

Final report for the project NKFIH PD-131536 ‘Refinement of the Middle Norian (Upper Triassic) conodont zonation based on faunas from Tethyan successions’

by

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The project focused on the problems and shortcomings of the Norian, particularly the middle norian conodont biostratigraphy of the Tethys Realm, which is hampered by oversimplified taxonomy. This is characterized by lumping (using only a few species names), and often couples with the lack of figuration of the specimens. It can be stated that almost no progress has been made since the 1980’s. The aim of this research was to reveal the true diversity of conodonts from the lower-middle Norian transition, and to study their taxonomy in detail, which is a fundamental step in the improvement of biostratigraphy and biozonation.

A very peculiar and common feature of the Middle Norian successions in the Tethys Realm is the dominance of juvenile specimens in the samples. These sections are difficult to date, because juvenile conodonts do not have the morphological characters, which are necessary for determination on the species level. This phenomenon was investigated at the beginning of the research based on material from the Dovško section (Slovenia), the Csővár Csv-1 core, the Valkó Hill section, the Mátyás Hill section and the outcrop at 45 Rác Aladár Road (Transdanubian Range, Hungary) (Karádi et al., 2020). Pectiniform conodont elements were counted and classified in growth stages from early juvenile (GS1) to late adult (GS6) using the study of Mazza & Martínez-Pérez (2015) as reference. Among broken specimens only those with at least half-preserved platform were considered in the analysis, in which the growth stage was possible to determine. Bar plots were generated within the R programming environment (v. 3.5.2), where each bar represents the number of specimens within a sample that fell into a given growth category (Fig. 1). The results of the research revealed that in certain sections this high rate of juvenile mortality is not present, and the middle Norian assemblages consist of a large number of adult specimens. Based on the microfacies analysis of the Dovško section and the previously published microfacies of the Csővár Csv-1 core (Haas et al., 1997) it is suggested that these faunas are mostly found in proximal periplatform environment.

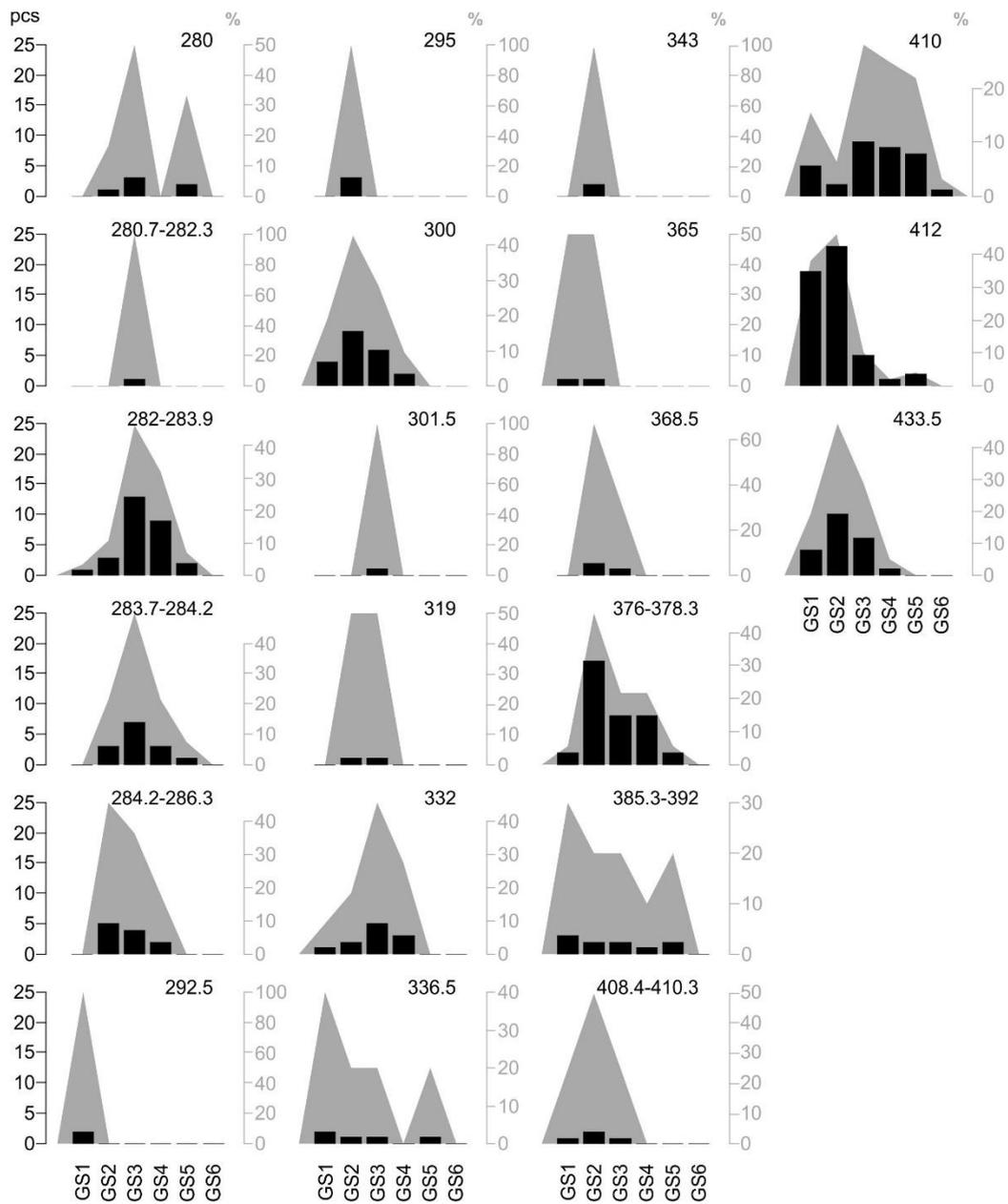


Figure 1. Distribution of observed growth stages on the example of the Csóvár borehole successions (from Karádi et al., 2020). Black bars on the plots represent the number of specimens within a sample divided into six growth stages (GS1: early juvenile, GS2: juvenile, GS3: late juvenile, GS4: early adult, GS5: adult, GS6: late adult) based on the study of Mazza & Martínez-Pérez (2015). General percentage distributions are visualized behind the bars with grey. Consider that the vertical axes for the percentage distributions have different scales, even within the same section.

