The latest Cretaceous terrestrial Șard Formation (Metaliferi sedimentary area and the adjacent zone of the Trascău Mountains) – landmarks in the history of knowledge

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Abstract. The present work highlights the main contributions to the understanding of the sedimentary area corresponding to the SE part of the Apuseni Mountains and the SW corner of the Transylvanian sedimentary basin. Throughout the evolution of studies, various geologists sketched various patterns regarding the superposition relationships of the Upper Cretaceous formations and have attempted parallels with coeval formations from other sedimentary basins, such as Hațeg and Rusca Montană. For the red beds-type deposits of the Șard Formation (sensu Codrea and Dica, 2005), various geological ages have been proposed, but the credible ones are those referring to the Late Mesozoic – (?) basalmost Paleogene time span. So far, a continuity into the Paleogene of this formation has not been clearly demonstrated in any studied section, probably also due to the erosional events that have affected the formation's top. The greatest problems in separating the formations in this perimeter were due to a misunderstanding of the tectonics and provenance of the sedimentary material. The Upper Cretaceous continental deposits in the studied area originated from two completely different areas. According to the study of pebble from alluvial/fluvial deposits, it was possible to identify a source area originating from the Trascău and Metaliferi mountains, and another one from the Sebeș-Lotru Mountains. The confusions were due to vertebrate fragments (dinosaurs, etc.) found in these sedimentary deposits, now in tectonic contact. Most likely, these rocks came into tectonic contact during Cenozoic time. The major fault separating these deposits is found at the confluence of the Secaș and Sebeș rivers, with a NW-SE orientation. This fault was also marked on maps by other authors, but they did not understand its significance.

Rezumat. Formațiunea continentală de Șard din Cretacicul terminal (aria sedimentară Metaliferi și zona adiacentă a Munților Trascău) – repere în istoria cunoașterii. Lucrarea de față punctează principalele contribuții la cunoașterea ariei de sedimentare aferentă porțiunii de SE a Munților Apuseni și a colțului de SV a bazinului sedimentar al Transilvaniei. Pe parcursul evoluției studiilor, diverși geologi au fomulat modele privind relațiile de superpoziție ale formațiunilor cretacic superioare și au încercat paralelizări cu formațiuni coevale din alte bazine sedimentare precum Hațeg și Rusca Montană. Pentru depozitele de tip red beds ale Formațiunii de Șard (sensu Codrea and Dica, 2005), diferite vârste geologice au fost propuse, însă de reținut drept credibile sunt cele care se referă la intervalul Mezozoic terminal – (?) Paleogen bazal. Deocamdată, o continuitate până în Paleogen nu a putut fi clar demonstrată pe nicio secțiune studiată, probabil și din cauza evenimetelor erozionale care au afectat coronamentul formațiunii. Cele mai mari probleme în separarea formațiunilor din acest perimetru s-au datorat neînțelegerii tectonicii și a proveniență materialului sedimentar. Depozitele continentale cretacic superioare din aria studiată au provenit din două areale total diferite. Conform studiului pe galeți din depozitele aluvial/fluviale s-a putut identifica o arie sursă cu proveniență din munții Trascău și Metaliferi, iar o alta din Munții Sebeș-Lotru. Confuziile s-au datorat fragmentelor de vertebrate (dinozauri, etc.) găsite în aceste depozite sedimentare, aflate acum în contact tectonic. Cel mai probabil, aceste roci au ajuns în contact tectonic în timpul Cenozoicul. Falia majoră ce separă aceste depozite se găseste la confluența dintre râurile Secaș și Sebeș, având o orientare NV-SE. Această falie a fost marcată pe harți și de către alți autori, doar că însemnătatea acesteia nu a fost înțeleasă.

Keywords: Metaliferi sedimentary area, Șard Formation, red beds, paleontology, stratigraphy, environments, Maastrichtian.
Cuvinte cheie: Aria sedimentară Metaliferi, Formațiunea de Șard, depozite roșii, paleontologie, stratigrafie, condiții de mediu, Maastrichtian.

The Șard Formation and the evolution on the geological knowledge in the area of SW Transylvania

This approach concerns the knowledge and clarification of the geological context of a highly challenging area of survey, i.e. the Metaliferi sedimentary area (Codrea and Dica, 2005; Codrea et al., 2010a,b,c) in the Transylvanian Basin. It is a portion in the south-western extremity of the basin, cut by the Mureș valley, nearby the south-eastern border of the Apuseni Mountains. In this area one can trace the incipient evolution of this sedimentary basin, which begins with the Bozeș Formation (Santonian-Maastrichtian), whose sedimentation ends with shallow-water marine deposits (Krézsek and Bally, 2006) and then deltaic, which can be well observed in the Stăuinii Valley and the Vințului Valley (under Zebernicului ruins), nearby Vurpăr, towards Hațegana. Disconformly, over this formation are the continental red-beds deposits of the Șard Formation (Maastrichtian- ?Paleogene; Codrea and Dica, 2005; = Sebeș Formation, in Csiki-Sava et al, 2016).

These red-beds have a particularly spectacular appearance in terms of their associated landscapes, the result of erosion, frequently differential, which has developed landforms of the hoodoo-type erosional pyramid type, reported in the geological literature as early as Koch (1900). They have also caught the attention of some non-geologists, the most remarkable representative being the famous writer Lucian Blaga (1965), who emphasized that 'My eastward area was surrounded by

the Coast with its vineyards and "red ravines", some bizarre geological formations like a fairy-tale architecture, or like a settlement of Egyptian temples, with flint and fire columns'.

Various points of view have been recorded regarding the geologic ages of these sedimentary deposits, issued from uncertainties resulting from gaps in our knowledge of the superposition/covering relationships with other formations. The chronostratigraphic patterns proposed by geologists of different generations can be summarized as follows: i. terminal Mesozoic, ii. Oligocene and iii. Miocene. It is worth mentioning that in the Transylvanian Basin the long-distance correlations between different formations are sometimes difficult to establish, due to the rarity of outcrops and the absence of clear marker levels in several situations.

A first detailed, systematic and unitary geological mapping of the territory of the Habsburg Empire started in the mid-19th century, initiated by the establishment of the Imperial and Royal Geological Institute (k. k. Geologische Reichsanstalt) in Vienna in 1849 (Pentelényi and Síkhegyi, 2010). However, some institutions (e.g., the Montanistischen Museum) were engaged in geological mapping of some of the territories even before the foundation of the above-mentioned institute. In 1856, Franz Ritter von Hauer carried out a survey for the general cartography of the Habsburg Empire at a scale of 1:288.000. Later, as a result of the geological mapping work, the same author published in Sibiu (at that time, Hermannstadt), the entire geological map of Transylvania at the scale of 1:576000 (Hauer, 1861), followed by the first geological monograph of Transylvania published in Vienna, entitled "Geologie Siebenbürgens" (Hauer and Stache, 1863, Korodi and Bartos-Elekes, 2016).

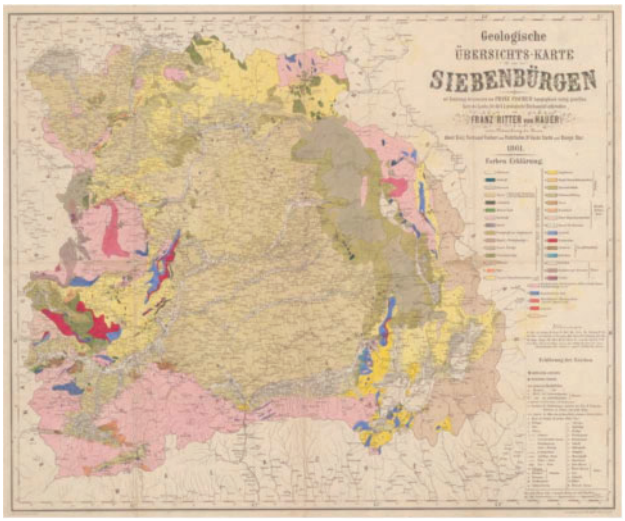

Figure 1. Geological map of Transylvania, 1:576000 (Hauer, 1861; Collection of the Library of Geological Studies, Austria; https://www.researchgate.net/profile/Negar-Alinaghi-2/publication/303689027/figure/fig71/AS:751189012525058@1556108825436/Geologische-Uibersichts-Karte-von-Siebenbuergen-1576-000-Hauer-1861-Source_W640.jpg)

The most remarkable achievement in terms of geological mapping is the Hauer, Štur, Stache (1863) comprehensive geological map of Transylvania at a scale of 1:288000, compiled in accordance with the above first-mentioned geological map and published in Vienna in 1863. The map is compiled based on the stratigraphic time scale classification system valid at that time (Korodi and Bartos-Elekes, 2016).

