi-medence nyugati sarkában (The „treasure map" – hunting for fossil sites, dinosaurs and ancient mammals in the western corner of the Haţeg Basin) **(Csiki-Sava, Z.** *Botfalvai, G.*, Makádi, L., Albert, G., Magyar, J., Kocsis, L., **Ţabără, D.**, Bodor, E.R.)

35th IAS Meeting of Sedimentology, Prague, the Czech Republic (21-25 June):

Sedimentological investigation of the famous dinosaur localities in the westernmost part of the Haţeg Basin (*Botfalvai, G.*, **Csiki-Sava, Z.**)

18th Conference of the European Association of Vertebrate Palaeontologists, virtual conference (5-9 July):

Multies of the Dawn – the oldest multituberculate occurrences in the uppermost Cretaceous of Transylvania, and mosaic evolution within the Kogaionidae (**Csiki-Sava, Z.**, *Meng, J.*, *Vremir, M.*, **Vasile, Ş.**, *Brusatte, S.L.*, *Norell, M.A.*)

Sedimentological, geochemical and palaeontological investigations of Late Cretaceous (Maastrichtian) vertebrate fossil localities from the Vălioara Valley (Densuş-Ciula Formation, Haţeg Basin, Romania) (*Botfalvai, G.*, **Csiki-Sava, Z.**, Kocsis, L., Makádi, L., Albert, G., Magyar, J., Bodor, E.-R., **Ţabără, D**.)

13th Romanian Symposium of Palaeontology, Iaşi (16-17 September):

Palynological and organic geochemical analyses of the Upper Cretaceous Bozeş Formation at Petreşti (southwestern Transylvanian Basin) - palaeoenvironmental implications (**Ţabără, D.**, **Vasile, Ş.**, **Csiki-Sava, Z.**, **Bălc, R.**, *Vremir, M.*, Chelariu, M.)

Oldies but goldies – chronostratigraphic and evolutionary implications of the oldest records of kogaionid multituberculates in the uppermost Cretaceous of the Transylvanian area (**Csiki-Sava, Z.**, **Vasile, Ş.**, *Vremir, M.*, *Meng, J.*, Magyar, J., *Botfalvai, G.*, *Brusatte, S.L.*, *Norell, M.A.*)

Of Mice and Men, Maps and Magyarosaurs – rediscovery and significance of Kadić's forgotten dinosaur localities in the Haţeg Basin (**Csiki-Sava, Z.**, *Botfalvai, G.*, Magyar, J., **Ţabără, D.**, Albert, G., Makádi, L., Kocsis, L., Bodor, E.-R.)

New data on the Late Cretaceous microvertebrate assemblage from Petreşti-Arini (SW Transylvanian Basin, Romania) (**Vasile, Ş.**, **Csiki-Sava, Z.**, *Vremir, M.*, *Norell, M.A.*, Totoianu, R., *Brusatte, S.L.*, **Bălc, R.**, **Ţabără**, **D.**)

Micropaleontological investigation of an Upper Cretaceous section from Petresti locality (Transylvanian Basin, Romania) (**Bălc, R.**, *Bindiu-Haitonic, R.*, Kovecsi, S-A., *Vremir, M.*, **Csiki-Sava, Z.**, **Ţabără, D.**, **Vasile, Ş.**)

Other than these presentations, strictly connected to the objectives and activities of the project, two other (national, with international attendance) conference participations, producing results secondary to the activities of the project, include:

Ţabără, D., **Csiki-Sava, Z.**, 2021. Monocotiledonate din Cretacicul superior al Bazinului Haţeg (Monocotyledons from the Upper Cretaceous of the Haţeg Basin). The „Grigore Cobălcescu" Scientific Symposium, LX edition, Iaşi - online.

- Magyar, J., **Csiki-Sava, Z.**, Ősi, A., Botfalvai, G., 2021. *Magyarosaurus* vagy *Paludititan*? Új eredmények a Valiora környékéről (Hátszegi-medence, Románia) előkerült Sauropoda csigolyákról (*Magyarosaurus* or *Paludititan*? New results concerning the sauropod vertebrae discovered around Vălioara (Haţeg Basin, Romania). 24. Magyar Őslénytani Vándorgyűlés, online.