As the next step in the project, I summarized the evolutionary trends of the *Ancyrogondolella* lineage through the Norian (Karádi, 2021). The main trend is characterized by the forward shifting of the pit, the posterior prolongation of the keel and the development of additional denticles in the posterior carina (Fig. 2). These strongly connected morphological changes represents the repetition of the evolutionary steps, which occurred between the species *Paragondolella noah* and *Metapolygnathus communisti* in the Carnian (Mazza et al., 2011). Besides the main trend, a decrease in the length of the free blade and an increase in the height

of the anterior platform denticles can be observed (Fig. 3). All of these significant morphological alterations initiated in the lower/middle Norian (Lacian/Alaunian) transition, after a more or less steady phase that characterized the Lacian. This faunal turnover marks the beginning of the gradual decrease in overall width and length of platform conodonts that led to the development of ancestral morphs by the latest Norian.

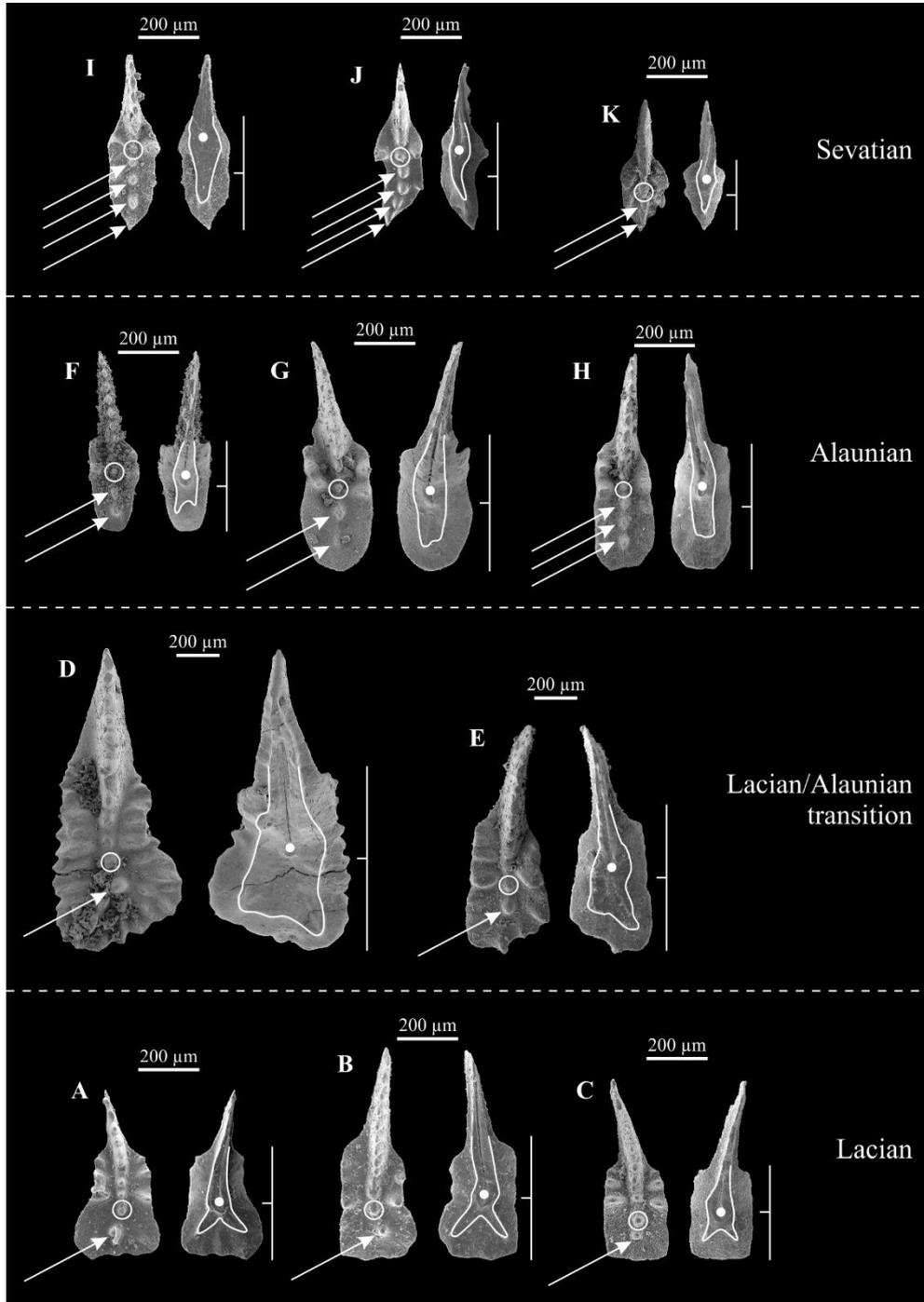


Figure 2. Main trend in the evolution of the *Ancyrogondolella* lineage during the Norian (from Karádi, 2021). White arrows point to the denticles of the posterior carina developed behind the cusp (open circle). Pit position (solid circle) is shown relative to the middle of the platform marked by the white bars on the right of the specimens. Posterior prolongation of the keel with respect to the position of the pit is reflected by the contour of the keel edge.