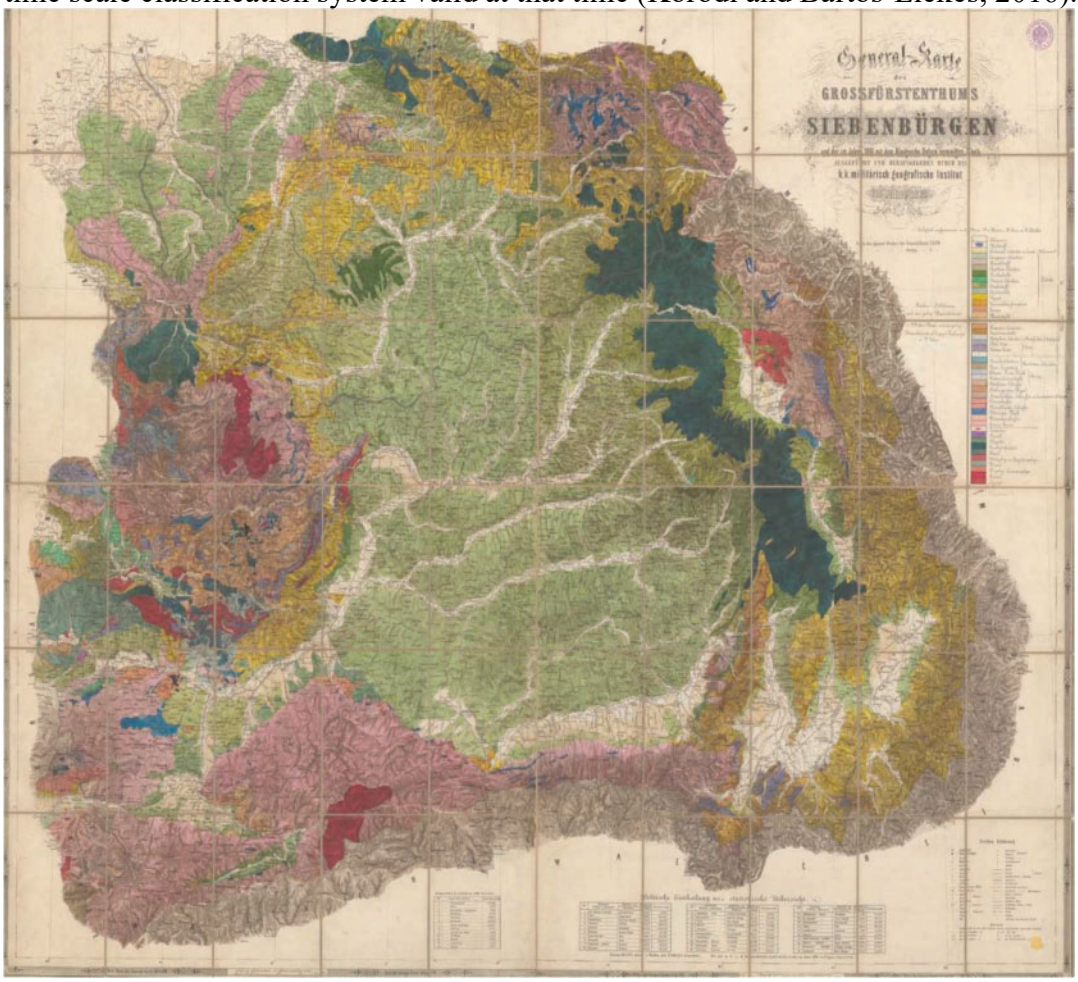

Figure 2. Geological map of Transylvania, 1:288,000 (Hauer et al. 1863; Collection of the Library of Geological Studies, Austria;

https://www.researchgate.net/profile/Eniko-Korodi/publication/305501862/figure/fig2/AS:667697562013707@1536202912929/Geologische-Uebersichts-Karte-von-Siebenbuergen-1288-000-Hauer-et-al-1863-Source_W640.jpg)

Among the early other mentions of the Upper Cretaceous sedimentary rocks in the specified area at the end of the 19th century one can mention the ones belonging to Hauer and Stache (1863) and Fischer (1887), who associate them with the Gosau facies. Herepey and Gáspár (1896) identified, probably in the 1860s, a sauropod bone at Bărăbanț (Alba-Iulia). The strata the bone originated from belongs to the Şard

Formation (latest Cretaceous - ?Paleogene) (Codrea and Dica, 2005; Codrea and Mărginean, 2007). Blankenhorn (1900) attributed the Upper Cretaceous sedimentary rocks to the Turonian-Lower 'Senonian' time range, based on the species of *Inoceramus schmidti*, considered indicative for the Lower Santonian. Subsequently, Pálfy (1902) and then Halaváts (1911), based on comparisons with fossiliferous deposits from Vidra and Vinţu de Jos, related them to the Turonian – 'Senonian' range.

Pálfy (1902), Roth Telegd (1906) or Halaváts (1911) considered the red beds to be Oligocene or Miocene, geological ages proven in the opinion of these authors by the presence of reworked calcareous boulders with *Nummulites fabianii* and alveolinides, together with other ruditic elements, collected from strata that reworked coarse detrital material or sandy clays, and by the presence of fragments of fossil bones of a presumed rhinocerotid, assigned by Koch (1894) as '*Aceratherium* cf. *goldfussi* KAUP'. The presence of oysters, noticed N and E of Alba Iulia by Halaváts (1911) and Lóczy (1918) (*Ostrea aginensis* and *O. digitalina*), justified the extension of the age of the red deposits up to the Lower Miocene level.

In these discussions, Antal (Anton) Koch's personality and geological experience has long played a heavy hanging role, with influences on other geologists. However, the vertebrate fossils associated by Koch with the "rhinoceros" taxon mentioned above were soon challenged by Nopcsa (1905a,b), who established that the fossil bones were in fact those of sauropod dinosaurs and not mammals. Consequently, he compared the red deposits with such remains with those from the Danian in the Haţeg Basin. At Râpa Roşie, Nopcsa reported the presence of a fragment of a sauropod ulna. Other fossil fragments were recovered from these deposits, belonging to sauropod, theropod and ankylosaurian dinosaurs. Bones and teeth of dinosaurs were also reported by him at Vurpăr, on the right bank of the Mureş valley. The bone fragments that were the subject of the systematic disagreements between Koch and Nopcsa were deposited at the evangelical college of Sebeş. They are no longer to be found in that collection, or in any other in that town (V. A. Codrea, personal observation).

On the right bank of the Mureş River, the Upper Cretaceous deposits has been identified at Vinţu de Jos (Pálfy, 1902), in the Ampoiului Valley (Roth Telegd, 1906; Gherman, 1943) and Geoagiu-Băi (Iacob, 1943).

Nopcsa (1905a,b) argues that after the marine sedimentation that occurred during the Campanian and probably early Maastrichtian, lacustrine, fluvial and alluvial sedimentation occurred from the Danian onwards. The continental red beds could be well observed in the Alba-Iulia - Sebeş area, where he identified some fossil fragments belonging to terrestrial representatives. The deposition of these deposits was greatly influenced by the topography of the mountain ranges and it can be assumed that there were large facies variations in the formation of these sediments. The Danian deposits are mainly characterized by mottled greenish and reddish clays, greenish and yellowish quartz sandstones and polymictic conglomerates with gallets of about 100 mm in diameter. The thickness of the sandstone and conglomeratic levels varies from 20 to 60 cm. Calcareous concretions and fossil vertebrate remains

occur in the clay layers. There have been various uncertainties about the facies association of these deposits with the 'Sânpetru Strata' in the Hațeg basin.

Macovei and Atanasiu (1934) mentioned in Danian a stage of regression in the Transylvanian Basin, which was then completely drained and dried up, after the sea had almost completely receded. The Maastrichtian on the western edge of this basin was the result of the presence of a channel along the Mureș Valley (in Teiuș - Deva area), passing through the Hațeg Basin. Although after the Maastrichtian most of the country's flooded territories were completely drained and returned to the continental domain, some regions, such as the southern edge of the Transylvanian Basin and the Hațeg Basin, were still covered by large areas of freshwater marshes and lakes, where torrential sedimentation processes occurred. At the end of the Maastrichtian, after the retreat of the seas, palm vegetation developed around the lakes and swamps that covered some regions in the south-western part of Transylvania. The sub-Hercynian and 'Laramian' tectonic pulses caused intense volcanic activities.

Ilie (1955) recognizes the presence of the Acvitanian (Early Miocene), on the left bank of the Mureș, in the region of Totoi, Hăpria, Drâmbari, Limba, Oarda, Lancrăm (Râpa Lancrăm), Sebeș (Râpa Roșie), Sibișeni, Pianu de Jos, Tărtăria and Cioara, argued on the basis of the numerous *Ostrea* valves ("*Ostrea aginensis* and *O. digitalina*") identified in the Bilagului Hill, near Alba Iulia. Previously, Károly Herepey's determinations of the *Ostrea* species (Herepey and Gáspár, 1896) showed that they are characteristic of the Acvitanian. The same authors also recognizes, in the Sebeș - Petrești - Pianu de Jos region, the presence of the Acvitanian on the basis of superposition relationships, where the Acvitanian formation discordantly covers the Upper Cretaceous and Paleogene marine deposits, being discordantly covered by Badenian ("Tortonian") marine rocks.

Ilie and Mamulea (1958) identified in the Pui region (Hațeg Basin) Eocene deposits with sandstones, conglomeratic sandstones, marls and gray-greenish clays and collected the only fossiliferous remains belonging to the *Palaeodictyon* ichnogene. They tried to demonstrate that the red beds considered as Danian by Nopcsa, which were identified at Pui (Hațeg Basin), would in fact show similarities with the red beds complex in the vicinity of Alba Iulia, which they considered as Acvitanian. Bizarrely, a similar point of view is recently found in Ilieș et al. (2020), who consider on their map the Pui red beds deposits as Paleogene, despite the Maastrichtian fossils reported in various papers (e.g., Codrea et al., 2002b, Itterbeeck et al., 2004, 2005).