Publications

The following scientific papers, related to the thematic of the project, mentioning it in the acknowledgment section as source of funding, were published or submitted for publication (being under review at the moment this report was written):

1. Botfalvai, G., **Csiki-Sava, Z.**, Kocsis, L., Albert, G., Magyar, J., Bodor, E.R., **Ţabără, D.**, Ulyanov, A., Makádi, L., 2021. 'X' marks the spot! Sedimentological, geochemical and palaeontological investigations of Upper Cretaceous (Maastrichtian) vertebrate fossil localities from the Vălioara valley (Densuș-Ciula Formation, Haţeg Basin, Romania).*Cretaceous Research* 123: 104781. https://doi.org/10.1016/j.cretres.2021.104781. (ISI, ranked Q1 in 2020 inPalaeontology; IF 2.176)

2. **Csiki-Sava, Z.**, Andrăşanu, A., online first. Meeting Island Dwarfs and Giants of the Cretaceous – The Haţeg Country UNESCO Global Geopark, Romania.*Geoconservation Research* 4(2). http://dx.doi.org/10.30486/gcr.2021.1926581.1089. (BDI)

3. **Csiki-Sava, Z.**, Vremir, M., Meng, J., **Vasile, Ş.**, Brusatte, S.L., Norell, M.A., in review. Spatial and temporal distribution of the island-dwelling Kogaionidae (Mammalia, Multituberculata) in the uppermost Cretaceous of the Transylvanian area (western Romania).

Bulletin of the American Museum of Natural History.

4. **Țabără, D.**, **Vasile, Ş.**, **Csiki-Sava, Z.**, **Bălc, R.**, Vremir, M., Chelariu, M., in review. Palynological and organic geochemical analyses of the Upper Cretaceous Bozeș Formation at Petrești (southwestern Transylvanian Basin) – biostratigraphic and palaeoenvironmental implications. *Cretaceous Research*.

Besides these completed manuscripts, a series of other manuscripts are in the final stage of completion or are finished and will most probably be submitted for publication, according to our planning, in the first trimester of 2022. These manuscripts have no definitive titles or author collectives, therefore only the general field and the first author responsible for their coordination will be listed (all these manuscripts are under preparation and were also mentioned in the present report):

Bălc et al. – the micropalaeontological study and integrated stratigraphy of the Upper Cretaceous succession from Petrești

Csiki-Sava et al. – the description of the kogaionid individual from Petrești

Vasile et al. – detailed palaeontological and palaeoecological report on the Late Cretaceous microvertebrate assemblages from Petrești

Csiki-Sava et al. – the description of the kogaionid remains from the Late Cretaceous microvertebrate assemblages from Petrești.

Other thematics are in less advanced stages of execution, but they are also planned/projected to be completed during 2022. They regard the Upper Cretaceous deposits of the Romanian Eastern Carpathians, the andesites from Densuș, the newly-discovered fossil vertebrates from the Ciula Mică-Vălioara area, the palynological assemblages recovered from the continental succession of, or the stratigraphy of Upper Cretaceous marine deposits from, the western part of the Hațeg Basin.

Public conferences

During 2021, two public conferences were given (online) by Zoltan Csiki-Sava to the students from the Faculty of Geology and Geophysics, University of Bucharest (July 2021), and to the volunteers of the Țara Hațegului UNESCO Global Geopark (June 2021), also discussing and presenting results of the Multi-Brain project.

Furthermore, the ISI paper published in 2021 (Botfalvai et al., 2021) has received wide media and public attention through various mass-media channels, from press releases issued by the home institutions of the two main authors (The Hungarian Natural Sciences, Budapest, and

the University of Bucharest), with mentions in written press, online press, radio and TV (see a list of these media mentions as separate attachment).