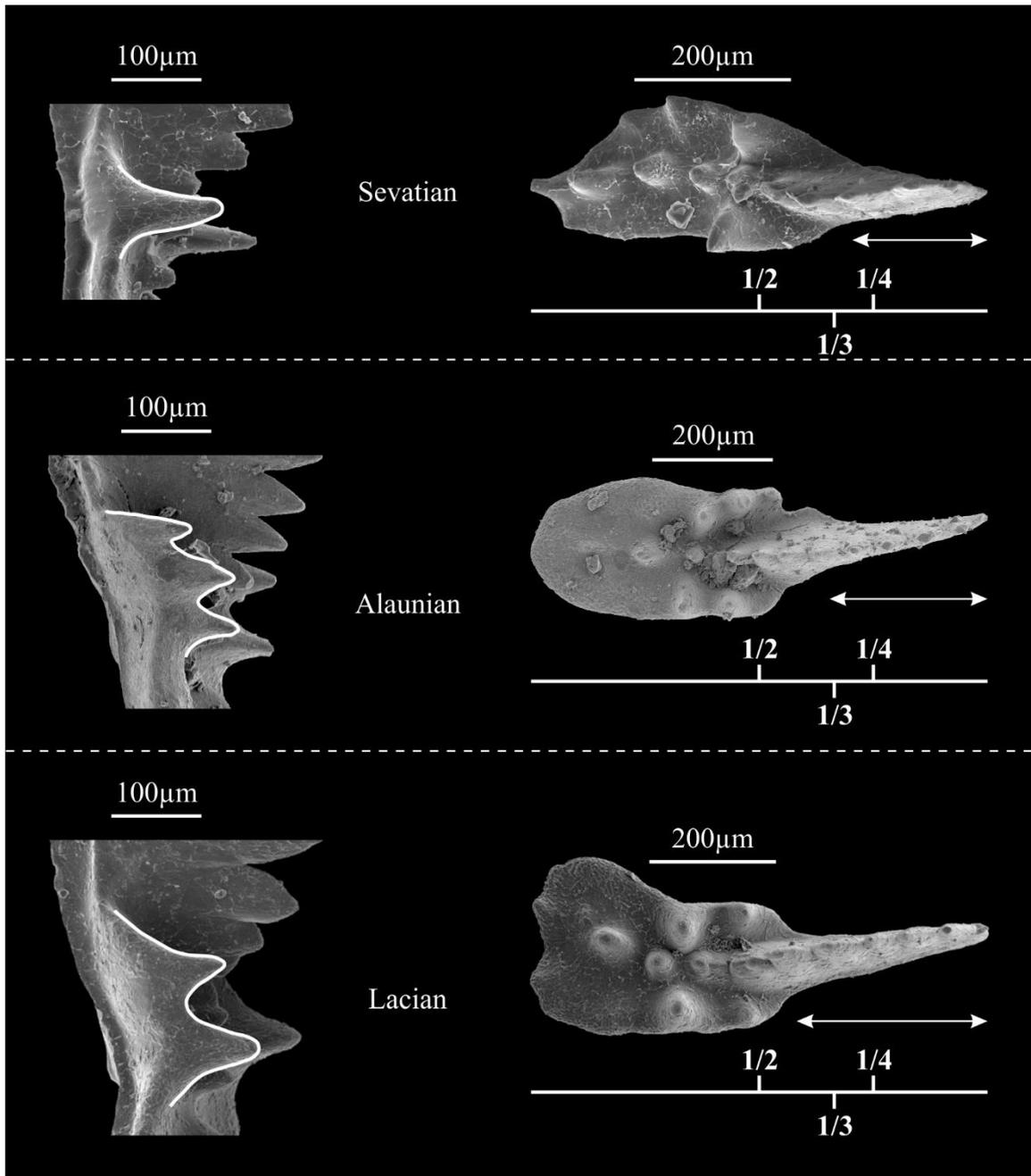


Figure 3. Modifications in the shape of the denticles of the anterior platform and in the length of the free blade in representatives of the *Ancyrogondolella* lineage during the Norian (from Karádi, 2021). Left side: anterior platform denticles are marked by white contour. Specimens are on the same scale. Right side: length of the free blade (double sided arrow) in comparison with the entire element length (bars showing 1/2, 1/3 and 1/4 unit length). Specimens are not on the same scale.

The contour of the lower margin of platform elements shows an abrupt change around the Laciaan/Alaunian transition. Adults of the Laciaan dominantly have an arched profile, whereas that of the Alaunian and Sevatian (upper Norian) specimens is mainly stepped or straight (Fig. 4). The presence of a secondary carina is characteristic through the Laciaan 2 to Alaunian 1 in certain species, however its development lacks any evolutionary trends. Contrary to early assumptions, it has no importance on the generic level, and its possible role in species differentiation is also questionable.

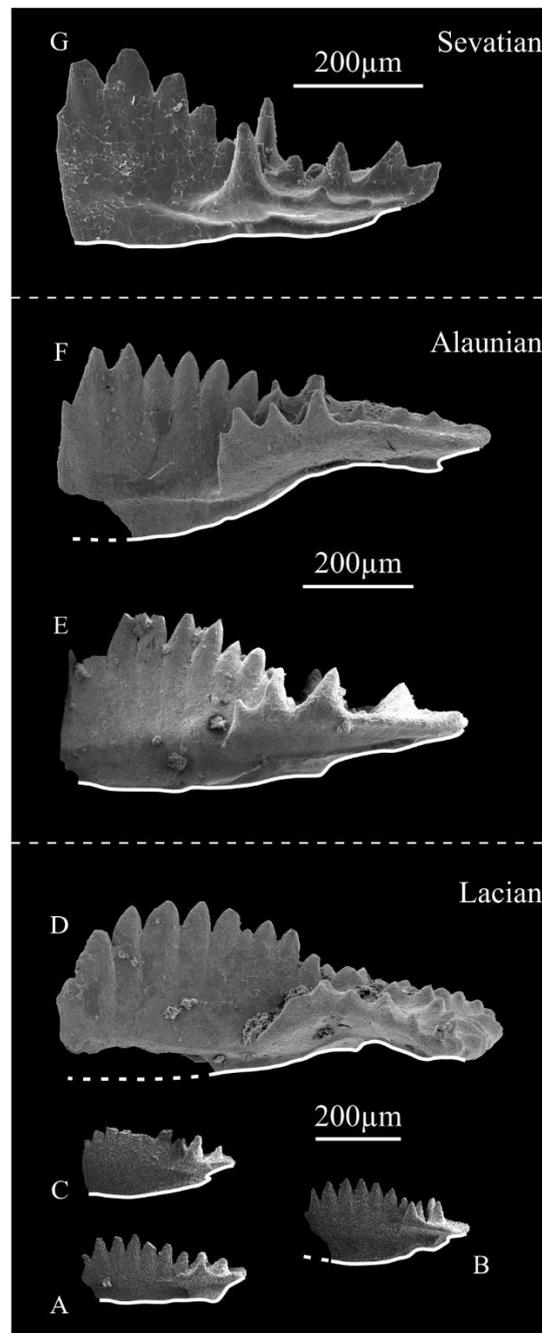


Figure 4. Different lower profiles (white contour) of Norian conodonts of the *Ancyrogondolella* lineage (from Karádi, 2021). Juveniles have straight (A), stepped (B) or upturned (C) lower margin, whereas adults have arched profile (D) in the Laciaan. Adult specimens of Alaunian age bear upturned (E) or stepped (F) lower margin, and adults of the Sevatian have quasi-straight profile. Specimens of different ages are not on the same scale.

After understanding the morphological changes that happened around the Laciaan/Alaunian boundary I started detailed taxonomic and biostratigraphic work on the conodonts from the Dovško section of Slovenia, the Mátyás Hill and the Csővár Csv-1 core of Hungary and the Dealu Runcu sections of Romania. Conodont samples generally weighed 3-4 kg. Rocks were processed using the standard dissolution technique of diluted (10%) acetic acid. Washing residues were enriched by density separation with bromoform only in the case of the Dovško section. Photos of conodonts were taken using scanning electron microscopes. Thin sections for microfacies analysis were prepared from the Dovško, the Mátyás Hill and the Dealu Runcu sections.