Vancea (1960) made numerous geological profiles of a series of outcrops in the Transylvanian Depression. On the south-western rim of the sedimentary basin, Neogene sequences occur in south overlying the metamorphic basement of the Southern Carpathians, and transgressing to the west over the eastern edge of the Apuseni Mountains. Lower Miocene deposits have been reported on both banks of the Mureș Valley in the areas of Bărăbanț - Ighiu, Micești - Vințu, Totoi - Lancrăm, Sebeș - Sibișeni and Pianul de Jos – Tărtăria - Cioara, on the basis of fossiliferous remains of "*Aceratherium"* and numerous *Ostrea* shells identified by forerunners in

the La Față Hill (East of Alba-Iulia) (Koch, 1894) and in the Bilagului Hill (North of Alba-Iulia) (Halaváts, 1911; Lóczy, 1918). The author carries out general petrofacies studies on the Râpa Roșie (Sebeș) outcrop. This succession has been related to the Acvitanian and comprises interbeddings of red-colored rocks, consisting of gravels, gray and red sandstones, white or gray-greenish quartz sands and red-brownish clays.

Dimian and Popa-Dimian (1963) assert the existence of Maastrichtian red terrestrial sequences on the left bank of the Mureș, at Râpa Roșie. These deposits were attributed to the Maastrichtian red beds, based on the petrographic composition and the fossil content with dinosaurs Nopcsa (1905a,b).

Giușcă et al. (1967), in the construction of the geological map of Romania, folio 18 - Turda (L-34-XVIII), accepted the Oligocene (Pg3) age for the red beds cropping out around Alba-Iulia. These include marls and striped clays accumulated in a terrestrial lacustrine environment, sandstones and polymictic conglomerates with reworked Priabonian limestones with *Nummulites fabianii* and Alveolinae. The red beds are in turn overlain by lower Miocene marls. The red beds have been assigned to the Oligocene (Dimian, 1965) by correlation with the "Ticu Strata" (Răileanu and Saulea, 1956) of the NW sector of the Transylvanian Basin.

Bleahu and Dimian (1967) outlined the presence of the continental complex of variegated reddish deposits with typical molasse features in the area between Bilag Hill and Râpa Roșie, together with the area on the right bank of the Mureș (Șard, continuing southwards). The deposits were assigned to the Oligocene, being correlated with the "Ticu Strata" (sensu Răileanu and Saulea, 1956), based on the frequent reworkments of upper Eocene limestones with *Nummulites fabianii* and Alveolinae occurring in these deposits, specifying that they were certainly sedimented post-Priabonian.

Other authors who refer to the Upper Cretaceous sedimentary rocks of the mentioned area are Savu et al. (1968). They entirely related the deposits between Pianu de Jos and Pianu de Sus to the “Senonian", once the geological map 26 Orăștie L-34-XXIV, scale 1:200000, was printed. Based on stratigraphic arguments, they were associated with the "Gosau facies", emphasizing their lithologic content dominated by conglomerates, sandstones, marls and clays. They cover in unconformity the metamorphic basement of the Middle Dacides of the Sebeș Mountains, largely covered on their turn by Badenian and Sarmatian s.str. sequences. In this approach, some lithological (macro- and microscopic) and sedimentary structure (mechanoglyphs, bioglyphs) descriptions are specified, with a comparison between the lower and upper portions of the ”Senonian” sedimentary succession. The capping portion of the succession includes levels of conglomerates reworking metamorphic rocks, as boulders.

Mészáros et al. (1969) identified a ”striped series” (red beds), which corresponds to the upper portion of the "new striped complex" and is known as the "Râpa Roșie", which Koch (1900) had correlated it with the “Hida Strata” (Răileanu, 1955; Ilie, 1955; Bombiţă, 1971; Moisescu, 1975), but without providing arguments that would accurately attest such geological age. They consider that the red beds developed at Râpa Roșie belongs to the Acvitanian – Badenian (“Tortonian”) time

span, according to Koch's assumption. In fact, the Badenian ("Tortonian" in Marincaș, 1966) rocks are overlaping at Râpa Roșie the much older red beds.

Bucur (1970) carries out geophysical survey using gravimetric and seismic methods, establishing that the Cretaceous, together with the Paleogene and Lower Neogene sequences occuring of the rims of the Transylvanian Depression developed large thicknesses and lie discordantly over the surrounding mountain chains of the depression. These deposits were established by the author of the first period of the evolution of the depression (Carboniferous - Early Neogene).

Ciupagea et al. (1970) pointed out the presence of pre-Neozoic deposits occuring on the southern and south-western edges of the Transylvanian Basin, product of the intense erosion of the Mesozoic sedimentary and metamorphic Getic-Supragetic rocks of the Lotru, Cibin and Sebeș massifs, strongly tectonically uplifted. On the eastern edge of the Apuseni Mountains, a south-north oriented crustal fracture between Alba-Iulia and Turda is considered. In the south-western sector of the basin, on the northern slope of the Sebeș Mountains, the fracture is deep crustal. The fracture located between Alba Iulia and Șeica Mare uplifts Miocene deposits. The Upper Cretaceous (”Senonian”) deposits of the southern and south-western branch of the depression occurs transgressively on the northern metamorphic basement of the Sebeș Mountains, in the Sebeș-Alba area. At the base, there are clays and grayish marls, followed by coarse sands with conglomerate interlayers, and sandstones with sandy interlayers above. The terminal portion of the ”Senonian” sedimentary succession is related to polymictic conglomerates with rolled quartzite clasts, micaschists, gneisses. The Eocene and Oligocene sedimentary rocks are reported in the Alba-Iulia region only on the right bank of the Mureș River (Șard, Bărăbanț, Ighiu and Bilagului Hill) and appear transgressive over the Upper Cretaceous red beds. The Râpa Roșie succession consists of alternating gravels with micaschist, diabase, porphyrite and jasper clasts with white and red quartzite sands and brownish and greenish clays. These have been attributed to the ”Tortonian”, without any geological age argument.

Bleahu et al. (1981), in the guidebook of the B3 (Alba Iulia - Aiud) excursion of the Carpathian-Balkanic Congress, conceived a note on the superposition relationships of the successions on the left bank of the Mureș River, specifying that Miocene deposits are discordantly superposed on top of various Cretaceous and Paleogene sequences, but still without arguments on the geological age.

Săndulescu (1984) specifies some general elements on the Transylvanian Depression, mentioning its superposition over the Dacides and Transylvanides and the framing of its post-tectogenetic cover up to the Early Miocene.

Grigorescu (1987) claims the presence of at least two terrestrial formations in the SW portion of the Transylvanian Basin: i. the Upper Maastrichtian formation (with fragmentary vertebrate fossils) occurring in the Pâclișa - Vurpăr area; ii. the Oligocene formation in the N, E and SE of Alba Iulia at Ighiu, Șard, Hăpria, Ciugud, Oarda de Sus and Râpa Roșie. He considered that Cretaceous sedimentation lasted until the Early Paleogene. In his opinion, the taphonomic modes of the dinosaur fossils are different in Râpa Roșie, compared to the ones unearthed in Pâclișa -

Vurpăr area. The eroded appearance of the articular portions in long bones would argue for fluvial transportation by high energy currents during periods of flooding. The Cretaceous deposits were later completely eroded during the Paleogene sedimentary cycle, and the resulting deposits occupied extended areas. The areas uplifted by the Paleogene vertical movements, i.e. the deposits that were eroded, acted as source areas for the accumulation of Oligocene detrital material, represented by continental formations accumulated in depressional depocenters. The presence of Cretaceous reptiles reworked at Râpa Rosie, after their fossilization in Cretaceous deposits, led to the idea of classifying the continental deposits in the specified area to the Eocene - Lower Oligocene (Ypressian - Rupelian) time span.

The same author (Grigorescu, 1992), on the basis of the palynological content of the Pâclișa sedimentary rocks (Antonescu, 1973) and the reptile bones identified at Vurpăr by Nopcsa (1905a), correlates this terrestrial unit with the formations of the Hațeg and Rusca Montană sedimentary basins. He admits that in all these three regions there are volcanic products (tuffaceous levels interbedded in red terrigenous strata) resulting from the strong magmatism that accompanied the late Cretaceous ('Laramian') tectogenesis. He described the red beds exposed on the left bank of the Mureș River with reference to the deposits at Râpa Roșie, which are bearing red hematitic clays, red silty clays, greenish sandstones and medium-sized gravels. The rarity and long pre-burial exposure of bones (sauropods, theropods and ankylosaurians) of allochthonous origin (Grigorescu, 1987) led to the conclusion that the red beds at Râpa Roșie are of Oligocene or lower Miocene age, being covered by middle Miocene marine formations.

Ciulavu and Bertotti (1994) specify the existence of coarse conglomerates and sandstones in the Upper Cretaceous deposits of the northern slopes of the Southern Carpathians and in the eastern Apuseni Mountains. As for the Paleogene, sedimentation in the Transylvanian Basin was probably not continuous. The Upper Cretaceous sediments on the eastern slopes of the Apuseni Mountains underwent strong shearing that decreased in intensity towards the east. In view of insufficient data on the tectonic processes involved in the development of the Transylvanian Basin, the Upper Cretaceous-Paleogene deposits of the basin have traditionally been parallelized with the final tectonic phases of the evolution of the Apuseni Mountains and the inner part of the Eastern Carpathians.

Givulescu et al. (1995) recovered a sample of fossil seeds (*Mastixia amygdalaeformis*) from the Oarda de Jos exposure, on the right bank of the Sebeș River. The sample described provided new insights into the paleoclimate. The authors suggested the Upper Oligocene - Miocene time span, associated with a humid subtropical climate (Mai and Walter, 1985).

Huismans et al. (1997) admit that the structures (isoclinal folds) in the Upper Cretaceous sedimentary of the western Transylvanian Basin are overlain by clastic sediments of Miocene age, which in turn are covered by carbonate successions of Badenian age. The stratigraphic model was realized only on the basis of relative age determination due to insufficient stratigraphic dating.