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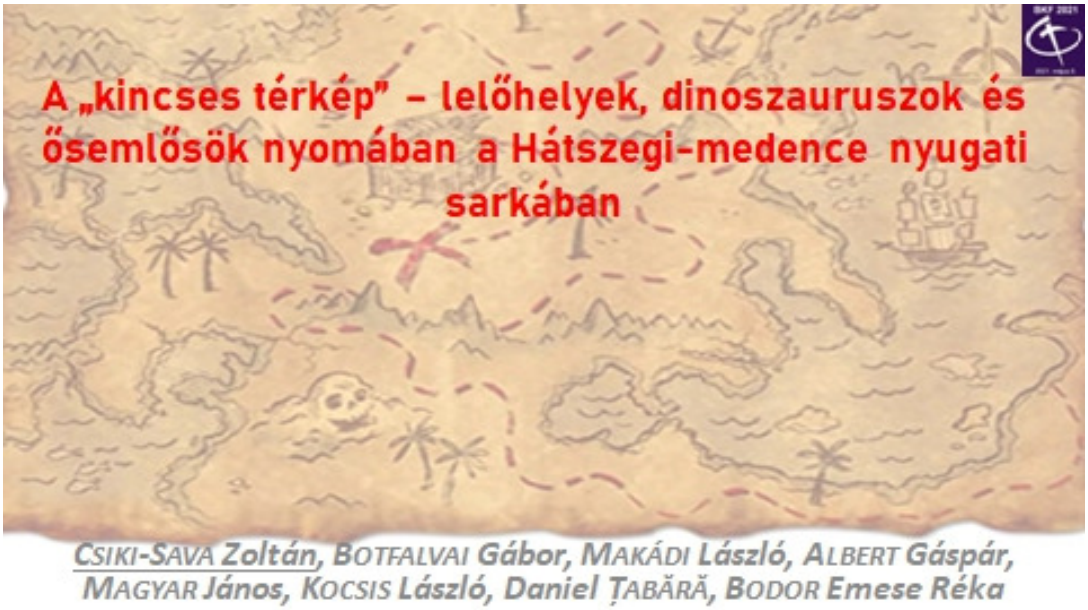
ANNEX – Presentations given at international scientific conferences in 2021

22nd Conference on Mining, Metallurgy and Geology



35th IAS Meeting of Sedimentology

SEDIMENTOLOGICAL INVESTIGATION OF THE FAMOUS DINOSAUR LOCALITIES IN THE WESTERNMOST PART OF THE HAŢEG BASIN

Gábor BOTFALVAI and Zoltán CSIKI-SAVA

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Thank you for your attention!

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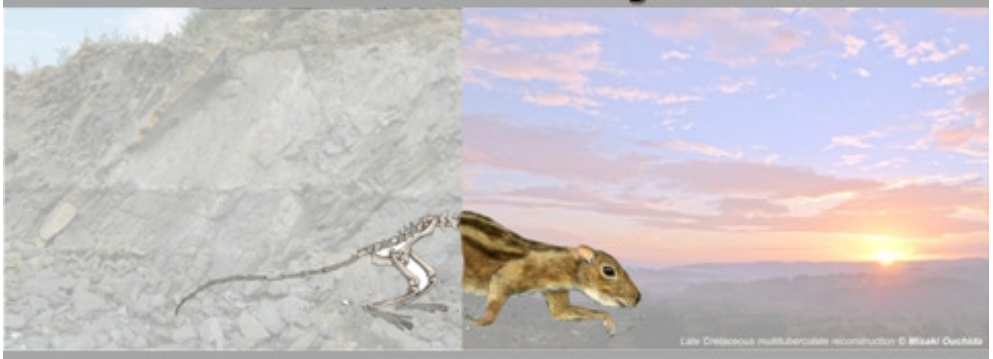
- Colleagues: Viktor Karsai, Attila Ősi, Pál Pellérdi, Réka Kalmár, Olga Pir, Timea Szilepák, Éva Fülöp, Kinga Szikoly

18th Conference of the European Association of Vertebrate Palaeontologists

MULTIES OF THE DAWN – the oldest multituberculate occurrences in the uppermost Cretaceous of Transylvania, and mosaic evolution within the Kogaionidae



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SEDIMENTOLOGICAL, GEOCHEMICAL AND PALEONTOLOGICAL INVESTIGATIONS OF LATE CRETACEOUS (MAASTRICHTIAN) VERTEBRATE FOSSIL LOCALITIES FROM VĂLIOARA VALLEY (DENSUŞ-CIULA FORMATION, HAŢEG BASIN, ROMANIA)

Gábor BOTFALVAI, Zoltán CSIKI-SAVA, László KOCSIS, László MAKÁDI, Gáspár ALBERT, János MAGYAR, Emese R. BODOR, Daniel ŢABARA

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Thank you for your attention!