Results of the Dovško section were published by Karádi et al. (2021). The Dovško succession is located in the Sava folds region in East Slovenia along the Dovški Potok Stream at Dovško, near Senovo. A total of 55 samples were taken for conodonts and microfacies analysis. Conodonts were present in all samples, and the colour of the elements is brownish grey to grey corresponding to the CAI value of 2–2.5. The age of the section spans from the Laciaan-1 to the Alaunian-1 (Fig. 5), though the paper focuses mainly on the Laciaan-3 to Alaunian-1 interval. The taxonomic problems of *Ancyrogondolella spatulata* are discussed in detail, because this name refers to a lower Laciaan species, but are mostly wrongly used for a very characteristic form of the Laciaan-3. The main result of the research is the description of 7 new species (*Ancyrogondolella? bohorensis*, *A. goldingi*, *Epigondolella buseri*, *E. kozjanskoensis*, *E. ritae*, *E. senovoensis*, *E. slovenica*) and 2 new subspecies (*Ancyrogondolella? praespiculata dovskoensis*, *Ancyrogondolella diakowi posterolobata*) from the Laciaan/Alaunian transition. These can be used as steady stratigraphic markers in the future. *Ancyrogondolella? bohorensis* was present in the Laciaan-3 interval, but interestingly this species bears traits that are found in Alaunian taxa (i.e. a forward shifted pit, a posteriorly prolonged keel, and a posteriorly prolonged carina). Faunal mixing is not likely, because *Ancyrogondolella? bohorensis* was not recovered from the Alaunian part of the section, despite the diverse and rich middle Norian assemblages. Important is the presence of the here introduced species, *E. ritae* in the uppermost part of the section from a biostratigraphic point of view, because this species allows correlation with the Alaunian-1 of the Hallstatt region of Austria. The occurrence of *Mockina? spinosa* outside the eastern Pacific is first documented in the Dovško section. Likewise, *Ancyrogondolella diakowi* and *Ancyrogondolella? praespiculata* were previously known only from western North America. Their western Tethyan representatives are slightly different, but show morphologies that are typical of these species. Therefore, they were separated as subspecies, although it cannot be excluded that they are only ecomorphotypes. *Ancyrogondolella equalis* was described from British Columbia (Canada) and its presence in the Dovško section makes it a good taxon for correlation between Tethys and the eastern Pacific.

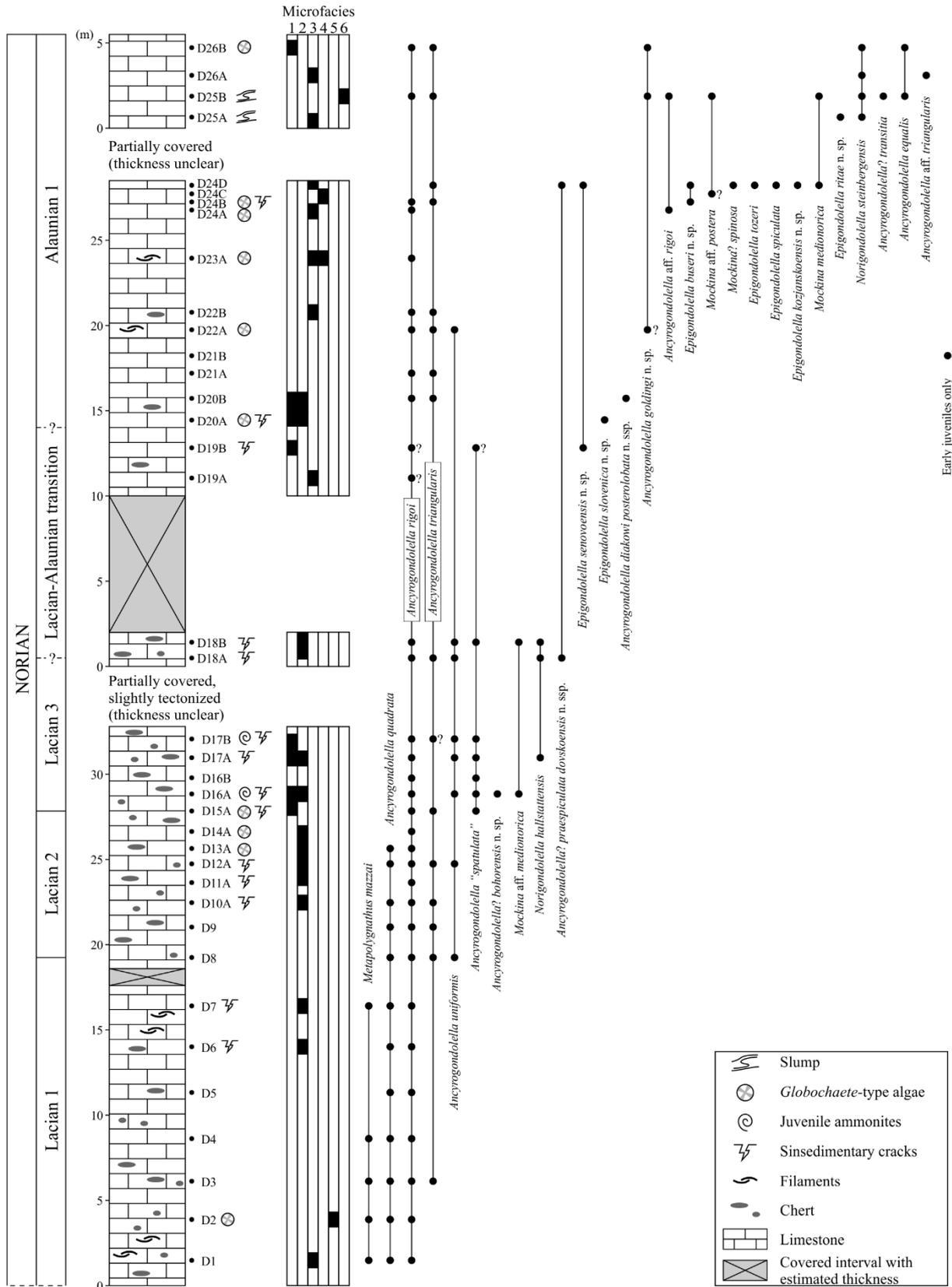


Figure 5. Stratigraphic log of the Dovško Section showing the distribution of microfacies types and the ranges of conodonts (from Karádi et al., 2021). Scale is in meters.