Throughout the Cretaceous-Paleocene time span, a contractional event produced folded structures that were more intense in the western part of the basin (Ciulavu and Bertotti, 1994). The intense shearing phase followed the NNE-SSW direction on the ”Senonian” sedimentary. In most situations, sedimentation during the Paleocene in the Transylvanian Basin rises problems due to the lack of covenient deposits proved to belong to this age. The problem becomes even more difficult in the case of the constant reworking of clasts across the Paleocene.

Later, in the northwestern region of the Transylvanian Depression, Codrea and Săsăran (2002) confirmed that Cenozoic sedimentation begins inside the Jibou Formation (Popescu et al., 1978), which is considered a thick pile of red deposits (possibly, over 1500 m in type-area) developed in fluvial and lacustrine facies accumulated in the Upper Maastrichtian-Lutetian time span. Nopcsa (1905a,b) argued that the base of the Jibou Formation begins with the Maastrichtian, on the basis of dinosaur rib fragments and crocodilian and turtle fragments collected by himself in these deposits. Later, Codrea and Godefroit (2008) enriched this inventory with some vertebrae and a scapula fragment related to the dinosaur *Zalmoxes*, confirming through this discovery the age of the base of the Jibou Formation. The lacustrine deposits have been considered to belong to the "Rona Limestone" (Popescu et al., 1978) accumulated during the Paleocene (Thanetian - ?Sparnacian) (Gheerbrant et al., 1999).

Codrea and Vremir (1997) identified a well-preserved plastron fragment assigned to *Kallokibotion bajazidi* from the red-beds of Râpa Roșie. The fossil is interpreted as having probably been reworked from the Maastrichtian deposits and either transported over a short distance/duration or endured long transportation and fragmented before resedimentation. This discovery extended the range of this taxon, which at that time was known only from the Hațeg basin.

Jianu et al. (1997) described a small collection of Maastrichtian dinosaur bones presumed as reworked in the deposits considered Oligocene/Miocene from Râpa Roșie, in the collection of the Museum of Paleontology and Stratigraphy of the Babeș-Bolyai University, Cluj-Napoca.

Codrea et al. (2001a) brought to attention the first approaches to the sedimentary environments and architecture of Maastrichtian red terrestrial deposits, dividing the sedimentary zone of the SW Transylvanian Basin into two areas. The first area Vințu de Jos - Vurpăr - Pâclișa - (?)Șard comprises red alluvial plain deposits, with well-outlined channel fills, alternating with overbank deposits. In the second area between Oarda de Jos - Lancrăm – Sebeș, the deposits appear with obvious lacustrine tendencies. The red continental succession has been divided into two main architectures: the channels which belong to a fluvial system specific to braided streams dominated by sand and gravel, and the floodplain which is represented by lacustrine deposits with blackish greyish-black clayey siltstones and nodular-flattened calcretes. The depositional architecture is part of a braided flow system that developed in the mid-distal surfaces of alluvial fans. Active and dynamic tectonic factors contributed to the involvement of coarse solid loading and flow variability on the Upper Cretaceous sediments. The deposits of Râpa Roșie still

remain, considered to be of post-Priabonian age, overlying the Maastrichtian deposits of Lancrăm and Sebeș. The great thickness of the Upper Maastrichtian successions (ca. 2500 m) is the result of the convergence relationship between two cratons (Preapulian to the west and Getic to the south; Balintoni, 1997). Age determination was based on the superposition over the bedrock of the two cratons and the dinosaur vertebrate content in these Upper Cretaceous deposits.

Figure 3. Șard Formation at Vurpăr (outcrops at "Râpele din Susul Dumbrăvii", Alba County). (Foto: C. Cerchia)

Figure 4. General view of the site Sebeș Red Ravine, Alba County. (Foto: C. Cerchia)

Vremir and Codrea (2002) identified from the terrestrial deposits bearing dinosaur bones of the latest Cretaceous ("Lower Red Beds") a site that exposes dinosaur footprints, located NW of the village of Lancrăm, on the Sebeș Valley. The "lower red beds" expose a variety of channel facies, crevasse splays, and floodplains, lakes, and swamps (Codrea et al., 2001a,b; 2002a). The purpose of this discovery lies in its stratigraphic significance, highlighting the Maastrichtian age for the continental deposits with dinosaur vertebrates along the Sebeș Valley, which were initially considered Oligocene or Miocene.

Vremir (2004) provides an overview of the fossil turtles in Romania within a stratigraphic context. For the left bank of the Mureș River, such fossils are mentioned at Oarda de Jos ("lower red strata" - Middle and Upper Maastrichtian), Râpa Roșie ("Râpa Roșie Formation" - reworked terrestrial Maastrichtian bones), Teleac ("Râpa

Roșie Formation" – idem), Dealul Feței (Lancrăm, lower section of "Râpa Roșie Formation" – idem) and Secașului Valley (Lancrăm, upper section of "lower red strata" - Upper Maastrichtian).

Codrea and Dica (2005) divided the sedimentary succession exposed in the SW area of the Transylvanian Basin into three red terrestrial formations: i. Șard Formation (Late Maastrichtian – Priabonian), ii. Bărăbanț Formation (?Rupelian – ?Upper Egerian), and iii. Sebeș Formation (? Late Egerian – Ottnangian), with two marine formations intercalated: Ighiu Formation (Late Priabonian – Lower Rupelian; = Merian) and Sântimbru Formation (Late Egerian – Aquitanian). The sedimentary zone corresponding to the Upper Cretaceous – Lower Miocene time span, which includes the Alba Iulia – Sebeș – Vințu de Jos region, has been named the "Metaliferi Area". Until then, the in-situ fossils (plants and vertebrates: dinosaurs, crocodilians, and turtles) were known only in certain regions where the Vurpăr and Șard formations are cropping out. On the left bank of the Mureș River, the authors mention the affiliation of the red beds to the "Șard Formation" for the Sebeș – Lancrăm – Oarda de Jos area, based on vertebrate remains such as dinosaurs, crocodilians, and turtles, which indicate an autochthonous condition. The Șard Formation has been paralleled with the NW part of the Transylvanian Depression (Jibou Fm., Maastrichtian – Bartonian; Popescu et al., 1978; Valea Nadășului Fm., Popescu et al., 1978, and the base of Cluj Limestone, Priabonian, Popescu et al., 1978), and its base possibly including latest Cretaceous succession, with the formations of this age from the Hațeg Basin. The red beds from Râpa Lancrămului and Râpa Roșie has been related to the Sebeș Formation (Marinescu et al., 1998), according to the geological map made for the Alba Iulia – Sebeș – Vințu de Jos area, aged ?Burdigalian (?Eggenburgian-Ottnangian). The authors considered that the fossils found in the Sebeș Formation were reworked: all dinosaur and other reptile fossils are likely derived from the Șard Formation (Maastrichtian – Priabonian) or Vurpăr Formation (Early Maastrichtian); the limestone boulders with nummulites recorded at Râpa Roșie were considered as originating from the Ighiu Formation (Priabonian – Rupelian), and oyster fragments are likely derived from the Sântimbru Formation (Aquitanian).