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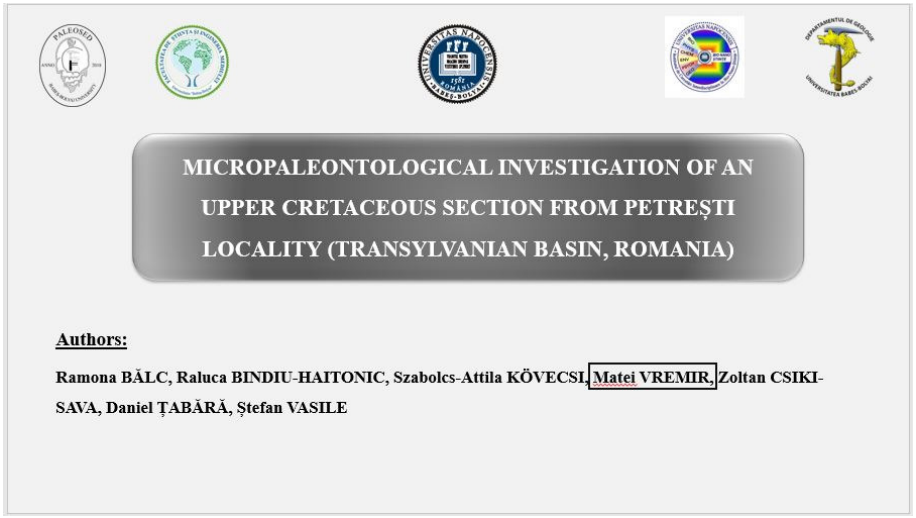
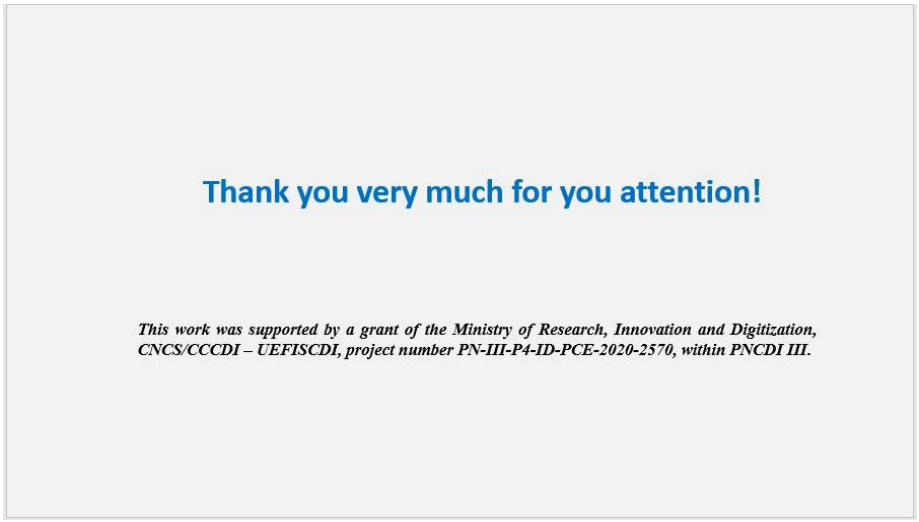
13th Romanian Symposium of Palaeontology





Thirteenth Romanian Symposium on Paleontology
Iași, 16-17 September 2021

Palynological and organic geochemical analyses of the Upper Cretaceous Bozeș Formation at Petrești (southwestern Transylvanian Basin) - palaeoenvironmental implications

Țabără, D., Vasile, Ș., Csiki-Sava, Z., Bălc, R., Vremir, M. & Chelariu, M.

Conclusions

- The palynomorph assemblage identified in the present study suggest a mid- late Campanian age for the Bozeș Formation, based on key fern spores and *Normapolles* taxa. The Sebeș Formation are palynological barren due to the dominantly oxidizing conditions during their sedimentation.
- The lower and middle part of the Bozeș Formation (Middle Campanian) is characterized by a palynological assemblage represented mainly by hygrophytic fern spores, which are consisted with plant communities growing in moist lowland habitats and warm climatic conditions. The Upper Campanian assemblage of the same formation included much more diversified early angiosperm communities, represented by *Normapolles* producing plants as well as ancestral Juglandaceae, and less significant free-sporing plant and gymnosperm communities. This picture of Upper Campanian vegetation suggests a co-existence of plants typical for fluvial to coastal areas, along with other palynofloral assemblages derived from higher altitude areas and cooler–wetter conditions.
- The palynofacies data, combined with geochemical data obtained for the lower and middle part of the Bozeș Formation, indicates that organic matter initially deposited in a transitional palaeoenvironment was subsequently transported on the slope to an outer neritic–distal area of the Late Cretaceous basin. The POM assemblage of the upper part of the Bozeș Formation is interpreted to reflect inner–middle neritic environment (proximal facies).