The Csővár Csv-1 core exposed a 622 m thick succession of Upper Triassic age. Samples (125 in total) were taken for bio- and chemostratigraphic investigations, the results of which are published by Karádi & Korte (2023). Conodont assemblages prove that the age of the section is Upper Carnian to Upper Rhaetian and thus, exposes the whole Norian (Fig 6.). The previous age determinations based on sporomorphs and foraminifers could be revised: the Carnian/Norian boundary is ~180 m lower and the Norian/Rhaetian boundary is ~ 90 m lower than proposed before. The Carnian part yielded a diverse conodont fauna with taxa previously reported only from western North America. This strongly suggests that the upper Carnian to lower Norian conodont taxonomy of the Tethys has to be revisited. The lower Norian faunas show similarities to the Dovško assemblages, but the middle Norian interval markedly differs in the two successions. In the Csővár area, the Alaunian is represented by the predominance of juveniles, which feature I mentioned at the beginning of the report. This might be related to the distal periplatform position. Based on the thickness of the Alaunian part, the possibility of gaps cannot be excluded, but the fauna was not suitable for drawing such conclusions.

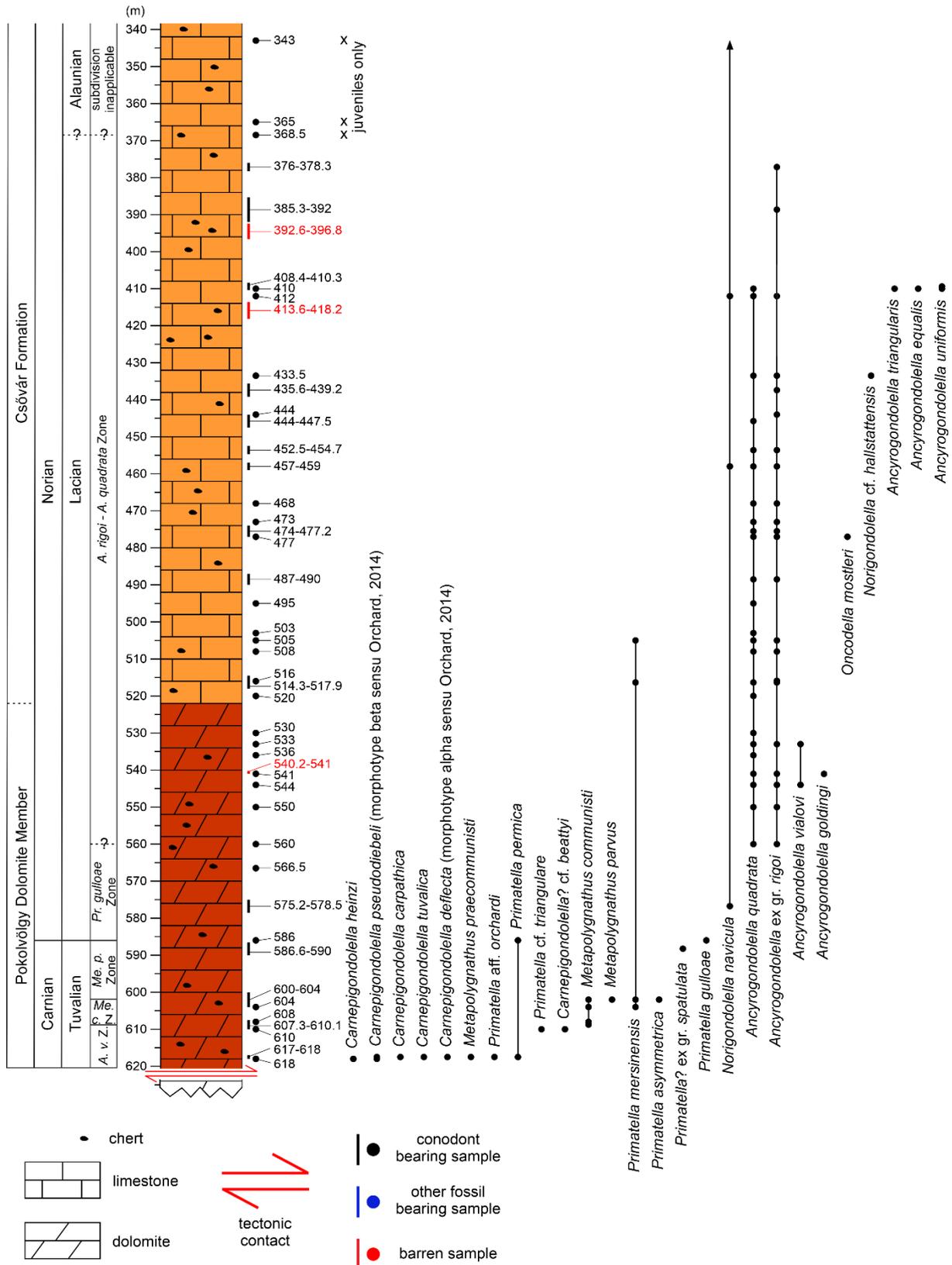


Figure 6. Stratigraphic log of the Csővár core (Csv-1) showing the position of the samples and the ranges of the conodont taxa (from Karádi & Korte, 2023). Abbreviations: A. – *Ancyrogondolella*, v. – *vialovi*, Z. – Zone, Me. – *Metapolygnathus*, c. – *communisti*, p. – *parvus*, Pr. – *Primatella*, Mo. – *Mockina*, Mi. – *Misikella*.