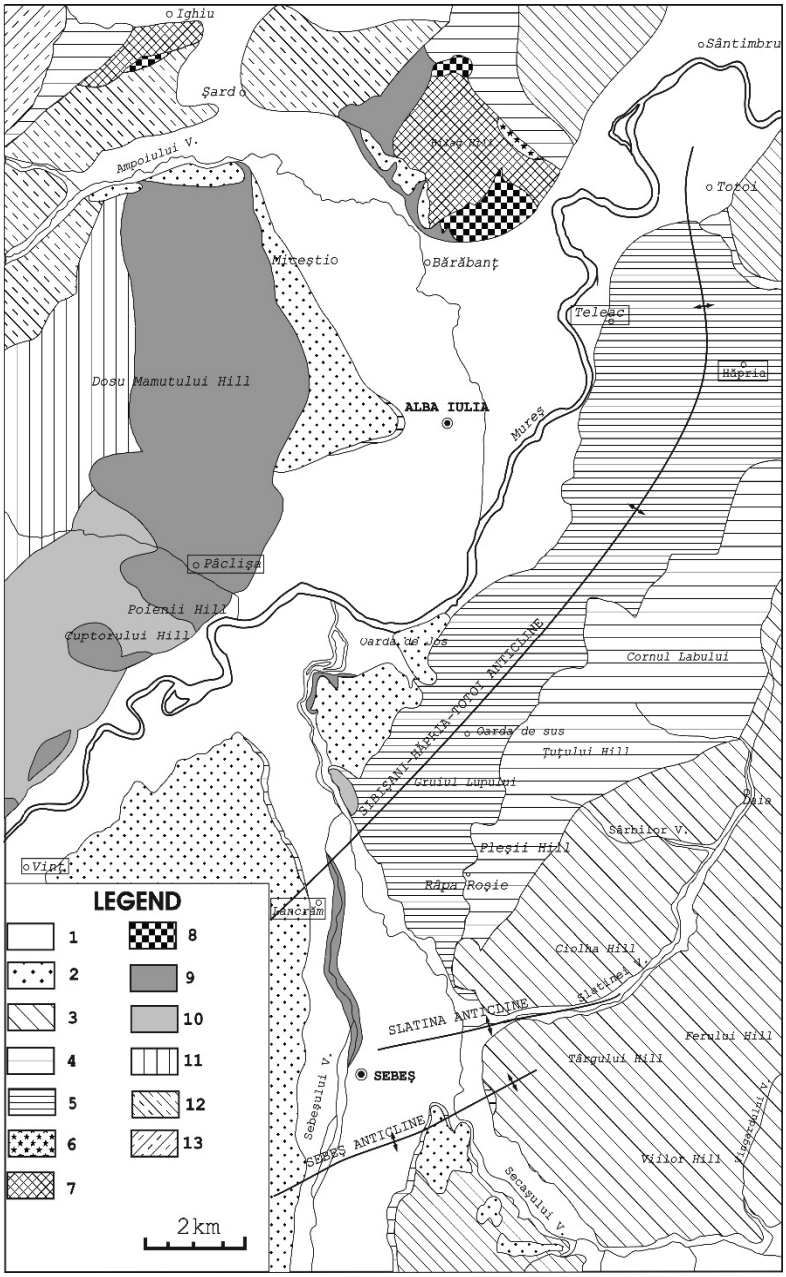

Figure 5. Geological map of Alba Iulia – Sebeş – Vinţu de Jos area, SW Transylvanian Basin (from Codrea and Dica, 2005):
1. alluvia;
2. lower terrace;
3. Pannonian *s.str.*;
4. Badenian;
5. Sebeş Fm., ?Burdigalian;
6. Sântimbru Fm., Aquitanian;
7. Bărăbanţ Fm., Rupelian – Chattian;
8. Ighiu Fm., Late Priabonian – Early Rupelian;
9. Şard Fm., Maastrichtian - Priabonian;
10. Vurpăr Fm., Early Maastrichtian;
11. Bozeş Formation, Santonian-Maastrichtian;
12. Aptian – Albian;
13. Barremian – Aptian.

Iamandei et al. (2005) described, from the red terrestrial formation (Oarda-Lancrăm and Râpa Roșie areas), the abundance of gymnosperm and angiosperm fossils associated with the mesophytic flora specific to the tropical climate, with very arid episodes during the Maastrichtian. They firstly described from the paleoflora of Romania a new taxon called *Telephragmoxylon transsylvanicum*, a conifer that probably belonged to the forest assemblages specific to the emerged areas of the Maastrichtian in Transylvania.

Therrien (2005) makes certain clarifications on the paleoenvironmental, paleoclimate and paleofauna conditions of the Maastrichtian "Red Continental Strata" from Vurpăr, suggesting the deposition of these successions through meandering rivers. These are dominated by red mudstone sequences with highly variable paleocurrent directions. Channel deposits are characterized by inclined heterolithic strata with paleocurrent indicators oriented perpendicular to the dipping strata. In the author's observations on the Densuș-Ciula Formation and the Pui beds in the Hațeg Basin, the fluvial system presents deposits specific to less sinuous rivers (braided rivers) compared to the deposits at Vurpăr. The warm and monsoonal paleoclimate characterized by seasonal precipitation is provided by the presence of pedogenetic features (iron oxides, rhizocretions and slickensides).

Krézsek and Bally (2006) conduct a lithostratigraphic analysis of the Upper Cretaceous (Santonian – Maastrichtian) sedimentary deposits in the Transylvanian Basin, which were deposited in deep and shallow marine environments as well as in continental environments in variable thicknesses (from a few hundreds to more than 1000 m). Based on regional seismic, stratigraphic, and sedimentological data, the sedimentary cover of the basin was divided into four megasequences corresponding to the Upper Cretaceous (rift megasequence), Paleogene (sag megasequence), Lower Miocene (flexural megasequence), and Middle-Upper Miocene (back-arc megasequence). At the end of the Upper Cretaceous megasequence, widespread terrestrial sedimentary piles were formed.

Codrea and Venczel (2008) mentioned the presence of a sauropod caudal vertebra (*Magyarosaurus*) at Râpa Roșie, considering that it was reworked from the underlying Șard Formation (Maastrichtian-Priabonian) to the Sebeș Formation (Lower Miocene). In this context, the red layers were considered younger than the Cretaceous, Paleogene, or Lower Miocene formations, but older than the Badenian ones. For this purpose, the red layers were included in the "Sebeș Formation," and Râpa Roșie represents a typical section of this formation. The red layers are then overlain by the lower Badenian conglomerates.

Delfino et al. (2008) described a skull from the Maastrichtian at Oarda de Jos that belongs to the taxon *Allodaposuchus precedens* Nopcsa. In comparison to the skull fragment that is the type specimen described by Nopcsa (1928), this fossil is by far much more complete, preserving a considerably greater number of characters. The preservation state allows to consider that the fossil could not have been reworked, being in situ. Cladistics confirm the phylogenetic hypotheses based on the fragmentary holotype from the Maastrichtian of Vălioara (Hațeg Basin), as well as on remains from quasi-contemporary localities in Spain and France.

Vremir et al. (2009) identified in the Sebeș – Alba region two fragments that can be attributed to pterosaurs: an incomplete and heavily crushed fragment of a fore limb bone belonging to a large-sized form from the coastal/brackish facies of the Upper Campanian/Lower Maastrichtian at Petrești-Sebeș, and a very large cervical vertebra from the Maastrichtian of Râpa Roșie - Sebeș. The Azhdarchid specimen from Râpa Roșie in the so-called "Sebeș Formation" was found in situ, in para-autochthonous condition, from channel fill deposits (conglomerates and coarse sandstones), associated with well-preserved hadrosaur, sauropod, chelonian, and crocodilian bones. In these circumstances, given the fragility of the fossil in question, any form of reworking from older formations (e.g., Vurpăr and Șard Fms.) was excluded, and the succession at Râpa Roșie was therefore also classified as Maastrichtian.

The absence of conclusive fossils from the deposits at Râpa Roșie, attributed to the "Sebeș Formation," has provided inaccurate information about their age. Consequently, Solomon et al. (2010a,b) attributed to the Maastrichtian the continental deposits at Râpa Roșie, considering the gigantic azhdarchid pterosaur cervical vertebra identified by Vremir et al. (2009). They also demonstrated that the limestone clasts found in the continental red beds at Râpa Roșie actually originate from gravitational fall from the base of the Badenian marine transgression that covers the Maastrichtian continental deposits, and therefore, these clasts do not constitute elements deposited coeval to the accumulation of the red beds. They are nothing more than the result of an actual burial process, by rain erosion. Consequently, the Paleogene age of the uppermost portion of the red bed deposits at Râpa Roșie has been excluded.

Codrea et al. (2010a) published a synthetic study of the dinosaur fauna in the regions around the localities of Alba Iulia, Jibou and in the Rusca Montană sedimentary basin, proving the correctness of Nopcsa's assumptions. Most of the taxa identified by Nopcsa in the Hațeg Basin are also present in the Șard Formation. In the same year, Codrea et al. (2010b) emphasize that the continental sequence at Râpa Roșie also belongs to the Maastrichtian and to the Șard Formation based on the cervical vertebra of an azhdarchid pterosaur and other reptile bones (Vremir et al., 2009), which show no signs of reworking.

Codrea et al. (2010c) reported dinosaur remains from the Metaliferi area, having similarities with the Hațeg Basin, with the aim of interpreting the paleoenvironments and paleogeography of the Late Cretaceous in Transylvania. In the diversity of terrestrial vertebrates, new identified fossil materials of already known taxa have been added, attributed to dinosaurs (Sauropoda: Sebeș, Oarda de Jos, and Lancrăm; *Telmatosaurus transsylvanicus*: Lancrăm and Oarda de Jos; *Zalmoxes, Strutiosaurus*: Vurpăr; Velociraptorinae or Theropoda *incertae sedis* and egg shell fragments: ?*Pseudogeckoolithus* and Megaloolithidae), crocodilians (*Allodaposuchus precedens*: Oarda de Jos), turtles (*Kallokibotion bajazidi*: mostly from Oarda), fish (Lepisosteidae), amphibians (Albanerpetontidae), lizards, and mammals (the multituberculates Kogaionidae, extremely frequent at Oarda de Jos).

Vremir (2010) highlights several stratigraphic aspects regarding the relationships of marine and terrestrial deposits in the Sebeș region and along the Sebeș Valley, or on other localities on the left bank of the Mureș Valley. The red beds are considered to belong to the "Sebeș Formation" (Maastrichtian) which concordantly overlays the flysch deposits of the Bozeș Formation (Campanian – Lower Maastrichtian) in the Petrești area or directly on the magmatic basement of the Supragetic Nappe. Among the sites identified with latest Cretaceous vertebrates in the Sebeș area are: Petrești (PT) in the "Sebeș Formation" and the marine-wetland transition at the top of the Bozeș Formation; Sebeș-Glod (SbG/A-D) which represents the lower part of the "Sebeș Formation" (terminal Lower Maastrichtian); Dealul Secaș-Feților (SFH/A-C) which represents the lower-middle section of the "Sebeș Formation" and the transition from the middle to the upper part of the same formation at Râpa Lancrămului; Lancrăm (Lc/A-D) which corresponds to the lower-middle part of the "Sebeș Formation" correlate with the previous profile; Oarda de Jos (Od/A-C) which corresponds to the middle profile of the "Sebeș Formation" considered as fluvio-lacustrine and overbank facies; Râpa Roșie (RR) which represents the middle-upper section of the "Sebeș Formation" and Râpa Lancrămului (RL), which is situated on the Viilor Hill, as the upper part of the same formation.

Grigorescu et al. (2011) recognize the affiliation of the red beds at Râpa Roșie to the Upper Maastrichtian, providing a brief note on the facies and depositional architectures as well as the fossil content. The succession was divided into three sections (the lower part with fine red layers with intercalations of channel fills, the middle part with superimposed coarse red or gray channels, and the upper one with fine red sandy deposits, conglomeratic sandy deposits, sandy conglomerates, and silty muds), all of which are discordantly covered by the Miocene marine deposits. Fossil vertebrates are not particularly abundant, many of them being isolated and fragmented.