Acknowledgments: This work was supported by a grant of the Ministry of Research, Innovation and Digitization, CNCS/CCCDI – UEFISCDI, project number PN-III-P4-ID-PCE-2020-2570, within PNCDI III.

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Dedicated to Professor emeritus Leonard Olaru at his 85th anniversary

New data on the Late Cretaceous microvertebrate assemblage from Petrești-Arini (SW Transylvanian Basin, Romania)

Ș. Vasile, Z. Csiki-Sava, M. Vremir, M.A. Norell, R. Totoianu, S.L. Brusatte, R. Bălc, D. Țabără

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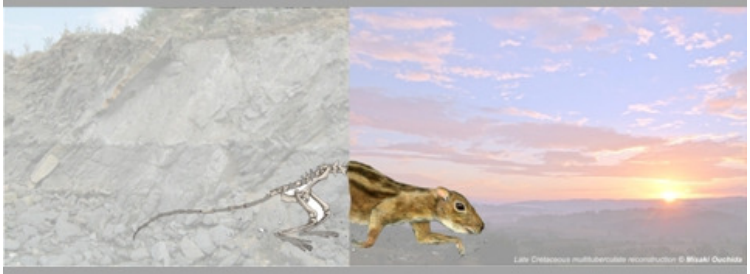

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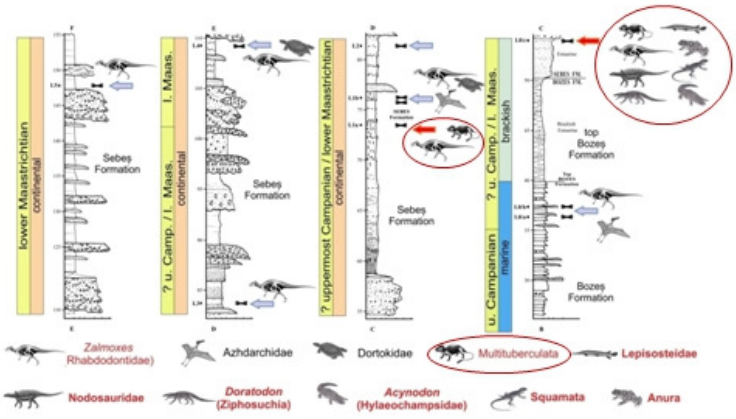
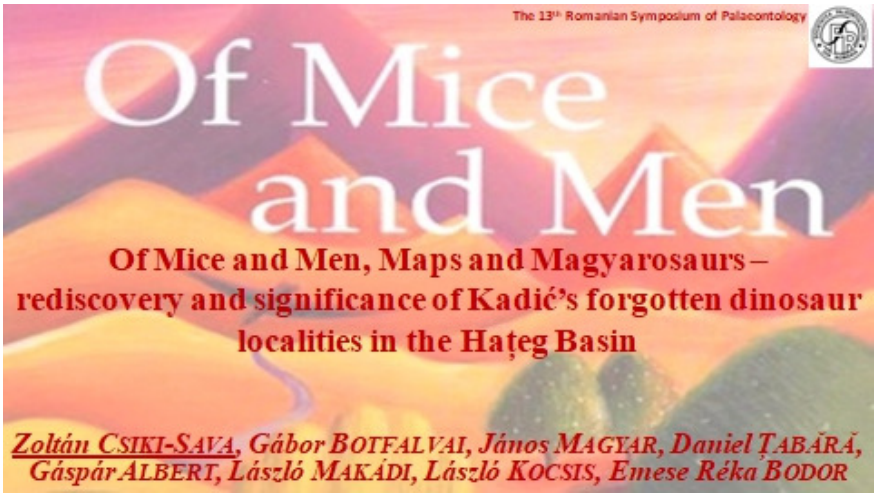
A succession of vertebrate-bearing levels



Vremir et al., 2015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