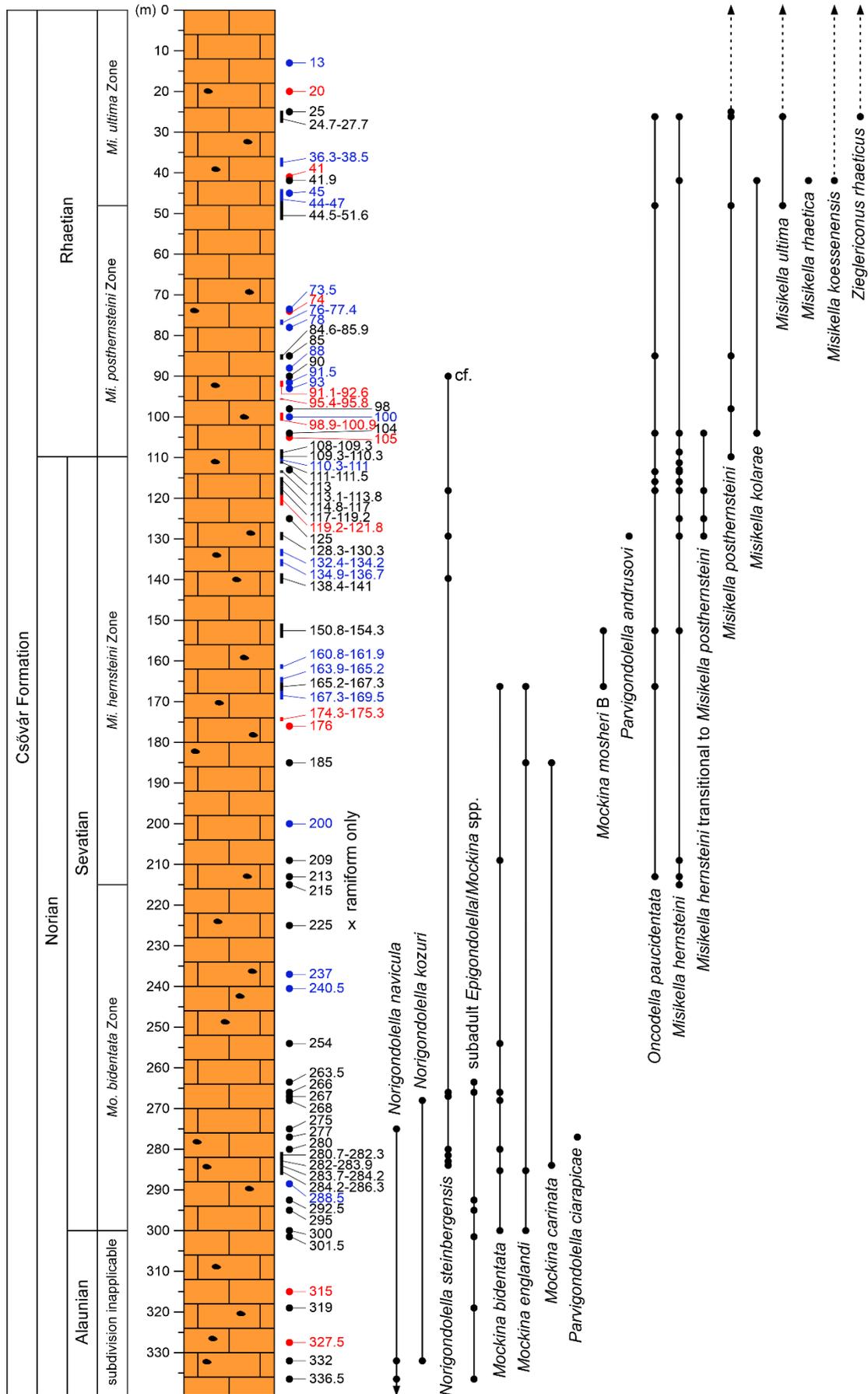


Figure 6. Continued.

The carbon isotope analysis revealed a long-term first order ~ 1.5 ‰ $\delta^{13}\text{C}$ background decline (~ 3.5 to ~ 2 ‰) through the Norian (light grey arrow in Fig. 7). This is similar to the trends of other successions. For example, even if a gap is present in the middle Norian, a ~ 1.5 ‰ decreasing trend is reported by Korte et al. (2005) for the pelagic carbonate succession at Silická Brezová in Slovakia. A similar trend occurs in the distal periplatform of the Northern Alps (Gawlick & Böhm, 2000) and in the Pizzo Mondello section in Sicily (Muttoni et al., 2004). This concordance in the long-term carbon-isotope trend suggests that this feature is global in extent.

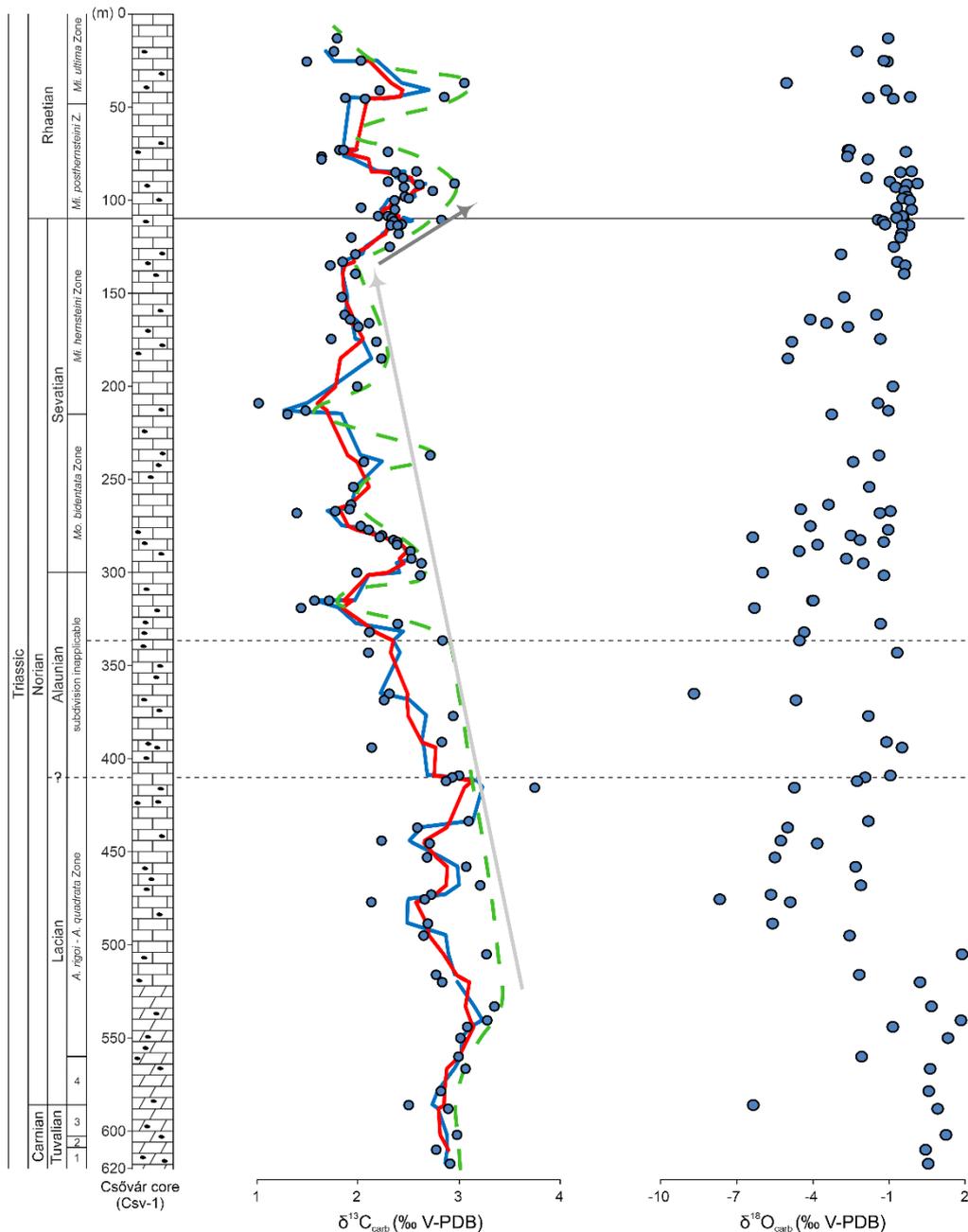


Figure 7. Bulk carbonate $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values of the Csóvár core succession plotted against lithology and conodont zonation (from Karádi & Korte, 2023). Three trends are specified for carbon isotopes: Blue: 3 point average running mean; Red: 5 point average running mean; Green: “Upper envelope” enclosing the heaviest $\delta^{13}\text{C}$ values and excluding potential light altered values. No trend is specified for oxygen isotopes because diagenetic alteration probably altered the primary isotope signal.