Maris (2012) redacted a facies and architectural study of the Șard Formation, investigating the outcrops from the right bank of the Ampoi Valley. Twelve types of facies (Gmm, Gcm, Gh, Gp, Sm, Sh, Sp, Sr, Fr, Bk, Bt, and K) were identified, grouped into seven facies associations (channels, rudaceous and arenaceous bars, rudaceous sheets, arenaceous sheets/lenses, lateral accretion of point bar, crevasse splay, and overbank). The discussed Maastrichtian red continental deposition is typical of the braided river alluvial depositional system, evidenced by the predominance of rudaceous elements in the succession, the high degree of clast roundness, poor sorting, and the presence of compact sedimentary deposits. For this area on the right bank of the Ampoi Valley, the red beds includes sedimentary material originating from the source area of the Southern Apuseni Mountains.

Codrea et al. (2012a) reported the presence of multituberculate teeth from the Kogaionidae family in the Metaliferi sedimentary area (the microvertebrate remains lens from "Oarda A" called ODAN, from Oarda de Jos, Șard Formation, Maastrichtian), alongside those previously identified in the Hațeg and Rusca Montană basins (Codrea et al., 2010a). Codrea et al. (2014) reported the new species of the genus *Barbatodon, B. oardanensis*. The family Kogaionidae is restricted to

the Maastrichtian – Paleocene time span. This find supplements the systematic biodiversity of the Maastrichtian fauna in the Metaliferi area. The Kogaionids from the Late Cretaceous are known only in Romania. The morphology of the teeth is markedly different from those of the Lower Cretaceous ones of Europe. The latest Cretaceous age of the rocks at Oarda de Jos is beyond any doubt.

Codrea et al. (2012b) proposed the necessity of a geopark in Alba County for the purpose of protecting the geological heritage, unique in Europe. The protected area will include several locations where Maastrichtian deposits are rich in vertebrate fossils. So far, however, only one reserve is legally protected, the Râpa Roșie with the red beds belonging to the Șard Formation.

Brusatte et al. (2013) reported the type specimen of *Balaur bondoc* (partial skeleton, lacking the skull and certain limb bones), relatively well-preserved, in the Late Cretaceous deposits of the "Sebeș Formation", in the locality of Sebeș-Glod. This holotype was considered a typical theropod specimen of the Late Cretaceous in Europe, and a critical synthesis on the evolution of dinosaurs in Europe was also drafted. Unfortunately, the holotype in question is missing both femurs, which would have clarified a differentiation or, conversely, a synonymy with *Elopteryx nopcsai* (Stoicescu et al., 2024).

Vremir et al. (2013) described a new taxon of azhdarchid pterosaur (*Eurazhdarcho langendorfensis*), identified at Sebeș-Glod (1.5 to 3 km north of Sebeș), on the Sebeș Valley, from the Maastrichtian deposits ("Sebeș Formation"). This discovery suggests that azhdarchids were reptiles that lived in continental environments (forests and river plains) that were not necessarily associated with marine coastal habitats. It remains to be more solidly argued whether the fossil materials from Sebeș-Glod (SbG/B) and Râpa Roșie are certainly quasi-contemporaneous, to support the stratigraphic understanding of the continental successions. The Maastrichtian vertebrate-bearing continental deposits have been referred to either as the recently redefined "Sebeș Formation" or as Vurpăr Formation and Șard Formation. "Sebeș Formation" is described here on the Sebeș riverbed as a continental succession consisting of alluvial deposits with red, brown, gray-blue clays, poorly sorted conglomerates with intercalations of red and gray stratified sandstones. Sedimentation occurred through proximal alluvial fans to meandering and occasionally braided distal river environments, which locally expose wooded lakes and swamps and extensively floodplain deposits. The same authors mention that the fluviopaludal facies from the Petrești-Arini locality appears at the top of the Bozeș Formation (Campanian – early Maastrichtian).

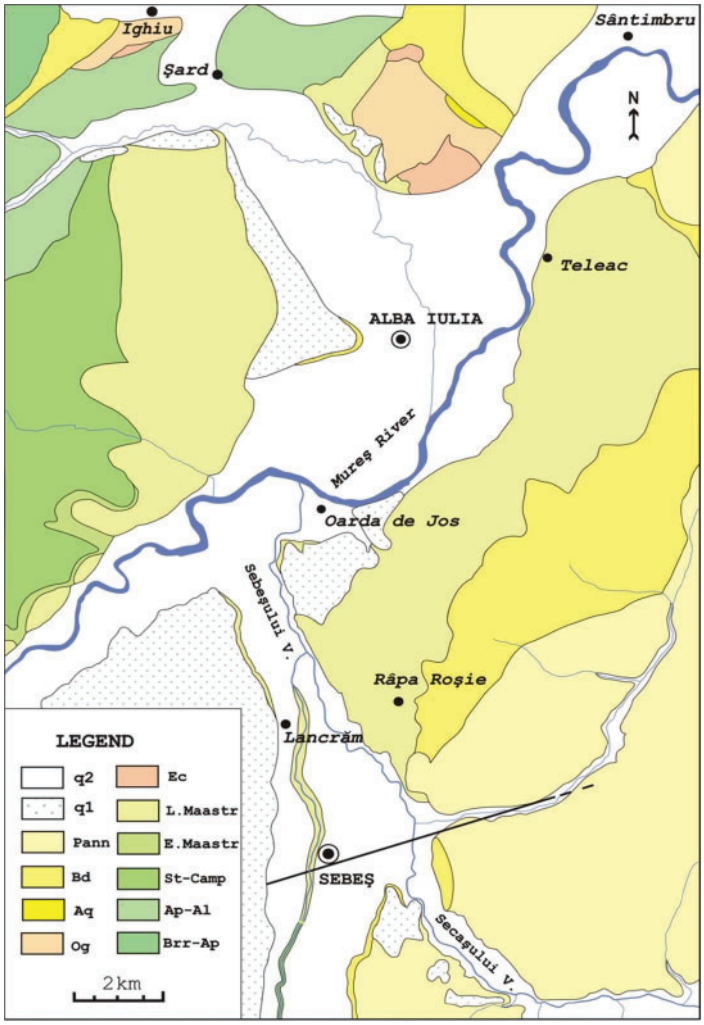

Figure 6. Geological map of the sedimentary area Metaliferi, including the localities with Maastrichtian vertebrates (from Codrea et al., 2012b).

Legend:
Brr-Ap. : Barremian – Aptian
Ap-Al : Aptian – Albian
St-Camp : Santonian – Campanian
E. Maastr : Early Maastrichtian
L. Maastr : Late Maastrichtian
Ec : Eocene
Og : Oligocene
Aq : Aquitanian
Bd : Badenian
Pann : Pannonian s.str.
q1, q 2 : Quaternary

Codrea et al. (2013) published a reexamination of the facies aspects and fossil content of the Maastrichtian sedimentary successions at Oarda de Jos (Oarda A and Oarda B). In general, the deposits exhibit a distinctive appearance due to their more restricted lateral and vertical facies extensions, which evolved from local environments (e.g., ox-bow lakes or abandoned channels). The red clays appear interbedded between channels filled with microconglomerates and sandstones. The channels are in lens geometry (approximately 4 m laterally extended and 1 m thick), filled with a light-colored fine sediment that appears at the top of the Oarda A succession. This deposit vanishes laterally until it completely transitions to the red mudstones. Above the channel bed, a layer of calcrete with diameters of a few centimeters appears, having been remobilized from its original position by ephemeral water currents. The Maastrichtian fluvial deposits at Oarda de Jos are defined as belonging to poorly drained floodplains. Rainy seasons have contributed to the occurrence of episodic water flows over these deposits. The deposits are fossil-rich in this area compared to the red beds recorded in the rest of the Metaliferi region. Being different from other deposits, the succession at Oarda de Jos contains

microvertebrates, vertebrates, eggshells, carapaces, and some invertebrates. The bones are generally black, indicative of relatively rapid burial after the animals' death. Some fossils are indigenous, originating from associations that frequented the site, while others were transported over shorter or longer distances.

Vremir et al. (2014) conducted studies in the Bozeș Formation in the Petrești-Arini area, identifying species of palynoflora and micro/macrofauna. Based on these, the formation in question is allocated to the same age (Santonian – Lower Maastrichtian) initially proposed by certain forerunners (Dimian and Popa-Dimian, 1963; Tomescu et al., 1969; Marincaș and Mânecan, 1971; Marincaș, 1973, and Antonescu, 1973). Recent studies based on calcareous nannofossil assemblages have indicated only the Santonian – Campanian interval for the Bozeș Formation in the northern area of the Sebeș Mountains, where the Upper Campanian – Lower Maastrichtian interval (CC22 and CC23 zones) was absent (Bălc et al., 2007, 2012; Bălc and Zaharia, 2013). The authors, considering the continuous sedimentation in the Petrești – Arini section, between the marine deposits of the Bozeș Formation and the overlying continental deposits of the "Sebeș Formation", were able to conclude that the deposition of the vertebrate-bearing continental successions of the "Sebeș Formation" took place sometime in the Upper Campanian – Lower Maastrichtian time span.