The Mátyás Hill section represents a more proximal depositional environment, consequently the Alaunian faunas contain many adult specimens. The conodont biostratigraphic dating of the 19 m thick section was based on 20 samples. The paper presenting the results is submitted to the journal *Geological Magazine* and is now under review. Most of the section represents the Lacian-3, and Alaunian beds are only found in the uppermost 2 m (Fig. 8). Difficulties in the research were caused by the faunal mixing throughout the Lacian part of the section. Unfortunately, thin sections revealed that rocks of the Mátyás Hill section have undergone pervasive dolomitization, which obscures the original texture of the rock and makes it impossible to study primary sedimentary features and thus, the cause of the mixed assemblages. Anyhow, the presence of fissure fills is the most likely explanation. If the faunal mixing was caused by synsedimentary breccias, the samples should contain a more diverse and abundant Alaunian assemblage (similar to that in sample MH58/21) throughout the Mátyás Hill section, into which the Lacian-3 conodonts have been reworked. In the lower 16 m of the section, however, the assemblage is dominated by the genus *Ancyrogondolella* over specimens assignable to the genera *Epigondolella* and *Mockina*.

An important result is the presence of *Ancyrogondolella? bohorensis* in the Lacian-3 of Mátyás Hill. This species with the Alaunian morphologies were found at almost the same level in the Dovško section. This suggests that it might be an early representative of middle Norian faunas and is a useful biostratigraphic marker. I made similar conclusions in the case of *Ancyrogondolella manueli*, a newly described species from Mátyás Hill. Although it was recovered together with unequivocally Alaunian species, this specimen shows typical characters of the Lacian ancyrogondolellids. It has a centrally located pit, a deeply bifid keel termination, and only one denticle in the posterior carina behind the cusp. It was previously found elsewhere in the Buda Hills, at 45 Rácz Aladár Road, there as well accompanied by an Alaunian assemblage. *Ancyrogondolella manueli* is suggested to be a late representative of the genus *Ancyrogondolella*. These two species revealed that the change from a lower Norian to a middle Norian assemblage was the result of stepwise evolution and not a sudden faunal turnover as it may seem in condensed successions.

Ancyrogondolella diakowi posterolobata and *E. kozjanskoensis* provide good possibility for correlation with the Dovško section. The presence of *A. transformis* and *A. inequalis* is of key importance, because these species are indicative of the lowermost Alaunian *A. transformis* Zone in the eastern Pacific. Their documentation in the western Tethys for the first time highly improves global correlation potential and may allow the usage of this zone in the Tethys as well.

In the Codru-Moma Mts. (Romania) two sections were sampled in the vicinity of Dealu Runcu. Unfortunately, the date of the sampling campaign had to be postponed due to the travel restrictions caused by the Covid-19 pandemic. Consequently, the whole sample processing procedure was done later than planned. By the end of the project the results were evaluated, but the manuscript is still in preparation. The plan is to submit it to an international journal later in 2024.

A total of 18 samples were taken from section I and 16 samples from section II. Section I represents fore reef to upper slope environment with sedimentary breccias including redeposited shallow-water clasts in several levels. Out of 18 samples 11 yielded conodont elements (Fig. 9). The fauna is mixed, as it was presumed based on the breccia fabric of the samples, containing Laciian-3 to Alaunian-1 taxa. The higher part of the section was rather poor in conodonts, so an additional 3 samples were taken during a second sampling campaign. Romanian colleagues took samples for microfacies analysis and for studying the shallow-water components. This will be an important contribution in the upcoming publication, because the age of the shallow-water organisms can be calibrated with the conodonts, even despite the evident faunal mixing in the conodont assemblages.

The beds exposed by section II were also deposited in slope environment, but in a somewhat more distal position compared to section I. Conodonts were found in 9 out of 16 samples (Fig. 10). The age of the section ranges from the Upper Carnian to the Middle Norian. In order to get a more refined subdivision an additional 6 samples were taken during the second sampling campaign. Faunal mixing cannot be excluded in the Laciian-3 part of the section, but it is not so obvious as in the case of section I, because the higher Laciian-3 is generally characterized by the transition from a Laciian-type fauna to an Alaunian-type assemblage. The exact age of these transitional forms is yet to be researched, but several specimens show great similarities to elements of the Mátyás Hill fauna. Fine dating of the Alaunian part could not be achieved, because the fauna only contains long-ranging taxa of the genus *Norigondolella*. This section will, for sure, gain international attention as it contains the Carnian/Norian boundary interval. The results of the Romanian sections will also contribute to the better understanding of the geology of the Codru-Moma Mts., because it reflects very well the complexity of the area.

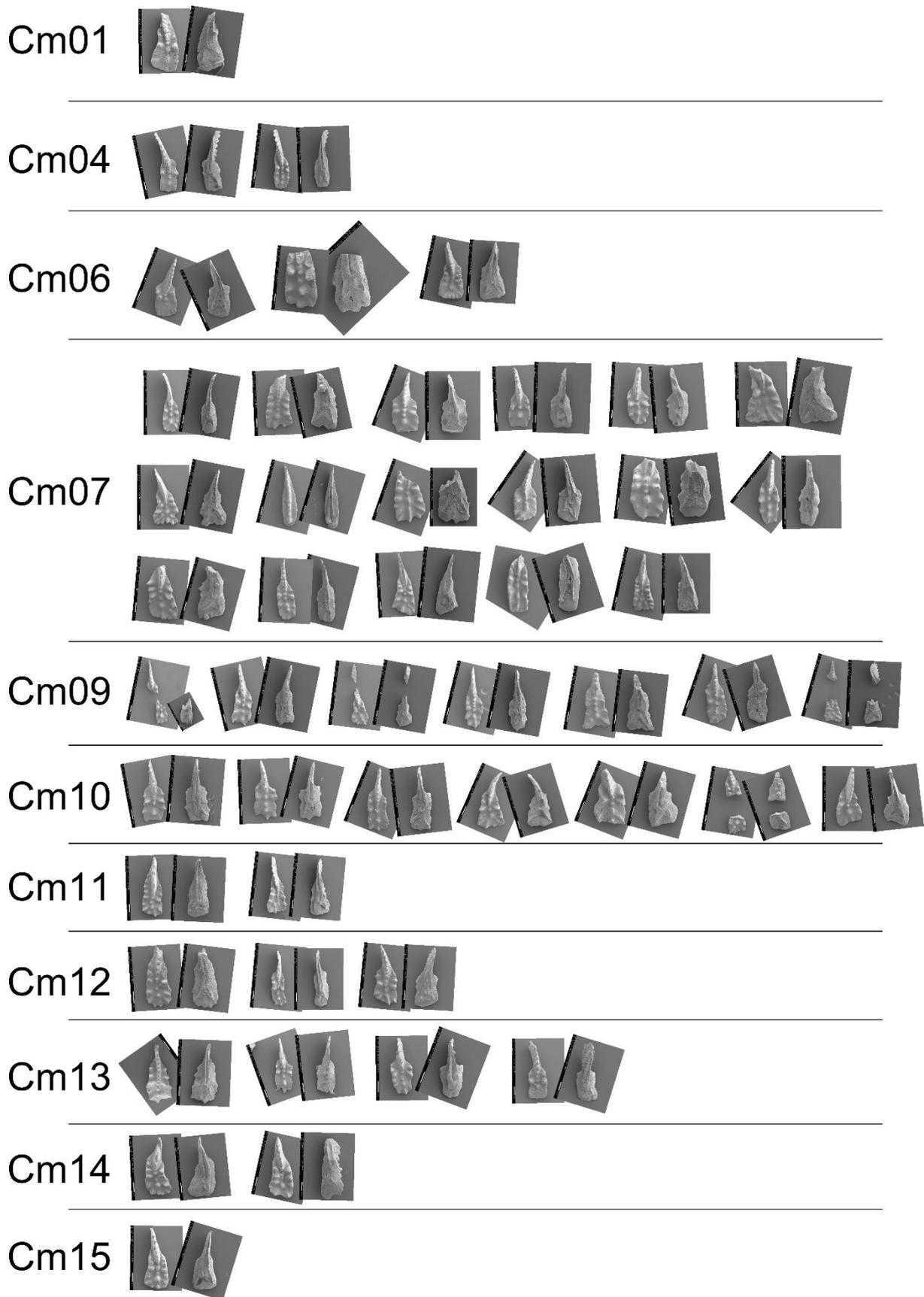


Figure 9. Scanning electron micrographs of the conodonts from the mixed Lacian-3 to Alauian-1 assemblage of Section I of the Dealu Runcu area. Sample Cm15 is from the lowest position in the section and Cm01 is from the highest part.

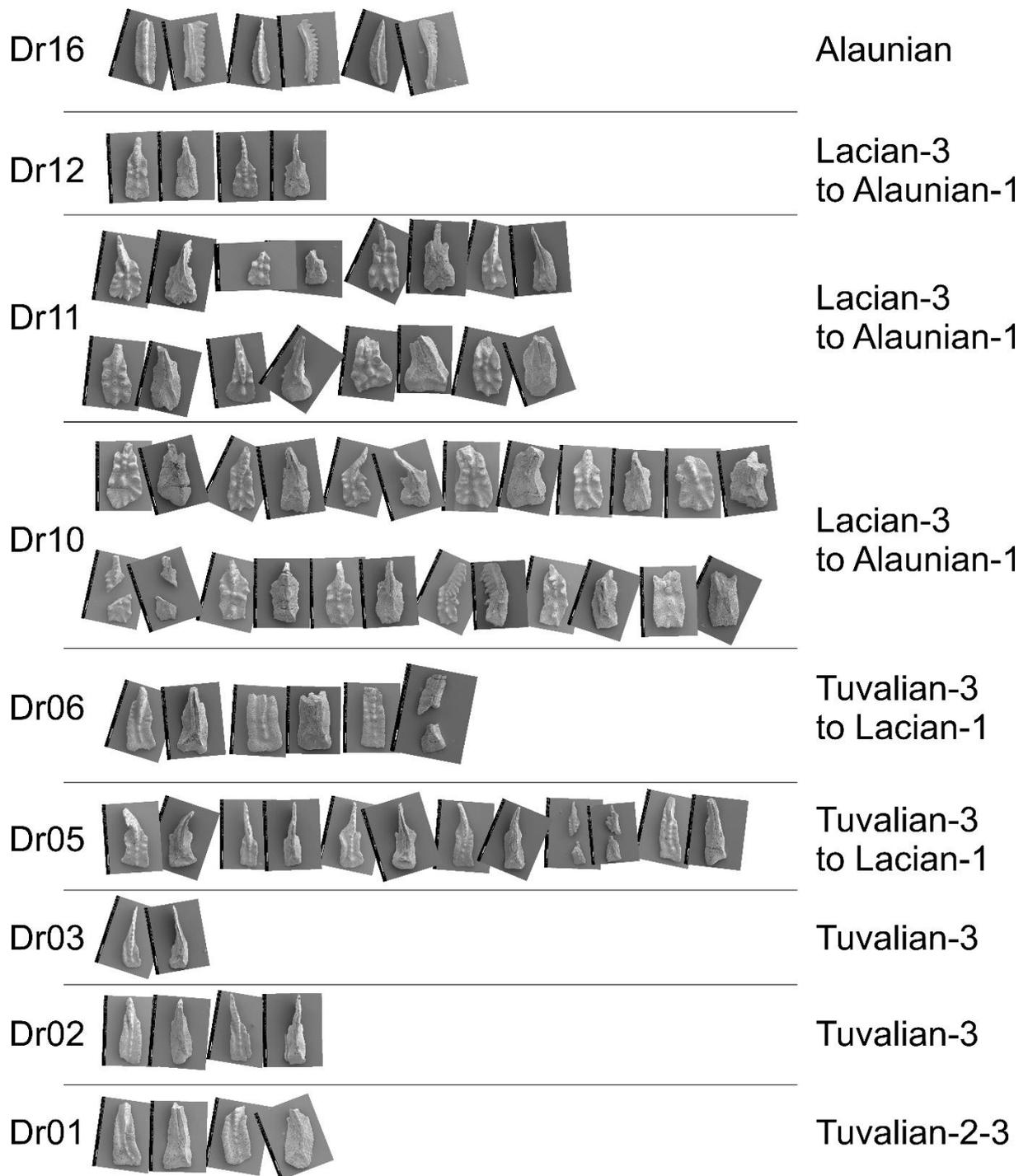


Figure 10. Scanning electron micrographs of the conodonts from Section II of the Dealu Runcu area. Sample Dr01 is from the lowest position in the section and Dr16 is from the highest part.

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