Vremir et al. (2015a) synthesized the data about the latest Cretaceous vertebrates from the Sebeș area, based on stratigraphic context, relative age, fossil content, taphonomy, and paleoenvironments. The synthesis focused on the top of the Bozeș Formation and the "Sebeș Formation", including the Vurpăr Formation (Lower and Upper Maastrichtian). The main mention will focus solely on the stratigraphic aspects of the deposits in the so-called "Sebeș" sedimentation area . The stratigraphic scheme proposed by the authors is summarized as follows: a) "Săsciori Formation" (= "Sebeșel Formation"; Santonian), which is unconformable disposed on the metamorphic basement of the Getic - Supragetic series and is concordant with the Bozeș Formation, exposed to the South and Southwest of Sebeș; b) "Sebeș Formation" ("Râpa Roșie strata" and the upper third of "Vurpăr Formation" or "*Sabal major* strata"; latest Campanian – latest Maastrichtian/?Paleocene), which is concordantly overlying Bozeș Formation, exposed on the left bank of the Mureș Valley between the Cugir Valley (the locality of Vinerea) to the South and the locality of Teleac to the North, and on the right bank of the Mureș Valley, between the localities of Vurpăr and Șard; c) "Șard Formation" (Priabonian), which is concordantly subjacent to "Ighiu Formation" exposed on the Tuiuș Valley, North of Bărăbanț and in the Ighiu – Cricău area; and d) "Bărăbanț Formation" (Rupelian - ?Chattian) which discordantly overlies "Ighiu Formation" being exposed in the Ighiu area, the Dâmbului Rotund and Bilagului hills, and North of Bărăbanț. The authors concluded that in the Sebeș area, a large part of the Paleocene-Eocene deposits are missing, and then two continental formations were combined together in a context of similar facies and different tectono-stratigraphy ("Sebeș Formation" – Maastrichtian in the lower part and "Șard Formation" in the upper part). The facies

similarity often creates confusion regarding the context of establishing the Upper Cretaceous age of the continental successions.

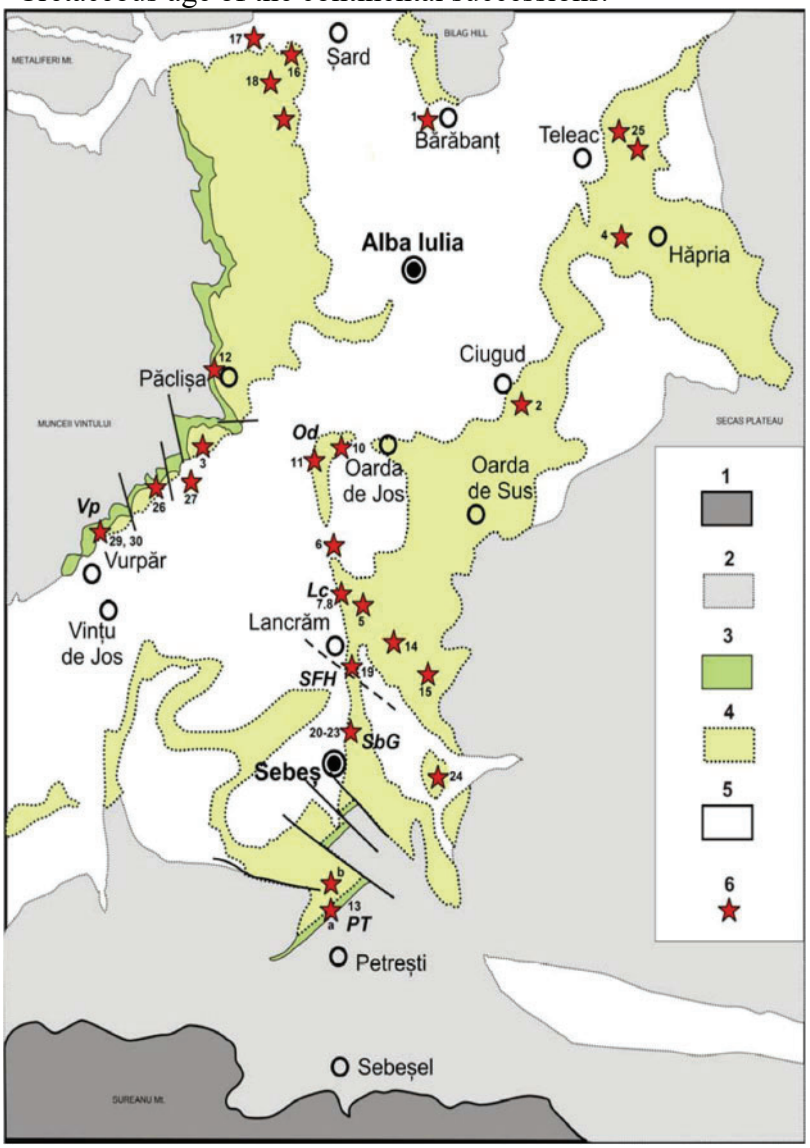

Figure 7. Simplified geological map of Sebeș area (according Vremir et al., 2015a).

Legend:
1. Metamorphic basement
2. Neogene sedimentary cover of the Transylvanian Basin;
3. Terrestrial deposits of transition latest Campanian – Lower Maastrichtian
4. Terrestrial deposits, Maastrichtian
5. Quaternary river terraces and alluvia
6. Fossiliferous localities

Vremir et al. (2015b) identified the presence of a lens rich in vertebrates belonging to a brackish environment in the Petrești area. The preliminary study showed the presence of faunal assemblages with fish, amphibians, lizards, crocodilians, dinosaurs, pterosaurs, turtles, and multituberculates. Based on all the faunal assemblages collected between 2012 and 2014 from various lenses, within the Petrești-Arini section there are two boundaries: Campanian/Maastrichtian and Bozeș Formation/"Sebeș Formation", transitioning through the brackish deposits.

Solomon et al. (2015) provided an overview of the most important discoveries of Mesozoic multituberculates in Europe that evolved from the Late Jurassic to the Paleocene, focusing on those from the Kogaionidae family in the so-

called ”Haţeg Island" of the Late Cretaceous. The most remarkable occurrence of multituberculates in the SW Transylvanian Basin was reported at Oarda de Jos, where a new species was identified based on tooth morphology - *Barbatodon oardaensis* (Codrea et al., 2014).

Grellet-Tinner and Codrea (2015) reported the presence of a "dwarf" pterosaur, *Thalassodromeus sebesensis*, from the family Tapejaridae, identified in the Maastrichtian of Oarda de Jos (ODA-28), from the Sebeș riverbed, which represents the base of the Șard Formation characterized by lacustrine, oxbow, and marsh deposits (Codrea et al., 2001, 2010a, b). This discovery brings new nuances to the enigmatic role of this Cretaceous Island as a refuge for endemic taxa. Later, Dyke et al. (2015) present new arguments regarding the new species *Thalassodromeus sebesensis* that was misidentified. The authors refer to a plastron piece of the turtle *Kallokibotion magnificum* (Nopcsa, 1923) and not from a pterosaur. *Thalassodromines* (Kellner and Campos, 2007) or *Thalassodromids* (Witton, 2009) are restricted only to the Lower Cretaceous of South America. Recently, Vlad Codrea extracted the bone in question from the host rock, observing that indeed the fragment in question does not belong to a pterosaur, but to a turtle (V. A. Codrea, personal observation). The systematic dispute is thus definitively settled.

Csiki-Sava et al. (2016) focused on certain clarifications regarding the events at the Cretaceous-Paleogene (K-Pg or K-T) boundary, based on the continental vertebrate fauna of the terminal Cretaceous, which was firstly described by Nopcsa during the years 1897 – 1929. Initially, the age was considered Lower Maastrichtian and little importance was placed on the events at the K-Pg boundary. It is specified that the Lower Maastrichtian of the transitional and continental deposits in the lower part of the "Sebeș Formation" are clearly disposed over the Upper Campanian deposits. In the Petrești area, it is mentioned that the deposition of these deposits began during the late Campanian (Vremir et al., 2014). The Maastrichtian age of the "Sebeș Formation" is further supported by palynological data from the lower part of the continental succession at Pâclișa (Antonescu, 1973; Antonescu et al., 1983) and by the significant thickness of the formation (450 m on the left bank of the Mureș River). Regarding the upper part of the "Sebeș Formation" the age data are somewhat inconsistent. It is considered that above the "Sebeș Formation" there are discordant continental red deposits (Priabonian) in the Alba-Iulia area and marine deposits (Badenian) in the Sebeș area. Consequently, there is no certainty whether at the K-Pg boundary in the SW Transylvania there was continuous sedimentation or an erosional hiatus that would attest to the separation of the Mesozoic and Cenozoic successions.

Codrea (2017) described the red fluviatile-lacustrine deposits at Râpa Roșie in the Sebeș – Alba region, specifying the vertical petrofacies change due to the presence of large extraclasts in the lower sequences, which become finer in the upper sequences. Clasts are evidence that the fluvial paleosystem was very dynamic at first, becoming slower in terms of flow dynamics later on. It is also specified that the Cretaceous succession at Râpa Roșie was later eroded by the transgressing waters from the Middle Miocene. The Miocene transgression (Badenian) also razed the

Paleogene deposits that were once located on the northern edge of the Southern Carpathians. Cenozoic rocks (especially Paleogene) that gravitate down the slopes of the Râpa Roșie remain trapped through recent rainfall processes in the older red beds, and have created evident confusions regarding their presumed older geological age.

Codrea et al. (2017) defined a new family of teiioid lizards based on materials recovered both previously and recently from the continental deposits of the latest Cretaceous (Maastrichtian), to highlight the squamate diversity of the ”Hațeg Island”. The material was recovered from Oarda de Jos, in the Șard Formation (= "Fm. de Sebeș", in Csiki-Sava et al., 2016). From this family, a new species has been described as *Oardasaurus glyphis*.

Solomon et al. (2020) described a new species of large azhdarchid pterosaur from Romania (*Albadraco tharmisensis*) in the Șard Formation at Oarda de Jos (well-preserved beak fragments and a cervical vertebra). This report increases the diversity of pterosaurs from the latest Cretaceous in Transylvania.

Codrea et al. (2021) provided a synthesis of the latest Cretaceous terrestrial deposits bearing microvertebrates in the Metaliferi sedimentary area. Currently, there are only two sites with these fossil records: Oarda de Jos (two sites) and Petrești de Jos, with paleoenvironments of lacustrine origin (probably "ox-bow" accumulations). Preliminarily, the presence of four groups of microvertebrates has been identified here: theropods, crocodilians, albanerpetontids, and fish. In the faunal assemblage, new materials have been identified (recovered in the spring of 2021): egg shells, sauropods, and dortokid turtles. The fossil content documents the possibility of the existence in the area of some Maastrichtian telmatic or incipient lacustrine environments.

Trif and Codrea (2022) identified several dental fragments of fish belonging to brackish water sharks from the continental deposits of the Șard Formation at Oarda de Jos. For this purpose, it was interpreted that the terrestrial surface included diverse aquatic environments, which occurred immediately after the "Laramide phase" at the end of the Cretaceous.

Țabără et al. (2022) developed biostratigraphic and paleoenvironmental interpretations based on palynological and geochemical studies of angiosperm pollen and fern spore samples collected from the Upper Cretaceous deposits of the Bozeș Fm. and "Sebeș Formation" that crop out in the SW Transylvanian Basin (Petrești area). The palynological assemblages were associated with riverine and coastal habitats, as well as those found in high-altitude and/or cooler-wetter conditions. The presence of the Normapolles assemblage supports the idea of the Bozeș Formation belonging to the Middle-Upper Campanian. Based on the palynofacies, corroborated with geochemical data, it was interpreted that the lower and middle sections of the Bozeș Formation in the Petrești area constitute deposits accumulated in the distal and external neritic sectors of the basin during the middle Campanian, while the upper sections belong to the internal neritic sector or are located proximal to the shore during the late Campanian.

Csiki-Sava et al. (2021, 2022) defined the spatio-temporal assemblage of kogaionid multituberculates from the ”Hațeg Island”, accepting that the *red beds* are extensive from the late Campanian to the late Maastrichtian, based on the identified fossils from the Hațeg, Rusca-Montană, and SW Transylvania basins. In constructing the facies model, it was assumed that the habitats of the kogaionids express a preference for well-drained and oxidized overbank environments.

Solomon et al. (2022a) reported new occurrences of Cretaceous multituberculates in the Metaliferi sedimentary area and the Hațeg Basin, which belong to the species *Barbatodon oardanensis*. The new records were based on more consistent samples of isolated new teeth that were recovered from the Oarda A fossil site (ODAN; Oarda de Jos). This study was intended to attest to the diversity of multituberculates in the three sedimentary areas (Hațeg, Rusca Montană, and the SW Transylvanian Depression). From the same locality and fossil site Solomon et al. (2022b) conducted a preliminary study on the more recently collected fossil material, identified in "ox-bow" type deposits. The sample contains a diverse faunal association of vertebrates (fish, anurans, squamates, turtles, crocodiles, sauropods, and theropods). Preliminary interpretations of the Maastrichtian environments in the studied area were also considered.

Codrea et al. (2023) arrived at the idea that, for further investigations, it is necessary to know whether there are sedimentary continuity relationships between the deposits in the Sebeș Valley riverbed and the sequences at Râpa Roșie or if there is any discontinuity between these deposits. The sedimentary facies at Lancrăm on the Sebeș riverbed exhibit different characteristics compared to those at Râpa Roșie, viewed in terms of lithological content and sediment deposition methods, but a detailed sedimentological study will be necessary to confirm these hypotheses.

Țabără and Csiki-Sava (2024), based on palynological, palynofacies, and organic geochemical investigations, redefine the age and attempt to improve previous interpretations regarding the depositional environments of the "Sebeș Formation" at Oarda de Jos. The abundance of woody tissues and large cuticles, along with the presence of opaque phytoclasts, frequently indicates low-energy swampy environments in the proximal portion of the river/lake system. The organic matter was deposited under anoxic and partially suboxic conditions within swamps or lakes. The interpretations obtained by the authors are in agreement with the previous environmental evaluations (Codrea et al. 2001a, b, 2010a, 2013, 2017; Jipa, 2012; Trif and Codrea, 2022). Based on the non-marine palynological content recovered from Oarda de Jos (*Polypodiaceoisporites hojrupensis*, *Oculopollis praedicatus*, and *Trudopollis granulosus*), the terrestrial deposits were dated to the early Maastrichtian. The age assessment was also based on the high frequency of Trudopollis-type pollen collected from these deposits, which also develops in the Carpathian areas during the Campanian – Lower Maastrichtian interval. Within the palynological assemblage, the abundance of Normapolles-type pollen in these deposits is suggested by the proximity of the lacustrine environments of Oarda de Jos to the vegetation of the elevated areas of the ‘Hațeg Archipelago’.

Bălc et al. (2024) indicated the Late Campanian age for the beginning of the sedimentation of continental deposits with vertebrate faunas, previously accepted as Maastrichtian age. The data also showed that Kogaionids could have potentially existed earlier in the fauna of the ”Hațeg Island”.

Conclusions

This contribution synthesizes the stratigraphic data and assessments regarding the age of the latest Cretaceous red beds of the Șard Formation (sensu Codrea and Dica, 2005) from the Metaliferi sedimentary area, with focus on Oarda de Jos – Lancrăm – Sebeș – Râpa Roșie area, on the left bank of the Mureș River. In the history of the field studies, various authors have expressed different opinions regarding the superposition relationships of this formation and its correlation with other comparable formations (from the Hațeg and Rusca Montană basins) in order to establish the exact geological age. Diverse opinions can be synthesized by specifying the interval of Late Mesozoic – Miocene.

Cretaceous terrestrial deposits have been included in complete chronostratigraphic and lithostratigraphic charts carried out on the sedimentary area of the SW Transylvanian Basin. The first attempt belongs to Codrea and Dica (2005), naming this area the ”Metaliferi sedimentary area” area, where the left bank of the Mureș Valley represents only the eastern and southeastern portions of this area; subsequently, Vremir et al. (2010, 2013, 2014, 2015a) proposed that the deposits in the same geographical area be named the "Sebeș" sedimentary area.

The latest Cretaceous red beds sedimentary history began in the early Maastrichtian (if we consider the basal most occurrence of Petreștii de Jos, the Campanian cannot be excluded). The top of Șard Formation seems to indicate an erosional surface, overlie by a Priabonian transgression. Initially, the name of the formation was used for certain portions of the Metaliferi area (the Vințu de Jos – Vurpăr – Pâclișa – Șard area on the right bank of the Mureș River and the Oarda de Jos – Lancrăm – Sebeș area on the left bank of the Mureș). Subsequently, the use of this nomenclature was also extended to the continental succession of Râpa Roșie too (Codrea et al., 2010 a, b), based on vertebrate fossils devoid of reworking marks. If they were indeed transported, this transport probably involved short distances. This stratigraphic attribution is in agreement with the assumptions of Nopcsa (1905a, b) and Macovei and Atanasiu (1934), who placed it somewhere in the Upper Maastrichtian – Danian time span.

In the stratigraphic chart of Vremir et al. (2015a), for the same latest Cretaceous terrestrial red beds of the so-called "Sebeș" sedimentary area, the name "Sebeș Formation" was used, a term used by Codrea and Dica (2005) only for the Lower Miocene age and not to the terminal Cretaceous. In the mentioned authors' conception, the "Sebeș Formation" (i.e., Șard Formation, sensu Codrea and Dica, 2005) is dated to the late Campanian – late Maastrichtian /?Paleocene time span, while the "Șard Formation" is dated only to the Priabonian, on the right bank of the Mureș River. Such a nomenclature rise confusions concerning the relationship

between the name and the geological age, as long as in Codrea and Dica (2005) for the Priabonian (marine) and Lower Oligocene (brackish) deposits cropping out in Șard and Ighiu localities, the name Ighiu Formation was coined, based on indicative assemblages of rich alga, foraminifers (Bombiță, 1963), bryozoans, mollusca, echinoderms or ostracoda (Băluţă, 1973, 1987; Moisescu and Mészáros, 1995).

We consider that, among all these approaches, the arguments for attributing the red continental formation to the Upper Maastrichtian - ?Paleocene time span to Șard Formation are more solid and respect the authentic interpretations offered by the early 20th geologists who studied the area. Therefore, we propose that the name Șard Formation be used for these Maastrichtian red beds in the Metaliferi sedimentary area, to avoid further confusion. Moreover, the Șard Formation appears to gain an accepted status by the Romanian Geological Institute (see the Lithostratigraphic Lexicon of Romania; https://formatiunigeologice.igr.ro/) for the Maastrichtian – ?Priabonian time span, which is exposed on both banks of the Mureș Valley. On the other hand, the "Sebeș Strata" (= "Sebeș Formation"; Marinescu et al., 1998) have an unaccepted status, in that case only the Upper Miocene is in question, with a succession accumulated in a sublittoral environment with depths of 10-50 m (Gheorghian, 1971), which appears in a completely different region (northern border of the Făgăraș Mountains), certainly not in the Metaliferi sedimentary area.

Regarding a series of writings and stratigraphic nomenclature proposals by Austro-Hungarian authors from the late 19th and early 20th centuries (invoked by several geologists who studied the area), we note that in those situations, the descriptions are far to follow the rules and requirements of the current International Stratigraphic Code, their value being rather a historical one.

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